

# Machinery Installation Design and Installation

API STANDARD 686

THIRD EDITION DRAFT

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# Machinery Installation Design and Installation

## Introduction

This document is the Third Edition in a series describing the fundamental requirements necessary to achieve a quality machinery installation that offers optimal reliability and operational availability with anticipated reduced maintenance. This 3<sup>rd</sup> Edition promotes the document from a Recommended Practice (RP) to a full API Standard. Any references to "must" from the previous editions has been replaced with "shall" or "should" as appropriate. The 3<sup>rd</sup> Edition has also been re-formatted to logically separate those topics addressing "designing for installation" from those topics dealing with the actual installation requirements that follows the normal progression of a project. Additionally, for users of the Second Edition, the Third Edition retains much of the old paragraph numbering structure making the new document a clearer progression and easier to use.

## Part A – General Information

### 1 Scope

#### 1.1 General

This standard is intended to provide procedures, practices, and checklists for the installation, commissioning, and start-up of new, existing, and reapplied machinery and to assist with the installation design of such machinery for petroleum, chemical, and gas industry services facilities. In general, this standard is intended to supplement API machinery specifications, documents and vendor instructions, and the instructions provided by the original equipment manufacturer (OEM).

This standard is not intended for use with side-entry mixers such as are used on API 650 tanks or pumps on tanks associated with lube oil systems.

The information from the OEM regarding equipment installation and checkout should be followed.

API 686 Part A contains general information that is to be used with API 686 Parts B, C, or D).

NOTE: API 686 is essentially a document that contains the procedures, practices, and checklists that have been identified to provide for reliable machinery and auxiliary systems.

##### 1.1.1. Life Cycle Analysis

It is the intent of this document to facilitate machinery installations that will provide the user with a reduced overall life-cycle analysis of equipment ownership

### 1.2 Part A – General Requirements

Part A of API 686 contains scope, normative references, along with terms & definitions, and acronyms & abbreviations pertinent to all machinery and auxiliary systems and is used with Parts B, C or D of this standard. API 686 Parts B, C, or D contain specific information for the purpose identified in the scopes of these parts.

— Part B Machinery and Auxiliary Systems Design for Site Receiving, Rigging, Lifting, Storage, Installation, Commissioning and Start-up.

— Part C Machinery and Auxiliary Systems Site Receiving, Rigging, Lifting, Storage and Installation.

— Part D Machinery and Auxiliary Systems Commissioning and Start-up

### 1.4. Coordination with Contractors

API 686 is written such that parts of the standard can be included in documents between an owner company and an engineering and construction (E&C) contractor. The major benefit is that it provides a detailed scope of supply for machinery installation requirements, with acceptance criteria, and documentation requirements. Properly applied, the standard reduces to negligible possible ambiguity amongst multiple E&C bidders as to the requirements for project machinery installation.

### **1.5 Alternative Installation**

The installation contractor or design contractor may offer alternative methods of equipment installation as mutually agreed upon by the user and equipment manufacturer.

### **1.6 Conflicting Requirements**

Any conflicts between this standard and/or the manufacturers' recommended procedures shall be referred to the user-designated machinery representative for resolution before proceeding.

**1.7** Checklists in API 686 Parts B, C, and D are provided to assist with reviewing specific requirements to meet the site's specific requirements such as for:

- a) rigging and lifting
- b) receiving of the machinery and protection during storage, installation prior to start-up
- c) foundations
- d) mounting plates
- e) piping
- f) shaft alignment
- g) lubrication systems
- h) commissioning and start-up

## **2 Normative References**

There are no normative references.

## **3 Terms, Definitions, Acronyms, and Abbreviations**

### **3.1 Terms and Definitions**

For the purposes of this document, the following terms, definitions, acronyms, and abbreviations apply.

#### **3.1.1**

##### **alignment**

The process of positioning two adjacent shafts connected by a coupling so that the center of rotation for each shaft is as near co-linear as practical during normal operation.

Note: Most misalignment is combination misalignment. It is a combination of parallel offset at a given point along the fixed machine centerline and angular misalignment in both the horizontal and vertical planes. The offset is dependent on the location along the fixed machine centerline where it is measured, normally the center of the coupling spacer.

#### **3.1.2**

##### **ambient offset**

The practice of misaligning two shaft centerlines at ambient conditions to account for the estimated relative changes in shaft centerlines from static ambient temperature conditions to steady state operating conditions.

#### **3.1.3**

##### **angular misalignment**

The angle between the shaft centerline of two adjacent shafts. This angle is normally reported in slope of millimeter of change per meter of linear distance (mils per in.) (1 mil = 0.001 in.). (see Figure 1).

Figure 1—Angular Misalignment



NOTE 1 Most misalignment is combination misalignment. It can be resolved into a parallel offset at a given point along the fixed machine centerline and angular misalignment in the horizontal plane, vertical plane, or both. The offset is dependent on the location along the fixed machine centerline where it is measured, normally the center of the coupling spacer.

NOTE 2 (double-engagement couplings) two minor angles between the extension of each machine centerline and the two flexible elements

NOTE 3 (single-engagement couplings) minor angle between the extensions of two machine-shaft centerlines

### 3.1.4

#### **baseplate**

#### **skid**

Fabricated steel structure designed to support the driver and/or driven equipment and other ancillaries that may be mounted upon it.

NOTE –The term “mounting plate” was used to refer to soleplate or baseplate and is no longer used.

### 3.1.5

#### **blowdown system**

A closed system connected to a machine used to de-pressure and decontaminate the machine preparatory to maintenance activities; also known as a maintenance dropout system.

### 3.1.6

#### **bolt bound**

Where any hold-down bolt is not free in the bolt hole, so that the ability to move for alignment the moveable element in a machinery train horizontally or axially is constrained.

### 3.1.7

#### **breakout spool**

#### **dropout spool**

A short, flanged length of pipe immediately connected to the machinery piping flanges. Lengths vary with the size of the pipe. The purposes of this spool is to facilitate machinery installation, allow piping modification to reduce pipe strain, isolate the machinery, facilitate commissioning activities such as flushing or blowing lines, and allow removal of temporary inlet strainers.

NOTE: recommendations for spool lengths can be found in Part B on Piping

### 3.1.8

#### **cementitious**

A type of grout material that is hydraulic cement based.

### 3.1.9

#### **cleanliness**

#### **clean**

Typically determined by grit or magnetic particles trapped by the filter screen, percent of filter screen plugged or PPM measure. See the relevant parts of API 614 for guidance.

### 3.1.10

**cold load setting**

The force exerted by a spring hanger or support on the piping with the piping at ambient temperature and empty of process fluid.

**3.1.11****cold stop**

A metal bracket, block or pin inserted into a piping spring hanger or spring support that locks the spring in place at the cold load setting.

NOTE: field terminology sometimes refers to this cold stop as “a gag”

**3.1.13****combination misalignment**

When the centerlines of two adjacent shafts are neither parallel nor intersect. This misalignment is normally described in both angular and offset terms.

**3.1.14****condensing service**

A gas stream that contains a vapor component that may condense to a liquid during start-up, operation, or shutdown of a compressor or blower. This may include pure vapors such as refrigerants as well as hydrocarbon gas streams. When condensate is present in the gas stream, the term wet gas may be used; wet gas may also be used as a synonym to condensing service.

**3.1.15****critical service**

Critical service is typically defined as those applications that are unsparred /single-train installations whereby loss of operation would result in significant loss of production, loss of primary process containment, or threat to personnel safety.

**3.1.16****dead-leg**

A length of piping with no flow.

**3.1.17****designated machinery representative**

The person or organization designated by the ultimate user of the equipment to speak on the user's behalf regarding machinery installation decisions, inspection requirements, and so forth. This representative may be an employee of the user, a third-party inspection company, or an engineering contractor delegated by the user.

**3.1.18****drop point**

A vertical section of oil mist distribution piping that is usually smaller in diameter than the main oil mist header. This piping rises out of a tee in the main oil mist header, turns horizontally, and extends downward to the machinery being lubricated.

**3.1.19****elastomeric coupling**

A coupling that obtains its flexibility from the use of a deformable, non-metallic element.

**3.1.20****engineering designer**

The person or organization charged with the project responsibility of supplying installation drawings, documents and procedures for installing machinery in a user facility after machinery has been delivered. In general, but not always, the engineering designer specifies machinery in the user facility.

### **3.1.21**

#### **epoxy grout**

A material that consists of a resin base that is mixed with a curing agent (hardener) and usually contains an aggregate.

### **3.1.22**

#### **equipment installer**

The person or organization charged with providing engineering services and labor required to install machinery in a user facility after machinery has been delivered. In general, but not always, the installer is the project construction contractor.

### **3.1.23**

#### **equipment train**

Two or more rotating machinery elements consisting of at least one driver and one driven element joined by a coupling.

### **3.1.24**

#### **equipment user**

The person or organization charged with operation of the machinery. In general, but not always, the equipment user owns and maintains the machinery after the project is complete.

### **3.1.25**

#### **final alignment**

The aligning of two adjacent machinery shafts after the measurement of piping and rigid conduit imposed strains on the machinery are verified as being within the specified tolerances.

### **3.1.26**

#### **flexible-element coupling**

A coupling that joins separate units of rotating machinery consisting of thin metal discs, flanges, bolts, and a disc and diaphragm couplings. A flexible-element coupling obtains its flexibility from the flexing of thin disks or diaphragm elements.

### **3.1.27**

#### **gear coupling**

A coupling that joins separate units of rotating machinery that obtains its flexibility by relative rocking and sliding motion between mating, profiled gear teeth.

### **3.1.28**

#### **general purpose application**

Refers to an application that is usually spared or is in noncritical service.

### **3.1.29**

#### **general-purpose equipment trains**

Those trains that have all general-purpose elements in the train. They are usually spared, relatively small (power), or are in noncritical service. They are intended for applications where process conditions will not exceed 50 bar (720 psi) pressure or 205 °C (400 °F) temperature (excluding steam turbines), or both, and where speed will not exceed 4000 revolutions per minute.

NOTE General-purpose equipment trains have all elements that are either manufacturer's standard or are covered by standards such as: ASME B73 pumps, small API 610 pumps, fans, API 611 steam turbines, API 672 air compressors, API 677 general-purpose gears, API 674 reciprocating pumps, API 676 rotary positive displacement pumps, API 680 reciprocating air compressors, and NEMA standard size motors

### **3.1.30**

#### **grout**

An epoxy or cementitious material used to provide a uniform foundation support and load transfer link for the installation of rotating machinery. This material is typically placed between an equipment foundation and its mounting plate.

### **3.1.31**

#### **grout pin**

A metallic pin or dowel used to better retain an epoxy grout pour to its concrete foundation to prevent delamination (or edge lifting) due to differential thermal expansion between the grout and the concrete.

### **3.1.32**

#### **head box**

A device used to funnel grout into a baseplate grout fill-hole to provide a hydraulic/hydrostatic head to aid in filling all baseplate cavities with grout.

### **3.1.33**

#### **isolation block valve**

#### **block valve**

#### **isolation valve**

A valve used to isolate a process machine preparatory to maintenance; also known as a block valve or isolation valve.

### **3.1.34**

#### **manufacturers or vendor representative**

The person or organization designated by the equipment manufacturer or warranty holder to speak on his/her behalf pertaining to the equipment handling, installation and use.

### **3.1.35**

#### **mechanical piping analysis**

An analysis of the piping connected to a machine to determine the stresses and deflections of the piping resulting from temperature, pressure and dynamic loadings such as pulsating flow (mixed phase flow). Determination of the type, location, and orientation of piping supports and piping guides results from this analysis.

### **3.1.36**

#### **minimum flow bypass**

See **recycle line**.

### **3.1.37**

#### **non-slam check valve**

A mechanically or hydraulically balanced check valve that allows closure of the valve in a controlled fashion. Wafer-style center-guided spring-loaded split-disc check valves or tilting-disc check valves are representative designs.

### **3.1.38**

#### **NPS**

#### **nominal Pipe Size**

value approximately equal to a diameter in inches

EXAMPLE- NPS 3/4

NOTE 1 - Refer to ASME B 31.3

NOTE 2 - The letters NPS are followed by a value which is related to an approximate diameter of the bore, in inches, for piping up to and including 12 in. diameter. For piping over 12 in. (NPS 12), the NPS value is the nominal OD.

### **3.1.39**

#### **oil mist**

A dispersion of oil droplets, of 1 to 3 microns in size in an air stream

### **3.1.40**

#### **oil mist application fittings**

#### **reclassifier**

Long path orifices that cause the small oil droplet size in the header ("dry mist") to be converted to larger size oil droplets ("wet mist") to lubricate equipment bearings.

### **3.1.41**

#### **oil mist console**

A system consisting of the oil mist generator, oil supply system, mist head, misting chamber/oil reservoir, air filtering system, oil mist header outlet, and necessary controls and instrumentation. Air and oil enter the console to produce oil mist.

### **3.1.42**

#### **oil mist distribution block**

A small rectangular block that has four or more holes drilled and tapped in opposite faces. Drop points terminate in distributor blocks. An oil mist distributor block may also be described as an oil mist manifold block.

### **3.1.43**

#### **oil mist distributor block**

#### **oil mist manifold block**

A small rectangular block that has four or more holes drilled and tapped in opposite faces. Drop points terminate in distributor blocks.

### **3.1.44**

#### **oil mist generator**

A device located inside the oil mist console that combines oil and air to make oil mist. Typical oil mist generators utilize a venture or vortex to achieve mixing of the oil and the air. It provides for inspection of mist flow without venting to atmosphere.

### **3.1.45**

#### **oil mist header**

A network of piping through which the oil mist is transported from the console where it is made to the machinery bearing housing where it is used.

### **3.1.46**

#### **oil mist lubrication**

lubrication method that employs oil mist produced by atomization in a central unit and transported to the bearing housing, or housings, by compressed air

### **3.1.47**

#### **oil mist supply manifold**

A small rectangular or hexagonal block with holes drilled and tapped on the faces. Drop points terminate in the distributor block or supply manifold. The oil mist distributor block or supply manifold may also include a viewing chamber or sight glass. An oil mist distributor block may also be described as an oil mist manifold block.

### **3.1.48**

#### **oil mist system**

A system designed to produce, transport, and deliver oil mist from a central location to a remote bearing housing. This system consists of the oil mist console, distribution piping headers and laterals, application fittings, and the lubricant supply tank and pump.



### **3.1.49**

#### **operating temperature (thermal) alignment**

A procedure to determine the actual change in relative shaft positions within a machinery train from the ambient (not running) condition and the normal operating (running) condition by taking measurements from startup to normal operating temperature while the machine(s) is (are) operating, or after the shafts have been stopped but the machines are still near operating temperature.

### **3.1.50**

#### **peg test**

A test performed on optical leveling equipment to ensure that the instrument is properly adjusted and its line of sight is coincident to true earth level.

### **3.1.51**

#### **piping stress analysis**

An analysis of the piping system connected to a machine to determine stresses, deflections, forces and moments on nozzle connections caused by various loading conditions such as pipe weight, liquid loads, and temperature, pressure, or fluid pulsation. These forces and moments are compared to vendor-allowable loads or national standards to ensure that nozzle loadings meet guidelines. This analysis includes specification of pipe anchors, guides, supports, and sometimes spring supports and expansion joints to control strain. Where large vertical piping displacements occur, machinery may sometimes be mounted on spring-supported baseplates to reduce nozzle loading.

### **3.1.52**

#### **preliminary alignment**

The aligning of two adjacent machinery shafts to ensure that final alignment can be achieved without being bolt bound. This is accomplished before grouting and the measurement of piping or rigid conduit strain on the machinery.

### **3.1.53**

#### **pulsation analysis**

An analysis of the piping system connected to a machine to determine the acoustical and mechanical effects of pulsating flow. For small machines a pulsation analysis can consist of comparison to other installations, and/or use of proprietary pulsation device design charts, formulas, or graphs. For large, complicated machines a pulsation analysis can consist of a detailed digital or analog modeling of the machine and the piping.

NOTE API 688 provides guidance for pulsation analysis.

### **3.1.54**

#### **pure oil mist lubrication**

##### **dry sump**

The application of oil mist to a machinery bearing housing to lubricate antifriction bearings. The oil mist passes through the bearing elements and oil droplets coalesce out of the air stream. All oil is drained from the machinery bearing housing and the mist alone provides complete lubrication.

### **3.1.55**

#### **pure oil mist lubrication**

Lubrication method in which the mist both lubricates the bearing and purges the housing.

NOTE There is no oil level in the bearing housing when using pure oil mist lubrication (i.e. dry sump).

### **3.1.56**

#### **purge oil mist lubrication**

The application of oil mist to a machinery bearing housing or reservoir to provide a slight positive pressure. Machinery lubrication is provided by the conventional ring oil or submerged bearing lubrication. This prevents contamination that could be caused by infiltration of corrosive agents or condensation of ambient moisture.

NOTE There is an oil level in the bearing housing when using purge oil mist lubrication and the bearing is lubricated by a conventional oil-bath, flinger or oil ring lubrication system. (i.e. wet sump).

### **3.1.57**

#### **recycle line**

A line from the discharge of a pump, blower, or compressor routed back to the suction system. A recycle line will usually include control elements such as meters or valves. The recycle line may connect directly into the suction line or may connect into suction vessels or liquid knockout vessels and may include a cooler; also known as bypass line, minimum flow bypass, or kickback line.

### **3.1.58**

#### **snug**

To tighten bolting with minimal torque. When piping flange bolting is initially tightened between finger tight approximately 10% of the final total torque it is understood to be snug.

### **3.1.59**

#### **soleplate**

Plate attached to the foundation, with a mounting surface for equipment or for a baseplate.

NOTE –The term “mounting plate” was used to refer to soleplate or baseplate and is no longer used.

### **3.1.60**

#### **special purpose application**

Machinery service for which the equipment is designed for uninterrupted, continuous operation in critical service and for which there is usually no spare equipment.

### **3.1.61**

#### **special-purpose equipment trains**

Equipment trains with driven equipment that is usually not spared, is relatively large size (power), or is in critical service. This category is not limited by operating conditions or speed.

NOTE Special-purpose equipment trains will be defined by the user. In general, any equipment train using equipment such as some high energy API 610 Pumps; API 612 Steam Turbines; API 613 Gears; API 617 Axial and Centrifugal Compressors and Expander-Compressors; API 618 Reciprocating Compressors; API 619 Rotary Screw Compressors; or API 616 Gas Turbines should be considered to be special-purpose.

### **3.1.62**

#### **static piping analysis**

An analysis of the piping system connected to a machine to determine forces and moments on nozzle connections caused by various loading conditions such as pipe weight, liquid loads, and thermal expansion or contraction. These forces and moments are compared to vendor-allowable loads or national standards to ensure that nozzle loadings meet guidelines. This analysis includes specification of pipe anchors, guides, supports, and sometimes spring supports and expansion joints to control strain. Where large vertical piping displacements occur, machinery may sometimes be mounted on spring-supported baseplates to reduce nozzle loading.

### **3.1.63**

#### **suction knockout vessel**

#### **liquid dropout vessel**

A vessel/drum located in the suction line to a compressor or blower used to separate any entrained liquid from the gas stream. It may contain a demister mat, centrifugal separators, or combination, to aid in this separation. Usually the compressor or blower takes suction from the top of the knockout vessel.

### **3.1.64**

#### **tabletop foundation**

An elevated three-dimensional reinforced concrete structure that consists of large beams or a thick slab connecting the tops of the supporting columns. The mechanical equipment is supported by the large beams or the slab located at the top of the structure.

### **3.1.65**

#### **total acid number**

#### **TAN**

The quantity of base (expressed in terms of milligrams of potassium hydroxide) that is required to titrate the strong acid constituents present in 1 gm of an oil sample (ASTM Method P664 or D974).

### **3.1.66**

#### **TIR**

#### **total indicator reading**

#### **total indicated runout**

The difference between the maximum and minimum readings (of a dial indicator or similar device), monitoring a face or cylindrical surface during one complete revolution of the monitored surface

NOTE For a cylindrical surface, the total indicated runout implies an eccentricity equal to half the reading. For a flat face the indicated runout implies an out-of-square equal to the reading.

### **3.1.67**

#### **user-designated machinery representative**

#### **user-designated representative**

The person or organization designated by the equipment owner to speak on its behalf with regard to machinery installation decisions, inspection requirements, and so forth. This representative may be an employee of the owner, a third-party inspection company, or an engineering contractor as delegated by the owner.

### **3.1.68**

#### **vendor**

Manufacturer or manufacturer's agent that supplies the equipment.

NOTE Typically, responsible for service support.

### **3.1.69**

#### **warm-up line**

A line used to purge warm or hot fluid through a process machine. The intention is to heat up or maintain the temperature of a machine to a temperature greater than the surrounding ambient temperature and minimize differential thermal growth.

## **3.2 Acronyms, and Abbreviations**

ACI	American Concrete Institute
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
PIP	Process Industry Practices
OSHA	Occupational Safety and Health Administration

# **API STANDARD 686 THIRD EDITION DRAFT**

## **Machinery Installation and Installation Design**

### **Part B – Designing for Site Receiving, Rigging, Lifting, Storage, Installation, Commissioning, and Start-up of Machinery & Auxiliary Systems**

#### **1 Scope**

**1.1** This part of API 686, in conjunction with API 686 Part A, specifies requirements for the design of Machinery and Auxiliary Systems installation. API 686 Parts C and D are used to complete the installation.

NOTE: Each site typically has specific requirements due to unique circumstances for the site. Part B – Design is required to accomplish the requirements of API 686 Parts C and D. API 686 is not intended to replace API Machinery Standards. It is to be used to supplement these API Machinery Standards to ensure that the specific site conditions allow API 686 Parts C and D to be accomplished.

**1.2** Check sheets, such as in Annex A, should be used to ensure specific capabilities to meet the site's specific requirements are included such as for:

- a) rigging and lifting
- b) jobsite receiving and protection during storage and installation prior to start-up
- c) foundations
- d) baseplates
- e) piping
- f) shaft alignment
- g) lubrication systems
- h) commissioning and start-up

NOTE: Annex A check sheets can be found in Part B, Part C, and Part D associated with the chapters for each category

#### **2. Normative References, Terms, Definitions, Acronyms, and Abbreviations**

Refer to API 686 Part A.

#### **3.0 Installation Design Requirements of API 686 Part B**

Clause 3 identifies requirements to be included within the machinery, auxiliary systems, or the site to accomplish API 686 Parts C and D. Typically, these requirements have not been included with the machinery and auxiliary systems and are part of the scope of the engineering contractor's responsibilities. The information in API 686 Part B provides the minimum requirements for installation design based on current industry "best practices".

If these requirements have not been included with the machinery or auxiliary systems, a review shall be completed to determine if other methods or procedures can be completed or if the requirements are to be included with the machinery or auxiliary systems.

NOTE: If clauses in Part B are not followed, then it may not be possible to meet all of Parts C and D.

#### **3.1 Rigging and Lifting**

3.1.1 Each piece of machinery and the associated auxiliary system(s) shall be reviewed to ensure that rigging and lifting can be accomplished with the provisions at the site for both receiving and installation.

3.1.2 The requirement for additional lifting points may be required on the machinery or auxiliary systems.

## **3.2 Jobsite Receiving and Protection**

### **3.2.1 Jobsite Receiving**

This is a responsibility identified for API 686 Part C.

### **3.2.2 Jobsite Protection**

The protection of the machinery and auxiliary systems is a requirement during API 686 Parts C and D. However, if there are features required to accomplish the protection of the machinery and auxiliary systems, then these features shall be provided to accomplish the requirements in API 686 Parts C and D. Protection systems that may require provisions from the machinery or auxiliary system suppliers are listed in 3.2.2.1 through 3.2.2. 2.

#### **3.2.2.1 Oil Mist during Site Storage Prior to Installation**

NOTE: Oil mist systems are typically specified on large projects where more than ten pieces of equipment will be stored longer than six months or if dust or dampness is excessive.

**3.2.2.1.1** If an oil mist preservation system has been specified to be used during storage, installation, and prior to start-up, it shall have the capability to protect the bearings, bearing housings, seal areas and process ends of the machinery and auxiliary systems or as identified. An oil mist protection system may be different for each phase of the project such as the storage and the installation.

**3.2.2.1.2** The machinery or auxiliary system to be protected shall have been designed to allow the specified oil such as to not damage internal components or housings.

**3.2.2.1.3** The machinery or auxiliary systems shall have the capability of allowing a mist flow through each application point.

**3.2.2.2** The oil mist system design shall be as follows, at minimum:

- a) The oil mist system shall be designed and sized for preservation service.
- b) As a minimum, the mist generator shall be equipped with the following instrumentation: air pressure regulator, pressure relief valve, level gauge, and mist pressure gauge.
- c) The oil mist header system shall be NPS 2 minimum galvanized schedule 40 pipe properly supported and sloped.
- d) The oil mist flow to each application point can be less than that required for lubrication during normal operation.
- e) Plastic tubing (temporary use only) can be used to connect from the mist header to the application point.
- f) Oil should not be drained to ground.

## **Annex E (Clause 3) (Informative)**

### **Machinery Preservation Recommendations**

#### **PURPOSE**

The purpose of this annex is to provide recommended best practice for preservation of Rotating Equipment and Spare Parts.

The recommendations are to ensure that this equipment is in "ready to use" condition and will not cause delays when needed. The annex should be used in the absence of Owner machinery protective documents or similar protection requirements or recommendations provided by the Manufacturer.

## APPLICATION

This Annex is applicable to the preservation of: Rotating Equipment (entire trains, and individual equipment), Spare Parts, and Ancillary equipment. This includes equipment that is stored in storage facilities, and installed at site during construction up to commissioning and startup.

## DEFINITIONS

**Aerosol coating** A petrochemical, soft-film spray coating designed to prevent rust and corrosion on steel, aluminum, and other metals

**Air Conditioned** An indoor area with temperature maintained at 80 °F (27 °C) or below, with scheduled monitoring and temperature recorded at least once per week.

**Climate Controlled** An indoor area with air conditioning, humidity control, or both systems that have scheduled monitoring and recorded.

### Fabricated Metal

#### Cannister (Steel

**Rotor Container)** A watertight metal transport/storage container suitable for vertical or horizontal storage and designed per API RP 687 Chapter 1 section 11.2.3 (This is often referred to as a “rotor coffin”)

**Humidity Control** An area which maintains humidity between 40% - 60% and maintains daily records of humidity from a routinely calibrated hygrometer.

**Indoor Storage** A sealed building, typically closed, with doors and windows on all openings. Equipment stored there is protected from exposure to precipitation, wind, and direct sunlight.

(See Part III, Annex A – Type C)

**Outdoor Storage** A totally exposed area such as an open field which may be referred to as “lay-down yard.”

(See Part III, Annex A – Type A, Type B and Type D)

### Material Manage-

**ment Team** The team (Contractor, Vendor, or Owner) that is responsible for management of; Stocked Materials and parts (both on-site, and offsite), including their preservation and fitness for service.

### Preservation

**Activities** Work performed to preserve the condition of parts or equipment, typically on a repetitive schedule.

**Protection Code** A set of numbers assigned to a preserved equipment or parts that defines the requirements for care during storage.

**Storage Facility** A space or building that contains items in storage.

**Storage Type** Number ranging from 1 to 6, assigned to a storage facility by engineering that indicates the level of protection provided by the environment maintained and procedures demonstrated there.

### Turbomachinery

**Rotor** The rotating assembly from: A Centrifugal Compressor, An Axial Compressor, A Steam Turbine, A turbo expander, or a Crankshaft from a Reciprocating Compressor.

**Under Roof** A semi-exposed storage area, shielded only by a roof which affords partial protection from rain and sunlight.

**VPCI** Vapor Phase Corrosion Inhibitor These are corrosion inhibiting compounds that release molecules into the air. When these compounds come in contact with metal surfaces, they form a very thin molecular layer.

## **E.1 STORAGE PRIOR TO INSTALLATION**

### **RESPONSIBILITY**

The Owner's Engineer, or his delegate, is responsible for selecting adequate levels of storage protection, preventative maintenance intervals, and auditing storage facilities and their procedures to ensure that the equipment is properly Preserved. The Materials Management team assumes responsibility of the components in storage and will initiate PM inspections that align with the requirements specified by the Owner's Engineer.

### **APPLICATION OF PROTECTION CODE**

The Owner's Engineer will specify the necessary requirements in the PROTECTION CODE for all parts under preservation with proper selections from the categories listed below. The 5th category is optional since not all equipment and parts require a particular facility. This will be listed in data retention software for all stored equipment and will not be changed without Owner's Engineers approval.

1. One selection from Storage Type #
2. One or more selections from Surface Protection
3. One or more selections from Crating or Packaging
4. One selection from PM & Inspection Interval
5. (Optional) A note in parenthesis will be included if there are any special facility requirements but should be an approved storage facility listed within this document

**EXAMPLE OF A PROTECTION CODE:**

Storage Area, Surface Protection, Crating or Packaging, PM & Inspection Interval, and (Special Storage Requirement)

2-A-m-ee (OEM Storage Location)

This code indicates:

**2** -"Indoor humidity controlled – **A** -Aerosol coating – **m** -Vertically hung – **ee** -1 year PM" (OEM storage location)

"OEM Storage Location" is an example of a special storage requirement indicating the item is to be stored at a particular facility.

Some parts have particular storage requirements or need technical authority onsite for inspection. In those cases, a particular facility may be indicated. If there are no special storage requirements, the note in parenthesis is not required.

This code is derived from the choices in the STORAGE AND PRESERVATION CODE KEY, defined in the next section of this document.

**STORAGE AND PRESERVATION CODE KEY****Storage Type #:**

Note: All storage facilities will be audited by Engineering and assigned a level of protection from 1 to 6

based on conditions found during audit. Materials Management will store all critical parts in an area providing the level of protection specified by Engineering with 1 being the greatest protection and 6 being the least. To be considered a Storage Type 1 or Storage Type 2, the facility should have on hand, and demonstrate procedures that show that required climate controls are maintained.

1. Indoor climate controlled for temperature and humidity
2. Indoor humidity control
3. Indoor air conditioned
4. Indoor
5. Under roof
6. Outdoor

**Surface Protection:**

Caution: Some forms of surface protection will cause hazards in the storage area. Examples of these are, but are not limited to Oil Mist and Nitrogen Purge. When using any hazardous protection, the area should be posted to warn of the hazard.

- A. Aerosol coating
- B. VPCI bags
- C. VPCI paper
- D. VPCI liquid spray or in oil
- E. Cosmoline type coating
- F. Grease or oil level maintained in equipment
- G. Light oil coating
- H. OEM packaging
- I. Oil Mist Lube
- J. Nitrogen purge
- K. None
- L. Poly stretch wrap
- M. Wax cloth, self-adhering, moldable ("ocean wrap")

**Crating or Packaging:**

- A. Bubble wrap
- B. Cardboard or paper (to separate from shelving)
- C. Fabricated crate



- D. Fabricated metal canister (steel rotor container)
- E. Preserved in a fabricated metal box, hard plastic box, or in a special canister. (This could be a specially designed cannister, or could be a kit box)
- F. Formed foam
- G. Open box with no internal components
- H. Wooden box
- I. Rotor stands or cradle
- J. Rubber mat
- K. Sealed package (shrink wrap or sealed bag)
- L. Styrofoam "Peanuts"
- M. Vertically hung
- N. Wooden pallet, or wooden supports
- O. Wooden sections for isolation
- P. Wooden supports

**PM & Inspection Intervals:**

- A. Equipment and parts in substandard storage (such as project "lay down yards" or under roof storage) may be maintained for short periods with heavy surface protection, packaging, and frequent inspections.
- B. Vertically hung turbomachinery rotors in humidity controlled facilities with aerosol type surface protection typically require a 1 year inspection interval.
- C. Some parts may never require re-inspection or preventive work depending upon storage area and material of construction.

- D. Some stationary components such as turbine or compressor diaphragms may require less frequent inspections such as 3 years or 5 years with good surface protection while stored in humidity controlled facilities.
- aa. Weekly
  - bb. 1 Month
  - cc. 3 Months
  - dd. 6 Months
  - ee. 1 Year
  - ff. 2 Years
  - gg. 3 Years
  - hh. 5 Years
  - ii. hand turn equipment 2 1/2 turns every 3 months
  - jj. No inspection necessary

## **E.2 EQUIPMENT REQUIRING SPECIAL CONSIDERATIONS:**

Some equipment and parts require capabilities beyond the limits of most storage sites.

Some assembled rotating equipment may require hand turning to prevent "false brinelling of the bearing surfaces (see "ii" of the Storage and Preservation Code Key)

Turbomachinery rotors are heavy and difficult to handle without causing damage. Supporting and handling them properly requires knowledge of their critical areas. Hanging the rotors vertically in storage requires special structures which need an engineered design. Having a technical authority onsite and the capability to conduct an inspection of the part is a necessity.

Users should audit storage facilities based on capability. Only facilities approved to the necessary protection level may be used for storage of critical equipment components.

## **REQUIREMENTS FOR VERTICAL ROTOR STORAGE FACILITIES:**

Turbomachinery rotors fall into the category of parts requiring special considerations. These parts will all have the code: 2-A-m-ee (And may have a specified storage facility).

A vendor should meet the following qualifications Turbomachinery rotor storage:

- A. Provide Indoor climate controlled for temperature and humidity.
- B. Maintain the humidity between 40% - 60% and be able to provide records of humidity from a routinely calibrated hygrometer.
- C. Provide hanging devices and support structures of an engineered design.
- D. Capability to perform onsite incoming and outgoing rotor inspection, including: Full TIR (radial and axial), low speed balance, axial locations, and overall condition.
- E. Capability to remove the rotor safely and efficiently from storage when called on.
- F. Capability to repair the rotor if necessary
- G. Provide a documentation package that is attached to the rotor with the last repair report and the incoming inspection documents.

### E.3 AUDITS OF STORED EQUIPMENT

#### PM & Inspection intervals

The Materials Management team is responsible to maintain records of inspections according to the assigned protection code and assure that the preservation is effective. .

#### Preservation Process Audits

The preservation process described in this Annex is to be audited every six months by at least one representative from the Materials Management team, and the Owner's Engineers designated auditor(s). The Owner's Engineers designated auditor is responsible to schedule and coordinate this audit. This inspection is to assure that all items are preserved as requested, and the equipment is in "ready to use" condition

#### Scope of Audit

This audit will be conducted every six months from receipt of the equipment, to review the storage of at least ten (10) stored equipment, selected by the audit team. The ten items should not include any items from the last three (3) audits, unless they were part of a non-compliant finding from one of those audits.

***NOTE: Non-compliant items from a previous audit will not be part of the ten items that are part of the current audit.***

The scope of this audit will, at a minimum, include:

- A. Verification that the part is stored according to the code
- B. The storage location meets the requirements of the code
- C. Verification that the part is the correct part (it matches the description and part number)
- D. Verification that the part is "ready to use" (no visible damage, corrosion, etc.)

If two or more of the audited items are found to be non-compliant in any of these audit categories, ten (10) more items will be selected for an extended audit. On completion of the extended audit, the audit team will review all of the findings and determine what type of corrective action, if any, is necessary.

The corrective action determination, and correction action, may include some of the following recommendations:

- A. Make immediate corrections required to correct the non-compliance
- B. Determine if the part has the correct preservation code.
- C. Expand the audit to include all similar parts
- D. Recommend replacement or repairs to a particular part (if condition warrants)

The audit will be documented on the Audit Form (" E.4, Storage Preservation Audit Form").

#### E.4 Storage Preservation Audit Form

Date: \_\_\_\_\_ Storage Location: \_\_\_\_\_

Audit Team Members: \_\_\_\_\_

**Audited Equipment –**

Equipment Technical ID Number: \_\_\_\_\_ OEM : \_\_\_\_\_

Description: \_\_\_\_\_

Preservation Code for Equipment: \_\_\_\_\_

Was equipment found to be stored in alignment with Preservation Code? (yes/no)

If not, describe non-compliance:

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Does the assigned preservation code properly protect the equipment? (yes/no)

If not, describe non-compliance:

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Is the audited equipment the correct as described in records? (yes/no)

If not, describe the finding:

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Was the audited equipment found to be “ready to use”? (yes/no)

If not, describe the finding:

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Comments and Recommendations:

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**NOTE:** Additional comments and findings may be added by attaching documentation to this form.

## E.5 Turbomachinery Rotor Storage Scope

### Purpose

The purpose of this scope is to clearly define how Turbomachinery rotors will be stored, preserved, and maintained as to be ready for service when needed.

### Facility Qualifications

The storage facility should meet the following requirements:

- A. Provide Indoor climate controlled for temperature and humidity.
- B. Maintain the humidity between 40% - 60% and be able to provide daily records of humidity from a routinely calibrated hygrometer.
- C. Provide hanging devices and support structures of an approved engineering design.
- D. Capability to perform onsite incoming and outgoing rotor inspection, including: Full TIR (radial and axial), probe area MRO/ERO measurements, low speed balance, axial locations, and overall condition.
- E. Capability to safely and efficiently remove rotor from storage when called on.
- F. Capability to repair the rotor if necessary
- G. Provide a documentation package that is attached to the rotor with the last repair report and the incoming inspection documents.

### Incoming Inspection

Prior to storage, each rotor will have a documented incoming inspection as follows:

- A. Visual inspection of the rotor. Document any visible indications of mechanical damage, wear, or erosion to the rotor in any of the following areas: Bearing Journals, Coupling Fit(s), Seal fits, Impellers (centrifugal compressors), Spacer sleeves (centrifugal compressors), Wheels (steam turbines and expanders), buckets/blades (steam turbines, expanders, and axial compressors).
- B. Measure and document radial and axial TIR (using .0001" indicator)
- C. Measure and document probe area MRO (mechanical run out), and ERO (electronic run out).
- D. Measure incoming balance condition. The balance report should include the balance machine used, the balance machine setup, and include all amplitude and phase of residual imbalance.

**Note: if the rotor was at-speed balanced, this is required to document the incoming condition. Balance corrections are not to be made on rotors that were high-speed balanced.**

- E. All incoming inspection data is to be reviewed with Owner's Engineer prior to storage.

**NOTE: if the rotor was repaired at the storage facilities shop, the rotor repair documents will meet the requirements of the incoming inspection if they include the inspection points described above.**

### Rotor hanging device and support structures

- A. Hanging devices need to be engineered for this purpose by the storage facility, and be capable of supporting the weight of the rotor while not causing damage to the rotor. This engineered design is subject to review by Owner's Engineer.
- B. The support structure that the rotors are suspended from should be suitable to support all of the rotors stored on the structure by the storage facility.
- C. The hanging devices and support structure should be arranged in such a way that rotors can be safely hung and retrieved with minimum risk of damaging the rotor during movements.

### Outgoing Inspection

When a rotor is removed from storage, the rotor will have a document outgoing inspection as follows:

- A. Visual inspection of the rotor. Document any visible indications of mechanical damage, wear, or erosion to the rotor in any of the following areas: Bearing Journals, Coupling Fit(s), Seal fits, Impellers (centrifugal compressors), Spacer sleeves (centrifugal compressors), Wheels (steam turbines and expanders), buckets/blades (steam turbines, expanders, and axial compressors).
- B. Measure and document radial and axial TIR (using .0001" indicator)

- C. Measure and document probe area MRO (mechanical run out), and ERO (electronic run out).
- D. Measure rotor residual magnetism. Demagnetize if residual magnetism is greater than 2 gauss.
- E. Measure outgoing balance condition. The balance report should include the balance machine used, the balance machine setup, and include all amplitude and phase of residual imbalance.
- F. All outgoing inspection data will be reviewed with Owner's Engineer. Any discrepancies between the incoming and outgoing inspections should be resolved prior to putting the rotor into service.

## **E.6 FIELD PRESERVATION REQUIREMENTS**

### **RESPONSIBILITY**

The Owner's Engineer, or his delegate is responsible to assure that equipment that is installed in the field, or being installed is preserved and will be ready for startup. The Owner's Engineer is also responsible to approve the preservation activity(or activities) recommended by the contractor. It is the responsibility of the Contractor, or their materials management team to recommend the field preservation activity (or activities) for each piece of equipment to the Owner's Engineer. It is also their responsibility to maintain the preservation of equipment that has been moved from the storage facility to the field until the equipment is commissioned or turned over to the owners.

### **PRESERVATION OPTIONS**

Equipment in the field can be preserved using one or more of the following preservation options:

- Oil Mist
- Aerosol coating
- Nitrogen purge
- VPCI liquid (spray or oil additive)
- VPCI bags, cannisters, or desiccant pouches
- Grease or oil level maintained in equipment
- Scheduled turning of rotating equipment
- Cosmoline type coating
- Wax cloth, self-adhering, moldable ("ocean wrap")
- Temporary climate controlled shelter
- Poly Stretch Wrap
- Paint

NOTE: Other methods not listed above may be considered

## **E.7 APPLICATION CONSIDERATIONS FOR PRESERVATION OPTIONS**

### **Oil Mist -**

Oil mist is the preferable method to preserve oil wetted areas of machinery, particularly bearing housings. A temporary mist header can be erected and mist distributed to each location using the smallest reclassifier that is suitable to purge the particular location. If a permanent mist system is installed in the area, it may be used for this purpose. Oil mist may only be used for preservation in other locations other than bearing housing as approved by the Owner's Engineer.

### **Aerosol coating –**

Aerosol coatings, especially the waxy Cosmoline type, can be applied to uncoated (unpainted) machined surfaces such as: baseplate machinery mounting pads, exposed shafts, exposed couplings, or any other exposed uncoated surfaces that might be subject to corrosion if unprotected. Care should be taken to not apply the aerosol coating in areas that may cause unwanted results such as: electrical connections, areas that may plug drains or ventilation, areas that may restrict moving parts, etc.

### **Nitrogen Purge –**

Nitrogen purge is an acceptable to preserve the following equipment types (not limited to this list):

- A. Oil reservoirs
- B. Gearboxes
- C. Compressor Casings
- D. Steam and Gas Turbine Casings
- E. Expanders
- F. Pumps
- G. Fans and Blowers
- H. Duct Work
- I. Piping Systems
- J. Large Motors
- K. Sealing Systems
- L. Parts in fabricated metal canister (steel rotor container)

**NOTE: Use of nitrogen should be restricted to equipment in an open area where any leakage can be dispersed quickly. Use of nitrogen on equipment that is in an enclosure, or enclosed area will make the atmosphere in the enclosed area oxygen deficient (making the area an asphyxiation hazard).**

Care should also be taken to prevent over-pressurization of the purged equipment.

#### **VPCI Liquid -**

Vapor phase corrosion inhibitors are available in formulas that can be mixed with oil, or water. VPCI can be mixed with oil in bearing housings when oil mist is not available or practical. When mixed with oil it creates a very thin layer of protection to the surfaces. When using VPCI/Oil mix, it should be changed according to the effective life of the product as specified by the VPCI manufacturer. Use of VPCI/Oil mix longer its effective life can stop its effectiveness. When VPCI/Oil mixture is used, it is recommended to turn the equipment several times during initial application to ensure that the oil/grease has been evenly distributed.

VPCI/Water mix can be sprayed into areas to be protected, and in some cases it can be “blown in” using a fan to direct it in a mist form through the equipment. This also has an effective life and should be replaced according to the manufacturer’s specifications.

#### **VPCI Bags, VPCI Cannisters, or Desiccant Pouches –**

VPCI bags or cannisters, or desiccant pouches may be used to protect relatively small areas that are mostly closed but may be subject to the effects of humidity or similar atmospheric conditions. When used the locations where installed should be clearly marked in a manner that will remind users to remove them prior to commissioning. These have an effective life and should be replaced according to the manufacturer’s specifications. Care should be taken not to place these devices in locations where they may loosen and fall into the equipment.

#### **Grease or oil level maintained in equipment –**

Some equipment may be adequately preserved by maintaining the proper oil level, or grease lubrication. This option should only be used if the preservation is less than six months, or if advised by the OEM of the equipment. When the grease or oil level option is used, it is recommended to turn the equipment several times during initial application to ensure that the oil/grease has been evenly distributed.

#### **Scheduled turning of rotating equipment –**

In conjunction with one of the other preservation options, most rotating equipment should be rotated on a regular basis. Recommended interval is 2¼ turns per week.

NOTE: Confirm with the equipment OEM that turning their equipment will not cause damage. Also confirm that hydrodynamic bearings were not shipped from the factory with a thin plastic insulator between the bearings and journals. Many manufacturers ship equipment with these materials installed to prevent dissimilar metal corrosion during shipping and storage.

#### **Cosmoline type coating –**

In areas where the protection offered by Aerosol coatings may not be effective, a Cosmoline type coating may be applied. The areas to be coated, and the cautions for application are the same as those described for Aerosol coatings.

**Wax cloth, self-adhering, moldable (“ocean wrap”) –**

Wax cloth, self-adhering, moldable wraps (often referred to as “ocean wrap”) can be effective protection in the following locations: Shaft ends, exposed piston rods, exposed linkages, exposed handles and levers, and any bare metal items that may rust during outside storage that are able to be wrapped with these materials.

***NOTE: caution should be taken to assure that the covered area will be able to be cleaned without damage when the wrapping is removed to commission the equipment.***

**Temporary climate controlled shelter –**

A temporary shelter may be used for applications that require climate control during specific activities, or until a permanent shelter is erected. This may be used for: climate control during grouting activities during adverse weather conditions, assembly steps that require the area to be clean and dry, or equipment that should be field installed prior to erection of a permanent structure. This can be built from scaffold materials, wood, or other materials and covered with materials suitable to maintain the desired conditions. Care should be taken to assure proper ventilation, access and safe emergency egress.

**Poly Stretch Wrap –**

Some equipment is shipped to the construction site wrapped in heavy poly wrapping. This is often applied with VPCI Bags, VPCI canisters, desiccant packs or similar preservation materials. If possible, these should be provided with an access location (a zipper type door) that will allow access to maintain the preservative materials until the final construction stage when the wrapping is to be removed. Care should be taken to consider this as a confined space and ensure that entry for preservation activities is safe.

**Paint –**

Most equipment is painted before it is shipped from the factory. The usual function of the paint is to preserve the equipment in the field. During construction the paint may be mechanically damaged and require touch-up. Paint touch-up activities should be done correctly including the following: proper preparation, proper paint materials, proper application, proper PPE, and proper disposal of waste materials.

Care should also be taken to prevent damage from painting areas that do not, or should not be painted.

**CHOOSING PRESERVATION OPTIONS**

Choosing the proper preservation option is based on the recommendation of the Contractor and the approval of the Owner's Engineer. The following should be considered when choosing preservation:

- A. OEM equipment specific preservation recommendations
- B. Site Climate environmental conditions (temperatures, expected precipitation, humidity, air particulates, etc.)
- C. Location of equipment in relationship to roads, running units, or any area that may affect the preservation of the equipment
- D. Equipment specific preservation needs (what level of preservation is required to assure the equipment will be ready for commissioning)
- E. Availability of preservation materials

**E.8 AUDITS**

**Inspection Intervals**



The Owner's Engineer's or his representative is responsible to schedule audits of equipment that has been delivered to the construction site from storage. The audits should include a member of the Contractor's materials management team, to assure that all items are preserved as requested, and the equipment will be "usable condition" when ready to commission.

### **Preservation Audits**

The Field Preservation of the equipment delivered to site is to be audited every six months by at least one representative from the Contractor's Materials Management team, and the Owner's Engineers designated auditor(s). The Owner's Engineers designated auditor is responsible to schedule and coordinate this audit. This inspection is to assure that all items are preserved as requested, and the equipment is in "ready to use" condition

### **Scope of Audit**

This audit will be conducted every six months from delivery of the equipment to the jobsite, to review the storage of at least ten (10) stored equipment, selected by the audit team. The ten items should not include any items from the last three (3) audits unless they were part of a non-compliant finding from one of those audits.

**NOTE: Non-compliant equipment from a previous audit will not be part of the ten items that are part of the current audit.**

The scope of this audit will, at a minimum, include:

- A. Verification that the equipment is being preserved according to the chosen preservation option.
- B. The preservation method is effectively preventing corrosion or other damage to the equipment.
- C. Verification that the audited equipment is the correctly labeled.
- D. Verification that the equipment will be "ready to use" (no visible damage, corrosion, etc.)
- E. Determine if the preservation options used is effective, but should be re-applied.

If two or more of the audited items are found to be non-compliant in any of these audit categories, ten (10) more items will be selected for an extended audit. On completion of the extended audit, the audit team will review all of the findings and determine what type of corrective action, if any, is necessary.

The corrective action determination, and correction action, may include some of the following recommendations:

- A. Make immediate corrections required to correct the non-compliance
- B. Determine if the selected preservation code is effectively protecting the equipment.
- C. Expand the audit to include all similar equipment that may have the same preservation non-compliance.
- D. Recommend an action plan for the specific equipment to correct the current non-compliance.

The audit will be documented on the Audit Form (" E.9, Field Preservation Audit Form").

**E.9 Field Preservation Audit Form**

Date: \_\_\_\_\_

Audit Team Members:

\_\_\_\_\_

**Audited Equipment –**

Equipment Technical ID Number: \_\_\_\_\_

Description: \_\_\_\_\_

Preservation Option(s):

\_\_\_\_\_

Inspection Method (Visual, Borescope,  
Other): \_\_\_\_\_

Was equipment found to be stored in alignment with Preservation Option? (yes/no)

If not, describe non-compliance:

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Does the assigned preservation option properly protect the equipment? (yes/no)

If not, describe non-compliance:

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Is the audited equipment the correct as described in records? (yes/no)

If not, describe the finding:

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Was the audited equipment found to be “ready to use”? (yes/no)

If not, describe the finding:

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Comments and Recommendations:

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**NOTE:** Additional comments and findings may be added by attaching documentation to this form.

## 4.0 Foundations

### 4.1 General Design Requirements

4.1.1 This section provides guidelines for the pre-installation design of soil-supported (including pile-supported) reinforced concrete foundations supporting machinery.

4.1.2 The final detail design of the foundation shall be performed under the direction of a qualified engineer considering all possible forces, deflection limitations, vibration responses, geotechnical conditions, and mechanical and environmental requirements.

4.1.3 The development of the foundation dimensions should consider the layout of the equipment, the piping arrangement, maintenance and installation clearances, concrete cover required for anchor bolts, and the minimum outline dimensions recommended by the equipment vendor.

- a) The following information, as a minimum is typically considered for the foundation design.
- b) Outline drawing of machine assembly for dimensions of machine base and location, type,
- c) Location of machine bearing supports and magnitude of load at each point.
- d) Weight of machine, rotor components, and eccentricity of unbalanced mass.
- e) Vertical and horizontal locations of center of gravity for combined machine assembly and each component.
- f) Dynamic loads
  - i. Rotary machinery - Machine speed ranges for rotor components.
  - ii. Reciprocating machinery - Frequency of unbalanced primary and secondary loads.
- g) Magnitude, direction, and point of application of unbalanced forces and/or couples, both vertical and horizontal.
- h) Machinery vendor foundation recommendations, including acceptable vibration amplitude.

4.1.4 All machinery, including vertical in-line pumps, shall be supported by a reinforced concrete foundation. Machinery that requires an elevated installation may be supported on structural steel, or a mezzanine foundation, of adequate stiffness and strength.

NOTE: Elevated machinery may be directly supported by structural steel provided adequate stiffness and strength is provided. The intent of 4.1.4 is to discourage the use of concrete foundations without reinforcing steel and stilt supported equipment.

4.1.5 The recommended minimum foundation dimensions, the sizes and locations of the anchor bolts, and the forces applied by the machinery shall be obtained from the equipment vendors to aid in the design of the foundation.

4.1.6 The elevation of the top of the foundation should be set to allow a minimum thickness of grout of 25-50 mm (1-2 in.). The designer shall include in the elevation of the top of the foundation that a minimum of 10 mm (0.375 in.) of concrete will be removed to prepare the foundation for grouting. For special purpose equipment, a minimum thickness of grout should be 50 mm (2 in.)

NOTE: Consult the grout manufacturer to determine the maximum and minimum thickness of grout for an installation. The flowability and heat generation of a grout are important factors to consider when determining the minimum and maximum thickness for a specific grout pour. Reference Chapter 5 of this standard for additional requirements for machinery grouting.

4.1.7 The bottom of the foundation shall be placed at a sufficient depth below the ground to prevent damage to the machinery or piping by the effects of frost penetration.

NOTE: The foundation can be designed to accommodate the effects of frost penetration or for application in permafrost. A geotechnical investigation that determines the frost susceptibility of soils is essential. Proper drainage is essential to ensure that the soils do not accumulate excess water.

4.1.8 The design engineer should also consider incorporating the individual foundations of several machines in the same vicinity into one common foundation mat. When multiple machines are placed on a single mat foundation, the dynamic and static analysis should consider all possible loading arrangements and combinations of the machines to produce the most unfavorable effects on the supporting foundation, including partial foundation loading due to removal of individual units for maintenance.

NOTE: Consider incorporating the foundations of several individual machines in the same vicinity into one foundation. A large, combined mat foundation is sometimes equivalent to several closely

spaced individual foundations. Machinery with rolling element bearings that sit idle while adjacent to operating machinery could experience brinelling or other damage to the idle equipment bearings.

4.1.9 The structural design of all reinforced concrete shall be in accordance with ACI 318 Building Code Requirements for Structural Concrete. Additional information regarding on design criteria, methods, and procedures may be obtained from ACI 351.3R– Report on Foundations for Dynamic Equipment and PIP STC01015 Structural Design Criteria.

4.1.10 The foundation design shall be capable of resisting all applied dynamic and static loads specified by the machinery manufacturer, loads from thermal movement, dead and live loads as applicable or as specified in the local building codes, wind or seismic forces, and any loads that may be associated with installation or maintenance of the equipment. Operating loads apply to any loads possible in the operating range.

4.1.11 For design, the loads specified in 4.1.10 shall be combined to produce the most unfavorable effect on the supporting foundation, but the effects of both wind and seismic activity need not be considered to act simultaneously.

NOTE: ASCE 7, Minimum Design Loads for Buildings and Other Structures, may be used as a guide for determining design loads unless otherwise specified by an applicable local building code, user design criteria, or the manufacturer's specifications. Design load combinations may be as specified in ACI 318.

4.1.12 The foundation shall have adequate strength and rigidity to meet the deflection limitations specified by the machinery manufacturer when subjected to all design load combinations specified in 4.1.13. The foundation shall be free of resonant frequencies within a minimum of  $\pm 20\%$  of the operating speed range of the equipment. If the analysis indicates that the foundation resonant frequency separation margins still cannot be met or that a non-critically damped response peak falls with the operating speed range and the purchaser and vendor have agreed that all practical design efforts have been exhausted, then acceptable amplitudes shall be mutually agreed upon by the purchaser and the vendor.

4.1.14 Machinery loads shall be supported directly by the foundation or primary steel or concrete tabletop. Auxiliary structures, such as access platforms and cranes, shall be supported independently of the machine supports and foundations.

NOTE: Machinery mounted on the top of the columns and/or major cross beams of a properly designed elevated frame foundation complies with this provision.

4.1.15 The driven machinery and the driver shall be supported from a common foundation.

NOTE: The common foundation is to reduce the possibility of differential settlement between the two components.

## 4.2 Geotechnical Design

4.2.1 Machinery foundations shall be proportioned for all loading conditions with respect to soil conditions. The foundation shall be designed to support the applied static service loading without exceeding the allowable bearing capacity of the soil (refer to 4.2.3) or the allowable limits for settlement to prevent damage to piping system connections, internal machinery alignment, or other connecting auxiliary equipment.

4.2.2 In the absence of known soil parameters, a qualified geotechnical consultant (soil specialist) shall establish the soil properties necessary for foundation design. Required soil properties should include allowable bearing capacity, settlement criteria, soil density and Poisson's ratio. For dynamic analysis additional properties should include dynamic shear modulus and shear wave velocity.

4.2.3 The maximum soil pressure due to static loads shall not exceed 50% of the allowable soil bearing capacity. The maximum soil pressure due to static and dynamic load combinations shall not exceed 75 % of the allowable soil bearing capacity. Allowable soil bearing capacity for load combinations including wind or seismic loads shall be determined by a qualified geotechnical consultant. Uplift of the foundation due to overturning moment from the equipment unbalanced forces shall be avoided (i.e. the soil bearing pressure shall be compressive across the footprint of the foundation).

4.2.4 The foundation shall be of adequate size to provide uniform bearing pressure and minimal differential settlement. To reduce the potential for differential static settlement, the center of mass of a machine foundation should coincide with the centroid of the soil foundation or pile resistance. The

horizontal eccentricity should be limited to 5% of the corresponding foundation dimension, or to the centroid of the pile group for piled foundations.

#### 4.3 Foundation Design & Analysis

4.3.1 If a dynamic analysis is not performed, the designer should use ACI 351.3R– Report on Foundations for Dynamic Equipment “rules of thumb” methods for proportion block foundation dimensions.

4.3.2 A dynamic analysis shall be performed on all foundation and structures supporting heavy machinery (greater than 500hp Centrifugal and 200hp reciprocating), all table-top-supported equipment and all special purpose equipment, unless otherwise specified.

4.3.3 A foundation dynamic test plan, if required, shall be developed during the design phase and approved by the User. Testing shall be conducted as soon as practical once machinery is installed in order to allow time to initiate corrective measures if vibration problems are discovered.

4.3.4 The dynamic analysis shall be performed in accordance with ACI 351. 3R– Report on Foundations for Dynamic Equipment including the following:

4.3.4.1 For shallow foundations, the response of the soil subject to dynamic loadings shall be based on "Elastic Half Space Model" theory.

4.3.4.2 The method for determining the response of piled foundations subject to dynamic loadings shall consider soil-pile interaction and dynamic group effects and be subject to approval by the User's Engineer.

4.3.4.3 The dynamic modulus of elasticity of concrete,  $E$  or  $E'$ , for use in dynamic analysis shall be calculated per ACI 351. 3R– Report on Foundations for Dynamic Equipment or other appropriate reference as determined by User's engineer.

4.3.4.4 For one or two degrees of freedom models, all undamped natural frequencies shall be outside the range of 0.7 to 1.3 times the machine operating speeds.

4.3.4.5 For multi-degrees of freedom analyses, frequencies associated with modes with effective mass greater than 5 percent of the total mass of the model shall be outside the range of 0.8 to 1.2 times the operating speeds.

4.3.4.6 Soil properties for use in the analysis shall be based on the results of a soil investigation. The foundation system shall be analyzed considering a range of soil shear modulus values as follows:

4.3.4.6.1 From 0.5 to 1.5 times the nominal value.

4.3.4.6.2 If the nominal soil shear modulus is determined by a direct soil testing method acceptable to User's Engineer (e.g., cross-hole field measurement or resonant column test), the range may be reduced to 0.75 to 1.25 times the nominal value.

4.3.4.7 Damping shall be limited as follows:

2.1.1.7.1.4.3.4.7.1 Total geometric damping shall not exceed 2/3 of the theoretical value or 0.7 for all modes.

4.3.4.7.2 Material damping for shallow foundations shall not exceed 0.05. Material damping shall not be used for piled foundations.

4.3.4.7.3 For piled foundations, the geometric damping ratio of the pile group, excluding the pile cap, shall not exceed 0.10 for rocking modes, nor 0.15 for horizontal, vertical, and torsional modes.

4.3.5 Criteria for peak-to-peak displacement and/or peak velocity at points on the machine and foundation shall be specified by the User's Engineer, OEM, or established per the guidance given in ACI 351.3R, as part of the dynamic analysis.

4.3.6 Foundation configuration shall be as follows:

4.3.6.1 Foundation design shall consist of clean simple lines. Beams, columns, and slabs shall be of uniform rectangular shapes. Pockets, where vapors could accumulate, are not permitted. Provision shall be made to drain oil and rainwater from under the equipment. Sufficient space shall be provided for installation, maintenance, operation, piping, and anchor bolts.

4.3.6.2 (\*) If specified, the foundation mat shall be proportioned to be rigid relative to the supporting soil. Refer to ACI 351.3R– Report on Foundations for Dynamic Equipment - for recommendations.

4.3.6.3 The foundation design for variable-speed equipment requires that the foundation be checked for resonant frequencies through the entire range of operating speeds. Machinery start-up procedures shall consider the potential for operating equipment at or near the natural frequency of the foundation. Start-up hold speeds should be set to avoid the foundation resonance range.

4.3.7 Reciprocating machinery and associated pulsation suppression devices shall be supported directly on a rigid foundation, as follows:

4.3.7.1 Supports for the crankcase, distance pieces, cylinder, and pulsation dampers shall be an integral part of the block (supported by a common foundation).

4.3.7.2 Baseplates or soleplates shall be anchored into the foundation.

4.3.7.3 Foundation design shall minimize re-entrant type corners and other details causing stress concentrations.

4.3.8 Reciprocating compressor trains in the same vicinity should be arranged (when practicable) with the crankshafts parallel to each other and not in line and the design shall be performed by a qualified foundation engineer.

NOTE: "Same vicinity" assumes that the trains are located close enough together that a common mat could be needed. By arranging them in parallel the foundation gets wider in the direction needed to resist rocking unbalance. Also, if trains are oriented in a line on a common mat, differential settlements causing shaft misalignment may be increased. This statement does not imply that a suitable in line arrangement cannot be designed, but by arranging them in parallel, some problems may be minimized.

4.3.9 Static design of foundations for reciprocating machines shall consider the following:

4.3.9.1 Weight of all machines on the foundation.

4.3.9.2 Unbalanced forces and couples, as specified by the machine Manufacturer.

4.3.9.3 Individual piston forces.

4.3.10 Dynamic design of foundations for reciprocating machines shall be as follows:

4.3.10.1 Primary forces, couples, and moments shall be applied at machine speed over the full range of specified operating speeds for calculation of primary amplitudes.

4.3.10.2 Secondary forces, couples, and moments shall be applied at twice machine speed over the full range of specified operating speeds for calculation of secondary amplitudes.

4.3.10.3 Total amplitudes shall be calculated by combining, in-phase, primary and secondary amplitudes. No total peak-to-peak amplitude on the foundation shall exceed 0.002 in. (0.05 mm).

4.3.11 (•) If specified, reciprocating compressor foundations shall be designed in accordance with Gas Machinery Research Council (GMRC) TR 97-2.

#### 4.4 Rectangular Block Foundation Design

4.4.1 This section provides guidelines for machinery block foundation design. The final detail dimensions and reinforcing steel requirements are dependent on a structural (static, dynamic, or both) analysis or other means to judge that the foundation will perform adequately.

4.4.2 A machinery block foundation supported on soil without piles should have a minimum mass ratio of three times the mass of the machinery for centrifugal and rotary screw machines and five to ten times the mass for reciprocating machines, unless dynamic analysis demonstrates that a lesser value will perform adequately as described ACI-351.3R – Report on Foundations for Dynamic Equipment.

4.4.3 For machinery block foundation supported on piles the ratio of the pile cap weight to the equipment weight should not be less than 2.5:1 for rotary equipment and 4:1 for reciprocating equipment, unless a dynamic analysis indicates that a lower weight ratio performs acceptably, as described ACI-351.3R– Report on Foundations for Dynamic Equipment.

4.4.4 The foundation shall be of sufficient width to prevent rocking and adequate depth to permit properly embedded anchor bolts. The width of the foundation should be at least 1.5 times the vertical distance from the base to the machine centerline.

4.4.5 The foundation shall be of sufficient width to accommodate the grout between the edge of the baseplate and the edge of the foundation.

4.4.6 The foundation shall provide a minimum factor of safety of 1.5 against overturning and sliding due to all applied forces and couples.

4.4.7 A larger factor of safety may be required depending on the type of soil.



4.4.8 The designer should neglect the contribution of passive resistance to stability if the possibility exists of soil loss due to excavation or erosion around the foundation after it is constructed.

4.4.9 The center of gravity of the machine foundation system shall be as close as possible to the lines of action of the unbalanced forces.

4.4.10 Block foundations supported by piles should be designed so that the width of the pile cap is not less than the vertical distance from the bottom of the pile cap to the centerline of the machine shaft.

4.4.11 The top of the finished foundation shall be elevated a minimum of 200 mm (8") above the finished elevation of the floor slab or grade to prevent damage to the machinery from runoff or wash-down water.

4.4.12 Reinforcement shall be designed per ACI 318 to resist all static loads, dynamic loads, and thermal stresses.

4.4.13 A minimum amount of reinforcing steel shall be specified to resist temperature and shrinkage stresses. Refer to ACI 351.3R for guidance on quantity and distribution of reinforcement depending on the foundation dimensions and type of supported machinery.

4.4.14 Reinforcing steel shall be placed on all exposed faces of foundations supporting machinery and be continuous from face to face with proper lap splices, and minimum concrete clear cover shall be provided per ACI 318.

NOTE 1: The required reinforcing steel necessary to resist the internal forces and moments is relatively small in most block foundations because of their massive size. Therefore, the minimum quantity of steel can be controlled by the amount of steel necessary to meet temperature and shrinkage requirements.

NOTE 2: Although ACI 318 does not specifically address the required steel in a block foundation, the requirement of 0.18 % of the cross-sectional area of the concrete can be sufficient for the amount of temperature reinforcing steel in a foundation using grade 60 reinforcing. If a foundation size greater than 1.20 m (48 in.) thick is required for stability, rigidity, or damping, then reinforcement quantities can be overly conservative and costly, and a minimum reinforcement of 22.2 mm (#7) bars at 30 cm (12 in.) on center on all foundation faces is recommended. Additional considerations and guidance on thermal crack control can be found in ACI 207.2R-07, Report on Thermal and Volume Change Effects on Cracking of Mass Concrete.

4.4.15 The maximum reinforcing bar spacing for perimeter reinforcing shall not exceed 300 mm (12 in.) on center, and the minimum bar size shall not be less than 12.7 mm (#4).

NOTE: Tie bars of 9.5 mm (#3) are typically acceptable to be used for prefabricated spiral wound reinforcements.

4.4.16 Block foundations for reciprocating machines shall be embedded adequately into the soil for lateral restraint and damping as quantified by foundation dynamic analysis.

NOTE Typically, the embedment depth will range from 20 % to 50 % of the total depth of the foundation.

NOTE A typical rectangular block foundation detail is shown in Annex B, Figure B.1

#### 4.5 Vertically Suspended Pump Foundation Design

4.5.1 The foundation shall be designed so that the pump can or base is directly attached to a baseplate and is removable without damaging the grout.

NOTE This feature requires that the pump be provided with an engineered baseplate that is grouted to the foundation.

4.5.2 The foundation shall be designed with inner foundation liners to prevent water from contacting the pump can. The foundation shall be watertight. Drain holes or openings in the foundation are not acceptable unless positive drainage can be assured. Consideration shall be given to ground water table proximity to the vertical suspended can pump foundation to determine if there is a need for anchoring.

4.5.3 A minimum annular clearance of 50 mm (2 in.) between the outside of the pump can and the inner liner surface of the foundation cavity shall be maintained unless otherwise specified.

**NOTE** Pumps in low-temperature service that require insulation (and possibly heating outside of the can to avoid ice formation) will need greater clearance to accommodate finished insulation dimensions and piping that may be external to the pump can.

4.5.4 The foundation shall be designed to allow sufficient axial clearance to the pump can, to prevent distortion due to thermal growth. The bottom surface of the cavity shall be at least 300 mm (12 in.) beneath the bottom of the pump can (refer to the typical suspended can pump detail in Annex B, Figure B.2).

#### 4.6 Elevated Frame Foundation Design

4.6.1 Elevated (table-top) structures for rotary machinery shall be designed as follows:

4.6.2 The upper table and the foundation mat or pile cap shall be rigid in the horizontal plane.

4.6.3 The width of the foundation mat or pile cap shall not be less than the vertical distance from the bottom of the mat or pile cap to the centerline of the machine shaft.

4.6.4 The weight of the upper table plus 1/2 of the weight of the columns shall be greater than the weight of the machine(s).

4.6.5 The foundation mat or pile cap shall not weigh less than the combined supported weight of the upper table, columns, or walls, and the machines resting upon them (including baseplates).

4.6.6 The effects of short circuit couples, faulty synchronizing conditions, oil whirl frequency, rotor critical speeds, and background vibration shall be considered.

4.6.7 Transverse frames or walls shall have the same vertical natural frequencies, within 5 percent.

4.6.8 Torsional and transverse horizontal natural frequencies shall be determined considering the whole structure. Individual transverse bents or walls shall have the same transverse horizontal natural frequencies, within 5 percent.

4.6.9 Multi degrees of freedom shall be considered for frames if a single degree of freedom system will not lead to an acceptable mathematical representation of the structure. A multi-degree of freedom analysis shall be used for foundations with walls.

4.6.10 Loaded beam and slab natural frequencies in both the horizontal and vertical directions, where possible, shall be above any machine speed. If beams or slabs require design parameters to have natural frequencies below machine speed, allowance shall be made for the stiffening effect of the baseplates and the machine.

4.6.11 Condensers and turbines shall be supported on a common foundation.

4.6.12 The height of an elevated frame foundation shall be kept to a minimum. The height shall be determined by the minimum number of straight runs of process piping, the required slope of the lube oil drain piping, or other mechanical and maintenance requirements.

#### 4.7 Effects of Equipment Design on Surrounding Area

4.7.1 The effects of vibrating equipment on the surrounding area shall be investigated. Consider the location and degree of isolation required for the foundation with respect to adjacent sensitive equipment, disturbance to people, and the effects to the supporting and/or adjoining structures.

**NOTE** In addition to taking measures to isolate the foundation from an adjacent slab or structure in the early stages of the project, it may be possible to locate the equipment to reduce the transmission of vibrations to the surroundings. The actual method of isolating the foundation from adjacent structures is left to the designer. The intent of this provision is to call attention to the need for foundation isolation due to vibration generated by the machinery.

4.7.2 The effects foundation construction may have on adjacent equipment, people, egress requirements, existing foundations supporting adjacent structures, and manufacturing production shall be considered in the design stages. Precautions (for example, trench boxes, sloping, proper spoil location) should be taken in the design to protect the safety of personnel directly exposed to the construction or working near construction.

**NOTE** One of the best times to address the effects that construction can have on the existing facility and personnel in the area is during the initial design stages. Proper location of the foundation may reduce the construction difficulties associated with protecting personnel and maintaining existing production.

#### 4.8 Concrete Design



4.8.1 Foundation materials shall be selected to prevent premature deterioration due to chemical attack or exposure to oil. In an aggressive environment, consider the use of protective coatings such as galvanizing or epoxy, polymer concrete, silica fume, calcium nitrite, additional concrete cover or any combination of these to protect the reinforcing steel.

NOTE Silica fume and fly ash admixtures can reduce concrete permeability. Calcium nitrite protects the steel and reduces permeability, so it can be used in combination with silica fume or fly ash.

4.8.2 All concrete shall have a minimum compressive strength of 28 MPa (4000 psi) at 28 days, unless otherwise specified by the user. Concrete mix shall contain air entraining agent sufficient to produce 4% to 6% entrained air. Other additives such as fly ash, silica fume, and calcium nitrite should be considered and if required, specified on the plans.

NOTE Use of fly ash as a substitute for up to 30% of the Portland cement is encouraged to reduce thermal effects and decrease permeability.

4.8.3 High early strength concrete shall not be used unless approved by the equipment user. If early strengths are desired for stripping forms or placing equipment, use mid to high range water reducing additives to achieve rapid placement and achieving early strengths.

4.8.4 When foundation thicknesses are greater than 120 cm (48 in.) thick, the engineer shall consult ACI 207.2R-07 and other ACI mass concrete requirements for concrete mixes and installation.

#### 4.9 Anchor Bolt and Reinforcing Steel Design

4.9.1 All reinforcing steel shall conform to the requirements of ASTM A615, Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement, Grade 60 with a minimum yield strength of 414 MPa (60 ksi).

4.9.2 Equipment shall be installed on baseplate(s), and the direct attachment of equipment feet to the foundation using the anchor bolts shall not be permitted. Baseplates shall be of sufficient strength and rigidity to transfer the applied forces to the foundation.

NOTE Anchor bolts extending through equipment feet are typically permitted on large reciprocating compressors and similar equipment with high vibrating forces.

4.9.3 Baseplates shall be attached to the foundation with anchor bolts in accordance with 4.9.4 through 4.9.16

4.9.4 Anchor bolts alone or in combination with shear attachments on the equipment baseplate shall be capable of transmitting the loading applied by the machinery and the design loads specified in 4.1.11 combined to produce the most unfavorable effects. The transfer of forces by means of grout adhesion of the baseplate to the foundation shall not be considered in the design.

NOTE: The intent of 4.9.4 is to neglect the contribution of the grout bond strength for transferring forces from the baseplate to the foundation. Although this adhesion may exist, a positive means of attachment by anchor bolts or shear keys is required.

4.9.5 The required embedment of anchor bolts in the foundation shall be determined by accepted engineering practices for cast-in-place anchors, by equipment or grout vendor recommendations for epoxy-grouted anchors, or by certified vendor information for adhesive type anchors.

4.9.6 The anchor bolt embedment shall be adequate to resist the torque values specified in the grouting section of this standard or the forces applied by the equipment or required by applicable codes.

4.9.7 Adhesive anchors having a bond strength in tension that is less than the anchor bolt steel strength in tension or less than the concrete breakout strength in tension are not permitted.

4.9.8 The design of anchor bolt embedment may be as suggested in Annex Figure B.3 and Figure B.4 or ACI 318. ACI 318 or ACI 349.

4.9.9 For general-purpose anchor bolts the bolt material shall be ASTM F1554 Grade 36.

4.9.10 For high strength special-purpose anchor bolts the bolt material shall be ASTM F1554 Grade 105 and shall be hot-dipped galvanized in accordance with ASTM A153.

