Machinery Protection Systems

API STANDARD 670

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Table of Contents

Table of Figures

Tables

Machinery Protection Systems

1 Scope

1.1 General

This standard covers the minimum requirements for a machinery protection system (MPS) measuring radial shaft vibration, casing vibration, shaft axial position, shaft rotational speed, crosshead vibration, piston rod monitoring, phase reference, crank angle reference, overspeed, surge detection, and critical machinery temperatures (such as bearing metal and motor windings). It covers requirements for hardware (transducer and monitor systems), installation, documentation, and testing.

NOTE A bullet (●) at the beginning of a subsection or paragraph indicates that either a decision is required or further information is to be provided by the purchaser. This information should be indicated on the datasheets (see Annex A); otherwise, it should be stated in the quotation request or in the order.

1.2 Conflicting Requirements

In case of conflict between this standard and the inquiry or order, the information included in the order shall govern.

2 Normative References

2.1 The editions of the following standards, codes, and specifications that are in effect at the time of publication of this standard shall, to the extent specified herein, form a part of this standard. The applicability of changes in standards, codes, and specifications that occur after the inquiry shall be mutually agreed upon by the purchaser and the MPS vendor.

API Recommended Practice 552, *Transmission Systems*

API 610, *Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries*

ANSI/API 611, *General Purpose Steam Turbines for Petroleum, Chemical, and Gas Industry Systems*

API 612, *Petroleum Petrochemical and Natural Gas Industries—Steam Turbines—Special-Purpose Applications*

ANSI/API 613, *Special Purpose Gear Units for Petroleum, Chemical and Gas Industry Services*

API 616, *Gas Turbines for the Petroleum, Chemical, and Gas Industry Services*

API 617, *Axial and Centrifugal Compressors and Expander-compressors*

API 618, *Reciprocating Compressors for Petroleum, Chemical, and Gas Industry Services*

API Recommended Practice 684, *Rotordynamic Tutorial: Lateral Critical Speeds, Unbalance Response, Stability, Train Torsionals, and Rotor Balancing*

ASTM E230/230M-23a [1], Standard Specification for Temperature-Electromotive Force (emf) Tables For Standardized Thermocouples

ASME Y14.2M [2], Line Conventions and Lettering

EN 61000-6-2:2005 [3], Electromagnetic Compatibility Generic Immunity Standard; Part 2: Industrial Environment

[1] American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, New York 10036, www.ansi.org.
[2] ASME International, 3 Park Avenue, New York, New York 10016-5990, www.asme.org.
[3] European Committee for Standardization, Rue de Stassart 36, B-1050 Brussels, Belgium, www.cenorm.be.

ICEA S-61-402 [4], Thermoplastic-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy

IEC 60079 [5], (all parts) Explosive atmospheres

IEC 60259, Degrees of protection provided by enclosures (IP Code)

IEC 61508, Functional safety of electrical/electronic/programmable electronic safety-related systems

IEC 61511, Functional safety—Safety instrumented systems for the process industry sector

IEC 60584, Thermocouples

IEC 62061, Safety of machinery—Functional safety of safety-related electrical, electronic and programmable electronic control systems

ISA S12.1 [6], Definitions and Information Pertaining to Electrical Instruments in Hazardous (Classified) Locations

ISA S12.4, Instrument Purging for Reduction of Hazardous Area Classification

ISA S84.00.01, Application of Safety Instrumented Systems for the Process Industries

ISO 13849, (all parts) Safety of machinery—Safety-related parts of control systems

ISO 16063-21, Methods for the calibration of vibration and shock transducers—Vibration calibration by comparison to a reference transducer

ISO 21789, Gas turbine applications—Safety

Military Specification MIL-C-39012-C [7], Connectors, Coaxial, Radio Frequency, General Specification for

Military Specification MIL-C-39012/5F, Connectors, Plug, Electrical, Coaxial, Radio Frequency [Series N (Cabled) Right Angle, Pin Contact, Class 2]

NEMA 250 [8], Enclosures for Electrical Equipment (1000 Volts Maximum)

NEMA WC 5, Thermoplastic-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy

NFPA 70 [9], National Electrical Code

NFPA 496, Purged and Pressurized Enclosures for Electrical Equipment

Schneider Electric PI-MBUS-300,13 Modbus® Protocol Reference Guide

2.2 The standards, codes, and specifications of the American Iron and Steel Institute (AISI) [10] also form part of this standard.

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[4] Insulated Cable Engineers Association, P.O. Box 1568, Carrollton, Georgia 30112, www.icea.net.
[5] International Electrotechnical Commission, 3, rue de Varembé, P.O. Box 131, CH-1211 Geneva 20, Switzerland, www.iec.ch.
[6] International Society of Automation, 67 T.W. Alexander Drive, Research Triangle Park, North Carolina, 22709, www.isa.org.
[7] S. Department of Defense, Document Automation and Production Service, Building 4/D, 700 Robbins Avenue, Philadelphia, Pennsylvania 19111-5094, https://assist.daps.dla.mil.
[8] National Electrical Manufacturers Association, 1300 North 17th Street, Suite 1752, Rosslyn, Virginia 22209, www.nema.org.
[9] National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169-7471, www.nfpa.org.
[10] American Iron and Steel Institute, 1540 Connecticut Avenue, NW, Suite 705, Washington, DC 20036, www.steel.org.

2.3 The purchaser and the MPS vendor shall mutually determine the measures that shall be taken to comply with any governmental codes, regulations, ordinances, or rules that are applicable to the equipment.

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

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

3.1.1
acceleration
The time rate of change of velocity. The unit for vibration acceleration is g. (see 3.1.42)

3.1.2
accelerometer
A sensor with an output proportional to acceleration.

3.1.3
accelerometer cable
An assembly consisting of a specified length of cable and mating connectors. Both the cable and the connectors shall be compatible with the particular accelerometer and (when used) intermediate termination.

3.1.4
accuracy
The degree of conformity of an indicated value to a recognized accepted standard value or ideal value.

3.1.5
active magnetic speed sensor
A magnetic speed sensor that requires external power and provides a conditioned (i.e. square wave) output. Typical excitation is between +5 Vdc to +30 Vdc.

3.1.6
active (normal) thrust direction
The direction of a rotor axial thrust load expected by the machinery vendor when the machinery is operating under normal running conditions.

3.1.7
alarm setpoint
A preset value of a parameter at which an alarm is activated to warn of a condition that requires corrective action.

3.1.8
alarm/shutdown/integrity logic
Violations of these setpoints or circuit fault criteria result in alarm or shutdown status conditions in the monitor system.

3.1.9
amplitude
The magnitude of vibration. Displacement is measured in peak-to-peak. Velocity and acceleration are measured in zero-to-peak or root mean square (rms).

3.1.10
analog
A continuous electrical signal with a time varying quantity, such as voltage or current, representing a sensed quantity such as displacement, pressure, or acceleration.

3.1.11
axial position
The average position, or change in position, of a rotor in the axial direction with respect to some fixed reference (see 3.1.6 **active (normal) thrust direction**).

3.1.12
bench test
A test performed on system components within the testing range.

3.1.13
best fit straight line
The line drawn through the actual calibration curve where the maximum plus or minus deviations are minimized and made equal.

3.1.14
buffered output
An unaltered, analog replica of the transducer input signal that preserves amplitude, phase, frequency content, and signal polarity. It is designed to prevent a short circuit of this output to monitor system ground from affecting the operation of the MPS. The purpose of this output is to allow connection of vibration analyzers, oscilloscopes, and other test instrumentation to the transducer signals.

3.1.15
casing vibration
The absolute vibration of machine housing or structure, usually measured on the bearing housing.

3.1.16
channel
The monitor system components associated with a single transducer. The number of channels in a monitor system refers to the number of transducer systems it can accept as inputs.

3.1.17
channel pair
Two associated measurement locations (such as the X and Y proximity probes at a particular radial bearing or the two axial proximity probes at a particular thrust bearing).

3.1.18
circuit fault
A MPS circuit failure that adversely affects the function of the system.

3.1.19
construction agency
The contractor that installs the machinery train or its associated MPS.

3.1.20
contiguous
Mechanically connected and included in the same housing or rack containing the signal processing and alarm/ shutdown/integrity logic functions of the monitor system.

3.1.21
controlled access
A security feature of a MPS that restricts alteration of a parameter to authorized individuals. Access may be restricted by means such as the use of a key or coded password or other procedures requiring specialized knowledge.

3.1.22
crank angle reference transducer
A gap-to-voltage device that consists of a proximity probe, an extension cable, and an oscillator-demodulator and is used to sense a once-per-revolution mark to determine speed and a reference to assist in determining top dead center (0° crank angle) for each throw.

3.1.23
critical speed
A shaft rotational speed at which the rotor-bearing-support system is in a state of resonance.

3.1.24
derived peak
A calculated estimate of the peak amplitude found by multiplying the RMS value by $\sqrt{2}$.

3.1.25
deviation from straight line
DSL
The maximum error (in mils) in the probe gap reading at a given voltage compared to nominal scale factor [7.87 mV/μm (200 mV/mil) for an 8mm probe and 3.93 mV/μm (100 mV/mil) for an 11 mm probe] best fit straight line. These errors are associated with errors in axial position or probe gap readings.

3.1.26
digital
A signal that carries information in the form of discrete states (for example, ON/OFF or 0V/2.5V/5V). The term can also refer to a binary communications protocol.

3.1.27
displacement
A vibration measurement that quantifies the amplitude in engineering units of mils (1 mil = 0.001 in.) or micrometers.

3.1.28
display
An analog meter movement, cathode ray tube, liquid crystal device, or other means for visually indicating the measured variables and status conditions from the MPS. A display may be contiguous with the MPS or mounted remotely.

3.1.29
distributed trip system
A system in which the trip system, overspeed protection and surge detection systems are independent of each other via dedicated hardware/software platforms.

3.1.30
dual voting logic
A monitor feature whereby the signals on two channels shall both be in violation of their respective setpoints to initiate a change in status (two-out-of-two logic).

3.1.31
dynamic range
The usable range of amplitude of a signal, usually expressed in decibels.

3.1.32
electrical runout
A source of error on the output signal from a noncontacting probe system resulting from nonuniform electrical conductivity properties of the observed material or from the presence of a local magnetic field at a point on the shaft surface.

3.1.33
electrically isolated accelerometer
An accelerometer in which all signal connections are electrically insulated from the accelerometer case or base.

3.1.34
extension cable
The interconnection between the proximity probe's integral cable and its associated oscillator-demodulator.

3.1.35
fault
The state of an item characterized by inability to perform a required function, excluding such inability during preventative maintenance or other planned actions or due to lack of external resources.

3.1.36
field changeable
Refers to a design feature of a MPS that permits alteration of a function after the system has been installed.

3.1.37
filter
An electrical device that attenuates signals outside the frequency range of interest.

3.1.38
final trip element
The device(s) that accepts relay contacts and actuates the mechanism to initiate a forced shutdown.

3.1.39
finite life
The components are designed to fail under normal operating conditions or date of planned obsolescence is known.

3.1.40
flow sensor
A device used for sensing the rate of fluid flow.

3.1.41
frequency
The repetition rate of a periodic vibration per unit of time. Vibration frequency is typically expressed in units of cycles per second (hertz), cycles per minute, or orders of shaft rotational speed.

3.1.42
g
A unit of acceleration equal to 9.81 m/s^2 (386.4 in./s^2).

3.1.43
gap voltage
A direct current (DC) voltage from a proximity transducer that quantifies the distance from the tip of the transducer to the observed shaft surface.

3.1.44
Hertz
Hz
The unit of frequency measurement in cycles per second.

3.1.45
inactive (counter) thrust direction
The direction opposite the active thrust direction.

3.1.46
inches per second
IPS
A unit of velocity equal to 25.4 mm/s (1 in./s).

3.1.47
incremental scale factor
ISF
The maximum amount the measured scale factor varies from nominal scale factor [7.87 mV/μm (200 mV/mil) for an 8mm probe and 3.93 mV/μm (100 mV/mil) for an 11 mm probe] when measured at specified increments throughout the linear range. Measurements are usually taken at 250 μm (10 mil) increments. This error is associated with errors in radial vibration and axial position readings.

3.1.48
integrated trip system
A system that includes all shutdown/trip functions in one hardware/software platform. System includes and is not limited to trips, Overspeed protection, Surge Detection.

3.1.49
linear frequency response range
The portion of the transducer’s voltage output versus frequency curve, between lower and upper frequency limits, where the response is linear within a specified tolerance.

3.1.50
linear range
The portion of a transducer’s output where the output versus input relationship is linear within a specified tolerance.

3.1.51
local
Refers to a device’s location when mounted on or near the equipment or console.

3.1.52
logic solver
Part of either a BPCS or SIS that performs one or more logic function(s)
Note 1 to entry: In IEC 61511 the following terms for logic solvers are used:
- electrical logic systems for electro-mechanical technology;
- electronic logic systems for electronic technology;
- PE logic system for programmable electronic systems.

Note 2 to entry: Examples are: electrical systems, electronic systems, programmable electronic systems, pneumatic systems, and hydraulic systems. Sensors and final elements are not part of the logic solver.

3.1.53
machine case
A driver (e.g. electric motor, turbine, or engine) or any one of its driven pieces of equipment (e.g. pump, compressor, gearbox, generator, fan). An individual component of a machinery train.

3.1.54
machinery protection system
MPS
The system that senses, measures, monitors, and displays machine parameters indicative of its operating condition. The system consists of the transducer system, signal cables, the monitor system, all necessary housings and mounting fixtures, and documentation. May include one or more of these functions such as: Vibration/Position/Temperature/Piston Rod Monitoring, Surge Detection, Overspeed Detection

3.1.55
machinery train
The driver(s) and all of its associated driven pieces of equipment.

3.1.56
magnetic speed sensor
Responds to changes in magnetic field reluctance as the gap between the sensor and its observed ferrous target (speed sensing surface) changes. By choosing a proper speed sensing surface, the magnetic speed sensor’s output will be proportional to the rotational speed of the observed surface. Magnetic speed sensors may be either passive (self-powered) or active (require external power).

3.1.57
Maximum allowable momentary rotor overshoot speed
Maximum momentary speed determined by the manufacturer at which no damage will occur to the turbine rotor that will require immediate maintenance intervention.

3.1.58
mechanical runout
A source of error in the output signal of a proximity probe system resulting from surface irregularities, out-of-round shafts, and such.

3.1.59
modules
Components in a rack that provide dedicated processing, input functions, and output functions such as vibration monitoring, communication gateways, temperature monitoring, and position monitoring.

3.1.60
natural frequency
The frequency of free vibration of a mechanical system at which a specific natural mode shape of the system elements assumes its maximum amplitude.

3.1.61
oscillator-demodulator
A signal conditioning device that sends a radio frequency signal to a proximity probe, demodulates the probe output, and provides an output signal suitable for input to the machinery protection system.

3.1.62
overall
A value representing the magnitude of vibration over a frequency range determined by the design of the instrument or as specified. Expressed as rms, zero-peak (0-P), or peak-to-peak (P-P).

3.1.63
overspeed detection system
ODS
A system that consists of speed sensors, power supplies, output relays, signal processing, and alarm/shutdown/ integrity logic. Its function is to continuously measure shaft rotational speed and de-energized its output relays when an overspeed condition is detected.

3.1.64
overspeed protection system
An electronic ODS and all other components necessary to shut down the machine in the event of an overspeed condition. It may include (but is not limited to) items such as shutdown valves, solenoids, and interposing relays.

3.1.65
owner
The final recipient of the equipment who will operate the machinery and its associated MPS and may delegate another agent as the purchaser of the equipment.

3.1.66
peak-to-peak value
PP
The difference between positive and negative extreme values of an electronic signal or dynamic motion.

3.1.67
phase reference transducer
A gap-to-voltage device that consists of a proximity probe, an extension cable, and an oscillator-demodulator and is used to sense a once-per-revolution mark.

3.1.68
piston rod monitoring
The use of proximity probe(s) to produce the measurements of piston rod drop, piston rod position and piston rod vibration.

3.1.69
piston rod drop:
A measurement intended to indicate piston rider band wear in the cylinder, measured using a single non-contacting displacement probe mounted vertically at the measurement plane (typically near the pressure packing case) on horizontal cylinders. It is calculated using the similar triangle principle.

3.1.70
piston rod position:
The movement (magnitude and direction) of the piston rod during one crank revolution with respect to the center of the cylinder bore at the measurement plane (typically near the pressure packing case) using orthogonally mounted (true vertical and true horizontal) non-contacting displacement probes.

3.1.71
piston rod vibration:
The peak to peak (max-min) displacement measurement of the piston rod at operating speed within one crank revolution. The measured vibration value(s) are reported directly at the measurement plane (typically near the pressure packing case) from the non-contacting displacement probe(s).

3.1.72
pitch
also diametral pitch
The ratio of number of gear teeth to the gear diameter.

3.1.73
positive indication
An active (i.e. requires power for annunciation and changes state upon loss of power) display under the annunciated condition. Examples include an LED that is lighted under the annunciated condition or an LCD that is darkened or colored under the annunciated condition.

3.1.74
positively attached
Member attached to the main rotor with a key or pin.

3.1.75
pressure sensor
A device that measures the force per unit area of liquids or gasses.

3.1.76
primary probes
Those proximity probes installed at preferred locations and used as the default inputs to the machinery protection system.

3.1.77
probe area
The area observed by the proximity probe during measurement.

3.1.78
probe gap
The physical distance between the face of a probe tip and the observed surface. The distance can be expressed in terms of displacement (mils, micrometers) or in terms of voltage (Vdc).

3.1.79
proximity probe
A noncontacting sensor that consists of a tip, a probe body, an integral coaxial or triaxial cable, and a connector and is used to translate distance (gap) to voltage when used in conjunction with an oscillator-demodulator.

3.1.80
proximity probe system
A noncontacting displacement measuring system consisting of a proximity probe, extension cable, and oscillator-demodulator.

3.1.81
purchaser
The agency that issues the order and specification to the vendor.

3.1.82
rack
A physical housing that holds and organizes the various machinery protection system modules.

3.1.83
radial shaft vibration
The vibratory motion of the machine shaft in a direction perpendicular to the shaft longitudinal axis.

3.1.84
range, operating
operating range
Represents temperatures over which the transducer and machinery protection system components are expected to operate in actual service conditions.

3.1.85
range, testing
testing range
A range of temperatures in which normal bench testing occurs. It allows verification of the accuracy and operation of transducer and machinery protection system components without the need for special temperature or humidity-controlled environments.

3.1.86
resistance temperature detector
RTD
A temperature sensor that changes its resistance to electrical current as its temperature changes.

3.1.87
resolution
The smallest increment of measure. In analog to digital conversion analog systems, resolution is calculated as the full- scale value divided by 2*n* where "*n*" is the number of bits of the analog to digital converter.

3.1.88
sensor
A device (such as a proximity probe or an accelerometer) that detects the value of a physical quantity and converts the measurement into a useful input for another device.

3.1.89
shutdown
A condition as determined by the equipment user that requires action to stop the equipment, may be automated or manual.

3.1.90
shutdown set point
A preset value of a measured parameter at which automatic or manual shutdown of the system or equipment is required.

3.1.91
signal cable
The field wiring interconnection between the transducer system and the machinery protection system.

3.1.92
signal processing
Transformation of the output signal from the transducer system into the desired parameter(s) for indication and alarming. Signal processing for vibration transducers may include, for example, peak-to-peak, zero-to-peak, or rms amplitude detection; pulse counting; DC bias voltage detection; and filtering and integration. The output(s) from the signal processing circuitry are used as inputs to the display/indication and alarm/shutdown/integrity logic circuitry of a machinery protection system.

3.1.93
spare probes
Probes installed at alternate locations to take the place of primary probes (without requiring machine disassembly) in the event of primary probe failure.

3.1.94
speed
The frequency at which a shaft is rotating at a given moment, usually expressed in units of revolutions per minute (rpm).

3.1.95
speed sensing surface
A gear, toothed-wheel, or other surface with uniformly-spaced discontinuities such as a shaft key or slot that causes a change in gap between the speed sensing surface and its associated speed sensor(s) as the shaft rotates.

3.1.96
speed sensor
A proximity probe or magnetic speed sensor used to observe a speed sensing surface. It provides an electrical output proportional to the rotational speed of the observed surface.

3.1.97
standard option
A generally available alternative configuration that may be specified in lieu of the default configuration specified herein.

3.1.98
surge
At a given head, the minimum volumetric flow for a specific set of gas conditions below which a centrifugal or axial compressor becomes aerodynamically unstable.

3.1.99
surge cycle
Consists of a flow reversal accompanied by fluctuations in the compressor pressure and temperature followed by flow recovery.

3.1.100
surge detection system
Consists of surge sensors (typically temperature, pressure, or flow), power supplies, output relays, signal processing, and alarm/shutdown/integrity logic. Its function is to continuously measure and count surge cycles.

3.1.101
surge limit line
The line formed by theoretical or tested surge points across the head range of the compressor.

3.1.102
surge point
(See **surge** in 3.1.98~~)~~

3.1.103
tachometer
A device for indicating shaft rotational speed.

3.1.104
temperature sensor
A thermocouple or RTD and its integral sensor lead.

3.1.105
thermocouple
A temperature sensor consisting of two dissimilar metals so joined to produce different voltages when their junction is at different temperatures.

3.1.106
transducer system
A proximity probe, accelerometer, or sensor, an extension or interconnect cable, and oscillator-demodulator (when required). The transducer system generates a signal, with AC and DC components, that is proportional to the measured variable.

3.1.107
transmitter
A device that consists of a sensor and a signal conditioner, usually combined into one assembly, designed to send a DC signal over long distances. The electrical output is proportional to the magnitude of the sensed condition and bounded by a range (lower and upper limits) (i.e. 4 mA to 20 mA). Transmitters are not used or included in the class of transducer systems defined in 3.1.106.

3.1.108
transmitter drift
A gradual shift in the signal offset over time resulting in reduced accuracy.

3.1.109
transverse sensitivity
An accelerometer’s response to dynamic loads applied in a direction perpendicular to the principal axis. It is also sometimes called cross-axis sensitivity.

3.1.110
trip setpoint
A preset value of a parameter at which automatic shutdown of the machine is required.

3.1.111
trip speed
Speed at which the independent emergency overspeed device operates to shut down the driver.

3.1.112
trip system (formerly referenced as ESD)
A safety instrumented system (SIS) as defined by IEC 61508 and IEC 61511, dedicated to stopping the machine under abnormal conditions.

3.1.113
Triple Modular Redundant
TMR
An arrangement in which three systems perform a process and that result is processed by a majority-voting system to produce a single output. If any one of the three systems fails, the other two systems can correct and mask the fault.

3.1.114
unbalance
A rotor condition where the mass centerline (principal axis of inertia) does not coincide with the geometric centerline, expressed in units of gram-inches, gram-centimeters, or ounce-inches.

3.1.115
unfiltered
Data that is not filtered and represents the original transducer output signal.

3.1.116
unit responsibility
Refers to the responsibility for coordinating the delivery and technical aspects of the equipment and all auxiliary systems included in the scope of the order. The technical aspects to be considered include, but are

not limited to, such factors as the power requirements, speed, rotation, general arrangement, couplings, dynamics, noise, lubrication, sealing system, material test reports, instrumentation (such as the MPS), piping, conformance to specifications, and testing of components.

3.1.117
velocity
The time rate of change of displacement. Units for velocity are inches per second or millimeters per second.

3.1.118
velocity sensor—piezoelectric
An accelerometer with integral amplification and signal integration such that its output is proportional to its vibratory velocity (6.17.3.3).

3.1.119
velocity sensor—moving coil
An electromechanical type of transducer that contains a moving coil as a seismic mass suspended in a permanent magnetic field and outputs an analog signal proportional to the instantaneous velocity of the machine case (6.17.3.3).

3.1.120
Vibration monitoring system
VMS
The system consists of the transducer system, signal cables, the monitor system, all necessary housings, mounting fixtures, and documentation. The system functionality includes Vibration/Position/Temperature/ Piston Rod Monitoring.

3.1.121
voted channel
A channel requiring confirmation from one or more additional channels as a precondition for alarm and shutdown relay actuation.

3.1.122
witnessed
A hold shall be applied to the production schedule and the inspection or test shall be carried out with the purchaser or his/her representative in attendance. For factory acceptance testing of the MPS, this requires written notification of a successful preliminary test.

3.2 Acronyms and Abbreviations

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

AFD	adjustable frequency drive
AIL	asset integrity level
AWG	American wire gage
CIL	commercial integrity level
CM	condition modifier
DC	direct current
DCS	distributed control system
DSL	deviation from straight line
EPR	events per revolution
HFT	hardware fault tolerance
HSE	health, safety, and environment
IPS	inches per second
LOPA	layer of protection analysis
MEL	mitigated event likelihood

MTTF	mean time to failure
$MTTF_d$	mean time to fail to dangerous condition
MTTR	mean time to repair
ODS	overspeed detection system
OEM	original equipment manufacturer
OSHA	Occupational Safety and Health Administration
PCB	printed circuit board
PES	programmable electronic system
PF	probability of failure
PFD	probability of failure on low demand
PFD_{avg}	probability of failure on low demand, average
PFH	probability of failure on high demand (1/h)
PHA	Process Hazard Analysis
PL	performance level
PLC	programmable logic controller
PP	peak-to-peak value
PTC	Proof Test Coverage
PTI	proof test interval
RBD	reliability block diagram
RFQ	request for quotation
RPS	revolutions per second
RMS	root mean square
RTD	resistance temperature detector
SDS	surge detection system
SFF	safe failure fraction
SIF	safety instrumented function
SIL	safety integrity level
SIS	safety instrumented system
SRP/CS	safety-related parts of control systems
SRS	safety requirement specification
SOV	solenoid operated valve
TMEL	target mitigated event likelihood
TMR	triple modular redundancy
USC	U.S. customary
VDMA	Verband Deutscher Maschinen - und Anlagenbau e.V. (German Engineering Federation)

4 Scope of Supply and Responsibility

4.1 Purchaser

For each system, the purchaser shall specify the agency or agencies responsible for each function of the design, scope of supply, installation, and performance of the protection system (see Annex B).

4.2 Details

The details of systems or components outside the scope of this standard shall be mutually agreed upon by the purchaser and MPS vendor.

5 Requirements

5.1 Units of Measure

Purchaser's use of a United States customary (USC) datasheet (see A.1) indicates the USC system of measurements shall be used for all data, drawings, and maintenance dimensions. Purchaser's use of Système International (SI) datasheet (see A.2) indicates that the SI system of measurements shall be used.

NOTE Datasheets are provided in Annex A with selections for SI units or for USC units.

5.2 Statutory Requirements

The purchaser and vendor shall determine the measures to be taken to comply with any governmental codes, regulations, ordinances, directives, or rules that are applicable to the equipment, its packaging, and any preservatives used.

5.3 Documentation Requirements

The hierarchy of documents shall be as specified.

NOTE Typical documents include purchase order, company and industry specifications, meeting notes, and modifications to these documents.

6 General Design Specifications

6.1 Temperature Ranges

MPS components have two temperature ranges, testing range and operating range, over which accuracy shall be measured and in which the system components shall operate, as summarized in Table 1.

6.2 Humidity

6.2.1 For transducer systems, the accuracy requirements of Table 1 shall apply at levels of relative humidity up to 100% condensing, nonsubmerged, with protection of connectors.

6.2.2 For machinery protection system components, the accuracy requirements of Table 1 shall apply at levels of relative humidity up to 95% noncondensing.

6.3 Shock

Accelerometers shall be capable of surviving a mechanical shock of 5000 g, peak, without affecting the accuracy requirements specified in Table 1.

6.4 Chemical Resistance

6.4.1 Probes, probe extension cables, and oscillator-demodulators shall be constructed of corrosion-resistant materials compatible with commonly encountered bearing lube oil environments.

NOTE Ammonia plants may contain atmospheres in which elevated levels of ammonia are present and for which a standard probe system may not be suitable.

● **6.4.2** If specified, probes, probe extension cables, and oscillator-demodulators shall be compatible for a corrosive environment containing other chemicals as specified.

6.5 Accuracy

6.5.1 Accuracy of the transducer system and machinery protection system in the testing and operating temperature ranges shall be as shown in Table 1.

6.5.2 If machinery protection system components or transducer system components will be used in applications outside the requirements of Table 1, the MPS vendor shall supply documentation showing how the accuracy is affected or suggest alternative transducer and monitor components suitable for the intended application.

NOTE Gas turbines may require special high-temperature sensors.

6.5.3 The proximity probe transducer system accuracy shall be verified on the actual probe target area or on a target with the same electrical characteristics as those of the actual probe target area (see Figure 1).

NOTE Minimum shaft diameter depends on probe tip diameter. Consult the manufacturer for more details.

6.5.4 When verifying the accuracy of any individual component of the proximity probe transducer system in the operating range, the components not under test shall be maintained within the testing range.

6.5.5 The accelerometer and piezo velocity transducer accuracy shall be verified utilizing frequency response calibration methodology per ISO 16063-21.

Table 1—Machinery Protection System Accuracy Requirements

Components	Temperature		Accuracy Requirements as a Function of Temperature	
	Testing Range	**Operating/ Storage Range**	**Within Testing Range**	**Outside Testing Range but Within Operating Range**
Proximity probes 8 mm	0 °C to 45 °C (32 °F to 110 °F)	–35 °C to 120 °C (–30 °F to 250 °F)	ISF: ±5 % of 7.87 mV/µm (200 mV/mil)	ISF: an additional ±5 % of the testing range accuracy
Extension cables	0 °C to 45 °C (32 °F to 110 °F)	–35 °C to 65 °C (–30 °F to 150 °F)	DSL: within ±25.4 µm (±1 mil) of the best fit straight line at a slope of 7.87 mV/µm (200 mV/mil)	DSL: within ±76 µm (±3 mil) of the best fit straight line at a slope of 7.87 mV/µm (200 mV/mil)
Oscillator-demodulators	0 °C to 45 °C (32 °F to 110 °F)	–35 °C to 65 °C (–30 °F to 150 °F)	Minimum linear range: 2 mm (80 mil)	Minimum linear range: same as for testing range
Proximity probes 11mm	0 °C to 45 °C (32 °F to 110 °F)	–35 °C to 120 °C (–30 °F to 250 °F)	ISF: ±10% of 3.94 mV/µm (100 mV/mil)	ISF: An additional ±15% of the testing range accuracy
Extension Cables	0 °C to 45 °C (32 °F to 110°F)	–35 °C to 65 °C (–30 °F to 150 °F)	DSL: within ±102 µm (±4 mils) of the best fit straight line at a slope of 3.94 mV/µm (100 mV/mil)	DSL: within ±508 µm (±20 mils) of the best fit straight line at a slope of 3.94 mV/µm (100 mV/mil)
Oscillator-Demodulators	0 °C to 45 °C (32 °F to 110 °F)	–35 °C to 65 °C (–30 °F to 150 °F)	Minimum linear range: 4 mm (160 mils)	Minimum linear range: same as for testing range
Accelerometers and accelerometer extension cables [a]	20 °C to 30 °C (68 °F to 86 °F)	–55 °C to 120 °C (–65 °F to 250 °F)	Principal axis sensitivity[d]: 100 mV/g ± 5 % Amplitude linearity: ±1% to 50 g peak[b] Frequency response[c]: ±3 dB from 10 Hz to 10 kHz, referenced to the actual measured principal axis sensitivity [f]	Principal axis sensitivity[d]: 100 mV/g ± 20 %
Standard frequency range piezo velocity sensor and extension cables [a]	20 °C to 30 °C (68 °F to 86 °F)	–55 °C to 120 °C (–65 °F to 250 °F)	Principal axis sensitivity[d]: 3.94 mV/mm/s (100 mV/in/s) ± 5 % Amplitude linearity: ±1% to 63.5 mm/s (2.5 in/s) peak [b] Frequency response [c]: ±3 dB from 10 Hz to 5 kHz, referenced to the actual measured principal axis sensitivity [d]	Principal axis sensitivity[d]: 3.94 mV/mm/s 100 mV/in/s ± 20 %
Low-frequency piezo velocity sensor and extension cables [e]	20 °C to 30 °C (68 °F to 86 °F)	–40 °C to 85 °C (–40 °F to 185 °F)	Principal axis sensitivity [d]: 3.94 mV/mm/s (100 mV/in/s) ± 5 % Amplitude linearity: 1 % from 0.1 in/s peak to 50 g peak [b] Frequency response [c]: ±3 dB from 1.5 Hz to 1 kHz, referenced to the actual measured principal axis sensitivity [d]	Principal axis sensitivity [d]: 3.94 mV/mm/s 100 mV/in/s ± 20 %

Table 1—Machinery Protection System Accuracy Requirements (Continued)

Components	Temperature		Accuracy Requirements as a Function of Temperature	
	Testing Range	Operating/ Storage Range	Within Testing Range	Outside Testing Range but Within Operating Range
Temperature sensors and leads	0 °C to 45 °C (32 °F to 110 °F)	–35 °C to 175 °C (–30 °F to 350 °F)	±2 °C (±4 °F) over a measurement range from –20 °C to 150 °C (0 °F to 300 °F)	±3.7 °C (±7 °F) over a measurement range from –20 °C to 150 °C (0 °F to 300 °F)
Machinery protection system components for measuring:				
radial vibration, axial position, piston rod monitoring, and casing vibration	0 °C to 45 °C (32 °F to 110 °F)	–20 °C to 65 °C (0 °F to 150 °F)	±1 % of full-scale range for the channel	Same as for testing range
temperature			±1 °C (±2 °F)	Same as for testing range
Speed			±1 % of alarm setpoint	Same as for testing range
Overspeed			±0.1 % of shutdown setpoint or ±1 rpm, whichever is less	Same as for testing range
Other machinery protection system components (such as: power supplies, relay, communication cards, displays)		–20 °C to 65 °C (0 °F to 150 °F)		

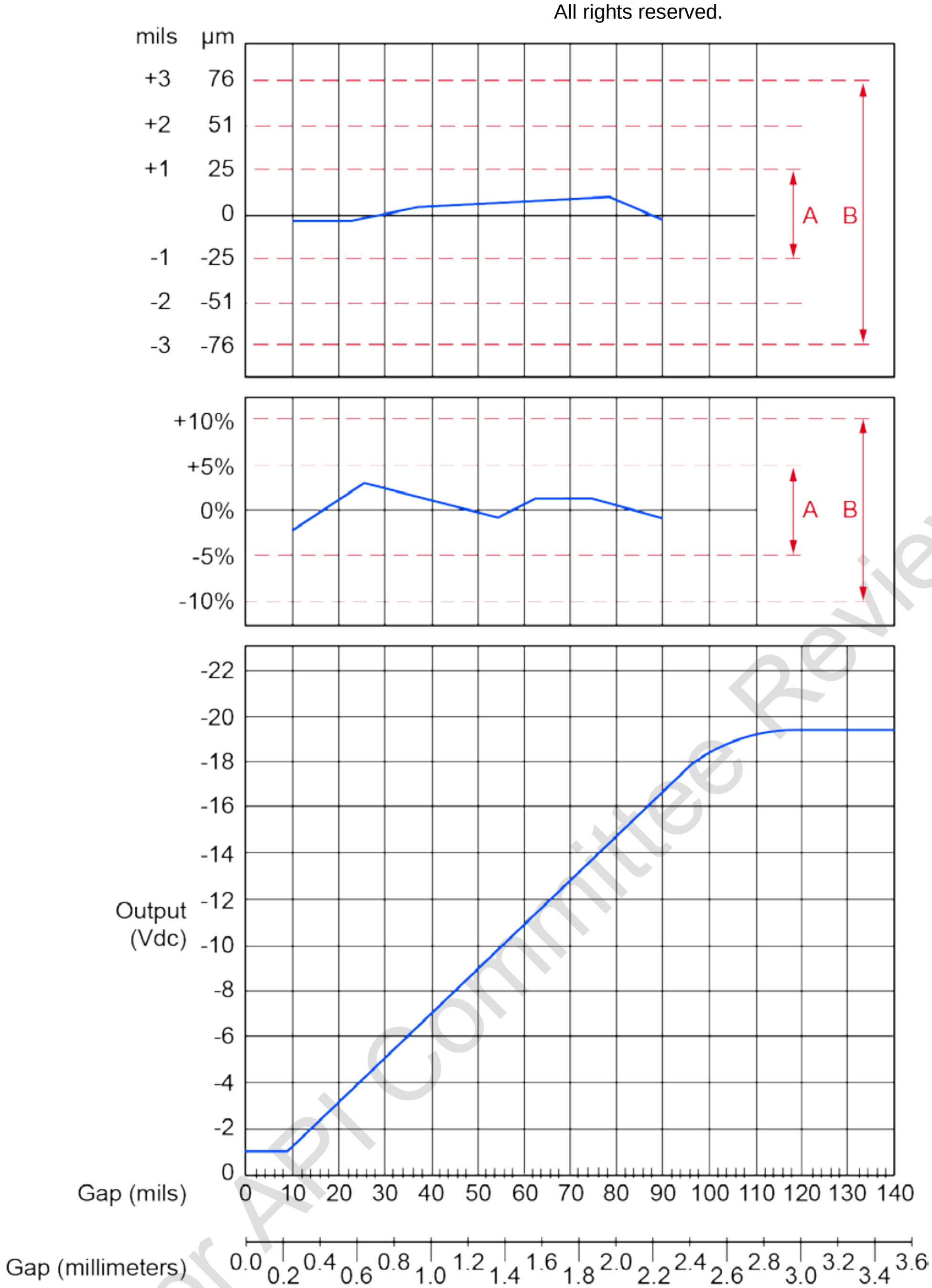
[a] During the testing, the parameter under test is the only parameter that is varied. All other parameters shall remain constant.

[b] Conditions of test: at any one temperature within the testing range, at any single frequency that is not specified but is within the specified frequency range of the transducer.

[c] Frequency response testing conditions: at any one temperature within the testing range, at an excitation amplitude that is not specified but is within the specified amplitude range of the transducer.

[d] Principal axis sensitivity testing conditions: (testing range) at any one temperature within the testing range, at 100 Hz, at an excitation amplitude that is not specified but is within the specified amplitude range of the transducer. Operating range: at any one temperature within the operating range, at 100 Hz, at an excitation amplitude that is not specified but is within the specified amplitude range of the transducer.

[e] Low-frequency piezo velocity sensors have greater gain at frequencies below 10 hertz than do the standard range piezo velocity sensors. A low-frequency piezo velocity sensor subjected to a sudden mechanical or electrical impulse is more likely to generate a low frequency signal that does not represent actual machine condition. For this reason, the standard range piezo velocity sensor should be used except for cases where important machinery vibration components fall below the standard sensor high pass corner (for example, frame vibration on a 200 rpm reciprocating compressor).



Top Pane	**Channel accuracy:** Deviation from best-fit straight line (DSL) at a slope of 7.87 mV per micrometer (200 mV per mil)
Middle Pane	**Channel accuracy:** ISF Referenced to 7.87 mV per micrometer (200 mV per mil)
Bottom Pane	Typical gap-to-voltage transducer characteristic
A	Maximum error during bench test within testing temperature range of 0 °C to 45 °C (30 °F to 110 °F).
B	Maximum error over operating temperature range.

Figure 1—Typical Curves Showing Accuracy of 8mm Proximity Probe System

6.6 Interchangeability

6.6.1 All components covered by this standard shall be physically and electrically interchangeable within the accuracy specified in Table 1. This does not imply that interchangeability of components from different MPS vendors is required or that oscillator-demodulators calibrated for different shaft materials are electrically interchangeable.

6.6.2 Probes, cables, and oscillator-demodulators shall be supplied calibrated to the standard flat reference target of AISI Standard Type 4140 steel with diameter greater than 3 times the probe tip diameter.

• **6.6.3** If specified, for shafts other than AISI Standard Type 4140 steel, the proximity probe system shall be calibrated to the specified target material.

6.7 Segregation

6.7.1 The MPS shall be separate from and diverse of all other control or protective systems such that its ability to detect an alarm within the required response time on any monitored parameter and activate its system output relays (6.11) does not depend in any way upon the operation of these other systems.

NOTE The intent of this subsection is to prevent the MPS hardware from being combined with hardware from other control and automation systems. It is not intended to prohibit the inclusion of condition monitoring functionality within the MPS, provided failure of those functions does not impact the protective functions.

6.7.2 Wireless technologies shall not be used for protective functions (see Table 2).

Table 2—Summary of Allowable Usage of Wireless Technology for Machinery Protection Systems

Input or Output	Type	Description	670 Subsection/ Paragraph	Integral Part of Machinery Protection Loop?	Wireless Media Permitted?	Notes
Output	Display	Circuit fault indicators	6.10.5 b)	Y	N	To annunciate circuit faults within the protection system, independent of other display functionality, such as bar graphs.
		Channel alarm indicator	6.10.8 e)	Y	N	
		Channel shutdown indicator	6.10.8 d)	Y	N	
		Channel shutdown bypass indication	6.10.8 f)	Y	N	
		Display indication	7.1.1.7	N	Y	When an optional display is specified, it may use a wireless connection. However, the requirements of 6.10.8, 6.10.6 , 7.1.4.8, and 7.1.7.4 still apply (these display requirements may not be wireless).
		System shutdown bypass indication	6.10.6 h)	Y	N	A relay contact that allows external annunciation that the monitoring system is bypassed and machinery protection functionality is disabled. For example, to turn on an indicator in an annunciation panel in a control room or a large red warning light on the machine control cabinet.
		Setpoint multiplier indication	7.1.4.8 a); 7.1.7.4	Y	N	The annunciation of this condition is absolutely critical so that if falsely activated, it can be rectified. It is unacceptable for the monitor to be in this condition and the operator not to know about it because a wireless transmission link has failed or updates too infrequently.
	Alarm	Signal from alarm detection circuitry to alert relay	6.10.6 b)	Y	N	
		Signal from shutdown detection circuitry to danger relay	6.10.6 c)	Y	N	
		System output relays	6.11	Y	N	These are the primary intended output mechanisms for providing machinery protection because of the integrity of relays, the speed with which they act, and the various facilities within the monitoring system to properly suppress the relays under circuit fault conditions or deliberate bypass conditions.

Table 2—Summary of Allowable Usage of Wireless Technology for Machinery Protection Systems (Continued)

Input or Output	Type	Description	670 Subsection/ Paragraph	Integral Part of Machinery Protection Loop?	Wireless Media Permitted?	Notes
Input	Transducers and Wiring	Proximity probes, extension cables, oscillator-demodulators, and field wiring from oscillator-demodulators to monitor modules	6.17.1.1; 6.17.1.3; 6.17.1.4; 6.17.1.5	Y	N	
		Magnetic speed sensors, cables, and field wiring from sensor to monitor	6.17.2	Y	N	
		Accelerometers, cables, and field wiring from accelerometers to monitors	6.17.3	Y	N	
		Temperature sensor wiring	6.17.4.2	Y	N	
	Configuration	Monitor configuration ports/switches	7.1.1.4 c)	Y	N	
		Gain adjustment	7.1.1.5 a)	Y	N	
	Switch	System shutdown bypass activation	6.10.8	Y	N	Typically a keylock or other controlled mechanism to bypass the monitoring system while it is being maintained. It could conceivably be activated via a wireless link, but the annunciation/indication that the monitor is in a shutdown bypass condition is too critical to entrust to a wireless link. It is unacceptable for the monitor to be in this condition and the operator to not know about it because a wireless transmission has failed or updates too infrequently.
		Setpoint multiplier activation	7.1.4.8 a), 7.1.7.4	Y	N	The purpose of this input is discussed in length in Annex I.
Output	Condition monitoring	Digital interface for connection to condition monitoring system/software	6.12	N	Y	Typically incorporates a proprietary protocol for use between a vendor's 670 protection system and that vendor's corresponding condition monitoring software.
		Buffered outputs	6.10.5 a)	N	Y	Intended for connection to portable instruments such as route-based data collectors, oscilloscopes, data acquisition instruments, and test/calibration equipment such as multimeters.
	Control system	Digital comm port for process control interface	6.10.5 d)	N	Y	Primarily intended for sending pertinent monitor information to a distributed control system (DCS), PLC, machine control system, of human machine interface, emulating status indicators and current values that are provided by the monitor's display.
		4 mA to 20 mA proportional analog outputs	6.10.5 c)	N	Y	Connection to strip chart recorders, or analog interfacing to process control systems to emulate display of variables measured by machinery protection system.
Input	Switch	Rear-panel remote alarm reset/ acknowledgment	6.10.6 k)	N	Y	This does not relax the requirement for a front-panel manual switch discussed in this paragraph.

6.8 System Enclosures and Environmental Requirements

6.8.1 Field-installed MPS installations shall be suitable for the area classification (zone or Equipment Protection Level, class, division and group) specified by the purchaser and shall meet the requirements of the applicable sections of IEC/EN 60079 (part 14 or part 25) or NFPA 70 (Articles 500, 501, 502, 504, and 505) as well as any local codes specified and furnished on request by the purchaser.

NOTE Explosion-proof or intrinsically safe instrumentation is acceptable for Class I, Division 1 and Division 2 hazardous (classified) locations; non-incendive instrumentation is acceptable for Class I, Division 2 hazardous (classified) locations when installed in accordance with Article 501, NFPA 70.

6.8.2 If instruments are located outdoors or are subject to fire sprinklers, their housings shall be watertight (IP 65/NEMA Type 4), as specified in IEC 60259/NEMA 250, in addition to any other enclosure requirements necessary for the area classification in which the instrument is installed.

6.8.3 When air purging is specified to meet the area classification, it shall be in accordance with IEC 60079-2, ISA S12.4 or with NFPA 496, Type X, Y, or Z, as required.

• **6.8.4** If specified, clean and dry air purging shall be used to avoid moisture or corrosion problems, even when weatherproof or watertight housings are used (see 6.8.1).

6.8.5 MPS's shall comply with the electromagnetic radiation immunity requirements of IEC 61000-6-2.

• **6.8.6** If specified, printed circuit boards (PCBs) shall have conformal coating to provide protection from moisture, fungus, and corrosion.

NOTE It may not be possible or desirable to conformal coat PCBs in all monitor applications. Examples include complex circuit boards containing heat sinks, DIP switches, or complex interconnections.