4.9.11 Galvanizing preparation on ASTM F1554 Grade 105 steel shall be abrasive blasting, because acid pickling may contribute to hydrogen embrittlement in high strength steels.

4.9.12 Anchor bolts for reciprocating compressors shall be ASTM A193 B7M.

4.9.13 (●) If specified, when the equipment is to be installed in an aggressive environment, the anchor bolts shall be fabricated from a corrosion-resistant material capable of resisting chemical attack. Not only is this necessary to prevent the reduction of the anchor bolt net section, but it will also facilitate the future removal of the equipment for maintenance.

4.9.14 The anchor bolt material selected for use shall be clearly marked on the structural drawings. This information is not only required for fabrication but will be helpful in future modifications to the foundation.

4.9.15 Anchor bolts shall be installed using sleeves, unless otherwise specified by the equipment user.

4.9.16 The inner diameter of the sleeve shall be at least twice the diameter of the anchor bolts.

4.9.17 The length of the sleeve shall be the greater of 150 mm (6 in.) or sufficient length to permit adequate elongation of the anchor bolt during tightening. This sleeve length is typically 10-15 bolt diameters.

4.9.18 The minimum distance from the edge of the anchor bolt sleeve to the edge of the foundation shall be the greater of 150 mm (6 in.), four anchor bolt diameters, or the edge distance necessary to transfer the forces in the anchor bolts to the concrete foundation.

NOTE 1 Anchor bolt sleeves are used to permit a section of the bolt to be protected from concrete or grout adherence. This section of the bolt is kept free from the concrete and grout to permit the proper elongation of the anchor bolt during the tightening procedure. Generally, a stretch length of 10 to 15 bolt diameters is adequate for tensioning. As shown in Figure B.3 and Figure B.4 of Annex B, the bolt head extends a minimum of 5 bolt diameters below the bottom of the sleeve. This allows adequate room for the concrete anchorage cone to develop. Also, the portion of the anchor bolt above the top of the sleeve to the bottom of the baseplate is protected from grout adherence to allow for "stretching" of the anchor bolt. Typically, urethane foam pipe insulation is used for this purpose.

NOTE 2 Additional details and requirements on anchor bolt preparation for grouting is specified in Section 5 of this standard.

4.9.19 Anchor bolts for machinery shall be cast-in-place, secured by epoxy grout, or adhesive type. Mechanical expansion-type anchors are not permitted. "J" and "L" bolts are not permitted.

4.9.20 Epoxy-grouted anchor bolts shall be studs with nut(s) and washer.

4.9.21 The washer shall conform to ANSI B18.22.1 and nut(s) shall be full size, heavy hex conforming to ANSI B18.2.2.

4.9.22 Anchor bolts shall project a minimum of 2 threads above the fully engaged nut(s).

#### 4.10 Drawing Design Information

4.10.1 In addition to the structural information necessary to construct the foundation, the drawings shall clearly indicate the elevation of the top of the finished (poured) foundation and the bottom of the baseplate, the locations of the anchor bolts and sleeves, the anchor bolt diameter, the depth of embedment into the foundation of the anchor bolts, the length of the anchor bolts threads, and the length of the anchor bolt projections.

NOTE Refer to the typical foundation detail in Annex B, Figure B.1, to clarify the location of the finished foundation level.

4.10.2 Structural drawings shall specify the 28 day minimum compressive strength of the concrete foundation, the yield strength of the reinforcing steel, the required admixtures such as air entraining agent, fly ash, silica fume, calcium nitrite, maximum aggregate size and reinforcing bar coatings.

NOTE Not only is this information necessary for construction of the foundation, but it may also be necessary in the future to identify the material properties for possible modifications or investigations of the foundation.

4.10.3 This information shall be placed on the design drawings permits its permanent retention with the foundation structural details.

4.10.4 The anchor bolt and sleeve materials, and anchor bolt torque requirements shall be specified on the structural drawing.

4.10.5 The allowable soil bearing capacity and other soil properties (refer to 4.2.2) shall be represented on the structural drawings.

#### 4.11 Soil Condition Design

4.11.1 Foundations designed to be directly supported on soil shall be constructed on undisturbed soil or fill material properly compacted in accordance with sound engineering practices and the project specifications.

NOTE The statement "sound engineering practices" requires that the fill be constructed from suitable fill material that has been properly installed and compacted under the guidance of a qualified soil engineer.

4.11.2 The contractor shall require a qualified soil specialist to inspect the soil supporting the foundation and determine its adequacy to provide the required bearing capacity. The contractor shall provide the equipment user with written documentation by the qualified soil specialist certifying the soil supporting the foundation has the minimum specified bearing capacity.

NOTE This requires the soil beneath the foundation to be examined by a qualified soil specialist or geotechnical engineer suitable to the equipment user before proceeding with the construction of form work or placement of concrete. It may also require that a test be performed to verify the safe bearing capacity of the soil.

4.11.3 Prior to the start of construction, the contractor shall submit to the equipment user for acceptance and review the qualifications of the person responsible for performing the soil inspection specified in 4.11.

#### 4.12 Formwork Design

4.12.1 All formwork and form accessories shall be in accordance with ACI 301 Specifications for Structural Concrete or PIP STS03001 Plain and Reinforced Concrete Specification.

4.12.2 All corners on permanently exposed surfaces or on edges of formed joints shall have a chamfer of at least 19 mm ( $\frac{3}{4}$  in).

4.12.3 Removal of formwork shall be in accordance with ACI 301 and PIP STS03001.

#### 4.13 Reinforcing Steel Design and Installation

4.13.1 Reinforcing steel materials, fabrication, and placement shall be in accordance with ACI 301 and PIP STS03001.

4.13.2 All reinforcing steel shall conform to the requirements of ASTM A615, Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement, Grade 60, with a minimum yield strength of 414 MPa (60 ksi)

#### 4.14 Concrete Mixing and Placement Procedures

4.14.1 Materials, formwork, handling, mixing, and placement of concrete or mass concrete shall conform to ACI 301 Specifications for Structural Concrete and PIP STS03001 Plain and Reinforced Concrete Specification.

4.14.2 At the point of delivery, concrete shall have maximum slump of 100 mm (4 in.) when achieved by water alone. If a slump greater than 100 mm (4 in.) is required for proper placement of concrete, it may be increased up to 200 mm (8 in.) using a high-range water-reducing agent.

### 5.0 Baseplate, Soleplates and Grouting General

5.1 The designer shall produce detailed design information of the grout layout for special-purpose machinery. Grout layout drawings shall be completed during engineering design and shall be submitted to the purchaser for review. These drawings shall be included in the design package for the machinery foundation.

5.2 Grouting design drawings (or typical datasheets) shall provide all necessary information for the installation of equipment on baseplates. These requirements do not necessarily require a

separate drawing, but the information shall be provided in some fashion to the user. This information shall include, but not be limited to, the following:

- a) expansion joint location,
- b) elevation to top of baseplate,
- c) elevation to top of grout,
- d) grout materials and estimated quantities, grout pocket location (if any), - A depression formed or chipped into the foundation to accommodate a rail, soleplate, or anchor bolt
- e) grout forming details (that deviate from Part C – Chapter 5 Annex G) and head-box elevation,
- f) baseplate grouting and vent holes,
- g) anchor bolt location and projection,
- h) grout pin locations and quantity (if used),
- i) shimming and leveling screw requirements.

### 5.3 Baseplate and Soleplate Design

The purpose of this section is to provide the foundation designer with baseplate design criteria necessary for proper installation.

5.3.1 All equipment shall be installed on baseplates or soleplates.

5.3.2 All baseplate or soleplate outside corners shall have a minimum 50 mm (2 in.) radius (in the plan view) to prevent cracking of the foundation grout due to stress concentration at the corners. All baseplates should have radiused corners appropriate to the baseplate design.

Note: For baseplates larger than API 610 or API 617 consider a larger corner radius dimension.

5.3.3 All baseplate anchor bolt holes shall have a minimum 3 mm (1/8 in.) diametral clearance with the bolt to allow for field alignment of baseplates.

5.3.4 Baseplate machined surfaces shall extend at least 25 mm (1 in.) beyond the outer three sides of equipment feet as installed.

NOTE: This provides sufficient area for leveling.

5.3.5 Baseplates shall be provided with vertical jacking screws combined with leveling pad (Part C – Chapter 5 Annex H)

5.3.5.1 Shims and wedges shall not be used.

5.3.5.2 Shims, dual wedges, or adjustable supports shall not be grouted in and become a permanent part of the foundation.

NOTE Shims and wedges, if left in place after grouting, can cause “hard” spots that interfere with the ability of grout to provide uniform base support. They can also allow moisture penetration and the resultant corrosion and grout spalling.

5.3.6 Elevation adjustment screws or nuts placed on the anchor bolt underneath the baseplate are not permitted under the baseplate that will be grouted in and become a permanent part of the foundation. This allows the baseplate to be supported by the grout, not by the leveling devices.

5.3.7 Baseplate leveling jackscrews shall be provided with leveling pads as shown in Annex (Part C – Chapter 5 Annex H ).

5.3.8 Typical baseplate jack-bolt arrangements for leveling are shown in Part C – Chapter 5, Annex F and Annex G.

5.3.9 The bottom of baseplates between structural members should be open.

5.3.9.1 When the baseplate has a covered top and is to be grouted, it should be provided with at least one grout hole having a clear area of at least 0.01 m<sup>2</sup> (20 in.<sup>2</sup>) and no dimension less than 10 cm (4 in.) in each bulkhead section.

5.3.9.2 These holes shall be located to permit grouting under all load-carrying structural members. Where practical for general-purpose equipment, the holes should be accessible for grouting with the equipment installed and should have 12 mm (½ in.) raised-lip edges.

5.3.10 Baseplate requirements stated in various API equipment standards (e.g. API 610, API 676, and API 685) supersede 5.3.9.

5.3.11 Vent holes of at least 12 mm (½ in.) in size should be provided at the highest point of and in each bulkhead section of the baseplate. These measures allow for controlled grout placement and verification that each section is filled with grout.

5.3.12 Vent holes of approximately 12 mm (½ in.) in diameter on 46 cm (18 in.) centers not exceeding shall be provided.

5.3.13 When specified, grouting pins of #6 reinforcing bar should be provided around the perimeter of the baseplate or soleplate on 150 mm (6 in.) centers to prevent delamination between the concrete foundation and the epoxy grout.

5.3.14 Grouting pins should be set in epoxy with a 100 mm (4 in.) minimum embedment depth before installation of grout on foundation and should not project above concrete higher than ⅔ of grout pour depth

5.3.15 Grouting pins are typically only required where the grout extends beyond the perimeter-edge of the baseplate 152mm (6 in.) or more.

5.3.16 When specified by the user or their designated representative, sole plates should be nickel plated for corrosion resistance according to ASTM B733-04 Type V, Service Condition SC4, Class I.

#### **5.4 Selection of Grout**

Unless otherwise specified by the User, all machinery shall be grouted using epoxy grouts. Epoxy grout shall be in accordance with the following physical properties

5.4.1 Minimum compressive strength (ASTM C579, Method B modified, load rate II): 80 MPa (12,000 psi) at 7 days

5.4.2 Maximum unrestrained linear shrinkage is no more than 1.0 percent when tested according to ASTM C531 after cured.

5.4.2.1 Maximum coefficient of thermal expansion (ASTM C531):  $54 \times 10^{-6}$  mm/mm/°C ( $30 \times 10^{-6}$  inch/inch/°F)

5.4.2.2 Maximum creep (ASTM C1181):  $5 \times 10^{-6}$  mm/mm (0.005 inch/inch), tested at 20°C (70°F) and 60 °C (140 °F) with 2.8 MPa (400 psi) applied vertical load

5.4.2.3 Minimum bond strength of epoxy grout to concrete (ASTM C882): 14 MPa (2000 psi)

5.4.2.4 The maximum allowable volume for a grout pour to control temperature within allowable limits shall be agreed by the Vendor and User.

5.4.2.5 Vapors shall be within OSHA 1926.55 allowable limits for personnel and the Vendor shall specify appropriate PPE.

5.4.3 The use of rapid-flow epoxy grouts shall be limited to applications where the depth of the grout pour is less than 19 mm (¾ in.). The reduction of aggregate quantity in grout mixtures to improve flow properties is not permitted. Rapid-flow epoxy grouts shall not be used unless specifically approved by the user.

Note: Typically, rapid-flow grouts are only used for grout pours of less than 19 mm ( $\frac{3}{4}$  in.).

5.4.4 [•] If approved by the user, a layered combination of non-shrink cement and epoxy grout may be used for machinery with large baseplates that have structural webs deeper than 9 in. as follows:

NOTE 1 The multi-layer pour does not necessarily have to be a combination of epoxy and cementitious grouts. It can be a multi-layer pour of epoxy grout in accordance with the grouting manufacturer's instructions as specified by the user's designated representative.

NOTE 2 Cementitious grouts have been used as "filler" materials to reduce the amount of epoxy grout required where temperature is not of concern. This type of grout is typically used as a "filler" inside structural steel baseplates; however, it is not recommended to layer pour sandwiched cementitious between epoxy pours.

5.4.5 Multi-layer pours using cementitious grouts extend installation time by many days.

5.4.5.1 The first layer for this type of installation shall be an epoxy grout poured to a level that is flush with the bottom of the baseplate. A primary perimeter pour is required to lock the baseplate into its leveled position and to seal the outer perimeter in preparation for the next pour.

5.4.5.2 A secondary pour of epoxy grout is then required to interlock all structural members and to ensure adequate support. This is particularly important if internal stiffeners are also used to support machinery mounting surfaces.

5.4.5.3 The second layer may be a non-shrink cementitious grout poured to a level that is approximately 50 mm (2 in.) from the underside of the baseplate decking.

5.4.5.4 The baseplate may also be completely filled with epoxy if required by the designated machinery representative. An all epoxy filled baseplate may require several pours so as to not exceed the grout manufacturer's maximum pour thickness.

5.4.5.5 The top layer shall be an epoxy grout and shall be poured to the top of the baseplate.

5.4.5.6 The successive layers for this type of installation shall not be done until the previous layer is properly cured. The grout provider can give guidance proper cure time.

## 5.5 Expansion Joints

5.5.1 Expansion joints shall be incorporated into large epoxy grout pours to reduce the possibility of cracking, especially when machinery-to-grout temperature differentials of at least 30 °C (50 °F). Expansion joints should be placed at approximately 1.4 m to 2.8 m (4 ft. to 6 ft) intervals in the grout foundation but shall not interfere with cross members and be at least 76 mm (3 in.) from foundation or leveling bolts.

5.5.2 Expansion joints should be made from 12 mm to 25 mm ( $\frac{1}{2}$  in. to 1 in.) thick closed-cell neoprene foam rubber. Polystyrene may also be used. Ensure that the expansion joint material is compatible with the grout.

5.5.3 Expansion joints require sealing after the grout has cured with elastic epoxy seam sealant (liquid rubber) or RTV silicone rubber (room temperature vulcanizable).

## 5.6 Grout Design for Auxiliary Equipment

When specified by the user or his/her designated representative, consoles and other auxiliary equipment skids should be installed with composite grout pours as specified in 5.4.4.



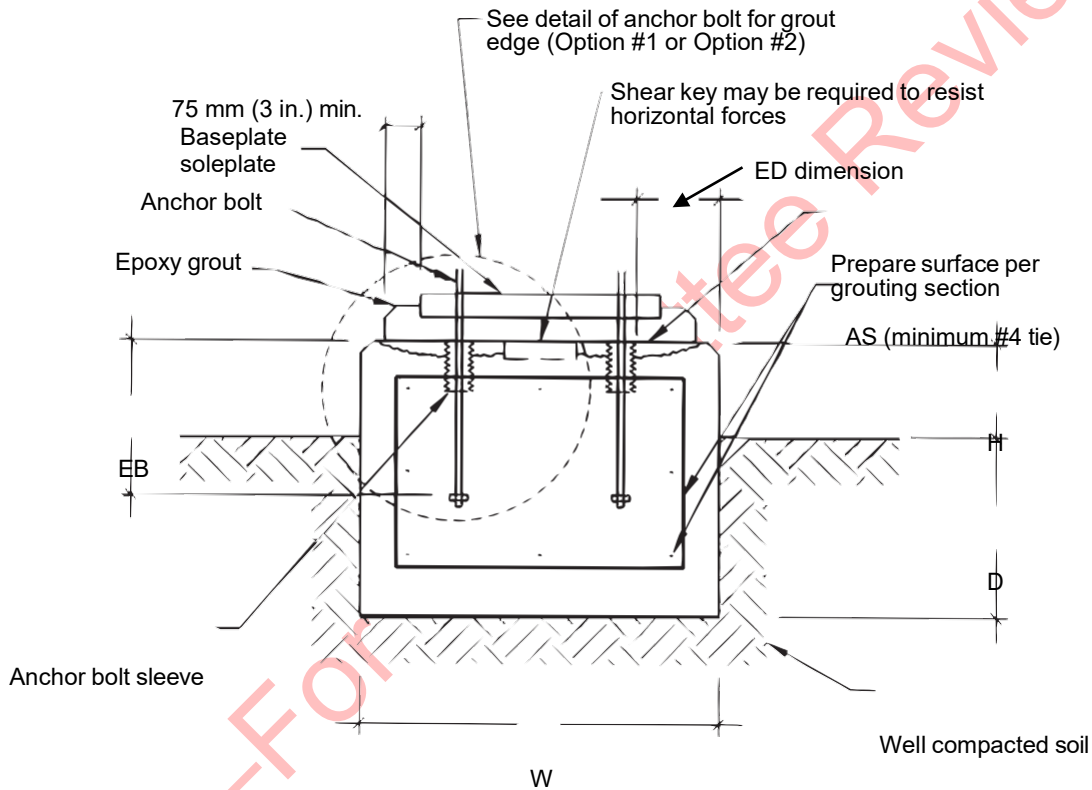
## **5.7 Pre-grouted baseplates**

As an alternative to many of the problems associated with field grouting of ANSI/API pump, and some other general-purpose baseplates, equipment baseplates may be pre-grouted at the equipment manufacturer's facility prior to shipment. This procedure involves inverting the equipment baseplate, filling all of the baseplate bottom area with grout, and allowing the grout to cure prior to final machining of the top mounting surfaces. This method of pre-grouting offers several advantages such as:

- 5.7.1 grout shrinkage and resultant baseplate distortion is mitigated by machining the equipment mounting surfaces after the grout has cured.
- 5.7.2 the possibility of grout voids is greatly diminished.
- 5.7.3 baseplate grout fill and vent holes are not required.
- 5.7.4 the likelihood of baseplate distortion during shipping is diminished; and
- 5.7.5 the equipment does not have to be removed from the baseplate to provide access to the grouting holes during final grouting in the field.
- 5.7.6 Pre-grouted baseplate designs are to be used only with epoxy grouts. The use of cementitious grouts is not permitted.

## Annex B (informative)

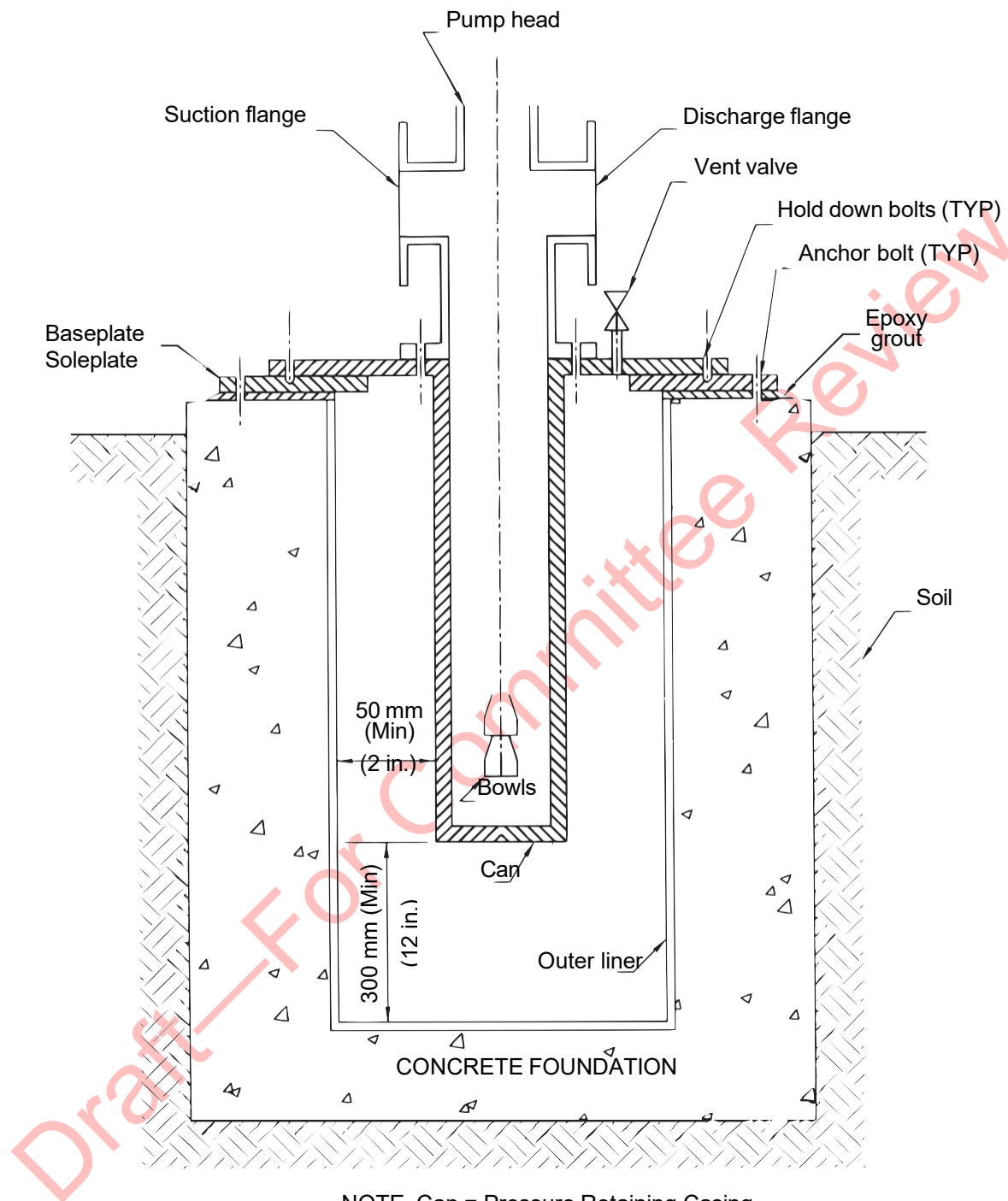
### Typical Foundation and Anchor Bolt Details



Section Through Foundation

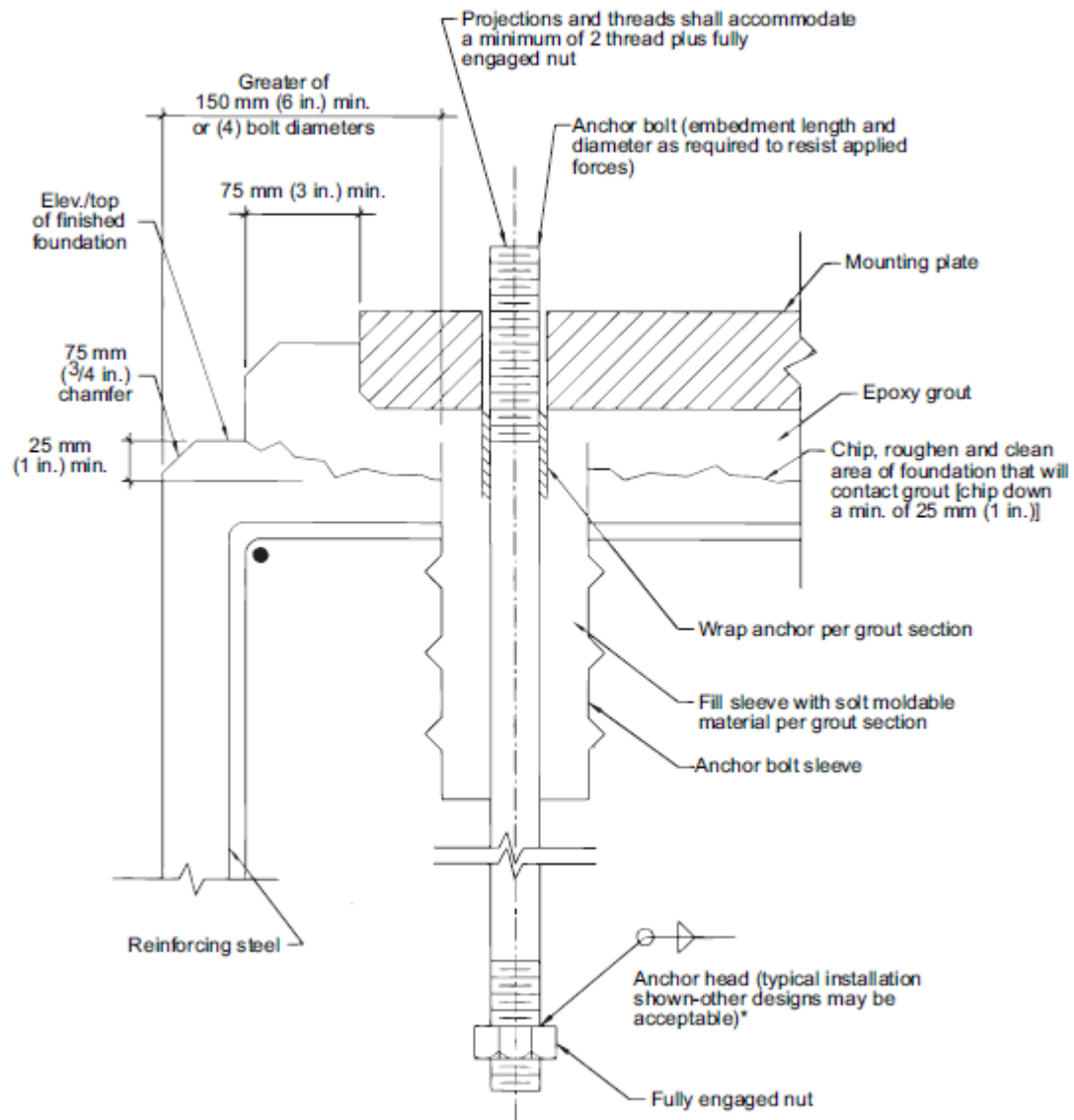
W	Width	Refer to foundation design section of specification
EB	Anchor Embedment	Shall be as required to resist anchor bolt forces
D	Depth Below Grade	Shall be adequate to prevent frost heave
H	Depth Above Grade	Shall be adequate to prevent damage to equipment from water due to runoff [100 mm (4 in.) minimum]
AS	Area of Reinforcing	Refer to the minimum area of steel requirements of the reinforcing section of foundation design
ED	Anchor Bolt Sleeve Edge Distance	Shall be adequate to develop required force on anchor bolt, a minimum of 150 mm (6 in.) or (4) bolt diameters (whichever is greater), or as recommended by anchor bolt manufacturer.





NOTE Can = Pressure Retaining Casing

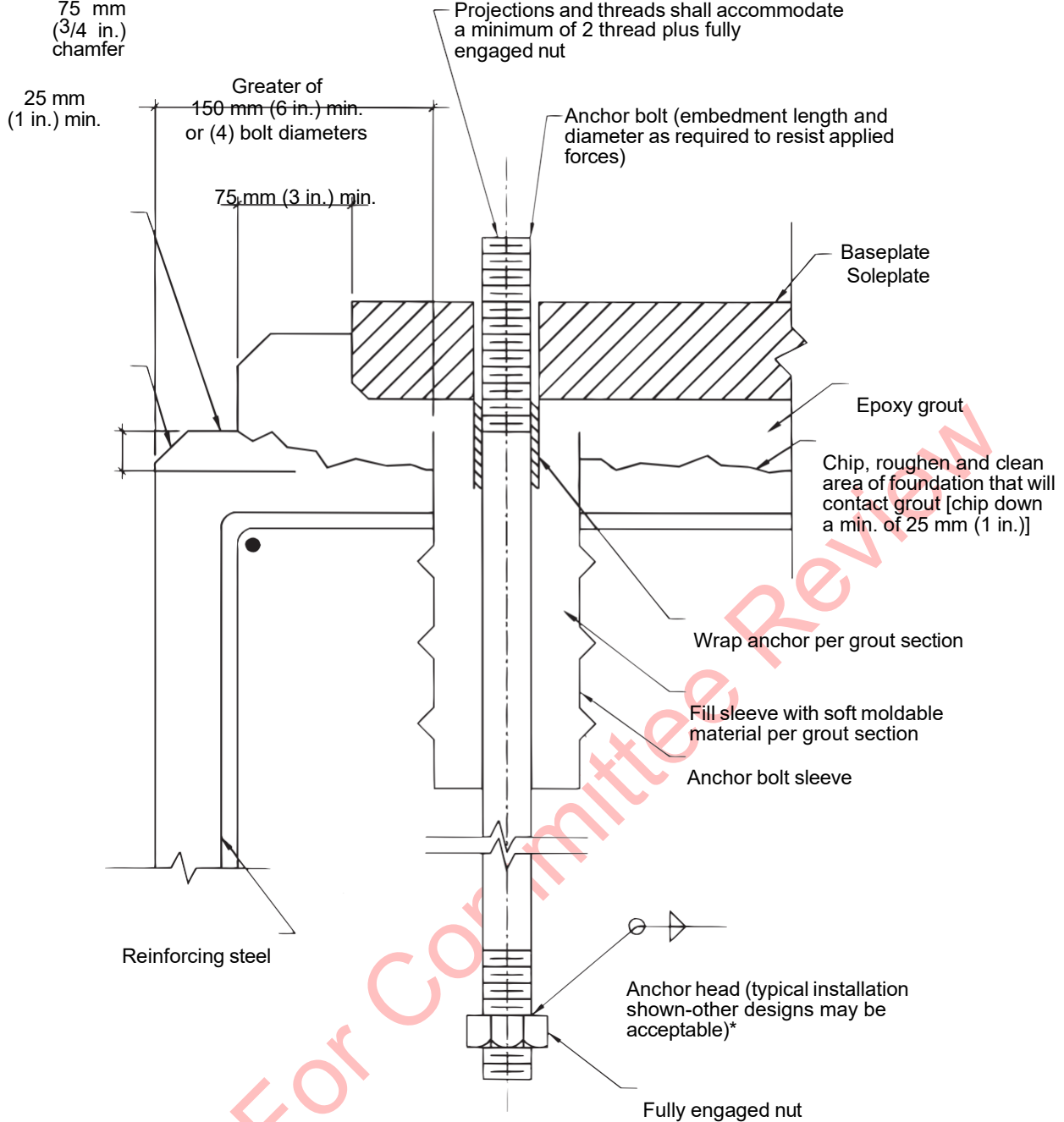
**Figure B.2—Typical Vertically Suspended Can Pump Foundation**



NOTE ACI 349 may be a possible design reference for anchor head.

Figure B.3—Typical Anchor Bolt Detail—Option 1, Grout Pour Not to Edge of Foundation

Elev./top of finished foundation



NOTE ACI 349 may be a possible design reference for anchor head.

**Figure B.3—Typical Anchor Bolt Detail—Option 1, Grout Pour Not to Edge of Foundation**

## **6.0 Machinery Piping Installation Design**

### **6.1 Scope**

The requirements in Part B, Section 6 specify the minimum requirements and provides recommendations for the installation and pre-installation design of piping that is connected to machinery in petroleum or chemical processing facilities.

6.2 Equipment user-specified piping specifications shall be utilized for determining piping materials as well as piping fabrication and testing requirements.

6.3 This Standard covers rotodynamic and positive displacement fluid-handling machinery and includes pumps, compressors, blowers, and turbines in both horizontal and vertical configurations.

### **6.4 General**

6.4.1 It is recognized that forces and moments imposed on the machinery by the piping are unique to each installation.

6.4.2 All piping directly connected to the machinery, excluding auxiliary piping such as lubrication or seal piping, shall be reviewed by a qualified piping stress analyst to determine if a static piping analysis is required to ensure nozzle loads are within equipment user-defined standards.

6.4.3 The piping engineering designer should use sound engineering judgment in conjunction with equipment user-defined standards to design a piping system that minimizes loads imposed on the machinery.

**6.4.4** For most machinery, maximum allowable nozzle loads (forces and moments) shall be established by the machine manufacturer.

**6.4.4.1** The equipment user typically adopts these nozzle loads as the equipment user-defined standard.

**6.4.4.2** On the basis of equipment user experience and preference, nozzle loadings more or less restrictive than that of the machine manufacturer may be specified as the basis for piping design.

6.4.5 Prior to initiating the piping design, the Equipment User, Engineering Designer, and the Manufacturer shall agree on the allowable nozzle loads to be used.

### **6.5 Accessibility for Operation and Maintenance**

6.5.1 Plant operating personnel shall have direct access to machinery to deal with maintenance and possible emergencies. Plant operating personnel may be required to isolate the equipment quickly in an emergency. Additional accessibility requirements for the piping designer include avoiding the creation of tripping hazards and low hanging piping that may result in head injuries as well as a desire to minimize the amount of work required to dismantle auxiliary piping and conduits to perform routine maintenance.

6.5.2 Process and auxiliary piping and conduit shall be routed to allow access to machinery for operation, inspection, and maintenance. Process and auxiliary piping arrangements for machinery layouts shall be reviewed during the equipment layout review with the users designated representative.

6.5.3 All auxiliary equipment, piping, conduit, instruments, coolers, seal pots, and so forth, that are mounted separately from the machine and driver should not interfere with removal of the machine or driver nor with access to the machinery for normal operation and maintenance.

NOTE: The location of seal pots and other auxiliary equipment adjacent to the machinery baseplate is acceptable when specified by the user-designated representative (see Figure B.1 for a typical pump installation).

6.5.4 Auxiliary support piping, conduit, instrumentation, and so forth, should be designed for a single drop area on baseplate-mounted machinery.

NOTE: The intention of a single drop area is to avoid clutter around the baseplate. This maximizes accessibility for operation and maintenance and minimizes the quantity of piping and conduit that requires removal for machinery maintenance (see Figure B.9).

6.5.5 Inlet and outlet isolation block valves and blinding stations around machinery shall be accessible from grade near the machinery.

6.5.6 Branch connections (including vents, drains, pressure, injection, relief, and safety valve connections) in areas that are difficult to access, such as under machinery decks, should be avoided.

6.5.7 Location of branch connections should be chosen so that connections are not subject to damage during maintenance or from personnel stepping or climbing on the connection.

## 6.6 Isolation Requirements

6.6.1 Isolation block valves shall be provided in the inlet and outlet piping to and from all machinery.

6.6.2 A positive isolation device shall be provided in the inlet and outlet piping to and from all machinery. Type of isolation to be determined by the Equipment User.

6.6.2.1 Isolation may use two block valves (closed position) and a vent valve located between the block valves (known as a "double block and bleed" arrangement). A single double block and bleed valve with vent may also be used for the same purpose.

6.6.2.2 Valves as in 6.6.2.1 is an acceptable alternative (subject to Purchaser review and approval) to spectacle blinds for machinery isolation, provided the process fluid is not toxic, corrosive, or flammable as defined by the Purchaser.

6.6.2.3 Removal of a breakout spool and installation of a blind flange is also an acceptable alternative to the use of spectacle blinds for machinery isolation.

6.6.3 Any temporary or permanent strainer shall be located between the inlet isolation block valve and the machinery inlet connection, and should require OEM consultation regarding location and type.

## 6.7 Piping Supports and Spring Hangers

6.7.1 Piping to and from machinery shall be adequately supported and controlled to meet the design requirements.

6.7.2 Piping design requirements shall include allowable flange loadings, thermal expansion, pulsation, vibration, and all other applied forces and moments. These requirements may be set by the machinery manufacturer, industry standards, or the equipment user.

6.7.3 Machinery inlet and outlet piping shall be supported as near to the machine as practical.

NOTE 1: Supporting the machinery inlet and outlet piping close to the machine removes most of the static load and allows identification of piping fit problems during installation as well as allowing easier removal of the machinery for maintenance.

NOTE 2: Results of pulsation studies for process gas services will identify optimum locations.

6.7.4 Only those supports specified as a result of the piping stress analysis and piping vibration analysis shall be installed.

6.7.5 Addition or deletion of piping hangers and supports during field construction may result in piping stresses not anticipated by the piping designer and is prohibited.

6.7.6 The piping engineering designer shall verify that piping spring hangers and supports are constructed of materials suitable for atmospheric conditions anticipated during equipment operation and maintenance.

NOTE 1: Cold service equipment such as refrigeration systems can be subject to extensive corrosion due to condensation in moist environments.

NOTE 2: Equipment installations near salt water can be subject to the accumulation of wind-borne salt particles. Springs and their enclosing metal "cans" will eventually corrode and lock up under these types of conditions.

NOTE 3: When the spring hanger or support is locked up the piping support system no longer functions as originally designed and excessive piping stresses may be imposed on the machinery resulting in machinery failure. Inspection of pipe hangers for binding or lockup is suggested—especially before reinstalling equipment after overhaul.

6.7.7 Allowable nozzle loads on rotating equipment shall be agreed between all parties prior to proceeding with detailed engineering.

## 6.8 Provision for Field Welds

6.8.1 For all piping NPS 10 or larger, the piping engineering designer shall include provisions for a final piping field weld to facilitate piping installation in accordance with the machinery flange fit-up requirements.

6.8.2 The final piping field weld shall be located between the face of the machinery flange and the first pipe support or isolation block valve (see Figure B.5.),

NOTE Piping smaller than NPS 10 typically has sufficient flexibility that there is usually little difficulty in achieving machinery flange fit-up requirements during field installation. However, thick walled pipe smaller than NPS 10 may require a final field weld due to the greater stiffness and difficulty in meeting flange fit-up requirements. Typical industry practice is to shop fabricate piping smaller than NPS 10 and not perform a final field weld providing flange fit-up requirements can be met.

6.8.3 The root pass of all butt welds on stainless steel pipe shall be made by tungsten inert-gas arc welding. Filler passes may be made by tungsten inert-gas arc welding or by the shielded metal arc process. Gas metal arc welding may be used when approved, for filler passes on DN 150 (6.0 in) and larger pipe.

## 6.9 Pressure Connections and Thermowells

6.9.1 Pressure measurement connections complete with isolation valves shall be provided on the inlet and outlet piping to and from all machinery and shall not be added on the machine.

6.9.2 The inlet pressure connection should be located between any permanent or temporary start-up strainer and the machinery inlet piping flange (see Figure B.3).

6.9.3 For compressors, inlet pressure measurements should be provided for each stage of the machine, including side streams.

6.9.4 The outlet pressure connection should be located between the machinery flange and the discharge check valve. (see Figure B.3)

6.9.5 If temperature measurement thermowells are required, they shall be located in the process piping and not in the machine casing. These thermowells should be located as close as possible to the inlet/outlet flanges of the machine.

NOTE Vendor performance predictions and guarantees for pumps, compressors and turbines are typically based upon operating conditions at the machine inlet/outlet flanges. Measurement equipment should be installed on those locations with the lowest vibration levels to avoid fatigue failure.

## 6.10 Inlet Pipe and Valve Sizing

6.10.1 Inlet piping and valves shall be the same size or larger than the machinery inlet nozzle. Mating flange to the machine nozzle shall match the machine flange size and rating.

6.10.2 Care should be taken in reducing down to the proper size as this may be done differently for pumps than for compressors. Refer to Section 6.21 of this document for machine specific design details.

6.10.2.1 A larger size pump suction line should be used to minimize suction line pressure losses resulting in greater net positive suction head available to the pump.

6.10.2.2 A larger sized compressor suction line may be used to minimize horsepower requirements of the compressor.

## 6.11 Inlet Strainers

### 6.11.1 Permanent Strainers

6.11.1.1 When specified, strainers shall be provided upstream of machinery handling fluids likely to contain foreign material such as sand, scale, and debris, unless the machinery is explicitly designed to handle this material.

6.11.1.2 The inlet strainer design shall be evaluated to verify that the strainer screen will not collapse under any differential pressures expected during machinery commissioning or operation if the strainer screen becomes completely blocked.

6.11.1.3 Where large accumulations of foreign material are expected and a machine is not spared, either a duplex strainer or two simplex strainers in parallel shall be provided in the inlet line to the machine. If the machine is spared then either a duplex strainer or a simplex strainer on each machine shall be provided.

6.11.1.4 Differential pressure indication shall be provided across the permanent strainer or strainers.

6.11.1.5 Venting capability for permanent strainers shall be provided.

6.11.1.6 Permanent strainers should not be located closer than 10 pipe diameters to the machinery inlet nozzle and shall not be closer than 5 diameters.

6.11.1.7 The open area of the permanent screen or strainer shall have a minimum of 150% of the open area of the piping.

6.11.1.8 The piping designer in consultation with the machinery manufacturer shall specify the screen mesh or hole size of permanent screens or strainers.

NOTE 1: The screen mesh or hole size is typically determined by the size of the largest particle that can pass through the machine without lodging or causing plugging.

NOTE 2: Typical strainer hole size is 6 mm (0.25 in.). However, there may be applications where a coarser or finer screen is required.

NOTE 3: For startup and commissioning the machinery manufacture shall specify the screen mesh size used over the permanent strainer.

### 6.12 Temporary Strainers

6.12.1 Machinery not equipped with a permanent inlet screen or strainer should be provided with a temporary start-up screen or strainer designed to be removed, without need to modify the process piping.

6.12.2 Piping designers should take into consideration requirements for lifting the temporary strainer for removal and providing lifting eyes if needed and adequate unit space for any required lifting equipment.

6.12.3 Temporary screens or strainers shall be clearly identified by an extended handle or other device, projecting beyond insulation material, with screen mesh, hole size, and individual identification marker clearly shown on this extended handle.

6.12.4 The open area of the temporary screen or strainer shall have a minimum of 150 % of the open area of the piping.

6.12.5 The piping designer in consultation with the machinery manufacturer shall specify the screen mesh or hole size of temporary screens or strainers.

NOTE 1: The screen mesh or hole size is typically determined by the size of the largest particle that can pass through the machine without lodging or causing plugging.

NOTE 2: Typical strainer hole size is 6 mm (0.25 in.). However, there may be applications where a coarser or finer screen is required.

NOTE 3: Screen mesh or hole size can sometimes be determined by a desire to protect equipment downstream of the machine.

NOTE 4: Plans are needed to remove any start-up screen not intended for continuous duty.

6.12.6 When fine mesh screen is required for a temporary screen or strainer, the screen shall be located on the upstream side of the strainer.

6.12.7 Applications requiring the use of a fine mesh screen or strainer shall be identified by the piping engineering designer.

NOTE: Temporary screens or strainers are intended only for protection of machinery during commissioning, start-up, and a short period thereafter if required. This type of screen or strainer can adversely affect machinery performance as a result of its resistance to flow and by causing flow



disturbances. Strainers are also not able to protect all components of machinery, such as mechanical seals.

6.12.8 Acceptable temporary strainer designs include: conical, truncated conical, and T-type or similar design.

6.12.9 The point of the conical or truncated cone strainers should face upstream in the piping (pointing into the flow). Screens in T-type strainers should point with the flow (downstream).

NOTE 1: Pointing the conical strainer upstream to the flow allows debris to fall to the outside of the cone around the perimeter of the pipe and so minimize the obstruction to the flow path. This is the preferred orientation for most machinery installations.

NOTE 2: Conical strainers can be installed with the point oriented downstream when explicitly specified by the designated machinery representative. This can be advantageous in situations where there are space limitations or where removal of the temporary strainer may result in the dropping of debris into the machine inlet (see Figure B.6).

6.12.10 Temporary screens or strainers should be installed in horizontal piping runs whenever possible.

NOTE: Locating temporary screens or strainers in horizontal piping facilitates the safe removal of debris. The location of temporary screens or strainers in vertical piping is acceptable but greater care shall be taken to prevent debris from falling into the piping when the screen or strainer is removed.

6.12.11 Screen or strainer material should be corrosion resistant, with the material selection based on the process service, and specified by the piping engineering designer.

6.12.12 The piping design engineer along with the supplier of the suction screen or strainer shall determine the maximum allowable differential pressure for the device. This information shall be provided to the designated machinery representative for use during machinery commissioning and start-up.

NOTE The intent of this requirement is to facilitate verification of screen or strainer integrity under any differential pressures

## 6.13 Valves and Check Valve Location

6.13.1 For suction and discharge, double block and bleed, through conduit valves with elastomeric seats and check valves with elastomeric seats are recommended if operating conditions permit (e.g. fluid properties and temperature).

6.13.2 A check valve shall be installed in the discharge line of all pumps, compressors, or blowers, unless there is no possibility of a reversal of flow or pressure surge (such as water hammer) under any conditions. The check valve shall be located between the machine discharge flange and the discharge block valve.

NOTE 1: Discharge check valves do not usually provide a tight seal and cannot be relied upon to provide pressure protection of the machinery or for isolation during maintenance.

NOTE 2: Check valves typically do not close rapidly enough to prevent a pressure surge from passing.

6.13.3 Discharge piping and isolation block valves shall be the same size or larger than the machinery outlet nozzle

6.13.4 Discharge check valves shall be the same size as the machinery outlet nozzle. Discharge check valves larger than the machinery discharge nozzle are acceptable, providing check valve minimum velocity requirements are met. Discharge check valves smaller than the machinery discharge nozzle may be used, providing pressure drop is evaluated as part of the system design.

NOTE 1: Check valve sizing and selection are critical. Some types of check valves require a minimum flow velocity to lift the disk or flapper. An oversized check valve may lack sufficient flow velocity to keep the disk or flapper open. A small check valve may result in excessive pressure drop and increased horsepower requirements. These problems can be avoided by a hydraulic evaluation during system design.

NOTE 2: For pump applications, the Hydraulic Institute publishes a chart on reverse runaway speed ratio vs specific speed. This chart provides guidance as to the susceptibility of a pump train to overspeed backwards. Check valve capability should be specified to avoid reverse runaway speed.

6.13.5 Check valves installed in vertical piping that require provision for draining liquid trapped above the check valve shall be equipped with an NPS 3/4 or larger bypass around the check valve. This bypass shall be attached to the body of the check valve and shall include a manual block valve. Alternatively, an NPS 3/4 or larger drain connection with block valve shall be provided above the check valve.



6.13.5.1 A check valve mounted vertically typically require greater pressure to open than one mounted horizontally, and should be evaluated as part of the system design.

6.13.5.2 These bypasses can also be used for temperature equalization.

#### 6.14 Vents and Drains

6.14.1 This section applies to machinery casings and process piping. Vents and drains on auxiliary systems may utilize vents and drains smaller than NPS  $\frac{3}{4}$  (DN 20) as well as tubing.

NOTE: This requirement for NPS  $\frac{3}{4}$  (DN 20) vents and drains is intended to provide sufficient strength and rigidity to prevent damage due to externally applied loads.

6.14.2 For piping NPS  $\frac{3}{4}$  (DN 20) or larger, all vent and drain connections shall be NPS  $\frac{3}{4}$  (DN 20) or larger. For piping smaller than NPS  $\frac{3}{4}$  (DN 20), the vent or drain connection shall be no smaller than NPS  $\frac{3}{4}$  (DN 20).

6.14.3 Vent and drain connections shall not be placed in angle sections of reducers.

6.14.4 Machinery casing drain valves shall be located in a safe and accessible location.

6.14.5 Drain valves shall be installed on each drain prior to any manifolding or piping away from the equipment.

6.14.6 Drain valves shall be mounted as near to the machinery as possible.

6.14.7 Drains shall be designed such that they have sufficient strength to prevent damage in the event they are stepped on by personnel.

6.14.8 Drain lines from machinery shall be NPS  $\frac{3}{4}$  (DN 20) or larger.

6.14.9 Vent and drain lines shall be suitably arranged, isolated, and valved to prevent leakage flow between machines or between separate portions of the same machinery train.

6.14.10 For tabletop mounted machinery, drain valves shall be located beneath the deck as close to the machine as possible. These drain valves shall be accessible from the deck by valve handle extensions or from grade by chain-operated valves.

NOTE: Drain valves are located beneath the deck to avoid tripping hazards for operating personnel. Locating the drain close to the machine case minimizes a dead-leg, which can collect undesirable liquids that can freeze or cause corrosion.

6.14.11 Valves NPS  $1\frac{1}{2}$  (DN 40) and smaller shall not be equipped with chain operators.

6.14.12 [●] All permanent vent and drain valves not connected to a closed system shall be flanged or with Purchaser agreement, have female pipe threads. These valves shall be covered with a blind flange or shall be plugged with a solid pipe plug. The flange or pipe plug shall be of material having the same metallurgical and physical properties as the associated piping.

#### 6.15 Warm-up Lines

6.15.1 Warm-up lines should be considered when the process fluid temperature differs by 200 °F (110 °C) or more from the ambient pump or turbine temperature.

6.15.2 Warm-up lines shall be provided with sufficient flanges to allow the piping spool between the machine and the outlet check valve to be removed and/or aligned separately from the warm-up line.

NOTE 1: Warm-up line flanges allow removal of small piping prior to rigging of machine piping spools. This prevents inadvertent damage to the small piping during rigging.

NOTE 2: The same strategy may be used to cool pumps to operating temperature.

6.15.3 One NPS 1 (DN 25) or larger reverse flow bypass line should be provided around the discharge check valve.

6.15.4 For all double suction and multistage machines, at least two NPS 1 or larger reverse flow bypass lines should be provided. One bypass line is around the discharge check valve. The second line bypasses the check valve and is connected into the machinery casing drain.

NOTE 1: One bypass line may be used rather than two individual lines. Proper valving should be installed to split flow to each delivery point.

NOTE 1: Some machinery may require an orifice or globe valve in each warm-up line to break down pressure and control the flow rate. Care should be exercised to ensure detrimental machine rotation does not occur (see Figure B.3).

6.15.5 Warm-up lines shall be heat traced and insulated if the product will solidify at expected ambient temperatures. Warm-up lines shall be insulated to protect personnel from burns if located where personnel normally have access for operation or maintenance of the machinery.

6.15.6 Warm-up lines shall be evaluated for adequate flexibility by the piping designer due to the possibility of differential expansion between the machinery discharge line and the warm-up line.

6.15.7 Warm-up line connections should be discussed with machinery supplier to minimize casing distortions.

6.15.8 Thermal checkpoints on the bottom and top of the casing may be necessary to measure and record the top and bottom casing temperatures as well as process fluid temperatures.

#### 6.16 Positive Displacement Machinery Pressure Relief (external to machine)

6.16.1 Positive displacement machinery shall be equipped with a pressure relief device. This pressure relief device shall be located between the machinery discharge connection and the check valve or first isolation block valve or blind whichever comes first in the direction of flow.

6.16.2 Pressure relief device discharge piping shall be routed to a designated system with consideration given in the design with respect to pulsations and vibration.

NOTE Typical designated systems include a flare, maintenance dropout or blowdown, thermal oxidizer, the atmosphere, scrubber, process trench, sump, storage tank, suction vessel or other process systems, or the machine suction line.

6.16.3 Pressure relief device discharge piping routed back to the machinery suction shall be reviewed by engineering to ensure an appropriate location is selected.

Reference additional requirements of reciprocating compressors (see 6.27.6 and 6.27.7).

#### 6.17 Piping Systems in Pulsating Service

6.17.1 A pulsation analysis and mechanical piping analysis should be conducted on piping systems for reciprocating machinery or machinery subject to pulsating flow. These analyses shall be used to develop piping systems that minimize pressure pulsation and piping vibration, consistent with the requirements with API 688. The pulsation and mechanical piping analyses shall be done in conjunction with a static piping analysis. All additional piping requirements and restraints identified as necessary by the mechanical piping analysis shall be re-checked with the static piping analysis.

NOTE 1 The nature of the analyses will vary with the size, complexity, and configuration of the system. For small, simple systems the analyses may be omitted or may be handled by manual methods. Large, parallel or complex systems may require a digital or analog study.

NOTE 2 Some rotary equipment such as lobe-type blowers and dry rotary screw compressors generate pressure pulsation that should be reviewed and pulsation compensation provided.

NOTE 3 Mechanical piping analysis: Analysis of the piping connected to a machine to determine the stresses and deflections of the piping resulting from temperature, pressure and dynamic loadings such as pulsating flow (mixed phase flow). Determination of the type, location, and orientation of piping supports and piping guides results from this analysis.

6.17.2 Pulsation dampeners, accumulators, volume bottles, orifices, and acoustically detuned piping systems can be provided to reduce pressure pulsation levels to acceptable limits per the applicable API standard by machine type.

6.17.3 Pressure taps with isolation valves shall be provided to enable measurement of pulsation at the machine suction and discharge connections as well as other locations specified by the designated machinery representative.

6.17.4 Based on the data obtained from pulsation and mechanical piping analyses the piping routing, piping supports, restraints, and anchors shall be located in accordance with these engineering analyses.

6.17.5 The number of branch connections should be minimized.

6.17.6 Branch connections (such as vents, drains, pressure gauge connections, and so forth) should be located at points where the run line is anchored.

6.17.7 Branch connections should be installed as far from the source of vibration as practical.

6.17.8 Piping should be routed as close to grade or to heavy concrete foundations as possible. Rigid anchors and restraints shall be used effectively to properly secure the piping.

6.17.9 Process lines shall be restrained by use of only those rigid pipe anchors, restraints, and friction slides determined necessary by the piping static and vibration analyses.

6.17.10 Pipe anchors shall be anchored to concrete piers or structural steel. Piers and structural steel shall be designed to provide lateral stiffness needed to restrain dynamic forces.

6.17.11 Reinforcing steel for piers shall be properly developed in the supporting mat or foundation. Any piping supports to be added after initial installation shall be reviewed by a mechanical piping static and vibration analysis. Supports required by the piping analyses added after initial installation shall be securely attached to the mat. Expansion bolts and other mechanical connections are not satisfactory for pulsating service and shall not be used.

6.17.12 Branch connections shall be kept as short as possible to minimize the vibration moment arm. Where large masses such as relief or safety valves cannot be avoided, they shall be properly braced.

#### 6.18 Miscellaneous Auxiliary Piping

6.18.1 Cooling water header piping, if used, shall be made from a minimum NPS 1 Schedule 80 steel pipe. Cooling water piping shall be no smaller than the largest connection to the water jacket or heat exchanger. For piping larger than NPS 2 a lighter schedule may be used.

6.18.2 Cooling water tubing, if used, shall be made of stainless steel with a minimum 1 mm (0.035 in.) wall thickness. Minimum acceptable size is 12 mm (0.5 in.) tubing diameter. Copper tubing is not acceptable.

6.18.3 When site thermodynamic performance measurements are to be made on a machine, sufficient pressure, temperature, flow, and sampling connections shall be provided.

NOTE Instrument type, location, accuracy, and redundancy can have a significant impact on the ability to obtain data with sufficient accuracy to determine field performance. For specifics on pressure, temperature, flow, and sampling connections refer to the relevant performance test code (PTC).

6.18.4 Elevation of the seal reservoir above the shaft centerline as well as the actual piping distance from the reservoir to the seal shall be in accordance with the recommendations of the mechanical seal manufacturer or the equipment manufacturer.

6.18.5 Instrument connections shall be arranged to permit free drainage of condensed liquids.

NOTE Avoid drain valves because impulse lines are not always drained on a regular basis.

#### 6.19 Commissioning Provisions

6.19.1 Where piping is to be steam cleaned or purged during commissioning, temperature limits and thermal effects shall be included in the design.

6.19.2 Where piping and vessels are to be chemically cleaned during commissioning, provisions to facilitate this cleaning shall be included in the piping design.

6.19.3 Steam inlet piping to machinery shall be designed such that steam blowing is possible for each branch and to each end use without major dismantling or difficult access. Any special steam blowing exits, supports, condensate drains, sample points, bypasses, and so forth, shall be included in the piping by the piping engineering designer.

6.19.4 The piping design of gas systems shall include provisions for draining and drying out the piping system after completion of hydrotesting.

NOTE Temporary supports may be required during hydrotest to prevent overstressing piping or machinery nozzles that remain connected.

6.19.5 The piping system shall be designed such that any hydrotesting procedure will not include the machinery.

#### 6.20 Oil Mist Systems

6.20.1 Oil mist main and branch headers shall not have valves.

NOTE Valves introduce unnecessary flow disruptions that may cause the oil to coalesce from the mist or they may be inadvertently shut.

6.20.2 Piping unions should be used at the oil mist console between the console and the main oil mist header, if allowed by Purchaser piping specifications. Unions allow disconnection of the mist header for cleaning and commissioning as well as replacement of the console.

6.20.3 Oil mist main and branch headers, and drop point lateral and vertical piping shall be screwed, galvanized steel pipe. Tubing used in the oil mist system shall be stainless steel.

6.20.4 Oil mist main and branch headers shall be sloped continuously back to the oil mist console. Only when obstructions prevent continuous sloping back to the console shall oil mist main and branch headers be sloped away from the oil mist console to a system designated by the equipment user.

NOTE As oil mist is transported, some of the mist coalesces and accumulates as oil in the piping. With oil mist piping sloped back to the oil mist console, liquid oil accumulating in the piping drains back to the oil mist generator reservoir. The oil usage is much lower because only mist that reaches the machinery is consumed. Liquid oil can accumulate in a pipe and block the mist flow if the pipe is not sloped properly.

6.20.5 Oil mist main and branch headers should be sloped a minimum of 2 cm per 5 m (1 in. per 20 ft). Greater slope is acceptable.

6.20.6 Oil mist main and branch headers shall be supported on top of horizontal beams or pipe racks with structural angle iron.

6.20.7 Pipe sag of oil mist main and branch headers shall not exceed one-third of the pipe inside diameter. Unsupported spans of oil mist main and branch headers shall not be greater than the distance between adjacent beams.

NOTE Coalesced oil will pool in low spots within the piping headers. Limiting piping sag to one-third of the pipe diameter prevents oil pools in the piping sag from blocking the flow of oil mist (see Figure B.7).

6.20.8 Horizontal bracing shall not be used to support horizontal oil mist main and branch headers.

6.20.9 Main oil mist headers should be run as close to the outside of the pipe rack as possible and in such a manner as to leave space for future additions of process piping in the pipe rack.

6.20.10 2.16.10 Oil mist branch headers shall be connected to the top of the main header with screwed tees.

6.20.11 Oil mist main and branch header piping shall be NPS 2 or larger. NPS 2 is usually adequate for most installations.

6.20.11.1 A larger pipe size may be required in oil mist systems serving a large number of lubrication points.

6.20.11.2 The size of the header should be large enough to limit the oil mist velocity to a maximum of 7 m/s (22 ft/s) at the maximum oil mist generator capacity.

6.20.11.3 Main and branch headers smaller than NPS 2 are discouraged due to the necessity of providing additional piping supports to prevent the increased sag resulting from the smaller pipe size and the greater vulnerability to mechanical damage.

6.20.12 Oil mist drop point lateral piping shall be NPS 3/4. Each drop point lateral should not have more than five 90 degree elbows.

6.20.13 Oil mist drop point lateral piping shall come vertically off the top of the main header through a screwed tee.

6.20.14 Oil mist drop point lateral piping shall slope continuously to the main or branch header. When obstructions prevent continuous sloping back to the header, oil mist drop point lateral piping shall slope continuously to the drop point.

6.20.15 Oil mist drop point lateral piping shall be sloped a minimum of 2 cm per 5 m (1 in. per 20 ft). Greater slope is acceptable.

6.20.16 Oil mist drop point vertical piping shall terminate at a distribution block. Distribution blocks should be located 1 m (3 ft) above the machinery to be lubricated.

6.20.17 Oil mist drop point piping should be located such that access for operation and maintenance of the machinery is not obstructed. Dismantling of oil mist drop point piping, the distribution block or supply manifold for maintenance is not acceptable.

6.20.18 Oil mist drop point lateral piping horizontal runs should not exceed 10 m (30 ft).

6.20.19 Block valves shall not be installed in oil mist drop point piping.

6.20.20 Oil mist drop point distribution blocks or supply manifolds shall include a sight glass.

**NOTE** The sight glass is typically a small, molded, clear plastic or glass device mounted at the bottom of the distribution block or supply manifold to provide an indication of condensed oil level in the drop point. The sight glass may also be provided as an integral part of the oil mist supply manifold.

6.20.21 Oil mist drop point distribution blocks or supply manifolds shall be equipped with a valve to permit the draining of oil. Distribution block drain valves shall be snap-acting, petcock, or other type that cannot be opened by vibration.

6.20.22 Oil mist application fittings (reclassifiers) should be mounted in the distribution block or supply manifold.

**NOTE** Mounting the oil mist application fittings (reclassifiers) in the distribution block or supply manifold is preferred as it prevents the loss of these fittings when the equipment is removed for maintenance. Oil mist application fittings (reclassifiers) may be mounted directly in the machinery bearing housing but care should be used when removing the machine for maintenance to prevent loss of the fittings or depressurization of the oil mist header.

6.20.23 Oil mist feed lines from the distribution block to the machinery bearing housing shall be 6 mm (1/4 in.) or larger diameter stainless steel tubing.

6.20.24 Oil mist feed lines shall slope continuously downward to the machinery bearing housing. Right angle turns or bends should be minimized.

6.20.25 Polytetrafluoroethylene (PTFE) thread sealant tape shall not be used on threaded connections in oil mist systems. Thread sealant such as PTFE based pastes are preferred.

6.20.26 Care should be taken when applying oil mist to electric motors due to the potential for oil contamination of the windings and terminal boxes. Consult the motor manufacture for guidance.

## **6.21 Machinery Specific Installation Design**

### **6.21.1 Pumps**

#### **6.21.1.1 General Requirements**

6.21.1.1.1 Auxiliary piping to pumps such as gland liquid, flushing liquid, cooling water, quench steam, and so forth, shall be equipped with isolation block valves located at the pump.

6.21.1.1.2 Non-slam check valves should be used in the discharge lines of centrifugal pumps in large systems. Acceptable non-slam check valves include wafer-style center-guided spring-loaded split-disc check valves or tilting-disc check valves.

**NOTE** Large systems are typically those used to transfer water or other fluids in large volumes, long distances, or both. Non-slam check valves should be considered for pumps with greater than 185 kilowatt (250 horsepower) nominal driver rating or NPS 12 or greater piping.

6.21.1.1.3 Pumps that handle volatile fluids at or near the fluid's vapor pressure and that are not self-venting should have a casing vent line back to the fluid source or other suitable system. Vent piping should not be less than NPS 3/4.

6.21.1.1.4 Expansion joints or flexible hose in permanently mounted pump suction and discharge lines shall not be used as a method of compensating for piping misalignment.

**NOTE** Properly designed piping with spring hangers and supports has sufficient flexibility that expansion joints and hoses are not necessary. Permanently mounted pumps are foundation mounted and exclude mobile equipment. Correction of piping misalignment is to be addressed using the methods described in Part C, Section 6, Annex D of this document.

#### **6.22 Pump Suction Piping**

6.22.1 Pump suction piping should be designed with input from the equipment manufacturer, such that the flow is as smooth and uniform as practicable at the pump suction nozzle. To accomplish this, the use of tees, crosses, valves, reduced port valves, strainers, near run-size branch connections, and short radius elbows shall be avoided near the suction nozzle.

6.22.2 The net positive suction head available (NPSHA) for the suction piping configuration shall be checked and compared to the net positive suction head required and purchaser specified margin (NPSH3). For centrifugal pumps, NPSHA shall be greater than NPSH3 in accordance with API 610, Centrifugal Pumps for Petroleum, Petrochemical, and Natural Gas Industry. For pumps other than centrifugal pumps, NPSHA shall be greater than NPSH3 in accordance with API 674, Positive



Displacement Pumps—Reciprocating, API 675, Positive Displacement Pumps—Controlled Volume, or API 676, Positive Displacement Pumps—Rotary, as applicable.

6.22.3 Suction piping shall be designed without high points to collect gas or vapors. When the liquid source is located above the pump centerline, the suction piping shall be sloped toward the pump. When the liquid source is located below the pump centerline the suction piping shall be sloped away from the pump. The slope of the suction piping shall be a minimum of 10 mm per m (1/8 in./ft) (see Figure B.10). NOTE 1 “Sloped toward the pump” means that the pump is lower than the piping. “Sloped away from the pump” means that the piping is lower than the pump.

NOTE 2 The objective of sloping the pump suction line is to prevent the accumulation of gas or vapor in pockets that can result in pump cavitation. Sloping the pump suction line toward the pump is preferred as it allows any gas or vapor to escape back to the suction tank or vessel. Sloping the suction line away from the pump allows gas or vapor to escape from the suction line into the pump case. Gas or vapor may then require manual venting to prime the pump if the pump is not of a self-venting design.

6.22.4 Refer to ASME/H.I. 9.6.6.6 for piping configurations. Reducers used in horizontal suction lines shall be eccentric and shall be installed to avoid pocketing of vapors in the suction line. The flat side of the eccentric reducer shall be on top. Drain connections shall not be placed on the angle of the reducer. Reducer sections shall include provision for draining.

6.22.5 Orienting the eccentric reducer with the flat side on top prevents the creation of a pocket that can trap gas or vapor. Other orientations have been found to be more advantageous in pipeline applications. To be effective the drain from the reducer shall be located at a low point and not in the angled portion of the reducer. The requirement of a drain is to ensure that all liquid can be removed from the suction line prior to removing the pump for maintenance.

6.22.6 When complete drainage is required to remove hazardous liquid or solids before performing maintenance the eccentric reducer in the horizontal pump suction line should be oriented with the flat side on the bottom. For example, it is desirable that hydrofluoric acid piping be completely drained to avoid pockets of material that may prove hazardous to maintenance personnel (see Figure B.10).

6.22.7 The reducer shall be concentric for overhead piping into a top suction pump.

6.22.8 The pump suction line shall have a minimum straight run of five pipe diameters between the pump suction flange and the first elbow, tee, valve, reducer, permanent strainer, or other obstruction. The straight run shall be of the same line size as the pump suction nozzle.

Note 1: The straight run length of five pipe diameters is usually sufficient to ensure stable and uniform flow at the pump impeller for typical centrifugal pumps. This configuration results in fewer pump failures over the life of the pump due to vibration caused by flow induced turbulence. High speed or high energy centrifugal pumps may require greater suction line straight run lengths. The pump manufacturer may be consulted for additional requirements for specific types of pumps.

Note 2: The pump suction line straight run requirement of at least five pipe diameters may be reduced through the utilization of appropriate engineered flow conditioning devices when explicitly approved by the designated machinery representative.

Note 3: It is preferable for the piping designer to meet the straight run requirements without the use of flow conditioning devices to avoid introducing additional pressure drop in the suction line as well as minimizing the potential for plugging.

6.22.9 The last pipe elbow in the suction line to a pump shall be a long radius elbow.

6.22.10 Pump suction lines shall be routed to avoid changes in the temperature of the fluid being pumped. Lines containing cold, high vapor-pressure fluids should not be routed near hot lines or equipment, as the heat from the hot lines may vaporize the cold fluid. Note: If cold lines are routed in close proximity to hot lines or equipment, insulation may be used to minimize the impact.

6.22.11 For pumps taking suction from vacuum towers or columns, an equalizing line from the pump back to the vapor space in the tower or column shall be provided to vent the pump at start-up.

6.22.12 Permanent strainers installed in the pump suction line shall be fully self-venting back to the liquid source.

NOTE Some strainer designs trap gas or vapor thus forming a gas pocket. These types of strainer are not suitable for use in the suction line to a pump. This may be of concern when a strainer is installed in the suction line to a standby lube oil pump for a machine train. Minute air bubbles that have not disengaged in the lube oil tank can migrate and disengage from the oil to create a vapor trap between the strainer and the lube oil pump. The standby lube oil pump may then fail to take suction when started. Consider the use of a conical strainer in place of a Y-strainer if this issue is possible.

6.22.13 When the pump is of a double suction impeller design, the piping designer shall consult with the pump manufacturer regarding the suction piping orientation including the position and orientation of elbows, tees, valves, reducers, and straight runs.

NOTE Elbows and valves improperly located or oriented can cause poor flow distribution and excessive turbulence resulting in cavitation and high thrust loads.

#### 6.22.14 Pump Minimum Flow Bypass

6.22.14.1 A minimum flow bypass shall be provided when the process or operating practice cannot ensure that the flow rate of the pump will be equal to or greater than the minimum continuous flow of the pump. Minimum continuous flow shall be a calculated or measured value provided by the pump manufacturer.

based on considerations of hydraulic stability and thermal rise. Note: The normal practice is to use the higher of these values for establishing minimum pump flow.

6.22.14.2 The minimum flow bypass line shall be routed from the pump discharge to the suction vessel, tank, sump, or pump suction line. An analysis shall be made that considers the thermodynamic properties of the liquid, the amount of liquid to be recirculated, and the size of the suction vessel, tank, sump, and piping fluid volume as well as pump internal recirculation. When indicated by this analysis, a cooler shall be installed in the bypass line. The designated machinery representative shall agree with the return entry location of the minimum flow bypass line.

6.22.14.3 When the minimum flow bypass line is routed into the pump suction line, it shall re-enter the suction line as far from the pump suction nozzle as practical. This re-entry to the suction line shall be at least five pipe diameters upstream of the pump suction nozzle.

NOTE 1 The intention of locating the minimum flow bypass re-entry to the suction line far from the pump suction nozzle is to minimize flow turbulence so as to avoid creating an additional pressure drop resulting in NPSH difficulties. The re-entry nozzle to the suction piping requires care in design to minimize the creation of additional turbulence.

NOTE 2 Bypass control is often used on high specific speed pumps, such as axial flow pumps, because the power requirement decreases with increased flow.

6.22.14.4 Control of flow through the recirculation line may be by any acceptable instrumentation including but not limited to a restriction orifice or a flow-sensing element with an associated control valve, a self-contained auto recirculation valve, or a combination of a flow-sensing element, solenoid valve, and restriction orifice.

#### 6.23 Vertical Pumps

6.23.1 Suction and discharge piping for vertical in-line pumps shall have adjustable supports. These supports shall be located within 1 m (3 ft) of the pump's suction and discharge flanges. The adjustable supports shall have a means of locking their positions to preclude change due to vibration or unwarranted casual adjustment.

6.23.2 Vertical pumps shall be piped to drain any fluid that accumulates in the driver support structure (space between driver and pump). This drain line shall be NPS 1 or larger.

6.23.3 Vertical pumps shall include provision for the venting of gases from the seal gland plate.

6.23.4 On API VS6 vertical can pumps, vent the can, and discharge before starting. Vent connections shall be connected to a designated system. As the seal is located at the highest point in a vertical pump, venting of any trapped air or vapor ensures the pump seal chamber is liquid-full prior to starting the pump. Typical designated systems include a flare, maintenance dropout or blowdown, thermal oxidizer, the atmosphere, scrubber, or other process systems.

6.23.5 Suction and discharge piping for vertical in-line pumps shall have adjustable supports. These supports shall be located within 1 m (3 ft) of the pump's suction and discharge flanges. With pipe supports adjusted and all piping made up, the pump shall be in solid contact with the foundation baseplate. The adjustable supports shall have a means of locking their positions to preclude change due to vibration or unwarranted adjustment.

#### 6.24 Canned Motor Pumps

6.24.1 All services where the pumped product contains particulate material shall have a flush injection as described in API 682, Plan 32 or API 685, Plan S 32.



6.24.2 Installed piping behind the motor end of the canned motor pump shall not create an obstruction for a distance equal to the length of the pump. This is necessary to allow disassembly of the pump in the field.

6.24.3 If the pump has an auxiliary flush, the flush piping shall be arranged so that none of the components are located in the area directly to the rear of the pump except for the final section of connecting tubing.

6.24.4 There shall be a breakout spool in the suction line between the suction strainer and the pump suction flange that is at least 300 mm (12 in.) long. The maximum recommended length is 900 mm (36 in.).

NOTE The purpose of this breakout spool is to allow visual access to the impeller to perform a motor rotation check and cleaning of the suction strainer.

## 6.25 Compressors and Blowers

### 6.25.1 General Requirements

6.25.1.1 Auxiliary process piping connected to compressors and blowers shall include isolation block valves and isolation blinds. This auxiliary piping includes connection to flare systems, suction vessel drain manifolds, compressor packing vents, distance piece drain manifolds, and so forth.

6.25.1.2 When a pre-commissioning test run is specified by the equipment user, the piping engineering designer shall include provisions for opening hand holes or manways on the suction vessel and piping and exhausting through restrained temporary piping.

NOTE A pre-commissioning test run consists of operating a machine on air prior to the introduction of process gas such as nitrogen, hydrocarbon, and so forth, during the machinery commissioning phase. This test run is done with open flanges and valves removed so that the machine does not build pressure or generate temperature and can freely inlet and exhaust to the atmosphere.

6.25.1.3 If compressor or blower piping will chemically or mechanically cleaned, it shall be designed to facilitate this cleaning without extensive piping removal.

6.25.1.3.1 Mechanical cleaning methods such as high-pressure water cleaning ("hydro-blasting") may be more cost effective for compressor piping larger than 10 NPS where the large volumes of chemical and subsequent waste disposal costs associated with chemical cleaning can be eliminated.

6.25.1.3.2 The piping designer should consult with the cleaning contractor to verify that the piping spools are designed for effective cleaning using these methods. For example, a "hydro-blasting" spray nozzle may not be able to navigate a piping spool with more than three 90° elbows.