6.9 Power Supplies

6.9.1 All machinery protection systems shall be capable of meeting the accuracy requirements specified in Table 1 with input voltage to the power supply of 90 Vac rms to 132 Vac rms or 180 Vac rms to 264 Vac rms, switch selectable, with a line frequency of 48 Hz to 62 Hz.

• **6.9.2** If specified, the following power supply options may be used.

• a) 19 Vdc to 32 Vdc

• b) 90 Vdc to 140 Vdc

6.9.3 All machinery protection system power supply(ies) shall be capable of supplying power to its components. Displays not contiguous with the MPS are exempted from this requirement and may be powered by external supplies.

6.9.4 All power supplies shall be capable of sustaining a short circuit of indefinite duration across their outputs without damage. Output voltages shall return to normal when an overload or short circuit is removed.

6.9.5 All transducer power sources shall be designed to prevent a fault condition in one transducer circuit from affecting any other channel.

6.9.6 All power supplies shall be immune to an instantaneous transient line input voltage equal to twice the normal rated peak input voltage for a period of 5 μs.

6.9.7 Transient voltage shall not damage the power supplies or affect normal operation of the machinery protection system.

6.9.8 All power supplies shall continue to provide sufficient power to allow normal operation of the machinery protection system through the loss of AC power for a minimum duration of 50 ms.

6.9.9 As a minimum, the input power supply transformer for all instruments shall have separate windings with grounded laminations or shall be shielded to eliminate the possibility of coupling high voltage to the transformer secondary.

6.9.10 In case of an insulation fault, the input voltage shall be shorted to ground.

• **6.9.11** If specified, the machinery protection system shall be fitted with a redundant power supply. Each power supply shall:

• a) independently supply power for the entire machinery protection system such that a failure in one supply and its associated power distribution busses shall not affect the other;

• b) allow removal or insertion with power applied without affecting the operation or integrity of the protection system;

• c) provide automatic switchover from one power supply to the other without affecting the operation or the integrity of the protection system.

6.9.12 The power supplies of all machinery protection systems shall be energized by the purchaser's independent and uninterruptible instrument branch power circuits.

6.10 Machinery Protection System Features/Functions

• **6.10.1** If specified, the requirements of SIS's shall apply to the required parts of the MPS.

6.10.2 The MPS supplier(s) and the SIS supplier shall provide the reliability/performance documentation to allow the vendor with unit responsibility to prove that the selected equipment meets all requirements of IEC 61508 and IEC 61511.

6.10.3 The internal clock time setting or synchronization shall be made with the master remote clock and the machinery protection system internal clock for effective time correlation of events.

6.10.4 At minimum, each MPS shall be provided with the following features and functions:

a) a method of energizing all indicators for test purposes if applicable;

b) an internal timeclock with provisions for remotely setting the time and date through the digital communication port of 6.12.1.

c) all modules capable of removal and insertion while the system is under power without affecting the operation of, or causing damage to, other unrelated modules.

NOTE It is not the intent of this paragraph to permit module removal/replacement in hazardous areas without appropriate precautions taken by the end user, such as in purged panels, explosion-proof housings, etc.

6.10.5 A MPS shall include the following signal processing functions and outputs:

a) Functional isolation to prevent a failure in one transducer from affecting any other channel.

b) A means of indicating internal circuit faults, including transducer system failure, with externally visible circuit fault indication for each individual channel. A no-fault condition shall be positively indicated (e.g. lighted). A common circuit fault relay shall be provided for each machinery protection system.

c) A circuit fault shall not initiate a shutdown or affect the shutdown logic in any way except as noted in 7.1.5.5 a) and b).

• d) If specified, a digital communications port shall be supplied for transmitting data.

6.10.6 A MPS shall include the following alarm/shutdown functions:

a) For each channel, alarm and shutdown setpoints that are individually adjustable over the entire monitored range. Alarm setpoints do not apply to overspeed and surge detection.

b) An alarm output from each channel or voted channels to the corresponding alarm indication (either digital communication or relay) is required.

c) A shutdown output from each channel or voted channels to the corresponding shutdown relay, as discussed in 7.1.4.5, 7.1.5.4, 7.1.6.8, and 7.1.8.5.

d) With exception of electronic overspeed detection (see Note 1), the time required to detect and initiate an alarm or a shutdown shall not exceed 100 ms. Relay actuation and the machinery protection system's annunciation of the condition shall be fixed by the time delay specified in 7.1.1.6 a).

NOTE 1 The 100 ms response time requirement applies after the system has executed any signal processing algorithms and/or filtering for disturbance rejection.

NOTE 2 Electronic ODS response is specified in 7.2.4.4.1.

e) Shutdown indication shall be provided for each channel that indicates channel alarm status independent of voting logic.

f) Shutdown indication shall be positive indication (e.g. illuminated when channel exceeds its shutdown setpoint).

• g) If specified, shutdown indication shall conform to operation of the voting logic.

• h) If specified, a tamperproof means for bypassing the shutdown function (except for ODS) and a visible indicator shall be provided for each channel.

i) Any bypassed condition shall activate a common relay. This relay shall be in accordance with 6.11 and may be used for remote annunciation.

j) Local and remote access for resetting latched alarm and shutdown conditions. For rack-based systems, front-panel switch and rear-panel connections shall be supplied.

k) A means to identify the first-out alarm and the first-out shutdown.

• **6.10.7** If specified, selected channels (or all channels) of the MPS shall be available so that a single circuit failure (power source and MPS power supply included) shall only affect the offending channel and shall not affect the state of alarm relays. This requirement is mandatory for all electronic ODS channels (7.2.1.9).

6.10.8 A MPS shall have the following indications:

a) power status,

b) digital communications link status,

c) system circuit fault,

d) system shutdown,

e) system alarm (except for ODS),

f) system shutdown function bypassed (except for ODS).

6.11 System Output Relays

6.11.1 The output relays described in this section shall be used for interconnecting the MPS to all other devices used as part of the shutdown loop.

6.11.2 The optional digital interfaces of 6.10.5 d) and 6.12 shall not be used as part of the shutdown loop.

6.11.3 Output relays shall be the epoxy-sealed electromechanical type.

• **6.11.4** If specified, either of the following relay types may be provided in lieu of epoxy-sealed relays.

• a) hermetically-sealed electromechanical type;

• b) solid state type. If a solid state relay interface between systems is proposed, the vendor with unit responsibility shall provide a complete review of the relay capabilities and requirements to ensure reliable operation.

6.11.5 The factory default shall be de-energize to alarm and de-energize to shutdown.

• **6.11.6** If specified, the relay control circuit shall be field changeable to be either normally de-energized or normally energized except for ODS.

6.11.7 All relays shall be double-throw type with electrically isolated contacts and all contacts available for wiring.

6.11.8 Shutdown, alarm, and circuit-fault relays shall be field changeable to latching (manual reset) or nonlatching (automatic reset). Latching shall be standard.

6.11.9 The circuit fault relay shall be normally energized. A failure anywhere in the MPS shall de-energize the circuit fault relay.

6.11.10 Contacts shall be rated at a resistive load of 2 amperes at 120 Vac, or 1 ampere at 240 Vac, or 2 amperes at 28 Vdc for a minimum of 10,000 operations. When inductive loads are connected, arc suppression shall be supplied at the load.

• **6.11.11** If specified, contacts rated at a resistive load of 5 amperes at 120 Vac shall be provided (via external relay if necessary).

6.11.12 For VMS with energized to trip output relays, an interruption of power [line power or direct current (DC) output power] shall not transfer the shutdown relay contacts regardless of the mode or duration of the interruption.

6.11.13 Each monitor subsystem in the MPS (overspeed exempted) shall be provided with a means to bypass the subsystem's shutdown capability, conforming to the following:

a) It may be internal or external to the monitor subsystem,

b) It shall be tamper proof,

c) A bypassed condition shall be locally annunciated,

d) Operation or maintenance of the monitor subsystem in the bypassed mode, including power supply replacements, shall not shut down the machine (see Note). Refer to IEC 61508 for governing requirements.

NOTE This feature is intended to be used during machinery protection system maintenance only

e) A bypassed condition shall be available for remote annunciation via the digital communications link of 6.12.

• f) If specified, two sets of isolated external annunciator contacts shall be provided.

• g) Transducer OK limits (when applicable)

6.12 Digital Communication Links

6.12.1 A digital output representative of each measured variable shall be provided at a communications port. A short circuit of this output shall not affect the MPS, and the output shall follow the measured variable and remain at full scale as long as the measured variable is at or above full scale. The standard digital output shall utilize a client/server data communication protocol.

NOTE This output is intended for transmitting data to process control systems. It is not designed or intended to replace the relays of 6.11 for machinery protection purposes.

6.12.2 Digital Communication shall not be used for safety related functions unless fully assessed through IEC 61508 or IEC 61511 application.

• **6.12.3** If specified, any one or more of the following shall also be available from the digital communications link of 6.12.1:

• a) Channel status of alarm or no alarm

• b) Enabled maintenance bypass

• c) Alarm storage for storing the time, date, and value for a minimum of 64 alarms;

• d) Channel value ±2% full-scale range resolution;

- e) Measured value as a percent of alarm and shutdown values to 1% resolution
- f) Channel status: armed/disarmed [see 6.10.6 h)];
- g) Transducer OK limits, if applicable;
- h) Hardware and software diagnostics;
- i) Communication link status
- j) Alarm setpoints;
- k) Gap voltage, when applicable;
- l) Current system time, time stamp, and date of event for all transmitted data;
- m) System entry log to include date, time, individual access code, and record of changes;
- n) Setpoint multiplier invokes (see 7.1.4.8 and 7.1.7.4).

6.13 System Wiring and Conduits

6.13.1 General

Installation shall be in accordance with the following:

a) Wiring and conduits shall comply with the electrical practices specified in NFPA 70 (see Figure 2 and Figure 3, Figure C.1, Figure C.2, and Figure C.3.

b) All conduit, signal and power cable, and machinery protection system components shall be located in well-ventilated areas away from hot spots such as piping, machinery components, and vessels.

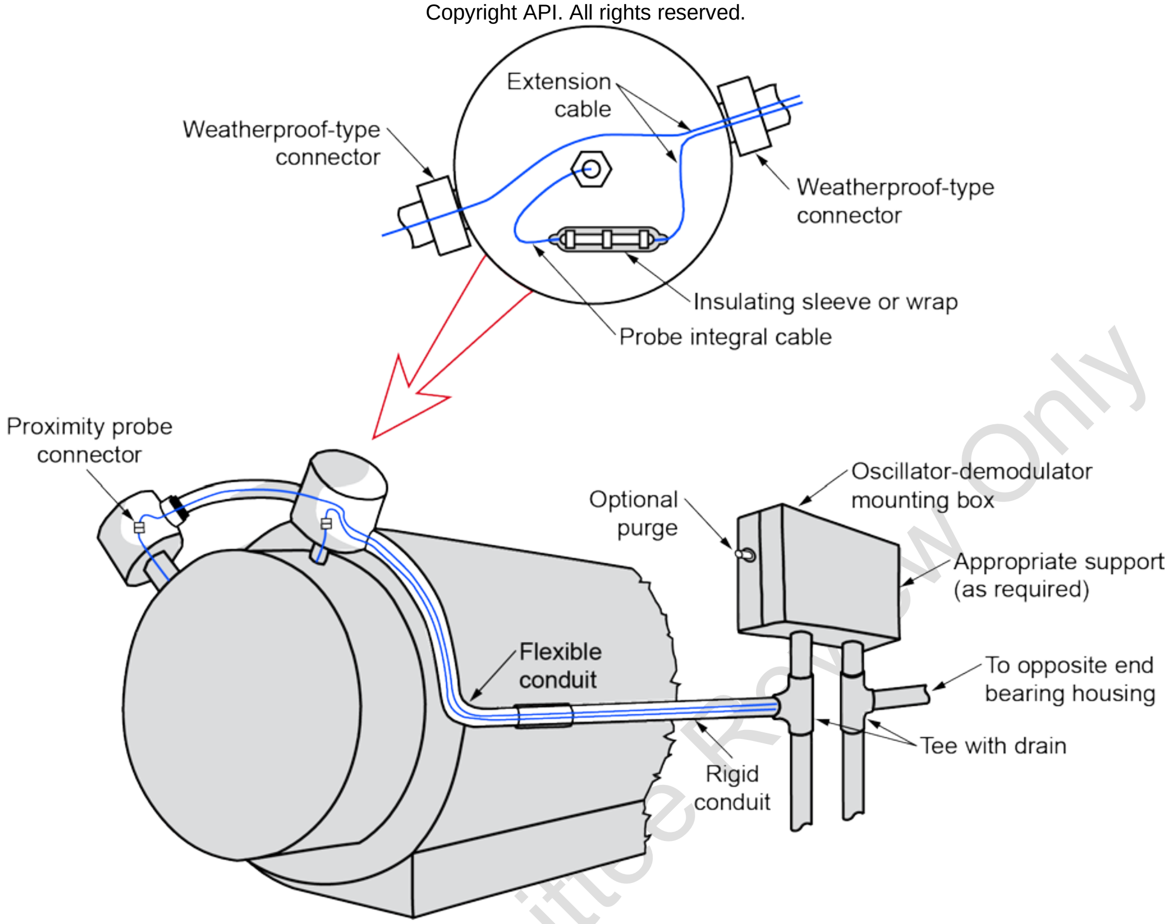
c) MPS components shall not be covered by insulation or obstructed by items such as machinery covers, conduits, and piping.

d) All conduits, armored cable, and similar components shall be located to permit disassembly and repair of equipment without causing damage to the electrical installation.

e) Signal and power wiring shall be segregated according to good instrument installation practices (see 6.13.2.4).

f) Signal wiring shall not be run in conduits or trays containing circuits of more than 30 V of either alternating or direct current.

g) Signal wiring shall be shielded, twisted pair, or shielded triad to minimize susceptibility to electromagnetic or radio frequency interference.



NOTE Proximity probe extension cable connectors insulated from ground (see 6.17.1.4.3)

Figure 2—Typical Conduit Cable Arrangement

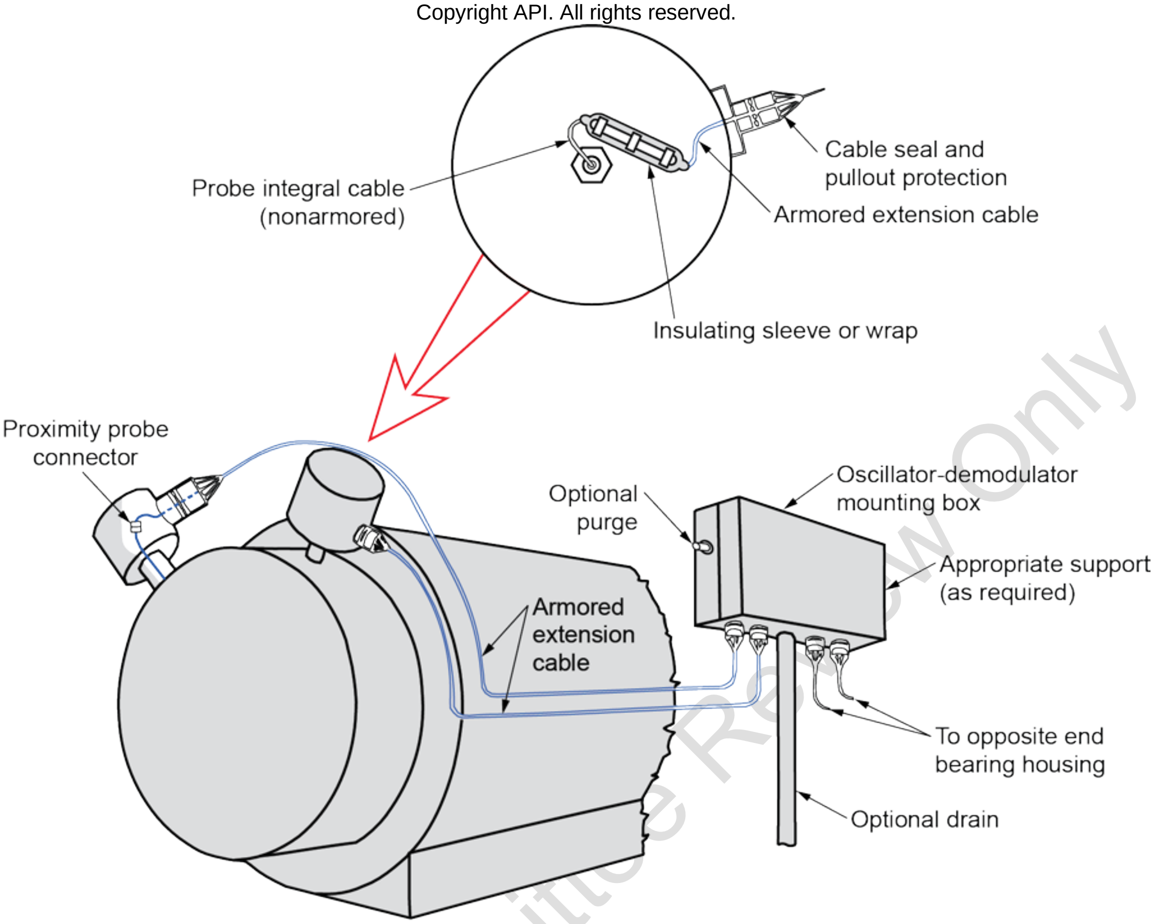


Figure 3—Typical Armored Cable Arrangement

6.13.2 Conduit Runs to Panels

6.13.2.1 Conduits shall be:

a) Weatherproof and of suitable size to meet NFPA 70 requirements for the size and number of signal cables to be installed,

b) Supplied with a drain installed at each conduit low point.

6.13.2.2 Signal cable installed in underground conduit shall be suitable for continuous operation in a submerged environment.

NOTE Underground conduit will accumulate moisture over long periods of time regardless of the sealing methods employed.

6.13.2.3 Signal cables shall:

a) Be supplied in accordance with the provisions of Annex D;

b) Not exceed a physical length of 150 m (500 ft). The use of longer cable run shall be reviewed and approved in writing by the MPS vendor;

c) Use continuous runs only. The use of non-continuous runs shall be approved by the owner and, if employed, the shield shall be carried across any junction.

6.13.2.4 The minimum separation between installed signal and power cables shall be as specified in Table 3.

NOTE More detailed information on signal transmission systems is available in API 552.

Table 3 – Minimum Separation Between Installed Signal and Power Cables

Voltage AC	**Minimum Separation**	
	mm	in.
120	300	12
240	450	18
480	600	24

6.14 Grounding of the Machinery Protection System

The responsible party as identified in Annex B shall ensure that:

a) the system is grounded in accordance with Article 250 of NFPA 70 and all metal components (i.e. conduit, field junction boxes, and equipment enclosures) are electrically bonded (see Figure 4);

b) all metal enclosure components are connected to an electrical grounding bus and that this electrical grounding bus is connected to the electrical grounding grid with a multistrand American Wire Gage (AWG) 4 or larger, dedicated copper ground wire;

c) mutual agreement is obtained from the purchaser and the MPS vendor with respect to grounding, hazardous area approvals required, instrument performance, and elimination of ground loops;

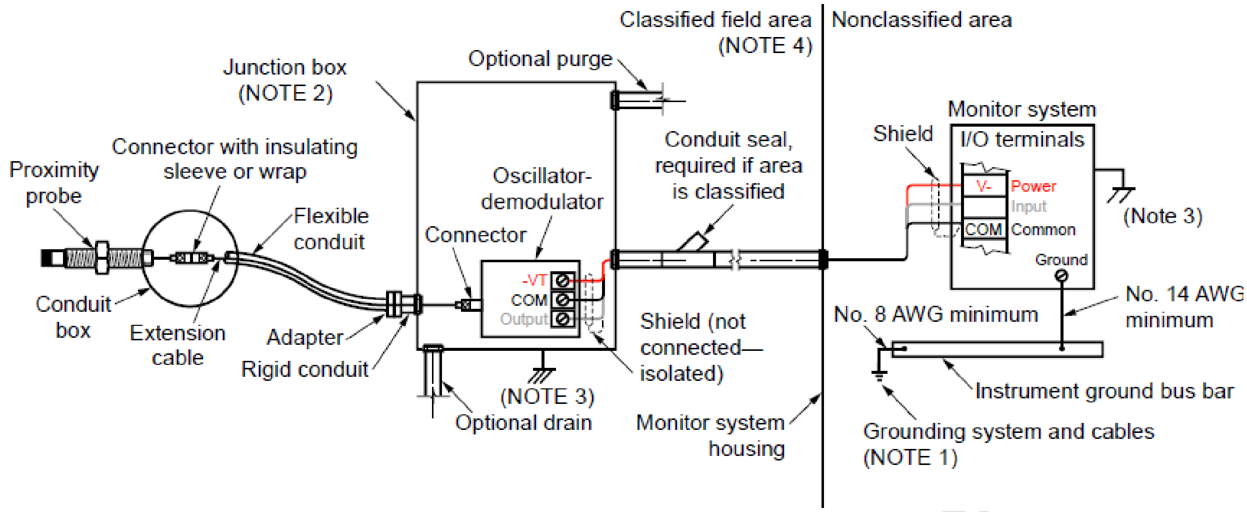
d) the transducer signal and common is isolated from the machine ground;

e) the MPS instrument common is designed to be isolated (not less than 500 Kohms) from electrical ground and installed with single-point connection to the instrument grounding system;

f) the signal cable shield is only grounded at the machinery protection system;

g) the shield is not used as the common return line;

h) shields are carried through any field junctions.



NOTE 1 Meet NFPA 70, Article 250 (common and probe circuit isolated from ground).
NOTE 2 NEMA 4, IP 65 or IP 66
NOTE 3 Metal housing bounded to safety ground.
NOTE 4 The figure represents an explosion-proof or purged installation.

Figure 4—Typical Instrument Grounding

6.15 System Security, Safeguards, Self-tests, and Diagnostics

6.15.1 Controlled access for machinery protection system adjustments shall be in the form of a programming access key located at the front of the machinery protection system rack or via software (i.e. password protection).

6.15.2 Configuration shall be stored in nonvolatile memory, so it is not lost in the event of a total power loss to the machinery protection system.

NOTE When configuring a system over the network, password protection alone may not prevent accidental downloading of a new configuration (resulting in possible machine shutdown condition). If this is a concern, both an access key and password protection can be considered.

6.15.3 The machinery protection system modules shall have the capability of onboard self-test.

6.15.4 The machinery protection system shall maintain an event list to log module/system alarms and diagnostic tests results. This event list shall be:

a) stored in the system's nonvolatile memory;

b) maintained in the event of a total loss of power or loss of communications.

6.15.5 Tests as per 6.15.1 to 6.15.4 do not replace diagnostic tests and proof tests as required by IEC 61508 and IEC 61511. For details refer to Annex L.

6.16 Reliability

6.16.1 The MPS Vendor shall advise in the proposal any component designed for a finite life.

• **6.16.2** The purchaser shall specify the period of uninterrupted continuous operation. Shutting down the equipment to perform maintenance or inspection during the uninterrupted operation is not acceptable.

NOTE 1 The period of uninterrupted continuous operation for a MPS will normally meet or exceed the interval for planned machinery maintenance outages. For example, a machine train with a five-year maintenance turnaround schedule will normally require a MPS with a mean time between failure of five years or more.

NOTE 2 Auxiliary system design and design of the process in which the equipment is installed are very important in meeting this objective.

NOTE 3 Section 9.2.3 j) requires the MPS vendor to identify any component or maintenance requirement that would result in the need to shut down the equipment within the uninterrupted operational period.

6.17 Sensors and Transducers

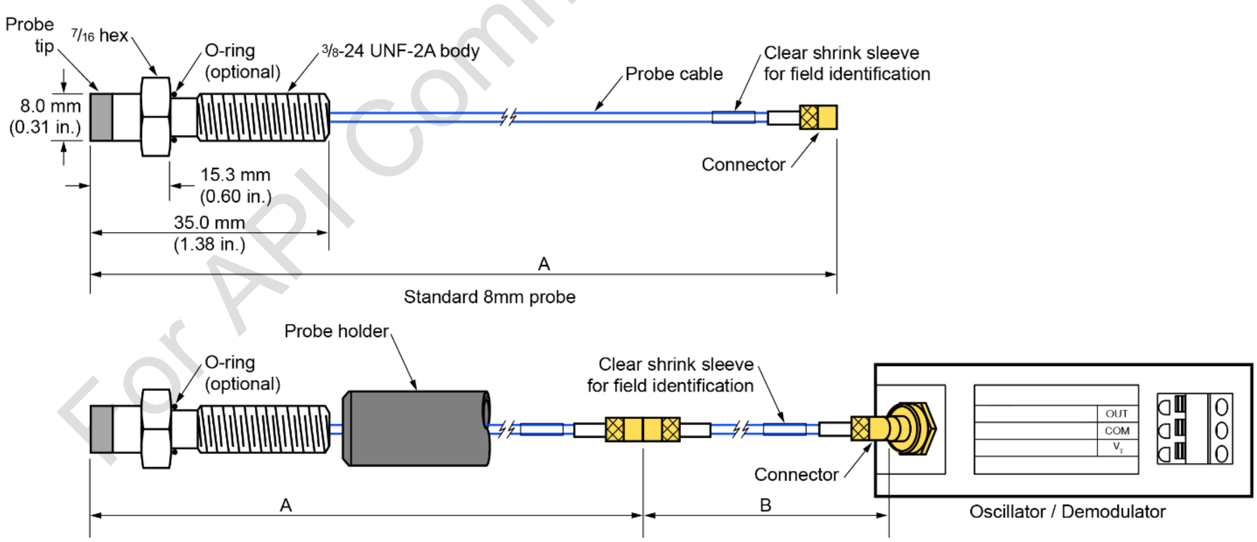
6.17.1 Proximity Probe system

A proximity probe system consists of a tip, a probe body, an integral coaxial cable or triaxial cable, a connector as specified in 6.17.1.4 and shall be chemically resistant as specified in 6.4 and completed with an oscillator demodulator**.** The 8mm assembly is illustrated in Figure 5 and the 11mm assembly in Figure 7**.**

6.17.1.1 8mm and 5mm Proximity Probes

6.17.1.1.1 The standard 8 mm radial vibration probe shall have a tip diameter of 7.6 mm to 8.3 mm (0.300 in. to 0.327 in.), with a reverse mount, integral hex nut probe body approximately 25 mm (1 in.) in length.

NOTE Reverse mount probes are intended for use with probe holders allowing external access to the probe and its integral cable which may allow easier access for maintenance. The use of a reverse mount probe as the standard radial vibration probe allows a single probe configuration and thread length to be used throughout the entire machine train. The length of the probe holder stem will typically vary from one probe mounting location to the next, but this can be trimmed in the field without the need to employ different probes.



Standard 8mm probe, holder, extension cable, and oscillator/demodulator

A	0.5 m (19.5 in.)
B	4.5 m (177 in.)

Figure 5—Standard 8mm Radial Vibration and Axial Proximity Probe System

6.17.1.1.2 The other standard 8mm options may consist of one or more of the following probe configurations (see Figure 6):

a) a tip diameter of 7.6 mm to 8.3 mm (0.300 in. to 0.327 in.) and straight-body 3/8-24-UNF-2A U.S. customary (USC) threads;

b) a tip diameter of 7.6 mm to 8.3 mm (0.300 in. to 0.327 in.) and M10 × 1 metric threads;

c) lengths other than approximately 25 mm (1 in.);

d) flexible stainless steel armoring attached to the probe body and extending to within 125 mm (5 in.) of the connector.

e) Forward mount, see Figure 6.

6.17.1.1.3 The 5mm standard options may consist of one or more of the following probe configurations (see Figure 6):

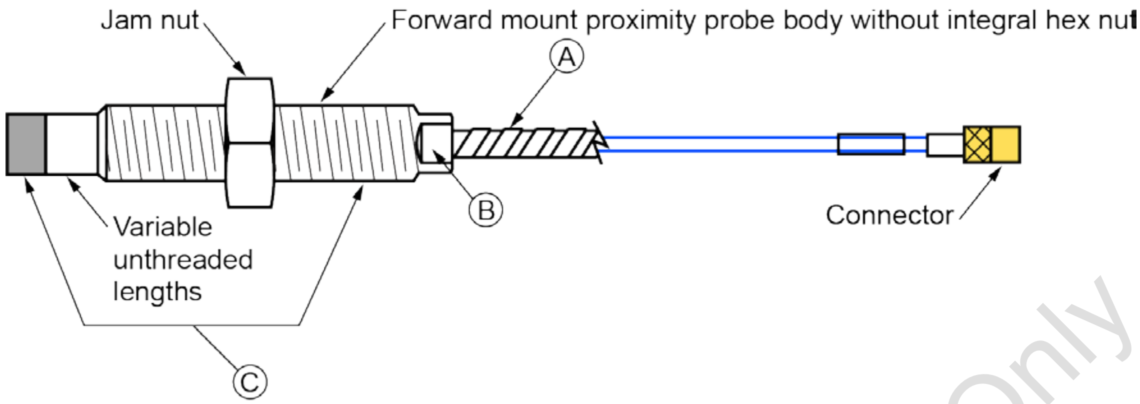
a) a tip diameter of 4.8 mm to 5.3 mm (0.190 in. to 0.208 in.) and 1/4-28-UNF-2A USC threads;

b) a tip diameter of 4.8 mm to 5.33 mm (0.190 in. to 0.208 in.) and M8 × 1 metric threads;

c) lengths other than approximately 25 mm (1 in.);

d) flexible stainless steel armoring attached to the probe body and extending to within 125 mm (5 in.) of the connector;

e) Forward mount, see Figure 6.



A	Flexible stainless-steel armoring (optional)
B	Wrench flats standard for forward mount probes (see Note 3)
C	Proximity probe tip diameter and threads (see Note 1) 8.0 mm (0.31 in.) with ⅜-24 UNF 2A threads 8.0 mm (0.31 in.) with M10 × 1 metric threads 5.0 mm (0.197 in.) with M8 × 1 metric threads (see Note 2) 5.0 mm (0.197 in.) with ¼-28 UNF 2A threads (see Note 2)

NOTE 1 The standard option proximity probe may consist of one or more of the options discussed in 0.

NOTE 2 Forward mount probes are generally available in case lengths longer than 20.3 mm (0.9 in.). A 1/4-28 (or M8 x 1) body more than 51 mm (2 in.) in length is undesirable from the standpoint of mechanical strength and availability.

NOTE 3 Wrench flats to be compatible with standard wrench sizes. The dimension of the flats will vary with the diameter chosen for the probe body.

Figure 6—Other standard Options for radial vibration and axial Proximity Probes

6.17.1.1.4 The nominal physical length of the probe and integral cable assembly shall be either 0.5 m (20 in.) or 1 m (40 in).

6.17.1.1.5 A piece of clear heat-shrink tubing (not to be shrunk at the factory) not less than 40 mm (1.5 in.) long shall be installed over the coaxial or triaxial cable before the connector is installed to assist the owner in tagging. If connector protectors are used, the portion that rests on the insulated cable shall not overlap the heat shrink to ensure proper seal.

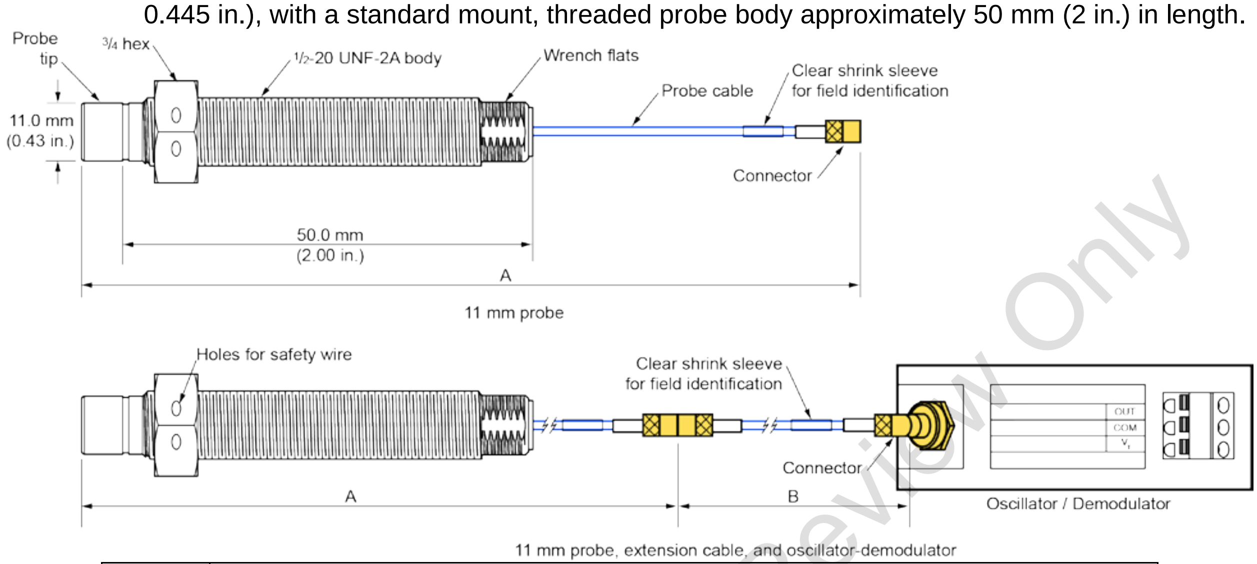
6.17.1.1.6 The probe tip shall be molded, or otherwise bonded into the probe body, in a secure fashion. Probes shall support a differential pressure of 6 bars (100 psid) between probe tip and probe body without leakage.

6.17.1.1.7 The integral probe lead cable shall be securely attached to the probe tip to withstand a pull test (without damage) of a minimum tensile load of 225 N (50 lb.).

6.17.1.1.8 The design shall allow sufficient room for tagging and connector protection while maximizing the protected length of the cable.

6.17.1.2 11mm Proximity Probes

6.17.1.2.1 The standard 11mm probe shall have a tip diameter of 10.6 mm to 11.3 mm (0.417 in. to 0.445 in.), with a standard mount, threaded probe body approximately 50 mm (2 in.) in length.



A	1.0 m (39.4 in.)
B	4.0 m (158 in.)

Figure 7—Standard 11mm Proximity Probe System

6.17.1.2.2 Piston rod monitoring applications shall not use reverse mount probes.

6.17.1.2.3 The other standard options may consist of one or more of the following probe configurations (see Figure 7):

a) a tip diameter of 10.6 mm to 11.3 mm (0.417 in. to 0.445 in.) and 5/8-18-UNF-2A U.S. customary (USC) threads;

b) a tip diameter of 10.6 mm to 11.3 mm (0.417 in. to 0.445 in.) and M14 × 1.5 metric threads;

c) tip diameter of 10.6 mm to 11.3 mm (0.417 in. to 0.445 in.) and M16 × 1.5 metric threads;

d) lengths other than approximately 50 mm (2 in.).

6.17.1.2.4 A piece of clear heat-shrink tubing (not to be shrunk at the factory) not less than 40 mm (1.5 in.) long shall be installed over the coaxial or triaxial cable before the connector is installed to assist the owner in tagging. If connector protectors are used, the portion that rests on the insulated cable shall not overlap the heat shrink to ensure proper seal.

6.17.1.2.5 The probe tip shall be molded, or otherwise bonded into the probe body, in a secure fashion. Probes shall support a differential pressure of 6 bars (100 psid) between probe tip and probe body without leakage.

6.17.1.2.6 The integral probe lead cable shall be securely attached to the probe tip to withstand a pull test (without damage) of a minimum tensile load of 225 N (50 lb.).

6.17.1.2.7 The design shall allow sufficient room for tagging and connector protection while maximizing the protected length of the cable.

6.17.1.3 Probe Extension Cables

6.17.1.3.1 Probe extension cables shall be coaxial or triaxial, with connectors as specified in 6.17.1.4.

6.17.1.3.2 The 8mm probe system standard 4.5m extension cable nominal physical length shall be 4.5 m (177 in.) with a minimum of 4.1 m (161 in.) (see Figure 5).

6.17.1.3.3 The 11mm probe system extension cable physical length shall be 4.0 m (157 in.) and shall be a minimum of 3.4 m (134 in.) (see Figure 7).

6.17.1.3.4 Shrink tubing shall be provided at each end in accordance with 6.17.1.1.5 and 6.17.1.2.4.

6.17.1.4 Connectors

6.17.1.4.1 The attached connectors shall meet or exceed the mechanical, electrical, and environmental requirements specified in Section 6 and in MIL-C-39012-C and MIL-C-39012/5F.

6.17.1.4.2 The cable and connector assembly shall be designed to withstand a minimum tensile load of 225 N (50 lb.).

6.17.1.4.3 Proximity probe extension cable connectors shall be insulated from ground.

6.17.1.5 Oscillator-demodulators

6.17.1.5.1 The standard oscillator-demodulator shall be designed to operate with the probes defined in 6.17.1.1.1 and 6.17.1.2.1 and the probe extension cable(s) as defined in 6.17.1.3.

6.17.1.5.1.1 The oscillator-demodulator output for 8mm probe system shall be 7.87 mV/μm (200 mV/mil) with a standard supply voltage of –24 Vdc.

6.17.1.5.1.2 The oscillator-demodulator output for 11mm probe system shall be 3.84 mV/μm (100 mV/mil) with a standard supply voltage of –24 Vdc.

6.17.1.5.2 The oscillator-demodulator shall be calibrated for the length of the probe assembly and extension cable supplied.

NOTE The oscillator-demodulator is electrically tuned for a unique combination of probe and extension cable lengths. Using an oscillator-demodulator with the incorrect probe or extension cable can cause measurement errors.

6.17.1.5.3 The output, common, and power-supply connections shall be suitable for at least 18 AWG wire (1 mm^2 cross section).

6.17.1.5.4 The output, common, and power supply connections materials shall be provided by the supplier for review.

6.17.1.5.5 The transducer system noise shall not exceed 20 mV PP when installed to the manufacturer's recommendations.

NOTE Not adhering to the probe manufacturer's installation guidelines may result in noise from probe cross-talk or electrical interference.

6.17.1.5.6 The oscillator-demodulator common shall be electrically isolated from ground.

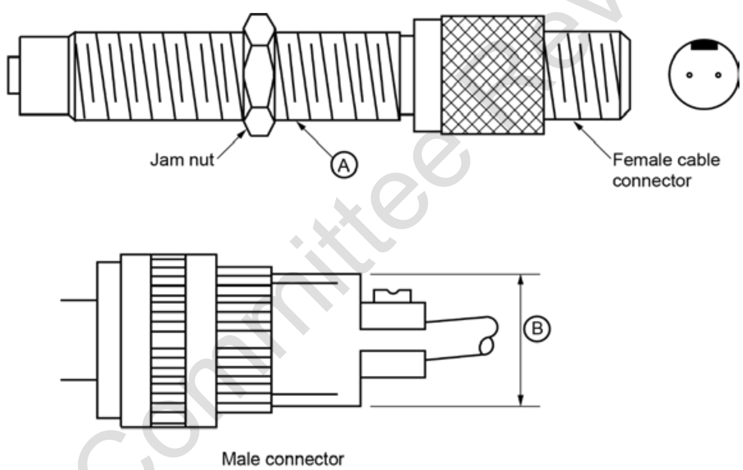
NOTE The intent of this subsection is that interchangeability requirements apply only to components supplied by the same vendor.

6.17.1.5.7 Oscillator-demodulators shall be supplied with a DIN rail mounting.

6.17.2 Magnetic Speed Probe

6.17.2.1 A magnetic speed probe consists of the encapsulated sensor (pole piece and magnet), threaded body, and cable.

6.17.2.2 The standard magnetic speed sensor shall be a passive (i.e. self-powered) type with a cylindrical pole piece. The standard body shall have M16-1.5 (5/8-18-UNF-2A) threads. The maximum diameter of the pole piece shall be 4.75 mm (0.187 in.) (see Figure 8).



A	⅝-18 UNF-2A
B	1.0 in. clearance required

Figure 8—Standard Magnetic Speed Sensor with Removable (Nonintegral) Cable and Connector

6.17.2.3 The standard magnetic speed sensor shall be chosen based on the area classification.

• **6.17.2.4** If specified, the speed sensor can be active (i.e. externally-powered).

NOTE 1 A passive probe does not need external power to sense the speed. A signal amplifier in the loop does not make a passive probe an active one.

NOTE 2 Proximity probes can be gapped further from the speed sensing surface than magnetic speed sensors and are therefore less likely to rub and fail during abnormal rotor vibration conditions (such as encroaching on a second critical speed during an overspeed condition).

NOTE 3 There is a possibility with active probes that they could fail to a high state resulting in spurious OSD trips.

6.17.2.5 If rotational speed indication below 250 rpm is required, then a separate active speed sensor is required.

NOTE Passive magnetic speed sensors do not typically generate a suitable signal amplitude at slow shaft rotational speeds.

6.17.2.6 The sensor body, mounting bracket, and any protective housings for the sensor shall be constructed of nonmagnetic stainless steel such as AISI Standard Type 303 or 304.

NOTE Magnetic stainless steel, such as AISI Standard Type 416, tends to alter the flux path and reduce the sensor's output voltage. Aluminum housings can decrease the sensor's output voltage and introduce phase shift as speed changes.

6.17.2.7 The sensor and its associated multitoothed speed sensing surface shall be compatible (see Annex J).

6.17.3 Casing/Housing Transducers

6.17.3.1 Accelerometer Sensors

6.17.3.1.1 The standard accelerometer shall be an electrically isolated transducer consisting of a case, a piezoelectric crystal, an integral amplifier, and a connector.

6.17.3.1.2 The accelerometer case shall be constructed from AISI Standard Type 316 or other corrosion-resistant stainless steel.

6.17.3.1.3 The accelerometer case shall be electrically isolated from the piezoelectric crystal and all internal circuitry.

6.17.3.1.4 The accelerometer case shall be hermetically sealed.

6.17.3.1.5 The accelerometer case shall have a maximum outside diameter of 25 mm (1 in.). The overall case height shall not exceed 65 mm (2.5 in.), not including the connector.

6.17.3.1.6 The accelerometer case shall be fitted with standard wrench flats (SI or US customary).

6.17.3.1.7 The mounting surface of the accelerometer case shall be finished to a maximum roughness of 0.8 μm (32 μin.) Ra (arithmetic average roughness). The center of this mounting surface shall be drilled and tapped (perpendicular to the mounting surface ±5 minutes of an arc) with a minimum of M8x1 (1/4-28-UNF-2A) threaded hole of 6 mm (0.25 in.) minimum depth.

6.17.3.1.8 All accelerometers shall be stud mounted, see Annex C for options.

6.17.3.1.9 The vendor shall supply with each accelerometer a standard mounting option consisting of a double-ended, flanged, 1/4-28-UNF-2A threaded, AISI Standard Type 300 stainless steel mounting stud. The stud shall not prevent the base of the accelerometer from making flush contact with its mounting (see Annex C).

• **6.17.3.1.10** If specified, accelerometer shall have M8x1 threaded stud

• **6.17.3.1.11** If specified, accelerometer shall have an integral mounted stud**.**

6.17.3.1.12 The standard accelerometer shall have a top connector with body material of AISI Standard Type 300 stainless steel and meeting the mechanical, electrical, and environmental requirements of the accelerometer.

6.17.3.1.13 When attached to the accelerometer cable (or when using an integral cable), the combined assembly shall withstand a minimum tensile load of 225 N (50 lb.).

6.17.3.1.14 The accelerometer transverse sensitivity shall not exceed 5 % of the principal axis sensitivity at 100 Hz.

6.17.3.1.15 The accelerometer transducer shall have a noise floor no higher than 0.004 g rms over the frequency range specified in Table 1.

6.17.3.2 Accelerometer Cables

6.17.3.2.1 Accelerometer cables shall be supplied by the accelerometer vendor and meet the mechanical, electrical, and environmental requirements of the accelerometer system.

6.17.3.2.2 The nominal physical length of the accelerometer cable shall be 5 m (200 in.).

6.17.3.2.3 A piece of clear heat-shrink tubing (not to be shrunk at the factory) 40 mm (1.5 in.) long shall be installed over the accelerometer cable at each end to assist the owner in tagging.

6.17.3.2.4 Connectors on accelerometer cables shall meet the mechanical, electrical, and environmental requirements of the accelerometer.

6.17.3.2.5 The connector body material shall be AISI Standard Type 300 stainless steel.

6.17.3.2.6 The connector shall be designed to withstand a minimum tensile load of 225 N (50 lb.).

• **6.17.3.2.7** If specified, the cable may be integral to the accelerometer.

6.17.3.3 Velocity Sensors

6.17.3.3.1 The standard velocity sensor shall be an electrically isolated, internally integrating accelerometer consisting of a case, a piezoelectric crystal, an integral amplifier, integrator, and a connector.

• **6.17.3.3.2** If specified, a velocity sensor utilizing a moving coil (electromechanical design) shall be used instead of an internally integrating accelerometer (except on reciprocating equipment), with performance specifications as mutually agreed by vendor and purchaser.

NOTE See Annex P for specific reciprocating compressor velocity transducer requirements.

6.17.3.3.3 The velocity sensor case shall be constructed from AISI Standard Type 316 or other corrosion-resistant stainless steel.

6.17.3.3.4 The velocity sensor case shall be electrically isolated from the piezoelectric crystal and all internal circuitry.

6.17.3.3.5 The velocity sensor case shall be hermetically sealed.

6.17.3.3.6 The velocity sensor case shall have a maximum outside diameter of 30 mm (1.2 in.). The overall case height shall not exceed 70 mm (2.75 in.), not including the connector.

6.17.3.3.7 The velocity sensor case shall be fitted with standard wrench flats.

6.17.3.3.8 The mounting surface of the velocity sensor case shall be finished to a maximum roughness of 0.8 µm (32 µin.) Ra (arithmetic average roughness). The center of this mounting surface shall be drilled and tapped (perpendicular to the mounting surface ±5 minutes of an arc) with a M8x1 (1/4 -28 -UNF-2A) threaded hole of 6 mm (0.25 in.) minimum depth.

● **6.17.3.3.9** All velocity sensors shall be stud mounted, see Annex C for options.

6.17.3.3.10 The vendor shall supply with each velocity sensor a standard mounting option consisting of a double-ended, flanged, ¼-28-UNF-2A threaded, AISI Standard Type 300 stainless steel mounting stud. The stud shall not prevent the base of the velocity sensor from making flush contact with its mounting.

● **6.17.3.3.11** If specified, the velocity sensor shall have a M8x1 threaded stud.