### 6.25.2 Suction Piping

6.25.2.1 Inlet piping to compressors and blowers shall be free of sections where liquid may accumulate during any of normal operation, start-up, shutdown. Where such sections are unavoidable, suitable drain facilities shall be provided.

6.25.2.2 When horizontal reducers are installed in the inlet piping to compressors or blowers, they shall be eccentric with the flat side on the bottom of the pipe to prevent the accumulation of any liquids.

6.25.2.3 Suction piping to compressors in condensing service shall be designed for automatic condensate removal from low points in the compressor piping systems when the machine shuts down.

6.25.2.4 Suction vessels for compressors handling a wet gas that may condense during shutdowns shall be located as close as possible to the compressor. Suction piping layout shall be free of sections where standing liquid may accumulate and shall slope back toward the suction vessel. Adequate drains on the piping shall be provided to remove any standing liquids. Suction lines to wet gas compressors shall be heat traced and insulated.

6.25.2.5 Suction knockout vessels (scrubbers) shall have demister pads and internal separators (if required) that assist in removing liquids.

NOTE Suction knockout vessels are designed to separate any entrained liquids from the gas stream.

6.25.2.6 Suction knockout vessels shall be independent of any pulsation suppression devices that may also be installed.

6.25.2.7 Drains on suction vessels shall be large enough to allow removal of any debris expected during normal operation.

6.25.2.8 The design of inlet ducting, nonmetallic seals and expansion joints, filters, and silencers in inlet ducts shall be such that no parts of the ducting, seals, or joints can be drawn into the machine in the event of material failure.

6.25.2.9 The suction line to each compressor or blower section shall be provided with a permanent or temporary strainer.

6.25.2.10 The screen size used in the strainer shall be specified by the compressor vendor. The sizing evaluation shall include a verification that the strainer/screen will not collapse under any differential pressures expected during compressor commissioning, operation including shutdown and trip, if the strainer screen becomes completely blocked.

NOTE Non-lubricated (NL) positive displacement compressors typically require finer mesh screens than lubricated positive displacement compressors. Typical strainer construction consists of perforated plate with holes approximately 6 mm (1/4 in.) in diameter. If finer mesh screen is used, it is typically attached to the perforated plate of the strainer using the perforated plate for backing support. The fine mesh screen is installed on the upstream side of the strainer. Other screen designs may be acceptable if approved by the designated machinery representative.

6.25.2.11 A flanged breakout spool with an in-line temporary strainer shall be considered in the horizontal run of the suction piping, as close as practical to any vertical run into the machine. Removal and cleaning of the strainer spool shall be considered in placement of the spool. Piping supports are required on each side of the spool piece. If the piping is supported by spring hanger or spring support, a locking device shall be permanently attached to the spring to lock the spring when the piping hanger or support is removed. Pressure connections shall be provided on both the upstream and downstream side of the screen or strainer.

NOTE As an alternative, consider installing a T-type strainer to minimize cleaning efforts during commissioning and start-up.

6.25.2.12 Compressor or blower suction lines larger than NPS 20 but less than NPS 30 shall have a permanent screen or strainer installed in the horizontal run of pipe downstream of the inlet block valve and as close as practical to any vertical run into the machine inlet. Pressure taps shall be provided on both the upstream and downstream side of the screen or strainer. The screen or strainer shall be able to withstand instantaneous loading assuming 100 % blockage of the holes and maximum suction pressure. The suction line shall have flanged clean-out holes upstream and downstream of the screen or strainer. Clean-out holes shall be one-half of the suction line size up to a maximum of NPS 10.

NOTE The requirement for a permanent strainer in large pipes is intended to facilitate removal of debris. It is also intended to avoid potential problems with the forces necessary to restrain a plugged temporary screen.

6.25.2.13 For "down-connected" tabletop mounted compressor or blower suction lines NPS 30 or greater, the suction line transition from horizontal to vertical shall be made using a tee with the long axis (run) oriented vertically. A blind flange or manway shall be provided at the lower end of the tee to provide access to physically inspect and remove debris from this line. Suction strainers are not required.

NOTE As tees may sometimes cause flow disturbances, a removable elbow may be used if approved by the designated machinery representative.

6.25.2.14 Compressor or blower suction lines greater than NPS 30 shall be provided with an additional tee/blind flange or manway in the horizontal run of pipe near the upstream vessel. This shall be conveniently oriented for access from an adjacent platform, ladder, and so forth. The intent is to allow 100% inspection of the compressor or blower suction piping from the suction vessel to the compressor or blower inlet flange.

NOTE It is sometimes advantageous to clean debris from NPS 30 or larger pipe by entering the pipe, and sweeping it out by hand or using a vacuum cleaner. This can be more cost effective than large screens for catching debris. Caution – Entering pipe is considered working in a confined space.

### 6.25.3 Recycle Lines

6.25.3.1 Routing of compressor recycle lines shall be designed to prevent liquid from accumulating in piping low points. Recycle piping layout shall be free of sections where standing liquid may accumulate and shall slope toward the suction vessel. Adequate drains on the piping shall be provided to remove any standing liquids. Recycle lines on compressors handling a wet gas shall be heat traced and insulated.

NOTE "Slope toward the suction vessel" means that the suction vessel end of the recycle line is lower than the compressor end of the recycle line. This is preferred as it allows the recycle piping to be free-draining.

6.25.3.2 Compressor recycle lines shall reenter the process stream on the top of the piping upstream of the suction vessel.

6.25.3.3 Possible flow-induced vibration should be considered during design. A designated nozzle in the suction vessel may be an acceptable alternative design.

6.25.3.4 An analysis shall be made that considers the thermodynamic properties of the gas, the amount of gas to be recycled, the size of the suction vessel, piping fluid volume as well as compressor internal recirculation or losses. When indicated by this analysis, a cooler shall be installed in the compressor recycle line. The designated machinery representative shall agree with the return entry location of the compressor recycle line.

NOTE Recirculation of process gas through a compressor recycle line for extended periods can result in excessive heating of the process gas. Limiting process gas temperatures to reasonable values is usually accomplished by installation of a cooler or by making the suction vessel and piping large enough to provide sufficient surface area that heat can be dissipated to the environment by convection.

6.25.3.5 For systems handling corrosive or erosive gases or vapors, the location of the recycle line tie-in to the process line shall be reviewed by a corrosion/materials engineer or metallurgist for potential corrosion problems.

6.25.3.6 Anti-surge recycle valves and discharge check valves shall be located as close as practical to the compressor. The discharge line shall be designed such that the volume of gas in the line between the compressor flange and the anti-surge valve and the discharge check valve does not exceed the compressor manufacturer's design limit.

6.25.3.7 Compressor anti-surge sensing instrumentation should be located between any permanent or temporary suction screen or strainer and the compressor suction nozzle – as close to the nozzle as practicable.

NOTE 1 The purpose of this requirement is to prevent the increased variable pressure drop associated with a screen or strainer from interfering with the compressor anti-surge controls.

NOTE 2 Temperature elements may be installed upstream of the strainer to prevent ingestion into the compressor.

6.25.3.8 Compressor discharge temperature measuring instrumentation shall be located in the compressor discharge piping between the compressor discharge flange and the recycle line.

6.25.3.9 The recycle line take-off from the compressor discharge line shall be located between the compressor discharge flange and the discharge check valve.

NOTE: The intent of this requirement is to prevent over pressuring the compressor suction line with discharge gas when the compressor is shutdown.

## 6.26 Centrifugal and Rotary Compressors and Blowers

6.26.1 A straight run of piping with a minimum length as specified by the compressor or blower manufacturer shall be provided between the machine inlet nozzle and the first elbow or tee. If this straight run length is not specified by the machine manufacturer, a straight run of at least five pipe diameters shall be provided. The minimum length shall be calculated using the diameter of the compressor or blower inlet nozzle.

6.26.2 A non-slam (damped) check valve shall be provided in the discharge pipe run from all compressors or blowers.

6.26.3 The discharge line for compressors and blowers should be designed such that the volume of gas in the line between the discharge flange and the anti-surge valve and the discharge check valve does not exceed the compressor or blower manufacturer's design limit.

NOTE This requirement relates to transient response of the compressor control system and affects compressor stability.

6.26.4 A mechanical stop shall be provided on inlet throttle control valves when utilized on centrifugal compressors or blowers with constant speed drivers. This mechanical stop shall be set to allow minimum flow through the machine as recommended by the machine manufacturer.

NOTE Some flow control can be provided by variable-speed drives, or inlet control valves, or guide vanes. For constant-speed motor drivers, throttling of the inlet valve provides reduced load for start-up.

6.26.5 Suction piping configuration for double flow centrifugal compressors or blowers shall be geometrically symmetrical.

## 6.27 Reciprocating Compressors

6.27.1 For compressors handling gases which may be close to liquid phase, the suction piping from the liquid knockout vessel shall be routed overhead to the compressor suction pulsation dampener

vessel. For gases expected to be fully in the vapor phase, other piping configurations may be considered entering the suction pulsation dampener vessel.

NOTE Overhead routing is consistent with the common cylinder top suction configuration.

6.27.2 Reciprocating compressor discharge lines should not have check valves. However, a check valve shall be provided and located downstream of the recycle line if the compressor is equipped with a recycle line.

6.27.3 The piping engineering designer shall verify that the check valve is suitable and designed for extended service in pulsating flow.

NOTE Conventional swing check valves are usually not suitable for use in pulsating flows because frequent flow reversals result in premature valve failure.

6.27.4 Vent lines from reciprocating compressor pressure packing in lubricated service shall be routed to a drain pot to remove liquids before being routed to the vapor disposal system. Vent and drain lines shall be routed so as not to obstruct any access covers or openings. Note: Compressor manufacturer should be consulted for recommendations on vent and drain best practices, including line sizes, considerations for purge and hazardous services along with safe connection to vapor disposal systems or atmosphere.

6.27.5 For reciprocating compressors handling gas compositions expected to be near liquid phase, the suction piping from the suction vessel to the compressor, may be heat traced and insulated to prevent liquid condensation in the piping. The compressor suction pulsation vessels may also be heat traced and insulated. Note: Vessels and piping covered by insulation should be properly protected from corrosion. Other temperature controls may be considered to prevent liquid condensation in the piping.

6.27.6 A pressure relief device or devices shall be provided for each compressor cylinder or stage of a reciprocating compressor. These relief devices may be located in either the discharge piping or on the liquid knockout vessels. Relief devices shall be located between the compressor cylinder and any permanent blinds or block valves.

6.27.7 Pressure relief devices shall be sized and rated to avoid exceeding the lesser of piping pressure ratings, pulsation vessel pressure ratings, cylinder pressure ratings, or rod loads.

NOTE Though rod load is a factor to be considered in the sizing and rating of reciprocating compressor discharge pressure relief protection, installation of discharge pressure relief protection does not, by itself, ensure rod loading requirements will not be exceeded. Rod load is a function of the differential pressure across a cylinder as well as inertia. Suction pressures less than or greater than the operating range indicated by the compressor manufacturer can result in unacceptable rod loads despite discharge relief protection.

6.27.8 Piping shall meet the design criteria specified by the pulsation analysis, piping mechanical analysis, and static piping analysis.

6.27.9 Drains from compressor distance pieces, packing vents, leak-offs from unloaders, and distance piece vents shall be routed in accordance with API 618 or as specified by the compressor manufacturer.

6.27.9.1 Drain lines shall be routed so as not to obstruct any access covers or openings. Process and vent piping shall not be routed over the compressor crankcase.

6.27.9.2 The area above the compressor crankcase shall be kept clear of all piping and electrical conduits.

6.27.10 Compressor knockout/scrubber and pulsation vessels shall include drain connections.

## 6.28 Rotary Screw Compressors

6.28.1 For rotary screw compressors handling condensing gases, the suction piping from the liquid knockout vessel shall be routed overhead to the compressor suction flange. For noncondensing gases, the piping may be routed to grade before going into the compressor suction flange.

6.28.2 For oil flooded rotary screw compressors, the compressor discharge line shall be sized and installed per API 619 to accommodate a mixed gas/oil flow.

6.28.3 Oil flooded rotary screw compressor discharge lines shall contain a check valve to minimize oil backflow upon shutdown. The piping engineering designer should verify that the check valve is suitable for extended service in pulsating flow of an oil/gas mixture.

NOTE Conventional swing check valves are typically acceptable for use in rotary screw compressor applications because pulsating flow variations are generally small.

6.28.4 The oil flooded rotary screw compressor scavenged oil line, from gas/oil separator coalescing filter downstream side, shall be routed back to the compressor as per manufacturer's directions.

Scavenged oil and compressor sump drain lines shall be routed so as not to obstruct any access covers or openings.

6.28.5 For rotary screw compressors handling condensing materials, the suction piping from the suction vessel to the compressor shall be heat traced and insulated to prevent liquid condensation in the piping. For oil flooded rotary screw compressors, the gas/oil separation vessels should be heat traced and insulated. Vessels and piping covered by insulation shall be properly protected from corrosion.

6.28.6 A pressure relief device or devices shall be provided for each compressor stage of a rotary screw compressor. These relief devices may be located on either the liquid knockout vessels or the downstream discharge piping. Relief devices shall be located between the compressor discharge flange and any permanent blinds or block valves.

6.28.7 Pressure relief devices used for rotary screw compressors shall be sized and rated to avoid exceeding the lesser of piping pressure ratings, liquid knockout vessel pressure ratings, housing pressure ratings, rotor deflection criteria, or rotor bearing loads.

6.28.8 Though rotor deflection and bearing load are factors to be considered in the sizing and rating of rotary screw compressor pressure relief protection, installation of pressure relief protection does not, by itself, ensure compressor design limitations will not be exceeded.

6.28.9 Rotary screw compressors operating with variable suction and discharge pressure levels shall be evaluated for maximum expected discharge temperature. This evaluation shall be based upon the worst combination of gas composition, suction pressure, discharge pressure and flow rate expected during commissioning, start-up, shutdown or normal operation. Suitable controls shall be provided on the basis of this evaluation to avoid piping damage from excessive temperature.

NOTE For rotary screw compressors operating with variable suction and discharge pressure levels, maximum allowable discharge temperature can occur before maximum allowable pressure occurs despite discharge relief protection. The rotary screw compressor manufacturer can provide guidance in the selection and configuring of suitable safeguarding controls.

6.28.10 Rotary screw compressor piping shall meet the design criteria specified by the piping mechanical analysis, and static piping analysis.

6.28.11 Drains and vents from the rotary screw compressor and associated equipment shall be routed in accordance with API 619. Drain lines shall be routed so as not to obstruct any access covers or openings.

6.28.12 Rotary screw compressor, vessel and piping drains shall be manifolded into a single drain line to facilitate complete drainage through low points without disassembly of piping. Drain line primary block valves shall be provided at each vessel or liquid source. Additional drain valves should be provided at the manifold.

## 6.29 Steam Turbines

6.29.1 Inlet piping to steam turbines shall be free of sections where liquid may accumulate during normal operation, start-up, and/or shutdown. Where such sections are unavoidable, suitable drain facilities shall be provided (see Figure B.2).

6.29.1.1 All sealing steam and leak-off steam lines connecting to the turbine shall have any horizontal piping runs sloping away from the turbine and lower than the turbine connection.

6.29.1.2 All sealing steam and leak-off steam lines shall be designed and field fabricated to be self-draining. Piping should slope away from the turbine so that any condensate will drain away from the turbine. Piping shall not be pocketed unless the pocketed (low point) location is provided with both a manual and automatic drain.

6.29.2 Reducers installed in the inlet piping to steam turbines shall be eccentric with the flat side on the bottom to prevent the accumulation of any liquid.

6.29.3 Steam turbine gland leak-off lines shall be routed to headers as close as possible to the turbine. The transfer line should be at least one pipe size larger than the connection furnished on the turbine.

6.29.4 A bypass around the inlet block valve shall be provided to allow control during warm-up, carbon ring break-in, and overspeed trip tests. This bypass shall be sized to provide sufficient steam to run the turbine uncoupled from the driven load.

NOTE This bypass line is provided around the steam inlet block valve—NOT around the turbine trip or trip-throttle valve.



- 6.29.5 Piping arrangements for steam piping into the turbine shall include provision for the temporary reorientation of steam inlet lines for the pre-commissioning “blowing” of the line. Piping arrangements shall also include provision for the installation of targets if targets are to be utilized in the pre-commissioning “blowing” of the line.
- 6.29.6 The steam piping arrangement shall adequately support the remaining piping when piping is temporarily reoriented for commissioning steam blowing of the line.
- 6.29.7 Condensing Turbines
- 6.29.7.1 Condensing steam turbines should be provided with a method for breaking vacuum or restoring turbine exhaust pressure to atmospheric pressure. Vacuum should be broken by allowing air into the condenser shell or into the exhaust piping downstream of the turbine.
- 6.29.7.2 Vacuum shall not be broken by allowing air to enter the turbine through casing drains, leak-offs, or sealing steam piping.
- NOTE The vacuum breaker can be as simple as a hand-operated valve that is opened when the turbine is shut down or it may be an automatic valve tied to the trip system.
- 6.29.7.3 Breaking the vacuum serves two purposes. On applications where the driven equipment produces no load during coast-down, breaking vacuum will decelerate the equipment quicker. Secondly, breaking vacuum prevents that cold air is drawn in along the shaft when sealing steam is turned off. Sealing steam shall not be turned off with the turbine exhaust under vacuum or the shaft may be bowed.
- 6.29.7.4 Condensing steam turbines equipped with valves that serve the dual function of a vacuum breaker and PSV often use a water seal to prevent air leakage through the valve into the condenser. Clean condensate should be supplied to maintain the water seal so that any leakage into the condenser does not cause contamination of the condensate being returned to the plant condensate collection system, and the water seal level sight glass should be installed at a position that is easily visible to the operator.
- 6.29.7.5 Valves using a water seal to prevent air leaking into the vacuum system shall be installed with its flanges level and its axis vertical to assure the water is equally distributed around the valve.
- NOTE If the valve is not level, the water seal may not be effective at preventing air leakage.
- 6.29.7.6 Atmospheric relief valves using a water seal to prevent air leaking into the vacuum system should be designed such that they are not allowed to accumulate excessive water seal levels, as this will cause an increase in the relief pressure.
- 6.29.7.7 Water seal level shall be controlled. This is best achieved by installing an unobstructed overflow pipe that automatically allows excessive water seal height to be drained away.
- 6.29.7.8 The overflow outlet shall be visible and drain to an open atmospheric pressure sewer such that personnel cannot be injured during slug flow.
- NOTE: Consider a drain on the seal so that water can be drained to prevent freezing when the turbine is not in operation.
- 6.29.7.9 An expansion joint may be used between the steam turbine and condenser. The expansion joint should be furnished with a flow liner and it should have the same construction rating as the turbine exhaust casing. The expansion joint shall be able to absorb the thermal growth of the turbine and condenser up to the construction rating temperature.
- 6.29.7.10 The connection joining the turbine and condenser shall have a means of absorbing this thermal growth.
- NOTE Condensing steam turbines and their condensers each will grow as temperature increases from the cold to the hot operating condition.
- 6.29.7.11 An alternative arrangement supports the condenser on spring supports. The condenser spring supports should be designed for the condenser operating weight with the hot well at its normal operating level and the water boxes and condenser tubes full of water. Condenser spring supports should be located symmetrically on either side of the turbine longitudinal axis producing minimal moments on the turbine exhaust nozzle.
- 6.29.7.12 All condenser piping connections shall be provided with either expansion joints or piping with sufficient flexibility that condenser movement is not inhibited.
- 6.29.7.13 Turbine sealing steam piping and turbine packing cases downstream of sealing steam control valves should be protected from excessive pressure by a suitably sized pressure safety valve per API 520

6.29.7.14 A sealing steam supply pressure safety valve may not be required if all components to which the steam is delivered are capable of operation at the maximum pressure and temperature of the sealing steam supply source.

6.29.8 The turbine casing shall be protected from piping weight and piping expansion strains. Piping weight should be carried by suitable supports.

NOTE Refer to NEMA standards SM 23 or SM 24 for a discussion of piping design in general and the method used to calculate the allowable maximum forces and moments the turbine flanges are designed to resist.

6.29.9 Before piping is connected to the turbine, mount at least two indicators either from the turbine coupling hub reading on the driven machine coupling hub or vice versa. One indicator should be arranged to measure vertical movement, the other indicator should measure horizontal movement. Then connect piping to turbine.

6.29.10 If the movement measured on either indicator exceeds 0.002 in. (0.05 mm), this indicates the piping loads are excessive and corrective action is necessary to reduce piping loads so the turbine support system and turbine casing are capable of working with the imposed loads without misalignment.

6.29.11 Casing drains are for intermittent operation during start-up (heating and draining) or shutdown (draining) and shall always have valves installed.

6.29.12 Drains shall be piped independently of one another to prevent flow from one drain at a higher pressure flowing into another drain at a lower pressure.

6.29.13 All steam piping connected to steam turbines, including inlet, exhaust, sealing steam, leak-off, etc., shall be provided with adequate valved drains to allow draining the piping of condensate before starting and after shutting down.

6.29.14 See Annex C for additional information on steam turbine piping design.

### 6.30 Hydrotest Design and Restrictions

6.30.1 Piping hydrostatic test should not be done through any type of machinery including vertical and horizontal pumps, steam turbines, blowers, or compressors. Separate hydrostatic test blinds should be installed or the inlet and outlet piping spools should be removed to isolate the machinery during piping hydrotest.

NOTE Piping hydrostatic test pressures are typically much greater than the normal operating pressures of the process machinery. Damage to process machinery components can result if machinery is subjected to hydrotest pressures. As it can be difficult to remove hydrotest water and debris from machinery internal passages, subsequent machine damage and process contamination can result when the equipment is put into service if machinery is hydrotested with the process piping.

6.30.2 The piping hydrotest layout around vertical barrel or can pumps should be designed to prevent water from entering the pump barrel or can.

6.30.3 Where possible, field welds required for piping alignment should be located between the isolation block valves and the machinery nozzles to permit the hydrotesting of short spools.

### 6.31 Oil Mist Piping Installation

6.31.1 All oil mist piping should be routed and supported in the field with all joints exposed to view. No underground piping is acceptable.

6.31.2 Oil mist piping should be fabricated to minimize the use of piping fittings. Reducing swage nipples and reducing couplings should be used in place of reducing bushings.

6.31.3 No welded joints in the oil mist piping system are permitted.

6.31.4 All piping joints should be threaded. Threaded connections should only be made with a thread lubricant/sealant approved by the designated machinery representative. PTFE tape should not be used to make up any threaded connections in the oil mist system. Unless explicitly approved otherwise by the designated machinery representative, alternative pipe thread sealants should not be used.

6.31.5 Oil mist branch header to main header connections as well as drop point lateral to header connections should be made at the top of the header pipe.

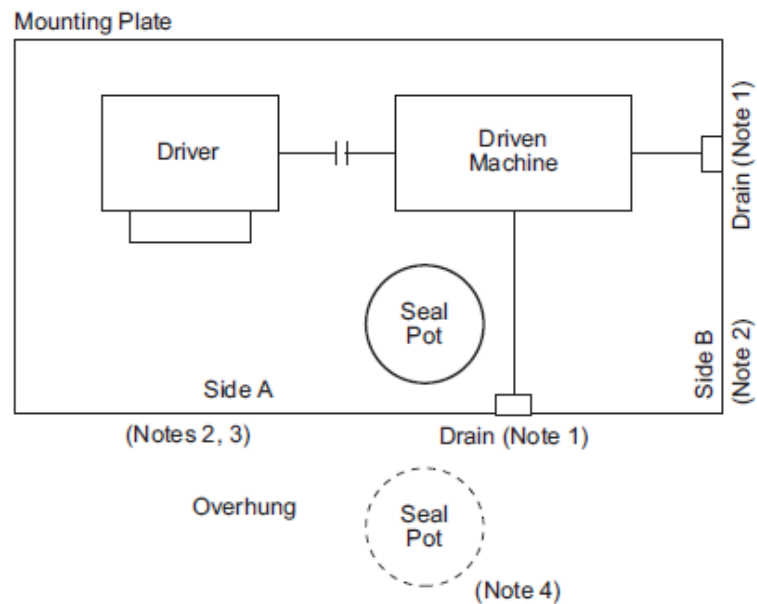
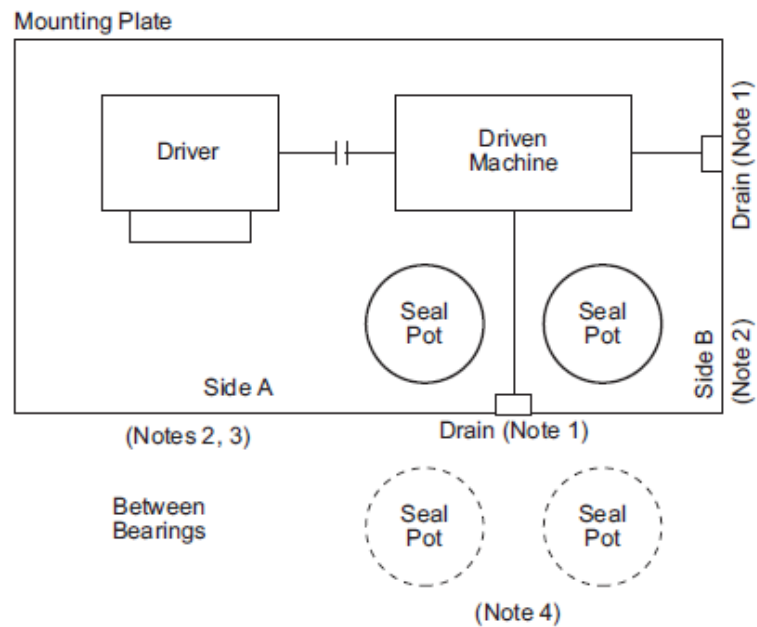
6.31.6 The oil mist application fittings (reclassifiers) should be connected to the machinery bearing housings with the tubing arranged to allow normal operation and maintenance access without moving the application fitting (reclassifier) or the tubing.



6.31.7 Oil mist tubing should be installed so that oil will not be trapped. Tubing benders should be used for bending so that the tubing will have no kinks, wrinkles, or flattened spots.

Draft—For Committee Review

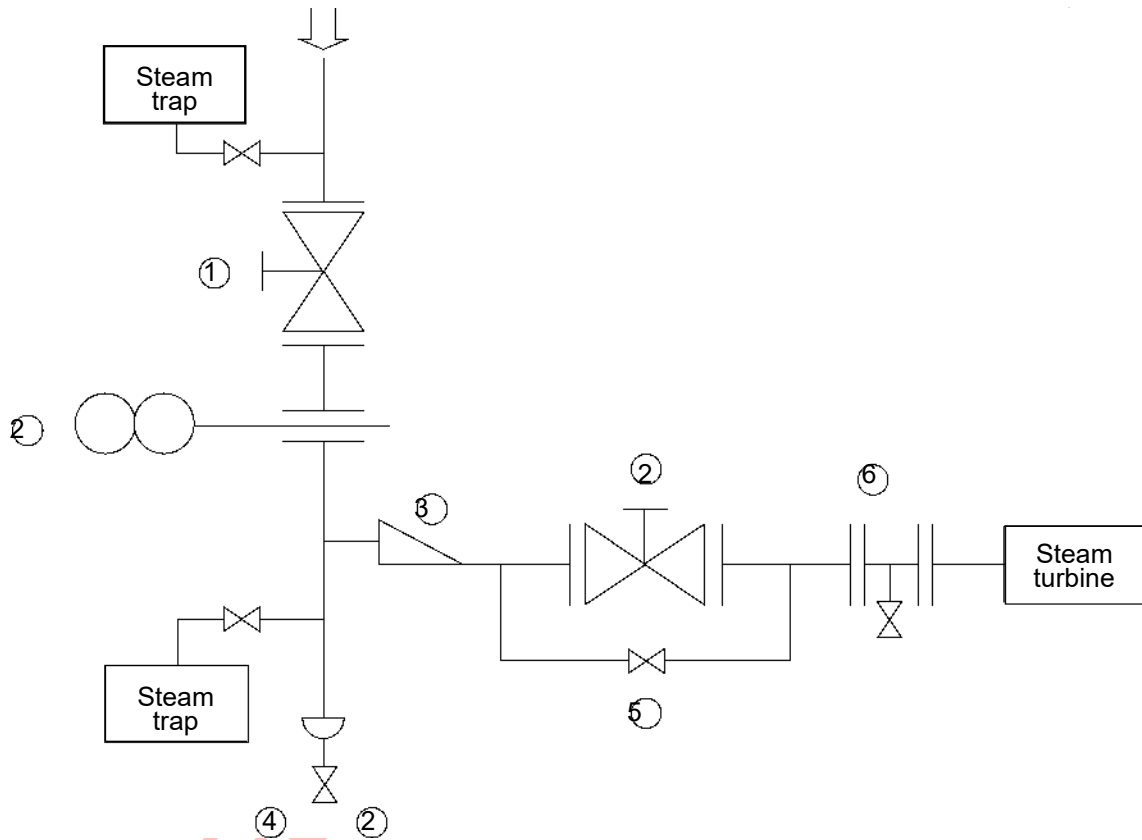
## Annex B (informative) Machinery Installation Piping Diagrams



- NOTE 1 Drain located at Side A or Side B.
- NOTE 2 All tubing and auxiliary piping routed to Side A or Side B.
- NOTE 3 Electrical connections made on Side A.
- NOTE 4 When specified, alternate seal pot locations alongside mounting plate are acceptable.
- NOTE 5 Verify that seal pot location and orientation does not conflict with shaft rotation and seal porting.

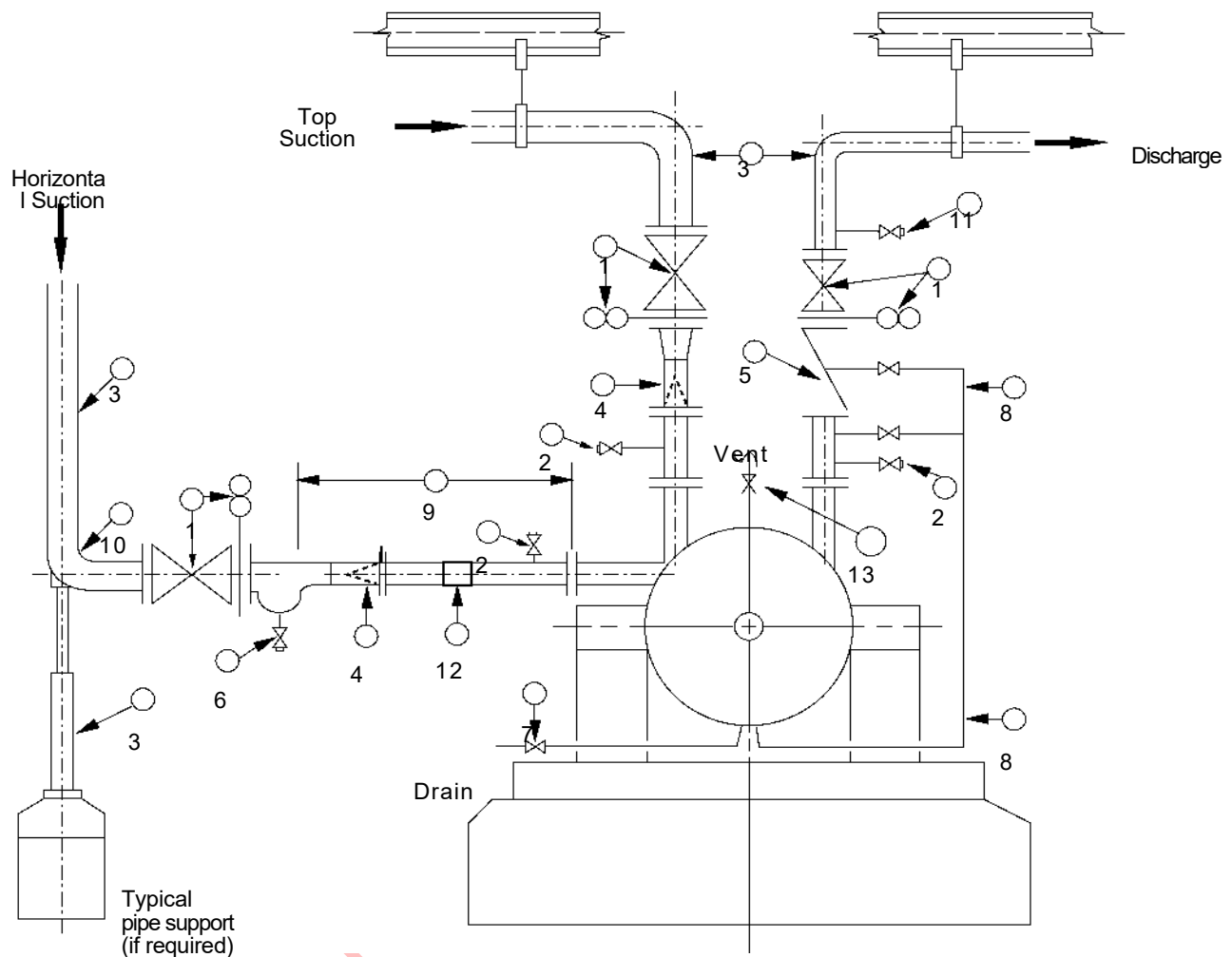
### B.1 Typical Seal Pot Location

## Machinery Installation—Piping



- 1 Isolation block valves required (6.6.1). Accessible from Grade (6.5.5)
- 2 Blinds or “Double block and bleed” suggested (6.6.2.1).
- 3 Eccentric reducer flat-on-bottom (6.29.2)
- 4 Suitable drain facilities for condensate (6.19.3)
- 5 Warm-up bypass valve (9.1.3)
- 6 Provision for pre-commissioning blowing of steam line (6.19.3)

**Figure B.2—Typical Steam Turbine Inlet Piping**



- 1 Isolation block valves required ( 6.6.1), Blinds shall be provided ( 6.6.1), block valves and blinds accessible from grade (6.5.5).
- 2 Pressure measurement connections with isolation valves ( 6.9.1 and 6.9.2).
- 3 Piping to and from machinery shall be adequately supported ( 6.7.1).
- 4 Inlet strainer required ( 6.11).
- 5 Discharge check valve required for centrifugal or rotary pumps, compressors, or blowers ( 6.9.4). Same size as outlet nozzle ( 6.13.4).
- 6 Vent and drain piping NPS  $\frac{3}{4}$  or larger ( 6.21.1.1.4).
- 7 Piping vents and drains not located in angle section of reducer ( 6.14.3 and 6.14.8). Located in a safe and accessible location ( 6.14.4). Drains routed to edge of baseplate (2.10.3).
- 8 Warm-up lines for hot materials ( 6.15.1).
- 9 Pump suction line straight run requirement ( 6.22.6).
- 10 Last pipe elbow to be long radius ( 6.22.7).
- 11 Bypass or drain valve for check valves in vertical piping ( 6.13.5).
- 12 Provision for field weld ( 6.8).
- 13 Pump vent or equalizing line ( 6.22.9).

**Figure B.3—Typical Machinery Piping Schematics**

6.8.1 For all piping NPS 10 or larger, the piping engineering designer shall include provisions for a final piping field weld to facilitate piping installation in accordance with the machinery flange fit-up requirements.

6.8.2 The final piping field weld shall be located between the face of the machinery flange and the first pipe support or isolation block valve.

#### NOTES

Piping smaller than NPS 10 typically has sufficient flexibility that there is usually little difficulty in achieving machinery flange fit-up requirements during field installation. Thick walled pipe smaller than NPS 10 may require a final field weld due to the greater stiffness and difficulty in meeting flange fit-up requirements. Typical industry practice is to shop fabricate piping smaller than NPS 10 and not perform a final field weld providing flange fit-up requirements can be met.

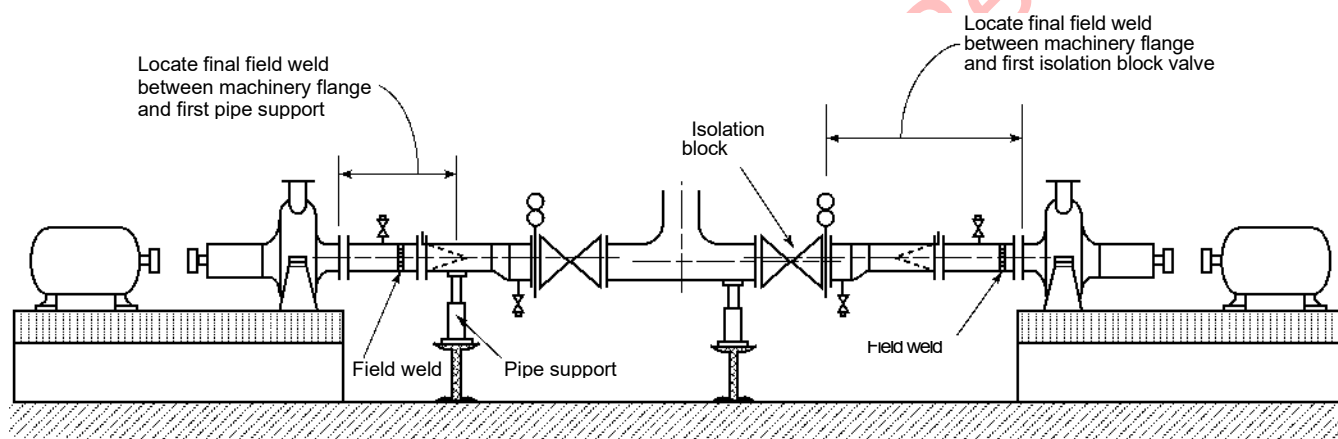
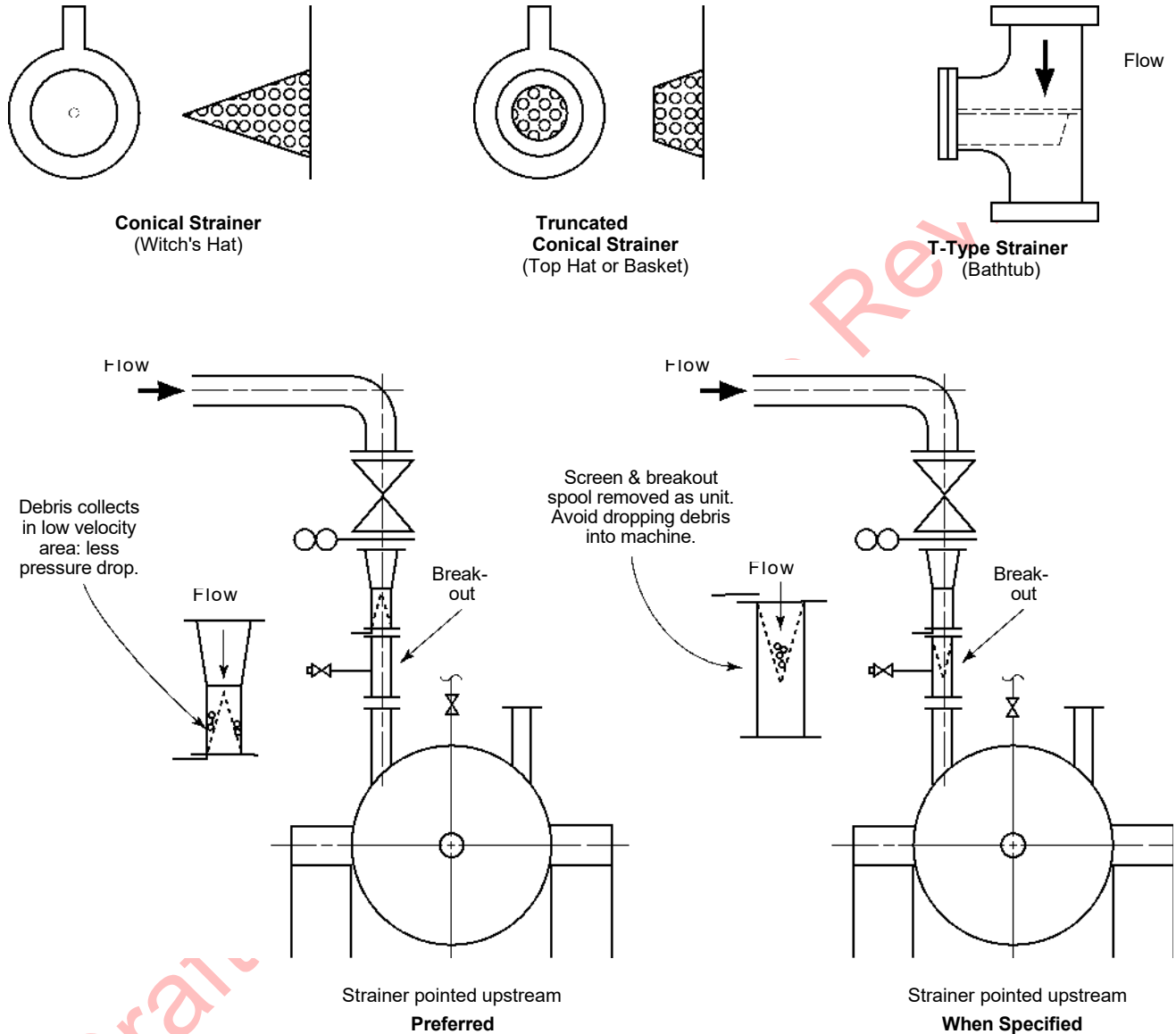


Figure B.5—Final Field Weld Location

## INLET STRAINERS

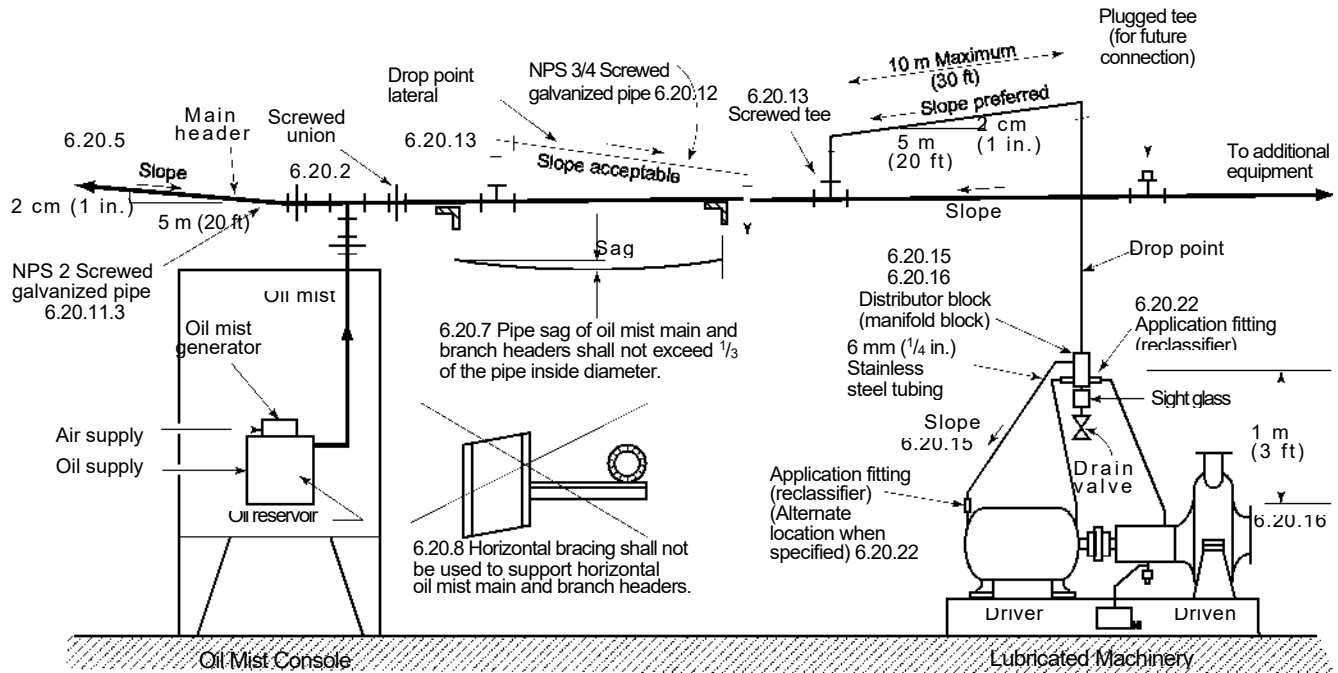
6.12.8 Acceptable temporary strainer designs include: conical, truncated conical, and T-type or similar design.



6.12.9 The point of the conical strainer shall face upstream in the piping. Screens in T-type strainers shall point with the flow.

**NOTE** Pointing the conical strainer upstream to the flow allows debris to fall to the outside of the cone around the perimeter of the pipe and so minimize the obstruction to the flow path. This is the preferred orientation for most machinery installations. Conical strainers may be installed with the point oriented downstream when explicitly specified by the designated machinery representative. This can be advantageous in situations where there are space limitations or where removal of the temporary strainer may result in the dropping of debris into the machine inlet.

**Figure B.6—Inlet Strainers**



6.20.1 Oil mist main and branch headers shall not be valved.

6.20.13 Oil mist drop point lateral piping shall come vertically off the top of the main header through a screwed tee.

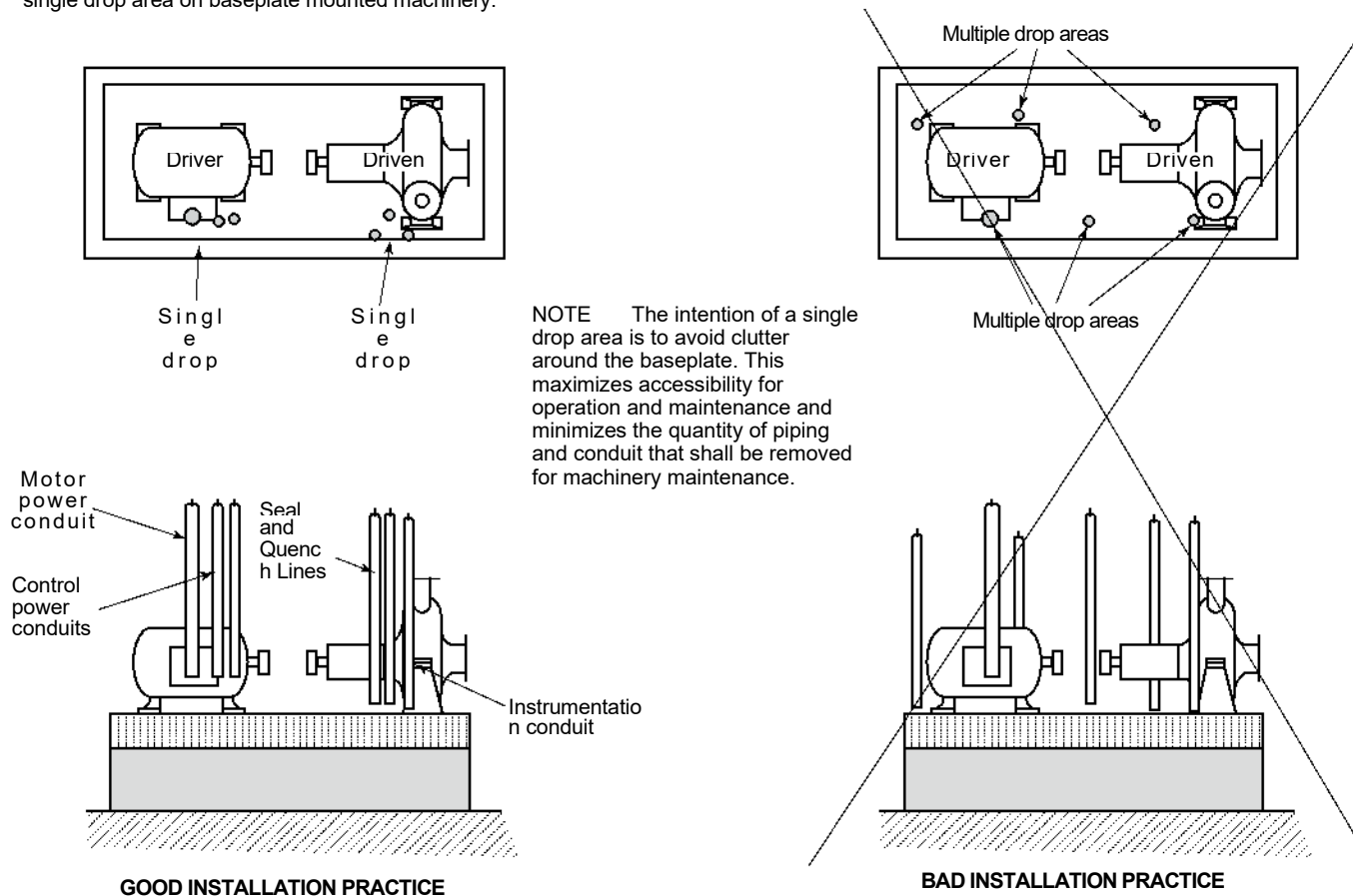
6.20.17 Oil mist drop point piping shall be located such that access for operation and maintenance of the machinery is not obstructed. Dismantling of oil mist drop point piping or the distribution block to remove the machinery for maintenance is not acceptable.

**Figure B.7—Oil Mist Piping**



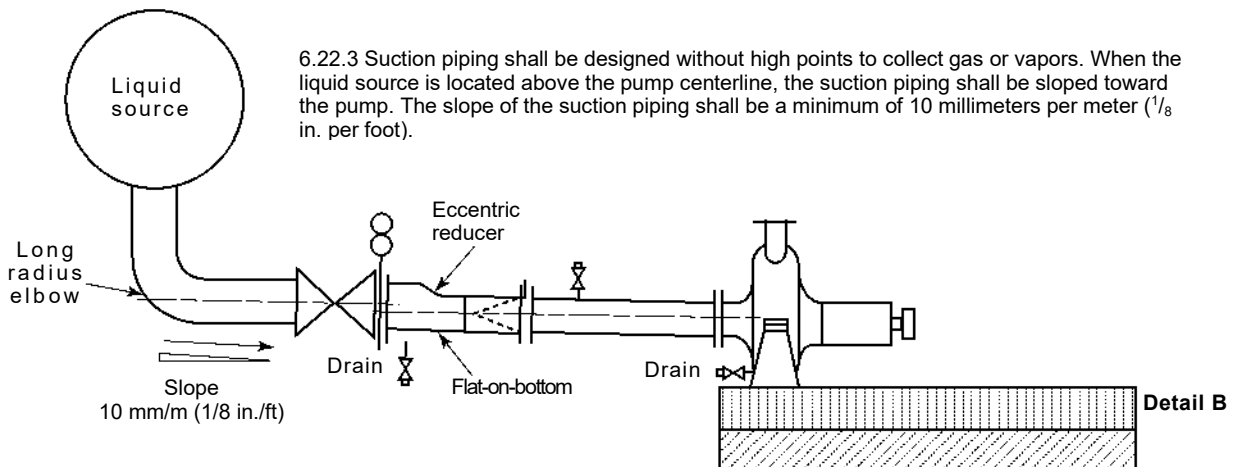
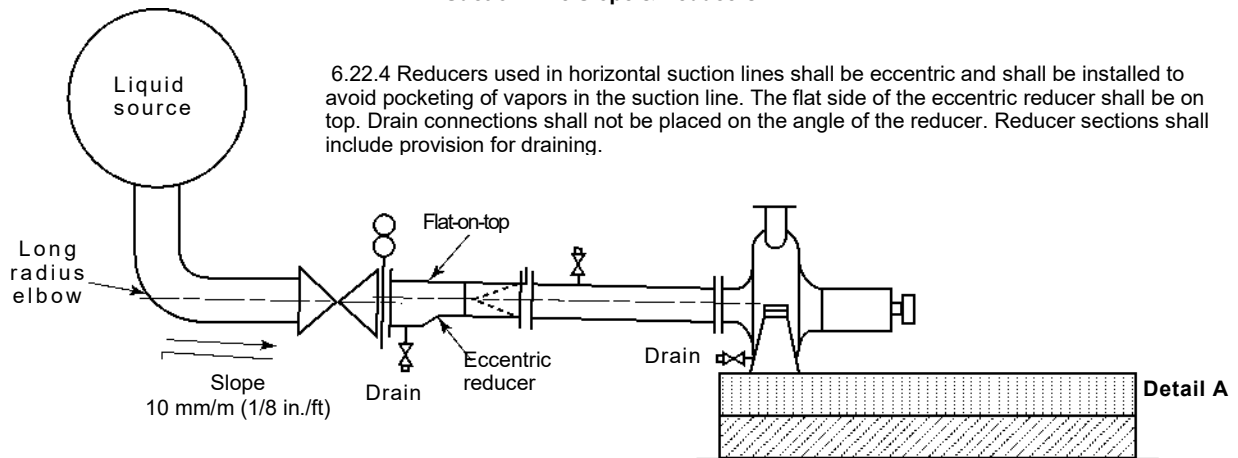
### Single Drop Area for Auxiliary Piping & Conduit

6.5.4 Auxiliary support piping, conduit, instrumentation, and so forth, shall be designed for a single drop area on baseplate mounted machinery.

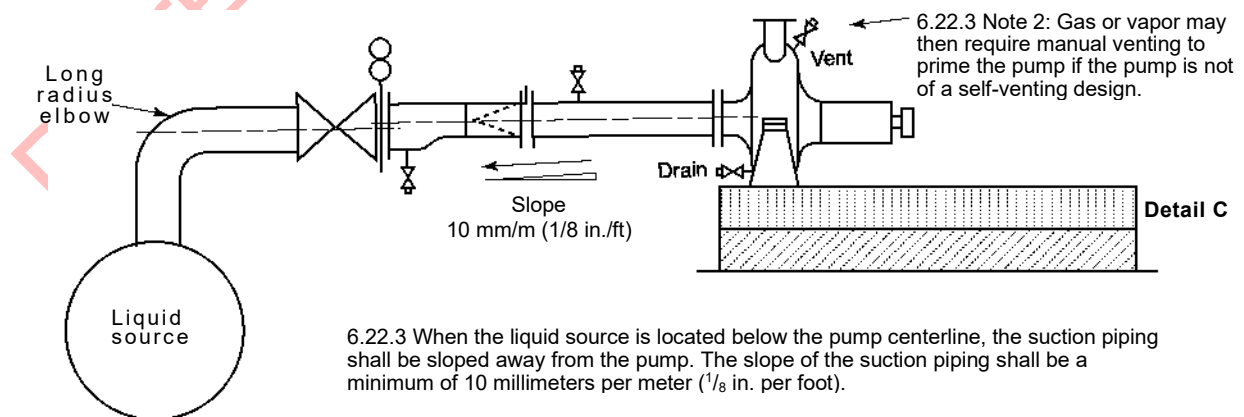


**Figure B.9—Single Drop Area for Auxiliary Piping and Conduit**

### Suction Line Slope & Reducers



6.22.6 When complete drainage is required to remove hazardous liquid or solids before performing maintenance, the eccentric reducer in the horizontal pump suction line should be oriented with the flat side on the bottom. For example, it is desirable that hydrofluoric acid piping be completely drained to avoid pockets of material that may prove hazardous to maintenance personnel.



**Figure B.10—Suction Line Slope and Reducers**

## Annex C (informative)

### Steam Piping for Turbines

The inlet and exhaust piping (including feedwater heating connections) for a steam turbine may have a marked effect on the satisfactory operation of the turbine and driven machine. Due to the close internal clearance, it is not advisable to have excessive forces that may cause deflection of the turbine case and supports and reduce internal clearances below a safe limit or result in excessive coupling misalignment; coupling alignment shall be maintained within close limits for satisfactory operation. Small lightweight high-speed turbines are especially susceptible to casing distortion. For these reasons the steam piping should be analyzed and properly laid out to prevent excessive forces from being transmitted to the turbine flanges.

Piping may exert forces from three basic causes: the dead weight, thermal expansion, and thrust due to expansion joints. Since thermal expansion also causes movement of the turbine flanges, this shall be considered a cause of pipe reaction. Because of the many locations of inlet and exhaust flanges and probable piping arrangements, it is not possible to present a piping arrangement to cover all cases. The purpose of this annex is to cover some of the basic principles of piping, particularly as applied to turbines. Piping design is covered quite thoroughly by manuals put out by the major piping fabricators and contractors, and it is not the intention of this annex to duplicate what may be found in these manuals.

Piping to the turbine flanges comes under the jurisdiction of the ASME *Boiler and Pressure Vessel Code*, the ASA *Code for Pressure Piping*, or the American Bureau of Shipping. The applicable code will determine the size and type of pipe used and will not be discussed in this annex.

#### C.1 Exhaust Piping

Low-pressure and vacuum lines are usually large and relatively stiff. It is common practice to use an expansion joint in these lines to provide flexibility. If an expansion joint is improperly used, it may cause a pipe reaction greater than the one it is supposed to eliminate. An expansion joint will cause an axial thrust equal to the area of the largest corrugation times the internal pressure. The force necessary to compress or elongate an expansion joint can be quite large, and either of these forces may be greater than the limits for the exhaust flange. In order to have the lowest reaction, it is best to avoid absorbing pipe line expansion by axial compression or elongation. If it is found that expansion joints are required it is essential that they be properly located and their function determined.

Figure C.1 shows an expansion joint in a pressure line. The axial thrust from the expansion joint tends to separate the turbine and the elbow. To prevent this, the elbow shall have an anchor to keep it from moving. The turbine shall also absorb this thrust and in doing so becomes an anchor. This force on the turbine case may be greater than can be allowed. In general this method should be discouraged.

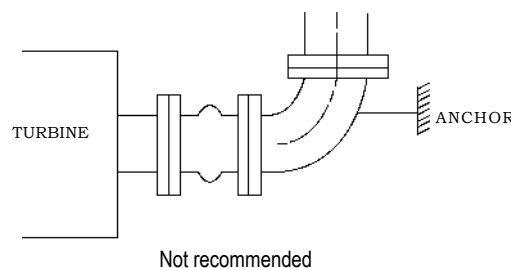


Figure C.1

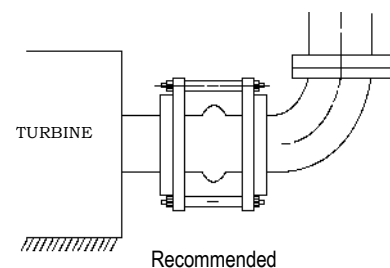
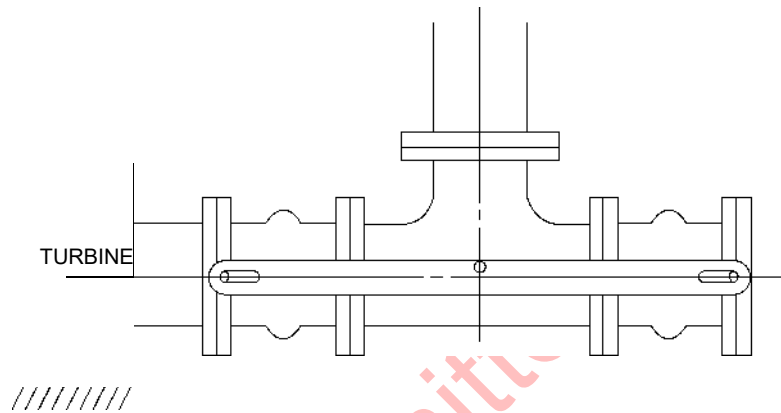


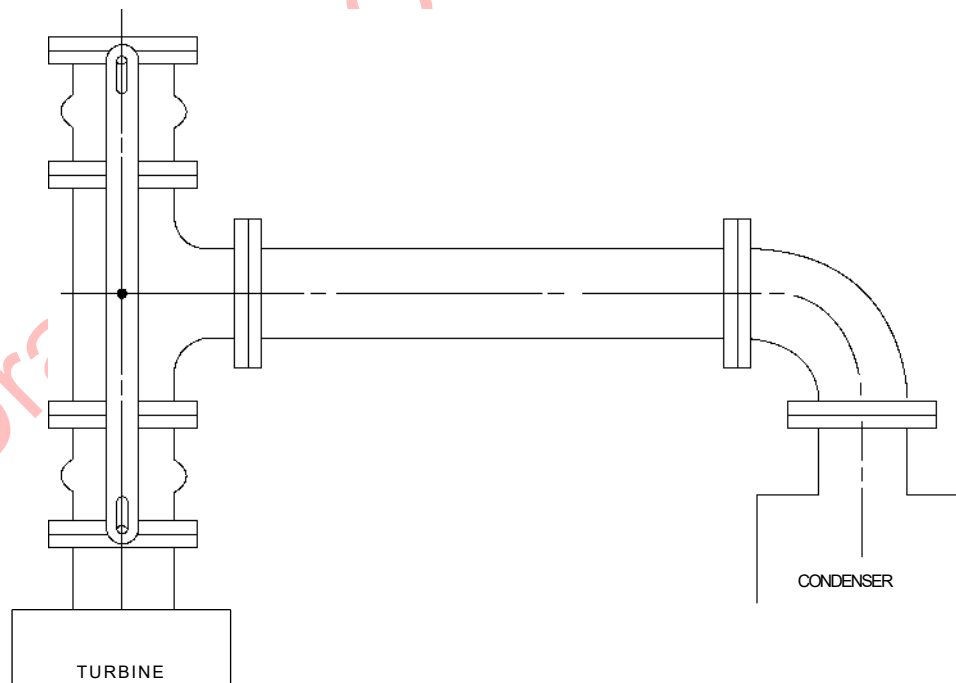
Figure C.2

Figure C.2 shows the same piping arrangement as Figure C.1 except for the addition of tie rods on the expansion joint. The tie rods limit the elongation of the joint and take the axial thrust created by the internal pressure so it is not transmitted to the turbine flange. The tie rods eliminate any axial flexibility, but the joint is still flexible in shear, that is, the flanges may move in parallel planes. The location of this type of joint in the piping should be such that movement of the pipe puts the expansion joint in shear instead of tension or compression.



**Figure C.3—Exhaust Piping Expansion Joint Application Utilizing Tie Rods**

Figure C.3 is an arrangement frequently used, having tie rods as indicated. This arrangement will prevent any thrust due to internal pressure from being transmitted to the exhaust flange and retains the axial flexibility of the joint. It may be used for either vacuum or pressure service.

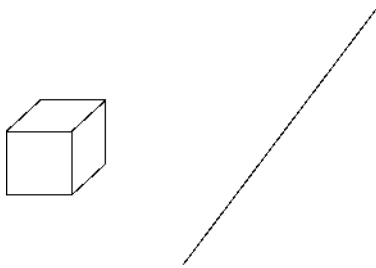


**Figure C.4—Condensing Turbine Expansion Joint with “UP” Exhaust**

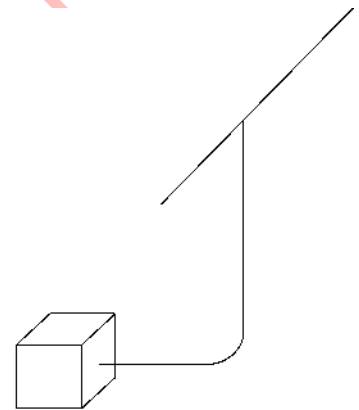
Figure C.4 shows a suggested arrangement for a condensing turbine with an up exhaust. This arrangement is recommended and frequently used. Due to the large exhaust pipe size normally encountered on condensing turbines, the exhaust piping will be relatively stiff, and an expansion joint shall be used at some point to take care of thermal expansion. An unrestricted expansion joint placed at the exhaust flange of the turbine will exert an upward or lifting force on the turbine flange, which in many cases is excessive. Figure C.4 provides the necessary flexibility to take care of thermal expansion without imposing a lifting force on the turbine. The expansion joint is in shear, which is the preferred use. The relatively small vertical expansion will compress one joint and elongate the other, which causes a small reaction only and will be well within the turbine flange limits.

On smaller and high-pressure exhaust lines it is frequently better to rely on the flexibility of the piping than on an expansion joint. Only after a careful analysis of the piping shows the need for an expansion joint should they be used.

In order to have flexibility in piping, short direct runs shall be avoided. By arranging the piping in more than one plane, torsional flexibility may be effectively used to decrease the force.



**Figure C.5**



**Figure C.6**

Figure C.5 shows a short direct run to an exhaust header. If the header is free to float in a horizontal plane, thermal expansion of the exhaust line will put very little direct thrust on the exhaust flange. If the header is fixed, the thermal expansion will tend to cause either the turbine or header to move and may cause damage. If thermal expansion causes the header to move in an axial direction, it will transmit a force and moment to the exhaust flange. Figure C.5 is not recommended, as it is difficult to prevent excessive forces from being transmitted to the exhaust flange. Figure C.6 is a variation of Figure C.5 and the same comments apply.

Figure C.7, through Figure C.9 show piping arrangements in 1, 2, and 3 planes where long runs of pipe are used to get flexibility. The length of the runs necessary for flexibility depends on the size and schedule of the pipe. In these cases it is assumed that the turbine is a fixed point and the point of connection to the header "A" is fixed. If "A" is free to move, it may relieve some of the forces caused by thermal expansion. If "A" is free and thermal expansion of the header causes it to move, it may cause additional forces to be transmitted to the turbine. With existing piping installations or new piping systems, it is necessary to examine the entire system and locate the fixed points from which deflection and movements may be measured. Guides, tie rods, and stops should be used to limit movements where necessary, to prevent excessive piping movement from creating forces and moments that exceed the turbine flange limits.

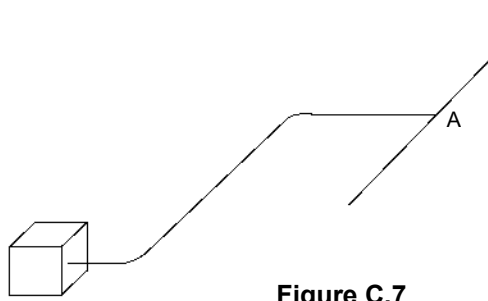
## C.2 Steam Inlet Piping

The forces on the steam inlet flange are normally due to thermal expansion. Expansion joints are seldom used due to the high pressures encountered; therefore, utilizing the pipe flexibility is the only means of keeping the forces below

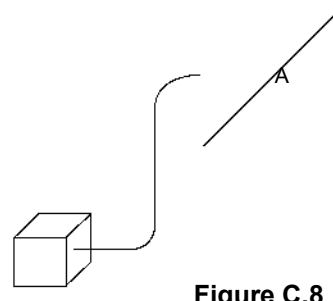
The specified limits. Figure C.7 through Figure C.9 apply to inlet piping as well as exhaust lines, except that the takeoff from a steam header should be on the top.

Figure C.10 shows the recommended method of taking a steam line from a header. Since any steam line, even with superheated steam, may have entrained moisture or condensate running along the bottom of the pipe due to radiation losses, boiler priming, or ineffective trapping, taking steam off the top of the header assures dry steam under normal conditions.

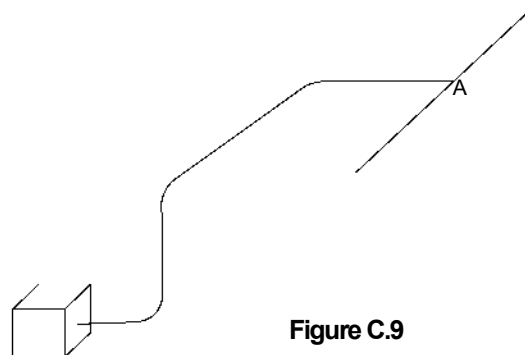
If a steam inlet line is at the end of a steam header, it should be taken off as shown in Figure C.11. Since any accumulation of condensate in the header will be carried along until it is trapped out or reaches the end of the header, the turbine on the end of the header may get a lot of water. The header should continue past the last steam take-off with a vertical drop-leg to accumulate the condensate to be trapped out. The use of a large, well-trapped drop-leg makes a very effective separator that will help to protect the turbine from large volumes of water such as caused by priming of a boiler.



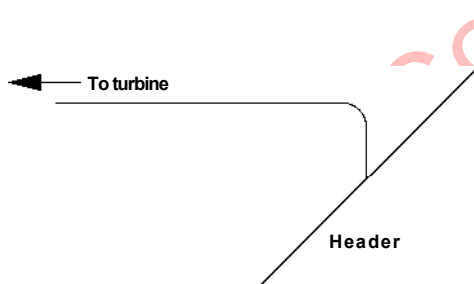
**Figure C.7**



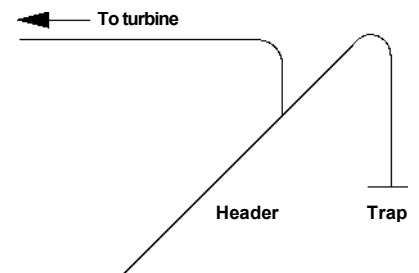
**Figure C.8**



**Figure C.9**



**Figure C.10—Recommended Turbine Inlet Piping Arrangement from Header**



**Figure C.11—Recommended Turbine Inlet Piping Arrangement at Header End with Drop Leg**



Avoid low spots or pockets in inlet piping that may accumulate water. A pipe partially filled with water may continue to pass the quantity of steam required by a turbine until the steam passage becomes too restricted by the water. At this point the steam will start to move the water, which builds up as a wave and is carried along as a slug of water that can cause serious damage to the piping and the turbine. This is more prevalent in oversize steam lines where the steam velocity is too low to carry all the entrained moisture along.

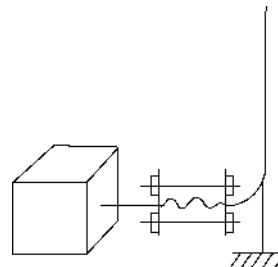
A new piping system should be blown out by disconnecting the steam line at the turbine and running it to atmosphere. Blow the line out by opening a shut-off valve as near the boiler as possible so a high steam velocity is attained in the piping. Alternate blowing and cooling will tend to loosen scale, welding beads, and debris so it will be blown out.

### C.3 Piping Supports

In the previous discussion the weight of the piping has not been considered. The dead weight of the piping should be entirely supported by pipe hangers or supports. There are basically two types of supports, rigid and spring. Rigid supports are necessary when an unrestricted expansion joint is used. Rigid supports may be used to limit the movement of a line to prevent excessive deflection at any point. A rigid support is not satisfactory where thermal expansion may cause the pipe to move away from the support.

On the two types of rigid supports shown in Figure C.12, the rise of the turbine case due to temperature would lift the base elbow from the support so the turbine would have to support the weight of the pipe. The expansion of the vertical run of pipe would relieve the pipe hanger of its load so the turbine would again have to support the weight of the pipe.

If an expansion joint with retraining tie rods is used, either a rigid pipe hanger or a base elbow with a sliding or rolling contact surface may be used as shown in Figure C.13.



**Figure C.12**

**Figure C.13**

When the thrust due to an expansion joint is less than the exhaust flange limits and no restraining tie rods are used, the pipe shall have an anchor as shown in Figure C.14. Since this condition rarely exists, it is better to use one of the better arrangements such as shown in Figure C.13, and eliminate as much pipe reaction as possible rather than just stay within the limits.

Spring hangers or supports are best suited to carry the dead weight when there is thermal expansion to be considered. The movement of the pipe will change the spring tension or compression a small amount and the hanger loading a small amount but will not remove the load from the hanger. The published manuals on pipe design provide information on hanger spacing to give proper support. In addition to this, it may be necessary to add additional supports or move existing supports if resonant vibration appears in the piping.

A spring support should not be used to oppose the thrust of an expansion joint, because when the pressure is removed from the line the spring support will exert a force the same as the expansion joint, only in the opposite direction.



**Figure C.14—Improper Use of Spring Support on Piping Expansion Joint**

## **7 Shaft Alignment**

There is no Shaft Alignment information in Part B

## **8 Lubrication Systems**

### **8.1 Scope**

8.1.1 This clause of API 686 establishes the minimum requirements for the machinery installation design, preservation, installation, and cleaning of new or overhauled machinery that either provides or requires lubrication for process or utility purposes (refer to API 614 for lube oil and seal oil system requirements).

8.1.2 Equipment providing lubrication includes equipment such as lube and seal oil systems, central air/oil systems, and oil mist lubrication systems.

8.1.3 Equipment requiring lubrication includes (as a minimum) equipment such as vertical and horizontal centrifugal and positive displacement pumps, centrifugal, axial and positive displacement compressors, blowers, fans, agitators, horizontal and vertical gearboxes, steam and gas turbines, expanders, electric motors, electric generators and systems such as refrigeration systems, plant instrument air systems, and extruders.

8.1.4 This clause provides procedures, design criteria, and requirements that enhance or facilitate the preservation, cleaning, inspection, assembly, installation and start-up of lubrication systems and details such as bearing cavities, bearing housings, and complete lube and seal oil supply systems. This section of API 686 does not include criteria for product lubricated equipment such as canned motor pumps, grease-lubricated equipment, or cylinder lubrication such as for reciprocating compressors.

8.1.5 All design and installation requirements shall be ensured as complete by completing the installation checklist in Part C, Annex A, or agreed equivalent, and submitting it to the user designated representative.

### **8.2 System Design Requirements**

8.2.1 The design shall provide access to fill and drain connections and for operation and maintenance.

8.2.2 The design will provide for fill and drain passages and connections that are sufficient in size and oriented such that servicing can be performed without spilling and does not require special equipment.

8.2.3 The design shall allow maintenance or operations to perform their required functions without being restricted by piping, conduits or supports.

8.2.4 The design shall allow maintenance or operations to perform their required functions and removal of components.

8.2.5 The design shall provide for drains that drain the components and systems as completely as practical without leaving the need for flushing the remainder.

8.2.6 The design shall provide for adequately sized and properly placed vents and drains to ensure complete removal of any material used during chemical cleaning and pickling.