6.17.3.3.12 If specified, velocity sensor shall have an integral stud**.**

6.17.3.3.13 The standard velocity sensor shall have a top connector with body material of AISI Standard Type 300 stainless steel and meeting the mechanical, electrical, and environmental requirements of the velocity sensor. When attached to the velocity sensor cable (or when using an integral cable), the combined assembly shall withstand a minimum tensile load of 225 N (50 lb.).

6.17.3.3.14 The velocity sensor transverse sensitivity shall not exceed 5 % of the principal axis sensitivity over the ranges specified in Table 1.

6.17.3.3.15 The standard frequency range velocity sensor shall have a noise floor no higher than 0.004 mm/s (0.0002 IPS) rms over the frequency range specified in Table 1.

6.17.3.4 Velocity Sensor Cables

6.17.3.4.1 Velocity sensor cables shall be supplied by the velocity sensor vendor and shall meet the temperature requirements of the velocity sensor.

6.17.3.4.2 The nominal physical length of the velocity sensor cable shall be 5 m (200 in.).

6.17.3.4.3 A piece of clear heat-shrink tubing (not to be shrunk by the manufacturer of the cable) 40 mm (1.5 in.) long shall be installed over the velocity sensor cable at each end to assist the owner in tagging.

6.17.3.4.4 Connectors on the velocity sensor cables shall meet the mechanical, electrical, and environmental requirements of the velocity sensor. The body material shall be AISI Standard Type 300 stainless steel and shall be designed to withstand a minimum tensile load of 225 N (50 lb.).

6.17.4 Temperature Sensors

6.17.4.1 Sensors

6.17.4.1.1 The standard temperature sensor shall be a 100-ohm, platinum, three-lead resistance temperature detector (RTD).

6.17.4.1.2 The standard RTD shall have a temperature coefficient of 0.00385 ohm/ohm/°C.

● **6.17.4.1.3** If specified, Type J, Type K, or Type N thermocouples shall be supplied in accordance with ASTM E230/E230M-23a (IEC 60584-1).

6.17.4.1.4 Temperature sensors for electrically insulated bearings shall maintain the integrity of the bearing insulation (see 6.18.2.4.8).

6.17.4.1.5 Sensor leads shall be coated, both individually and overall, with insulation.

• **6.17.4.1.6** If specified, flexible stainless steel overbraiding shall cover the leads and shall extend from within 25 mm (1 in.) of the tip to within 100 mm (4 in.) of the first connection.

6.17.4.1.7 A 40-mm (1.5-in.) piece of clear heat-shrink tubing (not to be shrunk by the manufacturer of the cable) shall be installed at the connection end to assist in the tagging of the sensor.

6.17.4.2 Wiring

6.17.4.2.1 Wiring from the temperature sensor to the monitor shall be as follows.

a) For RTDs, use three-conductor shielded wire in accordance with Annex D.

b) For thermocouples, use thermocouple extension wire of the same material as the thermocouple and in accordance with Annex D.

6.17.4.3 Connectors

6.17.4.3.1 The standard installation shall employ a single compression-type, like-metal-to-like-metal connection technique between the sensor and the monitor.

6.17.4.3.2 The connection shall be at a termination block external to the machine.

6.17.4.3.3 Temperature sensor wiring shall be located in a separate junction box from vibration sensors.

6.17.4.3.4 The junction box(s) shall not be mounted on the machine casing but in a vibration-free environment.

6.17.5 Surge Sensors and Transducers

See Section 7.3 for specific requirements.

6.18 Sensor and Transducer Arrangements

6.18.1 Locations and Orientation

See Annex H for typical system arrangement plans showing quantities and types of transducers for various machines.

6.18.1.1 Radial Proximity Probes

6.18.1.1.1 For monitored radial bearings, two radially oriented proximity probes shall be provided. These two probes shall be:

a) Coplanar, orthogonal (90° (±5°) apart) and perpendicular to the shaft axis (±5°);

NOTE Typically the shaft radial proximity probes are located 45°(±5°) from each side of the vertical center;

b) Referenced such that when viewed from the driver end of the machine train, the Y probe is always 90° counterclockwise of the X probe regardless of the direction of shaft rotation;

c) Located within 75 mm (3 in.) of the bearing;

d) Located the same with respect to the predicted nodal points as determined by a rotordynamic analysis of the shaft's lateral motion (e.g. both sets of probes shall be either inside or outside the nodal points) (refer to API TR 684);

e) Located such that they do not coincide with a predicted nodal point.

6.18.1.1.2 The surface areas to be observed by the probes (probe areas):

a) Shall be free from stencil and scribe marks or any other mechanical discontinuity, such as an oil hole or a keyway;

b) Shall not be metalized or plated;

c) Shall have a final surface finish that does not exceed 1 µm (32 µin.) rms;

d) Shall be demagnetized or otherwise treated so that the combined total electrical and mechanical runout does not exceed 6 µm (0.25 mil) or as specified in the mechanical equipment standard.

6.18.1.1.3 For all conditions of rotor axial float and thermal expansion, a minimum side clearance of one and one-half the diameter of the probe tip, from the probe centerline, is required (see Figure 9). The probe shall not be affected by any metal other than that of the probe's observed area.

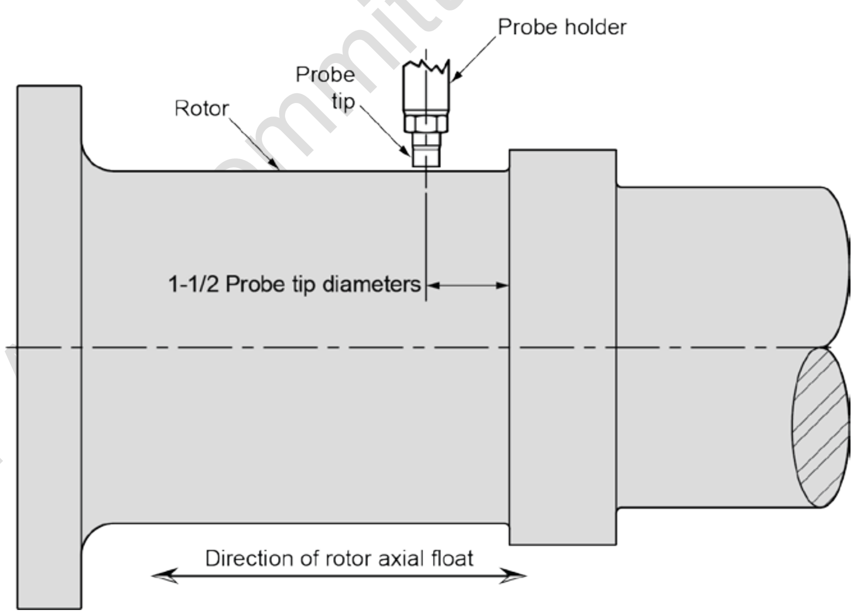


Figure 9—Side Clearance for Radial Vibration Probes

6.18.1.1.4 The probe gap shall be set at -10 Vdc (±0.2 Vdc).

6.18.1.1.5 It shall be possible to adjust the probe gap using commercially available wrenches. No special bent or split socket wrenches shall be required.

6.18.1.1.6 Minimum separation of radial proximity probe tips shall be at least 74 mm (2.9 in.).

NOTE Shaft diameters smaller than 50 mm (2 in.) can experience cross talk.

6.18.1.2 Axial Proximity Probes

6.18.1.2.1 Two axially oriented probes shall be supplied for the thrust bearing end of each casing.

6.18.1.2.2 Both axial probes shall sense the shaft itself or an integral axial surface installed within an axial distance of 300 mm (12 in.) from the thrust bearing (see Figure 10).

NOTE When choosing the locations for all probes used in direct shaft measurements, it is always more desirable to measure the shaft directly rather than a component attached to the shaft.

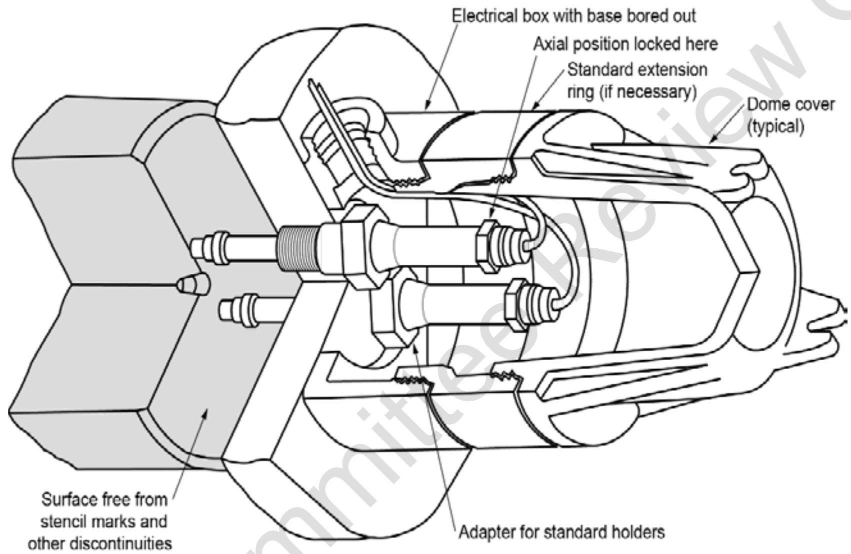


Figure 10—Standard Axial Probe Arrangement

6.18.1.2.3 It shall be possible to adjust the probe gap using commercially available wrenches. No special bent or split socket wrenches shall be required.

6.18.1.2.4 The electrical box shall protect the axial probe assembly so that external loads (e.g. those resulting from personnel stepping on the box) do not impose stress on the assembly and result in false shaft-position indication (see Figure 10).

6.18.1.2.5 Shaft and collar areas sensed by axial probes shall have a combined total electrical and mechanical runout of not more than 13 μm (0.5 mil) pp.

6.18.1.2.6 The provisions of 6.18.1.1.2 regarding surface finish and the requirement of 6.18.1.1.3 regarding minimum side clearance shall be observed.

6.18.1.2.7 The axial probe gap shall be set so that when the rotor is in the center of its thrust float, the transducer's output voltage is –10 Vdc (±0.2 Vdc).

6.18.1.2.8 Minimum separation of axial proximity probe tips shall be at least 7 probe tip diameters.

6.18.1.3 Piston Rod Proximity Probes

6.18.1.3.1 Piston rod proximity probes shall be mounted internally in the distance piece with a mounting block attached to the face of the pressure packing flange.

6.18.1.3.2 Piston rod monitoring measurements shall use a forward mount probe or probes. The use of reverse mount probes shall not be utilized.

6.18.1.3.3 The center of the probe tip measured from the packing flange shall not exceed 75 mm (3 in.). Proximity probes shall be mounted at least one and one-half probe tip diameters measured from the probe tip center to the face of the packing flange (see Figure 11).

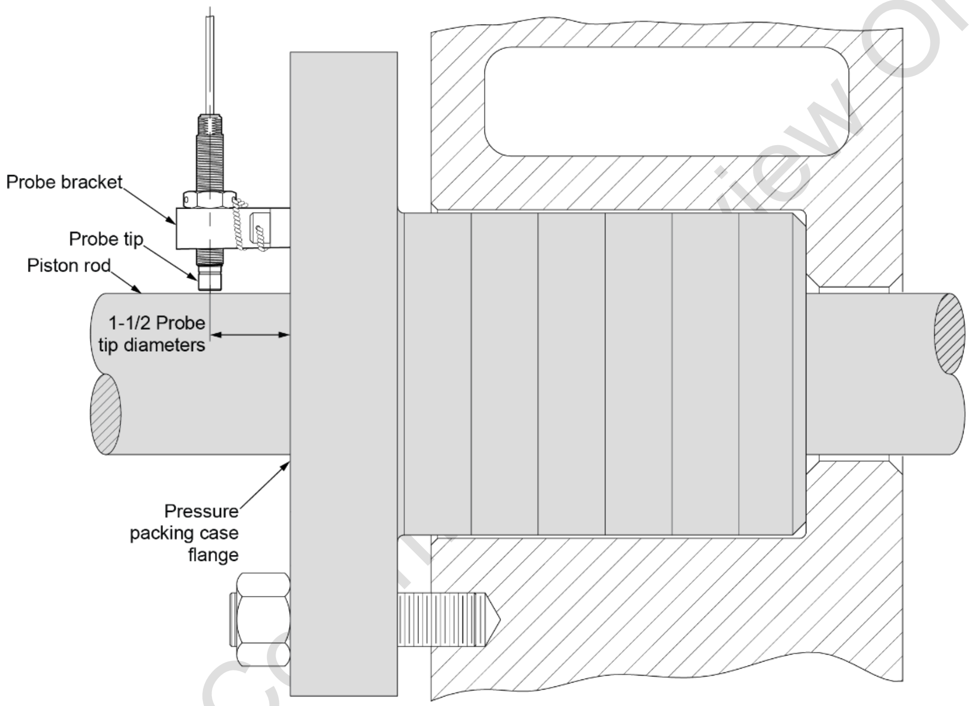
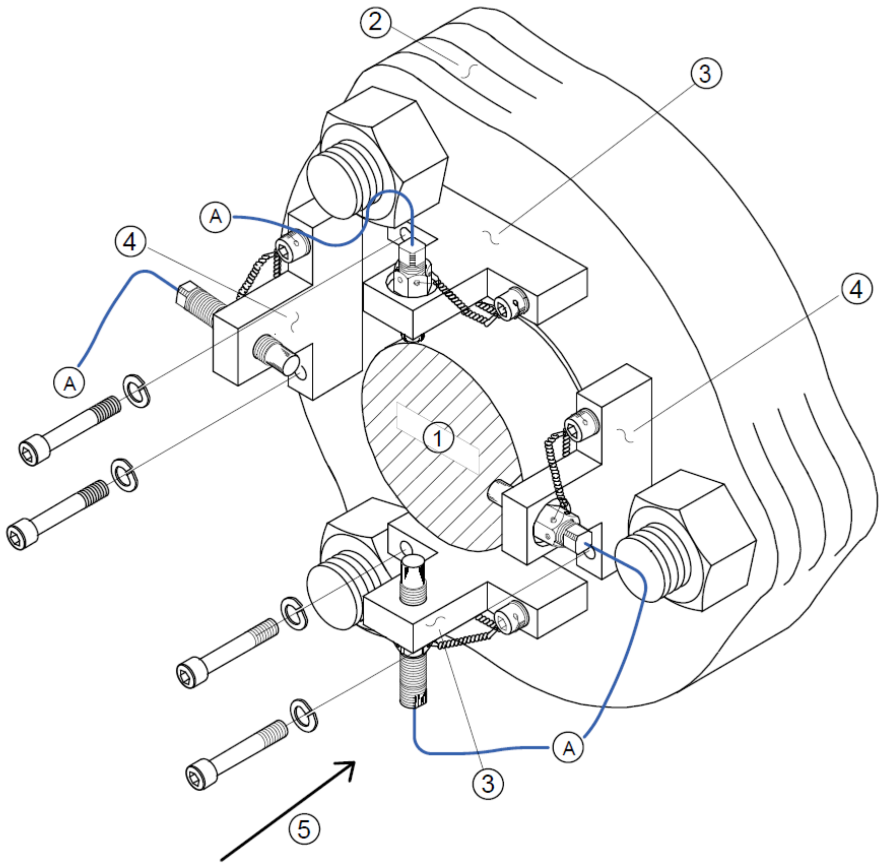


Figure 11—Piston Rod Probe Sideview Clearance

6.18.1.3.4 The primary piston rod proximity probe shall be mounted in a true vertical direction (see Figure 12).



Legend	
1	Piston Rod
2	Crank end piston rod pressure packing flange
3	Locations for vertical piston rod monitoring probe 6.18.1.3.4)
4	Location for optional diagnostic piston rod monitoring probe for Vertical-Horizontal rod vibration monitoring (6.18.1.3.12)
5	View direction from crankcase towards crank end of cylinder
A	To cable exit

Figure 12—Typical Piston Rod Probe(s) Arrangement

6.18.1.3.5 It shall be possible to adjust the probe gap using commercially available wrenches.

6.18.1.3.6 No special bent or split socket wrenches shall be required.

6.18.1.3.7 The proximity probe system verification curve shall be performed on the actual observed surface of the piston rod.

NOTE The intent of this subsection is to preclude the use of a representative target with similar metallurgy, rather than the actual piston rod surface. Coated probe areas will affect the system calibration. Coated probe areas require special verification of the probe system and depend not only on coating metallurgy but also coating thickness, roughness of parent material and the curvature of the piston rod.

6.18.1.3.8 When the piston rod is coated, the results of the verification curve obtained in 6.18.1.3.7 shall be used in programming the monitor system to compensate for any coated areas on the probe target area.

6.18.1.3.9 Supplier shall provide probe gap settings based on the application to optimize the linear range.

6.18.1.3.10 The initial piston rod monitoring probe gap shall allow the probe sufficient range to view the piston rod under the following two conditions**:**

a) with new rider bands installed after allowing for thermal expansion of the piston,

b) with the rider bands completely worn and the piston riding directly on the cylinder liner.

6.18.1.3.11 Probe diameter shall be selected to ensure available/measurement range meets application.

• **6.18.1.3.12** If specified, an additional probe shall be mounted in the horizontal plane to assist in protection in accordance with 7.1.6.4 (see Figure 12).

NOTE The convention for true horizontal and true vertical probes when making piston rod measurements is to view the probes from the crankshaft looking towards the cylinder.

6.18.1.3.13 For all conditions of machine operation and thermal expansion, a minimum side clearance of one and one-half the diameter from the probe tip is required. The probe shall not be affected by any metal other than that of the probe's observed piston rod target area.

6.18.1.4 Phase Reference Transducers

6.18.1.4.1 A one-event-per-revolution mark and a corresponding phase reference transducer shall be provided on the driver for each machinery train (see Figure H.4 for an example), and on the output shaft(s) of all gearboxes (see Figure H.2).

• **6.18.1.4.2** If specified, a spare phase reference transducer shall be installed per 6.18.2.1.3 c). The radial location of a spare phase reference transducer, relative to the primary phase reference transducer, shall be documented.

NOTE Loss of a phase reference transducer, when used as an input to a tachometer, results in loss of speed indication, and the loss of diagnostic capabilities for all other radial and axial transducers referenced to that shaft.

6.18.1.4.3 Phase reference probe mounting requirements and electrical conduit protection shall be identical to that of a radial shaft vibration probe (see 6.18.2.1.1).

6.18.1.4.4 The phase reference probe and its angular position shall be permanently marked with a metal tag on the outside of the machine casing.

6.18.1.4.5 The angular position of the one-event-per-revolution mark on the rotor shall be marked on an accessible portion of the shaft.

6.18.1.4.6 A change in the transducer's output voltage of at least 7 V shall be provided for triggering external analysis equipment and digital tachometers.

6.18.1.4.7 The one-event-per-revolution marking groove for phase reference transducers shall conform with the following:

a) minimum width shall be one and one-half times the diameter of the probe tip;

b) minimum length shall be one and one-half times the diameter of the probe tip;

c) minimum depth shall be 1.5 mm (0.06 in.);

d) shall be long enough to allow for shaft thermal expansion and rotor float.

6.18.1.4.8 The one-event-per-revolution mark shall not be placed in the path of the normal radial or axial vibration probes.

6.18.1.5 Crank Angle Reference Probes

6.18.1.5.1 A one-event-per-revolution timing mark and a crank angle reference probe shall be provided for each reciprocating compressor.

6.18.1.5.2 Crank angle reference probes shall be radially mounted to sense a one-event-per-revolution mark.

● **6.18.1.5.3** If specified, a redundant crank angle reference transducer shall be provided and its timing event shall occur at the same time as the primary crank angle reference transducer event.

● **6.18.1.5.4** If specified, a multi-event-per revolution signal shall be supplied that also contains a unique event to provide phase measurements.

6.18.1.6 Standard Tachometer Probes

6.18.1.6.1 The phase reference probe in 6.18.1.4 can be used as the input to the tachometer.

● **6.18.1.6.2** If specified, options for the tachometer include the following:

● a) the standard probe of 6.17.1.1.1 observing a multitooth speed sensing surface;

● b) the magnetic speed probe of 6.17.2 observing a multitooth speed sensing surface.

NOTE To achieve the required tachometer accuracy and response time, a multitooth speed sensing surface can be necessary, particularly for applications involving low shaft speeds (below 250 rpm) such as slow-roll or zero speed. See Annex J for application considerations pertaining to multitooth speed sensing surfaces.

6.18.1.7 Electronic Overspeed Detection System Speed Probes

6.18.1.7.1 Three separate speed probes that are not shared with any other system shall be provided for the electronic ODS (for probe selection see 6.17.2).

6.18.1.7.2 Mounting requirements and electrical conduit protection for speed sensors shall be identical to that required for radial shaft vibration probes (see 6.18.2.1.1).

6.18.1.7.3 A multitoothed surface for speed sensing may be shared by other speed probes but shall not be used as a gear for driving other mechanical components**.**

NOTE See Annex J for typical details of this multitoothed surface.

6.18.1.8 Accelerometers and Velocity Sensors

6.18.1.8.1 Location and number of accelerometers and velocity sensors shall be jointly developed by the machinery vendor and the owner.

6.18.1.8.2 Accelerometers or velocity sensors intended to monitor axial casing vibration shall be oriented axially located on or as near as possible to the thrust bearing housing**.**

6.18.1.8.3 Accelerometers or velocity sensors shall not be mounted across the split line**.**

6.18.1.9 Bearing Temperature Sensors

6.18.1.9.1 Radial Bearing Temperature Sensors

6.18.1.9.1.1 The intent of this section is to locate the temperature sensor as close to the highest metal temperature position.

NOTE Some equipment (such as gearboxes) have a load angle that is different from the gravity load which can affect the best location of the temperature sensor.

6.18.1.9.1.2 Temperature sensors for sleeve journal bearings shall be arranged as follows:

a) Bearings whose length-to-diameter ratio is greater than 0.5 shall be provided with two axially collinear temperature sensors located in the loaded half of the bearing, 30° (±10°) from the load centerline in the normal direction of rotation.

b) Bearings whose length-to-diameter ratio is less than or equal to 0.5 shall be provided with a single sensor axially located in the center of the loaded half of the bearing, 30° (±10°) from the load centerline in the normal direction of rotation.

6.18.1.9.1.3 Temperature sensors for tilting-pad journal bearings shall be arranged as follows:

a) Bearings whose length-to-diameter ratio is greater than 0.5 shall be provided with two axially collinear embedded temperature sensors located at the three-quarter arc length (75 % of the pad length from the leading edge).

b) Bearings whose length-to-diameter ratio is less than or equal to 0.5 shall be provided with a single sensor axially located in the center of the pad at the three-quarter arc length (75 % of the pad length from the leading edge).

c) For bearings with load-on-pad designs, the sensor or sensors shall be located in the loaded pad (see Figure 13).

d) For bearings with load-between-pad designs, the sensors shall be located in both loaded pads (see Figure 14).