Note: Chemical cleaning and pickling are not used in oil mist systems.

8.2.7 The piping system shall be provided with high point vents and low point drains.

Note: Not applicable for oil mist systems.

8.2.8 The piping system shall be provided in accordance with chapter 6 of this standard.

8.2.9 On equipment with circulating oil systems, the piping design should be provided with break-out spools for jumpers on the supply and return connections to each lubrication point on the machine to facilitate flushing of the oil system. Ability to bypass permanent lube oil filter shall be provided.

NOTE Permanent lube oil filters are not normally designed for high flow rates that are required for flushing. Temporary filters can be used for flushing purposes.

8.2.10 The design for the Lubrication System shall provide proper support and protection to prevent damage from vibration or from shipment, operation and maintenance.

8.2.11 The installation of the Lubrication System should be in a neat and orderly arrangement adapted to the contour of the machine without obstructing access to such items as junction boxes, couplings and instrumentation.

8.2.12 The design for the Lubrication System shall allow elimination of air pockets using valved vents or non-accumulating piping arrangements in accordance with clause 6 on piping.

8.2.13 The design for the Lubrication System shall allow complete drainage through low points without disassembly of piping, vacuuming or flushing.

8.2.14 Threaded openings (such as in small pumps) may be plugged with a threaded pipe plug; others should be provided with block valves and flanged connections with blind flanges.

#### 8.2.15 Tapped openings

8.2.15.1 Tapped openings shall be plugged with square-head, round-head or hex-head, steel plugs furnished in accordance with ASME B16.11. As a minimum, these plugs shall meet the material requirements of the piping system and requirements in clause 6 on piping.

8.2.15.2 A sealant that meets the proper temperature specification shall be used on all threaded connections. Tape shall not be applied to the threads of plugs or any other threaded connection inserted into oil passages. NOTE: Plastic plugs are only permitted for temporary purposes such as during transportation for example.

#### 8.2.16 Flanged openings

8.2.16.1 Flanged openings shall be provided with blind flanges.

8.2.16.2 Quantity and location of block valves at flanged openings shall be mutually agreed upon between the user-designated machinery representative and the vendor.

8.2.16.3 A specific lube oil flushing diagram shall be provided that clearly indicates temporary bypasses, screens, drop-out spools and removals required for lube oil flushing.

Note: A marked-up process and instrumentation diagram is acceptable for this purpose.

8.2.16.4 Component and system cleaning specifications, including the flushing diagram, shall be approved by and agreed upon between the Vendor and the user-designated machinery representative.

8.2.16.5 Equipment and oil systems shall be shipped clean, minimizing the need for cleaning and flushing in the field. The vendor shall demonstrate that oil passages and oil-containing components are free of dirt and debris prior to shipment in accordance with the requirements of the flushing clause 8.4 of part D this document.

8.2.16.6 In situations where oil mist is used to protect equipment during storage or when the equipment is idle, procedures and oil mist system design and arrangement shall be agreed upon between the vendor and the equipment user.

## **9 Commissioning and Start-up**

### **9.1 COMMISSIONING DESIGN**

#### **9.1.1 Scope**

This section is intended to assist the designer in selecting appropriate auxiliary equipment and instrumentation to facilitate a safe and smooth startup.

Note: For issues related to piping design refer to Section 6 and especially for start-up clause 2.15 Commissioning Provisions

#### **Strainers**

Design shall include either permanent strainers or capability to install temporary strainers in accordance with Chapter 6 requirements.

#### **9.1.2 Bypasses**

Any bypasses required for commissioning and start-up shall be included in the piping design.

Note: Bypasses can be used for the purpose of unloading the equipment or to maintain a minimum flow during start up.

##### **9.1.2.1 Turbine Inlet Block Valve Bypass**

The designer should evaluate the need for a startup by-pass valve around the inlet block valve for turbine initial warm up or for turbine solo control.

Note: The inlet block valve is upstream of the trip valve.

9.1.2.2 If a turbine inlet block valve bypass is provided, the designer and the turbine vendor shall agree on the size of the by-pass line to ensure the introduced steam to the machine will not over speed the turbine.

9.1.2.3 There shall be no bypass around the trip valve.

#### **9.1.3 Draining and Purging**

All equipment shall have the capability of controlled draining or purging.

#### **9.1.4 Instrumentation**

Instrumentation used for start-up and commissioning shall be specified to cover the range of operation through the commissioning and start-up conditions. This may require larger range instruments from those required for normal operation.

#### **9.1.5 Instrument Checkout**

Control loops and instrumentation loops shall be designed such that function can be verified with or without the process in operation.

**API 686 3<sup>rd</sup> Edition**  
**Part C – Site Receiving, Rigging, Lifting, Storage & Installation**  
**of Rotating Equipment & Auxiliary Systems**

General – Part A  
Design – Part B  
Installation – Part C  
Commissioning/Start-up – Part D

Chapter 1—Introduction  
Chapter 2—Rigging and Lifting  
Chapter 3—Jobsite Receiving and Protection  
Chapter 4—Foundations  
Chapter 5—Baseplate or soleplate  
Chapter 6—Piping  
Chapter 7—Shaft Alignment  
Chapter 8—Lubrication Systems  
Refer Chapter 9—Commissioning and Start-up

**1. Scope Normative References, and Definitions – Terms – Acronyms**

- 1.1. Refer to Part A for Scope
- 1.2. Refer to Part A for Normative References, and Definitions – Terms – Acronyms

**2. Chapter 2 Rigging and Lifting**

**2.1. Scope**

2.1.1. Chapter 2 of this standard provides general guidelines for rigging and lifting of machinery from shipping (trucks, railcars, and barges as examples), onto the foundation or platform, or to a temporary storage location. If not specified otherwise, this section shall be used for all machinery.

NOTE: Chapter 2 is intended to be used for all machinery. Even small pumps can be damaged by improper lifts. The extent of the rigging and lifting plan can be reduced when specified by the user. The lifting plan for small machinery could be in the form of a site meeting at the start of construction, if agreed to by the user.

2.1.2. Chapter 2 contains guidance intended to supplement the codes and regulatory requirements, such as state or local government inspections and permits, OSHA 1926, Subparts H and N, and ASME/ANSI B.30 with which compliance is mandatory for the rigging and lifting subcontractor (Installer).

**2.2. Pre-Planning**

For the purposes of this document, the following apply.

- 2.2.1. The Installer shall be responsible for obtaining the following as a minimum:
  - 2.2.1.1. shipping and net weights of each separate component of the machinery or machinery package; and
  - 2.2.1.2. manufacturer drawings indicating the location of lifting lugs/points, the expected load at each point, and the center of gravity;
  - 2.2.1.3. Review the ambient temperature of the equipment location and design temperature of the lifting lugs to preclude possible cracking of steel or welds due to low ductility with temperatures of below -20 °F (-30 °C)

NOTE: Lifting lugs are often provided on machinery to lift individual components and are not intended to be used to lift the entire machine (for example, lifting lugs on WP-II motor air housings cannot be used to lift the entire motor).

- 2.2.1.4. Manufacturer's recommendations for the lift including the use of spreader bars, slings, and rigging.

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2.2.2. The Installer shall prepare a rigging and lifting plan of action, for review and approval by the User, that includes the following:

2.2.2.1. A rigging plan showing the lifting points and including the load capacities of cranes, hoists, spreader bars, slings, cables, shackles, hooks, rings, and so forth. Load capacities shall be based upon a minimum safety factor of 1.5, unless otherwise agreed (refer to 2.2 c). Plans should also be made for lifting crated equipment.

2.2.2.2. Site conditions and soil stability shall be evaluated as part of the rigging plan. Personnel involved in lift operations shall agree on communication protocols and hand signals prior to execution of the lift. Special considerations and necessary safe guards shall be considered and/or put in place in the event the lift occurs over or near any energized system.

2.2.2.3. When the safety factor of 1.5 results in the selection of a larger, less maneuverable crane, the selection may be reduced upon an appropriate engineering review and agreement by both the Installer and the User designated representative.

2.2.2.4. The selected lifting equipment and confirmation that the load and lift radius are within the capacity and range ratings of the manufacturer of the lifting equipment.

2.2.2.5. Layout sketches showing the setup location for the lifting equipment in relationship to the initial pick point of the load and its final installation point. The sketch should also show the proximity to important structures, pipe racks, and overhead electrical services. OSHA 1926.550 gives clearance requirements for electrical services.

2.2.2.6. Qualifications and certifications of the equipment operator(s) shall be provided to the User designated representative.

2.2.2.7. Maintenance records for mechanical lifting equipment such as cranes and hoists shall be submitted to the User designated representative as part of lift planning.

2.2.2.8. Setup time for the lifting equipment and overall duration of the lift.

2.2.2.9. i) Coordinate with the plant traffic control personnel for any roadway blockages.

2.2.2.10. Check path to be taken by the lifting equipment when bringing machinery to final in-plant location. Check for overhead clearance, turn radius, road bed, high center railroad crossings, and load rating of access roads and bridges.

2.2.2.11. The Installer shall review with the User designated representative, site plans for all underground utilities in the area of lift. Outrigger cribbing pads (mats) shall be used to eliminate any damage to roads and also to reduce the possibility of outriggers breaking through soft or unstable soil, thereby reducing the capabilities of the crane.

2.2.3. The installer shall confirm that floor, or other concrete slabs, on which the crane may sit have cured adequately.

2.2.4. Installer shall confirm with the User designated representative that machinery foundations have cured and grout preparations or grouting have been completed.

2.2.5. If the machinery will be set in/on a partially completed structure, or if structural members shall be removed to lower the machinery into the structure, the lifting plan shall be reviewed and approved by the structural engineer responsible for the design of the structure. Temporary shoring, bracing, or supports shall be reviewed and approved by the structural engineer.

2.2.6. The installer shall confirm that all equipment is up to date with respect to permits and inspections. Request that the rigging spreader bars, slings, cables, and so forth, are field inspected just prior to the lift being started. Refer to OSHA 1926, Subparts H and N, for inspection requirements.

2.2.7. The installer shall hold a "day of" pre-lift meeting with the user to ensure that the lift plan is understood.

### **2.3. Lifting the Machinery**

2.3.1. The installer verifies that the cables and slings are bearing only on the intended lift points and are not transmitting any loads onto auxiliary piping, instruments, chain guards, or bearing housings for examples.

2.3.2. Lift points for individual pieces of machinery are not be used for lifting complete machinery skids or packages. This can apply to lifting lugs that may be found on motors, gearboxes, casings, or inspection covers. When in doubt, consult the manufacturer.

2.3.2.1. Equipment shafts shall not be used for lifting equipment.

NOTE: This does not include equipment components such as pump rotors, steam turbine or compressor rotors for example.

2.3.2.2. For baseplate or skid-mounted machinery, only use lift points on the baseplate or skid. Do not use the machinery as a lift point, unless approved by the manufacturer.

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- 2.3.2.3. Care should be exercised in lifting skid-mounted equipment where part of the machinery or its auxiliaries have been removed for shipment, thus changing the center of gravity.
- 2.3.3. The installer is responsible for preventing other subcontractors and plant personnel from working under the lift and keep them a safe distance away until the machinery is secured in place on its foundation or structure (for example, the use of barricades or "red tape").
- 2.3.4. 3.5 A lift across other equipment or involving two cranes should be reviewed and approved by User designated representative.
- 2.3.5. 3.6 Special-purpose machinery rotors are to be restrained (i.e. "blocked") to restrict axial travel prior

### 3. Jobsite Receiving and Preservation

#### 3.1. Scope

- 3.1.1. This series of clauses define the minimum requirements for protecting project machinery and related components from deterioration while in field storage, after installation, and during the period prior to commissioning.
- 3.1.2. In all cases where the manufacturer's requirements or recommendations differ from the instructions provided in this document, the user-designated representative shall be consulted to determine which takes precedence.
- 3.1.3. An inspection and protective maintenance program should be initiated and maintained by the user-designated representative for stored and installed equipment until it is turned over to the care, custody, and control of the user.
- 3.1.4. The User or user designated representative ensures that all design and installation requirements are met and completed and documented by completing the Machinery and Protection Checklist at the end of this.

#### 3.2. Responsibility

Overall responsibility for protecting project machinery from deterioration in the field, per this RP, rests with the construction manager and his/her designated representative until the machinery is turned over to the user.

##### 3.2.1. Preplanning

3.2.1.1. Verify that all procurement schedules, shipping lists, manufacturer's storage recommendations, installation manuals, and drawings have been forwarded to the designated machinery representative.

3.2.1.2. 2.1.2 Review weights, configuration, and method of shipping before arrival at the jobsite. Determine type of equipment required to unload the shipment, (that is, forklift, boom truck, crane, and so forth) and schedule accordingly.

**NOTE** Refer to – Rigging and Lifting, for further details. Ensure that safe and appropriate rigging procedures are followed.

3.2.1.3. If specified, schedule the manufacturer's representative for receiving inspection. Schedule user's inspectors, where required, such as rotating equipment, instrument, and electrical engineers.

3.2.1.4. Ensure that Vendor recommendations are followed within the preservation program as a minimum. Additional User preservation requirements should be reviewed and agreed with Vendor.

##### 3.2.2. Jobsite Receiving and Inspection

3.2.2.1. Upon arrival of the machinery or portions thereof at the jobsite, follow the steps below.

3.2.2.1.1. Visually inspect components for physical damage/contamination by opening packages & crates.

3.2.2.1.2. Hermetically sealed containers should not be opened, but visually inspected for damage maintain the hermetic seal.

3.2.2.1.3. Verify that shipping protection has been applied and is still in effect.

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- 3.2.2.1.4. Verify that shop inspection has been completed and that the vendor has supplied the purchase order documentation and packing lists.
- 3.2.2.1.5. Verify that loose components and separate packages match the packing lists.
- 3.2.2.1.6. Verify that special handling instructions are provided and carried out.
- 3.2.2.1.7. Verify proper identification of the components.
- 3.2.2.1.8. Perform visual inspection of components for compliance with project requirements.
- 3.2.2.1.9. Inspect carbon steel or other ferrous flange faces for damage and coat with Type A, Type B, or Type D preservative, unless prohibited by process application (see Note 1), then reinstall protective covers.
- 3.2.2.1.10. Where car seals on inspection covers or flanges have been specified, inspect the car seals for integrity (see Note 2).

NOTE 1: Preservative types are described in Annex A. Final selection of the preservative depends on the type of storage (indoor, outdoor, sheltered), weather conditions, and atmospheric corrosion potential. Review equipment datasheets and manufacturer's instructions to determine if there are specific preservative requirements. Refer to the notes in Annex A for additional details.

NOTE 2: Use caution with soft-gasketed flanges. Soft gaskets may absorb water and corrode carbon steel flanges.

- 3.2.2.1.11. Verify that plugs and caps are in place, desiccants are unsaturated, and equipment is lubricated, as required. Nonmetallic (such as plastic) plugs may be used with owner approval.
- 3.2.2.1.12. Verify that inert-gas-purged (see Annex D) equipment still has the required pressure applied. Report failures to the manufacturer and request corrective action. Ensure this equipment remains sealed unless otherwise instructed by the designated machinery representative.
- 3.2.2.1.13. Inspect grout surfaces for proper factory blasting and coating.
- 3.2.2.1.14. Close and seal tapped openings in the stuffing boxes and gland plates with pipe plugs. Plug material requirements are the same or better than seal gland plate metallurgy. As a minimum, the plugs should be austenitic stainless steel.
- 3.2.2.1.15. If specified, use impact-measuring devices to inspect and determine if the equipment has been exposed to any excessive shock loads. Where required, the manufacturing representative should be present.
- 3.2.2.1.16. Record all inspections (refer to Annex B and Annex C).
- 3.2.2.1.17. Report any damage to the shipping company and vendor immediately. Ensure that any claim forms required by the shipper or vendor are completed.

### 3.2.3. General Instructions—Jobsite Preservation/Protection

- 3.2.3.1. Manufacturer's or vendor's recommendations for storage and protective care should be reviewed by a user-designated representative and shall be strictly followed when transmitted to the field. If the manufacturer's recommendations are not available, the information included in this standard shall be used as a minimum acceptable guide.

NOTE: Failure to follow vendor's recommendation for storage and protective care can void the warranty.

- 3.2.3.1.1. Review the procurement documents to determine if the equipment had been prepared for a predetermined storage period. For example, if the equipment was procured per API standards, preparation for shipment would be "suitable for six months of outdoor storage from time of shipment, with no disassembly required before operation, except for inspection of bearings and seals. If storage for a longer period is contemplated, the purchaser will consult with the vendor regarding the recommended procedures to be followed."

Note: It is recommended that where machines are to be partially or completely disassembled for storage preservation or inspection by the contractor or user, the vendor's service representative should be on site to ensure the accuracy of the work and the preservation of the warranty.

- 3.2.3.1.2. Protective storage requirements for specific items of equipment such as pumps, blowers, fans, compressors, and gearboxes are found in subsequent sections of this procedure.
- 3.2.3.1.3. Ensure that sufficient quantities of preservative materials are available before equipment arrives on site.
- 3.2.3.2. Records documenting the following information are to be kept by field material control personnel using the forms referenced.
  - 3.2.3.2.1. Conditions of equipment and materials upon arrival at the jobsite before and after unloading. Use the checklist in Annex B.

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- 3.2.3.2.2. Maintenance and storage procedures followed, and dates maintenance was performed. See forms provided in Annex B and Annex C.
- 3.2.3.3. Store all equipment and material free from direct ground contact and away from areas subject to ponding water. As a minimum, laydown areas should be graveled.
- 3.2.3.4. For outdoor storage, even, cross-cut timber with at least a 4 in. x 4 in. (100 mm x 100 mm) nominal cross section, laid flat and level, should be used for laydown. Consider equipment weight when selecting timber size. Warped timber or telephone poles are typically not acceptable. Place timbers perpendicular to major support structures. Timbers should be full width of the skid or baseplate.
- 3.2.3.5. Indoor, environmentally controlled storage should be used whenever required by the Vendor. See definitions of types of controlled storage areas in Annex E.
- 3.2.3.6. Third-party storage facilities may prove to be the preferred method.
- 3.2.3.7. Temporary protective coverings shall allow free air circulation to prevent humidity condensation and collection of water.
- 3.2.3.8. The installer should attempt to preserve and maintain the integrity of the delivery packaging whenever possible. Replace packaging material after inspection. Review the integrity of control boxes and panels with respect to weather protection. Store indoors if required.
- 3.2.3.9. Protect all carbon and low alloy steel from any contact with corrosive or wet atmospheres so as to prevent rust formation.
- 3.2.3.10. Painted surfaces should not require additional protection but periodic examination for signs of rusting is required. Touch-up, using the manufacturer's recommended methods and materials, should be performed soon after any corrosion is evident.
- 3.2.3.11. All items with machined surfaces should be stored so that the machined surfaces can be examined periodically (monthly) for signs of rust.
- 3.2.3.12. Tag, protect, and store, per the vendor's and/or user's recommendations, any special parts and tools for construction purposes that accompany vendor shipments. All tags shall be stainless steel and attached with stainless steel wire to the special part or tool. Paper tags are not permitted.
- 3.2.3.13. Keep the storage area and equipment clean by providing physical protection and covering when work operations such as concrete chipping, sanding, painting, and rigging are performed in the area. Protect stainless steel from weld splatter and grinding dust of low alloy steel.
- 3.2.3.14. Periodic rotation of equipment will be discussed in subsequent sections. In all cases, determine that all shipping blocks on rotating components have been removed and that there is adequate lubrication before rotation. Determine that any desiccant bags or protective plastics are clear of moving parts. To rotate the shaft, use a tool such as a strap wrench that will not mark machined surfaces.
- 3.2.3.15. Preservatives and/or storage lubricants can adversely affect the safety and operating life of equipment if they react with the process fluid or operating lubricant. Specific examples are:
- 3.2.3.15.1. grease or oil-based products in contact with components to be installed in oxygen or chlorine service,
- 3.2.3.15.2. preservatives contaminating interiors of fluorochlorohydrocarbon refrigeration compressors, and
- 3.2.3.15.3. hydrocarbon flush oil contaminating synthetic oil passages.
- Note: Ensuring that all preservative and storage lubricants are suitable for the specific application is the responsibility of the installer.
- 3.2.3.16. Unless otherwise specified, store special-purpose equipment with a positive pressure, 2 mm to 3 mm Hg (1 in. to 2 in. of H<sub>2</sub>O), dry nitrogen purge (see Note 1 below). The equipment should have a temporary gauge to determine purge pressure. Remove the temporary gauge before start-up. Inspect the equipment weekly to ensure that purge integrity is maintained. If a positive pressure cannot be maintained, purge at a rate of 2 SLPM to 3 SLPM (4 SCFH to 6 SCFH).
- Note 1: Review all nitrogen purge installations with the user's safety personnel with respect to confined space procedures, warning signs, and asphyxiation hazards before putting the purge into service.
- Note 2: External (temporary) soft packing, held by adjustable stainless steel bands (geared clamps), can be placed against, or touching the labyrinths (or equivalent seals) of equipment rotating shafts to significantly reduce the amount of dry nitrogen purge.
- 3.2.3.17. All equipment cavities, cooling passages, mechanical seals, positive displacement pump plunger cavities, and similar areas, should be drained of all water to prevent damage due to freezing temperature.
- 3.2.3.18. Unless stated differently in subsequent sections on specific equipment, the following apply.

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3.2.3.18.1. Oil-lubricated bearing housings, seal housings, stuffing boxes, hydraulic equipment, and gear cases should be fogged and approximately one-fourth filled with a manufacturer-approved oil. Close and tightly seal all openings.

3.2.3.18.2. If specified by the user, every other month check the condition of the preservative oil by measuring the total acid number (TAN) of the oil. Replace with fresh oil if the TAN is greater than 0.2 mg KOH/gm. Check and record the date the TAN in the inspection records. Check with the oil supplier to determine if it needs to be heated for replacement.

Note: TAN (total acid number) is defined as the quantity of base (expressed in terms of milligrams of potassium hydroxide) that is required to titrate the strong acid constituents present in 1 gm of an oil sample (ASTM Method P664 or D974).

3.2.3.18.3. Coat all externally exposed, bare carbon steel or cast iron surfaces including shafts and couplings (except elastomeric components) with Type A, Type B, or Type D preservative. Coat all machined surfaces with Type A, Type B, or Type D preservative. Wrap all exposed machined surfaces with waxed cloth (see Note below).

NOTE: Moisture can be held under waxed cloth if not tightly sealed. Periodic inspections under the cloth may be warranted.

3.2.3.18.4. Verify that grease-lubricated bearings have been greased by the manufacturer with the specified grease. Some greases are not compatible when mixed.

3.2.3.19. If an oil mist preservation system is specified by the user, it should be as follows:

3.2.3.19.1. Oil mist systems should be specified on large projects where more than ten pieces of equipment will be stored longer than six months or if dust or dampness is excessive.

3.2.3.19.2. Use oil mist to protect the bearings, bearing housings, seal areas and process ends of the equipment.

- a) Use oil mist lubrication connections on equipment purchased for permanent oil mist lubrication.
- b) Equipment purchaser should have specified to equipment vendor that oil mist preservation will be utilized on the equipment.
- c) Cavities not normally mist lubricated during permanent operation will need to be fitted with supply and vent connections (typically NPS 1/4).

3.2.3.19.3. The oil mist system should be designed and sized for preservation service.

- a) As a minimum, the mist generator should be equipped with the following instrumentation: air pressure regulator, pressure relief valve, level gauge, and mist pressure gauge.
- b) The mist header system shall be NPS 2 minimum galvanized schedule 40 pipe properly supported and sloped.
- c) Mist flow to each application point can be less than that required for lubrication during normal operation.
- d) Plastic tubing (temporary use only) can be used to connect from the mist header to the application point.

3.2.3.19.4. The oil used in the mist system shall be a good quality, paraffin-free turbine oil. A temperature sensitive, vapor emitting oil should not be used in the oil mist system. Equipment preservative oils shall be compatible with the system elastomers and the oil used in the oil mist system to eliminate the need to disassemble and remove the preservative oil.

3.2.3.19.5. All machinery should be connected to the system immediately upon arrival on site.

3.2.3.19.6. Equipment is maintained in the storage yard by rotating shafts and periodically draining condensed oil from the housing.

3.2.3.19.7. Oil should not be drained to ground.

3.2.3.19.8. For equipment that will be permanently oil mist lubricated, the movement of equipment from the storage yard to permanent locations should be coordinated so that the maximum outage of mist preservation is minimized.

### 3.3. Lubricants and Preservatives

3.3.1. The table and notes in Annex A describe some of the physical characteristics, application methods, and life expectancies of preservative Type A, Type B, Type C, and Type D that are referred to in this practice. Final selection types shall be approved by the equipment manufacturer and user. Other methods of preservation not listed on the table include: vapor corrosion inhibitor (VCI), nitrogen purge, and desiccants.

Note: most VCI's have an expiration date and become ineffective or detrimental after that date.

3.3.2. Take care to ensure the compatibility of the preservative with elastomeric parts, seals, gaskets, and so forth.

3.3.3. All lubricant and preservative material safety datasheets (SDS's) shall be available, and associated hazards reviewed with all personnel handling and using these materials.

3.3.4. The term desiccant means silica gel or any other approved water absorbing material. Prior approval of all desiccants from the manufacturer or the user-designated representative is required. Check desiccant monthly. Replacements should be approved by the user.

3.3.5. Do not use preservatives on surfaces where prohibited by process application.

3.3.6. In succeeding sections, references are made to removing preservatives before the machinery is placed in service. This is always true for Type D preservative. However, with the proper selection of Type A, Type B, and Type C, removal can be eliminated. The preservative would need to be compatible with the permanent lubricating fluid, the process fluid, and materials of construction, that is, elastomers. The preservative shall also be inspected to be sure that it has not absorbed any abrasive dust or contaminants.

3.3.7. VCI's provide a self-healing barrier between the metal surface and moisture. All VCI's shall have prior approval from the manufacturer or the user-designated representative. Note that some VCI's may contain nitrites which attack copper and bronze.

3.3.8. Nitrogen purging provides protection by removing the moisture laden oxygenated atmosphere. Care should be taken when working with nitrogen to prevent asphyxiation.

Note: Nitrogen is heavier than air so working in any confined space or location lower than grade could present a hazard.

#### **3.4. Bolts**

3.4.1. All loose assembly bolts, nuts, and fasteners should be packaged, identified, and stored in a sheltered area.

3.4.2. Type B or Type C preservative should be applied to the threaded portion of all anchor bolts, washers, and nuts that are not galvanized or plated.

#### **3.5. Spare Parts, Special Tools, and Miscellaneous Loose Items**

3.5.1. Items purchased as spare parts and special tools shall be accurately identified with permanent markings and handed over to the user-designated machinery representative upon receipt and completion of jobsite receiving inspection per 3.2.2.

3.5.2. Storage and protective maintenance of miscellaneous loose items should be as directed by the manufacturer. This also includes any Vendor supplied lifting devices.

3.5.3. Extra drawings and manuals shipped with the equipment shall be saved and handed over to the user.  
NOTE: Formal distribution of these documents should have occurred before shipment per 2.1.1.

3.5.4. Special tools should be kept and preserved by the installer until work has been completed, then turned over to the user-designated machinery representative.

#### **3.6. Auxiliary Components for Rotating Equipment**

The following applies to auxiliary piping that is shipped loose for field assembly.

##### **3.6.1. Pipe Components**

3.6.2. Carbon steel pipe components that will require long-term storage outdoors during the construction period should be coated externally and internally with thinned Type B or a Type C preservative, unless prohibited by process application.

##### **3.6.3. Coating and Sealing**

3.6.3.1. Stainless steel pipe components that will require long-term storage outdoors in a salt water atmosphere during the construction period should be coated externally and internally with thinned Type B or a Type C preservative, unless prohibited by process.

Note: Stainless steel components can be adversely affected if chlorides are present in the preservation materials.

3.6.3.2. Contamination of dry gas seals may occur if Type B or Type C preservatives are used in gas seal supply piping. A VCI that can be removed prior to operation, may be an acceptable alternative.

#### 3.6.4. Flanges

3.6.4.1. Flanges received bolted face-to-face need not be separated for inspection; however, the face-to-face crevice should be coated with Type A, Type B, or Type D preservative prior to outdoor storage.

3.6.4.2. After inspection of loose flanges, flange gasket surfaces should be coated with Type A, Type B, or Type D preservative prior to outdoor storage. Flanges for prefabricated piping and lube oil systems shall be gasketed and covered with metal covers 3/16 in. thick for flanges NPS 10 and larger and 1/8 in. thick for flanges less than NPS 10.

Note: Temporary gaskets can usually be made from service sheet-gasket material.

3.6.4.3. Care should be taken to protect gasket surfaces of loose flanges from damage during handling and storage.

3.6.4.4. Flanges to be stored outdoors for periods exceeding six months or in corrosive atmospheres (saltwater air, industrial, and similar) shall be coated externally and internally with thinned Type B preservative.

3.6.4.5. Preservatives shall be removed from all surfaces with a suitable solvent prior to installation of the components.

#### 3.6.5. Valves

3.6.5.1. Valves should be stored indoors or under cover.

3.6.5.2. All machined surfaces such as valve stems (including threads), packing glands, and bonnet bolts shall receive a coat of appropriate grease or equivalent for atmospheric corrosion protection.

3.6.5.3. Valve flange gasket surfaces shall be coated with Type A, Type B, or Type D preservative prior to reinstalling protective covers after internal inspection.

3.6.5.4. Protective covers should be made of a weatherproof material and of such construction to provide a weather-tight seal. Plastic plugs and flange covers are not permitted.

3.6.5.5. All ball valve internals should be coated prior to reinstalling protective covers after internal inspection.

3.6.5.6. All ball valves shall be protected and stored horizontally in the open position, unless otherwise instructed by the valve manufacturer.

3.6.5.7. Gate valves shall be stored in a partially open position, unless otherwise instructed by the valve manufacturer. Valves shall be stored with valve openings horizontal to prevent water accumulation.

3.6.5.8. All valves shall be stored above grade on a well-drained, hard surface.

3.6.5.9. Periodic (at least once per month) checks should be made to ensure that protective procedures are effective. If deterioration is observed, the user shall be notified so that appropriate corrective action can be initiated.

3.6.5.10. Packing inhibitors are usually effective for only six months. Valves with packing that are stored for longer periods should be checked and protected against stem corrosion if necessary.

3.6.5.11. Preservatives shall be removed with solvent from all surfaces prior to installation of valves.

3.6.5.12. All ring joint flanges shall be examined when received and the condition recorded. Spot checks for corrosion should be made monthly while in storage.

#### 3.6.6. Vendor-supplied Associated Components

Vendor-supplied associated components that will require long-term storage outdoors during the construction period (or stainless steel in a salt water environment) shall be stored and protected per the vendor's and/or user's recommendations.

NOTE: Vendor-supplied associated equipment can include inlet air filters, pulsation suppressors, silencers, etc. that are specially designed for attachment to the main equipment but are shipped separately.

### 3.7. Machinery – General Short-Term Criteria

3.7.1. Clean and coat all flange gasket surfaces with Type A, Type B, or Type D preservative.

3.7.2. Install weatherproof protective covers of such construction to provide a watertight seal on all openings. Plastic plugs and flange covers are not permitted.

3.7.3. Consult the manufacturer to determine if additional intermediate rotor shaft supports are required. Provide the supports as necessary.

Restricted

- 3.7.4. Spare rotating elements shall be stored per manufacturer's specific instructions.
- 3.7.4.1. Rotating elements should be stored in a controlled environment room or nitrogen purged containers. Vertical storage and/or a shipping container may be required.
- 3.7.4.2. If compressor dry gas seals are shipped separately, then seals shall be stored in the Vendor container(s).
- 3.7.5. Preservatives for oxygen, ethylene and refrigeration compressors shall be approved by the equipment manufacturer.
- 3.7.6. Turn the equipment shaft or crankshaft by rotating per Vendor recommendations, or if Vendor doesn't specify, 2¼ revolutions monthly. Shaft rotation shall be accomplished with a strap wrench or other non-marring device. Verify that radial bearings have adequate lubrication before turning shaft. Check for rust spots. Record protective activity in the inspection records.
- NOTE 1: Some manufacturers recommend against rotating or turning.
- NOTE 2: The suggested rotation of the rotor or crankshaft is intended to help prevent permanent rotor sag/bow
- NOTE 3: Rotors having many stages and large bearing-span/shaft-diameter ratios are more prone to rotor sag.
- 3.7.7. Rotating equipment should not be turned or otherwise disturbed during shipment.
- 3.7.8. If the rotor was initially blocked for shipment, unblocking before turning will be required.
- 3.7.9. When applying the rotor turning requirement, if previously applied corrosion prevention is compromised, the corrosion inhibitors will need to be reapplied.
- 3.7.10. Prior to turning the rotor, heavy rotors may need to be lifted so as to reduce the load at the supporting journals.
- NOTE: lift can be accomplished by oil film or jacking oil.

### **3.8. Reciprocating Compressors**

Note: Refer to 3.7 for general criteria.

- 3.8.1. Coat exposed rods, eccentrics, plungers, and machined surfaces with Type A, Type B, or Type D preservative. If the valves have been shipped loose, tag and store per manufacturer's recommendations.
- 3.8.2. Compressors with non-lubricated cylinders and packing shall not be contaminated with oil. Such machines, if not already shop protected, should be sealed, purged of air, and kept pressurized with nitrogen at 2 mm to 3 mm Hg (1 in. to 2 in. of H<sub>2</sub>O).
- 3.8.3. Install a temporary pressure indicator to indicate nitrogen pressure. Remove the temporary gauge before compressor initial run-in.
- 3.8.4. Cylinders and crankcase should be inspected when the compressor is received on site by removal of the inspection covers. If water or dirt has entered the equipment through damaged covers, the equipment shall be cleaned out and rust preventive treatment restored.
- 3.8.5. If the compressor requires field assembly, remove the protective coatings from cylinder walls, valves, rods, and so forth, and clean all parts (including crankcase) with solvent.
- 3.8.5.1. Assemble using the manufacturer's recommended preservative freely on cylinder walls, valves, rods, bearings, and rubbing parts and fill crankcase as recommended by the manufacturer.
- 3.8.5.2. Do not install carbon rings or rod packing until the compressor is serviced for initial operation. Fill crankcase and lubricators as recommended by the manufacturer, with Type C preservative.
- NOTE: Where compressors require field assembly, the factory representative should be present to confirm inspection, preservation, and assembly procedures.
- 3.8.6. Rotor Turning of Reciprocating Compressors
- 3.8.6.1. Where applicable, open the drip feed lubricator and operate the force feed lubricators weekly. If the compressor has a manual priming main oil pump, operate it for at least one minute. Close the drip feed lubricators and refill the lubricators as necessary.
- 3.8.6.2. When applying the rotor turning requirement, if previously applied corrosion prevention is compromised, the corrosion inhibitors will need to be reapplied.
- 3.8.6.3. Large compressor frames [in excess of approximately 4 m (12 ft) in length] that are not skid mounted and that are to be stored more than a few days prior to installation should be stored, supported, and leveled following the manufacturer's recommendations to prevent permanent distortion of the compressor frame.

### **3.9. Centrifugal Compressors**

Restricted



Note: Refer to 3.7 for general criteria.

3.9.1. Open bearing housing and verify that vendor has applied protective coating to shaft journals and thrust bearing disc and that non-contacting vibration probe target areas are not disturbed. If deficient, reapply shaft lubricant and coat inside of housing with manufacturer's approved preservative.

3.9.2. Check all lubricant fill points, sight glass connections, and piping to seals to ensure that lubricants or protective fluids do not leak from any joints.

3.9.3. Ensure that a nitrogen purge, or vapor phase inhibitors and desiccant have been applied per the manufacturer's requirements.

3.9.4. Rotor Turning of Centrifugal Compressors

3.9.4.1. Before turning, open or otherwise inspect bearing housings as recommended by the manufacturer.

3.9.4.2. Type A, Type B, and Type D preservative shall be removed with solvent from all surfaces prior to final installation of compressor.

3.9.4.3. All compressors, if expected to be in field storage or if under construction longer than six months, should be purged with nitrogen.

NOTE 1: Consult the manufacturer's storage plan.

NOTE 2: Personnel safety is critical if nitrogen leakage could occur in an enclosed area. (see note at clause 3.3.8)

3.9.4.4. If nitrogen is not available, case openings shall be sealed.

3.9.4.4.1. Vapor phase inhibitor (VPI) and/or desiccant should be used to protect internals from rusting

3.9.4.4.2. The equipment shall be tagged indicating the number and location of all vapor phase inhibitor and/or desiccant bags.

3.9.4.5. Manufacturers typically ship compressors with gas seals installed to prevent damage to them. No further attention should be required other than keeping them clean and dry. A continuous nitrogen purge is recommended to accomplish this requirement.

3.9.4.6. Equipment with magnetic thrust and journal bearings and the secondary (start-up/shutdown) thrust and journal bearings do not require lube oil.

### 3.10. Fans and Blowers

The following procedure should be used for receiving and protecting fans and blowers.

Note: Refer to 3.7 general criteria.

3.10.1. Coat exposed machined surfaces and shaft extension with Type A, Type B, or Type D preservative.

3.10.2. Fill bearing housing to the top of the ID of the oil ring  $+\frac{1}{4}$ " with the manufacturer's recommended oil.

3.10.3. Rotor Turning of Fans and Blowers

3.10.3.1. Verify that radial bearings have adequate lubrication before turning shaft.

3.10.3.2. When applying the rotor turning requirement, if previously applied corrosion prevention is compromised, the corrosion inhibitors will need to be reapplied.

3.10.4. Preservatives shall be removed with solvent from all surfaces prior to installation of fans and blowers.

3.10.5. Install weatherproof protective covers of such construction to provide a watertight seal on all openings. Plastic plugs and flange covers are not permitted.

3.10.6. On fans, low point drains should be opened monthly to drain any accumulated moisture.

### 3.11. Gearboxes

The following procedure should be used for receiving and protecting gearboxes at the job site.

NOTE: Refer to 3.7 for general criteria.

3.11.1. Determine if gearbox oil level is correct. Add the manufacturer's recommended oil if gear case contains less than the required amount. Check bearing housing oil level; fill as necessary.

3.11.2. Coat exposed machined surfaces and shaft extension with Type A, Type B, or Type D preservative. Type D preservative shall be removed with solvent from all surfaces prior to installation.

3.11.3. Rotor turning of gearboxes: Mark low-speed shaft and rotate per 3.7.6

3.11.4. Purge gear case with nitrogen if required by the Vendor's instructions or if deemed prudent by the user for the climatic conditions at the site. Purge per 3.2.3.16.

Restricted

- 3.11.5. Record protective activity in the inspection records.

### **3.12. Pumps – General**

The following procedure should be used for receiving and protecting pumps during the storage and installation period at the jobsite.

NOTE: Refer to 3.7 for general criteria.

- 3.12.1. Coat coupling parts, except elastomeric parts and flexible stainless steel discs, with Type A, Type B, or Type D preservative.
- 3.12.2. Shipping covers should be removed, flange gasket surfaces inspected, and internals checked for cleanliness. Coat flange surfaces with Type A, Type B, or Type D preservative.
- 3.12.3. Tag all loosely shipped items (such as couplings, oilers, and seal system components, if loose) with the pump identification number and store in a covered area as a minimum, or as recommended by the manufacturer.

### **3.13. Centrifugal Pumps**

- 3.13.1. Install weatherproof protective covers of such construction to provide a watertight seal on all openings. Plastic plugs and flange covers are not permitted.
- 3.13.2. Fill bearing housings to the bottom of shaft with the manufacturer's recommended oil for pumps with oil lubricated bearings. Put oil mist on the bearing housings of pumps that are oil mist lubricated (if possible at this time or as soon as possible). An external note should be clearly visible that the oil housings are full of oil. Fill all barrier fluid piping and components with the manufacturer's recommended fluid.
- 3.13.3. For cast iron, carbon steel, and low alloy pumps, fill the pump casing with Type C preservative and rotate to coat the internals.
- 3.13.4. Rotor Turning of Centrifugal Pumps
- 3.13.5. Type D preservative shall be removed with solvent from all surfaces with solvent prior to installation of pump.
- 3.13.5.1. Fill the piping loop for the barrier fluid of a dual seal pump with a process compatible fluid if it contains any carbon steel components.

### **3.14. Vertically Suspended Pumps**

- 3.14.1. Apply Type C preservative to shaft journals at sleeve bearings and to thrust bearing disc.
- 3.14.2. Fill bearing housings to the bottom of shaft with Vendor's recommended oil.
- 3.14.3. Coat the bowl assembly with Type A, Type B, or Type D preservative and close both ends.
- 3.14.4. Coat barrel flange, discharge head flanges, stuffing box, and all other machined surfaces with Type A, Type B, or Type D preservative.
- 3.14.5. Install weatherproof protective covers of such construction to provide a watertight seal on all openings. Plastic plugs and flange covers are not permitted.
- 3.14.6. Type D preservative shall be removed with solvent from all surfaces prior to installation of pump.

### **3.15. Reciprocating Pumps**

- 3.15.1. Remove pistons and rods, if recommended by the manufacturer; coat with Type A, Type B, or Type D preservative; tag each part with the equipment number; and store in covered area.
- 3.15.2. Remove rod packing, if recommended by the vendor; tag; and store in covered area.
- 3.15.3. Remove suction and discharge valves; dip in Type A, Type B, or Type D preservative; wrap in waxed cloth; tag; and store in covered area.
- 3.15.4. Fill crankcase with Type C preservative to the proper (indicator line or "bullseye") level.
- 3.15.5. Coat cylinder wall and distance piece wall with Type C preservative.
- 3.15.6. Type D preservative shall be removed with solvent from all surfaces prior to installation of pump.

### **3.16. Steam Turbines**

The following procedure should be used for receiving and protecting turbines during the installation and storage period at the jobsite.

Restricted

NOTE: Refer to 3.7 for general criteria.

- 3.16.1. Coat stuffing box and shaft in packing areas with Type B or Type C preservative and replace on turbine.
  - 3.16.2. Clean and coat all flange gasket surfaces with Type A, Type B, or Type D preservative.
  - 3.16.3. Shipping covers shall be removed, flange gasket surfaces inspected, and internals checked for cleanliness. Plastic plugs and flange covers are not permitted.
  - 3.16.4. Install weatherproof protective covers of such construction to provide a watertight seal on all openings.
  - 3.16.5. Governor valves and trip throttle valves should be protected by weatherproof coverings to prevent corrosion between stem and bushing.
  - 3.16.6. Identify and tag all loosely shipped items and store in a covered area.
  - 3.16.7. General-purpose Steam Turbines
    - 3.16.7.1. If carbon shaft packing rings were not removed at the factory, removal and indoor storage is recommended.
    - 3.16.7.2. Apply a manufacturer approved rust preventive to the packing ring cavity after the rings are removed.
    - 3.16.7.3. Tag the turbine from which the rings have been removed.
    - 3.16.7.4. The carbon rings shall be reinstalled just prior to start-up. Removal and reinstallation shall be performed by qualified personnel.
    - 3.16.7.5. Open bearing housings and coat shaft journals with Type C preservative.
    - 3.16.7.6. Fill bearing housings to bottom of shaft with vendor recommended oil.
    - 3.16.7.7. Coat shaft extension with Type A, Type B, or Type D preservative.
    - 3.16.7.8. If a hydraulic governor is supplied, fill the hydraulic governor to the proper (indicator line or "bullseye") level.
    - 3.16.7.9. Type D preservative shall be removed from all surfaces with solvent prior to installation of turbine.
  - 3.16.8. **Special purpose Steam Turbines**
    - 3.16.8.1. Inspect and coat surfaces of valve rack, cam, and cam followers with Type A, Type B, or Type D preservative.
    - 3.16.8.2. Open bearing housings and coat shaft journals, thrust bearing disc, and bearing housing internally with Type C preservative.
    - 3.16.8.3. Coat shaft extension with Type A, Type B, or Type D preservative.
    - 3.16.8.4. Special-purpose turbine casings and internals should be protected with nitrogen purging.
      - a) Purge per 2.3.15.
      - b) Where this is not possible and approved by the user, spray turbine internals through openings with Type C preservative.
    - 3.16.8.5. Rotor Turning of Steam Turbines
- Note: See general guidelines in 2.8

### 3.17. Rotary Screw Compressors

NOTE: Refer to 3.7 for general criteria.

- 3.17.1. Coat exposed shafts, rods, and machined surfaces with Type A, Type B, or Type D preservative. If compressor's associated equipment, such as inlet filters, pulsation suppressors, silencers, have been shipped loose, tag and store per manufacturer's recommendations.
- 3.17.2. Non-Lubricated "dry screw" compressors with TFE or carbon rotor tip seals shall not be contaminated with oil. Such machines, if not already shop protected, should be sealed, purged of air, and kept pressurized with dry nitrogen at 2 mm to 3 mm Hg (1 in. to 2 in. of H<sub>2</sub>O).
  - 3.17.2.1. Install a temporary pressure indicator to indicate nitrogen pressure.
  - 3.17.2.2. Remove the temporary gauge before compressor initial run-in.
- 3.17.3. Compressor and associated compressor equipment should be inspected when the compressor is received on site by removal of the inspection covers.
  - 3.17.3.1. If water or dirt has entered the equipment through damaged covers, the equipment shall be cleaned out.
  - 3.17.3.2. Rust preventive treatment shall be restored.

Restricted

- 3.17.4. If the compressor and associated equipment requires field assembly, remove the protective coatings from shafts, flanges, rods, and so forth, and clean all parts (including oil sump) with solvent.
- 3.17.4.1. Assemble using the manufacturer's recommended preservative freely on shafts, flanges, rods, bearings, and rubbing parts as recommended by the manufacturer.
- 3.17.4.2. Fill oil reservoir, oil piping, and pre-lubricator systems to the proper (indicator line or "bullseye") level, or as recommended by the manufacturer, with Type C preservative.
- Note: Where compressors require field assembly, consideration should be given to bringing in the factory representative to confirm inspection, preservation, and assembly procedures.
- 3.17.5. Where applicable, operate the pre-lubricator pump weekly. If the compressor has a manual priming main oil pump, operate it for at least one minute. Refill the lubricators as necessary. Record protective activity in the inspection records.
- 3.17.6. On all rotary screw compressors, remove any rotor anti-rotation device or blocks prior to rotation.
- 3.17.7. If oil flooded compressors are being rotated, only rotate the driveshaft if the compressor rotor bore lubrication can be operated first.
- 3.17.8. On Non-Lubricated compressors, rotate the driveshaft only after confirming all desiccants have been removed and that a positive pressure, dry nitrogen purge is being maintained on the compressor.
- 3.17.9. Large compressor frames, exceeding approximately 4 m (12 ft) in length, that are not skid mounted and that are to be stored more than a few days prior to installation should be supported following the manufacturer's recommendations to prevent permanent distortion of the compressor frame.

### 3.18. Motors

The following procedure should be used for receiving and protecting electric motors during the installation period at the jobsite. Specific storage instructions are normally provided by all motor manufacturers. Users should follow either the manufacturer's instructions or the procedures below, whichever is the more stringent and provided that the procedures do not invalidate the warranty.

NOTE: Refer to 3.7 for general criteria.

- 3.18.1. Receiving Inspection of Motors
- After receipt at site but prior to any motor being stored or installed, the following should be performed.
- 3.18.1.1. An insulation resistance-to-ground test shall be made and recorded.
- a) The resistance to ground test should be based on the operating voltage of the motor and in accordance with IEEE or NEMA test procedures
- b) The log will show the dates of the test and the insulation resistance value.
- 3.18.1.2. Oil levels shall be inspected. An inspection should be made for any evidence of oil leakage.
- 3.18.1.3. Shafts shall be rotated and checked for freedom of movement in accordance with 2.8.6 through 2.8.10.
- 3.18.2. Storage
- 3.18.2.1. Fill bearing housing with recommended oil, if not factory lubricated, or the level is low.
- 3.18.2.2. Coat shaft with Type A, Type B, or Type D preservative.
- 3.18.2.3. Wrap shaft seal areas with waxed cloth.
- 3.18.2.4. Apply Type A, Type B, or Type D preservative to machined areas of baseplate and motor case feet.
- 3.18.2.5. Store motors indoors if possible (see Annex E on types of storage).
- a) A motor may be suitable for outdoor storage if the enclosure Type is TEFC or explosion proof.
- b) Motors without space heaters should not be stored outdoors without user's approval and unless provisions are made by the installer to supply an adequate source of heat to the motor to protect it from moisture.
- c) If unable to store indoors, motors shall be stored in their operating position on a well-drained hard surface.
- 3.18.2.6. The preferred storage method for vertical motors with ball bearings is vertical. However, these motors may be stored horizontally if they are oriented such that the drains are located at the low points to prevent any accumulation of water. The required storage position for vertical motors with sleeve type bearings is in the vertical position, unless otherwise instructed by the manufacturer.
- 3.18.2.7. If a space heater is provided by the manufacturer, it shall be connected, energized, and operated continuously until the motor becomes operational. Proper warning signs shall be installed to prevent injury or electrical shock to personnel.

Restricted

- 3.18.2.8. Preservatives shall be removed with solvent from all surfaces prior to installation of motor, using caution to not have solvent contact the windings.
- 3.18.3. Rotor Turning of Motors
- 3.18.3.1. When applying the rotor turning requirement, if previously applied corrosion prevention is compromised, the corrosion inhibitors will need to be reapplied.
- 3.18.3.2. Prior to turning the rotor, heavy rotors may need to be lifted so as to reduce the load at the supporting journals.
- 3.18.3.3. Rotor turning may not be practical during shipment and should commence as soon as practical after delivery to intermediate and final destination sites.
- 3.18.4. Testing
- 3.18.4.1. Insulation resistance of all motors shall be tested upon receipt, just prior to installation, and just prior to start-up and should be recorded in the inspection records.
- 3.18.4.2. The test voltage levels and the insulation resistance shall be per the manufacturer's instructions.
- 3.18.4.3. If the megger readings do not meet the manufacturer's requirements, winding dry-out may be required.
- 3.18.4.4. Dry out the stator per the motor manufacturer's instructions. Other methods may be harmful to the windings.

### **3.19. Instrumentation on Packaged Machinery**

- 3.19.1. All instruments should be inspected by qualified personnel for compliance to purchase specifications, arrival at site clean, dry, and with proper protection at all openings, proper tagging, and inspected for shipping damage.
- 3.19.2. After inspection, instruments are to be replaced in their original factory boxes, properly tagged, and stored on shelves in a dry enclosed area.
- 3.19.3. For instruments or control panels that have been pre-mounted on the machinery package that cannot be stored in a dry, enclosed area, the user and manufacturer shall be consulted.
- 3.19.3.1. Removal and indoor storage of pre-mounted instruments and control panels may be required if such devices cannot be protected from rain, humidity, temperature, or dusty conditions.
- 3.19.3.2. Explosion-proof enclosures are not necessarily weatherproof enclosures. Open conduit connections can allow entrance of moisture.
- NOTE: This subject should have been addressed during the procurement or shop inspection stage but is sometimes overlooked.

- 3.19.4. Electronic Instruments
- 3.19.4.1. Electronic instruments should be stored in a dust-free room between 45 °F through 115 °F (8 °C and 45 °C).
- 3.19.4.2. If humidity is consistently above 90%, seal and store the instruments in plastic wrap, place in a box with desiccant outside the plastic wrapping, and store indoors. Take care that the desiccant does not contact any wiring, terminals, or electronic parts.
- NOTE: The avoidance of dust and excessive humidity may not be needed except for non-weatherproof instruments.
- 3.19.4.3. The manufacturer's recommendations shall be reviewed to determine if climate-controlled storage facilities are required.

### **3.19.5. Pneumatic Instruments**

Storage in a dry enclosed area is sufficient for pneumatic instruments.

### **3.19.6. Instrument Cases**

- 3.19.6.1. Instrument cases with electronic parts, relays, and solid state control boards, should only be opened and checked by qualified personnel, unless shop inspections have been made and documented.
- 3.19.6.2. If the instrument case is in a weatherproof housing, reseal and store the instrument in a room between 45 °F through 115 °F (8 °C and 45 °C).
- 3.19.6.3. If in an explosion-proof housing, store in boxes with desiccant.

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3.19.6.4. If covers need to remain open and unsealed, place the boxes in an indoor storage environment.

3.19.7. Local Control Panels

3.19.7.1. Open packaging enough to identify the control panel, reseal, and place in a dry enclosed area between 45 °F through 115 °F (8 °C and 45 °C).

3.19.7.2. If in a high-humidity area, put desiccant inside packaging before resealing.

3.19.8. Dial Thermometers, Pressure Gauges, Gauge Glasses

3.19.8.1. Protect against physical damage from construction activities, or remove, tag, and store in a dry enclosed area.

3.19.8.2. Process connections should be capped or plugged with metal caps/plugs until the instruments are reinstalled.

Draft—For Committee Review

## Annex A (informative)

### A.1 Characteristics of Conventional Storage Preservatives

Storage Condition and/or Severity	Outdoor Storage, General Exposure to Elements	Indoor Storage Under Severe Conditions or Outdoor Storage (Partial Shelter) Under Moderate Conditions, or Outdoor Storage with Exposure to Elements for Short Term Only	Indoor Storage Under Moderate Conditions	Outdoor Storage with Exposure to Elements Under the Most Severe Conditions
	Type A	Type B	Type C	Type D
Product and typical characteristics	Firm coating, resistant to abrasion	Soft coating (self-healing)	Thin oily film	Asphaltic film, needs removal before part is used
Density kg/m <sup>3</sup> at 15 °C lb/gal 60 °F	868.5 7.25	923.7 7.71	876.9 7.32	922.5 7.70
Viscosity				
cSt at 40 °C	—	—	14	149
cSt at 100 °C	24.8	33.1	3.3	—
SSU at 100 °F	—	—	79	800
SSU at 210 °F	123	162	37.4	—
Flash Point				
°C	279	260	166	38
°F	535	500	330	100
Melting or pour point				
°C	73	66	-4	—
°F	164	151	+25	—
Unworked penetration				
At 25 °C (77 °F)	75	245	—	—
Film thickness, mil	1.6	1.6	0.9	3.0
Approximate coverage				
m <sup>2</sup> /liter	26	6	44	11
ft <sup>2</sup> /gal	1000	1000	1800	450
Non-volatiles, %	99	99	—	55
Methods of application/temperature, °C	dip/85 brush swab/60–71	dip/77 swab/18–27	roller coat, brush, mist	spray, dip, or brush/ambient
Maximum time until inspection and possible reapplication under condition				
Mild	Extended	Extended	6 to 12 Months	Extended
Moderate	1 to 3 Years	1 to 3 Years	1 to 6 Months	1 to 3 Years
Severe	6 to 12 Months	6 to 12 Months	Not recommended	6 to 12 Months
NOTE Extracted from proceedings of the Fourteenth Turbomachinery Symposium, Texas A&M University, Table I, Page 36, "Storage Preservation of Machinery" by Heinz P. Bloch.				

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NOTE 1 Table A.1 represents an overview of interacting factors that allows the specifying engineer to select the most appropriate preservative for a given situation. Indoor and outdoor storage protection is addressed, but lubricants or preservatives used for oil mist systems are not covered.

NOTE 2 The severity of indoor storage is a function of such factors as dampness, poor air circulation, widely fluctuating temperatures, or presence of corrosive fumes. If conditions are moderately severe, product "C" will provide an adequate oily film and some abrasion resistance. It does not contain water-displacing or fingerprint-suppressing agents.

NOTE 3 Product "B" has a grease-like consistency and leaves a thick film that will provide protection in the most severe indoor environments. If stored parts are sheltered from direct exposure to sun, rain, and snow, effective outdoor rust protection can be achieved with this product. Application of product "B" is preferably made by dipping at a temperature of 71 °C to 77 °C (160 °F to 170 °F). For parts too large to dip, application can be made by brush. This product forms a soft, thick, waxy coating on application, with the surface coating gradually drying to form a protective film or crust while the underlying material remains soft and plastic. This is an important characteristic because it affords a self-healing effect. If a minor break occurs, the softer material will slowly flow together and reseal the damaged film.

NOTE 4 The degree of protection obtained in exposed outdoor environments will depend to some extent on the thickness and durability of the barrier film provided by the rust preventive material. For relatively short-term storage, product "B" will give effective protection. For longer periods, product "A" is recommended. It provides the toughest coating for a product of this type, and is more resistant to film rupture than product "B." For dip application, product "A" should be heated to 85 °C (185 °F).

NOTE 5 Product "D" is a solvent-cutback asphaltic material. This product provides the best protection for long-term outdoor storage, but removal before the part is put into service is important. The preferred application method is by spray, although dipping and brush applications are also suitable. Product "D" dries to a thick, hard, durable, black film but may be removed with a good quality mineral spirits solvent.

NOTE 6 Although products "A" through "C" do not require removal before the part is placed in service, care should be taken to be sure that the coating has not absorbed abrasive dust.

NOTE 7 Many of the desirable attributes of premium preservatives are listed below:

- dry to a mildly tacky film that should not collect appreciable amounts of airborne particulates;
- provide freedom from oxidation in indoor and outdoor storage for extended periods of time;
- due to their polar nature, remove water from the pores of the metal, replacing the water with the rust preventive coating;
- in the form of films, have extremely low moisture transmission characteristics, even in contact with water;
- have the ability to neutralize acid, making a suitable rust preventive for acidic atmospheres and where fingerprints may create a corrosive action on metal surface;
- are self-healing, if in film form. If the film is accidentally ruptured, it should heal over the ruptured area;
- even as film, should be readily removed with solvent or a solvent-emulsion cleaner if desired;
- are safe to apply over partially painted or conventional elastomeric parts.

NOTE 8 Desiccants (moisture absorbing material), VCI products (provides self-healing barrier between the metal surface and moisture), and nitrogen purging (displaces oxygen) may be used and requires approval from the manufacturer or the user-designated representative.

NOTE 9 VCI products that contain nitrites will attack copper and bronze materials.

**Annex B**  
(informative)

**B.1 Machinery Receiving and Protection Checklist**

Project No.:	Equip. Tag No.:	Report No.:
Prepared by:	Storage Location:	Date:
Equipment Description:		

Equipment No.: _____			
Section	Requirements	Name	Date
<b>2.2</b>	<b>Jobsite Receiving and Inspection</b>		
2.2 a)	Visual inspection for physical damage or contamination. Comments (before unloading): _____ _____ _____		
	Comments (after unloading): _____ _____ _____		
2.2 b)	Shipping protection intact?		
2.2 c)	Have off-site (shop) inspections been made?		
2.2 d)	Loose components/packages match packing lists?		
2.2 e)	Are special handling instructions required (and carried out)?		
2.2 f)	Components properly identified?		
2.2 g)	Do components comply with project requirements?		
2.2 h)	Flange faces undamaged and properly coated?		
2.2 i)	Plugs/caps in place, desiccants unsaturated, and equipment lubricated?		
2.2 j)	For inert gas purged equipment, is the required pressure still applied?		
2.2 k)	Grout surfaces clean and coated?		
2.2 l)	Tapped openings in stuffing boxes and gland plates sealed?		
2.2 m)	Impact measuring devices inspected (if specified)?		
2.2 n)	All inspections recorded on Annex B and Annex C?		
2.2 o)	Damage reports completed and issued to shipper/vendor?		
<b>2.3</b>	<b>General Instructions—Jobsite Protection</b>		

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2.3.1	Are manufacturer's recommendations for storage and protection available and is equipment protected accordingly? Note: If so, the manufacturer's recommendations take precedence, but continue to follow this checklist for items not covered by the manufacturer.		
2.3.2	Records maintained in accordance with established procedures?		
2.3.3	Equipment/material free of ground contact? Laydown area graveled as a minimum!		
2.3.4	For outdoor storage, is equipment on timber?		
2.3.5	Is indoor storage available at site? Is third-party storage available?		
2.3.6	Do temporary coverings allow free air circulation?		
2.3.7	Is integrity of original shipping packaging maintained?		
2.3.8	All carbon and low alloy steels protected from corrosive environments?		
2.3.9	Painted surfaces should not require additional protection but should be examined periodically for signs of rusting. Touch-up, using the manufacturer's recommended methods and materials, should be performed within a practical and reasonable period of time.		
2.3.10	All items with machined surfaces should be stored so that the machined surfaces can be examined periodically (monthly) for signs of rust.		
2.3.11	Any special parts and tools for construction purposes that accompany vendor shipments shall be tagged, protected, and stored per the vendor's and/or user's recommendations. All tags shall be stainless steel and stainless-steel wired to the special part or tool. Paper tags are not permitted.		
2.3.12	Equipment protected from construction operations: chipping, sanding, painting, rigging, welding, for example?		
2.3.13	For periodic rotation of equipment, are shipping blocks, desiccant bags, and protective plastic clear of moving parts? Is equipment properly lubricated for rotation?		
2.3.14	Have proper preservatives been selected?		
2.3.15	Nitrogen purge in place for special-purpose equipment or where specified? Use Annex C for logging of purge inspections		
2.3.16	All cavities, cooling passages, and so forth, drained of water to prevent freezing?		
2.3.17	Unless stated differently in subsequent sections on specific equipment, the following applies.		
2.3.17 a)	Oil lubed bearing housings, seal housings, stuffing boxes, hydraulic equipment, and gear cases fogged and 1/4 filled with approved oil (other acceptable methods can include the use of nitrogen purge and VCI emitters)?		
2.3.17 b)	If specified, measure and record TAN number.		
2.3.17 c)	Exposed carbon steel coated with Type A, Type B, or Type D preservative? Machined surfaces coated with Type A, Type B, or Type D and wrapped with waxed cloth?		
2.3.17 d)	Grease-lubricated bearings greased by the manufacturer?		
2.3.18	Oil mist system required and in accordance with requirements?		
<b>2.4</b>	<b>Lubricants and Preservatives</b>		

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2.4.1	All desiccants have prior approval from the manufacturer or the user-designated representative and in accordance with Annex A?		
2.4.2	Are selected preservatives compatible with elastomeric parts, seals, gaskets, and so forth?		
2.4.3	SDS's on file and hazards reviewed?		
2.4.4	Desiccants approved by the manufacturer or user-designated representative and checked monthly?		
2.4.5	Do preservatives need to be removed prior to process contact?		
2.4.7	Do all VCI's have prior approval from the manufacturer or the user-designated representative. Note: Some VCI's may contain nitrites which attack copper and bronze.		
2.4.8	Nitrogen asphyxiation hazards removed?		
<b>2.5</b>	<b>Bolts</b>		
2.5.1	Loose bolts, nuts, and fasteners identified and stored in sheltered area?		
2.5.2	Preservative applied to non-galvanized or plated items?		
<b>2.6</b>	<b>Spare Parts</b>		
2.6.1	Spare parts inventoried and issued to user upon receipt?		
2.6.2	Storage and protective maintenance of miscellaneous loose items as directed by the manufacturer?		
2.6.3	Extra drawings and manuals shipped with the equipment saved and handed over to the user?		
2.6.4	Special tools turned over to the user-designated machinery representative at the end of the job?		
<b>2.7</b>	<b>Auxiliary Piping for Rotating Equipment</b>		
2.7.1	Pipe components coated internally and externally prepared for storage?		
2.7.3	Flanges inspected and prepared for storage?		
2.7.4	Valves inspected and prepared for storage? Ball valves in open position? Soft-seated gate and globe valves in closed/off-seat position and stored horizontal?		
2.7.5	Vendor supplied associated components that will require long term storage outdoors during the construction period (or stainless steel in a salt water environment) stored and protected per the vendor's and/or user's recommendations?		
<b>2.8</b>	<b>Machinery—General Short Term Criteria</b>		
2.8.1	All flange gasket surfaces cleaned and properly preserved?		
2.8.2	Watertight covers on all openings?		
2.8.3	Are intermediate rotor shaft supports required?		
2.8.4	Is vertical storage of rotating elements required by the manufacturer?		

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2.8.5	Preservatives and procedures for refrigeration, oxygen, and chlorine service approved by manufacturer?		
<b>2.9</b>	<b>Reciprocating Compressors</b>		
2.9.1	Exposed rods, eccentrics, plungers, and machined surfaces coated?		
2.9.2	Non-lubed compressors nitrogen purged, not contaminated with preservatives?		
2.9.3	Cover on openings in cylinders and crankcase undamaged? If damaged check for water or dirt inside.		
2.9.4	For field assembled compressors, have loose components been properly cleaned and preserved? Have carbon rings and rod packing been left out until just prior to initial operation?		
2.9.5	Crank shaft turned per Vendor recommendations, of if Vendor doesn't specify, 2 1/4 revolutions monthly and accomplished with a strap wrench or other non-marring device.		
<b>2.10</b>	<b>Centrifugal Compressors</b>		
2.10.1	Is bearing housing properly lubricated and preserved?		
2.10.2	Have the lubricant fill points, site glass, and piping been checked for leaks?		
2.10.3	Has a nitrogen purge, or vapor phase inhibitors and desiccant been applied?		
2.10.4	Compressor shaft turned per Vendor recommendations, of if Vendor doesn't specify, 2 1/4 revolutions monthly and accomplished with a strap wrench or other non-marring device?		
<b>2.11</b>	<b>Fans and Blowers</b>		
2.11.1	Have all exposed low alloy surfaces and shafts been coated with preservative?		
2.11.2	Bearing housing oil level correct?		
2.11.3	Rotor shaft turned per Vendor recommendations, of if Vendor doesn't specify, 2 1/4 revolutions monthly and accomplished with a strap wrench or other non-marring device?		
<b>2.12</b>	<b>Gearboxes</b>		
2.12.1	Is gearbox oil level correct and filled with manufacturer's recommended oil?		
2.12.2	Have machined surfaces and shafts been coated?		
2.12.3	Gearbox shaft turned per Vendor recommendations, of if Vendor doesn't specify, 2 1/4 revolutions monthly and accomplished with a strap wrench or other non-marring device?		
2.12.4	Has a nitrogen purge been applied, if specified?		
<b>2.13</b>	<b>Pumps—General</b>		
2.13.1	Coupling parts, except elastomers and stainless steel discs, coated?		
2.13.2	Shipping covers removed and flange surfaces inspected and coated?		
2.13.3	Have loose components been tagged and properly stored?		
<b>2.14</b>	<b>Centrifugal Pumps</b>		

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2.14.1	Have all openings been covered with a watertight seal?		
2.14.2 a)	Have bearing housings been filled with oil to bottom of shaft?		
2.14.2 b)	Oil mist installed where applicable?		
2.14.2 c)	All barrier piping filled with proper fluid?		
2.14.3	Have low alloy pump casings been filled with proper preservative and rotated to coat all internals?		
2.14.4	Pump shaft turned per Vendor recommendations, or if Vendor doesn't specify, 2 1/4 revolutions monthly accomplished with a strap wrench or other non-marring device?		
<b>2.15</b>	<b>Vertical Suspended Pumps</b>		
2.15.1	Has preservative been applied to shaft journals at sleeve bearing and thrust disc?		
2.15.2	Bearing brackets completely filled?		
2.15.4	Bowl assembly, barrel flange, discharge head flanges, stuffing box, and machined surfaces coated?		
2.15.5	Weatherproof covers installed on all openings?		
<b>2.16</b>	<b>Reciprocating Pumps</b>		
2.16.1	If recommended by manufacturer, have pistons and rods been removed, coated, tagged, and stored in covered area?		
2.16.2	Has rod packing been removed and tagged, if required?		
2.16.3	Have suction and discharge valves been removed, coated, and tagged, if required?		
2.16.4	Has crankcase been filled to the Vendor's recommended level with preservative?		
2.16.5	Have cylinder and distance piece walls been coated?		
2.16.6	Exposed shaft coatings with Type D preservatives removed prior to pump installation?		
<b>2.17</b>	<b>Steam Turbines</b>		
2.17.1	Have stuffing box, shaft in packing area, and flange gasket surfaces been coated?		
2.17.2	Are weatherproof covers on all openings?		
2.17.3	Have internals been inspected for cleanliness?		
2.17.4	Have loosely shipped components been tagged?		
<b>2.17.6</b>	<b>General-purpose Turbines</b>		
2.17.6.1	Have carbon rings been removed, tagged, and stored indoors, if required?		
2.17.6.2	Have shaft journals been lubricated?		
2.17.6.3	Have bearing housings been filled with proper lubricant?		
2.17.6.4	Have exposed shafts been coated?		
2.17.6.5	Has governor been filled with manufacturer's approved fluid?		

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2.17.6.6	Turbine shaft turned per Vendor recommendations, of if Vendor doesn't specify, 2 1/4 revolutions monthly and accomplished with a strap wrench or other non-marring device?		
2.17.6.7	Type D preservatives removed prior to installation of turbine?		
<b>2.17.7</b>	<b>Special-purpose Steam Turbines</b>		
2.17.7.1	Have valve racks, cam, and cam followers been inspected and coated?		
2.17.7.2	Have bearing housings, shaft journals, and thrust bearing discs been coated?		
2.17.7.3	Have exposed shafts been coated?		
2.17.7.4	Has the nitrogen purge been applied where possible or internals alternatively coated for preservation?		
<b>2.18</b>	<b>Rotary Screw Compressors</b>		
2.18.1	Exposed shafts and machine surfaces properly protected?		
2.18.2	"Dry" compressors maintained clean and dry with a nitrogen purge?		
2.18.3	Inspected upon shipment arrival and cleaned, preserved, and all openings covered and weather-tight?		
2.18.4	For field assembly units, clean and preserve as recommended by the manufacturer during assembly?		
2.18.5	Where applicable, pre-lube pump operated weekly? Shaft rotated 2 1/4 turns weekly with a strap wrench or other non-marring device?		
2.18.6	All anti-rotation devices removed before attempting to rotate?		
2.18.7	Ensure that rotor bores on oil flooded compressors are lubricated before rotating.		
2.18.8	Ensure that all desiccants have been removed and a nitrogen purge established on NON-LUBRICATED compressors before rotating.		
2.18.9	Large compressors aligned to prevent frame distortion?		
<b>2.19</b>	<b>Motors</b>		
2.19.1.a)	Has an insulation test been made and logged?		
2.19.1.b)	Have oil levels been checked and any leakage noted?		
2.19.1.c)	Shafts rotated and checked for freedom of movement?		
2.19.2.1	Bearing housing filled with manufacturer's recommended lubricant?		
2.19.2.2	Has shaft been coated with proper preservative?		
2.19.2.3	Have seal areas been covered with waxed cloth?		
2.19.2.4	Have motor baseplate machined surfaces or feet been coated?		
2.19.2.5	Have non-weatherproof motors been stored indoors?		
2.19.2.6	Have vertical motors been stored vertically?		
2.19.2.7	Have space heaters been energized? Have warning signs been posted?		

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2.19.2.8	Preservatives removed prior to installation?		
2.19.3	Shafts rotated per Vendor's recommendation, of if Vendor doesn't specify, 2 1/4 turns monthly with a strap wrench or other non-marring device?		
<b>2.20</b>	<b>Instrumentation on Packaged Machinery</b>		
2.20.1	Do instruments comply with specifications, and are they properly tagged?		
2.20.2	Are loose instruments stored in a dry enclosed area, in original factory packaging?		
2.20.3	Can pre-mounted instruments be stored outdoors?		
<b>2.20.4</b>	<b>Electronic Instruments</b>		
2.20.4.1	Are electronic instruments stored in a dry dust-free room?		
2.20.4.2	Are instruments stored in a humidity controlled area?		
<b>2.20.5</b>	<b>Pneumatic Instruments</b>		
2.20.5	Are instrument cases and local control panels stored in a dry enclosed area?		
<b>2.20.6</b>	<b>Instrument Cases</b>		
2.20.6.1	Electronic component cases opened and inspected?		
2.20.6.2	Check sealing of weatherproof enclosures and properly stored.		
2.20.6.3	Explosion-proof housings stored indoors with desiccant?		
2.20.6.4	Covers that shall remain open and unsealed stored indoors?		
<b>2.20.7</b>	<b>Local Control Panels</b>		
2.20.7.1	Packaging opened sufficiently to inspect components and then resealed for preservation.		
2.20.7.2	Desiccant bags placed in enclosures in high humidity areas?		
<b>2.20.8</b>	<b>Dial Thermometers, Pressure Gauges, Gauges</b>		
2.20.8	Are thermometers, pressure gauges, and gauge glasses protected from physical damage?		

**Annex C**  
(informative)

**Machinery Receiving and Inspection Checklist**

**Equipment No.:** \_\_\_\_\_

Periodic Services Between Time Received and Start-up (See Note)							
Item	Interval	Dates/Initials					
Visual inspection that coverings and coatings are intact	Monthly						
Inspection of painted surfaces	Monthly						
Inspection of machined surfaces	Monthly						
Inspect desiccant	Monthly						
Motor insulation resistance test	Monthly						
Inspect bearing housing; replace/refill as necessary	2 Months						
Check TAN of preservative oil, if specified	2 Months						
Oil check	2 Weeks						
Rotation of shafts	Weekly						
Compressors—lubrication	Weekly						

NOTE For nitrogen blanketing log, see Annex D.

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## Inert Gas Purge Maintenance Log

[illegible]

(b) Record flow rate in SLPm (SCFH) if a continuous flow purge is used in lieu of a constant pressure blanket.

## **4. Foundations**

### **4.1. General Installation Requirements**

- 4.1.1. (●) If specified, prior to the start of construction, the contractor shall submit to the equipment user for acceptance and review the qualifications of the person responsible for performing the soil inspection specified in PART B 4.11.2.

### **4.2. Formwork Installation**

- 4.2.1. All formwork and form accessories shall be in accordance with ACI 301 *Specifications for Structural Concrete* and PIP STS03001 *Plain and Reinforced Concrete Specification*.
- 4.2.2. All corners on permanently exposed surfaces or on edges of formed joints shall have a chamfer of at least 19 mm (¾ in.).
- 4.2.3. Removal of formwork shall be in accordance with ACI 301 *Specifications for Structural Concrete* and PIP STS03001 *Plain and Reinforced Concrete Specification*.

### **4.3. Anchor Bolts and Sleeve Installation**

- 4.3.1. Anchor bolts and sleeves shall be located to the manufacturer's specified tolerances in all three planes and securely supported to prevent misalignment during the concrete placement operation.
- 4.3.2. The anchor bolts shall not be reduced in diameter nor offset to facilitate alignment with the baseplate or soleplate.
- 4.3.3. Modification of the baseplate or soleplate to facilitate alignment is not permitted unless authorized by the designated machinery representative.
- 4.3.4. A template should be used to aid in the placement of anchor bolts. The template will assist in accurately placing the anchor bolts.

### **4.4. Field Verification Prior to Concrete Placement**

- 4.4.1. Immediately prior to concrete placement, the anchor bolt locations, projections, and diameters shall be field verified to match the anchor bolt hole location in the baseplate or soleplate. In the event that the baseplate is not at the site, the anchor bolts' location shall be verified against the structural foundation drawings and the manufacturer's drawings. The anchor bolts shall also be examined to verify that they have been installed plumb, have the correct length and projection, are adequately secured to prevent displacement during the concrete placement, and the threads are not stripped or damaged. All discrepancies or deficiencies shall be corrected before concrete operations begin.
- 4.4.2. All anchor bolt exposed threads and sleeves shall be covered or filled with a nonbonding moldable material to prevent entry of concrete.
- 4.4.3. Prior to concrete placement, the proposed elevation of the top of the foundation concrete shall be verified with the elevation specified on the foundation drawing, and the necessary procedures shall be taken to correct any discrepancies.

### **4.5. Concrete Mixing and Placement Procedures**

- 4.5.1. Materials, formwork, handling, mixing, and placement of concrete or mass concrete shall conform to ACI 301 *Specifications for Structural Concrete* and PIP STS03001 *Plain and Reinforced Concrete Specification*.
- 4.5.2. For mass concrete, control of the concrete temperature shall be maintained at the pour point.
- 4.5.3. At the point of delivery, concrete shall have maximum slump of 100 mm (4 in.) when achieved by water alone. If a slump greater than 100 mm (4 in.) is required for proper placement of concrete, it may be increased up to 200 mm (8 in.) using a high-range water-reducing agent.

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- 4.5.4. The field addition of water to increase the slump shall not be permitted without approval of the equipment user.
- 4.5.5. Foundations shall be made in one continuous pour unless otherwise approved by the equipment user or shown on the drawings.
- 4.5.6. Immediately after placement, concrete shall be protected from cold or hot weather extremes, mechanical injury, and premature drying and shall be cured as specified in ACI 301 Specifications for Structural Concrete and PIP STS03001 Plain and Reinforced Concrete Specification.

NOTE: ACI 301, *Specifications for Structural Concrete*, requires that normal concrete be cured (preservation of moisture) for seven days after placement.

- 4.5.7. The foundation preparation procedures for grouting specified in the grouting section of this specification or the setting of any equipment on the foundation shall not be permitted to begin until concrete curing in accordance with ACI 301 Specifications for Structural Concrete and PIP STS03001 Plain and Reinforced Concrete Specification has been completed, and the concrete has attained the specified 28-day compressive design strength as defined in ACI 301.

NOTE: The ability of concrete to reach the specified strength is a function of temperature and moisture retention. Normal concrete, when properly cured, attains the specified design strength approximately 28 days after placement. The concrete reaches the specified compressive design strength when the requirements of ACI 301 for removal of formwork have been met. If approved by the equipment user, the use of high early strength concrete may be used to reduce the duration time required to reach the desired strength in situations where cure time is on the critical path. Refer to ACI 301 and ACI 308 Guide to External Curing of Concrete for additional information on curing concrete.

- 4.5.8. All concrete shall have a minimum compressive strength of 28 mPa (4000 lb. per in.<sup>2</sup>) at 28 days, unless otherwise specified on the drawings.
- 4.5.9. High early strength concrete shall be used only with the approval of the equipment user.

#### **4.6. Concrete Quality Control**

- 4.6.1. The equipment user or the designated machinery representative reserves the right to subject the concrete foundation construction to inspection by an ACI-certified inspector or any user-designated testing agency.
  - 4.1.1. Tests of concrete compressive strength, air content, and slump shall be as designated by the equipment user, designated machinery representative, or in accordance with ACI 301 Specifications for Structural Concrete and PIP STS03001 Plain and Reinforced Concrete Specification.

**Annex A  
(normative)  
Machinery Foundation Checklist**

Section	Requirements	Name	Date
<b>4.1</b>	<b>General Installation Requirements</b>		
4.1.1	User has been supplied with written documentation from qualified soils specialist certifying that the soil is adequate to provide required bearing capacity		
<b>4.2.</b>	<b>Formwork Installation</b>		
4.2.1	Formwork and form accessories are in accordance with ACI 301 and PIP STS03001?		
4.2.2	Chamfer strips have been provided at all permanently exposed edges?		
4.2.3	Formwork removal is in accordance with ACI 301 and PIP STS03001?		
<b>4.3</b>	<b>Anchor Bolts and Sleeve Installation</b>		
4.3.1	Anchor bolts and sleeves are located within the manufacturer's specified tolerances?		
4.3.2	The anchor bolts shall not be reduced in diameter nor offset to facilitate alignment with the baseplate or soleplate		
4.3.4	Template used to aid in the placement of anchor bolts		
<b>4.4</b>	<b>Field Verification Prior to Concrete Placement</b>		
4.4.1	Anchor bolt locations, projections, and diameters match the anchor bolt holes in baseplate or soleplate?		
4.4.2	Anchor bolt exposed threads covered, and sleeves filled with soft moldable material?		
4.4.3	Elevation of top of concrete pour line agrees with the elevation specified on the foundation drawings?		
<b>4.5</b>	<b>Concrete Mixing and Placement Procedures</b>		
4.5.1	Concrete materials, formwork, handling, mixing, and placement conforms to ACI 301 and PIP STS03001?		
4.5.2	Control of the mass concrete temperature has been maintained at the pour point?		
4.5.3	Concrete slump has been measured and meets specifications?		
4.5.4	Water has NOT been added in the field to increase slump?		
4.5.5	Foundations made in one continuous pour?		
4.5.6	Concrete is protected and cured as specified in ACI 301?		
4.5.7	Concrete curing and strength adequate for grouting?		
4.5.8	Minimum concrete compressive strength meets specification?		
4.5.9	If high early strength concrete used, approval from equipment user was attained?		
<b>4.6</b>	<b>Concrete Quality Control</b>		
4.6.1	Was concrete foundation subject to inspection by an ACI-certified inspector or any user-designated testing agency?		
4.6.2	Tests of concrete compressive strength, air content, and slump as specified?		

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## 5. Baseplate or soleplates

### 5.1. Pre-grouted Baseplates Design and Application Requirements

- 5.1.1. Ensure that all top-side mounting holes (i.e. coupling guard mounting holes, etc.) are plugged to prevent the entrance of grout.
    - 5.1.1.1. All plugs shall be coated with paste wax to prevent grout adherence.
  - 5.1.1.2. Anchor bolt tubes shall be installed to exclude grout from the anchor bolt areas with the clearances as specified in Part B clause 5.3.3 as a minimum.
  - 5.1.2. Recommend using bolts with wax past, fully engaged. Ensure that the bottom of the baseplate including all areas to be in contact with grout has been properly degreased, sandblasted and primed using an epoxy primer approved by the grout manufacture etc., as would be the requirements for a conventional baseplate grout job and that the baseplate is at room temperature prior to filling with grout.
  - 5.1.3. Ensure that all leveling jackscrews have been properly waxed or provided with tubes to exclude the grout during curing.
  - 5.1.4. Ensure that the grout is properly mixed and placed at the correct temperature as recommended by the manufacturer.
  - 5.1.5. Ensure that the grout is poured to the top-most edge of the inverted baseplate. This will prevent air voids from occurring when the baseplate is field grouted.
  - 5.1.6. Do not disturb the baseplate until it has cured for at least 72 hours at the manufacturers recommended curing temperature. Final machining of the baseplate top machined surfaces shall only be completed by a competent machinist and after consultation with the baseplate manufacturer after proper grout curing.
  - 5.1.7. A pre-grouted baseplate may be considered when the baseplate size is within standard dimensions shown in API 610.
- NOTE: Limiting factors are depth of pour, support requirements, lifting capacity, machining capability, manufacturers and purchasers experience, etc.
- 5.1.8. No paint or coating is to be applied to the post-grouted baseplate as this would reduce the adhesion capability of the field secondary grout pour. Follow the grout manufacturer's instructions for surface preparation prior to the secondary field grouting.

### 5.2. Machinery Grouting Installation Requirements

#### 5.2.1. Scope

Pouring of the grout under machinery is only a small part of a grout job. Much preparation is required before the grout is actually poured. These pre-grout preparations can make the difference between a grout job lasting for the life of the machinery, or only a few months or years.

This section defines the minimum recommended procedures, practices, and inspections for the installation of grouted equipment baseplate or soleplates (soleplates and baseplates). These instructions provide guidelines for the installation of grouted baseplate or soleplates. Instructions supplied by the grout manufacturer should be carefully followed. Any questions regarding baseplate or soleplate installation and grouting are to be referred to the user-designated representative before proceeding.

#### 5.2.2. General/Special-purpose Equipment

This section addresses those grouting construction procedures associated with all machinery. Additional special-purpose machinery requirements are covered in the following annexes.

#### 5.2.3. Grouting Precautions and Personnel Protection

During the mixing, handling, and installation of grout materials, the following minimum practices shall be employed.

- 5.2.3.1. All grout material safety datasheets (SDS) shall be available and associated hazards reviewed with all grouting personnel.
- 5.2.3.2. Goggles or face shields and aprons should be worn by those personnel mixing and pouring the grout.
- 5.2.3.3. Protective gloves should be worn by all personnel involved in the grouting operation.
- 5.2.3.4. Dust masks or respirators (in accordance with SDS requirements) should be worn by those personnel exposed to the grout aggregate prior to and during mixing.
- 5.2.3.5. Soap and water should be available for periodic hand cleaning, should the need arise.
- 5.2.3.6. Some epoxy grouts exhibit a very strong exothermic reaction and the possibility of thermal burns exists. Caution shall be exercised in this regard.

#### 5.2.4. Foundation Curing

- 5.2.4.1. Check foundation curing time before proceeding with preparation for grouting.

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- 5.2.4.2. The foundation should be cured for at least seven days per ACI 301 prior to grout preparation.
- 5.2.4.3. Epoxy grout should never be poured on "green" or uncured concrete.
- 5.2.4.4. Concrete shall also be exposed to a drying-out period to ensure that the capillaries are free of moisture and will provide proper grout bonding.
- 5.2.4.5. Before grout is placed on newly pour concrete foundations, the concrete shall obtain a minimum of 80% of its design strength. This will allow the appropriate time for the moisture to mitigate and concrete shrinkage to occur. Refer to the concrete design mix for these details.
- 5.2.4.6. Additional curing time should be considered for heavy machinery.
- 5.2.5. Anchor Bolt Preparation**
- 5.2.5.1. Ensure that templates, if purchased, have been used for anchor bolt locations.
- 5.2.5.2. Verify that anchor bolt sleeves are clean and dry and have been filled with a nonbonding moldable material to exclude the grout from the anchor bolt sleeve. This material will prevent water accumulation in the anchor bolt sleeves and is pliable enough to allow for small anchor bolt movement, if needed.
- 5.2.5.3. Also ensure that anchor bolts are not tilted or bolt-bound and are perpendicular with respect to the bottom of the baseplate or soleplate.
- 5.2.5.4. Anchor bolt sleeves are not intended to provide sufficient movement to allow for gross misalignment of anchor bolts to their baseplate or soleplate holes. Lateral movement for alignment purposes should not exceed 6.5 mm (0.25 in.).
- 5.2.5.5. The anchor bolt threads should be covered with duct tape, foam pipe insulation, or other suitable means to keep them clean and to prevent any damage that might occur during the chipping and grouting operation.
- 5.2.5.6. All anchor bolt locations, projections, and diameters should be field verified to match the anchor bolt hole pattern in the baseplate or soleplate prior to grouting.
- 5.2.5.7. Anchor bolts system should be designed, to ensure the following free bolt pre-stretch length is provided:
- Centrifugal equipment: - 6 - 10 x Bolt Diameter.
  - Reciprocating equipment: 10-15 x Bolt Diameter.
- 5.2.5.8. Ensure after grouting, the anchor bolt sleeves have not been filled with grout and compromised the pre-stretch bolt length.
- 5.2.5.9. Adequate pre-stretch length is imperative to ensure that anchor bolts do not relax and fail due to cyclic stress.
- 5.2.6. Foundation Preparation Prior to Grouting**
- 5.2.6.1. A weather-protective cover may be necessary during inclement weather conditions. Wind, sun, rain, and ambient temperatures have a definite effect on the quality of a grouting installation.
- 5.2.6.2. During hot weather, the foundation and equipment shall be covered with a shelter to keep the uncured grout from being exposed to direct sunlight as well as dew, mist, or rain.
- 5.2.6.3. In cold weather, a suitable covering to allow the foundation to be completely enclosed should be constructed.
- 5.2.6.4. A convective heating source should be provided so as to raise the entire foundation and equipment temperature to above 18 °C (65 °F) for at least 48 hours prior to and after grouting.
- 5.2.6.5. In the areas that will be covered by grout, the foundation should be prepared by chipping away all laitance (poor quality concrete) and oil-soaked or damaged concrete down to exposed fractured coarse aggregate.
- 5.2.6.5.1. A minimum of 0.375 in. (10 mm) of concrete shall be removed in this chipping process.
- 5.2.6.5.2. Scarifying the surface with a needle gun or bushing tool or sandblasting or liquid surface etchant/ surface retarder to remove laitance from the foundation is unacceptable.
- 5.2.6.5.3. Concrete chipping and removal shall not be performed with heavy tools, such as jackhammers, as they could damage the structural integrity of the foundation.
- 5.2.6.5.4. A chipping hammer with a chisel bit is the preferred tool for this purpose.
- 5.2.6.5.5. The clearance between the concrete and the bottom of the baseplate or soleplate or pre-grouted baseplate is to be 38 mm to 50 mm (1-1/2 in. to 2 in.) (minimum).
- 5.2.6.6. Where practical, epoxy grout vertical thickness at the edge of the foundation should be equal to or greater than the distance from the foundation edge to the baseplate periphery.
- 5.2.6.6.1. For machinery foundations where the grout extends to the edge of the concrete, the corners of the concrete shall be chipped to form a 50 mm (2 in.) minimum 45° chamfer (see Figure G.1).
- 5.2.6.6.2. Grout forms should be placed so as to allow proper filling of the chamfer area.
- NOTE The purpose of the concrete foundation chamfer is to provide a shear plane at the grout-to-concrete interface to prevent delamination. Grouting pins may also be required as noted in 2.6.10.

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5.2.6.7. The foundation shall be kept free of contamination by oil, dirt, water, and so forth, after it has been prepared for grouting. Protective sheeting (such as sheets of clean polyethylene) should be used to cover the prepared surfaces when work is not in progress.

5.2.6.8. When the surface chipping is complete, the foundation should be thoroughly broom and or vacuumed cleaned and air-blown free of all dust with clean, dry, oil-free air.

#### **5.2.7. Grout Forms**

5.2.7.1. All grout forms shall be built of materials of adequate strength and securely anchored and sealed to withstand the liquid head and forces developed by the grout during placement.

5.2.7.2. Grout forms should be attached to the foundation or pavement with drilled anchors. Power nailing is not permitted.

5.2.7.3. The inside surfaces of all grout forms should have three coats of paste wax applied to prevent grout adherence. Oil or liquid wax is not permitted.

NOTE 1: Waxing of the form boards shall be performed prior to their placement on the concrete foundation to prevent contamination of the grout bonding surface.

NOTE 2: Three coats of paste wax is recommended.

5.2.7.4. Grout forms shall be properly sealed to prevent grout leakage. Grout leaks will not self-seal. Bitumastic or room temperature vulcanizable silicone rubber can be used for this purpose.

5.2.7.5. Grout forms shall have 25 mm (1 in.), 45° chamfer strips at all vertical corners and at the horizontal top surface of the grout.

NOTE 1: All chamfer edges required in the grout should be incorporated into the forms because epoxy grout cannot be easily cut or trimmed after hardening.

NOTE 2: Smoothing and cleanup of rough areas can be accomplished with a disc grinder.

5.2.7.6. Grout forms should extend vertically a minimum (25 mm (1 in.) higher than final grout elevation to prevent overflow.

#### **5.2.8. Conventional Baseplate or soleplate Design Verification (Not Pre-grouted)**

5.2.8.1. Unless direct grouting has been specified by the users designated representative, check to ensure that all equipment is to be installed on baseplate or soleplates and that no part of the equipment is to be direct grouted.

NOTE General and special-purpose equipment is typically installed on baseplate or soleplates and it is very rare today to see direct grouted equipment. Baseplate or soleplate installation facilitates equipment alignment and provides for easy removal of equipment for maintenance.

5.2.8.2. Check to ensure that all baseplate or soleplate outside corners have a minimum 50 mm (2 in.) radius to prevent cracking of the foundation grout due to stress concentration at the corners. All sharp grout contacted edges shall be broken (see Annex D, Figure D.1).

5.2.8.3. Check to ensure that all baseplate or soleplate anchor bolt holes have a minimum 6mm (1/4 in) radial clearance to allow for field alignment of baseplate or soleplates.

5.2.8.4. Check to ensure that all pump and other small baseplates have been provided with vertical leveling screws, as opposed to shims or wedges. Shims and wedges are not to be used.

5.2.8.5. Shims, dual wedges or adjustable supports shall not to be grouted in and become a permanent part of the foundation.

5.2.8.6. Check to ensure that baseplates have been provided with one 15.24 cm (6+ in.) (minimum) grout filling hole in the center of each bulkhead section with one 12 mm (1/2 in.) vent hole near each corner of the section. This allows for controlled grout placement and verification that each section is filled with grout.

5.2.8.7. Check to ensure that baseplate or soleplates have sufficient grout holes and air vents in each compartment to allow for proper grouting.

NOTE In general, vent holes of approximately 12 mm (1/2 in.) in diameter on 0.45 m (18 in.) centers are typically provided.

5.2.8.8. Check to ensure that elevation adjustment nuts under the baseplate that will be grouted in and become a permanent part of the foundation have not been supplied. This allows the baseplate to be supported by the grout, not by the leveling devices.

5.2.8.9. Check to ensure that baseplate leveling jackscrews have been provided with stainless steel leveling pads as shown in Annex H.

5.2.8.10. Check to ensure that all baseplate welds are continuous and free of cracks.

5.2.8.11. Check to ensure that all grout pour and vent holes are accessible.

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Note: This can require removal of the equipment from its baseplate or soleplate to provide access to the grout pour holes.

## **5.2.9. Preparation of Baseplate or soleplates (Conventional and Pre-grouted)**

### **5.2.9.1. Baseplate or soleplate Preparation**

5.2.9.1.1. Oil, grease, and dirt shall be cleaned from all grout surfaces of baseplate or soleplates. These can be removed with a solvent wipe-down.

5.2.9.1.2. The baseplate or soleplate grout surfaces should have been prepared and ready for installation by the machinery manufacturer; if not, then they shall be prepared as follows:

- a) baseplate or soleplates shall be blasted to "near white metal" to remove any rust or scale unless the surface has been coated with a primer approved by the grout manufacturer
- b) care shall be taken to avoid any damage to baseplate or soleplate machined top surfaces;
- c) final cleaning shall be done with a user-approved solvent. Mineral spirits cannot be used for this purpose due to the oily residue; and
- d) all "baseplate or soleplate" grout surfaces are then to be immediately coated with a primer approved by the grout manufacturer in preparation for grout placement.
- e) Epoxy primers have a limited life after application. The coating manufacturer should be consulted to ensure proper field preparation of the baseplate or soleplates for satisfactory bonding of the grout.
- f) Baseplates with interlocking structural members that have been pre-coated for grouting do not require sandblasting of the bottom of the base. Solvent cleaning is however required.

5.2.9.1.3. Baseplate or soleplate jackscrews should be liberally coated with paste wax or grease to prevent grout adherence.

- a) Liquid waxes and oil are not permitted.
- b) Care shall be taken to prevent thread coating from contacting the concrete foundation or metal surfaces that will be in contact with the grout.
- c) Wax should typically be used instead of grease as a thread coating from a contamination perspective.

5.2.9.1.4. All miscellaneous baseplate or soleplate holes (such as coupling guard holes) are to be plugged to prevent the entrance of grout. All plugs are to be coated with paste wax to prevent grout adherence.

5.2.9.1.5. Ensure that all equipment is isolated and in a strain-free condition with all piping, conduit, and so forth, disconnected.

NOTE The importance of equipment being grouted in a strain-free condition cannot be over emphasized. Once the equipment is installed with the grout, it is too late for mistakes.

## **5.2.10. Expansion Joints**

5.2.10.1. Expansion joints shall be made from 25 to 50 mm (1 to 2 in.) thick closed-cell neoprene foam rubber (polystyrene may also be used) and shall be placed on 1.4 m to 2.8 m (4 ft to 6 ft) intervals in line with the anchor bolts and perpendicular with the centerline of the baseplate or soleplate and in accordance with the grout manufacturer's instructions.

- a) Neoprene should be used because of its durability and ease to work with.
- b) Care shall be exercised for installations where polystyrene expansion joints are to be removed using hydrocarbon solvents due their inherent hazards.

5.2.10.2. Expansion joints shall be "glued" into position prior to the grout pour with room temperature vulcanizable silicone rubber or elastic epoxy seam sealant (liquid rubber).

5.2.10.3. Expansion joints shall not be "bridged" by a baseplate or soleplate.

NOTE The purpose of the expansion joint is to compensate for the differential thermal expansion between the concrete foundation and the epoxy grout during curing. An expansion joint bridged by a baseplate or soleplate defeats this purpose. However, for very long baseplate or soleplates. Expansion joints may be placed under bridged baseplate or soleplates to control the location of differential expansion grout cracks that are typically superficial and do not affect the integrity of the grouted foundation.

## **5.2.11. Soleplate Installation and Leveling**

5.2.11.1. All soleplate elevations are to be set in accordance with the construction drawings. On multiple soleplate installations, one of the soleplates is chosen as the "reference" soleplate with regard to elevation. This "reference" soleplate is usually the one under the equipment requiring "process" connections.

5.2.11.2. As a minimum, soleplate level shall be set with a master level or a precision machinist's level. Levels should always be checked before beginning the plate leveling process by checking level repeatability when reversing 180 degrees.

5.2.11.3. For special-purpose equipment, unless otherwise approved by the user's representative, soleplate level and elevations shall be set using a precision optical or laser level (see 3.9.3.6).

5.2.11.4. All other soleplates are then installed and leveled with respect to the reference plate. Individual soleplate elevations are to be set to a tolerance of  $\pm 0.063$  mm ( $\pm 0.0025$  in.) with respect to the reference plate.

5.2.11.5. Each individual soleplate level is to be set longitudinally and transversely to within 0.042 mm per meter (0.0005 in. per ft) with no more than 0.130 mm (0.005 in.) elevation difference between any two points taken on an individual soleplate. In addition, any pair of soleplates (where more than one soleplate is used under an individual piece of equipment) should be at the same elevation to within 0.130 mm (0.005 in.).

NOTE These requirements provide a mounting surface with co-planer tolerances consistent with the machined bottom surfaces of the machinery.

5.2.11.6. Soleplate level can be achieved by adjusting the jacking screws combined with leveling pad (H-1) or shimming sub-soleplates, or dual wedges with adjusting screws and then snugging the anchor bolt nut to hold the soleplate in place. It is **NOT** permitted to allow shims, dual wedges or adjustable supports to be grouted in and become a permanent part of the foundation.

NOTE This allows the soleplate to be supported by the grout, not by the point-loaded leveling devices.

5.2.11.7. Final elevation and level of all soleplates for critical equipment should be set with a precision tilting level and precision scale. To balance the length of sighting distance, the tilting level is to be set near the foundation within a 6 m (20 ft) radius of all soleplates. A peg test of the instrument prior to the start of the leveling is essential (see Annex I).

5.2.11.8. All shims used in sub-soleplates shall be AISI Standard Type 300 series stainless steel or if specified MAC's can be used

5.2.11.9. For equipment installations where the equipment is bolted to the soleplates prior to grouting, an initial alignment check in accordance with the alignment section of this document should be performed to verify that coupling spacing and final alignment can be achieved without modifying the hold-down bolts or the machine feet.

5.2.11.10. The grouting of soleplates with special-purpose equipment attached is not permitted. clause 5.2.11.9 allows for a preliminary check of equipment alignment prior to its grouting, but the expectation is that the equipment will be removed prior to installing the grout.

5.2.11.11. In addition to checking for post-grouting voids, removal of the equipment is also necessary in order to provide access for proper leveling of soleplates, to provide access to grouting holes, and to ensure that the weight of the equipment does not distort the soleplate during grouting.

5.2.11.12. All soleplate level and elevation readings are to be re-checked after removal of the equipment.

5.2.11.13. All level readings are to be measured and recorded on datasheets. Typical datasheets for this purpose are shown in Annex C.

#### **5.2.12. Baseplate Installation and Leveling (General Purpose Equipment and API Pumps)**

5.2.12.1. All baseplate elevations shall be set in accordance with the construction drawings.

5.2.12.2. Prior to grouting, an initial alignment check in accordance with the alignment section of this document shall be performed to verify that coupling spacing and final alignment can be achieved without modifying the hold-down bolts or the machine feet.

5.2.12.3. As a minimum, baseplate level shall be set with a master level or a precision machinist's level. Levels should always be checked before beginning the plate leveling process by checking level repeatability when reversing 180 degrees. All baseplate level measurements shall be taken on the equipment mounting surfaces. This may require removal of equipment to expose the mounting surfaces to take level readings.

5.2.12.4. General-purpose equipment and ASME pump baseplate mounting surfaces are to be leveled longitudinally and transversely to within 77 micrometers per meter (0.003 in. per ft). On VS6 or VS7 pumps, the can flange should be level within 0.002 inches per foot of diameter.

5.2.12.5. Refer to Annex D for baseplate leveling for horizontal centrifugal pumps.

NOTE This is the pre-grouting requirement. Some distortion may occur during grout cure. See 5.8 for post-grout cure limits.

5.2.12.6. API pump baseplate mounting surfaces are to be leveled longitudinally and transversely to within 0.050 mm per m (0.002 in. per ft.). This may require removal of equipment to access the machined mounting surfaces.

NOTE This is the pre-grouting requirement. Some distortion may occur during grout cure. See 5.8 for post-grout cure limits.

- 5.2.12.7. Baseplate level is achieved by adjusting the jacking screws and then snugging (tightening with minimal torque of not more than 10 % of final torque value) the anchor bolt nut to hold the baseplate in place.
- 5.2.12.8. All level readings are to be measured and recorded on datasheets. Typical datasheets for this purpose are shown in Annex C at the end of this section.

### **5.2.13. Baseplate Installation and Leveling (Axial and Centrifugal Compressors and Expander-Compressors)**

- 5.2.13.1. All baseplate elevations shall be set in accordance with the construction drawings.
- 5.2.13.2. Prior to grouting, an initial alignment check in accordance with the alignment section of this document shall be performed to verify that coupling spacing and final alignment can be achieved without modifying the hold-down bolts or the machine feet.
- 5.2.13.3. As a minimum, baseplate level shall be set with a master precision machinist's level.
- 5.2.13.4. Levels should always be checked before beginning the plate leveling process by checking level repeatability when reversing 180 degrees.
- 5.2.13.5. All baseplate level measurements should be taken on the equipment mounting surfaces. This may require removal of equipment to expose the mounting surfaces to take level readings.
- NOTE: On some baseplates, machined ref pads are provided in place of mounting surface for leveling.
- 5.2.13.6. Equipment mounting surfaces are to be leveled longitudinally and transversely to within 0.050 mm per m (0.002 in. per ft.). For larger base-plates 20' to 50' in length, 0.005 in per ft
- 5.2.13.7. Refer to Annex C, for baseplate leveling.
- NOTE This is the pre-grouting requirement. Some distortion may occur during grout cure. See 3.15 for post-grout cure limits.
- 5.2.13.8. 3.9.5.5 Baseplate mounting surfaces are to be leveled longitudinally and transversely to within 0.050 mm per m (0.002 in. per ft.). This may require removal of equipment to access the machined mounting surfaces.
- NOTE This is the pre-grouting requirement. Some distortion may occur during grout cure. See 3.15 for post-grout cure limits.
- 5.2.13.9. Baseplate level is achieved by adjusting the jacking screws and then snugging (tightening with minimal torque of not more than 10% of final torque value) the anchor bolt nut to hold the baseplate in place.
- 5.2.13.10. All level readings are to be measured and recorded on datasheets. Typical datasheets for this purpose are shown in Annex C at the end of this section.

### **5.3. Direct Grouted Reciprocating Compressors**

- 5.3.1. For direct-grouted reciprocating compressors and for those installations where the baseplate or soleplate is bolted to the bottom of the crankcase prior to grouting, alignment shall be verified and recorded before pouring any grout. Of particular importance are the following alignment readings.
- 5.3.1.1. Frame level, with the baseplate or soleplate in a plane that is parallel to the main bearing bore centerline.
- 5.3.1.2. Crankshaft web deflection (ideally this should be zero). A rule of thumb is that the web deflection should not exceed 8 micrometers per meter (0.0001 in. per in.) of piston stroke.
- 5.3.1.3. Crankshaft-to-main bearing side clearance (this provides an indication of crankshaft-to-main bearing alignment in the horizontal plane).
- 5.3.1.4. Rotor-to-stator air-gap clearance on single bearing motors (this should be equal all around the motor within a maximum variation of 10%).
- 5.3.1.5. Coupling alignment on two-bearing motors. (follow Part D, Clause 7 of this standard)
- 5.3.1.6. Crosshead guides shall be level axially and transversely.
- NOTE The intent of this requirement is to have cylinder flanges in a common plane and not rotated about their centerlines (i.e., good bottle to flange alignment). Refer to piping alignment section of Chapter 6.
- 5.3.2. The compressor frame hold-down bolts shall be snugged down (with minimal torque) to hold the frame in position during grouting.
- 5.3.3. After the frame is leveled and aligned, it shall be allowed to set for 24 hours prior to beginning the grouting. Level and frame alignment readings shall be re-checked before grouting.
- NOTE: Direct grouting of any equipment is STRONGLY discouraged and should be permitted only with the specific written approval of the user or his/her designated representative.

### **5.4. Pre-grout Meeting**

- 5.4.1. A pre-grout meeting should be held at least one week prior to the grout pour

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5.4.1.1. The meeting purpose is to understand and agree:

- a) on surface preparation, and forming procedures,
- b) to ensure all necessary materials are on hand, and
- c) to clarify grouting responsibilities.

5.4.1.2. The parties present at this meeting should include, as a minimum:

- a) the grout manufacturing technical representative,
- b) the designated machinery representative,
- c) the foreman in charge of the grouting activity,
- d) the foremen in charge of supporting the grouting activities (such as scaffolding and laborers),
- e) the grouting materials coordinator, and
- f) a site safety representative.

NOTE: Typically, this meeting is done for special-purpose equipment or prior to pouring the grout foundations for a group of similar equipment.

5.4.2. During the pre-grout meeting, contingency plans should be developed, such as how the job will be handled (or postponed) in the event of inclement weather, examples, environmental conditioning of equipment, foundation, materials, and material storage

5.4.3. During the meeting it shall be made clear that once the grout pour begins, it will continue without interruption until completion.

5.4.4. A representative from the grout manufacturer shall be required if the installation personnel are not familiar with the grouting materials, forming, installation, and so forth, or if a special-purpose equipment train is being installed.

5.4.5. One day prior to grout placement an additional pre-grout meeting is recommended to review all preparations.

#### **5.5. Pre-grout Setup**

5.5.1. Remove any dust or dirt accumulation from the grout-prepared surface with clean, dry, oil-free air.

5.5.2. Baseplate or soleplates are rigidly installed and anchor bolts have been snugged into position to prevent movement during grouting. Prior to pouring grout, the area between the top of the anchor bolt sleeves and the bottom of the baseplate or soleplates should be packed with a soft moldable material (such as foam pipe insulation) to exclude grout as shown in Annex F and Annex G. This is to ensure that the anchor bolt sleeves do not fill with grout and that the anchor bolts are free to move (for minor alignment correction and bolt-stretch) within the limits of their sleeves. Anchor bolt threads shall also be protected with duct tape or other suitable means.

5.5.3. Check the grout form elevation to ensure that the top surface of the grout will match the elevation shown on the construction drawings. Typically, the elevation to the top of the grout extends half the thickness of the soleplate.

5.5.4. Unless otherwise specified by the users designated representative, on pump and other general-purpose equipment baseplate or soleplates, the driven equipment and the driver should be removed from the baseplate or soleplate prior to grouting.

NOTE 1: Advantages of removing driven equipment and driver are as follows:

- a) baseplates are easily leveled, using the machined mounting pads to check for levelness, without distortion of the baseplate;
- b) access to grout holes for grouting is improved,
- c) with baseplates that are sloped, leakage from the lowest vent hole is more easily controlled;
- d) grout cleanup of equipment and driver is not required; and
- e) cleanup of baseplates is easier.

5.5.5. The removal of equipment from baseplate or soleplates may not necessarily be required for pre-grouted baseplates unless needed for access to machined surfaces for leveling. The user or his/her designated representative should be consulted to determine if equipment is to be removed prior to grouting of pre-grouted baseplates.

5.5.6. Re-check all baseplate or soleplates for elevation and level immediately before grouting.

5.5.7. Ensure that grouting material is in clean, dry, unopened containers and has been stored at a temperature of approximately 18 °C to 29 °C (65 °F to 85 °F) for 48 hours prior to grouting.

5.5.8. The aggregate shall be absolutely dry as even the slightest amount of dampness will grossly accelerate its cure time and cause difficulties in placement and effect physical properties of epoxy grout.

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5.5.9. Ensure that all foundation and metal surfaces are within the temperature range of 18 °C to 32 °C (65 °F to 90 °F).

5.5.10. Ensure that a sufficient quantity of grouting materials is on hand at the jobsite to complete the job (15 % to 25 % extra).

5.5.11. Ensure that clean tools, mixing equipment, and safety supplies are on hand at the jobsite.

5.5.12. Ensure that MSD and personnel protection requirements have been reviewed with all grouting personnel.

#### **5.6. Grout Mixing**

5.6.1. No partial units of epoxy, resins, hardener, or aggregate are to be used.

5.6.2. The resin and hardener are to be mixed at 200 rpm to 250 rpm with a "jiffy mixer" (also called a dual ribbon mixer and is attached to a drill motor) per the grout manufacturer's specified time period prior to introducing the aggregate.

5.6.2.1. Do not use a paint mixer as it can create a vortex that introduces air into the mixture.

5.6.2.2. There should be no entrained air in the resin/hardener mixture.

5.6.3. The blended resin and hardener are then poured into the mortar mixer and full bags of aggregate are to be slowly added and sufficiently mixed to completely wet-out the aggregate.

5.6.4. Grout shall be mixed in a clean, slow-speed (15 rpm to 20 rpm) portable mortar mixer.

5.6.4.1. A concrete mixer is not permitted.

5.6.4.2. Mix only long enough to completely wet the aggregate.

5.6.4.3. Overmixing will introduce excessive air into the mixture and reduce the grouts strength and can also result in voids.

5.6.4.4. For small pours, grout can be mixed in a clean wheelbarrow with a mortar hoe.

NOTE A mortar mixer is required to properly coat the grout aggregate with the resin and hardener without over-mixing and adding entrained air.

#### **5.7. Placement of Grout**

5.7.1. To pour the grout, start at one end of the forms and fill the cavity completely while advancing toward the other end. Pour the grout along only one side of the baseplate or soleplate allowing it to slowly flow under the plate to the opposite side.

5.7.1.1. Do not pour around the perimeter of the baseplate or soleplate as this will cause air entrapment.

5.7.1.2. Do not vibrate the grout as a means of helping it flow as this tends to separate the aggregate from the resin binder. Limited use of push tools may be employed to help distribute the grout, using long strokes rather than short jabs.

5.7.1.3. Violent ramming of the grout is not permitted.

5.7.1.4. Pour approximately half of the expansion joint depth before moving to the next compartment to prevent overturning the joint material

5.7.2. Pumping of epoxy grouts is an acceptable method of grout placement or transfer, with purchaser agreement.

5.7.3. The grout volume used should be checked against the estimated cavity volume. This is a good way to check for air pockets and insufficient filling.

5.7.4. Check frequently for grout leaks. Leaks will not self-seal, and if not stopped, will cause voids.

5.7.4.1. The grouting of a baseplate, either fabricated or cast, will typically require a minimum of two grouting pours.

5.7.4.2. The first pour is made to the bottom of the baseplate to seal and lock the members into position for the secondary pour.

5.7.4.3. After the grout has cured, a second, or perhaps third pour, may be required to completely fill the baseplate depending upon the manufacturer's instructions for maximum pour thickness.

5.7.4.4. Attempting to make a baseplate grout pour in one step will most likely result in leaks and voids under the baseplate.

5.7.5. If specified for special-purpose equipment, a grout sample shall be obtained for each batch number mixture in accordance with ASTM C579 Method B, Load Rate II, 2 in. brass cubes for compressive strength testing. All samples are to be labeled and their batch placement location notes.

NOTE: The purpose of these samples is to enable testing and evaluation of the "as-poured" grout mixture.

5.7.6. Air bubbles rising to the surface of epoxy grout may be removed by lightly spraying the bubble surface with the grout manufacturer's cleaning solvent or approved equal.

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5.7.7. If required, the exposed surface of the grout can be troweled or broomed when it is in a tacky state to provide a non-skid surface. Troweling and brooming may be facilitated by the use of grout solvent. Troweling and brooming should be carried out in a manner that precludes excessive blending of the grout solvent into the surface of the grout.

5.7.8. Remove any grout head boxes after the grout has set sufficiently. Do not plug any baseplate fill and vent holes until the grout has set (this can cause base distortion due to grout expansion or contraction).

#### **5.8. Post-grouting Instructions**

5.8.1. Typically, three days after the grout has been poured (or less, depending on ambient temperature), the grout should be of sufficient hardness to remove jackscrews and grout forms. This will ensure that the grout has obtained most of its strength and hardness.

NOTE: Hardness - Barcol: 40-44 fully cured ASTM D-2583 35 minimum.

5.8.2. For general-purpose equipment and ASME pumps, the post-grout cure level criteria is a maximum of 0.008 in. per ft (both longitudinally and transversely). Baseplates that settle unevenly and/or beyond the specified level tolerance shall be corrected. Correction of level may include removal and re-grouting or field machining of the equipment mounting surfaces.

5.8.3. For API pumps, the post-grout cure level criteria is less than 0.005 in. per ft (both longitudinally and transversely).

5.8.3.1. Baseplates that settle unevenly and/or beyond the specified level tolerance shall be corrected.

5.8.3.2. Correction of level may include removal and re-grouting or field machining of the equipment mounting surfaces.

5.8.4. Baseplate or soleplate jackscrew holes shall be filled with a flexible sealant material (not grout) such as room temperature vulcanizable silicone rubber or with short cap screws that do not extend below the threaded holes in the baseplate or soleplate.

5.8.5. After the grout has cured, expansion joints should be sealed with elastic epoxy seam sealant (liquid rubber) or room temperature vulcanizable silicone rubber.

5.8.6. The entire top of the machinery foundation can then be painted with a grout-compatible nonskid protective coating to protect the foundation cap from oil and weathering. This coating should extend down from the top of the foundation at least 45 cm (18 in.) if possible.

5.8.7. Lubricate all anchor bolt threads liberally with mineral oil and torque anchor bolts in accordance with the equipment manufacturer's recommendations. Table B.1 may be used as a guide if manufacturer information is not available.

NOTE: Table B.1 is based on threads lubricated with mineral oil and will provide a bolt stress of 30,000 psi. This table is NOT applicable if anti-seize thread lubricants are used.

5.8.8. All anchor bolts shall have full penetration of the anchor bolt nut and at least 2 1/2 threads protruding above the anchor bolt nut.

#### **5.9. Filling Grout Voids**

5.9.1. After the grout has cured, check for voids by tapping along the top deck of the baseplate.

5.9.1.1. Mark the void areas to allow for proper identification when filling.

5.9.1.2. A solid thud indicates a good grout area while a drum-like hollow sound indicates a void requiring filling.

NOTE: Grout voids ought not be expected as being "normal." Voids are the result of an inadequate baseplate design or improper placement of the grout.

5.9.2. Void areas are to be filled by drilling NPT 1/8 holes in opposite corners of each void area.

5.9.2.1. One hole in each void is to be tapped for installation of a NPT 1/8 grease fitting;

5.9.2.2. The other holes serve as vents.

5.9.2.3. Grout is then pumped into each void with a grout gun until the grout emerges from the vent holes.

5.9.2.4. A "new," unused, and unpainted grease gun can be used as a grout gun.

5.9.2.5. The grease gun shall be completely disassembled and cleaned with the grout manufacturer's approved solvent.

5.9.2.6. Complete immersion of the gun into the solvent is required to ensure proper cleaning.

5.9.3. Care shall be exercised in filling voids as high pressures created from the grout gun can lift or distort the baseplate. It is therefore extremely important that the grout and vent holes are in communication with each other.

5.9.3.1. An air squeeze bottle may be used to test for communication by blowing air into the grout hole and noting its exit at the vent hole (do not use high-pressure air).

5.9.3.2. A dial indicator supported from a main beam should also be used to monitor baseplate movement during void filling. Remove all grease fittings when finished.

5.9.4. Clean up any spilled grout with the grout manufacturer's approved solvent.

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5.9.5. After the void grout has cured, re-check the baseplate to ensure that all voids are filled with grout. If void areas still exist, repeat the drilling and pumping procedures as necessary.

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**Annex A**  
(normative)

**Grouting Checklists**

Section	Requirements	Name	Date
<b>5.1</b>	<b>Pre-grouted Baseplates</b>		
5.1.1	Ensure that all top-side mounting holes (i.e. coupling guard mounting holes, etc.) are plugged to prevent the entrance of grout.		
5.1.1.1	All plugs shall be coated with paste wax to prevent grout adherence.		
5.1.1.2	Anchor bolt tubes shall be installed to exclude grout from the anchor bolt areas with the clearances as specified in Part B clause 5.3.3 as a minimum.		
5.1.1.3	Ensure that all leveling jackscrews have been properly waxed or provided with tubes to exclude the grout during curing.		
5.1.1.4	Ensure that the grout is properly mixed and placed at the correct temperature as recommended by the manufacturer.		
5.1.1.5	Ensure that the grout is poured to the top-most edge of the inverted baseplate. This will prevent air voids from occurring when the baseplate is field grouted.		
5.1.1.6	Do not disturb the baseplate until it has cured for at least 72 hours at the manufacturers recommended curing temperature. Final machining of the baseplate top machined surfaces shall only be completed by a competent machinist and after consultation with the baseplate manufacturer after proper grout curing.		
5.1.1.7	A pre-grouted baseplate may be considered when the baseplate size is within standard dimensions shown in API 610. NOTE: Limiting factors are depth of pour, support requirements, lifting capacity, machining capability, manufacturers and purchasers experience, etc.		
5.1.1.8	No paint or coating is to be applied to the post-grouted baseplate as this would reduce the adhesion capability of the field secondary grout pour. Follow the grout manufacturer's instructions for surface preparation prior to the secondary field grouting.		
<b>5.2.4</b>	<b>Foundation Curing</b>		
5.2.4.1	Check foundation curing time before proceeding with preparation for grouting.		
5.2.4.1	The foundation should be cured for at least seven days per ACI 301 prior to grout preparation.		
5.2.4.3	Epoxy grout should never be poured on "green" or uncured concrete.		

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5.2.4.4	Concrete shall also be exposed to a drying-out period to ensure that the capillaries are free of moisture and will provide proper grout bonding.		
5.2.4.5	Before grout is placed on newly pour concrete foundations, the concrete shall obtain a minimum of 80% of its design strength. This will allow the appropriate time for the moisture to mitigate and concrete shrinkage to occur. Refer to the concrete design mix for these details.		
5.2.4.6	Additional curing time should be considered for heavy machinery.		
<b>5.2.5</b>	<b>Anchor Bolt Preparation</b>		
5.2.5.1	Ensure that templates, if purchased, have been used for anchor bolt locations.		
5.2.5.2.	Verify that anchor bolt sleeves are clean and dry and have been filled with a nonbonding moldable material to exclude the grout from the anchor bolt sleeve. This material will prevent water accumulation in the anchor bolt sleeves and is pliable enough to allow for small anchor bolt movement, if needed.		
5.2.5.3.	Also ensure that anchor bolts are not tilted or bolt-bound and are perpendicular with respect to the bottom of the baseplate or soleplate.		
5.2.5.4.	Anchor bolt sleeves are not intended to provide sufficient movement to allow for gross misalignment of anchor bolts to their baseplate or soleplate holes. Lateral movement for alignment purposes should not exceed 0.25 in. (6.5mm).		
5.2.5.5.	The anchor bolt threads should be covered with duct tape, foam pipe insulation, or other suitable means to keep them clean and to prevent any damage that might occur during the chipping and grouting operation.		
5.2.5.6.	All anchor bolt locations, projections, and diameters should be field verified to match the anchor bolt hole pattern in the baseplate or soleplate prior to grouting.		
5.2.5.7.	Anchor bolts system should be designed, to ensure the following free bolt pre-stretch length is provided: a. Centrifugal equipment: - 6 -10 x Bolt Diameter. b. Reciprocating equipment: 10-15 x Bolt Diameter.		
5.2.5.8.	Ensure after grouting, the anchor bolt sleeves have not been filled with grout and compromised the pre-stretch bolt length.		
5.2.5.9.	Adequate pre-stretch length is imperative to ensure that anchor bolts do not relax and fail due to cyclic stress.		
<b>5.2.6</b>	<b>Foundation Preparation</b>		
5.2.6.1.	A weather-protective cover may be necessary during inclement weather conditions. Wind, sun, rain, and ambient temperatures have a definite effect on the quality of a grouting installation.		
5.2.6.2.	During hot weather, the foundation and equipment shall be covered with a shelter to keep the uncured grout from being exposed to direct sunlight as well as dew, mist, or rain.		
5.2.6.4.	A convective heating source should be provided so as to raise the entire foundation and equipment temperature to above 18 °C (65 °F) for at least 48 hours prior to and after grouting.		
5.2.6.5.	In the areas that will be covered by grout, the foundation should be prepared by chipping away all laitance (poor quality concrete) and oil-soaked or damaged concrete down to exposed fractured coarse aggregate.		

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5.2.6.5.1.	A minimum of 0.375 in. (10 mm) of concrete shall be removed in this chipping process.		
5.2.6.6.1.	For machinery foundations where the grout extends to the edge of the concrete, the corners of the concrete shall be chipped to form a 50 mm (2 in.) minimum 45° chamfer (see Figure G.1).		
5.2.6.6.2.	Grout forms should be placed to allow proper filling of the chamfer area.		
5.2.6.7.	The foundation shall be kept free of contamination by oil, dirt, water, and so forth, after it has been prepared for grouting. Protective sheeting (such as sheets of clean polyethylene) should be used to cover the prepared surfaces when work is not in progress.		
5.2.6.8.	When the surface chipping is complete, the foundation should be thoroughly broom and or vacuumed cleaned and air-blown free of all dust with clean, dry, oil-free air.		
<b>5.2.7</b>	<b>Grout Forms</b>		
5.2.7.1	All grout forms shall be built of materials of adequate strength and securely anchored and sealed to withstand the liquid head and forces developed by the grout during placement.		
5.2.7.2	Grout forms should be attached to the foundation or pavement with drilled anchors. Power nailing is not permitted.		
5.2.7.3.	The inside surfaces of all grout forms should have three coats of paste wax applied to prevent grout adherence. Oil or liquid wax is not permitted. NOTE 1: Waxing of the form boards shall be performed prior to their placement on the concrete foundation to prevent contamination of the grout bonding surface. NOTE 2: Three coats of paste wax is recommended.		
5.2.7.4.	Grout forms shall be properly sealed to prevent grout leakage. Grout leaks will not self-seal. Bitumastic or room temperature vulcanizable silicone rubber can be used for this purpose.		
5.2.7.5.	Grout forms shall have 25 mm (1 in.), 45° chamfer strips at all vertical corners and at the horizontal top surface of the grout. NOTE 1: All chamfer edges required in the grout should be incorporated into the forms because epoxy grout cannot be easily cut or trimmed after hardening. NOTE 2: Smoothing and cleanup of rough areas can be accomplished with a disc grinder.		
5.2.7.6	Grout forms should extend vertically a minimum (25 mm (1 in.) higher than final grout elevation to prevent overflow.		
<b>5.2.8</b>	<b>Baseplate or Soleplate Design Verification (Not Pre-grouted)</b>		
5.2.8.1.	Unless direct grouting has been specified by the users designated representative, check to ensure that all equipment is to be installed on baseplates or soleplates and that no part of the equipment is to be direct grouted. NOTE General and special-purpose equipment is typically installed on baseplates or soleplates and it is very rare today to see direct grouted equipment. Baseplate or soleplate installation facilitates equipment alignment and provides for easy removal of equipment for maintenance.		

5.2.8.2	Check to ensure that all baseplate or soleplate outside corners have a minimum 50 mm (2 in.) radius to prevent cracking of the foundation grout due to stress concentration at the corners. All sharp grout contacted edges shall be broken (see Annex D, Figure D.1).		
5.2.8.3.	Check to ensure that all baseplate or soleplate anchor bolt holes have a minimum 6mm (1/4 in) radial clearance to allow for field alignment of baseplate or soleplates.		
5.2.8.4.	Check to ensure that all pump and other small baseplates have been provided with vertical leveling screws, as opposed to shims or wedges. Shims and wedges are not to be used.		
5.2.8.5.	Shims, dual wedges or adjustable supports shall not to be grouted in and become a permanent part of the foundation.		
5.2.8.6.	Check to ensure that baseplates have been provided with one 15.24 cm (6+ in.) (minimum) grout filling hole in the center of each bulkhead section with one 12 mm (1/2 in.) vent hole near each corner of the section. This allows for controlled grout placement and verification that each section is filled with grout.		
5.2.8.7.	Check to ensure that baseplate or soleplates have sufficient grout holes and air vents in each compartment to allow for proper grouting. NOTE In general, vent holes of approximately 12 mm (1/2 in.) in diameter on 0.45 m (18 in.) centers are typically provided.		
5.2.8.8.	Check to ensure that elevation adjustment nuts under the baseplate that will be grouted in and become a permanent part of the foundation have not been supplied. This allows the baseplate to be supported by the grout, not by the leveling devices.		
5.2.8.9.	Check to ensure that baseplate leveling jackscrews have been provided with stainless steel leveling pads as shown in Annex H.		
5.2.8.10	Check to ensure that all baseplate welds are continuous and free of cracks		
5.2.8.11.	Check to ensure that all grout pour and vent holes are accessible.		
<b>5.2.9</b>	<b>Preparation of Baseplate or soleplates (Conventional and Pre-grouted)</b>		
<b>5.2.9.1</b>	<b>Conventional Baseplate or soleplate Preparation</b>		
5.2.9.1.1.	Oil, grease, and dirt shall be cleaned from all grout surfaces of baseplate or soleplates. These can be removed with a solvent wipe-down.		
5.2.9.1.2.	The baseplate or soleplate grout surfaces should have been prepared and ready for installation by the machinery manufacturer; if not, then they shall be prepared as follows:		
5.2.9.1.2.a	Baseplate or soleplates shall be blasted to "near white metal" to remove any rust or scale unless the surface has been coated with a primer approved by the grout manufacture		
5.2.9.1.2.b	Care shall be taken to avoid any damage to baseplate or soleplate machined top surfaces;		

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5.2.9.1.2.c	Final cleaning shall be done with a user-approved solvent. Mineral spirits cannot be used for this purpose due to the oily residue; and		
5.2.9.1.2.d	All "baseplate or soleplate" grout surfaces are then to be immediately coated with a primer approved by the grout manufacturer in preparation for grout placement.		
5.2.9.1.2.e	Epoxy primers have a limited life after application. The coating manufacturer should be consulted to ensure proper field preparation of the baseplate or soleplates for satisfactory bonding of the grout.		
5.2.9.1.2.f	f)Baseplates with interlocking structural members that have been pre-coated for grouting do not require sandblasting of the bottom of the base. Solvent cleaning is however required		
5.2.9.1.3.	Baseplate or soleplate jackscrews should be liberally coated with paste wax or grease to prevent grout adherence.		
5.2.9.1.3.a	Liquid waxes and oil are not permitted.		
5.2.9.1.3.b	Care shall be taken to prevent thread coating from contacting the concrete foundation or metal surfaces that will be in contact with the grout.		
5.2.9.1.3.c	Wax should typically be used instead of grease as a thread coating from a contamination perspective.		
5.2.9.1.4.	All miscellaneous baseplate or soleplate holes (such as coupling guard holes) are to be plugged to prevent the entrance of grout. All plugs are to be coated with paste wax to prevent grout adherence.		
5.2.9.1.5.	Ensure that all equipment is isolated and in a strain-free condition with all piping, conduit, and so forth, disconnected. NOTE The importance of equipment being grouted in a strain-free condition cannot be over emphasized. Once the equipment is installed with the grout, it is too late for mistakes.		
<b>5.2.10</b>	<b>Expansion Joints</b>		
5.2.10.1	Expansion joints shall be made from 25 to 50 mm (1 to 2 in.) thick closed-cell neoprene foam rubber (polystyrene may also be used) and shall be placed on 1.4 m to 2.8 m (4 ft to 6 ft) intervals in line with the anchor bolts and perpendicular with the centerline of the baseplate or soleplate and in accordance with the grout manufacturer's instructions.		
5.2.10.1.a.	Neoprene should be used because of its durability and ease to work with.		
5.2.10.1.b.	Care shall be exercised for installations where polystyrene expansion joints are to be removed using hydrocarbon solvents due their inherent hazards		
5.2.10.2	Expansion joints shall be "glued" into position prior to the grout pour with room temperature vulcanizable silicone rubber or elastic epoxy seam sealant (liquid rubber).		
5.2.10.3.	Expansion joints shall not be "bridged" by a baseplate or soleplate.		

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	NOTE The purpose of the expansion joint is to compensate for the differential thermal expansion between the concrete foundation and the epoxy grout during curing. An expansion joint bridged by a baseplate or soleplate defeats this purpose. However, for very long baseplate or soleplates. Expansion joints may be placed under bridged baseplate or soleplates to control the location of differential expansion grout cracks that are typically superficial and do not affect the integrity of the grouted foundation		
<b>5.2.11</b>	<b>Soleplate Installation and Leveling</b>		
5.2.11.1.	All soleplate elevations are to be set in accordance with the construction drawings. On multiple soleplate installations, one of the soleplates is chosen as the "reference" soleplate with regard to elevation. This "reference" soleplate is usually the one under the equipment requiring "process" connections.		
5.2.11.2.	As a minimum, soleplate level shall be set with a master level or a precision machinist's level. Levels should always be checked before beginning the plate leveling process by checking level repeatability when reversing 180 degrees.		
5.2.11.3.	For special-purpose equipment, unless otherwise approved by the user's representative, soleplate level and elevations shall be set using a precision optical or laser level (see 3.9.3.6).		
5.2.11.4.	All other soleplates are then installed and leveled with respect to the reference plate. Individual soleplate elevations are to be set to a tolerance of $\pm 0.063$ mm ( $\pm 0.0025$ in.) with respect to the reference plate.		
5.2.11.5.	Each individual soleplate level is to be set longitudinally and transversely to within 0.042 mm per meter (0.0005 in. per ft) with no more than 0.130 mm (0.005 in.) elevation difference between any two points taken on an individual soleplate. In addition, any pair of soleplates (where more than one soleplate is used under an individual piece of equipment) should be at the same elevation to within 0.130 mm (0.005 in.) NOTE This allows the soleplate to be supported by the grout, not by the point-loaded leveling devices.		
5.2.11.6.	Soleplate level can be achieved by adjusting the jacking screws combined with leveling pad (H-1) or shimming sub-soleplates, or dual wedges with adjusting screws and then snugging the anchor bolt nut to hold the soleplate in place. It is NOT permitted to allow shims, dual wedges or adjustable supports to be grouted in and become a permanent part of the foundation.		
5.2.11.7.	Final elevation and level of all soleplates for critical equipment should be set with a precision tilting level and precision scale. To balance the length of sighting distance, the tilting level is to be set near the foundation within a 6 m (20 ft) radius of all soleplates. A peg test of the instrument prior to the start of the leveling is essential (see Annex I).		
5.2.11.8.	All shims used in sub-soleplates shall be AISI Standard Type 300 series stainless steel or if specified MAC's can be used		
5.2.11.9.	For equipment installations where the equipment is bolted to the soleplates prior to grouting, an initial alignment check in accordance with the alignment section of this document should be performed to verify that coupling spacing and final alignment can be achieved without modifying the hold-down bolts or the machine feet.		

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5.2.11.12.	All soleplate level and elevation readings are to be re-checked after removal of the equipment.		
5.2.11.13.	All level readings are to be measured and recorded on datasheets. Typical datasheets for this purpose are shown in Annex C.		
<b>5.2.12</b>	<b>Baseplate Installation and Leveling (of General-purpose Equipment and API Pumps)</b>		
5.2.12.1	All baseplate elevations set in accordance with the construction drawings.		
5.2.12.2	Prior to alignment, an initial alignment check is made to verify that coupling spacing and final alignment can be achieved without modifying the hold-down bolt or equipment feet.		
5.2.12.3	As a minimum, baseplate level shall be set with a master level or a precision machinist's level. Levels should always be checked before beginning the plate leveling process by checking level repeatability when reversing 180 degrees. All baseplate level measurements shall be taken on the equipment mounting surfaces. This may require removal of equipment to expose the mounting surfaces to take level readings.		
5.2.12.4.	General-purpose equipment and ASME pump baseplate mounting surfaces are to be leveled longitudinally and transversely to within 77 micrometers per meter (0.003 in. per ft). On VS6 or VS7 pumps, the can flange should be level within 0.002 inches per foot of diameter.		
5.2.12.5.	Refer to Annex D for baseplate leveling for horizontal centrifugal pumps.		
5.2.12.6.	API pump baseplate mounting surfaces are to be leveled longitudinally and transversely to within 0.050 mm per m (0.002 in. per ft.). This may require removal of equipment to access the machined mounting surfaces.		
5.2.12.7.	Baseplate level is achieved by adjusting the jacking screws and then snugging (tightening with minimal torque of not more than 10 % of final torque value) the anchor bolt nut to hold the baseplate in place.		
5.2.12.8.	All level readings are to be measured and recorded on datasheets. Typical datasheets for this purpose are shown in Annex C at the end of this section.		
5.2.13.	Baseplate Installation and Leveling (Axial and Centrifugal Compressors and Expander- Compressors)		
5.2.13.1.	All baseplate elevations shall be set in accordance with the construction drawings.		
5.2.13.2.	Prior to grouting, an initial alignment check in accordance with the alignment section of this document shall be performed to verify that coupling spacing and final alignment can be achieved without modifying the hold-down bolts or the machine feet.		
5.2.13.3.	As a minimum, baseplate level shall be set with a master precision machinist's level.		
5.2.13.4.	Levels should always be checked before beginning the plate leveling process by checking level repeatability when reversing 180 degrees.		

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5.2.13.5.	All baseplate level measurements should be taken on the equipment mounting surfaces. This may require removal of equipment to expose the mounting surfaces to take level readings. NOTE: On some baseplates, machined ref pads are provided in place of mounting surface for leveling.		
5.2.13.6.	Equipment mounting surfaces are to be leveled longitudinally and transversely to within 0.050 mm per m (0.002 in. per ft.). For larger baseplates 20' to 50' in length, 0.005 in per ft		
5.2.13.8.	Baseplate mounting surfaces are to be leveled longitudinally and transversely to within 0.050 mm per m (0.002 in. per ft.). This may require removal of equipment to access the machined mounting surfaces.		
5.2.13.10.	All level readings are to be measured and recorded on datasheets. Typical datasheets for this purpose are shown in Annex C at the end of this section.		
<b>5.3</b>	<b>Direct Grouted Reciprocating Compressors</b>		
5.3.1.1.	Frame level, with the baseplate or soleplate in a plane that is parallel to the main bearing bore centerline		
5.3.1.2.	Crankshaft web deflection (ideally this should be zero). A rule of thumb is that the web deflection should not exceed 8 micrometers per meter (0.0001 in. per in.) of piston stroke.		
5.3.1.3.	Crankshaft-to-main bearing side clearance (this provides an indication of crankshaft-to-main bearing alignment in the horizontal plane).		
5.3.1.4.	Rotor-to-stator air-gap clearance on single bearing motors (this should be equal all around the motor within a maximum variation of 10 %).		
5.3.1.5	Coupling alignment on two-bearing motors per Chapter 7 of API 686.		
5.3.1.6.	Crosshead guides shall be level axially and transversely. NOTE The intent of this requirement is to have cylinder flanges in a common plane and not rotated about their centerlines (i.e., good bottle to flange alignment). Refer to piping alignment section of Chapter 6.		
<b>5.5</b>	<b>Pre-grout Setup</b>		
5.5.1.	Remove any dust or dirt accumulation from the grout-prepared surface with clean, dry, oil-free air.		
5.5.2	Baseplate or soleplates are rigidly installed and anchor bolts have been snugged into position to prevent movement during grouting.		
5.5.3.	Prior to pouring grout, the area between the top of the anchor bolt sleeves and the bottom of the baseplate or soleplates should be packed with a soft moldable material (such as foam pipe insulation) to exclude grout as shown in Annex F and Annex G. This is to ensure that the anchor bolt sleeves do not fill with grout and that the anchor bolts are free to move (for minor alignment correction and bolt-stretch) within the limits of their sleeves. Anchor bolt threads shall also be protected with duct tape or other suitable means.		

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5.5.4.	Check the grout form elevation to ensure that the top surface of the grout will match the elevation shown on the construction drawings. Typically, the elevation to the top of the grout extends half the thickness of the soleplate.		
5.5.5.	Unless otherwise specified by the users designated representative, on pump and other general-purpose equipment baseplate or soleplates, the driven equipment and the driver should be removed from the baseplate or soleplate prior to grouting.		
5.5.7.	Re-check all baseplate or soleplates for elevation and level immediately before grouting.		
5.5.8.	Ensure that grouting material is in clean, dry, unopened containers and has been stored at a temperature of approximately 18 °C to 29 °C (65 °F to 85 °F) for 48 hours prior to grouting.		
5.5.10.	Ensure that all foundation and metal surfaces are within the temperature range of 18 °C to 32 °C (65 °F to 90 °F).		
5.5.11.	Ensure that a sufficient quantity of grouting materials is on hand at the jobsite to complete the job (15 % to 25 % extra).		
5.5.12	Clean tools, mixing equipment, and safety supplies are on hand at the jobsite.		
5.5.13	MSD and personnel protection requirements have been reviewed with all grouting personnel.		
<b>5.6</b>	<b>Grout Mixing</b>		
5.6.1	No partial units of epoxy resin, hardener, or aggregate are to be used.		
5.6.2.	The resin and hardener are to be mixed at 200 rpm to 250 rpm with a "jiffy mixer" (also called a dual ribbon mixer and is attached to a drill motor) per the grout manufacturer's specified time period prior to introducing the aggregate.		
5.6.2.2.	There should be no entrained air in the resin/hardener mixture.		
5.6.3.	The blended resin and hardener are then poured into the mortar mixer and full bags of aggregate are to be slowly added and sufficiently mixed to completely wet-out the aggregate.		
5.6.4.	Grout shall be mixed in a clean, slow-speed (15 rpm to 20 rpm) portable mortar mixer.		
5.6.4.3.	Overmixing will introduce excessive air into the mixture and reduce the grouts strength and can also result in voids.		
5.6.4.4.	For small pours, grout can be mixed in a clean wheelbarrow with a mortar hoe. NOTE A mortar mixer is required to properly coat the grout aggregate with the resin and hardener without over-mixing and adding entrained air.		
5.7.	Placement of Grout		

5.7.0.1	Grout is placed within its pot life. Time at beginning of pour: _____ (AM) (PM).  Time at end of pour: _____ (AM) (PM).		
5.7.1.	To pour the grout, start at one end of the forms and fill the cavity completely while advancing toward the other end. Pour the grout along only one side of the baseplate or soleplate allowing it to slowly flow under the plate to the opposite side.		
5.7.1.1.	Do not pour around the perimeter of the baseplate or soleplate as this will cause air entrapment.		
5.7.1.2.	Do not vibrate the grout as a means of helping it flow as this tends to separate the aggregate from the resin binder. Limited use of push tools may be employed to help distribute the grout, using long strokes rather than short jabs.		
5.7.1.3.	Violent ramming of the grout is not permitted.		
5.7.2.	Pumping of epoxy grouts is an acceptable method of grout placement or transfer, with purchaser agreement.		
5.7.3.	The grout volume used should be checked against the estimated cavity volume. This is a good way to check for air pockets and insufficient filling.		
5.7.4.	Check frequently for grout leaks. Leaks will not self-seal, and if not stopped, will cause voids.		
5.7.4.2.	The first pour is made to the bottom of the baseplate to seal and lock the members into position for the secondary pour.		
5.7.4.3.	After the grout has cured, a second, or perhaps third pour, may be required to completely fill the baseplate depending upon the manufacturer's instructions for maximum pour thickness.		
5.7.4.4.	Attempting to make a baseplate grout pour in one step will most likely result in leaks and voids under the baseplate.		
5.7.5.	If specified for special-purpose equipment, a grout sample shall be obtained for each batch number mixture in accordance with ASTM C579 Method B, Load Rate II, 2 in. brass cubes for compressive strength testing. All samples are to be labeled and their batch placement location notes.		
5.7.6.	Air bubbles rising to the surface of epoxy grout may be removed by lightly spraying the bubble surface with the grout manufacturer's cleaning solvent or approved equal.		
5.7.7.	If required, the exposed surface of the grout can be troweled or broomed when it is in a tacky state to provide a non-skid surface. Troweling and brooming may be facilitated by the use of grout solvent. Troweling and		

Restricted

	brooming should be carried out in a manner that precludes excessive blending of the grout solvent into the surface of the grout.		
5.7.8.	Remove any grout head boxes after the grout has set sufficiently. Do not plug any baseplate fill and vent holes until the grout has set (this can cause base distortion due to grout expansion or contraction).		
<b>5.8</b>	<b>Post-grouting Instructions</b>		
5.8.1.	Typically, three days after the grout has been poured (or less, depending on ambient temperature), the grout should be of sufficient hardness to remove jackscrews and grout forms. This will ensure that the grout has obtained most of its strength and hardness.		
5.8.2.	For general-purpose equipment and ASME pumps, the post-grout cure level criteria is a maximum of 0.008 in. per ft (both longitudinally and transversely). Baseplate or soleplates that settle unevenly and/or beyond the specified level tolerance shall be corrected. Correction of level may include removal and re-grouting or field machining of the equipment mounting surfaces.		
5.8.3.	For API pumps, the post-grout cure level criteria is less than 0.005 in. per ft (both longitudinally and transversely).		
5.8.3.1.	Baseplate or soleplates that settle unevenly and/or beyond the specified level tolerance shall be corrected.		
5.8.3.2.	Correction of level may include removal and re-grouting or field machining of the equipment mounting surfaces		
5.8.4.	Baseplate or soleplate jackscrew holes shall be filled with a flexible sealant material (not grout) such as room temperature vulcanizable silicone rubber or with short cap screws that do not extend below the threaded holes in the baseplate or soleplate.		
5.8.5.	After the grout has cured, expansion joints should be sealed with elastic epoxy seam sealant (liquid rubber) or room temperature vulcanizable silicone rubber.		
5.8.6.	The entire top of the machinery foundation can then be painted with a grout-compatible nonskid protective coating to protect the foundation cap from oil and weathering. This coating should extend down from the top of the foundation at least 45 cm (18 in.) if possible.		
5.8.7	<p>Lubricate all anchor bolt threads liberally with mineral oil and torque anchor bolts in accordance with the equipment manufacturer's recommendations. Table B.1 may be used as a guide if manufacturer information is not available.</p> <p>NOTE: Table B.1 is based on threads lubricated with mineral oil and will provide a bolt stress of 30,000 psi. This table is NOT applicable if anti-seize thread lubricants are used.</p> <p>Anchor Bolt Size: _____</p> <p>Anchor Bolt Torque Specification: _____</p> <p>Installed Torque: _____</p>		

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5.8.8.	All anchor bolts shall have full penetration of the anchor bolt nut and at least 2 1/2 threads protruding above the anchor bolt nut.		
<b>5.9</b>	<b>Filling Grout Voids</b>		
5.9.1.	After the grout has cured, check for voids by tapping along the top deck of the baseplate or soleplate		
5.9.1.1.	Mark the void areas to allow for proper identification when filling.		
5.9.1.2.	A solid thud indicates a good grout area while a drum-like hollow sound indicates a void requiring filling. NOTE: Grout voids ought not be expected as being "normal." Voids are the result of an inadequate baseplate or soleplate design or improper placement of the grout.		
5.9.2.	Void areas are to be filled by drilling NPT 1/8 holes in opposite corners of each void area.		
5.9.2.1.	One hole in each void is to be tapped for installation of a NPT 1/8 grease fitting;		
5.9.2.2.	The other holes serve as vents.		
5.9.2.3.	Grout is then pumped into each void with a grout gun until the grout emerges from the vent holes.		
5.9.2.4.	A "new," unused, and unpainted grease gun can be used as a grout gun.		
5.9.2.5.	The grease gun shall be completely disassembled and cleaned with the grout manufacturer's approved solvent.		
5.9.2.6.	Complete immersion of the gun into the solvent is required to ensure proper cleaning.		
5.9.3.	Care shall be exercised in filling voids as high pressures created from the grout gun can lift or distort the baseplate. It is therefore extremely important that the grout and vent holes are in communication with each other.		
5.9.3.1.	An air squeeze bottle may be used to test for communication by blowing air into the grout hole and noting its exit at the vent hole (do not use high-pressure air).		
5.9.3.2.	A dial indicator supported from a main beam I should also be used to monitor baseplate movement during void filling. Remove all grease fittings when finished.		
5.9.4.	Clean up any spilled grout with the grout manufacturer's approved solvent.		

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5.9.5.	After the void grout has cured, re-check the baseplate to ensure that all voids are filled with grout. If void areas still exist, repeat the drilling and pumping procedures as necessary.		
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EQUIPMENT IDENTIFICATION NUMBER \_\_\_\_\_

GROUTING INSPECTOR \_\_\_\_\_ DATE \_\_\_\_\_

**Annex B**  
(informative)

**Anchor Bolt Torque Tables**

**Table B.1—30,000 psi Internal Bolt Stress**

Nominal Bolt Diameter (in.)	Number of Threads (per in.)	Torque (ft-lb)	Compression (lb)
1/2	13	30	3780
5/8	11	60	6600
3/4	10	100	9060
7/8	9	160	12,570
1.0	8	245	16,530
1 1/8	8	355	21,840
1 1/4	8	500	27,870
1 1/2	8	800	42,150
1 3/4	8	1500	59,400
2.0	8	2200	79,560
2 1/4	8	3180	102,690
2 1/2	8	4400	128,760
2 3/4	8	5920	157,770
3.0	8	7720	189,720

NOTE 1 All torque values are based on anchor bolts with threads well-lubricated with oil (NOT anti-seize compound)

. The use of anti-seize compounds will reduce these torque values.

NOTE 2 In all cases the elongation of the bolt will indicate the load on the bolt.

Restricted



**Table B.2—2110 kg/cm<sup>2</sup> Internal Bolt Stress**

<b>Nominal of Bolt Diameter (mm)</b>	<b>Torque Newton-Meters</b>	<b>Compression (lb)</b>
M12	31	1778
M16	110	3311
M24	363	7447
M30	1157	18,247
M52	3815	37,136

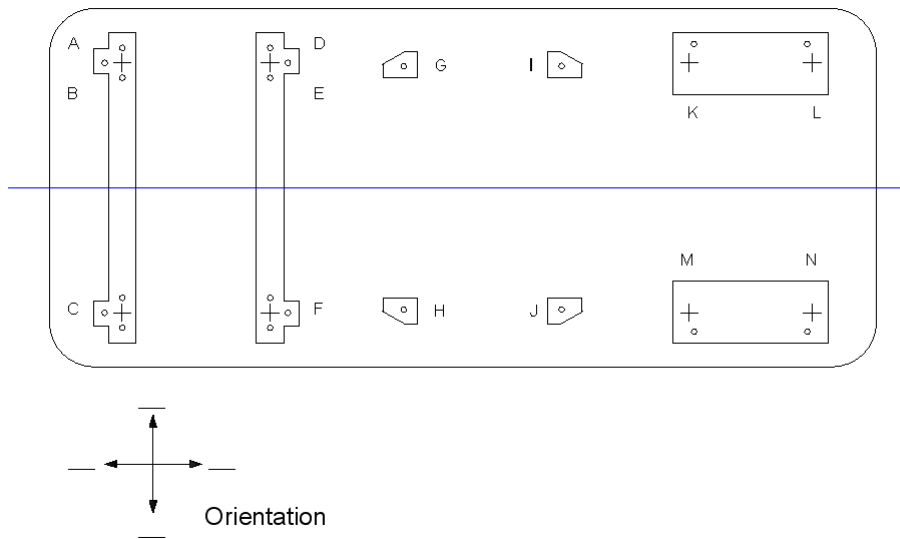
NOTE 1 All torque values are based on anchor bolts with threads well-lubricated with oil (NOT anti-seize compound)

. The use of anti-seize compounds will reduce these torque values.