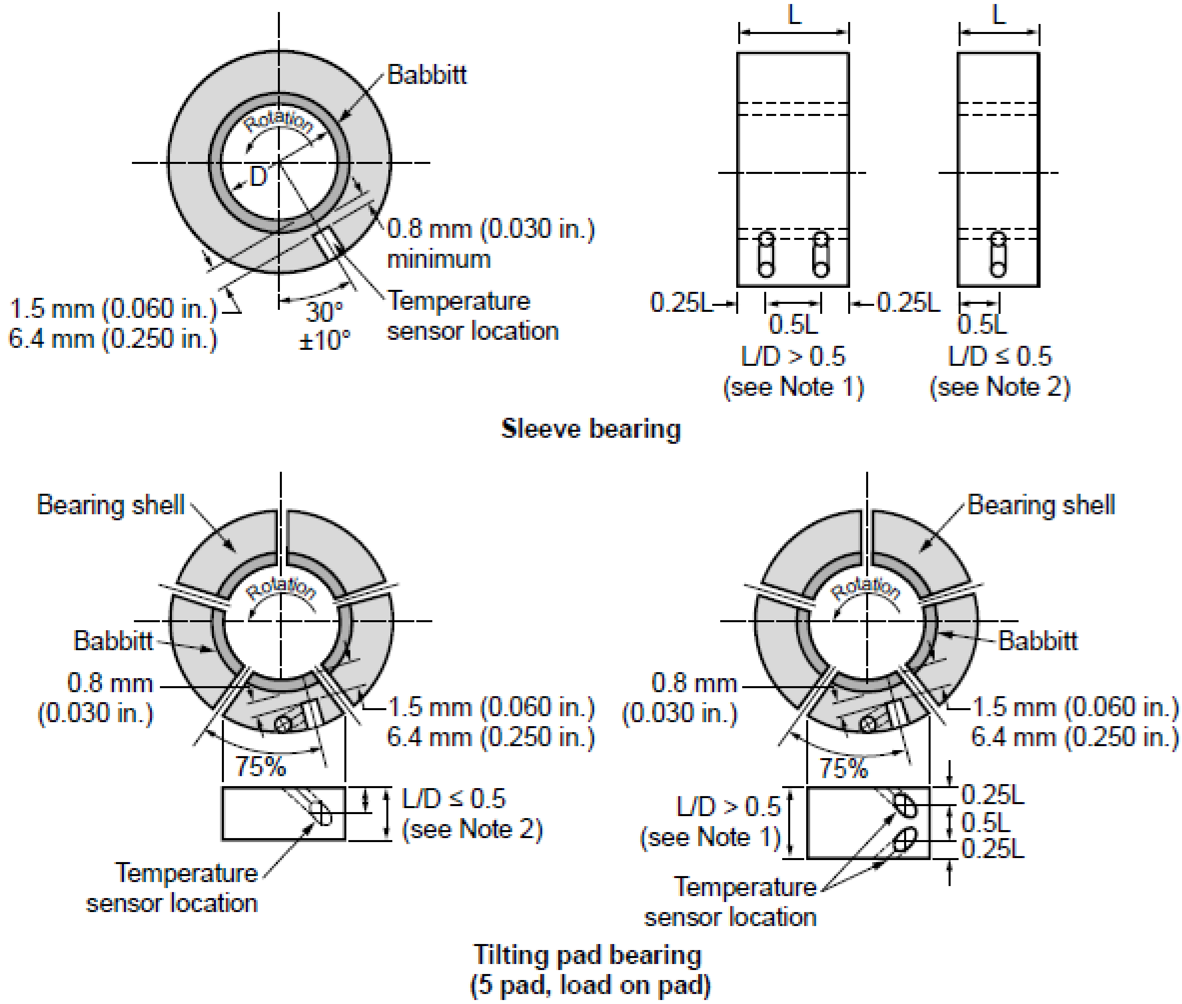


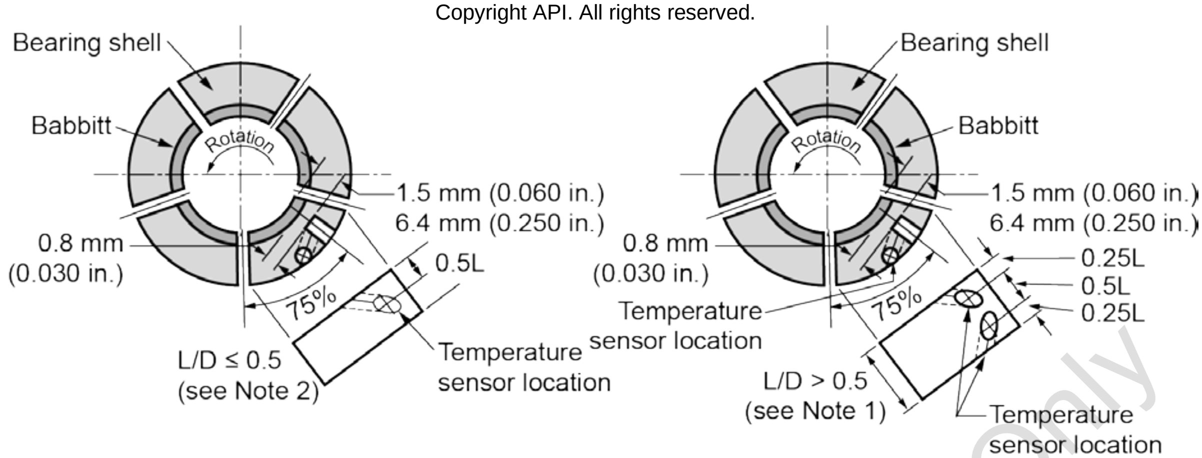
Figure 13—Typical Installations of Radial Load on Pad Bearing Temperature Sensors

6.18.1.9.1.4 For machines such as gearboxes, the shaft operating attitude shall be considered in determining the exact location of the temperature sensors. Sensors should be placed as close to the high load region as possible.

NOTE The gearbox manufacturer should be consulted to define the normal shaft-to-bearing load points when selecting the exact location of temperature sensors, because the position of the journal in the bearing depends on such considerations as transmitted power and direction of gear mesh.

6.18.1.9.2 Thrust Bearing Sensors

6.18.1.9.2.1 A temperature sensor shall be located in each of two shoes in the normally active thrust bearing at least 120° apart. (see Figure 15).



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NOTE 1 If the length-to-diameter (L/D) is greater than 0.5, two sensors are installed, each located at a distance of 0.25L from the end of the bearing's running face [see 6.18.1.9.1.3a)].

NOTE 2 If the L/D ratio is less than or equal to 0.5, a single sensor is axially located in the center of the bearing [see 6.18.1.9.1.3b)].

Figure 14—Standard Installation of Radial Load Between Pad Bearing Temperature Sensors

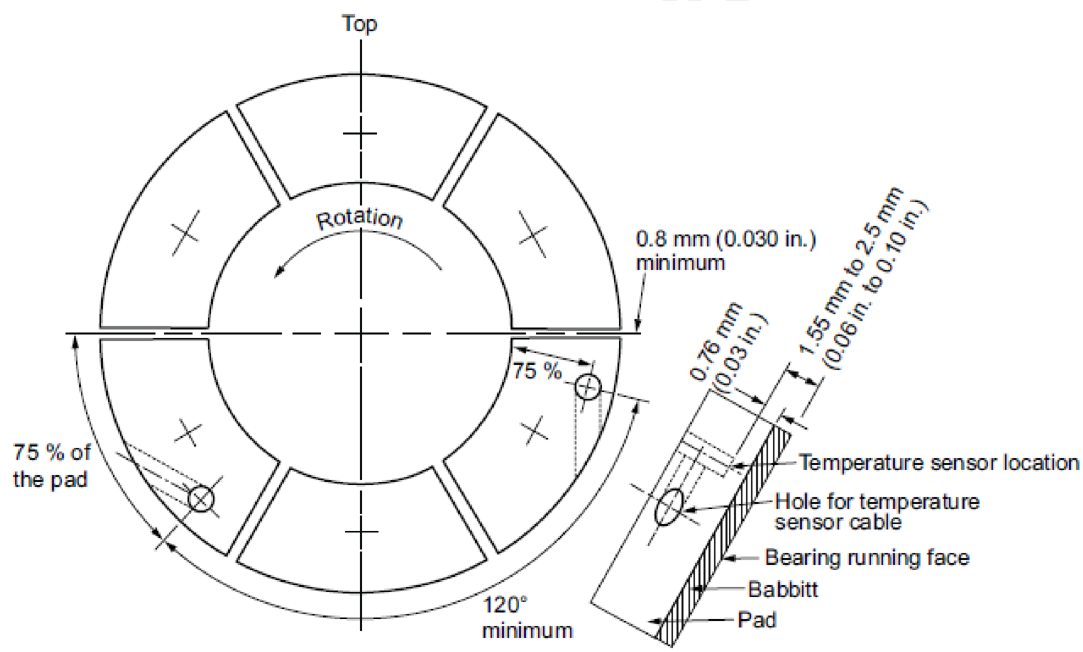


Figure 15—Typical Installation of Thrust Bearing Temperature Sensors

6.18.1.9.2.2 Thrust bearing temperature sensors shall be placed at 75 % of the pad width radially out from the inside bearing bore and at 75 % of the pad length from the leading edge (see Figure 15).

6.18.1.9.2.3 At least two additional temperature sensors shall be provided in the normally inactive thrust bearing, arranged as specified in 6.18.1.9.2.1 and 6.18.1.9.2.2.

6.18.1.9.2.4 The temperature sensor shall be located 1.5 to 2.5 mm (0.060 to 0.100 in.) from the bearing running face and not less than 7.6 mm (0.030 in.) from the (white metal) babbitt/pad interface. The holes shall be finished with a bottoming drill with all corners broken.

6.18.1.9.2.5 The sensor lead shall be routed from the bearing to the outside of the machine through a penetration fitting. The sensor lead shall be secured, with no internal connections, to prevent damage as a result of whipping, chafing, windage, and oil. The sensor lead shall not restrain pivoting thrust shoes.

6.18.2 Mounting

6.18.2.1 Proximity Probes

6.18.2.1.1 All probes (except piston rod probes) shall be mounted in external holders that permit adjustment outside the machine casing or bearing housing.

• **6.18.2.1.2** If specified, redundant probes shall be provided.

6.18.2.1.3 The default location for the installed redundant probes is as follows:

a) *Radial Probes*—180° radially from that of the installed primary probes. If this mounting location is inaccessible, spare probes shall be mounted where space permits but shall always be mounted 90° apart from one another per 6.18.1.1.

b) *Axial Probes*—Spare axial probes shall be mounted to observe the same axial surface(s) as that of the installed primary probes. Their radial orientation relative to one another can vary depending on machine design.

c) *Phase Reference Probes*—Spare phase reference probes will ideally be at the same circumferential location as the installed primary phase reference probes.

d) *Crank Angle Reference Probes*—Spare crank angle reference transducer shall be installed such that its timing event shall occur at the same instant as the primary crank angle reference transducer.

6.18.2.1.4 Probe holders shall have natural frequencies greater than 10X running speed for rotating machinery and 100X for reciprocating machinery.

6.18.2.1.5 The free cantilevered length of a probe holder sleeve shall not exceed 200 mm (8 in.). Longer lengths require the use of a probe holder sleeve support guide.

6.18.2.1.6 When a probe is internally mounted, the probe holder shall be at least 10 mm (3/8 in.) thick.

6.18.2.1.7 All cable connections shall be made in conduit boxes located outside the machine.

6.18.2.1.8 The probe lead shall be securely tied down to prevent cable whipping or chafing resulting from windage or oil.

6.18.2.1.9 In the standard configuration, all extension cables shall be protected in conduit as shown in Figure 2.

6.18.2.1.10 Extension cable connectors shall be electrically isolated from conduit using an insulating sleeve or wrap located in an externally accessible junction box.

• **6.18.2.1.11** If specified, armored extension cable as shown in Figure 3 shall be provided.

6.18.2.2 Oscillator-demodulators

The number, location, and installation of mounting boxes for oscillator-demodulators shall be approved by the owner. The following requirements shall be met.

a) At least one per machinery casing.

b) Located on the same side of the equipment train.

c) Mounted separate from the machine in a location to minimize vibration.

d) Temperatures in conformance with Table 1.

6.18.2.3 Accelerometers and Velocity Sensors

6.18.2.3.1 The machinery vendor shall provide machined and finished accelerometer mounting points as shown in Annex C. The boss or surface shall be part of the machine casing.

6.18.2.3.2 All cables shall be enclosed in conduit. The conduit shall be attached to an enclosure, not to the accelerometer (see Annex C for typical mounting and enclosure arrangements).

• **6.18.2.3.3** If specified, the accelerometer cable shall be protected by a weatherproof, flexible armor (see Annex C for additional details).

6.18.2.4 Bearing Temperature Sensors

6.18.2.4.1 Embedded temperature sensors shall be provided.

6.18.2.4.2 The temperature sensors shall not contact the babbitt (white metal).

6.18.2.4.3 The temperature sensors shall be located in the bearing backing metal (see Figure 13, Figure 14, and Figure 15).

6.18.2.4.4 Through-drilling and puddling of the babbitt is not permitted when mounting the temperature sensor.

6.18.2.4.5 The heat-sensing surface of the temperature sensor shall be held in positive contact by either spring or adhesive with the bearing backing metal not less than 0.75 mm (30 mil) from the babbitt bond line. The recommended distances from the babbitt running face are as follows (see Figure 13, Figure 14, and Figure 15):

a) for tilting-pad bearings, from 1.5 mm to 2.5 mm (60 mil to 100 mil);

b) for sleeve bearings, from 1.5 mm to 6.4 mm (60 mil to 250 mil).

• **6.18.2.4.6** If specified, spring-loaded (bayonet type) temperature sensors that contact the outer shell of the bearing metal are permitted without bonding or embedment for fixed geometry bearings.

6.18.2.4.7 The leads from all temperature sensors shall:

a) be oriented to minimize bending or movement during operation and maintenance;

b) be secured to prevent cable whipping and chafing resulting from windage or oil without restricting pad movement;

c) be free from connections inside the machine;

d) utilize a terminal head outside the machine for all cable connections;

e) be free from splices.

NOTE The default configuration does not permit connectors on temperature sensor leads inside the machine which allows connector problems to be addressed without machine shutdown and disassembly.

• **6.18.2.4.8** If specified, the temperature sensor tip shall be electrically insulated from the bearing.

NOTE Many machines, notably electric motors and generators, require electrically insulated bearings to prevent circulating shaft currents. (see 6.14 and 6.17.4.1.4).

6.18.2.4.9 The temperature sensor signal cables shall not permit liquid or gas to leak out of the bearing housing. Acceptable arrangements include the following:

a) Potted, encased sleeves that are sealed with compression seals;

b) Molded signal leads within an elastomeric material that is sealed with a tapered compression fitting;

c) Hermetic seals;

6.18.3 Identification of Sensor Systems

Each sensor, extension cable, and oscillator-demodulator (when applicable) lead shall be plainly marked to indicate the customer tagging of its associated probe or sensor and be visible without disassembly of machine.

7 Monitoring and Protection Systems

7.1 Vibration, Position, and Temperature Monitoring Systems (VMS)

7.1.1 General

7.1.1.1 The manufacturer of the VMS shall provide documentation affirming the system's compliance with and/or exceptions to all aspects of this standard except those that are configuration and/or installation related.

7.1.1.2 Unless otherwise specified, features and functions for the VMS (except transducer systems) specified in Section 6 shall be contained in one rack.

7.1.1.3 A VMS shall include the following signal processing functions and outputs:

a) Individual unfiltered buffered output connections for all vibration and tachometer/phase system transducers shall be provided via front-panel bayonet nut connectors (BNCs) and rear panel connections.

• b) If specified, the monitor system shall employ connectors other than BNC.

• c) If specified, a 4 mA to 20 mA DC analog output shall be provided for each measured variable used for machine protection in addition to the digital output of 6.12.1.

NOTE This output is designed and intended for transmitting VMS data to recorders and other control/automation equipment. It is not designed or intended to replace the relays of 6.11 for machinery protection purposes.

7.1.1.4 As a minimum, the VMS shall be provided with the following features and functions.

a) An installation design ensuring that a single circuit failure (power source and monitor system power supply excepted) shall not affect more than two channels (regardless of channels available on the monitor module) of vibration and position.

b) All radial shaft vibration, axial position, rod monitoring, and casing vibration channels, associated outputs, and displays shall have a minimum resolution of 2 % of full scale. Temperature channels, associated outputs, and displays shall have 1° resolution independent of engineering units. Tachometer and electronic ODS channels, associated outputs, and displays shall have a resolution of 1 rpm.

c) Electrical or mechanical adjustments for zeroes, gains, and alarm and shutdown setpoints that are field changeable and protected through controlled access. The means for adjustment, including connection(s) for a portable configuration device, shall be accessible from the front of the monitor system. The monitor system alarm and shutdown functions shall be manually or automatically bypassed in accordance with 6.11.13 during adjustment.

d) Each machine train shall have dedicated modules.

• e) If specified, modules to monitor more than one machine train may be installed in the same rack.

f) Each machine case shall have a dedicated VMS phase reference transducer input.

7.1.1.5 A monitor system shall include the following signal processing functions and outputs for proximity probes:

a) gain adjustment for each radial shaft vibration and axial position channel,

b) default gain adjustment shall be factory preset to 7.87 mV/μm (200 mV/mil).

7.1.1.6 A monitor system shall include the following alarm and integrity comparison functions.

a) Fixed time delays for shutdown relay activation that are field changeable (via controlled access) to require from 1 to 3 seconds sustained violation. A delay of 1 second shall be standard.

b) Alarm indication for each channel.

● **7.1.1.7** If specified, a monitor system shall include a display capable of indicating the following:

a) all measured variables;

b) alarm and shutdown setpoints;

c) DC gap voltages (for radial shaft vibration, axial position, piston rod drop, speed indicating tachometer, and electronic ODS channels used with noncontact displacement transducers);

d) update interval of one second or less.

7.1.2 Transducer Power Supplies

The output voltage to all oscillator-demodulators shall be –24 Vdc with sufficient regulation and ripple suppression to meet the accuracy requirements specified in Table 1.

7.1.3 System Output Relays

7.1.3.1 The output relays described in this section shall be used for interconnecting the MPS to all other devices used as part of the auto-shutdown loop.

7.1.3.2 The optional digital interfaces of 6.10.5 d) and 6.12.1 and the optional analog outputs of 7.1.1.3 shall not be used for machinery protection purposes.

7.1.3.3 As a minimum, one pair of common relays—alarm and shutdown—shall be provided for each of the following monitored variable types per machine train:

a) axial position,

b) radial shaft vibration,

c) casing vibration,

d) bearing temperature,

e) piston rod monitoring.

7.1.4 Radial Shaft Vibration Monitoring

● **7.1.4.1** The full-scale range for monitoring radial shaft vibration shall be from 0 to 125 μm (0 to 5 mil) non-derived (true) peak-to- peak displacement. Peak-to-peak values factored from any other intermediate value or calculated measurement, other than the transducer or signal interface is not acceptable.

• **7.1.4.2** If specified, the standard optional full-scale range can be from 0 to 250 µm (0 to 10 mil) true peak-to-peak displacement.

7.1.4.3 The radial shaft vibration circuit fault system shall be set to actuate at 125 µm (5 mil) less than the upper limit and 125 µm (5 mil) more than the lower limit of the transducer's linear range. The minimum allowable setting for the lower limit shall be 250 µm (10 mil) absolute gap.

7.1.4.4 Radial shaft vibration shall be monitored in paired orthogonal ("X-Y") channels from the two transducers mounted at each bearing.

7.1.4.5 Dual voting logic ("2oo2") shall be standard.

7.1.4.6 The radial shaft vibration shutdown system shall be field changeable so that "1oo2" (single voting logic) or "2oo2" (dual voting logic) orthogonal ("X-Y") transducer signals shall persist at or above the setpoint to activate a shutdown relay.

NOTE Considerations for a single (one-out-of-two) versus a dual voting (two-out-of-two) system include the potential for a significant elliptical shaft orbit (due to misalignment or other potential unidirectional load conditions) where one transducer detects shutdown limits while the other transducer remains within acceptable limits. With a significant elliptical orbit, a single voting system provides protection while a dual voting system does not. The disadvantage of a single voting system is the possibility of false shutdowns and unnecessary loss of production. Where the probability of a significant elliptical shaft orbit is low, the use of a dual voting system provides a higher level of reliability and fewer false shutdowns.

7.1.4.7 In a dual voting logic system, the shutdown relay shall not activate until both channels persist at or above the shutdown setpoint for the time delay specified in 7.1.1.6 a). In the event of failure of a single radial shaft vibration channel transducer or circuit, only the circuit-fault alarm will activate [i.e. the shutdown relay will not activate].

• **7.1.4.8** If specified, a controlled-access setpoint multiplier function shall be provided with the following capabilities:

• a) Actuation by an external contact closure causes the alarm and shutdown setpoints to be increased by an integer multiple, either two (2) or three (3). A multiplier of three (3) shall be standard.

• b) Shall be provided on the monitor system when the multiplier is invoked.

• c) Elevation of the setpoint shall not attenuate the actual input signal nor alter the proportional digital or analog outputs representing the channel's amplitude.

NOTE The use of setpoint multiplication is not recommended. See Annex I for guidance on when setpoint multiplication may be required.

7.1.4.9 Altering a vibration measurement to arithmetically subtract (suppress) mechanical or electrical runout or electrical noise shall not be allowed.

7.1.5 Axial Position Monitoring

• **7.1.5.1** The full-scale range for axial position monitoring shall be from –1 mm to +1 mm (-40 mil to +40 mil) axial movement.

7.1.5.2 The axial position circuit-fault system shall be set to actuate at the end of the transducer's linear range but not closer than 250 μm (10 mil) of absolute probe gap.

7.1.5.3 Axial position shall be monitored in paired channels. The monitoring system shall be capable of displaying the deviation from zero for both channels.

7.1.5.4 The axial position shutdown system shall be field changeable so that one (single logic) or both (dual voting logic, see 7.1.5.5) transducer signals shall reach or violate the shutdown setpoint to actuate the shutdown relay. Dual voting (two-out-of-two) logic shall be standard.

7.1.5.5 In an axial position dual voting logic system, both channels shall jointly and continuously be at or above the shutdown setpoints for the time delay specified in 7.1.1.6 a)
before the shutdown relay activates. In the event of the failure of a single transducer or circuit, only the circuit-fault alarm and the alarm shall activate [i.e. the shutdown relay will not activate]. The shutdown relay shall activate when any of the following conditions occur:

a) both axial position transducers or circuits fail.

b) either channel has failed, and the other channel has violated the shutdown setpoint.

c) both channels jointly violate the shutdown setpoint.

7.1.5.6 Each axial position monitoring channel shall be field changeable so that the display will indicate either upscale or downscale (from the neutral position) with increasing probe gap. Indicating upscale with increasing probe gap shall be standard.

7.1.6 Piston Rod Monitoring

7.1.6.1 Piston rod monitoring shall be provided (see Annex P).

7.1.6.2 The piston rod monitor system shall include a once-per-crank-revolution signal using a crank angle reference transducer of 6.18.1.5 for timing the measurement location on the piston rod and for diagnostic purposes (see Figure 17).

7.1.6.3 The piston rod monitor system shall be supplied with one channel per piston rod with the probe mounted in the vertical plane (see Figure 17).

• **7.1.6.4** If specified, the piston rod monitor system shall be supplied with two channels per piston rod with one probe mounted horizontally and the other mounted vertically (see 6.18.1.3.12).

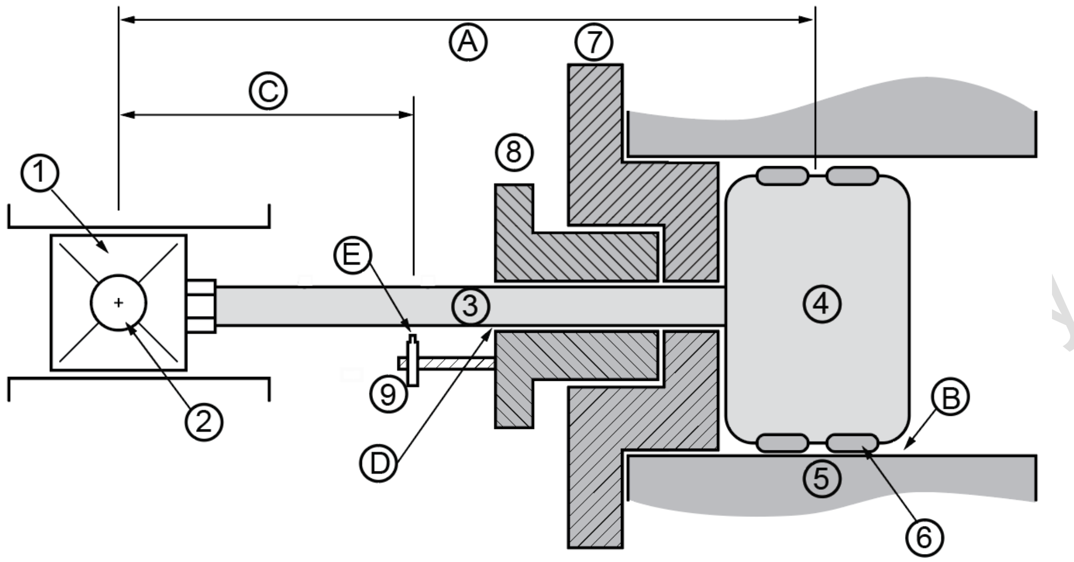
7.1.6.5 The piston rod monitor display shall have a minimum resolution of 25 μm (1 mil) resolution.

7.1.6.6 See Figure 16 to determine rod drop limiting clearance. The limiting clearance may be the clearance between the rod and the pressure packing case.

7.1.6.7 The piston rod monitor circuit-fault system shall be set to actuate at the end of the transducer's linear range but not closer than 1 mm (40 mil) of absolute proximity probe gap.

• **7.1.6.8** If specified, the piston rod monitor's shutdown function shall activate if any individual sensor value reaches the shutdown setpoint for that channel.

7.1.6.9 Voting of multiple sensors (i.e., horizontal and vertical sensors) or multiple measurements from one sensor (i.e., rod drop and piston rod vibration PP) is not allowed.



Legend: 1. Crosshead 2. Crosshead Pin 3. Piston Rod 4. Piston 5. Cylinder 6. Rider Bands 7. Crank End Head 8. Packing Case Flange 9. Piston Rod Monitoring Probe	A = Length crosshead pin center to piston center	______
	B = Clearance between piston and cylinder, bottom	______
	C = Length crosshead pin center to center piston rod monitoring transducer at BDC	______
	D = Clearance pressure packing case to bottom piston rod	______
	E = Clearance piston rod to transducer tip	______

Calculation 1: Drop of piston rod limiting clearance determination.
This calculation is required to determine whether the component limiting the running clearance is the pressure packing case clearance or the bottom piston-to-cylinder clearance.
a) If A x D/C < B, then the pressure packing case clearance is limiting: otherwise the piston-to-cylinder clearance is limiting.
b) If the piston-to-cylinder clearance is limiting, the maximum drop of piston rod at the transducer is C x B/A.

Calculation 2: Convert the drop of piston rod at the measurement probe to piston drop inside the cylinder. A change in clearance E represents a loss of bottom piston-to-cylinder clearance as follows:
piston position = ΔE x A/C.

Figure 16—Piston Rod Drop Calculations

7.1.6.10 The piston rod monitor shall be able to calculate piston rise or piston drop based on the position of the piston rod, the position of the proximity probe, and measurements of different machinery components.

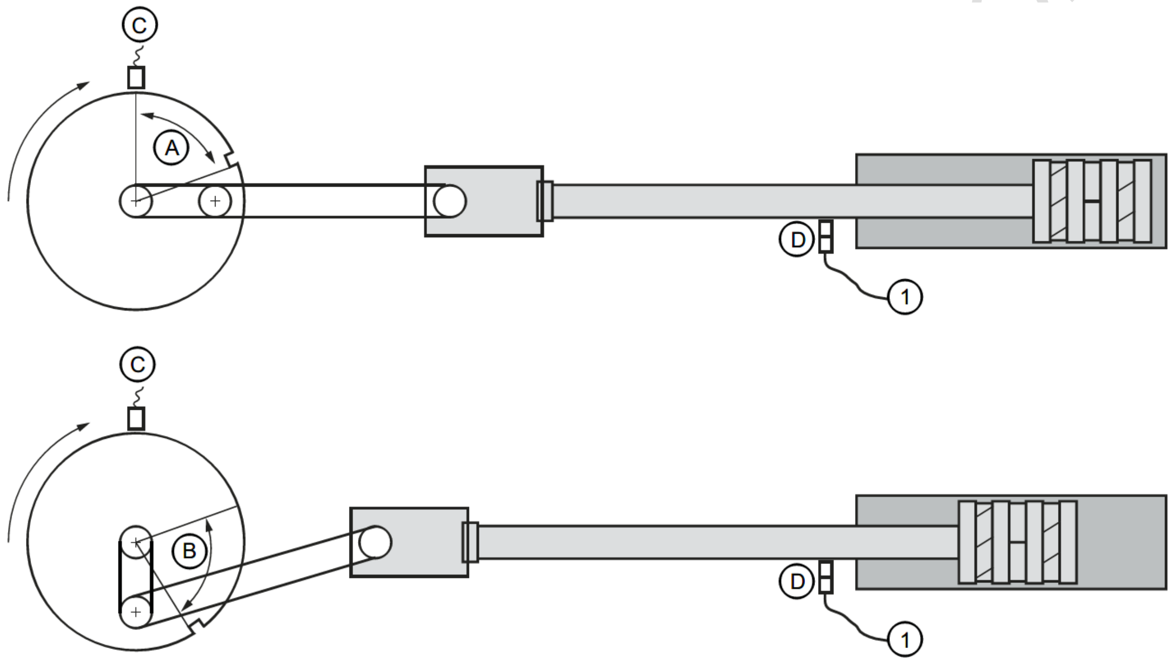
7.1.6.11 The piston rod monitor system shall be capable of being reset to its new rider band wear setting after reaching operating temperature to compensate for thermal growth of the piston.

NOTE The initial running position of the piston rod will change because of thermal growth of the piston and pressures encountered when in operation.

7.1.6.12 The scale factor for each transducer shall be determined from running a curve with the probe system on the actual piston rod target surface and used in the monitoring system (ref. 6.18.1.3.7).

7.1.6.13 The piston rod monitor system scale factor shall be able to use within ±50 % of the nominal sensitivity value to accommodate different materials, coatings, curvature effects of small diameters and coating thicknesses on the piston rod. Linearity of the system shall meet the requirements of Table 1.

NOTE Piston rods or plungers can be manufactured from (or coated with) a variety of materials and are often coated with chrome or tungsten carbide. These factors can affect transducer sensitivity requiring field calibration of the piston rod monitor system. For nonstandard materials and calibrations, the adjustable scale factor allows the accuracy to be calibrated to the material type.



KEY	
A	Piston Angle (PA) = the number degrees of crankshaft rotation from when the crank angle reference transducer fires on the once per reference mark until the piston reaches its top dead center position
B	Trigger Angle (TA) = the number degrees of crank shaft rotation from top dead center to when triggered reading is to be taken Industry may want to use items for determining TA value such as: 1) piston rod is in tension 2) this piston rod displacement value is consistent at different compressor loads 3) the piston is close to the probe (minimizes correction factor)
C	Crank Angle Reference Transducer
D	Vertical Piston Rod Monitoring Transducer
NOTE 1	Vertical transducer mounting can be below or above the piston rod

Figure 17—Piston Rod Drop Measurement Using Crank Angle Reference Transducer for Triggered Mode

7.1.6.14 The piston rod monitoring system shall be capable of displaying rider band wear in two separate modes.

a) *Triggered Mode*—Display rider band wear based on the instantaneous gap voltage at a specific and consistent point on each piston stroke.

b) *Average Mode*—Display rider band wear based on the average gap voltage throughout the stroke

NOTE The most effective way of interpreting piston rod drop measurements is through the application of long- and short-term trending. This trending allows users to reliably determine rider band wear.

7.1.7 Casing Vibration Monitoring

7.1.7.1 Requirements in this section apply to monitoring casing vibration utilizing acceleration and velocity transducers.

NOTE 1 When casing vibration is used for machine protection, velocity measurements are recommended (see Annex E).

NOTE 2 It is generally not recommended to use acceleration for machinery protection.

7.1.7.2 The monitored frequency range of each casing vibration channel shall be fixed with two field-changeable filters, high and low pass. Filters used to set the frequency range shall have the following characteristics.

a) Unity gain and no loss in the filter greater than 0.5 dB, referenced to the input signal level.

b) A minimum roll-off rate of 24 dB per octave at the high and low cutoff frequency (–3 dB).

c) Filtering shall be accomplished prior to integration.

d) Casing velocity shall be monitored within a filter passband from 10 Hz to 1000 Hz.

7.1.7.3 The casing vibration circuit fault system shall activate whenever an open circuit or short circuit exists between the monitor system and accelerometer. The circuit fault system shall be latching. This will inhibit the operation of the affected channel until the fault is cleared and the channel reset.

• **7.1.7.4** If specified, a controlled-access setpoint multiplier function shall be provided with the following capabilities.

a) Actuation by an external contact closure causes the alarm and shutdown setpoints to be increased by a multiplier of three (3).

b) Positive indication (e.g. lighted) shall be provided on the monitor system when the multiplier is invoked.

c) Elevation of the setpoint shall not attenuate the actual input signal nor alter the proportional digital or analog outputs representing the channel’s amplitude.

NOTE The use of setpoint multiplication is not recommended. See Annex I for guidance on when setpoint multiplication may be required.

7.1.7.5 Casing vibration on machines equipped with rolling element bearings or machines that require high frequency measurements shall be monitored as follows.

a) For gear unit without rolling element bearings, casing vibration shall be monitored in acceleration and velocity modes from a single accelerometer.

   i) Acceleration shall be monitored in a frequency range between 1000 Hz and 10 kHz;

   ii) Velocity shall be monitored in a frequency range between 10 Hz and 1000 Hz.

b) For machines equipped with rolling element bearings:

   i) Velocity shall be monitored in a frequency range from 10 Hz to 1000 Hz:

● ii) If specified, acceleration shall be monitored from the same transducer in a frequency range from 10 Hz to 10 kHz;

   iii) Equipment operating at shaft speeds from 750 rpm down to 300 rpm shall be monitored in a frequency range from 5 Hz to 1000 Hz.

● **7.1.7.6** If specified, a casing vibration monitor system shall include one or more of the following options:

a) monitor and display of single channel acceleration or velocity,

b) monitor and display two channels in either acceleration or velocity,

c) monitor and display alternate filter or frequency ranges.

d) monitor and display unfiltered overall vibration.

e) monitor and display in true rms.

f) monitor and display in true peak,

g) alternate full-scale ranges,

h) dual voting logic (“2oo2”),

i) single voting logic (“1oo2”)

7.1.8 Temperature Monitoring

7.1.8.1 The full-scale range for temperature monitoring shall be available in either metric (SI) or USC units as specified, with a minimum range of 0 °C to 150 °C (32 °F to 300 °F). A resolution of 1° independent of engineering units shall be provided.

7.1.8.2 When thermocouples are used, temperature monitor systems shall be suitable for use with grounded and ungrounded thermocouples. (See 6.18.1.9 for application descriptions).

7.1.8.3 A fault in the temperature monitor or its associated transducers shall initiate the circuit-fault status alarm. Downscale failure (i.e. a failure in the zero direction) shall be standard.

7.1.8.4 Temperature monitoring shall include the capability of displaying all monitored values. The display shall include automatic capability to display the highest temperature.

7.1.8.5 The temperature monitoring shutdown function shall be field changeable to allow either of the following two possible configurations:

a) Any individual sensor shall reach or violate the shutdown setpoint,

b) Dual voting logic between predetermined pairs of sensors shall reach or violate the shutdown setpoint.

7.1.8.6 Dual voting logic (“2oo2”) shall be standard when two sensors are installed per 6.18.1.9 . Single voting logic (“1oo2”) shall be standard for all other sensor configurations.

7.1.9 Speed Indicating Tachometer

• **7.1.9.1** If specified, a speed indicating tachometer with the ability to record and store the highest measured speed (rpm) shall be provided.

• **7.1.9.2** If specified, controlled access reset capability for the highest measured speed shall be available both locally and remotely.

7.1.9.3 The system shall accept transducer inputs from either standard proximity probes or magnetic speed sensors.

7.1.10 Location of Monitor Systems

• **7.1.10.1** The purchaser shall specify whether monitor systems are to be located indoors or outdoors.

7.1.10.2 Outdoor installations shall be designed and located to avoid adverse vibrational and environmental effects.

7.2 Electronic Overspeed Detection System

7.2.1 General

7.2.1.1 The Electronic Overspeed Detection System (ODS) is comprised of speed measuring devices, logic solver for comparing speed to a limit, and output devices.

NOTE This standard does not address other components such as solenoids, interposing relays, shutdown valves, etc.. Details pertaining to other components can be found in the relevant API standard corresponding to the specific machine type (e.g. API 610, API 611, API 612, API 616, API 617).

7.2.1.2 The ODS shall be designed to comply with the requirements of IEC 61508, IEC 61511, and this standard. The complexity of the ODS will be determined by the required SIL.

• **7.2.1.3** If specified, the design of the ODS shall conform to IEC 62061 (machinery safety), ISO 21789 (gas turbine safety), or ISO 13849 (machinery safety), as applicable for the machine type.

7.2.1.4 The manufacturer of the ODS shall provide documentation affirming the system’s compliance with and/or exceptions to all aspects of this standard except those that are configuration and/or installation related.

7.2.1.5 The entity(ies) responsible for configuration and installation of the system shall provide documentation affirming the system's compliance with and/or exceptions to all aspects of this standard that are configuration and/or installation related.

7.2.1.6 The speed sensing surface shall be integral or positively attached and locked to the shaft of the driver.

7.2.1.7 The speed sensing surface shall not be used to drive other mechanical equipment.

NOTE Some integrally geared expanders use the main gear as the speed sensing surface.

7.2.1.8 Multiple sensors may share the speed sensing surface.

7.2.1.9 The system shall be provided with fully redundant power supplies in accordance with 6.9.

● **7.2.1.10** If specified, adjustable frequency drive (AFD) motors shall include an electronic ODS.

7.2.1.11 The party responsible for the MPS shall verify that the ODS response time meets the required system response time to prevent the rotor speed of all rotors in the train from exceeding their maximum rated rotor speed.

7.2.1.12 The ODS can be a distributed system (as per Section 7.4.4.2) or an integrated system (as per Section 7.4.4.3).

7.2.1.13 The ODS sensors and wiring shall conform to Section 6 of this standard. High quality, shielded, low-capacitance and low-inductive cabling shall be used for speed sensors. Particular attention should be paid to grounding practices as identified in Section 6.14.

7.2.2 Accuracy

7.2.2.1 The accuracy of the overspeed system shall be in accordance with Table 1.

7.2.2.2 Considerations of speed sensor and target designs are addressed in Annex J.

7.2.3 Segregation

7.2.3.1 The input speed sensors used as inputs to the electronic ODS shall not be shared with any other system. The speed signal as measured by the ODS can be used in other systems if communicated through analog outputs or data links.

7.2.3.2 Electronic overspeed detection shall be separate and distinct from the speed control system, with exception of final control elements. The ODS has independent Input/Output, processing, and other components separate from the speed control system.

● **7.2.3.3** If specified, an integrated trip system, surge detection, and ODS shall be provided see 7.4.4.3.

7.2.3.4 Combining the ODS with any non-safety system, such as control, or condition monitoring systems shall not be allowed. This restriction includes the VMS of Section 7 and in accordance with IEC 61511.

7.2.3.5 Integrated systems must meet the most stringent requirement of each integrated function.

●

7.2.3.6 If specified, overspeed protection of multiple machines on a single machinery train may be included on a single ODS, provided that the specified shutdown times and other requirements are met.

7.2.3.7 When communication interface links are provided, they shall not be used as part of the shutdown function.

7.2.3.8 Failure of a communication link shall not compromise the ability of the overspeed system to carry out its protective functions.

NOTE The intent of this subsection is to allow status and other data from the electronic ODS to be shared with process control, machine control, trip system, or other control and automation systems via digital or other interfaces, but without compromising the integrity of the overspeed shutdown function.

7.2.4 Functions

7.2.4.1 Number of Circuits and Alarm Logic

7.2.4.1.1 Overspeed detection shall use three independent measuring channels and two-out-of-three (2oo3) or Triple Modular Redundancy (TMR) voting logic for each shaft.

NOTE 2oo3 configurations enhance reliability while providing more convenient system verification and reduction in likelihood of spurious shutdowns (see Annex M).

● **7.2.4.1.2** If specified, two independent measuring channels in a one-out-of-two configuration may be used.

● **7.2.4.1.3** If specified, degradation to one-out-of-one voting in the case of a loop fault in a two channel system is allowed.

7.2.4.1.4 An overspeed condition sensed by any one channel shall initiate an alarm.

7.2.4.1.5 An overspeed condition sensed by two out of three channels shall initiate a shutdown.

7.2.4.1.6 Failure of a channel shall initiate an alarm only. The failure shall be treated as a vote to trip.

7.2.4.1.7 A manual reset shall be required for any of the conditions in 7.2.4.1.4 through 7.2.4.1.6.

7.2.4.2 System Output Relays

7.2.4.2.1 All the requirements of 6.11 shall apply except as follows.

7.2.4.2.1.1 If 2oo3, TMR, or 1oo2 voting logic is executed in the logic solver, as shown in Figure 18, the shutdown relay(s) on all channels of the ODS shall be actuated when the voting logic as specified in (7.2.4.1) reaches the overspeed trip setpoint.

7.2.4.2.1.2 If the 2oo3 or 1oo2 voting logic is executed outside of the logic solver, as shown in Figure 19, (e.g. hydraulics or relays), then the requirements of 7.2.4.2.1.1 does not apply.

7.2.4.2.1.3 Any additional response delay from the addition of an interposing relay shall be considered in the response time calculation. This is critical in de-energize-to-shutdown applications as the time to energize a relay is typically less than the time to de-energize.

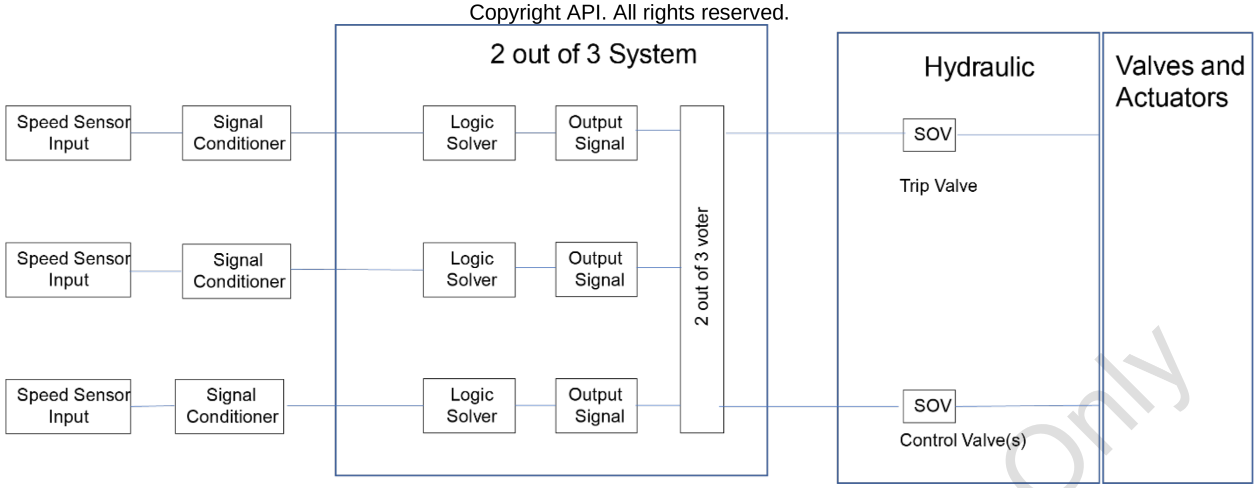


Figure 18—2oo3 voting as part of logic solver.

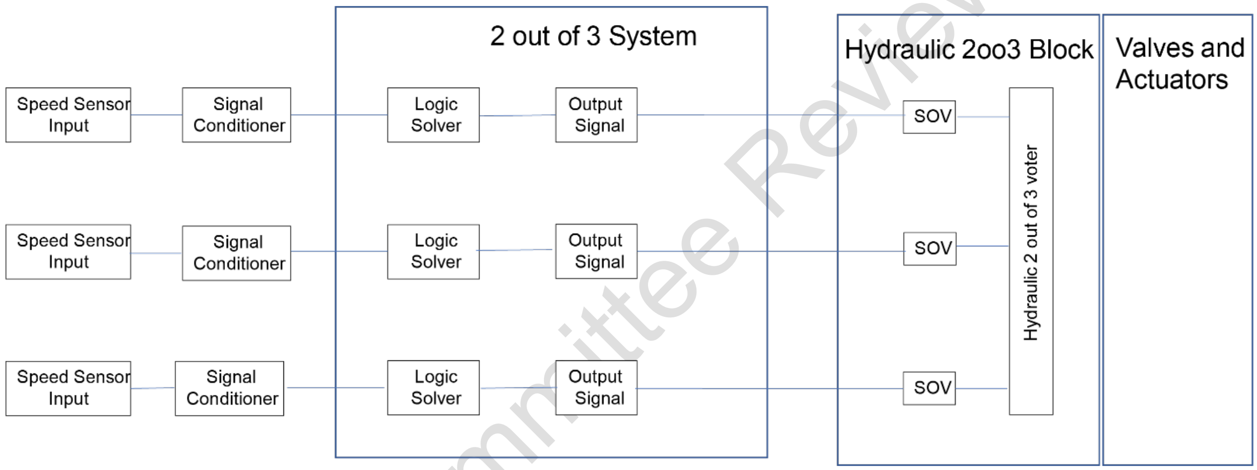


Figure 19—2oo3 voting as part of hydraulic circuit.

7.2.4.3 Inputs, Outputs, and Configuration

7.2.4.3.1 Sensors for the electronic ODS shall comply with the requirements of 6.18.1.7.

7.2.4.3.2 The electronic ODS shall accept speed sensor inputs from either magnetic speed sensors (6.17.2) or proximity probes (6.17.1.1).

7.2.4.3.3 The ODS shall be suitable to be tested using frequency generators. For these tests, the same inputs as for the speed probes may be used.