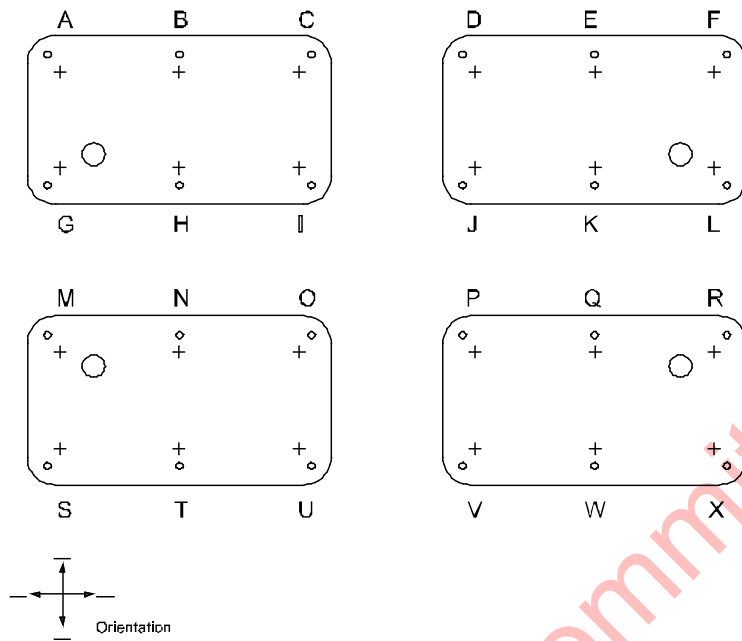
NOTE 2 In all cases the elongation of the bolt will indicate the load on the bolt.

**Annex C**  
(informative)

**Leveling Datasheet and Drawings**



**Figure C.1—Typical Baseplate or soleplate Layout for Elevation and Level Measurement**



**Figure C.2—Typical Soleplate Layout for Elevation and Level Measurement**

**Typical Baseplate or soleplate Level Datasheet**  
**(Sheet 1 of 2)**

Elevation Specified on Civil Drawing \_\_\_\_\_

Elevation of Soleplate at Location "A" \_\_\_\_\_

Civil Drawing Reference No. \_\_\_\_\_

Location	Elevation Referenced to Location "A"	Comments
----------	--------------------------------------	----------

B	_____	
C	_____	
D	_____	
E	_____	
F	_____	
G	_____	
H	_____	
I	_____	
J	_____	
K	_____	
L	_____	
M	_____	
N	_____	

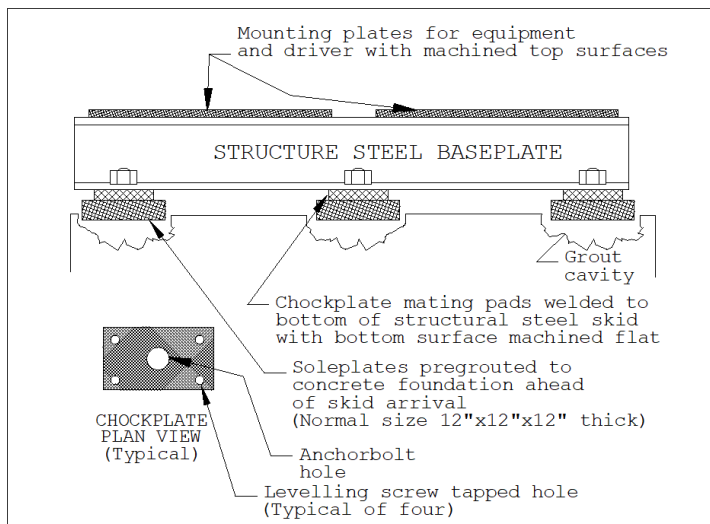
CHECK BY \_\_\_\_\_ CONTRACTOR DATE \_\_\_\_\_

APPROVED BY \_\_\_\_\_ (USER) DATE \_\_\_\_\_



**Annex D**  
(informative)

**Typical Soleplate Arrangement for Baseplate Mounted Special-purpose Equipment**



**Figure D.1—Typical Baseplate or soleplate Arrangement for Baseplate Mounted Special-purpose Equipment**

**Note to API Editors: Need to use Figure D.1 from 686 2<sup>nd</sup> Edition and replace  
"Mounting Plate" with "Soleplate"**

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## **Annex E**

(informative)

### **Baseplate Leveling for Horizontal Centrifugal Pumps (for Use When a Pump and/or its Driver are Not Removed from the Baseplate for Grouting)**

#### **Procedure**

1) Determine high end of baseplate. Then, start leveling across pads on high end by adjusting leveling bolts adjacent to the pad that is being leveled. For example, when leveling driver pads A and B in crosswise direction, level at anchor points 1 and 2 (see Figure E.1) with level positioned as shown by Figure E.3. Continue leveling until baseplate is level in crosswise direction at places illustrated by Figure E.2 and Figure E.3—pads A and B shall be level across middles and across ends, particularly those ends nearest pump.

NOTE Use only equipment mounting pads for determining level. *Never* use nozzles or baseplate rails.

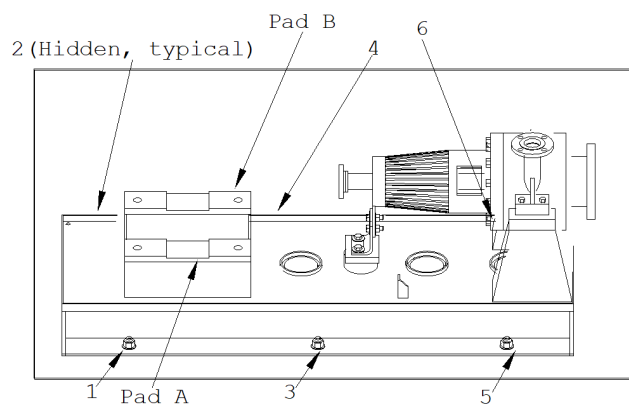
2) Level both sides of baseplate in lengthwise direction by adjusting leveling bolts adjacent to pad that you are leveling. For example, when leveling pad A, level at anchor points 1, 3, and 5, Figure E.1, with level positioned as shown by Figure E.4. Continue leveling until both sides of baseplate (that is, pads A, B, and each side of pump) are level in lengthwise direction at places illustrated by Figure E.4 and Figure E.5.

3) Tighten foundation anchor bolts and pump feet hold-down bolts. As you tighten bolts, position level as illustrated in the four leveling figures and check leveling in both crosswise and lengthwise directions. If tightening bolts disturbs leveling, adjust leveling bolts until baseplate is level in both directions at place where leveling was disturbed. Again tighten bolts and verify leveling in both directions. Continue this procedure until all bolts lengthwise and crosswise directions are tight.

NOTE Grouting of baseplates (baseplate or soleplates) without removal of equipment is allowed only when specifically permitted by the user or his/her designated representative (exception is noted for pre-grouted baseplate designs that have sufficient area to place leveling devices).

Figure E.1 through Figure E.5—Single Stage Overhung Pump

Figure E.6 through Figure E.10—Between Bearing Single or Multistage Pump

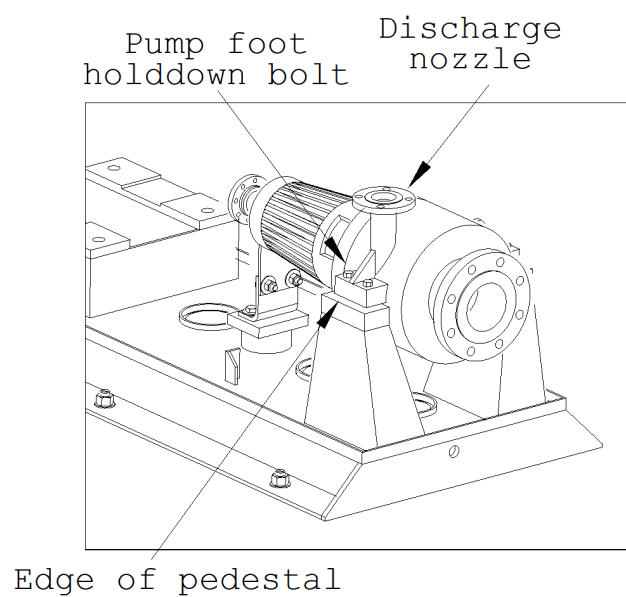


Note: Points 2, 4, and 6 directly from Points 1,3 and 5, respectively.  
 Figure E.1 —Baseplate Top View

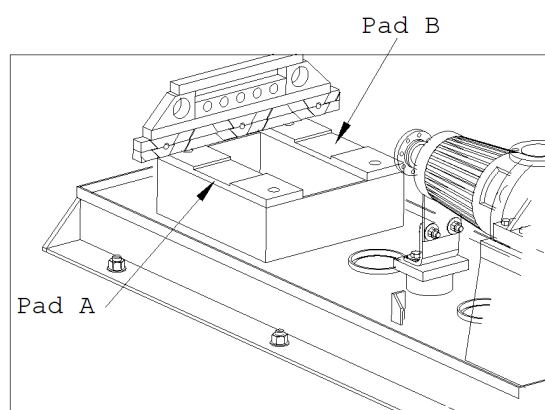
NOTE Points 2, 4, and 6 are directly across from points 1,3, and 5, respectively.

**Figure E.1—Baseplate Top View**

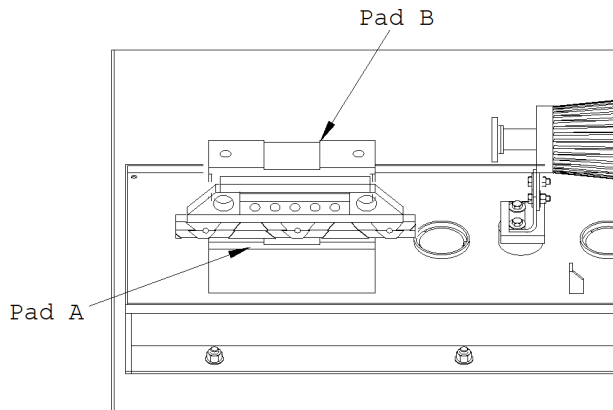




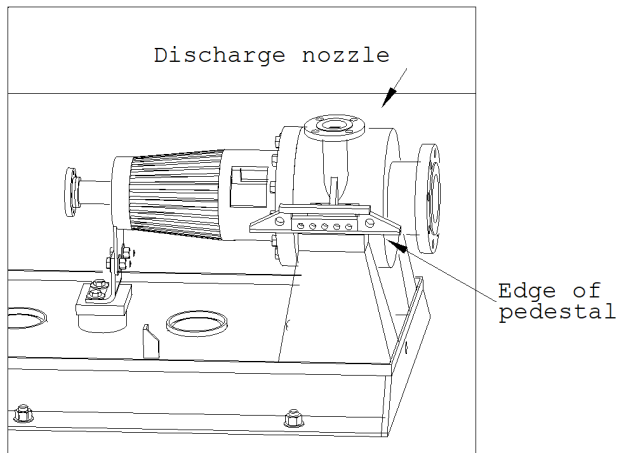
**Figure E.2—Leveling Pump End Crosswise**



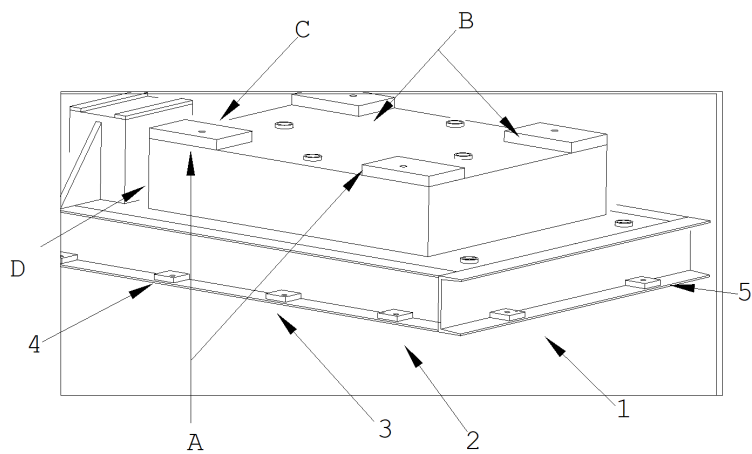
**Figure E.3—Leveling Driver End Crosswise**



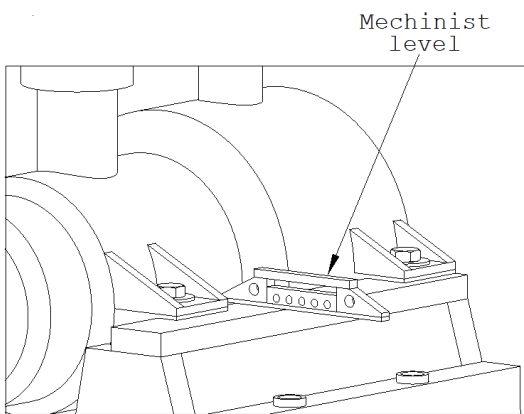
**Figure E.4—Leveling Driver End Lengthwise**



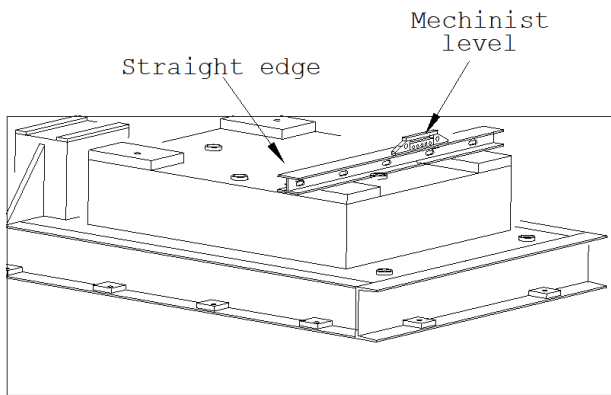
**Figure E.5—Leveling Pump End Lengthwise**



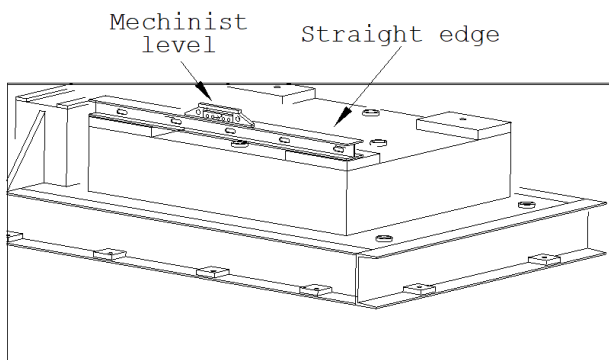
**Figure E.6—Baseplate Top View (Typical)**



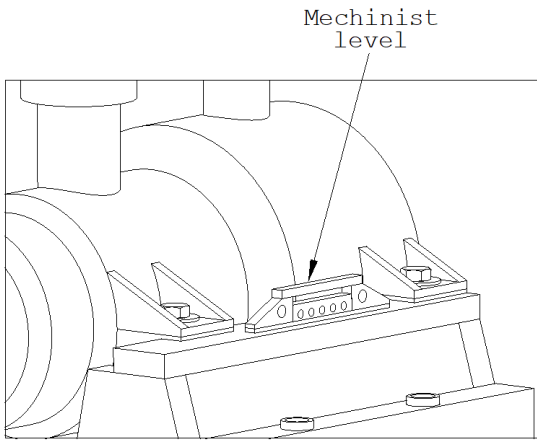
**Figure E.7—Leveling Pump End Crosswise**



**Figure E.8—Leveling Driver End Crosswise (Typical)**



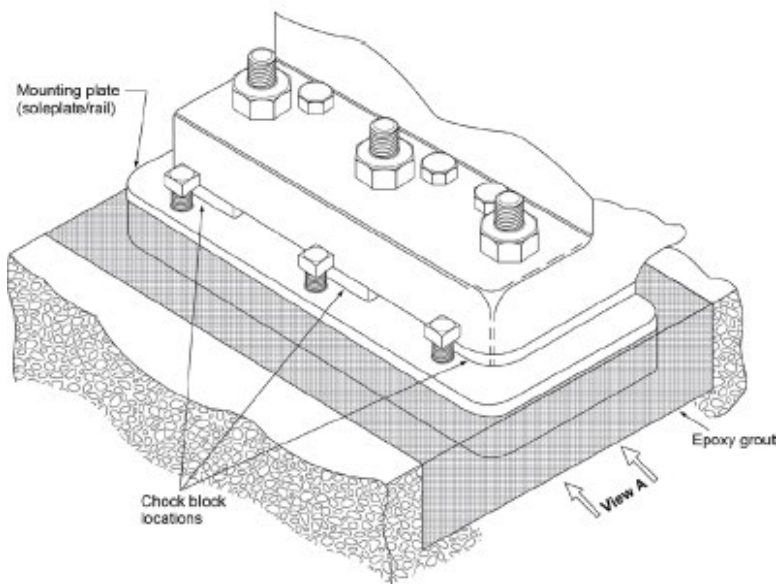
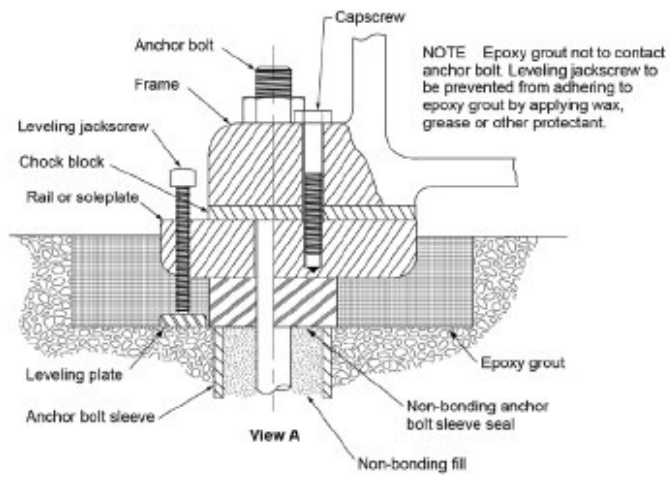
**Figure E.9—Leveling Driver End Lengthwise (Typical)**



**Figure E.10—Leveling Pump End Lengthwise**

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F.2—???



## Annex G (informative)

### Typical Grouting of Baseplates for Pumps and Special-purpose Equipment

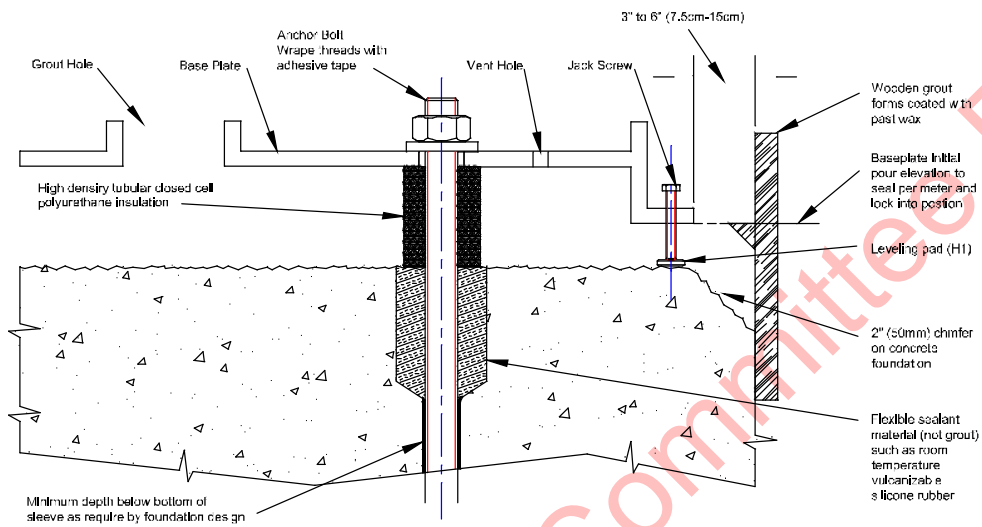
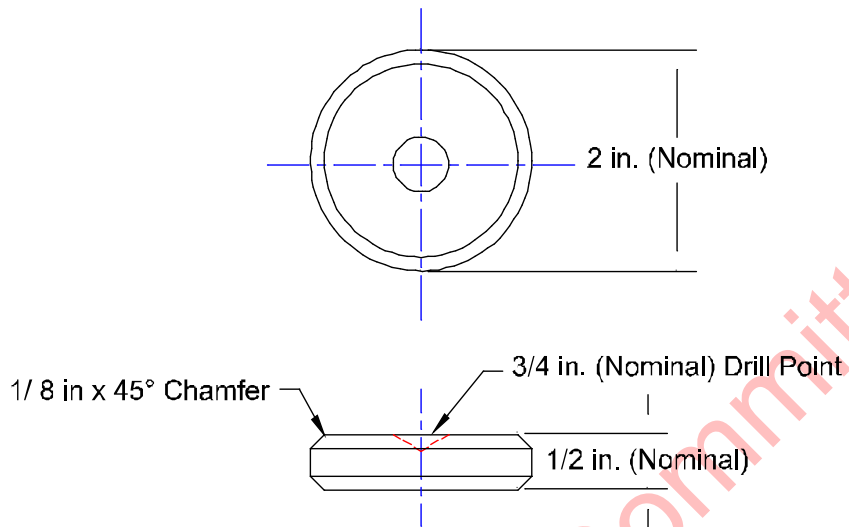


Figure G.1—Typical Grouting Installation of Baseplates for Pumps and General-purpose Equipment

**Annex H**  
(informative)

**Typical Baseplate or soleplate Leveling Pads**



**Notes**

1. Material Stainless Steel
2. Cleanliness free of dirt, oil, scale and burrs
3. The 3/4 in. drill point is only required when the leveling pads are NOT to be grouted in position

**Figure H.1—Typical Baseplate or soleplate Leveling Pads**

## **Annex I**

### **(informative)**

#### **Optical Leveling Scope Peg Test**

The peg test adjustment is a standard pre-check instrument adjustment used to ensure that accurate leveling (i.e. of soleplates) is achieved. The objective of the peg test is to make the line of optical sight through the scope level when the instrument bubble is centered on or "in" coincidence with the scope. It is essentially the optical equivalent of a 180° reversing of a machinists level to check for repeatability.

The procedure for the peg test is as follows:

- 1) Set the optical tooling scales at points 1 and 2 as shown in Figure I.1 and at a distance of approximately 40 ft (12.2 m) apart. These scales shall be placed absolutely vertically utilizing magnetic bases and placed on a firm base not subject to vibration or settlement and provide good illumination for the scales.
- 2) Set up the instrument equipped with optical micrometer at point "M" midway between points 1 and 2.
- 3) With the main bubble centered or in-coincidence, take five readings at "A" and "B," and record the average of each set of these readings.
- 4) Move the instrument to position "P." Position "P" should divide the distance between the two scales into the ratio of 1:5 [i.e. if the distance between the two scales is 40 ft (12.2 m), "P" should be 8 ft (2.44 m) from Scale #1 and 32 ft (9.75 m) from Scale #2].
- 5) With the main bubble centered or in-coincidence, take five readings at "C" and "D," and record the average of each set of these readings. If the instrument is within adjustment tolerance (equal to or less than 0.0005 in./ft), "A" minus "B" will equal "C" minus "D." If this is not the case, calculate what reading  $D_1$  should be to make the line of sight level by using the following formula:

$$D_1 = \frac{4}{3} [(B + C) (A + D)] + D$$

Actual adjustment procedures for correcting of coincidence misalignment will vary by different manufactures of optical leveling instruments. Consult the OEM's manual for instructions on how to correct for coincidence misalignment.

This document is not intended to be specific as how to adjust every manufacturers optical level, rather the purpose is to provide a method of testing the intended instrument to be used to ensure its reliability and that a quality leveling job will be achieved prior to grouting.

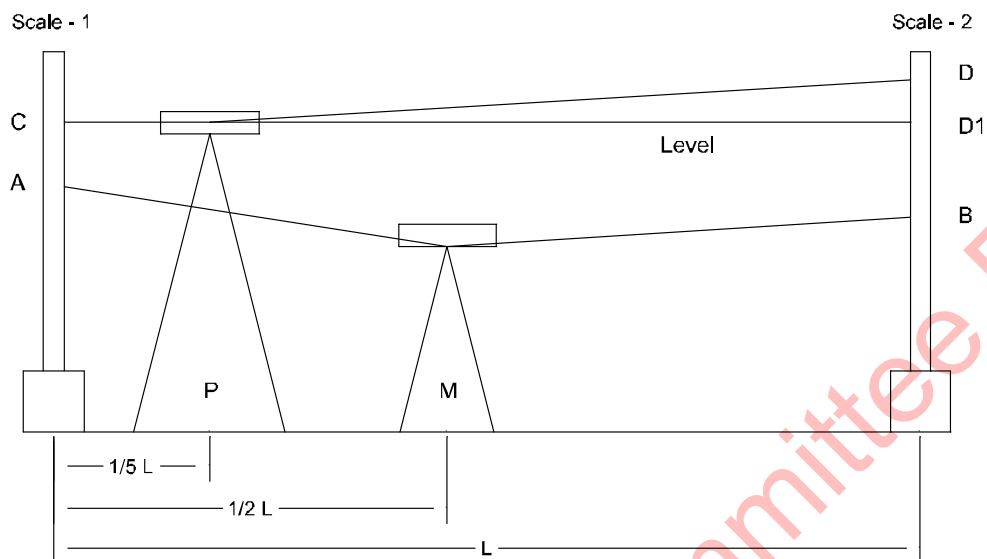


Figure I.1—Peg Test Diagram

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## 6. Piping

**6.1. Machinery Piping Installation** Comment if this is design why isn't it in Part B? This section should begin with what is now 6.2 below

6.1.1. The addition or deletion of piping hangers and supports during field construction can result in unacceptable static piping stresses, nozzle loads and vibrations not anticipated by the piping designer and is prohibited. (duplicate number via API)

6.1.2. The final piping field weld shall be located between the face of the machinery flange and the first pipe support or isolation block valve (see Figure B.5.),

6.1.3. Piping smaller than NPS 10 typically has sufficient flexibility that there is usually little difficulty in achieving machinery flange fit-up requirements during field installation.

6.1.3.1. Thick walled pipe smaller than NPS 10 may require a final field weld due to the greater stiffness and difficulty in meeting flange fit-up requirements.

6.1.3.2. Typical industry practice is to shop fabricate piping smaller than NPS 10 and not perform a final field weld providing flange fit-up requirements can be met.

6.1.4. The root pass of all butt welds on stainless steel pipe shall be made by tungsten inert-gas arc welding.

6.1.4.1. Filler passes may be made by tungsten inert-gas arc welding or by the shielded metal arc process.

6.1.4.2. Gas metal arc welding may be used when approved, for filler passes on DN 150 (6.0 in) and larger pipe.

### 6.1.5. Temporary Strainers

6.1.5.1. Machinery not equipped with a permanent inlet screen or strainer should be provided with a temporary start-up screen or strainer and be such that when the screen is removed, there is no need to modify the process piping.

6.1.5.2. Piping designer should take into consideration requirements for lifting the temporary strainer for removal, by providing lifting eyes if needed and adequate unit space for any required lifting equipment.

6.1.5.3. Temporary screens or strainers shall be clearly identified by an extended handle or other device, projecting beyond insulation material, with screen mesh, hole size, and individual identification marker clearly shown on this extended handle.

6.1.5.4. Plans should be provided to remove any start-up screen not intended for continuous duty.

6.1.5.5. When fine mesh screen is required for a temporary screen or strainer, the screen shall be located on the upstream side of the strainer.

6.1.5.6. The point of the conical strainer should face upstream in the piping (pointing into the flow). Screens in T-type strainers should point with the flow (downstream).

6.1.5.6.1. Pointing the conical strainer upstream to the flow allows debris to fall to the outside of the cone around the perimeter of the pipe and so minimize the obstruction to the flow path.

6.1.5.6.2. This is the preferred orientation for most machinery installations.

6.1.5.6.3. Conical strainers may be installed with the point oriented downstream when explicitly specified by the designated machinery representative. This may be advantageous in situations where there are space limitations or where removal of the temporary strainer may result in the dropping of debris into the machine inlet (see Figure B.6).

6.1.5.7. Temporary screens or strainers should be installed in horizontal piping runs whenever possible.

NOTE: Locating temporary screens or strainers in horizontal piping facilitates the safe removal of debris.

6.1.5.8. The location of temporary screens or strainers in vertical piping is acceptable but greater care shall be taken to prevent debris from falling into the piping when the screen or strainer is removed.

6.1.5.9. All sealing steam and leak-off steam lines shall be designed and field fabricated to be self draining.

6.1.5.9.1. Piping should slope away from the turbine so that any condensate will drain away from the turbine.

6.1.5.9.2. Piping shall not be pocketed unless the pocketed (low point) location is provided with both a manual and automatic drain.

### 6.2. Machinery Piping Installation

#### 6.2.1. General Requirements

Restricted

6.2.1.1. Piping shall not be connected to the machinery until grouting, machinery shaft preliminary alignment, and final field welding have been completed.

6.2.1.2. Piping hangers and supports shall be installed as specified by design to minimize piping applied strain on the machinery. The addition or deletion of piping supports during field construction can result in piping strain not anticipated by the piping designer and is prohibited.

6.2.1.3. Layout and installation of field run piping and conduit shall be jointly coordinated to provide operation and maintenance accessibility.

NOTE: The intention is that the piping and electrical/instrumentation equipment installers will work together in the field routing of piping and conduit. The objective is a machinery installation where the piping and conduit do not block access for operation and maintenance.

6.2.1.4. Electrical power and instrumentation connections to machinery shall be made with conduit of sufficient length and flexibility to not interfere with machinery alignment.

NOTE As with piping, conduit to motors or instruments can impose strains on machinery. Since either flexible or rigid conduit may be used, the intent is to minimize conduit-imposed strain on the machinery.

6.2.1.5. If rigid conduit is used, it may be necessary to measure conduit-imposed strains on the machinery in a manner similar to that performed for piping.

6.2.1.6. Ensure that fluid passages of machinery are free from dirt, foreign objects, and other contamination.

6.2.1.7. Temporary blinds shall be made of metal and installed at the machinery flanges to prevent dirt and debris from entering the machinery during installation.

6.2.1.7.1. Alternative materials can be proposed and approved by the Purchaser.

6.2.1.7.2. All machinery threaded openings are to be plugged with a threaded pipe plug to prevent contamination or leakage.

6.2.1.7.3. Plastic pipe plugs shall not be used in pressure containing parts without purchaser approval.

6.2.1.7.4. Care should be taken when installing stainless steel plugs into stainless tapped holes because they can gall and cause thread damage.

NOTE Plastic threaded pipe plugs are sometimes installed prior to painting the machinery. Once covered with paint, the plastic pipe plug becomes difficult to detect. When the equipment is put into service and subjected to process pressures and temperatures, the plastic pipe plug can "blow-out" releasing process liquid or gas to the environment in an uncontrolled manner. This may create a hazardous condition for operating personnel.

6.2.1.8. Any solid preservatives such as desiccant bags shall be removed from the machinery prior to connection of piping during commissioning.

6.2.1.9. A solid metal cover with rubber gasket to cover flange openings during installation should be used to close/cover pipe openings or flanges.

6.2.1.10. Pipe flange openings should be kept covered during installation until the piping is connected to the process machinery.

6.2.1.11. Duct tape and plastic should not be used for covering the ends of pipe flanges as it is prone to tearing loose and lodging within the machine. Heat-shrink wrap is acceptable.

6.2.1.12. Rags and towels shall not be used to block the open ends of pipe or flanges.

## 6.2.2. Field Installation of Auxiliaries

6.2.2.1. Field-installed auxiliary equipment, piping, conduit, instruments, coolers, seal pots, consoles, for example, should be mounted separately from the machine and driver. These items should not interfere with removal of the machine or driver nor with access to the machinery for normal operation and maintenance (see Figure B.1).

6.2.2.2. Auxiliary support piping, conduit, instrumentation, for example, should be located for a single drop area on the machinery baseplate or soleplate. It is undesirable to have piping, conduit, and other support systems installed at multiple locations on the base making maintenance and operation difficult.

6.2.2.3. Openings for branch connections of NPS 1 or smaller should be made by drilling the run pipe. Torch cutting of any opening smaller than NPS 1 diameter is not acceptable.

6.2.2.4. Process-compatible pipe joint compounds approved by the designated machinery representative should be used for all threaded connections.

6.2.2.4.1. PTFE tape pipe sealant and/or anti-seize lubricants shall not be used to make up any threaded connections in lubricating oil, seal fluid, separation gas, buffer gas, process, or utility connections to any machine.

6.2.2.4.2. Anti-seize lubricants are not a sealing compound and shall not be used as pipe joint compounds.

6.2.2.5. To ensure proper thread engagement, all threaded connections should have two to five exposed pipe threads after making up the joint.

6.2.2.6. The field routing of pipe or tubing to and from seal pots should be approved by the designated machinery representative (see API 682).

#### 6.2.3. Hydrostatic Test Restrictions

6.2.3.1. Piping hydrostatic test should not be done through any type of machinery including vertical and horizontal pumps, steam turbines, blowers, or compressors. Separate hydrostatic test blinds should be installed or the inlet and outlet piping spools should be removed to isolate the machinery during piping hydrotest.

NOTE: Piping hydrostatic test pressures are typically much greater than the normal operating pressures of the process machinery. Damage to process machinery components can result if machinery is subjected to hydrotest pressures. It can be difficult to remove hydrostatic test water and debris from machinery internal passages. Subsequent machine damage and process contamination can result when the equipment is put into service if machinery is hydrotested with the process piping.

6.2.3.2. The piping hydrotest layout around vertical barrel or can pumps should be designed to prevent water from entering the pump barrel or can.

6.2.3.3. A copy of the piping and instrumentation drawings should be created clearly indicating all of the piping hydrotest blinding locations. This blinding drawing should be reviewed and approved by the designated machinery representative prior to the initiation of any hydrotesting.

6.2.3.4. Hydrostatic testing of the piping should be performed after preliminary piping alignment and fit-up to the machinery. The equipment installer should exercise care to prevent the draining of hydrotest liquids into the machinery.

6.2.3.4.1. Piping hydrostatic test may be required if piping welds are made to achieve piping alignment. However, hydrostatic test blinds and field welds can result in changes in piping-to-machinery alignment.

6.2.3.4.2. The intent is that piping is preliminarily aligned to the machinery, major piping modifications made, and hydrostatic testing should be completed before final piping alignment checks are made with hydrotest blinds removed.

#### 6.2.4. Stray Electrical Currents

NOTE: Stray currents from welding or electrical heating stress relieving can cause damage to seals, bearings, and other machinery components. Stray electrical currents can also magnetize machinery components that can later generate damaging currents.

6.2.4.1. The following requirements in 6.2.4.1 through 6.2.4.4 should be met for all field welds around machinery.

6.2.4.1.1. Welding ground cables should be attached adjacent to the place where the weld is being made.

6.2.4.1.2. The welding clamps should be clamped onto the pipe near the weld and the welding machine properly grounded.

6.2.4.1.3. Spring-type alligator clamps should not be used.

6.2.4.1.4. A double ground cable should be located on each side of the weld within 305 mm (12 in.).

6.2.4.2. Ground leads should not be attached to any part of the machinery, auxiliary systems, or supports for any reason.

6.2.4.3. If it is necessary to attach piping to the machinery for the purpose of field welding or electrical field stress relief of pipe strain:

6.2.4.3.1. The machinery should be isolated from the pipe flange by using a full-circle 3 mm (0.125 in.) thick composition gasket. Insulated bolts or studs should then be installed.

6.2.4.3.2. A continuity check should then be performed to prove the electrical isolation of the machine from the piping.

6.2.4.3.3. Replace the composition gaskets and insulated bolts, studs and/or nuts upon completion of welding, with components that meet the piping/process design.

NOTE: The composition gasket is used to electrically insulate and protect the machinery from stray electrical currents.

6.2.4.4. Machinery magnetic flux density readings should be measured and recorded before and after welding. If residual magnetism is in excess 0.2 milli-tesla (2 gauss), degaussing is required.

NOTE: The intent is to prevent possible machinery bearing damage due to residual magnetism caused by stray electrical currents.

#### 6.2.5. Design Verification

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Prior to checking final piping alignment to the machinery, the piping system should be complete as follows in 6.2.5.1 through 6.2.5.7.

6.2.5.1. Pipe hydrotesting and drying out of the system should be finished and all hydrotest blinds removed.

6.2.5.1.1. Test blinds shall be removed and major field welds completed before piping alignment checks are made, as hydrotest blinds and field welds can result in changes in piping-to-machinery alignment.

6.2.5.1.2. Where possible, field welds required for piping alignment should be located between the isolation block valves and the machinery nozzles to permit the hydrotesting of short spools.

6.2.5.2. All permanent supports (fixed, sliding, spring supports, and hangers) should be installed and adjusted.

6.2.5.3. All temporary supports and hangers should be removed.

6.2.5.4. All the system piping components and machinery should be at the same ambient temperature within a range of 10 °C (18 °F) before starting final piping alignment checks

6.2.5.5. The piping engineering design inspector should verify that the machine inlet and outlet piping is properly constructed in accordance with the piping design. This inspection should include verification of gasket material, gasket size, the material, size, and length of flange bolts, studs, and nuts.

6.2.5.6. Before proceeding with piping alignment checks, the piping engineering design inspector should verify that spring hangers and spring supports are installed with the preset spring hanger stops in position so that the springs are locked at the cold load setting. The piping engineering design inspector should also verify that there are no visible gaps between the piping and fixed piping supports.

6.2.5.7. The machine should be inspected to verify that it is still removable. This means that sufficient flanged and threaded piping connections exist to completely remove the machinery from the baseplate or soleplate for maintenance without requiring the cutting or welding of pipe or tubing.

6.2.6. Piping Alignment Requirements

6.2.6.1. Flanges of connecting piping should not be sprung into position.

NOTE: If the following criteria are met there is typically little difficulty in meeting shaft deflection requirements.

6.2.6.2. Pipe flange bolt holes should be lined up with machinery nozzle bolt holes within 1.5 mm (0.0625 in.) maximum offset from the center of the bolt hole to permit insertion of bolts without applying any external force to the piping.

NOTE The intent of this requirement is to ensure that flange bolts can be easily installed without the application of external force.

6.2.6.3. The machine and piping flange faces should be parallel to less than 0.01 mm per centimeter (0.001 in. per in.) of pipe flange outer diameter up to a maximum of 0.75 mm (0.030 in.).

6.2.6.4. For piping flange outer diameters smaller than 250 mm (10 in.), the flanges should be parallel to 0.25 mm (0.010 in.) or less.

6.2.6.5. For special-purpose machinery, pipe to machinery flange spacing measurements should be recorded on the Piping alignment datasheet shown in Figure B.4. For raised face flanges, feeler gauge readings should be taken at the raised face. For flat faced flanges, feeler gauge readings should be taken at the flange outside diameter.

6.2.6.6. Flange face separation should be within the gasket spacing  $\pm 1.5$  mm (0.0625 in.). Only one gasket per flanged connection should be used.

6.2.6.7. Preliminary shaft alignment, including soft foot verification should be done prior to piping alignment.

6.2.7. Piping Alignment

The objective of the following requirements is to verify that strains imposed by the piping on the machinery are minimized. Less strain imposed on the machine casing results in less distortion of running clearances and better machine performance and reliability.

6.2.7.1. The basic method of verifying pipe strain consists of bolting up the piping to the machine flanges while measuring the deflection of the machine shaft with dial indicators or laser tooling. This is done with spring hanger and spring support stops installed so that the springs are locked in the cold position to prevent spring function from masking shaft movement caused by piping-imposed strains.

6.2.7.2. Excessive movement of the machine shaft as the piping is bolted up indicates that the pipe is imposing excessive strain on the machine. Spring hanger and spring support stops are then removed as a means of indicating any gross mismatch between the piping and the supports.

6.2.7.3. Due to the weight of the liquid, caution is necessary when spring hanger or spring support stops are removed and the piping is full of liquid. The equipment installer should be aware of the design basis (empty or liquid-full) before removing spring hanger or spring support stops.

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For an overview of the piping alignment process refer to Annex D following this section, "Supplemental Tutorial—Field Relief of Pipe Strain."

6.2.8. Machinery inlet and outlet piping systems should be separately worked into position to bring the piping flanges into satisfactory alignment with the matching machinery flanges. The machinery should not be moved to achieve strain free piping alignment.

6.2.9. Bringing the flanges of the pipe into alignment may be done by a number of means.

6.2.9.1. All temporary supports for piping alignment (such as chain falls and wedges) should be removed during final alignment readings and piping bolt-up.

6.2.9.2. Piping should be supported by permanent fixed and spring supports and hangers.

6.2.9.3. Piping should not be binding on pipe guides or restraints.

6.2.9.4. If spring hanger or spring support stops are not installed, the spring hangers or spring supports should be adjusted to the cold load settings and stops installed before proceeding with piping alignment checks.

NOTE 1: Methods for achieving piping alignment include shimming supports, adjusting spring hanger tie-rod turnbuckles, retorquing flanges, installing piping support spacers, selectively heating one side of the pipe (diamond heating), ring heating, cutting and rewelding, or completely refabricating the piping. The method or methods selected are determined by the piping configuration and materials and will be different for each installation.

6.2.9.5. Spring hanger and spring support stops shall be in place to ensure the piping system is rigid during the piping alignment check. This ensures that spring movements do not mask pipe strains.

6.2.9.6. The equipment installer should exercise care that the stopped spring hanger or support is not used as a jack or chain hoist to force the piping into position.

NOTE: With spring stops in place and the load plate bound up against the coil side stop, it may be difficult to know the magnitude of load being applied.

6.2.10. Adjusting the spring tension of spring hangers or spring supports as a method of achieving piping alignment is not acceptable.

NOTE: Spring hangers and spring supports are selected by the piping engineering designer to compensate for piping movements caused by pressure, thermal, and dynamic changes. Adjusting spring tension results in changes in the force exerted by the spring hanger or support. The spring hanger or support may no longer function as originally designed.

6.2.11. Piping movement should be observed when spring hanger and support preset stops are removed back to the first fixed anchor point. If any spring hangers or supports are "topped-out" or "bottomed-out," the piping design and spring hanger or support selection should be verified by the piping engineering designer. Further pipe strain checks should not be made until corrections are made to the piping system. Preset stops should then be reinstalled in the spring hangers and supports to lock them into cold position.

NOTE: There typically is little movement of the piping when spring hanger and spring support stops are removed. The spring hangers and spring supports typically remain at their cold setting positions. Some upward movement may be expected on liquid lines. Larger liquid lines will usually move more than smaller lines. Refer to Figure B.8 for an overview of spring hanger and spring supports.

6.2.12. If flange alignment is to be accomplished by heating or welding of the piping, the procedure should be approved for each type of pipe material in advance by a welding engineer or materials specialist.

6.2.13. Piping should be disconnected from the machinery before selectively heating one side of the pipe as a method of achieving piping alignment.

NOTE 1: When diamond heating (selectively heating one side of the pipe in a diamond pattern) is used, the piping is free of the machine to allow it to move. If the piping is fixed to the machine and diamond heating is used, the piping can impose excessive strains on the machinery resulting in machine distortion or flange breakage.

NOTE 2: When ring heat (heating the piping in a circumferential band near the machinery) is used, the piping is attached to the machinery with a thermally insulating gasket. The intention with ring heat is to force the piping flange to conform to the machine flange. Typical industry practice is to apply this ring heat to the piping at a sufficient distance from the flanges that heat conduction through the insulating gasket is negligible. The direct application of heat to the machinery flange is prohibited due to the risk of damage to the internal components of the machine. There is no pipe size limitation on the use of ring heat. The magnitude of the piping misalignment to be corrected, the piping metallurgy, the pipe wall thickness, the location of pipe supports as well as piping flexibility are factors to be considered when making the decision to apply ring heat or alternative methods.

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6.2.14. Pipe strain should be measured while all piping connections are being made to the machine. This includes lube oil piping, cooling water piping, auxiliary piping such as steam, air, and flushing medium, as well as process piping and electrical conduits.

Note: Pipe strain checks should also be done while connecting piping to the driver.

6.2.15. For pieces of machinery with common piping such as pairs of pumps, both shaft alignments should be monitored during piping-up operations. Additionally, all of the machinery should be bolted up at the same time with indicator readings taken on each shaft simultaneously.

#### 6.2.16. Pipe Strain Measurement

6.2.16.1. A dial indicator stem should be positioned on the coupling hub or shaft of the machine being checked for pipe strain.

6.2.16.2. Indicators should be mounted on the coupling hub to measure vertical and horizontal movement as the pipe flange bolts are being tightened using a torque wrench.

NOTE: The use of laser alignment tooling to measure movement during pipe strain checks is an acceptable and often preferred alternative to dial indicators. A dial indicator positioned in the axial direction can be used if it is suspected that the piping is moving the equipment along the axis of the shaft.

6.2.16.3. Bolt-up of the piping flanges to the machinery flanges should proceed with the largest flanges first. Bolt-up shall be completed in a continuous effort without disturbing the location of the dial indicators or laser alignment tooling.

6.2.16.4. Initial tightening of the flange bolts should be snug (equal to or less than 10% of total torque).

6.2.16.4.1. Flange bolts should then be tightened to 30% of total torque.

6.2.16.4.2. The flange bolts should then be tightened to 100% of total final torque.

6.2.16.4.3. Piping bolt torque values should be specified by the piping engineering designer or the OEM depending on whether bolt threads are lubricated or non-lubricated.

NOTE: Torque values or methods can be specified by the equipment OEM, gasket manufacture, or piping designer.

6.2.16.5. The maximum shaft movement in either the vertical or horizontal directions after all the machinery flanges have been tightened should be 0.05 mm (0.002 in.) or less.

6.2.16.5.1. If the shaft movement is more than 0.05 mm (0.002 in.), the piping flanges should be loosened from the machinery and corrections made to the piping or supports.

6.2.16.5.2. All of the flange gaskets should then be replaced and the procedure repeated.

6.2.16.5.3. For special-purpose machinery shaft movement during piping bolt-up should be recorded on the piping alignment datasheet shown in Figure B.4.

6.2.16.5.4. Movement greater than 0.05 mm (0.002 in.) is permissible during the tightening procedure, provided that the final alignment tolerances are not exceeded.

6.2.16.5.5. For some types of equipment (such as integrally geared compressors that have a relatively flexible casing) alternate methods such as dial indicators located on the machinery casing may be necessary to indicate piping alignment issues. The original equipment manufacturer (OEM) should be consulted in this regard.

6.2.16.6. For canned motor pumps bolted to a baseplate or soleplate, pipe strain should be checked by monitoring deflection of the casing. Indicators should be mounted to measure horizontal and vertical movement of the rear end cover and the casing of the pump relative to the baseplate or soleplate as the piping is being bolted up. Maximum allowable deflection is 0.125 mm (0.005 in.).

NOTE: For non-typical installations where canned motor pumps are not bolted to baseplate or soleplates, an indicator bracket can be attached to one piping flange to measure the deflection of the other flange as flange bolts are tightened.

6.2.16.7. Reciprocating compressor piston rod runouts should be measured before and after connection of process gas piping to the compressor cylinders and/or pulsation vessels and compared to the compressor manufacturer's allowable runouts or API 618, as applicable. Piston rod runouts exceeding allowable runouts are not acceptable, and the process gas piping should be modified to reduce measured piston rod runouts.

#### 6.2.17. Spring Hanger and Spring Support Function Check

6.2.17.1. After satisfactory piping alignment has been obtained, spring hanger and spring support function should be verified. The piping should be empty of all liquid and de-pressured prior to performing spring hanger and spring support function checks.

NOTE For an overview of the spring hanger function checking process refer to Figure B.8.

6.2.17.2. All spring hanger turnbuckle locknuts should be verified as tight.

- 6.2.17.3. With dial indicators or laser alignment tooling on the coupling, movement of the machinery shaft should be observed as the preset stops are removed to activate the spring hangers and spring supports.
- 6.2.17.4. All spring hanger and spring support load indicators should be inspected to verify that the springs remained at their cold load setting. If spring hangers or spring supports are not at the cold load settings, they should be adjusted to the cold load settings.
- 6.2.17.5. If there is movement at the machinery coupling, then machinery alignment should be verified as being within the specified tolerances. These machinery alignment tolerances should be specified by the designated machinery representative and may be different for different types of machinery.
- 6.2.17.6. If any of the spring hangers or spring supports are topped or bottomed out or if the machinery alignment is no longer within the specified tolerances, the piping design and spring hanger and spring support selection should be verified by the piping engineering designer.
- 6.2.17.7. Spring hanger and spring support stops removed for function checks should be chained or otherwise secured to the spring housing to prevent loss.
- 6.2.18. Oil Mist Piping Installation
- 6.2.18.1. All oil mist piping should be routed and supported in the field with all joints exposed to view. No underground piping is acceptable.
- 6.2.18.2. Oil mist piping should be fabricated to minimize the use of piping fittings. Reducing swage nipples and reducing couplings should be used in place of reducing bushings.
- 6.2.18.3. No welded joints in the oil mist piping system are permitted.
- 6.2.18.4. Cut pipe or tubing should be deburred or reamed so that there is no reduction of the inside diameter or any burrs at the pipe cut.
- 6.2.18.5. All piping joints should be threaded. Threaded connections should only be made with a thread lubricant/sealant approved by the designated machinery representative. PTFE tape should not be used to make up any threaded connections in the oil mist system. Unless explicitly approved otherwise by the designated machinery representative, alternative pipe thread sealants should not be used.
- NOTE: Oil mist application fittings (reclassifiers) contain small diameter orifices. Typical pipe thread sealants harden in service, forming particles. These particles migrate through the oil mist system and can plug oil mist application fittings (reclassifiers). Oil mist flow to the machinery bearings is then blocked and eventual bearing failure can result.
- 6.2.18.6. Each piece of pipe and all fittings should be swabbed with a clean, lint-free, unused cloth or wiper prior to joining and threading connections. The equipment installer should exercise care to keep the interior of all piping, tubing, and machinery clean.
- 6.2.18.7. Oil mist branch header to main header connections as well as drop point lateral to header connections should be made at the top of the header pipe.
- 6.2.18.8. The oil mist application fittings (reclassifiers) should be connected to the machinery bearing housings with the tubing arranged to allow normal operation and maintenance access without moving the application fitting (reclassifier) or the tubing.
- 6.2.18.9. Oil mist tubing should be installed so that oil will not be trapped. Tubing benders should be used for bending so that the tubing will have no kinks, wrinkles, or flattened spots.
- 6.2.18.10. Machinery that has previously been grease-lubricated should have the grease fitting and vent passages cleaned before connection to the oil mist system.
- 6.2.18.11. Unless provided by the OEM, machinery bearing housings lubricated using purge mist should have a permanent vent connection. The vent connection should consist of stainless steel tubing 10 cm (4 in.) long attached to the top of the bearing housing and bent to point directly downward to serve as a vent. Alternative vent arrangements may be acceptable when approved by the designated machinery representative.
- 6.2.18.12. For machinery lubricated using purge mist and a constant level oiler or oil level sight assembly, the constant level oiler or oil sight level assembly should be modified with an adjustable overflow device so that a rising oil level can overflow from the bearing housing. Modification of the oiler or oil level sight glass assembly to allow a rising oil level to drain from the oiler or sight glass assembly is acceptable when specified by the designated machinery representative.

NOTE: On purge mist installations, constant level oilers provide the primary lubrication to the bearings. Mist oil that coalesces within the bearing can raise the oil level in the bearing housing. If bearing housing oil level is allowed to rise too high, bearing elements can overheat due to oil churning. Constant level oiler modifications sometimes consist of the addition of a level overflow tube or by the drilling of a small hole in the side of the oiler

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cup located slightly above the normal oil level. The use of an overflow tube is preferred when the excess oil is to be collected to prevent oil from accumulating on the machinery baseplate.

6.2.18.13. For machinery lubricated using pure mist, an oil sight glass should be installed in the bearing housing drain connection.

NOTE 1: The sight glass is typically a small, molded, clear plastic or glass device mounted at the bottom of the bearing housing to provide an indication of coalesced oil level and condition. An overflow connection is provided on top of the sight glass to drain excess oil from the bearing housing to ensure a dry sump and provide a vent. When an oil collection system is provided this overflow connection is connected to a collection container located below the equipment.

NOTE 2: If a coalesced oil return system is used, alternative drain configurations may be required.

6.2.18.14. Machinery bearing housing oil mist connections should remain plugged until all oil mist system commissioning is completed and the oil mist console is placed in operation.

6.2.19. Miscellaneous Requirements

6.2.19.1. After final piping bolt-up, final shaft alignment should be verified

6.2.19.2. All machinery should be hand rotated to ensure that neither binding nor case distortion has occurred during piping installation.

6.2.19.3. Piping spring hanger and spring support stops should be installed during final shaft alignment checks.

6.2.19.4. All spring hanger turnbuckle locknuts should be verified as tight.

6.2.19.5. The piping installation checklist (see Annex A) should be completed by the equipment installer and forwarded to the equipment user as specified.

6.2.19.6. The machinery piping installation diagrams in Annex B should be utilized by the piping designer and equipment installer as specified.

6.2.19.7. For steam piping installations, Annex C should be utilized by the piping designer and equipment installer as specified.

6.2.19.8. Annex D is recommended for field relief of pipe strain for proper piping alignment.

**Annex A**  
(normative)

**Machinery Piping Installation Checklist**

Section	Requirements	Name	Date
<b>6.2</b>	<b>General Requirements</b>		
<b>6.2.1.1</b>	Grouting, preliminary shaft alignment and field welding completed?		
<b>6.2.1.2</b>	Piping hangers and supports installed per design to avoid applying strain on the machinery?		
<b>6.2.1.3</b>	Layout and installation of piping and conduit jointly coordinated?		
<b>6.2.1.4</b>	Electrical power and instrumentation connections to machinery made with conduit sufficiently flexible?		
	Does suction and discharge piping for vertical in-line pumps have adjustable supports located within 1 m (3 ft) of the pump's suction and discharge flanges?		
	Is the pump in solid contact with the foundation baseplate or soleplate?		
	Are adjustable supports locked in position?		
<b>6.2.1.7</b>	Temporary blinds installed at the machinery flanges to prevent dirt and debris from entering the machinery?		
<b>6.2.1.7.1</b>	All threaded openings plugged with a threaded pipe plug to prevent contamination?		
<b>6.2.1.7.3</b>	No plastic pipe plugs used to plug openings?		
<b>6.2.1.8</b>	Any solid preservatives such as desiccant bags removed prior to connection of piping?		
<b>6.2.1.11</b>	No duct tape or plastic used for covering pipe flange ends?		
<b>6.2.1.10</b>	Pipe flange openings kept covered during installation?		
<b>6.2.1.12</b>	Rags and towels not used to stuff into the open ends of pipe or flanges?		
<b>6.2.2</b>	<b>Field Installation of Auxiliaries</b>		
<b>6.2.2.1</b>	All auxiliary equipment, piping, conduit, instruments, coolers, seal pots, consoles, for example mounted separately from the machine and driver?		
	These items do not interfere with removal of the machine or driver nor with access to the machinery for normal operation and maintenance?		
<b>6.2.2.2</b>	Auxiliary support piping, conduit, instrumentation for example should be located for a single drop area on the machinery baseplate or soleplate?		
<b>6.2.2.3</b>	Openings for branch connections of NPS 1 or smaller made by drilling the run pipe?		
<b>6.2.2.5</b>	All threaded connections have two to five exposed pipe threads after making up the joint?		
<b>6.2.2.6</b>	The diameter and field routing of pipe or tubing to and from seal pots approved by the designated machinery representative?		

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Section	Requirements	Name	Date
<b>6.2.3</b>	<b>Hydrotest Restrictions</b>		
<b>6.2.3.1</b>	Machinery isolated for hydrotesting of piping?		
<b>6.2.3.3</b>	A copy of the piping and instrumentation drawings indicating all the piping Hydrotest blinding locations reviewed and approved by the user-designated representative prior to hydrotesting?		
<b>6.2.3.4</b>	Machinery piping alignment and fit-up completed?		
<b>6.2.4</b>	<b>Stray Electrical Currents</b>		
<b>6.2.4.1.1</b>	A double ground cable located on each side of the weld within 305 mm (12 in.) installed?		
<b>6.2.4.1.2</b>	The welding clamps clamped onto the pipe and welding machine grounded?		
<b>6.2.4.2</b>	Ground leads not attached to any part of the machinery, auxiliary systems, or supports?		
<b>6.2.4.3.1</b>	Machinery isolated from the pipe flange by using a full-circle 3 mm (1/8 in.) thick composition gasket with insulated bolts or studs?		
<b>6.2.4.3.2</b>	Continuity check performed to prove the electrical isolation of the machine from the piping?		
<b>6.2.4.4</b>	Magnetic flux density measured and recorded before and after welding?		
<b>6.2.5</b>	<b>Design Verification</b>		
<b>6.2.5.1</b>	Pipe hydrotesting and drying out of the system finished and all hydrotest blinds removed?		
<b>6.2.5.2</b>	All permanent supports and hangers installed and adjusted?		
<b>6.2.5.3</b>	All temporary supports and hangers removed?		
<b>6.2.5.4</b>	All the system piping components and machinery at the same ambient temperature within a range of 10 °C (18 °F) before starting final piping alignment checks?		
<b>6.2.5.5</b>	The piping engineering design inspector verifies that the machine inlet and outlet piping is properly constructed in accordance with the piping and instrumentation drawings?		
<b>6.2.5.6</b>	The piping engineering design inspector verifies that spring hangers are installed with the preset spring hanger stops in position such that the springs are locked at the cold load setting before proceeding with piping alignment checks?		
<b>6.2.5.6</b>	The piping engineering design inspector verifies that there are no visible gaps between the piping and fixed piping supports?		
<b>6.2.5.7</b>	The machine inspected to verify that it is still removable?		
<b>6.2.6</b>	<b>Piping Alignment Requirements</b>		
<b>6.2.6.1</b>	Flanges of connecting piping not sprung into position?		
<b>6.2.6.2</b>	Pipe flange bolt holes lined up with machinery nozzle bolt holes within 1.5 mm (1/16 in.) maximum offset from bolt hole center?		

Restricted

Section	Requirements	Name	Date
6.2.6.3	The machine and piping flange faces parallel to less than 10 micrometers per cm (0.001 in. per in.) of pipe flange outer diameter up to a maximum of 750 micrometers (0.030 in.)?		
6.2.6.4	If piping flange outer diameters are smaller than 250 mm (10 in.), are the flanges parallel to 0.25 mm (0.010 in.) or less?		
6.2.6.3	Piping alignment datasheet (see Figure B.4) completed?		
6.2.6.6	Flange face separation within the gasket spacing $\pm 1.5$ mm (0.0625 in.)?		
6.2.7	<b>Piping Alignment</b>		
6.2.9.1	Have all temporary supports for piping alignment (such as chain falls and wedges) been removed for final alignment readings and piping bolt-up?		
6.2.9.2	Piping supported by permanent fixed and spring supports and hangers?		
6.2.9.3	Piping not binding on pipe guides or restraints?		
6.2.11	No spring hangers or supports "topped-out" or "bottomed-out" when stops are removed?		
6.2.11	Stops reinstalled as preparation for final pipe strain check?		
6.2.12	Heating procedure approved in advance by welding engineer or materials specialist?		
6.2.16	<b>Pipe Strain Measurement</b>		
6.2.16.2	Indicators or laser tooling mounted on the coupling hub to measure vertical and horizontal movement on the opposite machine as the pipe flange bolts are being tightened using a torque wrench?		
6.2.16.4	Initial tightening of the flange bolts snug (10% of total torque)?		
6.2.16.4.1	Flange bolts then tightened to 30% total torque?		
6.2.16.4.2	Flange bolts then tightened to 100% of total flange torque?		
6.2.16.4.3	Total Bolt Torque:		
6.2.16.4.3	Lubricated Threads?		
6.2.16.4.3	Non-lubricated Threads?		
6.2.16.5	The maximum shaft movement in either the vertical or horizontal directions after all the flanges are tightened is 0.05 mm (0.002 in.) or less?		
6.2.16.5.1	Machine shaft total vertical movement:		
6.2.16.5.1	Machine shaft total horizontal movement:		
6.2.16.5.3	Final piping alignment measurements recorded on the piping alignment datasheet, Figure B.4?		
6.2.17	<b>Spring Hanger and Spring Support Function Check</b>		
6.2.17.1	Spring hanger and spring support function verified as acceptable (no springs or spring supports topped out or bottomed out and machinery shaft alignment within the specified tolerances)?		

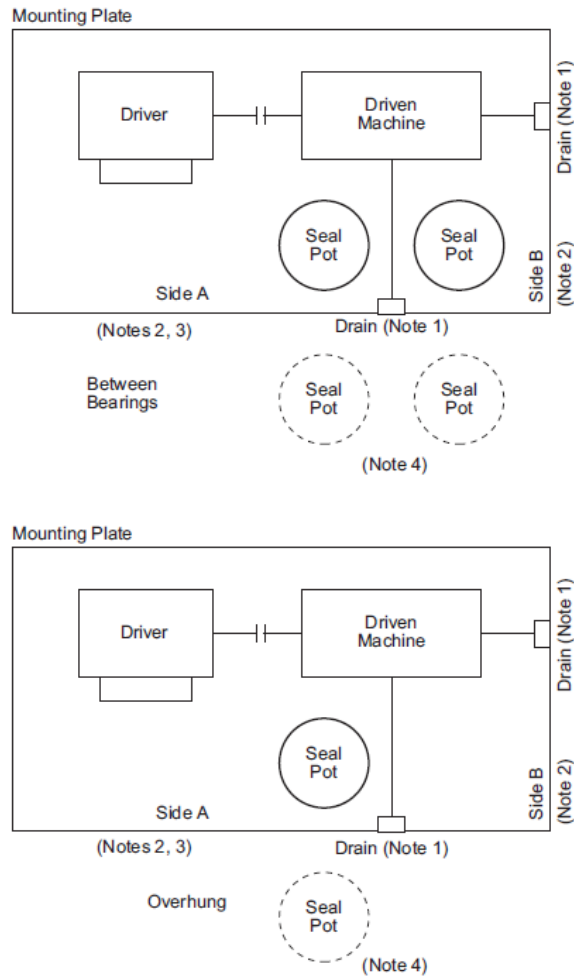
Restricted

Section	Requirements	Name	Date
6.2.17.2	All spring hanger turnbuckle lock nuts verified as tight?		
6.2.17.3	Spring hanger and spring support preset stops removed while observing dial indicators or laser tooling on the machinery coupling?		
6.2.17.4	All spring hanger and support load indicators at cold load settings?		
6.2.17.7	Spring hanger and support stops chained or otherwise secured to the spring can, to prevent loss?		
6.2.18	Oil Mist Piping Installation		
6.2.18.1	All oil mist piping joints exposed to view?		
6.2.18.2	Reducing swage nipples and reducing couplings used in place of reducing bushings?		
6.2.18.3	No welded joints in the oil mist piping system?		
6.2.18.4	Cut pipe or tubing deburred or reamed so that there is no reduction of the inside diameter or any burrs at the pipe cut?		
6.2.18.5	All piping joints threaded?		
6.2.18.5	Threaded connections only made with thread lubricant/sealant?		
6.2.18.5	PTFE tape not used?		
6.2.18.6	Each piece of pipe and all fittings swabbed with a clean, lint-free, unused cloth or wiper prior to joining and threading connections?		
6.2.18.7	Oil mist branch header to main header connections as well as drop point lateral to header connections made at the top of the header pipe?		
6.2.18.8	The oil mist application fittings (reclassifiers) connected to the machinery bearing housings with the tubing arranged to allow normal operation and maintenance access without moving the application fitting (reclassifier) or the tubing?		
6.2.18.9	Oil mist tubing installed such that no oil will be trapped?		
	Tubing benders used for bending such that the tubing will have no kinks, wrinkles, or flattened spots?		
6.2.18.10	Machinery that has previously been grease-lubricated has the grease fitting and vent passages cleaned before connection to the oil mist system is made?		
6.2.18.11	Machinery bearing housings lubricated using purge mist have permanent vent connections?		
6.2.18.12	Constant level oiler or sight glass assembly modified so that a rising oil level can overflow for machinery lubricated using purge mist?		
6.2.18.13	Oil sight glass installed in the bearing housing drain connection for machinery lubricated using pure mist?		



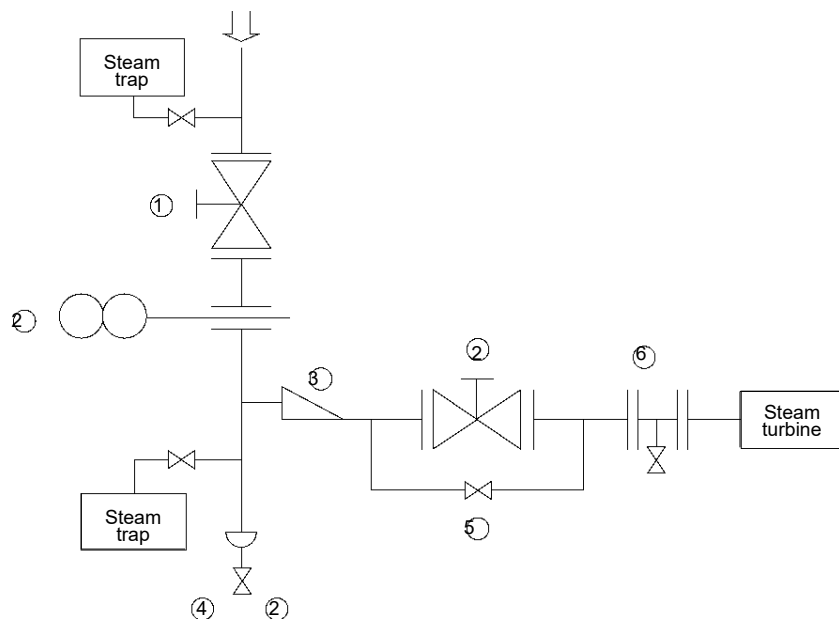
Section	Requirements	Name	Date
6.2.19	Miscellaneous Requirements		
6.2.19.1	Final shaft alignment verified after final piping bolt-up?		
6.2.19.2	Machinery shaft hand rotated to ensure that neither binding nor case distortion has occurred?		
6.2.19.4	Spring hanger turnbuckle locknuts tight?		
6.2.19.5	This piping installation checklist forwarded as specified?		
Piping Inspector:		Date:	

## Annex B (informative) Machinery Installation Piping Diagrams



- NOTE 1 Drain located at Side A or Side B.  
 NOTE 2 All tubing and auxiliary piping routed to Side A or Side B.  
 NOTE 3 Electrical connections made on Side A.  
 NOTE 4 When specified, alternate seal pot locations alongside mounting plate are acceptable.  
 NOTE 5 Verify that seal pot location and orientation does not conflict with shaft rotation and seal porting.

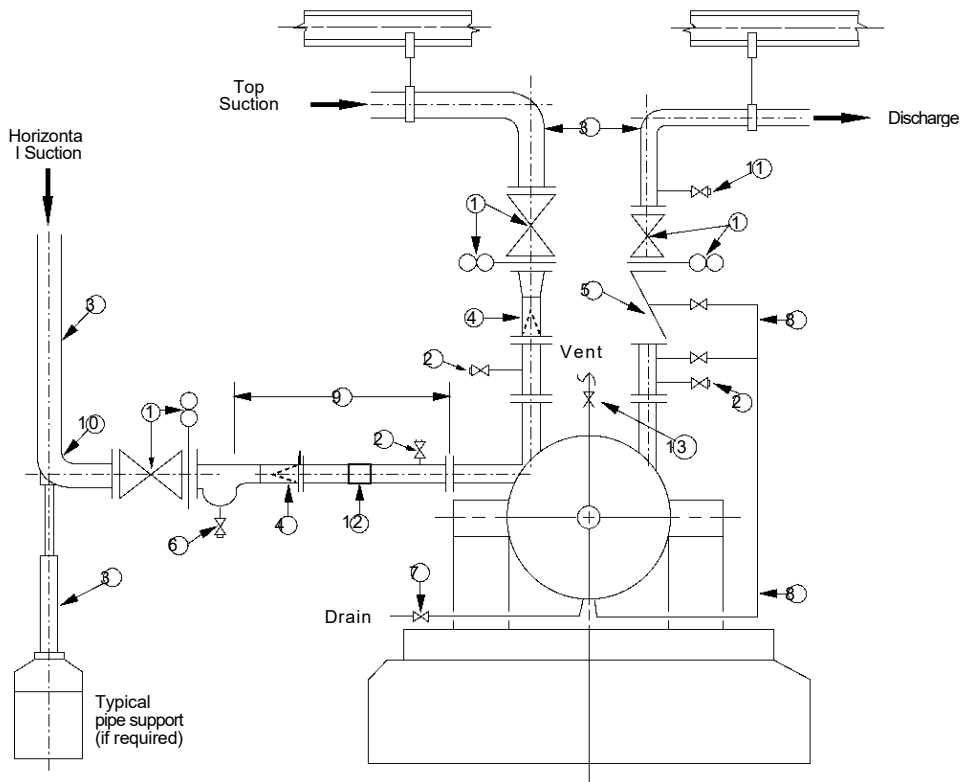
**Figure B.1—Typical Seal Pot Location**



- 1 Isolation block valves required (6.6.1). Accessible from Grade (6.5.5)
- 2 Blinds or "Double block and bleed" suggested (6.6.2.1).
- 3 Eccentric reducer flat-on-bottom (6.29.2)
- 4 Suitable drain facilities for condensate (6.19.3)
- 5 Warm-up bypass valve (6.15)
- 6 Provision for pre-commissioning blowing of steam line (6.19.3)

NOTE: References are contained in Part B

**Figure B.2—Typical Steam Turbine Inlet Piping**



- 1 Isolation block valves required (6.6.1), Blinds shall be provided (6.5.5), block valves and blinds accessible from grade (6.6.5.5).
- 2 Pressure measurement connections with isolation valves (6.9.1 and 6.9.2).
- 3 Piping to and from machinery shall be adequately supported (6.7.1).
- 4 Inlet strainer required (6.11).
- 5 Discharge check valve required for centrifugal or rotary pumps, compressors, or blowers (6.9.4). Same size as outlet nozzle (6.13.4).
- 6 Vent and drain piping NPS  $\frac{3}{4}$  or larger (6.21.1.1.4).
- 7 Piping vents and drains not located in angle section of reducer (6.14.3 and 6.14.8). Located in a convenient location (6.14.4). Drains routed to edge of baseplate if requested by Owner.
- 8 Warm-up lines for hot materials (6.15.1).
- 9 Pump suction line straight run requirement (6.22.6).
- 10 Last pipe elbow to be long radius (6.22.7).
- 11 Bypass or drain valve for check valves in vertical piping (6.13.5).
- 12 Provision for field weld (6.8).
- 13 Pump vent or equalizing line (6.22.9).

NOTE: References are contained in Part B

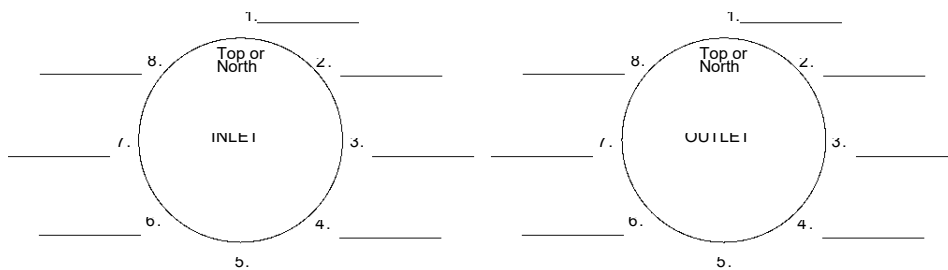
**Figure B.3—Typical Machinery Piping Schematics**

Machinery Installer: \_\_\_\_\_ Machinery Identification: \_\_\_\_\_

Feeler Gauge Readings Between  
Gasket Faces

Flange Size: \_\_\_\_\_

**Maximum Allowable Tolerances: (difference between high & low readings)**



- 0.10 mm/cm (0.001 in./in.) of flange outside diameter, not to exceed 0.75 mm (0.030 in.).
- Piping smaller than NPS 10: 0.25 mm (0.010 in.) or less.
- Only 4 feeler gauge readings, equally spaced, required on flanges 150 mm (6 in.) outside diameter and smaller.

Note: \_\_\_\_\_

**Pipe Strain Readings**

- For horizontal machinery - Dial indicator or laser readings on coupling hub flange.
- For vertical machinery - Dial indicator or laser readings on driver-mount flange.

Net Indicator Readings	Inlet Flange Bolt Up	Outlet Flange Bolt Up
Horizontal Orientation (1)	+ or – _____ $\mu\text{m}$ or in.	+ or – _____ $\mu\text{m}$ or in.
Vertical Orientation (2)	+ or – _____ $\mu\text{m}$ or in.	+ or – _____ $\mu\text{m}$ or in.

- (1) For vertical machinery, the horizontal orientation is perpendicular to pipe centerline when viewed from top.  
(2) For vertical machinery, the vertical orientation is parallel to pipe centerline when viewed from top.  
(3) Maximum shaft movement in either direction is 50 micrometers (0.002 in.)

Remarks: \_\_\_\_\_

Piping Inspector: \_\_\_\_\_

Date: \_\_\_\_\_

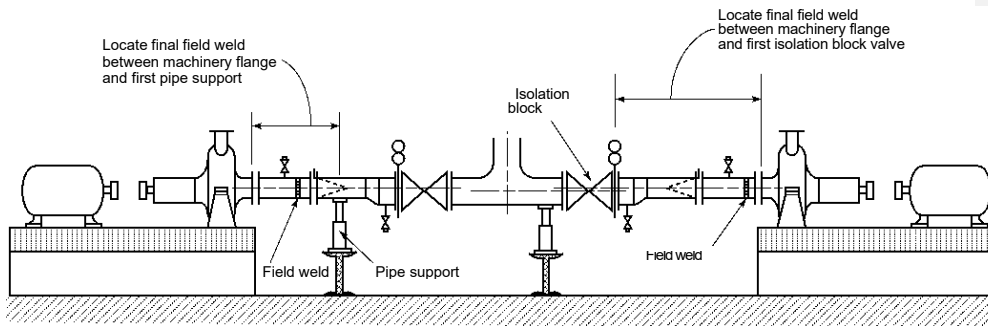
**Figure B.4—Piping Alignment Datasheet**

6.8.1 For all piping NPS 10 or larger, the piping engineering designer shall include provisions for a final piping field weld to facilitate piping installation in accordance with the machinery flange fit-up requirements.

6.8.2 The final piping field weld shall be located between the face of the machinery flange and the first pipe support or isolation block valve.

#### NOTES

Piping smaller than NPS 10 typically has sufficient flexibility that there is usually little difficulty in achieving machinery flange fit-up requirements during field installation. Thick walled pipe smaller than NPS 10 may require a final field weld due to the greater stiffness and difficulty in meeting flange fit-up requirements. Typical industry practice is to shop fabricate piping smaller than NPS 10 and not perform a final field weld providing flange fit-up requirements can be met.



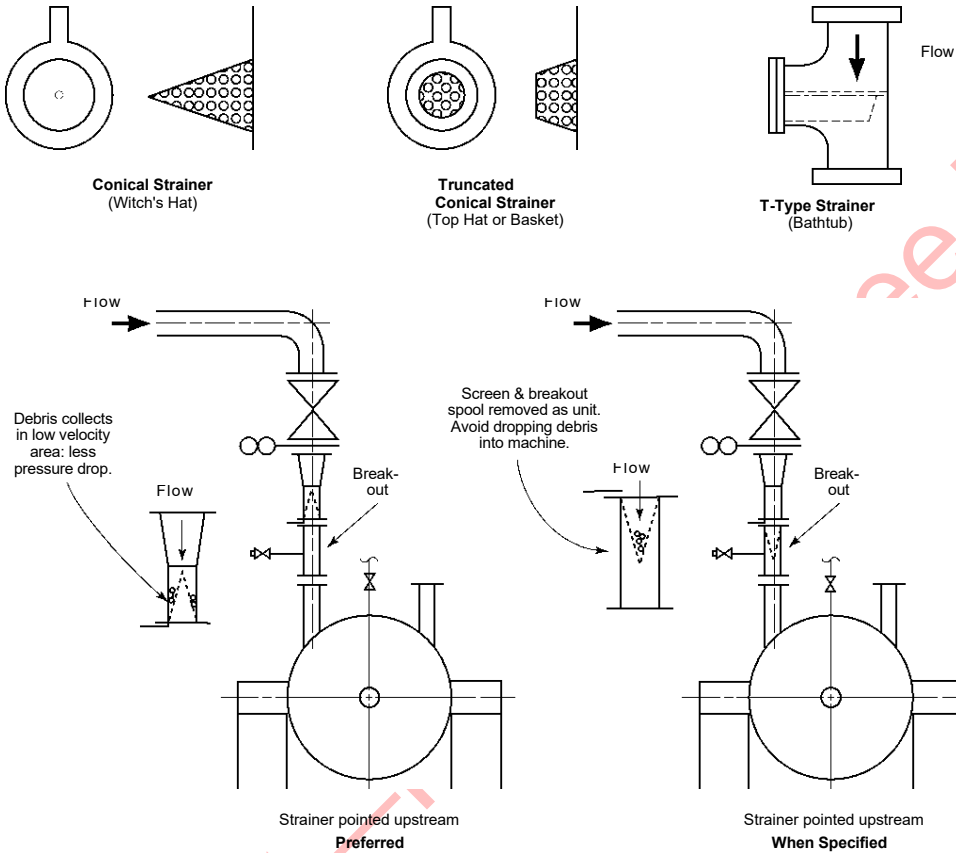
NOTE: References are contained in Part B

**Figure B.5—Final Field Weld Location**

## INLET STRAINERS

6.12.8 Acceptable temporary strainer designs include: conical, truncated conical, and T-type or similar design.

6.12.9 The point of the conical strainer shall face upstream in the piping. Screens in T-type strainers shall point with the flow.



**NOTE** Pointing the conical strainer upstream to the flow allows debris to fall to the outside of the cone around the perimeter of the pipe and so minimize the obstruction to the flow path. This is the preferred orientation for most machinery installations. Conical strainers may be installed with the point oriented downstream when explicitly specified by the designated machinery representative. This may be advantageous in situations where there are space limitations or where removal of the temporary strainer may result in the dropping of debris into the machine inlet.

**NOTE:** References are contained in Part B

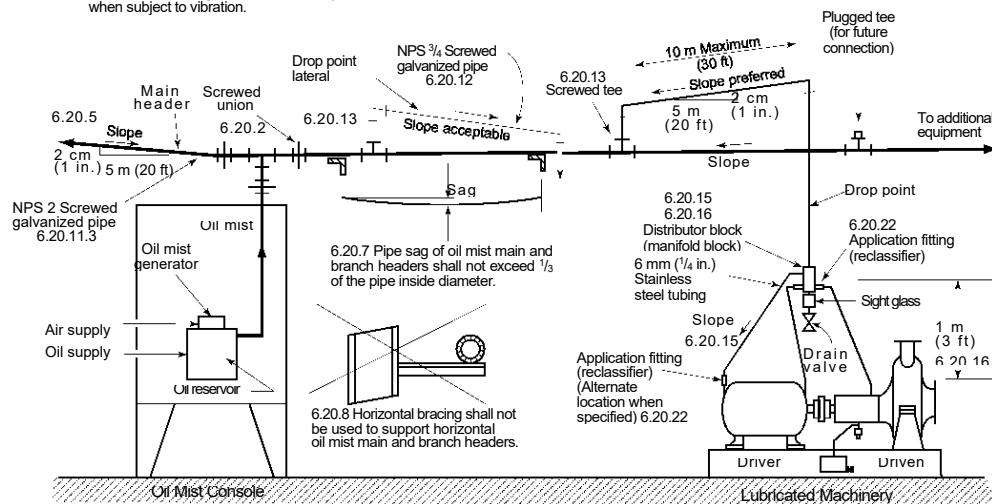
**Figure B.6—Inlet Strainers**

6.20.1 Oil mist main and branch headers shall not be valved.

6.20.13 Oil mist drop point lateral piping shall come vertically off the top of the main header through a screwed tee.

6.2.20 Oil mist drop point distribution blocks shall be equipped with a valve to permit the draining of oil. Distribution block drain valves shall be snap acting, petcock, or other type that cannot open when subject to vibration.

6.20.17 Oil mist drop point piping shall be located such that access for operation and maintenance of the machinery is not obstructed. Dismantling of oil mist drop point piping or the distribution block to remove the machinery for maintenance is not acceptable.



NOTE: References are contained in Part B

Figure B.7—Oil Mist Piping



## Spring Hanger Function Checks

### OVERALL OBJECTIVE:

To verify that spring hangers & spring pipe supports will function correctly.

6.2.7.3 Remove preset (cold) stops from spring hanger or spring support.

6.2.9.4 If spring hangers or supports are not at the cold load setting, then adjust until it is at the cold setting.

6.2.17.7 Spring hanger and support stops removed for function checks shall be chained or otherwise secured to the spring housing to

Stop Spring Support

Adjust spring  
6.2.7.3 remove preset (cold) stops from spring hanger or spring support.

6.2.17.6 If any of the spring hangers or spring supports are topped or bottomed out, or if the machinery alignment is no longer within the specified tolerances, THE PIPING DESIGN AND SPRING HANGER/SPRING SUPPORT SELECTION SHALL BE VERIFIED BY THE PIPING ENGINEERING DESIGNER.

CONSTANT

Do not adjust turnbuckle

Piping bolted-up to the machine

Install dial indicators or laser alignment tooling

6.2.17.1 Spring supports and hangers are only checked AFTER all pipe strain has been corrected. The piping shall be empty of all liquid and de-pressured prior to performing spring hanger and spring support function checks.

6.2.17.2 Verify that all spring hanger turnbuckle locknuts are tight.

6.2.17.3 The basic procedure consists of removing the preset stops from the springs and observing movement of the machinery shaft with dial indicators or laser alignment tooling.

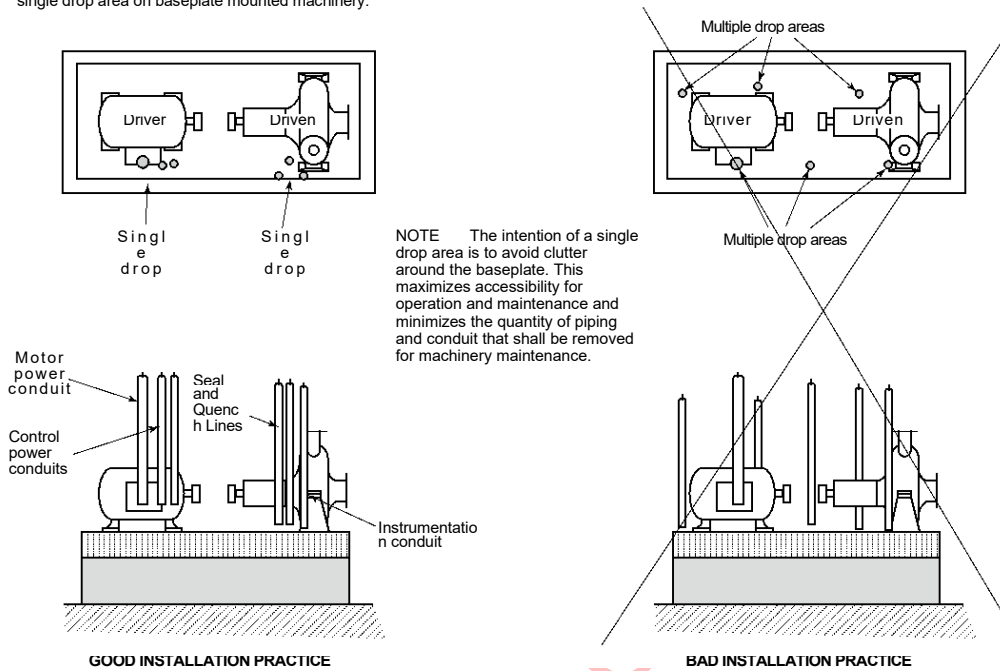
6.2.17.4 Verify that spring hangers or supports remain at (or near) the cold load setting.

6.2.17.5 If there is movement at the machinery coupling, then verify that the machinery alignment is still within the specified tolerances.

Figure B.8—Spring Hanger Function Checks

### Single Drop Area for Auxiliary Piping & Conduit

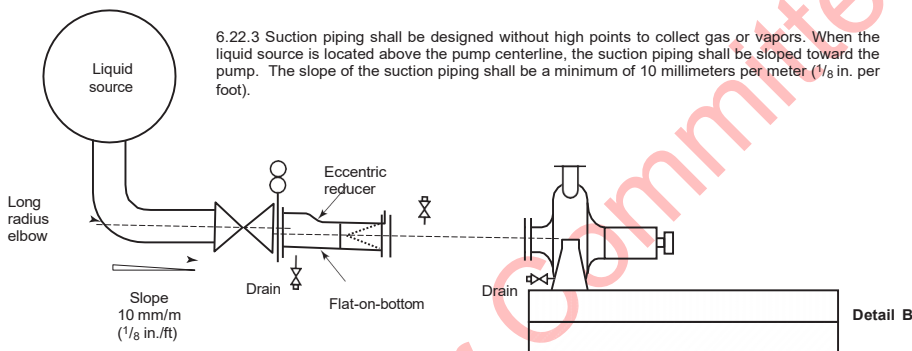
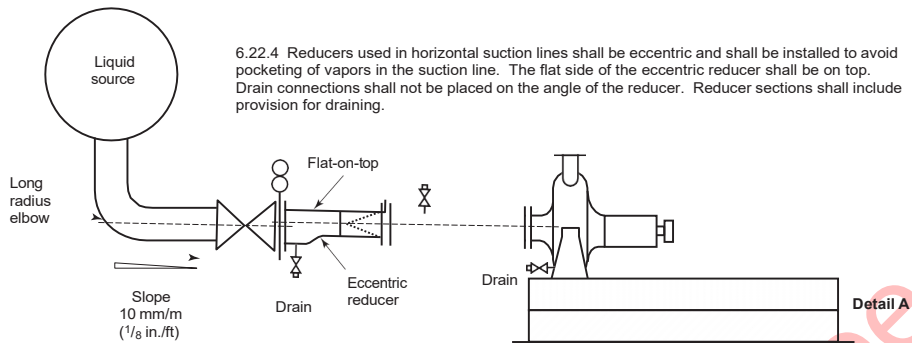
6.2.2.2 Auxiliary support piping, conduit, instrumentation, and so forth, shall be designed for a single drop area on baseplate mounted machinery.



### Single Drop Area for Auxiliary Piping & Conduit

Figure B.9—Single Drop Area for Auxiliary Piping and Conduit

## Suction Line Slope & Reducers



6.22.4 Note 2: When the piping must be completely drained to remove hazardous liquid or solids before performing maintenance, the eccentric reducer in the horizontal pump suction line may be oriented with the flat side on the bottom. For example, it is desirable that hydrofluoric acid piping be completely drained to avoid pockets of material that may prove hazardous to maintenance personnel.

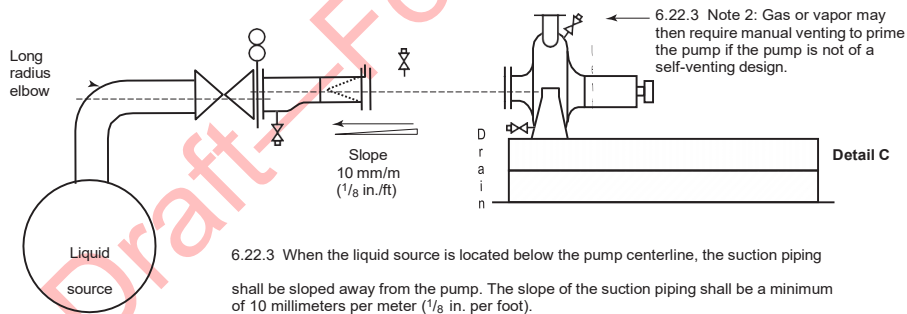


Figure B.10 – Suction Line Slope and Reducers

## Annex D (informative) Field Relief of Pipe Strain

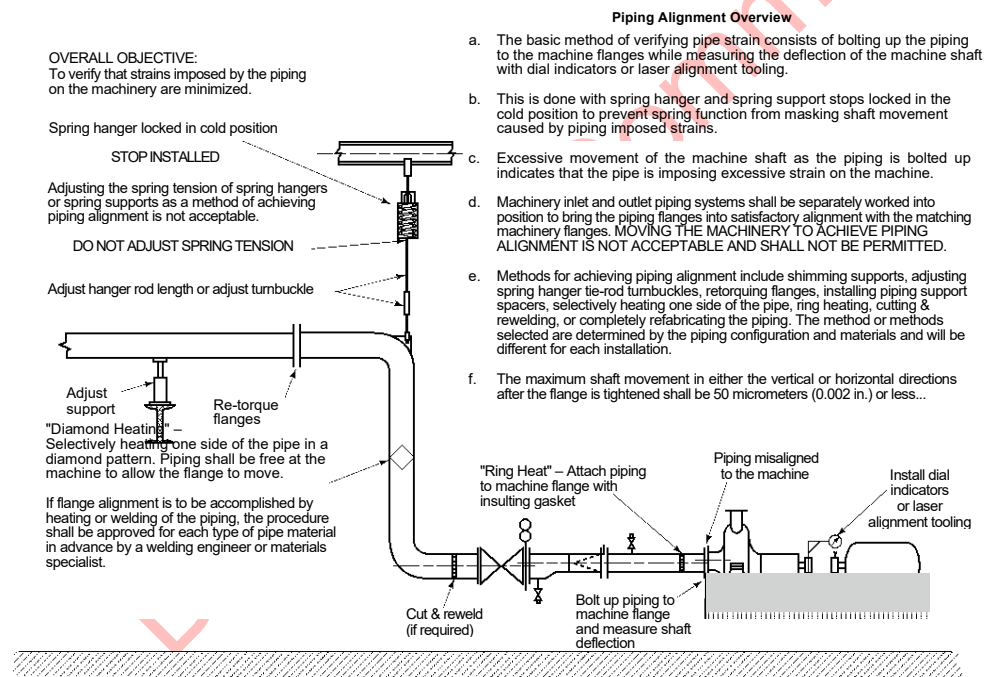
### D.1 Introduction

**D.1.1** The objective of this annex is to provide additional background instruction on the subject of the field relief of pipe-strain. The intent is that field personnel will use this information to prepare their own detailed procedures to more effectively perform this work.

**D.1.2** Refer to Figure D.1 for an overall view of the process.

### D.2 Preliminary Considerations

**D.2.1** It is essential that a metallurgist or materials engineer review all welding, stress relief and heat treatment procedures before any heating of piping in the field is attempted. This review consists of evaluating all of the piping materials, welding materials, welding fluxes, and temperatures to verify that metallurgical structures will not be adversely changed as a result. The issues to be considered include avoiding the creation of brittle areas or sensitized areas that are more susceptible to corrosion or cracking in service.



**Figure D.1—Piping Alignment Overview**

**D.2.2** It is usually advantageous to relieve excessive pipe strain by mechanical methods rather than heating of pipe. Adjusting the height of spring supports or adjusting spring hanger turnbuckles is typically more cost effective than heating or welding pipe. Consider heating pipe only after all other mechanical means have been attempted.

**D.2.3** It is important that all piping be complete before attempting to correct pipe strain. This means that the following items shall be completely installed and completed before correcting for excessive pipe strain as follows:

**D.2.3.1** The inlet and outlet piping to/from the machine shall be completely installed with all specified fittings and blinds in place.

**D.2.3.2** If temporary suction screens are specified to be in the suction of the machine, then these screens shall be installed before beginning the pipe strain relief process.

**D.2.3.3** All specified pipe supports and/or spring hangers shall be installed in the specified locations.

**D.2.3.4** All piping hydrotesting shall be complete and all temporary hydrotesting blinds removed.

**D.2.3.5** All spring supports and spring hangers shall have cold setting stops installed and be at the cold (or specified initial) settings.

### **D.3 Initial Pipe Strain Measurement**

**D.3.1** Disconnect inlet and outlet piping to/from the machine.

**D.3.1.1** For most equipment this means disconnecting the primary inlet/outlet (suction/discharge) piping. Large piping typically has greater stiffness than small piping hence can impose larger forces on the equipment.

**D.3.1.2** Auxiliary piping and/or large conduits shall also be disconnected to obtain accurate pipe strain measurements. For example, lube oil drain piping typically is of a sufficiently large size that misalignment of the piping can adversely impose pipe strain on the machine bearing housing resulting in shaft misalignment.

**D.3.2** Remove all bolts from the machinery flanges.

**D.3.3** Adjust spring supports and/or spring hanger turnbuckles to bring the piping flanges into alignment with the machine flanges.

**D.3.4** For both top and side connected piping a slight gap should be visible between the pipe flange and the machine flange. If not, then adjust the spring supports or hangers until a slight gap is visible. A slight gap means spacing approximately equal to the gasket thickness.

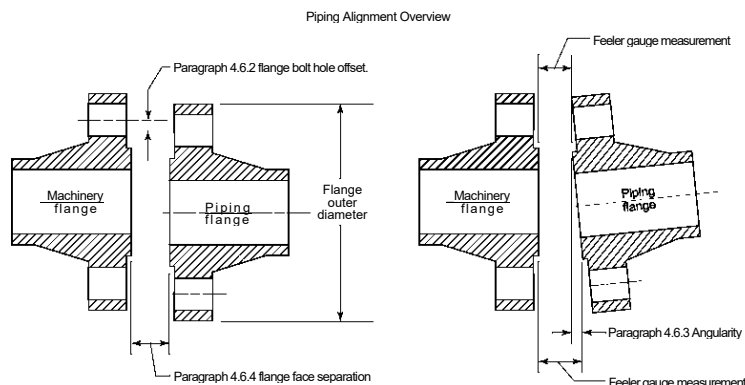
**D.3.5** Install dial indicators on the machinery shaft-coupling hub. Alternately, laser alignment tooling can be used in place of dial indicators. The dial indicators will be used to measure shaft deflection as the piping is connected.

**D.3.6** Verify pre-alignment of the driver shaft to the machine shaft. Verify that there is no machine soft-feet and that the machines are not "bolt bound." "Bolt bound" means that a machine foot is hard against a hold-down bolt and that further movement to correct misalignment cannot be made.

**D.3.7** Measure piping misalignment using feeler gages between the piping flanges.

**D.3.7.1** Piping alignment requirements are specified in Section 4. Please refer to Figure D.2 for additional guidance.

**D.3.7.2** Both axial spacing as well as angular misalignment shall be measured and compared to the specified requirements.



6.2.6.2 Pipe flange bolt holes shall be lined up with machinery nozzle bolt holes within 1.5 mm (0.06 in.) maximum offset from the center of the bolt hole to permit insertion of bolts without applying any external force to the piping.

6.2.6.4 Flange face separation shall be within the gasket spacing plus or minus 1.5 mm (0.06 in.). Only one gasket per flanged connection shall be used.

6.2.6.3 The machine and piping flange faces shall be parallel to less than 10 micrometers per centimeter (0.001 in. per in.) of pipe flange sealing surface outer diameter up to a maximum of 750 micrometers (0.030 in.). For piping flange sealing surface outer diameters smaller than 25 cm (10 in.), the flanges shall be parallel to 250 micrometers (0.010 in.) or less. Feeler gauge readings shall be taken at the outer diameter of the flange sealing surfaces.

NOTE The sealing surface of a raised face flange is the raised face. Thus feeler gauge readings are taken at the raised face. The sealing surface of a flat faced flange is the entire flange face. Thus feeler gauge readings for a flat faced flange are taken at the flange outer diameter. The sealing surface of a ring-joint flange are taken at the outer diameter of the raised face.

**Figure D.2—Piping Alignment Requirements**

### D.3.8 Measure alignment of piping flange bolt holes.

**D.3.8.1** Two flanges may be parallel and have the correct axial spacing yet still be misaligned either due to rotation of one flange relative to the other or lateral displacement of one flange to the other.

**D.3.8.2** Verification of lateral and rotational piping flange alignment is usually performed visually. If all of the flange bolting can be installed without the imposition of external force on the flanges, then the flanges are considered aligned. If there is any difficulty with insertion of the flange bolting then measurement of the flange bolt hole lateral and rotational offset is required.

**D.3.9** Work the piping flanges into alignment by shimming spring supports and adjusting spring hanger turnbuckles. Only if these mechanical methods fail then proceed with heating piping as described following.

## D.4 Heating Carbon Steel Pipe

### D.4.1 General Considerations

**D.4.1.1** The location on where to apply heat is dependent upon the piping configuration.

**D.4.1.2** Heat is to be applied to the side of the piping that is to be shortened.

**D.4.1.3** When a pipe side is shortened, the gap on that side of the flange is widened.

**D.4.1.4** Heating applied to welds and elbows tends to result in larger pipe movements.

**D.4.1.5** The piping flanges shall be loose from the machine flanges. This allows the end of the piping to move as the piping cools.

**D.4.2** A large torch heating tip is used to apply heat to the piping in an approximate diamond shape. The torch heating tip is commonly referred to as a "rosebud" tip. This process is typically referred to as "diamond heating" due to the pattern of the applied heat, please refer to Figure D.3 for guidance.

**D.4.3** The required temperature range to move the piping is between 611 °C to 722 °C (1100 °F to 1300 °F). This is a dull red color.

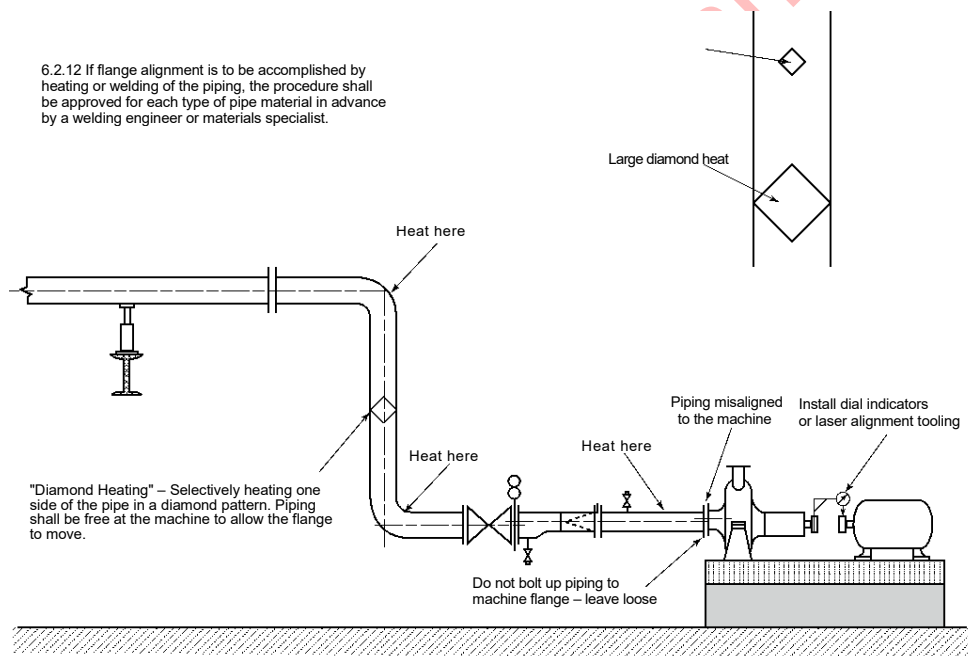
**D.4.4** Measurement of piping temperature can be done by several methods. However, portable direct reading infrared temperature instruments or contact pyrometers give the best results.

**D.4.5** Some scaling of the pipe can be expected, particularly in the upper end of the temperature range.

**D.4.6** Water quenching of the heated pipe shall not be used if the temperature inadvertently exceeds the upper end of the temperature range because of the possibility of hardening and cracking the pipe.

**D.4.7** Do not force the piping into alignment. The thermal contraction of the piping will provide the forces necessary to move the pipe.

6.2.12 If flange alignment is to be accomplished by heating or welding of the piping, the procedure shall be approved for each type of pipe material in advance by a welding engineer or materials specialist.



**Figure D.3—Diamond Heating Pipe Strain Relief**

## **D.5 Final Piping Alignment**

**D.5.1** Repeat the measurement of pipe flange alignment using visual inspection and feeler gage measurements as described previously. Pipe flanges shall be loose from the machine flanges with a visible air gap between the flange faces for this to be a meaningful measurement.

**D.5.2** Verify that the pipe flange alignment measurements are within the specified requirements.

**D.5.3** Verify that the shaft coupling hub dial indicators and/or laser alignment tooling are properly zeroed.

**D.5.4** Install the specified flange gasket and bolting into one of the machinery inlet/outlet flanges.

**D.5.5** Begin tightening the flange bolts using a "crisscross" or "star" pattern in which flange bolts on opposite sides of the flange are gradually tightened. Continue to tighten in this manner until all of the flange bolts have been tightened to the total final torque value. Initial tightening of the flange bolts shall be snug (10% of total torque). Flange bolts shall then be tightened in increments of 30% of the total torque until achieving 100% of final torque. Piping bolt torque values shall be as specified by the piping engineering designer or the machinery manufacturer taking into account whether bolt threads are lubricated or non-lubricated.

NOTE The intent is that all of the flange bolts are tight such that the proper compression of the gasket has been achieved.

**D.5.6** Observe the dial indicators or laser alignment tooling mounted on the machinery shafts or shaft coupling hubs while tightening the flange bolts. Continue to tighten the flange bolts until the final bolt torque values are reached.

NOTE It is essential to use two dial indicators during the flange bolt tightening such that both horizontal and vertical coupling movements may be observed simultaneously.

**D.5.7** The machinery shaft movement may exceed 0.05 mm (0.002 in.) while the flange bolts are being tightened. This is acceptable providing that the final movement of the machinery shaft is less than the 0.05 mm (0.002 in.) requirement.

**D.5.8** The above requirement of shaft movement less than 0.05 mm (0.002 in.) represents the total shaft movement after all machinery flanges have been tightened,

**D.5.9** If two or more machines share a common manifold or header, then all of the machines connected to the manifold or header shall be monitored for shaft movement while connecting the piping to the machine.

**D.5.10** After correct piping alignment has been completed, final alignment of the driver and driven machines may be initiated.

## **D.6 Considerations for Heating Chrome-moly Steel Pipe**

**D.6.1** Electrical methods shall be used for heating alloy steel pipe instead of open-flame/torch-based methods.

**D.6.2** Hardness tests shall be taken of the piping before and after the heating process.

**D.6.3** Bolt the pipe flange to the machinery flange using an insulating gasket between the flange faces. The purpose of this insulating gasket is to provide thermal insulation between the flanges. This insulating gasket will prevent excessive heat from being conducted across the flange faces and into the machinery case.

**D.6.4** Use electrical pipe stress heating coils with blanketing insulation to apply heat in a "ring" around the circumference of the piping.



**D.6.5** Always apply "ring" heat to the piping side of the flanges. Never apply "ring" heat to the machinery side of the pipe flange to avoid distorting the machinery casing or damaging internal components.

**D.6.6** Ring heat is typically applied in a band at least 50 mm (2 in.) wide.

**D.6.7** The required temperature is between 675 °C to 705 °C (1250 °F to 1300 °F). The piping shall be held at this temperature for at least four hours and then allowed to cool slowly.

**D.6.8** Measurement of piping temperature is best done by direct reading contact pyrometers (thermocouples).

**D.6.9** Do NOT water quench the piping due to the susceptibility to hardening.

**D.6.10** Once the piping has cooled, repeat hardness measurements and compare to initial readings. The Materials Engineer or Metallurgist shall review these hardness measurements and verify that no objectionably hard spots exist on the piping and to ascertain the need for further stress relief.

**D.6.11** Loosen the piping flange from the machine flange. Remove all flange bolts and the insulating gasket.

**D.6.12** Proceed with final piping alignment measurements as described above.

Draft—For Committee Review

## 7. Shaft & Piping Alignment

### 7.1. Introduction and Conflicting Requirements

Proper shaft-to-shaft alignment of rotating machinery is essential for long-term reliable operation. Current industry best practice indicates that following information, when applied to shaft machinery train alignment, has increased the reliability, and lowered the overall cost to operate machinery throughout the equipment life cycle. The following clauses are focused on limiting the amount of acceptable misalignment as practical, between two rotating shafts connected by a coupling. Equipment trains with more than one coupling are divided into two or more single coupling trains and treated in sequence. This section outlines specifications as recommendations for information based on Manufacturer's recommendations and current industry consensus.

#### 7.1.1. Scope

Section 7 is limited to machinery elements where at least one element is free to move in the horizontal, vertical, and axial directions. Any equipment trains in a user facility, where one or more of the elements in the train are covered by API rotating equipment standards or ASME pump standards, should use the clauses in Section 7. It is the responsibility of the supplier and purchaser to provide acceptable alignment before this type of machinery is installed in the field. The user may consider checking the alignment of this type of equipment when it is installed in the field. The procedures may be developed jointly between the user, equipment installer, and equipment supplier. Also excluded is internal equipment alignment of rotating shaft to stationary elements or internal alignment of equipment by adjusting support positions (e.g. reciprocating compressors alignment by web deflection).

#### 7.1.2. Conflicting Requirements

Any conflicts between this standard and/or the equipment vendor's procedures or tolerances should be referred to the user or the user's designated machinery representative. In general, the most restrictive tolerances should apply.

### 7.2. Definitions

Refer to Part A of this standard

### 7.3. General Requirements

#### 7.3.1. Installation Data

7.3.1.1. Prior to installation or upon receipt of equipment, the designated machinery representative or engineering project contractor needs to provide datasheets and equipment arrangement drawings with, as a minimum, the information required in 3.1.1 through 3.1.6 completed for each equipment train.

7.3.1.2. It should be the designated machinery representative's scope to obtain the necessary alignment-related information from all vendors no matter how the equipment train is purchased or packaged and to coordinate all information necessary for alignment. Further, the designated machinery representative is responsible for providing the alignment information to the equipment installer in the specified format.

7.3.1.3. All design and installation requirements need to be verified complete and signed off by machinery supplier, installation company, user and alignment technician by completing the Installation Checklist in Annex A and submitting it to the user or their designated representative.

7.3.1.4. Define movable and fixed machines in a train.

7.3.1.5. Provide equipment outline drawings with the DBSE and/or coupling spacer gap length. Detailed coupling drawings clarifying DBSE as a reference plane on the shaft or coupling needs to be provided by the coupling manufacturer.

7.3.1.6. When hydraulically mounted or keyed taper fit coupling hubs are used, the pull up dimension needs to be provided by the coupling manufacturer.

Restricted

7.3.1.7. When applicable per 3.4, ambient offset alignment ideal target readings needs to be supplied to alignment technician.

7.3.1.7.1. The coupling spacer or DBSE readings and ambient offset readings shall/should/may be at operating conditions. All factors that can have an influence upon the relative position of the rotor center of rotation or axial position needs to be considered. This includes, but is not limited to, factors such as load, ambient temperature, process pressure, and process temperature. Probably should be a clause – check all notes for this.

7.3.1.7.2. For special-purpose equipment trains the equipment vendor shall provide expected thermal growth changes and ambient offset.

1.1.1 Provide the locations of dowel pins, centering keys, keyways, bushings, and other similar items, when they are part of the equipment or required by the user.

7.3.1.8. The type of alignment method to be used by the equipment installer.

#### **7.4. Format**

7.4.1. The user may specify the checklist and alignment datasheets from this RP. Alternately, the user or designated machinery representative may furnish installation checklists and datasheet forms for documentation of equipment alignment in the field.

7.4.2. Datasheets for trains consisting of more than two shafts that should be aligned need to be reviewed and agreed between the equipment installer and the user.

NOTE The standard datasheet format can be used if a datasheet is made for each coupling and the two machinery elements connected by the coupling.

#### **7.5. Ambient Offset**

7.5.1. Ambient offset alignment readings need to be provided for general-purpose equipment trains with gearboxes by the vendor with overall unit responsibility.

7.5.2. Ambient offset alignment readings for special-purpose equipment trains need to be included on the datasheets.

NOTE For special-purpose equipment, the vendor with overall unit responsibility normally provides the thermal growth and ambient offset readings for the train. The designated machinery representative ensures this information is included on the datasheets.

#### **7.6. Operating Temperature Alignment**

The user will identify which equipment trains are to be operating temperature aligned by the equipment installer.

7.6.1. Operating temperature alignment may be required when the equipment train operates above 165 °C (325 °F).

7.6.2. Operating temperature alignment may be required on equipment trains where the user or the equipment vendor has experienced alignment-related vibration problems.

7.6.3. It may also be required on equipment trains (prototype equipment trains) where the vendor has insufficient data to accurately predict equipment growth.

#### **7.7. Alignment Fixtures and Tools**

7.7.1. The equipment installer should provide alignment fixtures (brackets) for the type of alignment specified by the user or user-designated representative. For general-purpose equipment trains, alignment brackets may be built by the equipment installer or may be a commercially available type specified by the user.

7.7.2. Unless otherwise specified, for special-purpose equipment the alignment fixtures should be made for each special-purpose equipment train. The design of the fixture needs to be agreed upon by the equipment installer and the user or the user-designated representative.

7.7.3. The equipment installer should furnish the special tools and/or equipment required for the type of alignment specified by the user.

Restricted

7.7.4. Unless specifically exempted, in the agreement between the user and the equipment installer, all special tools, alignment fixtures, and alignment brackets need to be tagged with equipment train item (identification) number and turned over to the user at the end of the project.

7.7.5. When the equipment installer is required by the user to perform operating temperature alignment requiring special tools, the equipment installer needs to be responsible for providing the special tools unless specifically excluded from the installer's scope of supply. The equipment installer needs to permanently tag and turn over to the user the operating temperature alignment fixtures and jigs at the completion of the project.

7.7.6. The use of magnetic alignment fixtures (brackets) is not recommended without approval by user designated machinery representative.

#### **7.8. Service Representative Hold Points**

The user or the designated machinery representative in conjunction with the equipment installer shall identify on the project construction plan any equipment the vendor's service representative needs to witness to maintain the equipment warranty.

#### **7.9. Alignment Types**

##### **7.9.1. General**

The user or the designated machinery representative and the equipment installer should mutually agree on the appropriate type of alignment to be used for rotating equipment trains.

##### **7.9.2. Dial-Indicator-Based Alignment**

7.9.3. Unless otherwise specified by the user, the equipment installer should use laser alignment methods to align equipment trains.

7.9.4. General requirements for reverse rim (dial) indicator method are listed in 4.2.1.1 through 4.2.1.6.

7.9.4.1. Equipment needs to be turned by hand whenever possible. When turning by hand is not possible, a strap wrench should be employed. Pipe wrenches, chain wrenches, or any other turning devices that can damage the shaft or coupling are not allowed even if the shaft is protected during turning.

7.9.4.2. Reverse rim (dial) alignment needs to be performed while turning both shafts at the same time in the direction of rotation.

NOTE 1: It is acceptable but less accurate and not efficient to do reverse dial (rim) alignment by installing a bracket on only one shaft at a time so long as both shafts are moved at the same time maintaining the same relative position.

NOTE 2: The benefit from rotating both shafts is that it maintains the same relative position and minimize the error introduced from individual shaft run out.

CAUTION Some equipment can be damaged by rotating it in the opposite direction of normal rotation. Turning of the equipment without lubrication on the sliding surfaces can cause damage.

7.9.4.3. The alignment brackets should not be used to rotate equipment. The only exception is for alignment brackets that have been specifically designed to rotate the equipment shaft without disrupting the indicators.

7.9.4.4. Readings need to be at 90 degree increments in the horizontal and vertical planes.

7.9.4.5. The installer should use a level or other positive means to locate the vertical and horizontal planes.

7.9.4.6. For readings to be considered valid, the readings and zero should repeat within 0.02 mm (0.001 in). The algebraic sum of the horizontal readings should also be equal to the algebraic sum of the vertical readings within 0.05 mm (0.002 in.) after correction for bracket sag. Typical datasheets for reverse rim indicator alignment are depicted in Annex B.

Restricted

7.9.4.7. When specified, rim and face alignment should be used for machinery alignment. General requirements for rim and face indicator method are listed in 4.2.3.1 through 4.2.3.5.

NOTE Rim and face alignment is recommended when the coupling hub or shaft end flange diameter is greater than the spacing between indicators or one of the train elements cannot be turned.

7.9.4.8. Equipment needs to be turned by hand whenever possible. When turning by hand is not possible, a strap wrench should be employed. Pipe wrenches, chain wrenches, or any other turning devices that can damage the shaft or coupling are not allowed even if the shaft is protected during turning.

7.9.4.9. Both shafts should be turned together unless it is not possible to rotate one of the machinery element shafts during the alignment process.

CAUTION—Some equipment may be damaged by rotating it in the opposite direction of normal rotation. Turning of the equipment without lubrication on the sliding surfaces can cause damage.

7.9.4.10. The alignment brackets should not be used to rotate equipment. The only exception is for alignment brackets that have been specifically designed to rotate the equipment shaft without disrupting the indicators.

7.9.4.11. Rim readings should be taken with a dial indicator.

7.9.4.12. When rim readings are made to a stationary shaft or hub, the equipment installer needs to confirm the machined surface of the stationary machine is concentric to the centerline of rotation and that the hub runout is 0.02 mm (0.001 in) or less.

NOTE This might not be possible if one of the equipment shafts cannot be turned and requires pre-installation verification and advanced planning.

7.9.4.13. Face readings should be taken with a dial indicator whenever possible.

7.9.4.14. When there is insufficient space or one of the shafts cannot be rotated, dial indicator measurements to accuracy of 0.01 mm (0.0005 in) should be used during the alignment.

7.9.4.15. Typical datasheets for reverse rim indicator alignment are depicted in Annex C.

#### 7.9.5. Non-dial-indicator-based Alignment

7.9.5.1. The laser alignment method should be used for machinery shaft alignment. General requirements for laser alignment are listed in 7.9.5.1.1 through 7.9.5.1.8.

NOTE Laser alignment is alignment by a laser beam where the laser is mounted on one shaft and a receiver or reflector is mounted on the other shaft. The deviation in the beam is measured as the shaft is rotated. There are several commercially available systems, each with different options for alignment configuration and transducer mounting.

NOTE The calibration date for the laser alignment apparatus should always be checked prior to its use. As a general rule, laser alignment tools have their calibration checked annually.

7.9.5.1.1. Interpretation of the data needs to be done by an alignment computer supplied with the laser alignment system and configured for the equipment train dimensions and ambient offset.

7.9.5.1.2. The laser alignment equipment needs to be installed for a period of time sufficient for the temperature of the brackets to equalize with the surroundings.

7.9.5.1.3. Equipment should be turned by hand whenever possible. When this is not possible, a strap wrench should be employed to rotate the equipment. Pipe wrenches, chain wrenches, or any other turning devices that can damage the shaft or coupling are not allowed even if the shaft is protected during turning.

7.9.5.1.4. Both shafts should be turned together unless it is not possible to rotate one of the machinery element shafts during the alignment process.

**NOTE** This is commonly done with the coupling temporarily bolted up. The concerns of backlash and windup can be avoided in this manner.

**CAUTION**—Some equipment may be damaged by rotating it in the opposite direction of normal rotation. Turning of the equipment without lubrication on the sliding surfaces can cause damage.

7.9.5.1.5. Alignment fixtures should not be used to rotate the equipment.

7.9.5.1.6. The location where readings are taken needs to be measured with a level or other device to positively locate the reading points in the horizontal and vertical plane.

7.9.5.1.7. Laser alignment equipment should be operated by qualified personnel.

7.9.5.1.8. The equipment installer needs to comply with all safety and control requirements for electrically powered equipment.

**NOTE** The various types of alignment procedures along with their associated advantages and disadvantages are detailed in Annex D following clause 7.

#### 7.9.6. Operating Temperature (Thermal) Alignment

7.9.6.1. There are several recognized systems for determining the change in alignment between ambient conditions and operating conditions. The designated machinery representative and the equipment installer need to agree on which equipment trains operating temperature will be used and which alignment system to use for the project. Several of the currently recognized methods for operating temperature alignment are outlined in Annex D.4.

**NOTE** Methods that involve shutting the equipment down and attempting to get alignment readings while the machine cools down are normally unacceptably inaccurate. In some cases where the machines can be checked by heating to operating conditions while the equipment is stopped, it may be acceptable to do operating condition alignment. An example of this would be to monitor alignment readings as a pump is preheated to operating temperature by back-flowing through the pump.

7.9.6.2. When operating temperature alignment is required, alignment checks need to be done with the equipment in operation. The procedure and tolerances for operating temperature alignment need to be mutually agreed upon by the designated machinery representative and the equipment installer.

7.9.6.2.1. If an equipment train exhibits misalignment-related symptoms during initial plant start-up or site testing, check first that the operating conditions are in-line with the predicted conditions and sufficient time has been allowed to assure that the equipment train is thermally stabilized (see Chapter 9 on commissioning)

7.9.6.2.2. Other potential causes, such as pipe strain, should also be investigated.

7.9.6.2.3. See the piping section of this RP (see Chapter 6) for pipe strain requirements and checks.

7.9.6.2.4. If an equipment train continues to exhibit misalignment symptoms, the user or designated machinery representative may coordinate with the equipment installer to fit an operating temperature alignment system that will indicate changes in relative shaft position of equipment from ambient conditions up to operating conditions.

7.9.6.3. The equipment installer may be directed during testing or start-up to adjust ambient offset of an equipment train provided with an operating temperature alignment system. The ambient cold offset data should be provided by the designated machinery representative.

#### 7.10. Field Alignment Requirements

##### 7.10.1. Pre-alignment

Prior to alignment of an equipment train, the pre-alignment activities outlined in 5.1.1 through 5.1.13 should be completed by the equipment installer.

7.10.1.1. A pre-alignment meeting should be held between the designated machinery representative and the installer's personnel responsible for machinery alignment activities.

7.10.1.2. The foundation needs to be cured and baseplate or soleplate installed and levelled in accordance with the procedures outlined in other sections.

7.10.1.3. The equipment needs to be installed on the **baseplate or soleplate** or plates with the component that is designated fixed, not obstructed by hold-down bolts.

Restricted

NOTE It's desirable but not always possible for the designated fixed piece of equipment to be centered in the hold down bolts.

7.10.1.4. Prior to beginning alignment activities, the coupling hubs should be installed in accordance with the equipment arrangement drawing and instructions including design pull-up and final hub position on the shaft.

7.10.1.5. Coupling hub run-out readings need to be taken at the coupling hub rim on machined surfaces perpendicular to the centerline of rotation.

7.10.1.6. Coupling hub run-out readings need to be taken on the face of the coupling hub machined surfaces as far as practical from the shaft center of rotation.

7.10.1.7. Installed coupling hubs should have 0.025 mm (0.001 in.) or less total indicated runout (TIR) or the equipment vendor's requirements, whichever are more restrictive. This limitation applies both to the coupling rim as well as to the coupling face. Consider using "radial reference surface" and consider a 0.002" or 0.003" TIR

7.10.1.7.1. Special-purpose equipment coupling hub run-out requirements often will be more restrictive.

7.10.1.7.2. General-purpose equipment with elastomeric-style couplings may be exempted if there are no machined surfaces provided on the coupling hub.

7.10.1.7.3. The presence of significant runout (half of the alignment tolerance or more) will require the rotation of the shafts together (temporarily coupled) or remedial actions.

7.10.1.8. Prior to grouting, a preliminary shaft alignment should be complete.

7.10.1.9. Final alignment tolerance need not be achieved, but the equipment installer needs to confirm that the required axial, horizontal, and vertical alignment tolerances are achievable during final alignment without modifications to the machinery or hold-down bolts.

7.10.1.10. The designated machinery representative should approve the machinery preliminary alignment prior to grouting.

7.10.1.11. Grouting of the machinery baseplate or soleplate should be completed, cured, and approved by the designated machinery representative.

7.10.1.12. If dial indicator alignment is to be done, the sag measurement for the fixture to be used need to be completed and recorded.

7.10.1.13. Sag measurements should be recorded for the 3, 6, 9, and 12 o'clock positions.

NOTE: Alignment brackets may have different amounts of sag in the 3 and 9 o'clock positions and should be compensated for while doing the alignment.

7.10.1.14. The torque requirements for the equipment feet hold-down bolting are established in accordance with the vendor's specification or user's requirements. If there is no figure available from the equipment vendor and the designated machinery representative approves, Annex E torque values can be applied.

7.10.1.15. The equipment installer needs to confirm there is necessary lifting equipment, suitable jacks, or jack bolts to elevate the movable equipment sufficiently to install shims.

7.10.1.16. If jack bolts were not provided, the equipment installer should provide suitable means to horizontally and axially move and restrained machinery accurately to 0.02 mm (0.001 in).

7.10.1.17. The equipment installer should confirm equipment hold-down bolts and any special washers supplied are available. Undercut hold-down bolts are not acceptable.

7.10.1.18. Before starting alignment, the equipment needs to be disconnected from piping and conduit as much as possible.

7.10.1.19. Except in special cases agreed upon by the user, both the movable and fixed equipment should be free to turn.

Restricted

7.10.1.20. Pumps with mechanical seals should have the seal locking tabs disengaged before turning the equipment to obtain alignment readings.

7.10.1.21. Any packing or blocking material that interferes with shaft rotation needs to be removed from the machinery.

7.10.1.22. Provide lubrication for bearings during turning. See machinery instruction manual for lubrication type and proper viscosity.

7.10.1.23. Equipment outline drawings and vendor's instructions should be available during alignment.

7.10.1.24. Datasheets with desired final readings should be provided for the type of alignment specified by the equipment design company.

7.10.1.24.1. Prepare an alignment table for the rotating equipment on sizable projects (sizable meaning a large number of grouted pieces of equipment).

7.10.1.24.2. The table should include the alignment method, cold alignment target, hot alignment target (if appropriate) and the required tolerances.

7.10.1.24.3. The size and required torque of the hold-down bolts should also be included.

#### 7.10.2. Qualifications

7.10.2.1. The equipment installer for a project needs to demonstrate the competence of personnel to perform alignment of general-purpose equipment trains to the satisfaction of the designated machinery representative. It is not the user's responsibility to train the equipment installer's personnel in analytical or graphical methods of alignment.

#### 7.10.2.2. Documentation and Witness of Alignment

7.10.2.2.1. It is the responsibility of the equipment installer to record and maintain all alignment records and datasheets in the user-specified format.

7.10.2.2.2. At the completion of the project, the equipment installer should provide original copies of alignment records along with other project rotating equipment records to the user.

7.10.2.2.3. When applicable, documents should include raw and sag compensated alignment readings, axial spacing and shaft axial positions relative to thrust bearings and gear mesh. The readings at 3 and 9 o'clock positions need to be referenced to some physically fixed position near the equipment.

7.10.2.2.4. The equipment installer should provide notice to the designated machinery representative of witness (hold) points.

7.10.2.2.5. The notification period should be agreed on between the equipment installer and the designated machinery representative. As a guideline, the notification should be 24 hours for local (resident) representatives. Five working days' notice may be necessary when the representative is not local or when vendor's service representative witness "hold" point is required.

7.10.2.2.6. The designated machinery representative or designee should be witnessed and accept final alignment with and without pipes connected, or any other critical points defined by the user.

#### 7.10.3. Alignment Tolerances

##### 7.10.3.1. Axial Spacing Tolerance

7.10.3.1.1. For flexible-element couplings, the coupling spacer gap length or distance between shaft ends (DBSE) needs to be set as specified on the construction package datasheet or general arrangement drawing or within  $\pm 0.50$  mm ( $\pm 0.020$  in) unless a closer tolerance is specified by the vendor.



- 7.10.3.1.2. For spacer couplings, the coupling spacer free length needs to be measured and documented when setting the spacer gap length.
- 7.10.3.1.3. When applicable, the expected relative movement of the shafts should be included in the calculation of the spacer gap length for general-purpose equipment.
- 7.10.3.1.4. For special-purpose equipment, the expected relative movement of the shafts needs to be accounted for in the setting of spacer gap length. The manufacturer should provide axial spacing and tolerances.
- 7.10.3.1.5. Axial alignment needs to be done after the motor magnetic center is marked during field or factory run-in.
- 7.10.3.1.6. The motor shaft needs to be located on magnetic center.
- 7.10.3.1.7. If the motor cannot be run for magnetic center due to an end fan, the motor manufacturer needs to specify the shaft position.
- 7.10.3.1.8. Spacer gap length for steam turbines and process equipment with hydrodynamic thrust bearings need to be set with the shafts against their respective active thrust bearings.
- 7.10.3.1.9. The axial tolerance for DBSE or spacer gap length of equipment trains with gear or elastomeric couplings should be set as required by the coupling or machinery vendor.
- 7.10.3.1.10. The DBSE or spacer gap length shown on equipment arrangement drawing or coupling vendor's drawings should be held within 1.00 mm ( $\pm 0.040$  in) unless a closer tolerance is specified.
- 7.10.4. Shim Requirements
- 7.10.4.1. The maximum allowable number of shims under any equipment support foot is five.
- 7.10.4.2. The movable machine should have a minimum of 3 mm (0.125 in.) of series 300 stainless steel shims under each support foot.
- 7.10.4.3. The maximum shim stack height under each foot should not exceed 6 mm (0.25 in).
- 7.10.4.4. Only one 3 mm (0.125 in) or thicker shim per mounting foot is recommended.
- 7.10.4.5. All shims should be full face load bearing. Properly selected, commercially available precision cut slotted shims are acceptable on general purpose equipment.
- 7.10.4.6. Shims for special-purpose equipment should be supplied from the equipment vendor.
- 7.10.4.7. If a shim needs to be made on site, it should be patterned from the equipment vendor's shim or support foot.
- 7.10.4.8. Ground shims should have a surface finish of 64 Ra.
- 7.10.4.9. The use of tapered shim packs, laminated or peel-able shims, brass shims, aluminium shims, plastic shims and shims thinner than 0.05 mm (0.002 in) is not permitted.
- 7.10.4.10. Shims should be finished flat to within 0.1 mm per dm (0.001 in.. per in.) of length.
- 7.10.4.11. Pre-cut shims from the equipment vendor or a commercial source acceptable to the user shall be used.
- 7.10.4.12. If agreed by the user or user's designated representative, cut shims from rolled shim stock may be substituted.

Restricted

7.10.4.13. Shims should have cut outs approximately 6 mm (0.25 in.) larger than the diameter of any vertical jack bolts, so as to clear the jack bolt.

7.10.4.14. Individual shim thickness should be measured prior to installation.

7.10.4.15. For large shims, greater than 150 mm (6 in.) long or with an area greater than 150 cm<sup>2</sup> (25 in<sup>2</sup>), the measurement needs to be in two or more locations to confirm the flatness requirement.

7.10.4.16. The final stack-up of shims under each equipment support point used for alignment should be measured and documented on equipment installation records.

7.10.4.17. Measurement should be recorded to the nearest 0.02 mm (0.001 in).

7.10.4.18. Alignment shims used on centerline or near centerline-supported equipment should not extend beyond the machined support pads.

7.10.4.19. The use of shims under special-purpose machinery gearboxes to correct for soft-foot or gear tooth contact is NOT permitted.

7.10.5. Mechanically Adjustable Chocks, if specified can be used.

OEM instructions should be followed to install mechanically adjustable chocks

7.10.6. Bolts and Bolt Clearance

7.10.6.1. Under cutting of hold-down bolts for alignment is not permitted.

NOTE Vendors can supply special reduced diameter hold-down bolts for engineered increased stretch at a given preload. These specialty bolts are not provided for additional alignment movement, nor should the reduced section come into contact with other metal surfaces.

7.10.6.2. Lock washers are not permitted at machinery hold-down bolts.

7.10.6.3. If special washers are not provided by the equipment vendor or standard washers yield when the hold-down bolts are torqued to the required value, the installation contractor should provide thick, hardened and ground washers at the hold-down bolts.

7.10.6.4. In the absence of suitable washers from the equipment vendor, the equipment installer should obtain washers that do not permanently deform. The user may provide the size (thickness, outside diameter, and inside diameter) and material requirements for the washers.

NOTE Due to the clearance necessary for hold-down bolts, standard thickness washers often are insufficient to distribute the bolt clamping force to the equipment foot without excessive deflection or yielding of the washer.

7.10.6.5. Hold-down bolts shall not be bolt bound.

7.10.6.6. The equipment installation contractor should record the following on the datasheets for special-purpose equipment:

- a) the size of the hold-down bolt,
- b) confirmation that the minimum clearance is acceptable, and
- c) the torque to tighten the bolt.

Table E.1 and Table E.2 should be used for torque value unless otherwise specified by the user or the equipment vendor.

NOTE Some types of equipment have hold-down bolts that are not to be tightened fully and are set to allow thermal expansion. These applications may also include a sleeve to maintain a gap from 0.005 in. to 0.010 in. (0.1 mm to 0.25 mm) between the top of the foot and the bottom of the bolt head. The vendor's installation manual should be consulted to determine if there are movable feet under any hold-down bolt and tighten accordingly.

7.10.7. Soft Foot

Restricted

7.10.7.1. The soft-foot check needs to be done with piping disconnected from the equipment.

7.10.7.2. A soft-foot check needs to be made prior to grouting and after grouting during final alignment on each equipment foot.

7.10.7.3. The maximum permissible movement is 0.05 mm (0.002") at each foot.

NOTE In certain applications with high thermal growth anticipated, higher soft-foot values can be acceptable with approval between the manufacturer and the user or their designated machinery representative (under hot running conditions, this soft-foot condition is eliminated).

7.10.7.4. All hold-down bolts should first be tightened to the specified torque value.

7.10.7.5. If available, use the torque specified by the equipment vendor at the support foot hold-down bolts.

7.10.7.6. If there are no torque requirements specified by the vendor, then use Table E.1 and Table E.2.

7.10.7.7. Measurement should be taken as the bolt is loosened.

7.10.7.8. The hold-down bolt should be tightened before going to the next foot.

7.10.7.9. Soft foot checks need to be made on each equipment foot when aligning with dial indicators and not at the coupling.

NOTE: Casing distortion due to soft-foot is sometimes not readily measurable at the shaft end using dial indicators. Sensitivity of the equipment to distortion can cause alignment or operational problems even with little detectable (at the shaft end) soft-foot. The measurement of soft-foot close to the foot-hold-down-bolt location is always preferable when using dial indicator alignments methods.

7.10.7.10. After soft-foot checks are made, the installer should confirm hold-down bolts at equipment sliding feet are torqued in accordance with the vendor's instructions.

#### 7.10.8. Recording of Alignment Readings

7.10.8.1. Alignment readings should be recorded before and after connecting the piping and conduit (see 4.8 of Chapter 6 for allowance).

7.10.8.2. The alignment both before and after the piping is connected should be within the alignment acceptance criteria of 7.10.8.

#### 7.10.9. Shaft Centerline Relationship Tolerance

7.10.9.1. Unless the vendor's tolerance is more restrictive, the installer needs to align all machinery trains to the tolerance given in 5.4.6.2.

NOTE Remember to account for factors, such as, thermal offset, dial indicator sag, etc. during alignment.

7.10.9.2. When using reverse rim (dial) indicator methods or laser alignment equipment that resolves alignment into reverse rim equivalent readings, the maximum out of tolerance is 0.25 mm per meter (0.0025 in. per in.) at both flex plane locations.

7.10.9.2.1. Actual misalignment is TIR/2 divided by the distance between indicators.

7.10.9.2.2. Misalignment capability is determined by the coupling design and the separation between the flexing planes (or typically the spacer length). Coupling alignment capabilities shall not be used as the alignment criteria for rotating equipment.

## SHAFT ALIGNMENT TOLERANCES

RPM	OFFSET (mils)		GAP (mils/10")		SPACER SHAFT (mils/in.)	
	EXCELLENT	FAIR	EXCELLENT	FAIR	EXCELLENT	FAIR
600	5.0	9.0	10.0	15.0	1.8	3.0
900	3.0	6.0	7.0	10.0	1.2	2.0
1200	2.5	4.0	5.0	8.0	0.9	1.5
1800	2.0	3.0	3.0	5.0	0.6	1.0
3600	1.0	1.5	2.0	3.0	0.3	0.5
7200	0.5	1.0	1.0	2.0	0.15	0.25

All Speeds: Maximum Soft Foot Reading 2.0. Use OEM or in-house tolerances if available.  
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7.10.9.3. Angularity needs to be determined at each hub on spacer couplings. The tolerance applies at each hub (flex plane) location.

NOTE 1 Close coupling increases the severity of misalignment effects and thus requires at least the same level of precision as other arrangements.

NOTE 2 The choice of coupling type (and its published "capability") is not the determiner of the equipment alignment requirements.

7.10.9.4. After completion of alignment and installation of piping, all equipment should be turned by hand or strap wrench to ensure that detrimental case distortion has not occurred during the equipment alignment.

7.10.9.5. Final alignment should be done after the process piping is complete and hydrostatic test blinds have been removed from the system.

7.10.9.6. If the piping is disturbed after final alignment has been accepted by the user, equipment train alignment should be re-checked and approved by the user.

7.10.9.7. If equipment movement was not monitored during the piping changes, the entire alignment check should be redone starting with the piping disconnected and the flanges separated at the machine.

7.10.9.8. If the piping is disturbed after final alignment has been accepted by the user; equipment train alignment should be re-checked and approved by the user.

7.10.10. Sag

7.10.10.1. The maximum allowable sag for dial indicator brackets/fixture system used for alignment should not exceed 0.8 mm per meter (0.0008 in. per in.) of span.

7.10.10.2. Sag should be measured by the installation contractor and recorded on quality forms.

7.10.10.3. Each dial indicator and fixture combination to be used during alignment of a given equipment train will be measured for sag prior to equipment alignment.

7.10.11. Gear Procedures

7.10.11.1. The gear vendor needs to provide the relative change between the at-rest and the operating centerline of the gears.

7.10.11.1.1. If not given by the gear vendor, Figure F.1 and Figure F.2 may be used to locate the running loaded position of the gear and pinion relative to the bearing clearance.

7.10.11.1.2. The mechanical movement should be added to the thermal growth when determining ambient offset.

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7.10.11.1.3. Whenever gear train with hydrodynamic bearings is aligned, the shaft lift due to gear reaction forces should be accounted for as well as the thermal growth.

7.10.11.1.4. The shaft lift of the gear and/or pinion at load within the bearing clearances may be more than the equipment alignment tolerance.

7.10.11.2. For double helical gears, the axial spacing between the shaft end of the gear and adjacent equipment should be determined after the gear (low-speed) shaft is set in the center of the thrust bearing float. The pinion is centered axially.

**7.10.11.3.** The thermal growth in the horizontal and vertical direction should be included in the calculated alignment for gear trains.

7.10.11.4. The gearbox is typically considered to be the fixed element. Prior to alignment of coupled equipment to the gear, gear soft-foot and tooth contact pattern and area checks should be made and approved by the user.

7.10.11.5. Shimming of gears to correct gear contact pattern is not permitted unless approved by the user and the gear vendor.

7.10.11.6. If a shim needs to be used to adjust gearbox height it should be a ground shim (spacer) under the entire gearbox support area.

7.10.11.7. Gear tooth contact pattern, contact area, and soft-foot should be approved by the designated machinery representative after the shim (spacer) is installed.

NOTE: Shimming of a gearbox to correct gear contact pattern is usually indicative of a poor/non-level gearbox support base or a manufacturing error in the gearbox or a soft foot. Gear tooth contact pattern and area are very important to the life of a gearbox and need to be within the gear vendor's guidelines. Manufacturing tolerances are very close, and relatively small distortion of the gear case during initial installation can significantly reduce gear life.

#### 7.10.12. Bearing Type

Ambient offset needs to account for special case bearing types where running position centerline may deviate significantly from the rest position.

NOTE The type of bearing can significantly alter the running position versus rest position of the shaft centerline. An example of this is a radial tilt pad bearing with load between pads.

#### 7.10.13. Fixed Component

General guidelines for determination of fixed and moveable elements in a train are outlined in 5.8.1 through 5.8.3.

7.10.13.1. Trains with a gear typically have the gear as the fixed element.

7.10.13.2. For trains without a gear, the equipment with the most rigid process nozzle should be considered as the fixed element.

7.10.13.3. For trains with a motor, the motor should be the movable element.

#### 7.10.14. Dowels

7.10.14.1. Tapered dowels with threaded outer ends and hex nuts (self-extracting) should be used for doweling equipment.

7.10.14.2. With the exception of gearboxes (see 5.9.4), equipment feet for general-purpose trains should not be doweled unless specified by the user.

7.10.14.3. When doweling is specified by the equipment manufacturer, the equipment should be doweled by the installer in accordance with the instructions of the designated machinery representative.

7.10.14.4. Dowels should be installed after final alignment.

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7.10.14.5. Unless otherwise specified by the user or gear vendor, a gear should be doweled as close as possible to the vertical centerline of the highest speed gear element.

**7.10.14.6.** When the gear is the fixed element in the equipment train, dowels should be installed after alignment with the piping connected, but before the equipment train is in operation.

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**Annex A**  
(normative)

**Machinery Installation Shaft Alignment Checklist**

Section	Requirements	Name	Date
<b>7.10</b>	<b>Pre-alignment</b>		
<b>7.10.1.1</b>	Pre-alignment meeting held.		
<b>7.10.1.2</b>	Foundation cured and baseplate or soleplate installed.		
<b>7.10.1.3</b>	Equipment installed and fixed machine centered on holes.		
<b>7.10.1.4 thru 7.10.1.6</b>	Coupling hubs runout rim and face readings are 0.05 mm (0.002 in.) or the manufacturer's requirement, whichever is less.		
<b>7.10.1.5</b>	Initial alignment made and approved by user's representative.		
<b>7.10.1.11</b>	Grout installed.		
<b>7.10.2.2.3</b>	Fixtures and tools on hand. Record sag measurements at clock positions.		
<b>7.10.1.14</b>	Torque requirements for the hold-down bolts _____.		
<b>7.10.1.15</b>	Equipment available to lift the movable machine and move it in the horizontal and axial directions.		
<b>7.10.6.3 thru 7.10.6.4</b>	The washers are thick enough at the hold-down bolts, and if not, obtain sufficiently thick washer.		
<b>7.10.7.1</b>	All piping is disconnected.		
<b>7.10.13.1 thru 7.10.13.3</b>	Fixed and moveable machine shafts free to turn.		
<b>7.10.1.20</b>	Pump seal locking devices disengaged.		
<b>7.10.1.21</b>	Packing or blocking material removed.		

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7.10.1.22	Lubrication provided for bearings.		
7.10.1.23	Drawings and datasheets available. With complete installation information, including; hub draw, methods, hot/cold offset, and torques.		
7.10.3	<b>Alignment Tolerances</b>		
7.10.1.18	All piping is disconnected.		
7.10.3.1.1	Movable and fixed machine rotors DBSE or coupling spacer gap length = _____ when set to running position.		
7.11.3.1	Coupling spacer free length = _____.		
7.3.1.7.2	DBSE or coupling spacer gap length corrected for thermal growth required = _____ and is within $\pm 0.5$ mm ( $\pm 20$ mils) of required DBSE or actual coupling spacer free length for and flex couplings. For gear and elastomeric couplings the requirement is $\pm 1.00$ mm ( $\pm 40$ mils).		
7.10.4.1	Maximum five shims under any support.		
7.10.4.2	Shims series 300 stainless steel or better material, (not laminated) and flat to $1/1000$ in. At least 3 mm (0.125 in.) but not more than 6 mm (0.25 in.) under movable machine foot. Not more than one 3 mm (0.125 in.) thick shim under any foot.		
7.10.4.5	Shims and spacers are full load bearing or properly selected commercially available slotted shims on general purpose equipment.		
7.10.1.17	Bolts are not undercut.		
7.10.6.2	Washers are not lock washers and do not yield when hold-down bolts are tightened.		
7.10.6.4	Record the hold-down bolt size, acceptance of the minimum clearance, the required bolt torque and any required "expansion gap" value (for movable feet).		
7.11.6.4	Hold-down bolts tightened to manufacturer's or user's instructions.		
7.10.7.3	Soft-foot is not more than 0.05 mm (0.002 in.) at the hold-down bolt.		
7.9.4.6	Sag of alignment fixture recorded _____ and no more than 0.8 mm per m (0.8 mils per in.).		
7.10.3	Alignment within tolerance (see 5.4.6) before pipes and conduit attached.		

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	Pipe strain checks made in accordance with procedure in Chapter 6 (6.2.16).		
<b>7.10.3</b>	Alignment within tolerance (see 5.4.6) after pipes and conduit attached. Actual datasheets and alignment achieved attached or turned over to the equipment user (see 5.3.1 and 5.3.2). This should include both the raw data and the sag compensated data and both clearly indicate orientation of the data to a common fixed reference/position.		
<b>Equipment Identification Number:</b>			
<b>Alignment Inspector:</b>		<b>Date:</b>	

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**Annex B**  
(informative)

**Reverse Rim Dial Datasheet**

Project Number: \_\_\_\_\_

Plant: \_\_\_\_\_

Unit: \_\_\_\_\_

Movable: Item: \_\_\_\_\_  
Type: \_\_\_\_\_

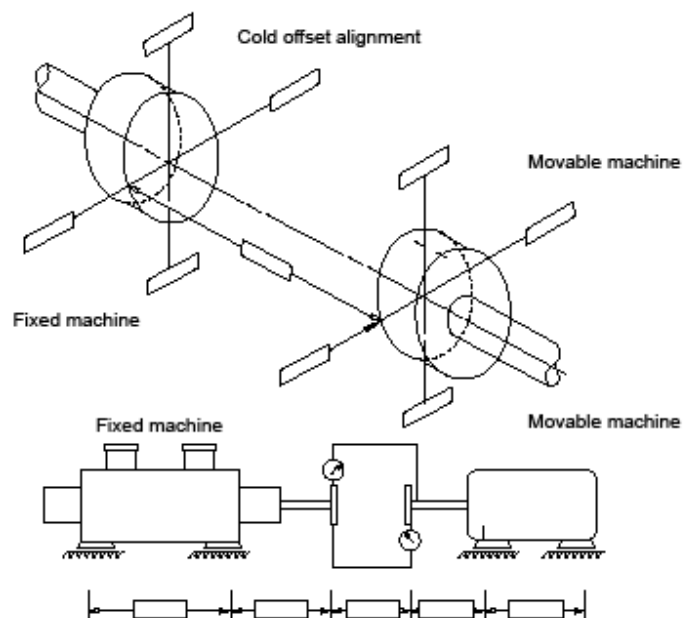
Manufacturer: \_\_\_\_\_  
Serial \_\_\_\_\_

No.: \_\_\_\_\_

Fixed: Item: \_\_\_\_\_

Manufacturer: \_\_\_\_\_

No.: \_\_\_\_\_



Date: \_\_\_\_\_

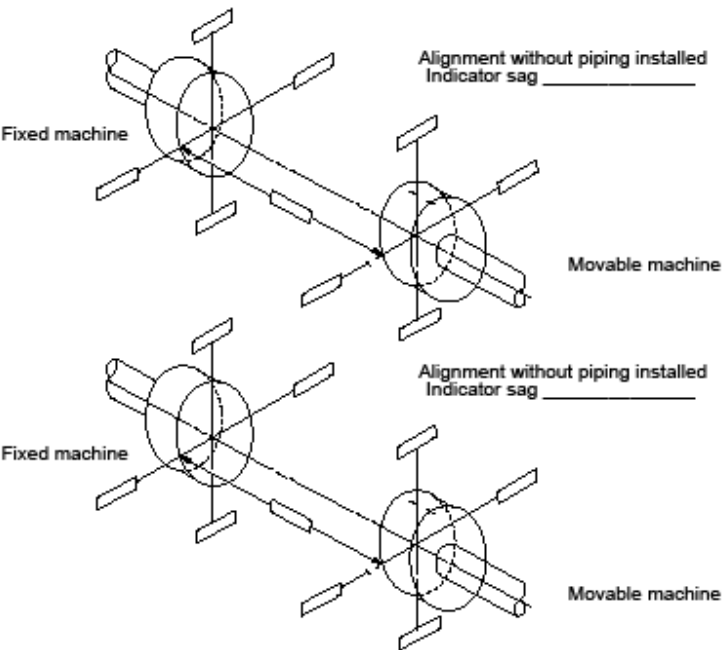
Project Number: \_\_\_\_\_

Plant: \_\_\_\_\_

Restricted

Unit: \_\_\_\_\_

Movable:      Item: \_\_\_\_\_  
Type: \_\_\_\_\_



**Shims Tabulation**

Fixed IB Left	_____	Move. IB Left	_____
Fixed IB Right	_____	Move. IB Right	_____
Fixed OB Left	_____	Move. OB Left	_____
Fixed OB Right	_____	Move. OB Right	_____

NOTE    All shims are recorded looking to the fixed machine from the movable machine.

Witnessed by: \_\_\_\_\_ Date: \_\_\_\_\_

# **Annex C** (informative)

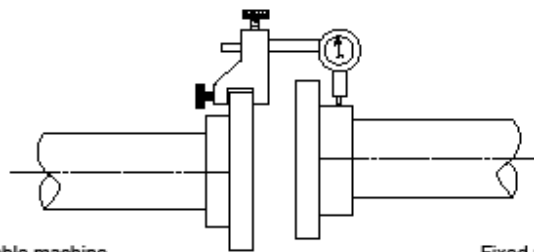
## **Rim and Face Datasheet**

Project Number: \_\_\_\_\_

Plant: _____	Unit: _____
Movable: Item: _____	Manufacturer: _____
Type: _____	Serial No.: _____
Fixed: Item: _____	Manufacturer: _____
Type: _____	Serial No.: _____




### **Rim Readings**

Set proper face readings before taking rim readings



Swept diameter X \_\_\_\_\_  
D = Axial distance between shaft hubs X \_\_\_\_\_

INDICATOR READINGS: "Left" and "Right" indicator readings are determined by looking from the back of the movable machine toward the fixed machine.

<u>THEORETICAL</u> and Tolerance	<u>ACTUAL (PIPE OFF)</u> Corrected for Axial Float	<u>ACTUAL (PIPE ON)</u> Corrected for Axial Float
<div style="text-align: center;"> Top _____  Left  Right  Bottom _____ </div>	<div style="text-align: center;"> Top _____  Left  Right  Bottom _____ </div>	<div style="text-align: center;"> Top _____  Left  Right  Bottom _____ </div>

Prepared by: \_\_\_\_\_ Date: \_\_\_\_\_

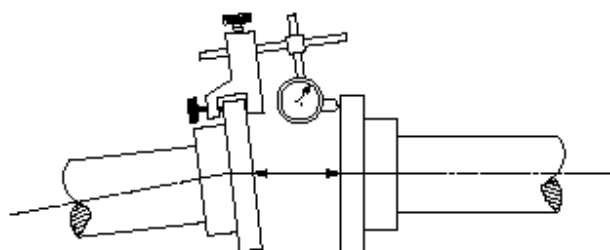
Project Number: \_\_\_\_\_

Restricted

Movable: Item: \_\_\_\_\_  
 Type: \_\_\_\_\_  
 Fixed: Item: \_\_\_\_\_  
 Type: \_\_\_\_\_

Indicator bar sag: \_\_\_\_\_ Indicator bar number: \_\_\_\_\_

#### Face Readings

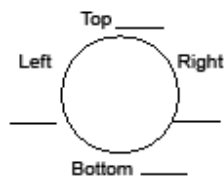


Movable Machine

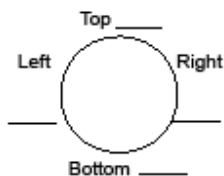
Fixed Machine

INDICATOR READINGS: "Left" and "Right" indicator readings are determined by looking from the back of the movable machine toward the fixed machine.

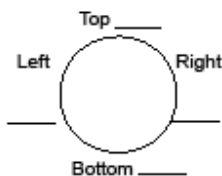
#### THEORETICAL and Tolerance



#### ACTUAL (PIPE OFF) Corrected for Axial Float



#### ACTUAL (PIPE ON) Corrected for Axial Float



#### Shims Tabulation

Fixed IB Left	_____	Move. IB Left	_____
Fixed IB Right	_____	Move. IB Right	_____
Fixed OB Left	_____	Move. OB Left	_____
Fixed OB Right	_____	Move. OB Right	_____

NOTE All shims are recorded looking to the fixed machine from the movable machine.

Witnessed by: \_\_\_\_\_ Date: \_\_\_\_\_

Restricted

## Annex D (informative)

### Types of Alignment

#### D.1 Reverse Rim (Dial) Alignment

**D.1.1** Reverse rim (dial) alignment is the process of determining the misalignment of two adjacent rotating machinery elements by radial dial indicator readings taken on the coupling hub rim or shafts of two machines while they are rotated at the same time (see Figure D.1). The key aspect is that the dial indicators are rotated about the machinery shaft's center of rotation. The process is normally done while turning both shafts together and taking readings as close as possible to vertical and horizontal planes.

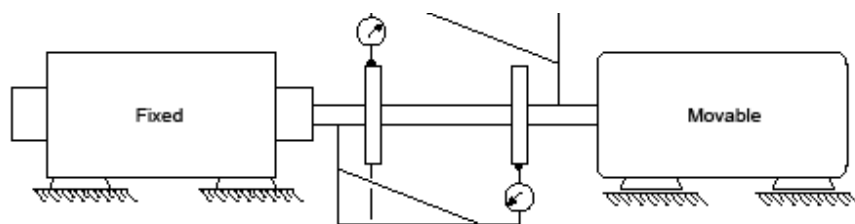


Figure D.1—Reverse Rim (Dial) Alignment

#### D.1.2 Advantages and Disadvantages

##### D.1.2.1 Advantages

**D.1.2.1.1** Most maintenance personnel are familiar with this alignment method.

**D.1.2.1.2** By spanning a spacer coupling, angular misalignment measurements are more sensitive. A span of 400 mm (16 in.) gives angular misalignment readings four times more sensitive than face readings of a typical 100 mm (4 in.) diameter hub. Most couplings for new equipment in petrochemical facilities have spacers much longer than the hub diameter.

**D.1.2.1.3** The requirement to remove the coupling spacer is eliminated with proper design of the alignment brackets. This reduces wear and tear on the coupling.

**D.1.2.1.4** When both shafts are turned together, the errors of coupling hub runout are eliminated. It is also possible with care to achieve equal accuracy with the shafts uncoupled. For new installations, it is recommended that the coupling spacer be left out to reduce the wear and tear on the coupling and bolts. At construction sites, it is likely the coupling spacer or fasteners will be lost or damaged if the coupling is assembled and subsequently removed. The equipment train driver should be positively prevented from inadvertent energization before the coupling spacer is installed.

**D.1.2.1.5** Axial float errors are eliminated by eliminating the face readings.

**D.1.2.1.6** It lends itself to both graphical and calculated methods of alignment correction.

Restricted

**D.1.2.1.7** There are several general-purpose reverse dial indicator shaft adapter kits commercially available. Generally, these commercially available kits are designed for minimum sag.

#### **D.1.2.2 Disadvantages**

**D.1.2.2.1** Both machines should be turned to align them unless special brackets are made.

**D.1.2.2.2** Indicator sag should be measured and included in the calculations.

**D.1.2.2.3** To be done properly, brackets should be made to fit the machinery train correctly and still swing the shafts together 360 degrees without interference.

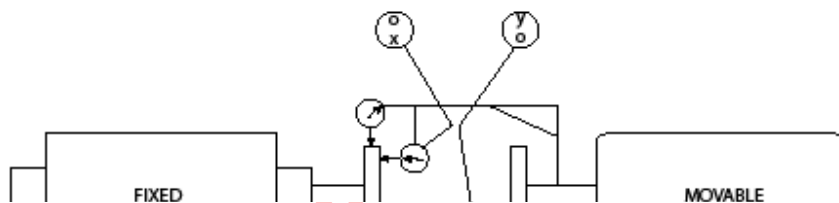
**D.1.2.2.4** Purchasing commercial or manufacture reverse dial indicator brackets can be costly.

**D.1.2.2.5** It is not as accurate for equipment where coupling diameter is greater than DBSE length.

**D.1.2.2.6** Any hub surface disconformity in the mechanically indicated surfaces should be compensated for when rotating only one shaft at a time.

## **D.2 Rim and Face Alignment System**

**D.2.1** Rim and face alignment is the process of determining misalignment between two adjacent shafts by measuring the differences in DBSE or coupling faces (face readings) and the difference in the center of rotation with dial indicator radial readings (rim readings). The angular misalignment is determined by the face readings, and the parallel misalignment at the dial is determined by dial indicator readings in the radial direction on the rim of the coupling or shaft. Relative face distance is determined at two points in the vertical direction and two points in the horizontal direction. This may be done by micrometer, or dial indicator. Rim readings (two in the horizontal plane and two in the vertical plane) together.



**Figure D.2 Rim and Face Alignment System**

#### **D.2.2 Advantages and Disadvantages**

##### **D.2.2.1 Advantages**

**D.2.2.1.1** It is more accurate than double reverse dial when the machinery train is close coupled and the dial indicator span is less than the coupling hub diameter.

Restricted

**D.2.2.1.2** The face readings give the angularity and the rim readings give the offset at the dial indicator. This is intuitive to most mechanics and millwrights and easier to understand than reverse dial (rim) alignment.

**D.2.2.1.3** Dial indicator rim and face readings only require one shaft to be rotated. This should only be done when necessary because dimensional errors in hubs or shaft ends will cause an error in the readings. Any hub surface disconformity in the mechanically indicated surfaces should be compensated for when rotating only one shaft at a time.

#### **D.2.2.2 Disadvantages**

**D.2.2.2.1** Unless the three dial rim and face method is used to subtract shaft end-play, it is likely to give erroneous face readings as the shaft is rotated.

**D.2.2.2.2** Rim readings should be corrected for sag.

**D.2.2.2.3** For machinery with spacer couplings, the face readings do not have as good resolution as reverse dial readings. Most equipment specifications require coupling spacers of 5 in. or more for ease of maintenance and to reduce the coupling alignment change from cold to hot operation.

### **D.3 Laser Alignment Systems**

#### **D.3.1 General**

**D.3.1.1** Laser alignment is the process of determining misalignment by a laser beam where the laser is mounted on one or both shafts and a receiver or reflector is mounted on the other. Both shafts are turned at the same time. The deviation in the laser beam is measured as the shaft is turned. The interpretation of the data is done by configuring an alignment computer supplied with the laser alignment system.

#### **D.3.2 Advantages and Disadvantages**

##### **D.3.2.1 Advantages**

**D.3.2.1.1** The calculations are directly fed into the alignment computer by the instrument, eliminating operator errors.

**D.3.2.1.2** Potential accuracy of laser instruments is better than dial indicators.

**D.3.2.1.3** The required moves and actual misalignment in the horizontal and vertical plane or angle is directly read out.

**D.3.2.1.4** There is no sag in the readings. Very good for long DBSE alignments.

**D.3.2.1.5** Universal brackets are provided for the instrument, which allows for setup on most machines without special fabrications.

**D.3.2.1.6** There is a relatively short training period for new mechanics (millwrights) in order to become proficient in machinery alignment.

**D.3.2.1.7** The laser alignment equipment normally provides a printout of the alignment for record purposes. This eliminates translation errors and provides consistency from one mechanic (millwright) to the next.

##### **D.3.2.2 Disadvantages**

**D.3.2.2.2** The mechanic (millwright) does not get the feel for the actual alignment process because dial indicator calculations or graphs are eliminated. It is recommended that laser alignment only be done by persons familiar with dial indicator alignment.

Restricted



**D.3.2.2.3** The mechanic (millwright) should be sure the instrument is suitable for the area classification or obtain a safety permit.

**D.3.2.2.4** Vibration of the machinery can cause the instrument to be nonfunctional.

**D.3.2.2.5** Both shafts should be turned or special jigs provided to align equipment where the shaft cannot be turned.

**D.3.2.2.5** Direct sunlight or steam can affect the laser alignment equipment.

## **D.4 Operating Temperature Alignment**

### **D.4.1 General**

**D.4.1.1** Operating temperature alignment is the process of determining the relative change in alignment from the ambient conditions to operating conditions.

### **D.4.2 Operating Temperature Alignment Systems**

The generally recognized systems for hot alignment of rotating equipment trains are described in D.4.2.1 to D.4.2.5.

**D.4.2.1** A frequently used type of operating temperature alignment for hot service pumps is to back-flow hot fluid through a pump while it is not in service. The change in alignment is monitored from the ambient condition to the hot condition. This is not usually as accurate as other methods where the equipment is in operation (as listed in D.4.2.2 through D.4.2.5) but is often sufficient for many general-purpose pumps.

**D.4.2.2** Alignment indicator stands are set up with a constant temperature coolant flowing through them. The readings are taken with dial indicators or proximity probes on machined surfaces attached to the bearing brackets. The change in the dial indicators or proximity probe gap is measured as the machinery train is operated at normal conditions. These measurements are used to verify ambient offset readings.

**D.4.2.3** Accurate measurements are made between fixed benchmarks located on the machinery train bearing brackets and the foundation when the equipment is not running. The equipment is then started and run at operating conditions and the measurements are repeated. The relative changes in the measurements are related back to ambient condition alignment readings.

**D.4.2.4** Optical operating temperature alignment is similar to the physical measurement of benchmarks, except precision optical readings are taken of benchmarks when the machine is at ambient conditions and after it is put in service.

**D.4.2.5** Low sag brackets with four proximeter probes are attached inside the coupling cover to the bearing housing. The relative change is related directly back to initial proximeter readings and reverse dial indicator readings taken when the machinery train was at ambient conditions.

## Annex E (informative)

### Hold-down Bolt Torque Tables

**Table E.1—30,000 psi Internal Bolt Stress**

Nominal Bolt Diameter (in.)	Number of Threads (per in.)	Torque (ft-lb)	Compression (lb)
1/2	13	30	3780
5/8	11	60	6600
3/4	10	100	9060
7/8	9	160	12,570
1.0	8	245	16,530
1 1/8	8	355	21,840
1 1/4	8	500	27,870
1 1/2	8	800	42,150
1 3/4	8	1500	59,400
2.0	8	2200	79,560
2 1/4	8	3180	102,690
2 1/2	8	4400	128,760
2 3/4	8	5920	157,770
3.0	8	7720	189,720

NOTE 1 All torque values are based on anchor bolts with threads well-lubricated with oil (NOT anti-seize compound)

. The use of anti-seize compounds will reduce these torque values.

NOTE 2 In all cases the elongation of the bolt will indicate the load on the bolt.

**Table E.2—2110 kg/cm Internal Bolt Stress**

<b>Nominal of Bolt Diameter (mm)</b>	<b>Torque Newton-Meters</b>	<b>Compression (lb)</b>
M12	31	1778
M16	110	3311
M24	363	7447
M30	1157	18,247
M52	3815	37,136

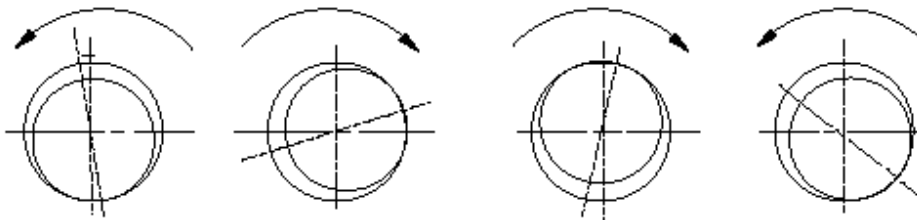
NOTE 1 All torque values are based on anchor bolts with threads well-lubricated with oil (NOT anti-seize compound)

. The use of anti-seize compounds will reduce these torque values.

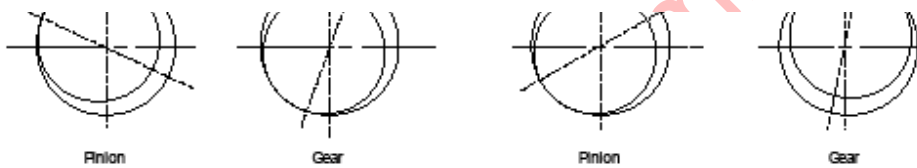
NOTE 2 In all cases the elongation of the bolt will indicate the load on the bolt.

**Annex F**  
(informative)

**Gearbox Shaft Movement**



**Figure F.1—Pinion Driving (Gear Driven)**



## 8. Lubrication Systems

### 8.1. Scope

8.1.1. This clause establishes the minimum requirements for the machinery installation and cleaning of new or overhauled machinery that either provides or requires lubrication for process or utility purposes (refer to API 614 for lube oil and seal oil system requirements).

8.1.2. Equipment providing lubrication includes equipment such as lube and seal oil systems, central air/oil systems, and oil mist lubrication systems.

8.1.3. Equipment requiring lubrication includes (as a minimum) equipment such as vertical and horizontal centrifugal and positive displacement pumps, centrifugal, axial and positive displacement compressors, blowers, fans, agitators, horizontal and vertical gearboxes, steam and gas turbines, expanders, electric motors, electric generators and systems such as refrigeration systems, plant instrument air systems, and extruders.

8.1.4. This chapter provides procedures, design criteria, and requirements that enhance and/or facilitate the preservation, cleaning, inspection, assembly, installation and start-up of lubrication systems and details such as bearing cavities, bearing housings, and complete lube and seal oil supply systems. This section of API 686 does not include criteria for product lubricated equipment such as canned motor pumps, grease-lubricated equipment, or cylinder lubrication such as for reciprocating compressors.

8.1.5. All installation requirements shall be ensured as complete by completing the installation checklist in Annex A, or agreed equivalent, and submitting it to the user designated representative.

8.2. For terms and definitions, refer to Part A of this standard. For design criteria and use in preservation for lubrication refer to Part B

### 8.3. System Design Requirements

8.3.1. The design shall provide access to fill and drain connections and for operation and maintenance.

8.3.2. The design will provide for fill and drain passages and connections that are sufficient in size and oriented such that servicing can be performed without spilling and does not require special equipment.

8.3.3. The design shall allow maintenance or operations to perform their required functions without being restricted by piping, conduits or supports.

8.3.4. The design shall allow maintenance or operations to perform their required functions and removal of components.

8.3.5. The design shall provide for drains that drain the components and systems as completely as practical without leaving the need for flushing the remainder.

8.3.6. The design shall provide for adequately sized and properly placed vents and drains to ensure complete removal of any material used during chemical cleaning and pickling.

Note: Chemical cleaning and pickling are not used in oil mist systems.

8.3.7. The piping system shall be provided with high point vents and low point drains.

Note: Not applicable for oil mist systems.

8.3.8. The piping system shall be provided in accordance with chapter 6 of this standard.

8.3.9. On equipment with circulating oil systems, the piping design should be provided with break-out spools for jumpers on the supply and return connections to each lubrication point on the machine to facilitate flushing of the oil system. Ability to bypass permanent lube oil filter shall be provided.

Note: Permanent lube oil filters are not normally designed for high flow rates that are required for flushing. Temporary filters can be used for flushing purposes.

8.3.10. The design for the Lubrication System shall provide proper support and protection to prevent damage from vibration or from shipment, operation and maintenance.

8.3.11. The installation of the Lubrication System should be in a neat and orderly arrangement adapted to the contour of the machine without obstructing access to such items as junction boxes, couplings and instrumentation.

8.3.12. The design for the Lubrication System shall allow elimination of air pockets using valved vents or non-accumulating piping arrangements in accordance with Chapter 6 on piping.

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8.3.13. The design for the Lubrication System shall allow complete drainage through low points without disassembly of piping, vacuuming or flushing.

8.3.14. Threaded openings (such as in small pumps) may be plugged with a threaded pipe plug; others should be provided with block valves and flanged connections with blind flanges.

#### 8.4. Tapped openings

8.4.1. Tapped openings shall be plugged with square-head, round-head or hex-head, steel plugs furnished in accordance with ASME B16.11. As a minimum, these plugs shall meet the material requirements of the piping system and requirements of chapter 6 on piping.

8.4.2. A sealant that meets the proper temperature specification shall be used on all threaded connections. Tape shall not be applied to the threads of plugs or any other threaded connection inserted into oil passages.

Note: Plastic plugs are only permitted for temporary purposes such as during transportation for example.

#### 8.5. Flanged openings

##### 1.1.1 Flanged openings shall be provided with blind flanges.

8.5.1. Quantity and location of block valves at flanged openings shall be mutually agreed upon between the user-designated machinery representative and the vendor.

8.5.2. A specific lube oil flushing diagram shall be provided that clearly indicates temporary bypasses, screens, drop-out spools and removals required for lube oil flushing.

Note: A marked-up process and instrumentation diagram is acceptable for this purpose.

8.5.3. Component and system cleaning specifications, including the flushing diagram, shall be approved by and agreed upon between the Vendor and the user-designated machinery representative.

8.5.4. Equipment and oil systems shall be shipped clean, minimizing the need for cleaning and flushing in the field. The vendor shall demonstrate that oil passages and oil-containing components are free of dirt and debris prior to shipment in accordance with the requirements of section 3.6 of this chapter.

8.5.5. In situations where oil mist is used to protect equipment during storage or when the equipment is idle, procedures and oil mist system design and arrangement shall be agreed upon between the vendor and the equipment user.

#### 8.6. Lubrication System Installation

##### 8.6.1. Receiving and Protection

8.6.1.1. In the event that the lubrication system or equipment will not operate within six months, a long-term preservation program should be agreed upon between the vendor and equipment user. The program should clearly state the responsibilities of the individual parties.

8.6.1.2. An inspection procedure should be established indicating intervals and special activities to be performed, such as equipment condition, inspection, preservation, and shaft rotation while the equipment is idle (refer to Chapter 2 of this standard).

8.6.1.3. The manufacturer's/vendor's instructions shall be followed unless otherwise specified. These instructions should be agreed upon between equipment user and vendor.

8.6.1.4. Any conflicts between this standard and the manufacturers' recommended procedures should be referred to the user-designated machinery representative for resolution before proceeding.

8.6.1.5. The equipment should be protected against mechanical damage and internal and external corrosion at all times. When specified, a temporary oil mist preservation system should be provided in accordance with section 3.2 of this chapter.

##### 8.6.2. Temporary Oil Mist Systems

8.6.2.1. In the case where 10 or more pieces of equipment are to be stored for a period longer than six months from time of receiving, an oil mist protection system shall be considered.

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8.6.2.2. Oil mist should be used to protect the bearings, bearing housings, seal areas, and any other unprotected internal area, and if feasible, the process end of the equipment.

8.6.2.3. For equipment provided with permanent mist lubrication connections, these connections should be used in conjunction with the temporary oil mist system.

8.6.2.4. Equipment cavities not normally mist lubricated during permanent operation, should be fitted with mist supply and vent connections, typically NPS 1/4 and in accordance with chapter 6 on piping.

8.6.2.5. The oil mist system should be designed and sized for preservation service. Mist flow to each application point may be less than that required for lubrication during normal operation. A mist preservation manifold with eight (8) ported outlets should be considered to eliminate the need for reclassifiers.

Note: Preservation service also referred to in clause 8.6.2

8.6.2.6. The mist generator shall be equipped with an air pressure regulator, pressure relief valve, level gauge, and mist pressure gauge instrumentation as a minimum.

8.6.2.7. The mist header shall be NPS 2 galvanized schedule 40 pipe supported and sloped at a minimum of 2 cm per 5 m (1 in. per 20 ft) back to the mist generator. Greater slope is acceptable and should be in accordance with Clause 6 on piping.

Note: Pickling and chemical cleaning is not typically required in this type of pipe.

8.6.2.8. Plastic tubing may be used to connect the mist header to the mist application point.

8.6.2.9. The equipment should be connected to the oil mist system within '24 hours after arrival on the storage or plant construction site' to protect equipment against internal and external corrosion as prescribed and agreed upon by the equipment vendor and the equipment user. For further reference see Part B, clause 3.2.2.

8.6.2.10. The compatibility of preservatives and sealants with process streams and machinery components should be evaluated by the user-designated machinery representative.

8.6.2.11. Unless otherwise specified by the user's designated representative, oil used in the mist system should be a good quality, paraffin-free turbine oil.

8.6.2.12. A temperature-sensitive, vapor-emitting oil should not be used

8.6.2.13. Shafts supported by hydrodynamic (sleeve) bearings shall not be rotated without injecting suitable oil into the bearings – purge oil mist may not be adequate for rotation of such bearings by hand.

8.6.2.14. Under no circumstances shall a machine be rotated without the specific approval of the manufacturer's representative and/or the user designated representative.

8.6.2.15. Drained oil should be disposed of per the equipment user's established environmental protection procedures.

8.6.2.16. Interruption of oil mist preservation, such as during transport of equipment from storage to the construction site, should be minimized.

8.6.2.17. Oil mist preservation (or other preservation procedures) should be immediately re-established once the equipment is placed on the foundation.

**Annex A**  
(normative)

**Lube Oil Systems Installation and Installation Design Checklist**

Section	Requirements	Name	Date
<b>8.3</b>	<b>System Design Requirements</b>		
<b>8.3.1</b>	The design provides for easy access to fill and drain connections and for operation and maintenance.		
<b>8.3.2</b>	Adequate size and orientated drains provided for servicing.		
<b>8.3.3</b>	Maintenance or operations can be performed without piping, conduit or supports restriction.		
<b>8.3.4</b>	Operations or maintenance can perform their required functions and remove components.		
<b>8.3.5</b>	Adequate drains provided for additional flushing.		
<b>8.3.6</b>	Adequate vents and drains provided for chemical cleaning.		
<b>8.3.7</b>	Adequate vents and drains in piping system.		
<b>8.3.9</b>	Pipe design incorporates break-out spools on supply and return lines to each lubrication point		
<b>8.3.10</b>	Proper support provided to prevent damage from vibration, shipment, operation and maintenance.		
<b>8.3.11</b>	Design allows installation to be neat and orderly without obstructions.		
<b>8.3.12</b>	Design eliminates air pockets.		
<b>8.3.13</b>	Design allows complete drainage through low point drains.		
<b>8.3.14</b>	All openings meet the requirements of section 2.9. 8.3.14		
<b>8.5.1</b>	Quantity and location of block valves agreed upon.		
<b>8.6</b>	<b>Lubrication System Installation</b>		

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<b>8.6.1</b>	<b>Receiving and Protection</b>		
<b>8.6.1.1</b>	Long-term preservation program agreed upon by user and vendor.		
<b>8.6.1.2</b>	Inspection, preservation, rotation procedure established		
<b>8.6.1.3</b>	Vendor/user agreed on instructions for installation, oil mist preservation system (if applicable), cleaning and flushing procedures were followed.		
<b>8.6.1.4</b>	Recommended procedures conflicts, if any, have been referred and resolved.		
<b>8.6.1.5</b>	Proper mechanical and corrosion protection provided at all times.		
<b>8.6.2</b>	<b>Temporary Oil Mist Systems</b>		
<b>8.6.2.1</b>	Oil mist protection system required?		
<b>8.6.2.2</b>	Oil mist system sufficient and placed at all required locations.		
<b>8.6.2.3</b>	Permanent oil mist connections utilized where provided.		
<b>8.6.2.4</b>	Temporary oil mist connections provided where required.		
<b>8.6.2.5</b>	Oil mist system designed and sized for preservation service.		
<b>8.6.2.6</b>	Necessary instrumentation provided.		
<b>8.6.2.7</b>	Header slope back to mist generator adequate.		
<b>8.6.2.9</b>	Equipment connected within 24 hours of receipt.		
<b>8.6.2.10</b>	Preservative and lubricant compatibilities addressed.		
<b>8.6.2.11</b>	Oil is good quality, paraffin-free turbine oil.		
<b>8.6.2.12</b>	Temperature-sensitive, vapor-emitting oil not used		
<b>8.6.2.15</b>	Drained oil properly disposed of.		
<b>8.6.2.16</b>	Interruption of oil mist preservation minimized.		

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**9. Commissioning and Start-up**

*Refer to Part D for Commissioning and Start-up*

Draft—For Committee Review

**API 686 3<sup>rd</sup> Edition**  
**Part D – Commissioning & Start-up of**  
**Rotating Equipment & Auxiliary Systems**

**General – Part A (use with Parts B, C, D)**

**Design – Part B**

**Installation – Part C**

**Commissioning/Start-up – Part D**

**1. Scope Normative References, and Definitions – Terms – Acronyms**

**1.1** Refer to Part A for Scope

**1.2** Refer to Part A for Normative References, and Definitions – Terms – Acronyms

**2. Rigging and Lifting**

Refer to Parts B and C for Rigging and Lifting

**3. Jobsite Receiving and Protection**

Refer to Parts B and C for Jobsite Receiving and Protection

**4. Foundations**

Refer to Parts B and C for Foundations

**5. Baseplates and Soleplates (and Grouting)**

Refer to Parts B and C for Baseplates, Soleplates, and Grouting

**6. Piping**

Refer to Parts B and C for Piping

**7. Shaft & Piping Alignment**

Refer to Parts B and C for Shaft and Piping Alignment

## **8. Lubrication Systems**

### **8.1 Cleaning**

**8.1.1** The equipment vendor, flushing contractor and user-designated machinery representative should determine and agree on the locations for temporary bypasses and screens for example during the installation design phase.

**8.1.2** Unless approved by the manufacturer and user designated machinery representative, circulation of any flushing medium shall not take place through the bearings.

#### **8.1.3 Interconnecting Piping**

**8.1.3.1** All interconnecting piping shall meet the requirements of section 6.

**8.1.3.2** The piping shall be thoroughly cleaned before it is installed by blowing large quantities of air, or nitrogen through the piping or by flushing the piping with a solvent approved by the manufacturer and user designated machinery representative.

**8.1.3.3** Care should be exercised to ensure that the pre-cleaned interconnecting piping is kept clean during its installation.

**8.1.3.4** If a solvent is used for cleaning, then the piping shall be dried by blowing with instrument quality air or nitrogen. Steam, water or oil should not be used as a means for this type of cleaning.

**8.1.4** Flow restrictions such as orifices and probes should be removed to obtain maximum velocities during the cleaning and subsequent flushing procedures. All equipment removed should be tagged and inventoried for later reinstallation into its proper location.

### **8.2 Mechanical Cleaning of Piping**

**8.2.1** All loose foreign material such as scale, sand, weld splatter particles and cutting chips shall be removed from the inside of piping assemblies and reservoirs, filter housings and all other components in the lube oil system.

**NOTE** Hammering on the outside of piping with a non-marring hammer will aid in freeing weld splatter, scale, dirt, and rust.

**8.2.2** Where accessible, the inside of piping should be wire brushed.

**8.2.3** Carbon steel wire brushes shall not be used on stainless steel piping.

**8.2.4** Pipes shall be blown out with instrument quality air, steam or hydro-blasting after hammering and brushing. If steam or hydro-blasting is performed, subsequent blowing with instrument quality air or nitrogen is required.

**8.2.5** On piping where sufficient cleaning by mechanical means is not achievable, additional chemical cleaning or hydro-blasting shall be performed.

### **8.3 Chemical Cleaning of Carbon Steel Piping Systems**

**8.3.1** Chemical cleaning is only applicable to carbon steel piping. Stainless steel piping should not be chemical cleaned.

**8.3.2** Flushing materials containing chlorinated hydrocarbons such as 1,1,1-trichloroethane shall not be used in carbon steel piping systems with stainless steel components as this can result in chloride stress corrosion cracking of the stainless-steel components.

**8.3.3** Warning tags shall be installed on components such as oil pumps and control valves, which must be isolated from the piping during chemical cleaning.

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**8.3.4** All system pumps, control valves and inline filters shall be removed or bypassed, hand cleaned if necessary and protected from contamination while the piping system is chemically cleaned.

**8.3.5** Where chemical cleaning or pickling is performed, see Annex B for typical procedure.

#### **8.4 Flushing of Oil Systems**

**8.4.1** System pumps shall be reviewed to verify that a minimum of Reynolds number 5,000 is achievable. If pumps do not provide the adequate minimum flow a temporary pump and filtration system shall be utilized to meet required flow rates.

**8.4.1.1** Each system lubricating oil pump should be operated. Operation of parallel pumps at the same time may aid in dislodging solid contaminants.

**8.4.1.2** Sparging the flushing oil with nitrogen, "hammering" the fittings, using mechanical vibrators, and cycling oil temperature are ways of loosening dirt particles.

**8.4.2** The equipment and oil systems received from the manufacturer shall be in a clean condition, requiring minimal flushing after installation.

**8.4.3** After cleaning (mechanical and/or chemical), and only when the system is considered completely dry (free of water), the filter elements shall be reinstalled.

**8.4.4** Temporary bypass piping shall be installed around all equipment bearings and any critical components that can be damaged during the flushing process.

**8.4.5** Temporary bypasses, screens for example, shall be located and installed per the flush diagram agreed upon during the installation design phase.

**8.4.6** A removable strainer made from ASTM Series 300 stainless steel with a minimum open flow area equal to 150% of the cross-sectional area of the suction pipe shall be installed in the suction piping of each pump.

**8.4.7** If system pumps are used the temporary strainer shall be identified by a protruding tab and have a mesh size adequate to stop all objects that could damage the pump.

**8.4.8** The piping arrangement shall permit the removal of the strainer without disturbing the alignment of the pump.

**8.4.9** The maximum strainer hole size shall be 3 mm (1/8 in.).

**8.4.10** Cone strainers shall be installed in spool pieces to minimize piping removed.

NOTE: Strainer can be cone, basket, or Y-type. For typical ASME and API pumps, a mesh size of 100 is sufficient. For canned, screw, and magnetic drive pumps, a 100 to 200 mesh screen could be necessary.

**8.4.11** The system should be filled with lubricating oil of the same type and grade as will be used in operation.

**8.4.11.1** Oil should be filtered (10 microns or better) as it is filled into the reservoir (refer to OEM specifications for cleanliness requirements),

**8.4.11.2** Special booster or other specific flush pumps may have to be used to achieve Reynolds number 5,000 in the piping to facilitate effective flushing.

**8.4.11.3** If Reynolds number 5,000 is not achievable with the same type and grade of oil to be used in operation a lighter (less viscous) flushing oil may be used.

**8.4.12** If different oil is used the type of oil shall be mutually agreed upon between the vendor and the user designated machinery representative.

**8.4.13** Flushing oil shall be clean and free of any water.

**8.4.14** The temperature of the oil should be alternated between 40 °C (100 °F) and 70 °C (160 °F) every four hours.

**8.4.14.1** Reservoir heaters may be used to assist in this process.

**8.4.14.2** Heating and cooling may be obtained by

- (a) Alternate circulation of hot water (not steam) and cold water through the cooler(s). The thermal expansion and contraction will help to loosen any residue in the pipe. The piping should be tapped with a non-marring hammer at all flanges and welds to assist in loosening any weld spatter or pipe scale.
- (b) Temporarily halting flush to allow system pipes to cool to ambient. Then sending heated fluid through the system, causing a thermal shock to the piping.

**8.4.14.3** Care should be exercised in this procedure to not exceed the temperature design limitations of the oil cooler, as damage could occur.

**8.4.15** Oil filter elements shall be replaced if there are signs of plugging or if the differential pressure rises more than 1 kg/cm<sup>2</sup> (15 psi) (or as specified by the manufacturer) above the original clean filter reading.

**8.4.16** The procedure for circulation and checking for cleanliness should be repeated every 12 hours until the system is proven to be clean as defined in API 614:1 Table D.6.

**8.4.16.1** Cleanliness of the oil should be checked at convenient discharge locations with a telltale (such as clean white gauze cloth, or the use of mesh inspection screens at critical points in the system).

**8.4.16.2** These locations should be indicated on the lube oil flushing diagram as agreed upon between the vendor and the user-designated machinery representative.

**8.4.17** After satisfactory flushing, temporary bypass piping and screens shall be removed and the permanent oil supply and return piping shall be reinstalled with temporary 100 mesh screens backed with minimum 20 mesh screens.

**8.4.18** The temporary screens shall be installed upstream of the bearing housing flange connection(s). Additional eight-hour flushing through a clean set of screens shall be performed until no particles, gritty to the touch and the dirt count on each screen conforms to the limits in API 614:1 Table D.6.

**8.4.18.1** On large systems, portions of the system proven to be clean do not require the screens to be reinstalled.

**8.4.18.2** If the screens indicate the system is not clean after one or two such cycles, re-cleaning of the piping downstream of the filters should be considered.

**8.4.19** A sample shall be taken at the completion of the oil flushing procedure from the reservoir bottom and checked for water content and dirt contamination.

**8.4.20** If the lube oil is found to be contaminated with water, the oil shall either be processed with an oil re-claimer until clean oil (free of water and particles) is proven or the contaminated oil is replaced with a fresh charge of clean oil.

## **8.5** Final Assembly

**8.5.1** After the system is proven to be clean all permanent oil piping shall be reconnected in accordance with section 6 in Part B and Part C of this standard.

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**8.5.2** All temporary screens shall be removed from the oil piping, and the permanent gaskets installed.

**8.5.3** Suction strainer(s) of all lubricating oil pumps shall be cleaned or replaced (if required)

**8.5.4** All flow orifices and instrumentation previously removed shall be re-installed and connected.

**8.5.5** Lubricating oil filter element(s) shall be replaced with new element(s)

**8.6** Pre-Operation Checks for Oil System

**8.6.1** Prior to final operation, the lube oil pump pressure relief valve shall be checked for proper operation and setting. The manufacturer's instruction manual should be referenced for specific setting procedures.

**8.6.2** The oil system shall be operated as designed and each branch checked for proper pressure and flow.

**NOTE** Check any sight glasses for quantity and quality (such as foaming) of flow.

**8.6.3** All pressure reducing valves in the oil system shall be checked and adjusted to specification if required. The oil temperature shall be allowed to rise to the design operating temperature before setting the oil pressure control valves for the system.

**8.6.4** Vibration and temperature levels of the oil system pumps and drivers shall be checked. If vibration and temperature levels are found to be out of limits, necessary corrective measures shall be taken.

## Annex A

(normative)

### Lube Oil Systems Installation and Installation Design Checklist

Section	Requirements	Name	Date
<b>8.2</b>	<b>Mechanical Cleaning of Piping</b>		
<b>8.2.1</b>	All loose foreign material removed from piping and components.		
<b>8.2.2</b>	Carbon steel piping wire brushed where accessible.		
<b>8.2.4</b>	Piping blown clear after mechanical cleaning.		
<b>8.3</b>	<b>Chemical Cleaning of Carbon Steel Piping Systems</b>		
<b>8.3.1</b>	Verified that piping system is carbon steel.		
<b>8.3.2</b>	Chlorinated hydrocarbon flushing fluids not used on carbon steel.		
<b>8.3.3</b>	Warning tags placed on isolated components.		
<b>8.3.4</b>	All system pumps, control valves and inline filters removed or bypassed.		
<b>8.3.5</b>	Pickling and passivating procedure followed.		
<b>8.4</b>	<b>Flushing of Oil Systems</b>		
<b>8.4.1</b>	Checked if Reynold's number of 5,000 achievable and utilized temporary pump and filtration system otherwise.		
<b>8.4.3</b>	Verified that system is completely drained and dry before oil fill.		
<b>8.4.5</b>	Clean filters installed for oil flushing. By-passes installed as agreed between vendor and user.		
<b>8.4.6 / 8.4.7</b>	Temporary / removable oil pump suction strainers installed.		
<b>8.4.11</b>	System filled with lubricating oil of same type and grade as will be used in operation.		
<b>8.4.12</b>	If different oil used, oil type mutually agreed between Vendor and used designated machinery representative		
<b>8.4.13</b>	Flushing oil clean and free of any water.		
<b>8.4.14</b>	Oil temperature cycled as specified. Operations of both oil pumps in parallel.		
<b>8.4.15</b>	Oil filters replaced if required during flushing.		
<b>8.4.16</b>	Oil circulation checked for optimum cleaning effect at 12 hour intervals.		
<b>8.4.17</b>	Jumpers removed and 100-mesh screens backed with 20 mesh screens installed before bearing areas.		



8.4.18	Temporary screens installed upstream of the bearing housing flange connection(s).		
8.4.19	Oil samples free of water and contamination.		
8.5	<b>Final Assembly</b>		
8.5.1	All permanent piping properly installed in accordance with chapter 6 on piping.		
8.5.2	Temporary screens removed and permanent gaskets installed.		
8.5.3	Pump suction strainers removed, cleaned, and reinstalled.		
8.5.4	Piping, valves, orifices, instrumentation installed with proper gaskets as designed. All controls adjusted per instructions.		
8.5.5	New filter elements installed.		
8.6	<b>Pre-operation Checks for Oil System</b>		
8.6.1	Lube oil pump pressure relief valves checked for proper operation and setting.		
8.6.2	Lube oil pressure reducing valves checked for proper operation and setting.		
8.6.3	Circulating system shows acceptable flows, pressures, and temperatures.		
8.6.4	Oil pumps and drivers, vibration, and temperature acceptable.		

## **Annex B**

(Informative)

### **B.1 Typical procedure for chemical cleaning**

Chemical cleaning is performed to remove physical pollution such as grease, welding waste, pitting, slag, sand and oxides from metal surfaces. This procedure involves surface cleaning (degreasing and pickling), conditioning (passivation, neutralization and drying) and conservation.

### **B.2 Surface cleaning**

a) Representative “dirty” metallic coupons should be installed at several strategic locations in the piping system. The coupon presence should be clearly indicated for later removal after the cleaning procedure is complete.

Note: Coupons should be checked and replaced if required at least every hour.

b) A 2% caustic solution (in water) should be circulated for three hours at 80 °C to 90 °C (175 °F to 195 °F) to remove oil and grease-type protective films that may be in the equipment.

Note: Sufficient flushing velocities should be achieved to remove foreign materials from the piping passages.

c) The system should then be drained and flushed with clean water and blown with instrument air to remove any pockets of solution that may remain.

d) The system should then be filled with a citric acid solution containing 10 kg (20 lb) of acid per 400 liters (100 gal) water.

e) The solution should be maintained at a temperature of 80 °C to 90 °C (175 °F to 195 °F) and circulated for a minimum of two hours.

Note: The initial circulating solution should have an acidity of approximately pH 3.

f) Test coupons should be checked to ensure that they are clean before stopping the circulation.

### **B.3 Conditioning**

a) After the test coupons indicate a clean system, ammonia should be added in a sufficient quantity to bring the acidity up to pH 8.0 and circulated for 30 minutes to neutralize and passivate the system.

b) A final passivation with a 0.25% caustic plus 0.25% soda ash (nitrox passivator) in water should be performed.

c) The system should then be drained and blown dry with instrument air or Nitrogen.

### **B.4 Preservation**

a) If the system is not ready for immediate oil flushing, then a nitrogen purge should be established to protect the chemically cleaned surfaces.

## 9. Commissioning and Start-up

### 9.1 Scope

**9.1.1** This standard specifies requirements and guidelines for the commissioning of general and special purpose machinery and the design practices that affect the commissioning of those machines. Unless otherwise specified by the user, instructions supplied by the machinery vendor shall be included as part of this standard.

**9.1.2** All design and installation requirements shall be ensured as complete by completing the installation checklist in Annex A or agreed equivalent and submitting it to the user designated representative.

**Note** Special purpose machinery typically requires more detailed and rigorous attention during commissioning.

**9.1.3** In case of a conflict between Chapter 9 of this standard and governing equipment standard, the governing equipment standard shall take precedence.

### 9.2 Driver Horsepower

Drivers shall be of sufficient horsepower and torque for start-up conditions.

**9.2.1** These conditions include different fluid physical and thermodynamic properties and flow rates, inlet/outlet temperatures and pressures, from normal conditions.

**9.2.2** Purchaser shall provide the start-up conditions to the vendor to allow vendor selecting the proper driver for start-up condition.

### 9.3 Special Conditions

**9.3.1** If **special** conditions are anticipated during initial plant commissioning, purchaser shall provide details to the vendor.

**Note:** Special conditions during commissioning and start up can be the use of alternative gases and fuels, alternative steam condition, different temperature and pressure of the gas or liquid supply to the machinery.

**9.3.2** **The vendor shall provide instructions (e.g. performance maps.) and procedures for special start up conditions as necessary.**

**9.3.3** The design shall allow isolation of the equipment and lockout-tag out of the driver.

### 9.4 Field Commissioning

This section provides guidelines that should be followed for commissioning and start-up of equipment.

#### 9.4.1 General

The commissioning phase outlines the first time the equipment is started and run at its final installation location. This includes procedures employed in preparation of the equipment for commissioning.

#### 9.4.2 Commissioning and Start up Meeting

**9.4.2.1** A meeting should be held to define roles, responsibilities, authority of commissioning personnel as well as the schedule and sequence of the events.

**9.4.2.2** **3.1.2.2** Lines of communication should also be established to facilitate efficient and accurate information exchange and problem resolution.

**9.4.2.3** **3.1.2.3** All manufacturer's requirements for commissioning and start up should be identified and addressed throughout commissioning phase.

#### 9.4.3 Pre-operational Checks

**3.2.1** Verify all special hardware for use during shipment has been removed.

**9.4.3.1** Obtain the completed checklists for the foundation, piping, grouting, and alignment activities for the particular equipment train to be started.

**9.4.3.2** It is necessary to have clean piping before start-up. Basic cleaning of the piping system shall be performed to remove any foreign object out of the lines in a new system prior to flanging up to the new equipment.

**9.4.3.2.1** Inlet piping shall be free of dirt and debris, blown clean, and verified as clean using a target method.

**Note:** Refer to Annex B for target procedure.

- 9.4.3.2.2** Ensure that manufacturer recommended start-up screens are installed. The mesh size and the size of opening shall be equal or finer than that required by the vendor.
- 9.4.3.3** Instrumentation and control equipment to be prepared for startup as per 4.2.3.1 to 4.2.3.7:
- 9.4.3.3.1** Control valves and instrument loops shall be loop function tested before start-up.
- 9.4.3.3.2** Guide vanes actuator (if supplied), motor operated valves and control valves shall be full stroke travel tested before start-up.
- 9.4.3.3.3** Set points for controllers, and transmitters shall be verified.
- 9.4.3.3.4** Devices such as trip and throttle valve and motor switch gear, intended to initiate shutdowns of the train, shall be loop checked to the final trip device.
- 9.4.3.3.5** Verify that all transmitters and switches have been calibrated either by the manufacturer when supplied new, or by the installer if existing transmitters or switches are used.
- 9.4.3.3.6** Verify radial and axial vibration protective devices are set for both amplitudes, velocities and time delay as per Vendor recommendations (see API 670).
- Note: In some applications, time delays for shut down are applied for startup period or during normal operation.
- 9.4.3.3.7** Axial and radial position monitors and probes shall be calibrated.
- 9.4.3.3.8** The radial vibration probe gap shall be verified.
- 9.4.3.3.9** The axial probe gap and the float zone shall be verified (See API 670 for axial position probe).
- 9.4.3.4** The latest revision of the piping and instrument diagrams of the system shall be checked to verify that the unit piping, controls, and instrumentation are built per the design.
- Note: Vendor supplied auxiliary systems are sometimes captured in the vendor supplied design documents, such as data sheets, piping plan, etc.
- 9.4.3.5** All temporary instruments and devices installed to facilitate pre-commissioning activities shall be removed.
- 9.4.3.6** Verify seal flush/buffer/barrier piping installation conforms to the seal and equipment vendor drawings.
- NOTE: Seal flush, vent, quench, drain, etc. details are often not found on piping and instrument diagrams. The seal/flush purchasing datasheets and drawings can be referenced for this information.
- 9.4.4** 3.3 Check List Completion
- 9.4.4.1** All checklist items shall be completed satisfactorily.
- 9.4.4.2** If any items have not been completed, obtain the proper craft to verify compliance.
- 9.4.4.3** The turnover punch list for construction shall be completed and turned over to the designated user's representative.
- 9.4.4.4** The designated commissioning personnel shall review all vendor requirements for operation and start-up.
- 9.4.4.5** After completion of punch list modifications, the check list should be reviewed to ensure compliance.
- 9.4.4.6** Verify that all required vibration analysis and condition monitoring equipment are operational and properly calibrated.
- 9.4.4.7** Verify that the user-required data to be obtained during commissioning has been defined and that the appropriate data logs have been prepared.

**9.4.5** Lockout-Tagout  
Verify that all lockout and tagout procedures have been followed.

Note: Lockout-Tagout is sometimes referred to as System De-energization and includes isolation of the equipment from mechanical, electrical, hydraulic, pneumatic and elevation energy.

#### **9.4.6** Oil Lubricated Bearing Preparation

- 9.4.6.1** Bearing Housing Flush
- 9.4.6.1.1** Drain all liquids from the bearing housing
- 9.4.6.1.2** Refill and drain with clean lubricant until clean lubricant comes out the drain.
- 9.4.6.1.3** Verify that proper lubricant has been added to the correct level as indicated on the bearing housing.

**9.4.6.1.4** When constant level oilers are to be installed on the, they shall be used to fill the bearing housing. Verify that the oiler is set to maintain the required oil level as indicated on the bearing housing or machinery drawing.

**9.4.6.2** Bearing housings with a sight level indicator shall be filled to the indicated proper level.

**9.4.6.3** Verify that the oil rings or slingers are in the proper location and free to rotate.

**9.4.6.4** For sleeve and pressurized thrust pad bearings, the bearing caps should be removed unless otherwise specified, and necessary inspections should be performed to verify no foreign material has entered the bearing housing area. Also verify all temporary shipping material has been removed.

#### **9.4.7 Grease-lubricated Bearings Preparation**

**9.4.7.1** For grease-lubricated bearings, install grease fittings with required extensions for access without removing covers.

**9.4.7.2** Remove vent plugs and inject a compatible grease until new grease comes out the vent. Replace vent after greasing. Additional lubricant (grease) shall not be added to permanently lubricated bearings.

#### **9.4.8 Oil Mist**

**9.4.8.1** Oil mist lubricated bearings shall have the reclassifiers installed at the pump bearing housings or manifolds as defined by the user.

**9.4.8.2** Verify the orifice sizes stamped on the reclassifiers.

**9.4.8.3** Verify all connection points and drains are installed in correct locations.

#### **9.4.9 Cooling Water**

All cooling water piping should be flushed and then connected to the machinery prior to operation.

#### **9.4.10 Vents and Drains**

All vents and drains not permanently piped shall be blinded with a flange or plugged with a solid pipe plug of similar material as the material to which the plug is installed.

NOTE A possible exception to this is the pump seal flange drain port when using a quench.

#### **9.4.11 Strainers and Filters**

Verify all permanent/temporary strainers and filters are installed prior to start-up.

#### **9.4.12 Pipe and Equipment Cleaning and Purging**

**9.4.12.1** All foreign material shall be removed from the pipe before connecting to the equipment. Foreign material may consist of water, weld spatter, corrosion products, construction debris, scale, and dirt.

**9.4.12.2** All packing material (such as desiccant bags) to be removed from the machinery before connecting pipes to the equipment.

**9.4.12.3** Inlet lines to steam turbines shall be blown out with nominal steam pressure, typically 690 kPa (100 psi). Verify cleanliness by target method.

Note: Refer to annex B for steam blowing procedure.

**9.4.12.4** Auxiliary oil piping (lube oil and seal oil) shall be cleaned in accordance with the lubrication systems section of this standard (see Chapter 8).

**9.4.12.5** Verify all auxiliary seal piping and ancillary equipment (flush lines, purge lines, separation, quench lines, drains, vents, reservoirs, etc) are clean. For dry gas seals and dry running mechanical seals, verify the auxiliary lines and ancillary equipment are dry.

**9.4.12.6** Machinery with an external seal oil system shall not be over pressurized.

Note: It is possible for over pressurization to occur due to flushing out, steaming out, or operating the machinery at a pressure above the seal oil system.

**9.4.12.7** Purging through the machinery may be held to a minimum period of time to minimize the foreign material in the seal area.

**9.4.12.8** When purging equipment with steam, verify that seals with elastomeric sealing components will not be heated above their allowable temperature limits.

**9.4.12.9** Verify all the purge media is drained and vented after completion of purge.

#### **9.4.13 Mist System**

For oil mist systems, the mist system shall be in operation at least 24 hours before starting equipment lubricated by the system.

#### **9.4.14 Coupling Preparation for Solo Run**

**9.4.14.1** Verify the coupling design is capable of a driver solo run. Certain coupling types will require an adapter plate in order to solo the driver. If the coupling requires a solo plate, mount it to the driver coupling.

**9.4.14.2** Verify that the driver solo operation will not cause any contact with the driven equipment.

**9.4.14.3** A second set of coupling bolts may be required after the solo run in order to connect the driver to the driven equipment.

NOTE Coupling bolts are typically supplied in matched sets from the coupling supplier, and are only good for a limited number of re-assemblies. If one bolt assembly from the set needs to be replaced, it is usually good practice to replace all the bolts on that side of the coupling.

**9.4.15** If an adapter plate is used for the solo run, torque all coupling bolts to the adapter plate to their required value.

#### **9.4.16 Coupling Safety Area**

Rope off the area around the driver to keep people away from the coupling.

#### **9.4.17 Shaft Viewing**

Ensure that the area adjacent to the driver will allow viewing of the coupling during operation in order to verify the direction of rotation.

#### **9.4.18 Lockout-tagout**

Verify that all lockout and tagout procedures have been followed so the driver can be energized.

Note: Lockout-Tagout is sometimes referred to as System De-energization and includes isolation of the equipment from mechanical, electrical, hydraulic, pneumatic and elevation energy.

#### **9.4.19 Rotation Check**

Driver pre-rotation checks shall be made to verify that the installation is correct, safe, and that no damage will occur to the equipment on the initial start. Motor vendor should be contacted prior to pre-rotation check for synchronous and DC motors.

Note 1: the driven equipment drawings state the required direction of rotation.

**9.4.19.1** The driver shall be uncoupled prior to rotation check.

**9.4.19.2** Bump the motor start button. This procedure will allow the motor to be energized for a very short period-of-time to verify correct motor rotation. Wait for the motor to come to a stop after the bump.

#### **9.4.20 Motor Solo Run**

Motor solo runs are made to determine if any problems exist with the motor operation as soon as possible in order to provide maximum time for correction. Consult with motor manufacturer to verify any special requirements or precautions to be observed during the solo run.

**9.4.20.1** Motor solo requires that the motor and driven equipment not be connected.

**9.4.20.2** Once the motor is turning with the correct rotation, restart the motor and run for one-half hour minimum or until the bearing temperatures and vibration have stabilized, whichever is longer.

**9.4.20.3** If motor bearing temperature monitoring device is provided, monitor motor bearing temperatures during solo run and record the values.

**9.4.20.4** Monitor motor vibration during solo run and record the values. If vibration monitoring probes are not provided, use a hand held vibration monitoring device.

NOTE Typically major motor problems will show up in a short unloaded run. Some of the other motor problems will not manifest until the motor is loaded and up to temperature. If there is a problem with the motor on the solo run, it is typical that there will be a more serious problem during a loaded run.

**9.4.20.5** Monitor motor amps during solo run.

NOTE Due to the relatively low current draw during the solo run, temporary intervention could be required to keep the motor starter from tripping offline.

**9.4.20.6** Monitor motor winding temperatures if available during solo run.

**9.4.20.7** Verify the motor rotor is located at its axial magnetic center.

#### **9.4.21** Turbine Solo Run

**9.4.21.1** Turbine drive solo should be made as soon as possible after the steam system has been commissioned in order to provide maximum time to correct any turbine problems.

**9.4.21.2** Verify that piping system is complete and cleaned.

**9.4.21.3** Verify that lockout-tagout procedures have been completed.

**9.4.21.4** Verify Inlet strainers, either permanent or temporary, are installed in the inlet line upstream of the trip and throttle valve. The integral strainer to the trip and throttle valve may not be sufficient as a start-up strainer.

**9.4.21.5** Unless otherwise specified, the exhaust line shall be opened before the inlet line to avoid over-pressuring the turbine exhaust casing.

**9.4.21.6** Verify turbine seal leak-off piping is open and that carbon rings (or other sealing system) are installed, if required.

**9.4.21.7** Verify that the turbine cooling water lines are open.

**9.4.21.8** Ensure that required pressure and temperature gauges are installed.

**9.4.21.9** Verify that a working speed indicator system is available to determine the turbine speed. If a handheld unit is to be used, verify access to signal generator.

**9.4.21.10** Exercise the turbine trip and throttle valves prior to admission of steam. Follow Manufacturer-specified instructions for trip system function verification before start-up. Verify the set point of the overspeed trip device is the same as the trip speed specified by the manufacturer.

**9.4.21.10.1** For extraction turbines, verify that the extraction steam line trip valve functions properly.

**9.4.21.10.2** If applicable, verify that proper governor oil level has been achieved for all governor oil systems.

**9.4.21.10.3** Identify any speed ranges to avoid for each turbine during start up. Verify the vendor speed ramping logic takes into consideration the required ramp up rate through the critical speeds.

Note: There could be critical speeds on larger turbines that will need to be avoided during start-up.

**9.4.21.10.4** If recommended by the vendor, turbines with carbon seals should be commissioned with a break-in period where the speed is raised and then reduced, to properly wear-in the carbons. Vibration should be monitored during this period until no jumps in vibration are noticed with increasing speed.

**9.4.21.10.5** Once minimum continuous speed is reached, the speed should be maintained to check operability of the governor and mechanical stability of the turbine.

NOTE: Unloaded turbines will typically require a small amount of steam (relative to a loaded condition) to reach minimum governor speed. Exercise caution not to overspeed the turbine accidentally. To help control the turbine in a solo run, the steam inlet block valve is normally throttled.

**9.4.21.11** Record vibration data periodically as agreed until the operating conditions have stabilized.

**9.4.21.12** Record minimum and maximum governor speed and trip speed.

**9.4.21.13** Check bearing temperatures and bearing vibrations during the coast-down after trip. The turbine should coast down smoothly and not come to an abrupt halt.

**9.4.21.14** The maximum allowable exhaust temperature shall not be exceeded during solo runs, so as not to damage the turbine.

#### **9.4.22** Driver to Driven Couple-up

**9.4.22.1** Equipment shall be Locked-out and tagged-out as required per plant operating procedures.

**9.4.22.2** Solo plates shall be removed.

Restricted



**9.4.22.3** Verify alignment data has been recorded, including any pre-stretch, compression of the coupling spacer and thermal growth offset of the hubs.

Note: Refer to clauses in section 7 of Parts B and C for further requirement for alignment.

**9.4.22.4** Install the coupling spacer to the required shaft end spacing (DBSE). Line up match marks if provided. Verify non-spacer coupling DBSE is correct before bolting coupling flanges.

Note: For grease-packed or oil-lubricated couplings, refer to coupling vendor instructions for lubrication and bolting.

**9.4.22.5** Torque the coupling bolts to the required torque. Torque bolts to 50 % of required torque in a pattern across the diagonal. After all bolts are torqued to 50 % then torque all bolts in a similar sequence to 100 % of required torque.

**9.4.22.6** Machinery shaft shall be manually rotated for more than 360 (one full turn) after the equipment has been coupled together to ensure freedom of operation.

**9.4.22.7** On cartridge seal assemblies, verify the drive collars are tightened to the correct torque and that the locating cams have been rotated out of position, so as not to come in contact with the rotating shaft. "Snug" the fasteners in a "star" pattern. Torque the fasteners to 50% of required torque in a "star" pattern. After all fasteners are torqued to 50% then torque all fasteners in a similar sequence to 100% of required torque.

Note: Vendor will advise the correct torque values – this value should be on the seal drawing.

**9.4.22.8** Install coupling guard.

**9.4.22.9** Verify all jack screws used for alignment have been loosened so as to eliminate any residual load from the jack screws that might affect alignment.

#### **9.4.23** Start-up

**9.4.23.1** During initial start-up of the equipment, operating conditions such as inlet and outlet pressures, temperatures, and flow rates should be recorded.

**9.4.23.2** Verify pumps are filled and vented.

**9.4.23.3** Verify valve positioning is correct.

**9.4.23.4** Each machine vibration signature should be obtained and recorded to ensure vibration is within the acceptable limits.

Note: Vibration signature of the machine can be obtained from different locations of the machine, such as bearing, bearing housing, casing or frame.

**9.4.23.5** For motor drives, motor current shall be obtained and recorded.

**9.4.23.6** All connections shall be inspected for leaks.

**9.4.23.7** Record that proper start-up procedures have been followed.

**9.4.23.8** Piping supports/spring hangers shall be adjusted accordingly when the system is in service at operating temperature (see Chapter 6).

**9.4.23.9** If an extraction turbine is used as a main driver, verify extraction map boundaries are enforced during operation (e.g. max exhaust flow).

#### **9.4.24** Compressors

##### **9.4.24.1** Commissioning - General

This section contains general guidelines for the commissioning of compressors.

**9.4.24.1.1** Commissioning team to determine whether a vendor service representative being required on-site to support the commissioning and to inspect the equipment prior to start up.

**9.4.24.1.2** Obtain the completed checklists to verify installation and cleanout is completed.

**9.4.24.1.3** Commissioning and start up procedure shall be verified for consistency with the vendor start up procedure and commissioning requirements.

**9.4.24.1.4** Verify all temporary bypasses are removed and the piping and equipment are returned to normal configuration.

**9.4.24.1.5** Temporary bypasses, such as those used during oil system flushing, process piping cleanout, etc., are typically used during commissioning phase.

Restricted



- 9.4.24.1.6** If start up process requires, the process piping to be in a different configuration than the normal operation, the implementation of alternative configuration shall be verified.
- 9.4.24.1.7** Verify all instrumentation has been calibrated and functionally tested, using instrument supplier's documentation.
- 9.4.24.1.8** Verify all control loops have been functionally tested and are operational.
- 9.4.24.1.9** Verify all the control valve(s) are operational. Also verify the full stroke travel of the actuator, the stroke time and positioner calibration.
- 9.4.24.1.10** Verify that the control and protection systems and condition monitoring system and DCS are configured per the final vendor approved control philosophy and alarm/shutdown set points.
- 9.4.24.1.11** Verify that all alarm and trip systems have been functionally tested and all start permissive and interlocks are functional.
- 9.4.24.1.12** Verify that plant operating instructions have been clearly understood and that all valves are in proper position and that controllers, shutdown devices and position indicators are set for startup.  
Note: During start up, the valves and controller can be in a different position compared to normal operation.
- 9.4.24.1.13** Verify the start-up scenario is consistent with the start-up case defined in the compressor design documents, and the performance data associated with this case are provided.
- 9.4.24.1.14** The start-up scenario should have been defined in the compressor design documents at the design phase.
- 9.4.24.1.15** If there is a requirement for startup on air or nitrogen, ensure the vendor has studied start up under air or nitrogen and has provided the relevant curves and performance data.
- 9.4.24.1.16** Compressor and auxiliary systems operating pressure and temperature, while running under start up gas should be verified against the pressure and temperature limits of the casing and system.
- 9.4.24.1.17** The driver should be verified against overload under start up condition.  
Note: For variable speed drivers, operating speed with start-up gas could be different from normal operating condition.

#### **9.4.24.2 Start-up Centrifugal Compressors**

- 9.4.24.2.1** Verify surge control valve(s) and hot gas bypass valve(s) (if applicable) are operational. Also verify the full stroke travel of the actuator, the stroke time and positioner calibration.
- 9.4.24.2.2** If a pipe blow out operating case is required, the control valves in the loop shall be protected from blow out stream. Protecting control valves against blowout stream can be done by replacing control valves with a spool.
- 9.4.24.2.3** To avoid running on stone wall, anti-surge valve should be replaced with a restriction orifice, designed for this case.
- 9.4.24.2.4** Verify that the compressor separation gas system is in service and that all flows, temperatures and pressures are within manufacturer's recommended range.
- 9.4.24.2.5** Verify that the lube oil system is in service and the lube oil flows, levels, temperatures and pressures are within manufacturer's recommended range.
- 9.4.24.2.6** Verify the lube oil backup pump, and emergency pump (if applicable), is in the "auto" position.
- 9.4.24.2.7** If rundown tank is provided, verify the rundown tank is filled.
- 9.4.24.2.8** If a pipe blow out operating case is required, there should be a temporary source of dry seal gas considered for operation on air or nitrogen. The source of seal gas for air or nitrogen run should be agreed upon and specified during design phase.  
Note: Nitrogen is typically used as the seal gas for air or nitrogen run.
- 9.4.24.2.9** Any control valve replaced with spool or an orifice for air blow out or nitrogen run shall be reinstalled before initiation of start up with process gas.
- 9.4.24.2.10** Startup team shall verify that the seal gas is not introduced to the dry gas seal until the seal gas reaches the start permissive temperature level.
- 9.4.24.2.11** Verify that the seal gas and buffer gas systems are operational and temperatures, pressures and flowrates of the supply and vent lines are within manufacturer's recommended range.  
Note: In the static position, seal gas leakage is typically much less than steady state consumption.
- 9.4.24.2.12** Verify that the system purge is complete and the compressor loop is fully charged with the startup gas.
- 9.4.24.2.13** Verify the start permissive is satisfied. This includes permissive required for startup of the driver.
- 9.4.24.2.14** Verify inlet control valve/inlet guide vane setting is at the position recommended by the vendor for startup.

Note: Typical constant speed motor drives require inlet valve/inlet guide vane position to be set for minimum flow to minimize acceleration time.

**9.4.24.2.15** Ensure the anti-surge system is in service and the anti-surge valves are fully open and in manual mode before start-up.

Note: In some cases, in order to avoid overloading the driver, the anti-surge valve is set at a partially open position.

**9.4.24.2.16** Once the compressor is started, the capacity control and the surge control systems shall be adjusted and tuned to achieve smooth and safe operation of the compressor throughout the operating range.

Note: Final tuning and adjustment of the anti-surge valve and capacity control is completed when the unit is operating with the design process gas.

**9.4.24.2.17** Ensure the compressor operating data are recorded. Operating data during start up should be recorded on short intervals until a design load is reached. Once at design load, it may take up to 12 hours until all thermal influences are stabilized. Data should be recorded through this period and maintained as unit baseline performance for future reference.

### **9.4.24.3 Start-up Reciprocating Compressors**

**9.4.24.3.1** Verify that the lube oil system is in service and the lube oil flows, levels, temperatures and pressures are within manufacturer's recommended range. If the main lube oil pump is crank shaft driven, the stand by lube oil pump should be operated for start-up period until the compressor is operating and the main pump takes over.

**9.4.24.3.2** Verify that the cylinder jacket water system (if applicable) is in service and the flows, levels, temperatures and pressures are within manufacturer's recommended range.

**9.4.24.3.3** Start cylinder lubricator system (if applicable). The cylinder lubricator should not operate for extended period of time while the compressor is not operating to avoid accumulation of oil in the cylinders.

**9.4.24.3.4** Rotate the compressor using the barring device. This will distribute the cylinder oil and verify that there are no mechanical tight spots during the revolution. If the machine will not bar over, then check for mechanical interference in the running gear or in the cylinders. Do not operate the compressor until it is free to rotate.

**9.4.24.3.5** For reciprocating compressors a no load mechanical run should be performed in order to verify mechanical integrity. This run is a non-pressurized operation of the compressor.

- a) Each compressor end should be configured for unloaded operation. If the suction valve is removed for this operation, provisions shall be considered to avoid introducing objects into the cylinder.

Note: Unloading can be achieved by utilizing suction unloaders (if applicable) or by removing at least one suction valves from each cylinder end.

- b) Following break-in start up periods for atmospheric operation should be implemented.

- c) After operating for 5 to 10 minutes, shut down and check for signs of distress, such as high temperature, metal wear or metallic debris in areas of crosshead, connecting rod and main bearing.

Note: Temperatures can be checked with a thermal gun or contact pyrometer.

- d) If first run is acceptable, operate for 30 to 45 minutes and recheck.

- e) If the first two runs show no problems, then run for four hours or until bearing temperatures stabilize, and recheck.

- f) If the result of inspections are acceptable, make compressor ready for operation.

**9.4.24.3.6** Perform an inert gas leak test to verify the integrity of the process gas system.

Note: For guidance on selecting the proper gas for leak test refer to API 618.

**9.4.24.3.5** Operate all capacity controls before start-up and verify action.

**9.4.24.3.6** Verify that the buffer gas system is in service and the flows and pressures are within manufacturer's recommended range.

**9.4.24.3.7** Follow plant procedures for venting and introducing process gas to the compressor.

**9.4.24.3.8** Start compressor at minimum capacity. Ensure the compressor will not run at fully unloaded condition beyond the maximum allowable time recommended by the vendor.

Note: Continuous operation of reciprocating compressors while fully unloaded can present detrimental condition for the machine.

**9.4.24.3.9** Load compressor to users required capacity per vendor instructions.

**9.4.24.3.10** Record compressor operating data on datasheet.

**9.4.24.3.11** Verify compressor operation is satisfactory and that all auxiliary systems are working properly.

#### **9.4.24.4 Screw Compressors**

##### **9.4.24.4.1 Dry Screw Compressors**

a) Any control valve replaced with a spool or an orifice shall be reinstalled before initiation of start up with process gas.

b) For a dry gas seal application, verify that the compressor separation gas system is in service and that all flows, temperatures and pressures are within manufacturer's recommended range.

Note: Other type of seal systems are common for dry screw compressors such as oil cooled mechanical contact seals, nitrogen buffer carbon rings, which do not require a separation seal and separation gas.

c) Verify that the lube oil system is in service and the oil flows, levels, temperatures and pressures are within manufacturer's recommended range.

Note 1: The lubrication system should be typically started several minutes before the compressor is first operated in order to ensure oil is at the appropriate compressor oil delivery points, such as bearings, mechanical seal.

i. For oil cooled mechanical contact seals applications, verify the seal oil separator vessel contains the minimum required oil level as specified by vendor.

ii. For oil cooled mechanical contact seals applications, verify that the seal oil system is in service and the oil flows, levels, temperatures and pressures are within manufacturer's recommended range.

iii. Verify the lube oil backup pump is in the "auto" position.

d) If rundown tank provided, verify the rundown tank is filled out.

e) Verify that the seal gas and buffer gas systems are operational and temperatures, pressures and flowrates of the supply and vent lines are within manufacturer's recommended range.

Note: In the static position, seal gas leakage is typically much less than steady state consumption.

i. There should be a temporary source of dry gas seal considered for running on nitrogen or alternative process gas during commissioning stage.

Note: Nitrogen is typically used during commissioning. The source of seal gas for commissioning phase should have been agreed and specified during design phase.

ii. Startup team should verify that the seal gas is not introduced to the dry gas seal until the dry gas seal reaches the start permissive temperature level.

Note: When a seal gas heater is required to warm up the gas before introducing it into the dry gas seal, consider a seal gas vent line to flare downstream of the heater to flare cold gas until the required minimum seal gas temperature is achieved. If such provision is not considered in design phase, commissioning team to agree upon a reliable start up procedure with vendor and system designer.

- a) If the compressor is equipped with forced ventilated noise enclosure, ensure the ventilation fan(s) are in operation.
- b) Verify that the system purge is complete and the compressor loop is fully charged with the startup gas.
- c) Verify the start permissive is satisfied. This includes permissive required for startup of the driver.
- d) The suction low pressure protection instruments should be in service before start up.

Note: Screw compressors can reduce the suction pressure in case of operation under blocked inlet condition. This could be detrimental to the compressor or system and the machine or system should be protected against such condition.

- e) Verify the start-up scenario is the same as the start-up case defined in the compressor design documents and performance data associated with this case are provided.

Note: If there is a requirement for startup on air or nitrogen, ensure the vendor has studied start up under air or nitrogen and has provided the relevant performance data.

- f) 4.5.1.11 Operate the compressor as directed by the compressor manufacturer, observing compressor operating conditions as compared with predicted performance.
- g) 4.5.1.12 When compressor and associated systems have reached normal operating temperatures, verify compressor train integrity and operation is acceptable.
- h) 4.5.1.13. After test run is completed and prior to operation with specified process gas, confirm that compressor alarms and shutdown values are properly reset for specified operating conditions.

#### **9.4.24.4.2 Wet screw compressors**

**9.4.24.4.3** Verify the start-up scenario is the same as the start-up case defined in the compressor design documents and performance data associated with this case are provided.

Note: If there is a requirement for startup on air or nitrogen, ensure the vendor has studied start up under air or nitrogen and has provided the relevant performance data.

- a) 4.5.2.2 Any control valve replaced with a spool or an orifice shall be reinstalled before initiation of start up with process gas.

Note: An oil flooded screw compressor is not normally used for blowing the downstream piping, because of the oil carry over to downstream pipes.

- b) 4.5.2.3 If the compressor is equipped with forced ventilated noise enclosure, ensure the ventilation fan(s) are in operation.
- c) 4.5.2.4 Verify that the system purge is complete and the compressor loop is fully charged with the startup gas.
- d) 4.5.2.5 Verify the start permissive is satisfied. This includes permissive required for startup of the driver.

Note: Typically the compressor is fully unloaded at start up. The slide valve recycle valve, either or both, are normally at full open position. If recommended by the vendor, move the slide valve to a minimum turndown position after start up, to avoid the slide valve being jammed at a fully retracted position.

- e) 4.5.2.6 Verify that the Lube-oil and seal-oil system is in service and the oil flows, levels, temperatures and pressures are within manufacturer's recommended range.

Note 1: The oil system is typically started just prior to start-up of the compressor. This short duration is to minimize the possibility of flooding the compressor before start-up.

- f) 5.5.2.6.1 Verify the lube oil backup pump is in the "auto" position.
- g) 5.5.2.7 Startup up and operate the compressor as directed by the compressor manufacturer, observing compressor operating conditions as compared with predicted performance.

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**Annex B**  
(informative)  
**Steam Blowing Procedure**

**B.1 Scope**

The purpose of steam blowing is to remove the foreign material from the steam piping. Particles carried by the steam into the turbine will damage the governor valve, nozzle block, and turbine wheel blading.

**B.1.1** Remove the piping spool between the turbine trip valve, and the isolation block for the turbine inlet. If there is a steam strainer downstream of the block valve, the strainer must be removed.

**B.1.2** Support inlet piping to withstand the reactive force from the steam blow.

**B.1.3** Place a covering over the turbine inlet flange. The cover protects the turbine from particles entering during the steam blow, and acts as a device to hold the target. Typically a blind flange can be used with brackets on the outside to hold the target plate. Certain applications will require a re-directional spool be installed in order to direct the steam in a safe direction.

**B.1.4** Target mounting methods must ensure that the targets will remain safely attached during the steam blowing process. Actual target material shall be polished 304 or 316 stainless steel. At least two targets shall be supplied for the test.

**B.1.5** Close the inlet valve at the header and open the inlet valve at the turbine.

**B.1.6** Blow steam through the system without any backpressure at flows as close to maximum as possible until no particles can be observed from the line. Several cycles of blowing may be required to remove the particles. Sometimes a cooling process followed by a rapid heating can assist the process.

NOTE Steam blowing allows hot steam to be discharged around the turbine area. Particles will be discharged from the open valve at high velocities requiring the area to be clear. Steam blowing generally causes an increase in the local noise levels and proper instruction for noise hearing protection should be provided.

**B.1.7** Close the header valve once no particles are seen, and securely attach the polished target on the target support.

**B.1.8** Open the steam header valve and blow for at least 15 minutes. Close the header valve and inspect the target.

**B.1.9** Acceptance criteria for piping cleanliness is based on the following:

- a) an acceptance target will have no raised pits;
- b) an acceptable target will have less than three pits in any square centimeter of the target, and no pit shall be larger than 1 mm;
- c) steam blowing shall be repeated until the acceptance criteria has been met.