7.2.4.3.4 Each overspeed circuit shall provide an output for speed readout. The speed signal can be provided in hardwire or data link.

7.2.4.3.5 All settings incorporated in the overspeed circuits shall be field changeable and protected through controlled access.

7.2.4.3.6 A method of capturing peak speed shall be provided to indicate the maximum speed reached since last reset. This can be accomplished with a peak hold feature with controlled access reset or an appropriate high-speed data logger.

NOTE Depending on system design, it can be necessary to reset the peak hold feature after testing to ensure that maximum rotor speed reached during an actual overspeed event is captured.

7.2.4.3.7 Overspeed systems shall not have a system bypass. See items a) through d) of 6.10.8 for an MPS.

● **7.2.4.3.8** If specified, the ODS shall provide diagnostic details with system performance information. This can include first out, channel status, and other information that is helpful for troubleshooting purposes.

● **7.2.4.3.9** If specified, the ODS shall provide high-speed data logging functionality.

7.2.4.4 Response Time and Verification

7.2.4.4.1 The ODS shall sense an overspeed event and change the state of its output relays within 40 ms or as determined by overspeed calculations whichever is more restrictive.

7.2.4.4.2 Annex O shall be used if the individual API machinery standard does not address the overspeed calculation.

NOTE The response time is measured from change of sensor input frequency to change of state of the relay output (contact opens).

7.2.4.4.3 The predicted maximum allowable momentary rotor overshoot speed that can occur during an overspeed event shall be determined using the individual equipment standard or calculation methodology of Annex O. Worst case component delay times shall be used in the overspeed calculations to verify that the system response is fast enough to prevent the machine from exceeding the maximum allowable momentary rotor overshoot speed.

● **7.2.4.4.4** If specified, the machine vendor or responsible party (4.1) shall verify that the response of the entire overspeed protection system including final control elements is fast enough to prevent the prime mover and any of its driven machines from exceeding their maximum allowable momentary rotor overshoot speed.

NOTE 1 The intent of this subsection is to ensure that the entire overspeed protection system meets the required response time to safely shut down the machine, no matter which system architecture is utilized.

NOTE 2 The use of intrinsic safety barriers to meet hazardous area classification requirements can introduce signal delays that preclude the system from meeting acceptable response time criteria. Care should be taken to consider these effects when designing the electronic ODS and choosing components.

● **7.2.4.4.5** If specified, after complete field installation of the machine and its associated overspeed protection system, the vendor or responsible party (4.1) shall provide test results of the installed system to demonstrate that it does not exceed the required response time of 7.2.4.4.1 or 7.2.4.4.2. This test shall conform to the following:

a) The actual measured and logged system response time will be compiled for at least three overspeed trip events or simulated overspeed trip events. The time shall be measured from change of input frequency of the speed sensor until closure of the trip valve.

b) The simulated shaft rotational speed at which each electronic trip is initiated shall meet the criteria listed in Table 1.

c) The shaft rotational speed at which each shutdown test is initiated shall not exceed ±0.5 % of the speed setpoint value.

7.3 Surge Detection Systems

7.3.1 General

7.3.1.1 The function of the surge detection system shall be to detect surges and provide output for use in minimizing the number of surge cycles when surge cannot be prevented by antisurge control. The antisurge control system is not covered by this standard.

7.3.1.2 An electronic surge detection system shall be supplied for axial flow compressors.

● **7.3.1.3** If specified, surge detection shall be supplied on centrifugal compressors.

7.3.1.4 A risk assessment shall be completed to verify the need for and complexity level of the SDS.

● **7.3.1.5** If specified, a safety assessment with SIL evaluation shall be performed.

7.3.2 Detection, Accuracy & Repeatability

7.3.2.1 Flow (dp) transmitter for detection of surge should be installed as close as possible to the compressor. Long term signal stability and fast response is more important than accuracy.

7.3.2.2 Pressure, temperature, and other sensors needed for surge detection shall meet requirements of Table 1.

7.3.3 Segregation

7.3.3.1 Operation of the surge detection system shall be independent of the antisurge control function, except as noted in 7.3.3.2 through 7.3.3.4. Any failure of the antisurge control system shall not affect the surge detection. Any failure of the surge detection system shall not affect the antisurge control.

NOTE The purpose of the surge detection system is to protect the compressor from repeated surge in the event of a failure of the antisurge control system (See Annex K). Functional segregation of the two systems and adequate redundancy of any shared components (such as logic solvers and/or input sensors) is therefore essential to help prevent common-point failures.

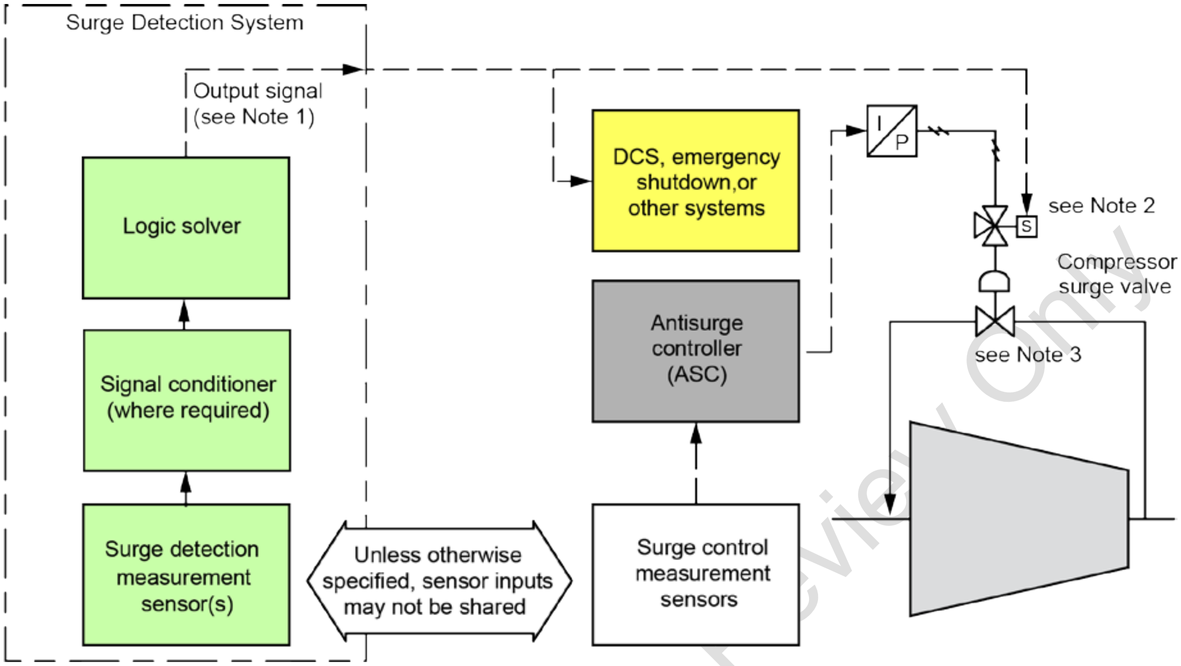
7.3.3.2 The electronic surge detection system is only one component in the compressor system. The surge detection system is comprised of sensors, transducers, logic solver, surge counter, and outputs that may be used by other logic and annunciating systems. The architecture for the surge detection system shall follow the design shown in Figure 20.

NOTE The primary purpose of the surge detection system is to generate an alarm that the compressor is experiencing surge cycles. This alarm can indicate the failure of the antisurge control system. Functional segregation of the surge detection system and antisurge control and adequate redundancy of any shared components is therefore essential to help prevent common-point failures.

7.3.3.3 Sensors used for compressor surge detection shall be independent from the antisurge control. Simplex sensors shall not be shared between the surge detection and antisurge control.

7.3.3.4 Tapping points used for compressor surge detection shall be independent from antisurge control.

7.3.3.5 A single flow element or inlet cone with two transmitters may be used for surge detection and antisurge control.



NOTE 1 Output signal may be used in various systems.

NOTE 2 Actuator may be pneumatic or hydraulic.

NOTE 3 Recycle loop shown, but other configurations are possible.

Figure 20—Surge Detection and Antisurge Control Systems

- **7.3.3.6** If specified, the surge detection logic solver may be integrated with a redundant antisurge control system. The redundant antisurge control system shall be comprised of redundant controllers and redundant sensors having independent tapping points. (see Annex K).

- **7.3.3.7** If specified, an integrated trip system, surge detection, and ODS shall be provided see 7.4.4.3.

7.3.3.8 The trip system shall be independent from the antisurge control system.

7.3.3.9 Antisurge valves and valve actuators can be shared by the antisurge control and surge detection systems.

7.3.3.10 A common logic solver can be used across multiple compressors on the same machine train.

7.3.4 Functions

7.3.4.1 Detection Methods

7.3.4.1.1 General

7.3.4.1.1.1 The compressor surge detection system shall be capable of detecting each surge cycle. If several trigger methods are used for surge detection, the electronic logic solver shall ensure each surge is counted only once.

7.3.4.1.1.2 A compressor surge is characterized by a rapid decrease and recovery of flow or discharge pressure, or a rapid increase and recovery of inlet temperature, or a combination of these. One or more of the following methods shall be used to detect a surge cycle.

7.3.4.1.2 Flow Decrease or Rate of Change

The flow decrease detection method monitors the sudden drop in flow. A surge is detected if the flow drops below a fixed preset threshold or by a high rate of change in the flow. The flow measurement shall be measured as follows:

7.3.4.1.2.1 Use the principles of differential pressure across a flow restriction,

7.3.4.1.2.2 Scale the flow transmitter to detect the differential pressure in the surge flow range.

NOTE In some cases, the flow transmitter used for surge detection may need to be configured with a smaller range than the full range flow to reliably sense the flow change.

7.3.4.1.3 Inlet Temperature Change

7.3.4.1.3.1 The inlet temperature change method monitors the sudden increase in the compressor inlet temperature. The compressor inlet temperature shall be measured as follows:

a) The sensor shall be a thermocouple

b) The thermocouple shall be placed as close to the compressor stage as possible

c) The sensor tip diameter shall not exceed 1 mm and shall not be inserted in a thermowell.

NOTE 1 The tip diameter and thermowell restrictions help achieve a fast response time for the thermocouple.

NOTE 2 The inlet temperature change method is not suitable for use in hazardous or toxic gas applications and higher than ambient pressure because of safety requirements of a thermowell.

7.3.4.1.3.2 To improve surge detection, the inlet temperature should be temperature compensated with the upstream gas temperature (Figure 21). This will require a second temperature measurement located upstream of the compressor inlet. This sensor is typically a robust process temperature sensor installed within a thermowell and may have a large time lag.

7.3.4.1.3.3 If temperature rate-of-change is used instead of comparison to the process temperature, then a single inlet thermocouple (less than 1 mm and no thermowell) can be used.

7.3.4.1.4 Discharge Pressure Change

The discharge pressure change method monitors for a sudden drop in discharge pressure.

NOTE Use this method with caution as other causes of a drop in discharge pressure may exist and may result in false surge indications. For example, the sudden opening of the anti-surge valve may drop the discharge pressure faster than a surge. A discharge check valve which fails to close totally may inhibit a pressure drop during surge.

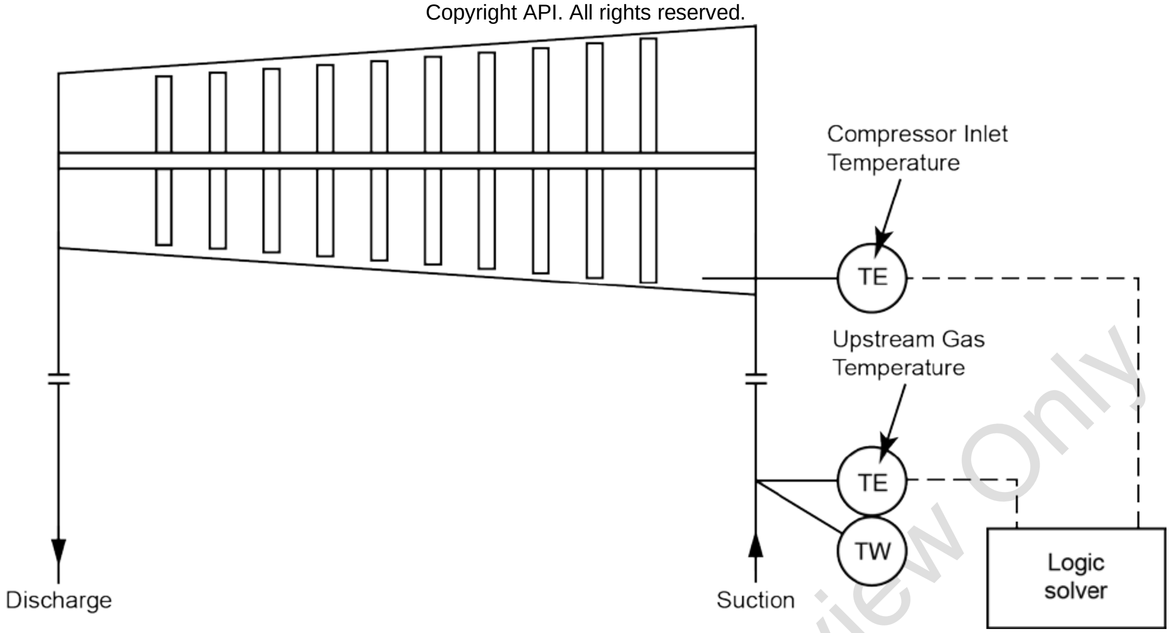


Figure 21—Surge Detection with Compressor Inlet Temperature

7.3.4.1.5 Others

7.3.4.1.5.1 Any other proven method may be used for compressor surge detection when mutually agreed to by purchaser and vendor.

NOTE Other agreed upon methods can include changes in motor current, incipient surge detection with vibration, thrust or speed.

7.3.4.1.5.2 A fixed threshold limit or a rate of change of the sensor signal shall be used to detect surge as indicated in 7.3.4.1.2 through 7.3.4.1.4. Rate of change shall only be used if the magnitude of the rate of change is significantly greater than changes which the compressor sees under normal operating conditions. Adequate selection should be validated through surge testing when possible. See Annex K for surge testing considerations.

7.3.4.1.5.3 A non-resettable counter shall be triggered once for each surge.

7.3.4.2 System Output Relays

All output relays shall conform to 6.11.

7.3.4.3 Inputs, Outputs and Configuration

7.3.4.3.1 An alarm output shall be generated whenever a surge is detected.

NOTE Individual input channel alarm are not normally required in surge detection. Pre-surge alerts may be useful in certain applications but are not mandated.

7.3.4.3.2 The surge detection system shall be capable of initiating further actions such as initiating advanced valve response functions, shutdown of the main driver, or communicate with the antisurge controller or other agreed upon actions.

7.3.4.3.3 All surge detection devices shall be tested during initial commissioning and after major changes that may affect the aerodynamic properties of the compressor system.

7.3.4.3.4 The surge detector shall be capable of disabling the alerting and counting functions during compressor start-up or shutdown.

• **7.3.4.3.5** If specified, the surge detection system shall include a provision for continuously recording the surge detector measurement sensor readings and output signals. The data logging rate shall be 200 ms or less and shall provide the ability to store values for a minimum of one minute both prior to and after surge detection.

7.3.4.3.6 A manual reset of the surge detection system (not the surge counter) shall be required if a surge event is detected.

7.3.4.4 Response Time

7.3.4.4.1 All components including, but not limited to, the logic solver, valves, solenoids, interposing relays, etc. shall be evaluated for adequate functionality and response time.

NOTE The use of intrinsic safety barriers, isolators, or other signal conditioning equipment can introduce signal delays that preclude the system from meeting the acceptable response time criteria as determined on a case-by-case basis using theoretical, shop test, or field test methods. Care should be taken to consider these effects when designing the electronic surge detection system and choosing components.

7.3.4.4.2 The electronic logic solver (see Figure 20) shall have a total program execution time of 100 ms or less.

7.3.4.4.3 The response time of any input device used for the measurement of a critical process variable for use by the surge detection algorithm shall be less than or equal to 200 ms @ 90% of the sensor range.

NOTE Repeatability and response time are the critical considerations in selecting an input device for surge detection. Accuracy is a less important criterion for surge detection but may be more important for antisurge control. Care should be taken to ensure that the needs of both the antisurge and surge detection systems are considered if sourcing common input devices.

7.3.4.4.4 The overall compressor surge detection response time, as measured at the surge detector output, shall be less than 500 ms.

7.3.4.4.5 All transducers and sensors used for surge detection should be located in proximity to the suction or discharge flanges of compressor to minimize the resultant lag time in measurement.

7.4 Trip Systems

7.4.1 General

7.4.1.1 The function of the trip system is to act as the logic solver that consolidates all trip commands to ensure proper timing and sequencing to safely stop the equipment.

7.4.1.2 The trip system shall be designed to comply with the requirements of IEC 61508, IEC 61511, and this standard. The complexity of the trip system will be determined by the required SIL.

NOTE The trip system may be simple (e.g. set of relay contacts in series) or complex (e.g. PLC type) based on the type of machine train and application (e.g. steam or gas turbines, electric drives, expanders, pumps, or compressors).

• **7.4.1.3** If specified, the design of the trip logic solver shall conform to IEC 62061 (machinery safety), ISO 21789 (gas turbine safety), and ISO 13849 (machinery safety), as applicable for the machine type.

7.4.1.4 The trip system performs the machine train trip logic by integrating all trip and shutdown functions and interfaces with the final trip element(s). The default architecture shall be distributed (see 7.4.4.2).

NOTE In machine trains where the trip system and/or the ODS include automated test routines of the final element(s) an integrated architecture may be required to ensure that the systems' test routines do not affect each other.

7.4.1.5 The entity(ies) responsible for installation and configuration of the trip system shall provide documentation affirming the system's compliance with (and/or exceptions to) all aspects of this standard that are configuration- and/ or installation-related.

NOTE Certain aspects of the trip system are hardware dependent, such as performance and most aspects of reliability. However, many aspects of the standard are installation dependent, such as the configurable capabilities of a system (e.g. alarm and relay configuration). The hardware vendor will not be able to affirm total system compliance in cases where they do not also perform installation and configuration.

7.4.1.6 The system design shall ensure that no single circuit failure will disable the trip system from meeting its functional requirements.

7.4.1.7 The trip system shall meet the environmental requirements listed in Table 1 and Section 6 and any hazardous area requirements per 6.8.

7.4.1.8 The trip system shall be provided with an internal time clock.

7.4.1.9 The trip system shall have provisions for synchronizing the internal time clock's time and date with an external master clock.

7.4.1.10 The trip system shall maintain an event list to log module/system alarms and diagnostic tests results.

7.4.1.11 The event list shall be stored in the trip system's nonvolatile memory.

7.4.1.12 The event list shall be maintained in the event of a total loss of power or loss of communications.

7.4.1.13 The trip system event list requirements are as follows:

a) event time stamp shall have 1 ms resolution

b) 30-day retention or 10,000 events,

c) event log based on a first-in/first-out sequence.

7.4.2 Functional Requirements

7.4.2.1 The trip system shall satisfy the following requirements:

a) The level of redundancy of the system shall be determined by the corresponding API machinery standard and a SIL analysis (see Annex L).

b) The system shall be capable of responding to a trip condition in less than 100 ms.

NOTE The 100 ms time requirement only includes the time from the change detected in the input to the change in the output. If using a digital system, this would imply a scan rate of less than 50 ms.

c) Any trip condition sensed shall, at a minimum, trip the driver and both initiate and indicate an alarm of the specific condition. In simple systems, this may be accomplished at the individual monitor systems (e.g. indication at a local panel).

d) Failure of a shutdown sensor, power supply, or logic device in any circuit shall, as a minimum, initiate and indicate a condition-specific alarm.

e) Items c) and d) shall require manual alarm reset (i.e. latching alarms).

f) All configuration and settings incorporated in the trip logic solver shall be field changeable and protected through controlled access.

g) Required test intervals are determined by the responsible party unless the system is designed to meet IEC 61508 or IEC 61511 standards.

h) The trip system’s proof test (per IEC 61508) interval shall meet or exceed the owner specified uninterrupted operation period of the equipment, if the proof test requires the shutdown of equipment.

7.4.2.2 The purchaser shall specify the safety critical shutdown signals to the trip system that can affect plant personnel safety.

7.4.2.3 The vendor with unit responsibility shall specify machine protection shutdown and trip initiators.

7.4.2.4 Any condition external to the trip system that initiates a shutdown shall activate the trip system shutdown logic.

7.4.2.5 The level of redundancy and fault tolerance for the trip logic solver shall, as a minimum, meet the same uninterrupted service requirements as the main machine control system. See applicable API standard for the respective requirements.

7.4.2.6 Initiation of any trip condition shall cause the system’s trip valve(s) and governor-controlled valve(s) to close and/or the main driver circuit breaker(s) to open.

7.4.2.7 Both the trip and governor-controlled valves shall be designed to fail close on loss of actuator power or control signal (hydraulic, pneumatic, or electrical).

7.4.2.8 If the trip system is supplied by the machine vendor, the machine vendor shall have responsibility for the entire trip system response time.

7.4.2.9 If the trip system is not supplied by the machine vendor, the supplier shall provide the total trip system response time and the machine vendor shall review and accept or reject the proposed system.

7.4.2.10 The trip system shall utilize internal, automatic self-testing that provides (at a minimum) all of the following:

a) microprocessor operation,

b) program execution,

c) input output integrity,

d) communication port operation.

e) an event log containing all self-test failures.

7.4.3 Trip System Security

7.4.3.1 The stored software application program shall be protected under management-of-change processes and at least two levels of programming security.

7.4.3.2 Controlled access (a keylock switch or other interlocking device) in addition to password protection shall be provided, inhibiting access to configuration and programming functions when in the on/run position.

● **7.4.3.3** If specified, an alarm shall be activated when a trip function bypass is engaged.

7.4.3.4 Password encryption capability meeting industry standards shall be provided.

7.4.3.5 A keypad and display, or computer access, shall be provided for password entry.

7.4.3.6 A log of changes and user ID associated with the change shall be provided.

7.4.3.7 The trip system shall have the capability to support at least 16 individual user accounts.

7.4.3.8 Program shall be protected by nonvolatile semiconductor memory such that indefinite power loss does not result in program loss.

7.4.3.9 A communication port allowing updates to and backups of the trip system programming shall be provided.

● **7.4.3.10** If specified, remote access shall be provided for troubleshooting purposes. The trip system vendor and the end user shall implement security measures to ensure that the functions of the trip system are not compromised while a machine is under power.

7.4.4 Trip System Arrangement

7.4.4.1 General

7.4.4.1.1 Trip systems may be broadly categorized into two types: distributed (see 7.4.4.2) and integrated (see 7.4.4.3).

7.4.4.1.2 The trip system shall be of distributed type such that it is separate from and independent of all other monitoring systems defined by this standard.

● **7.4.4.1.3** If specified, an integrated trip system, surge detection, and ODS shall be provided see 7.4.4.3.

NOTE Distributed systems with separate automated testing intervals could coincide and cause a spurious shutdown.

7.4.4.2 Distributed System

7.4.4.2.1 The vendor with unit responsibility shall clearly define the final element interface and ODS/trip system shutdown circuit power requirements.

7.4.4.2.2 If redundant trip outputs to the final element are specified, careful consideration shall be given to the configuration and any online testing requirements in accordance with IEC 61508 and IEC 61511.

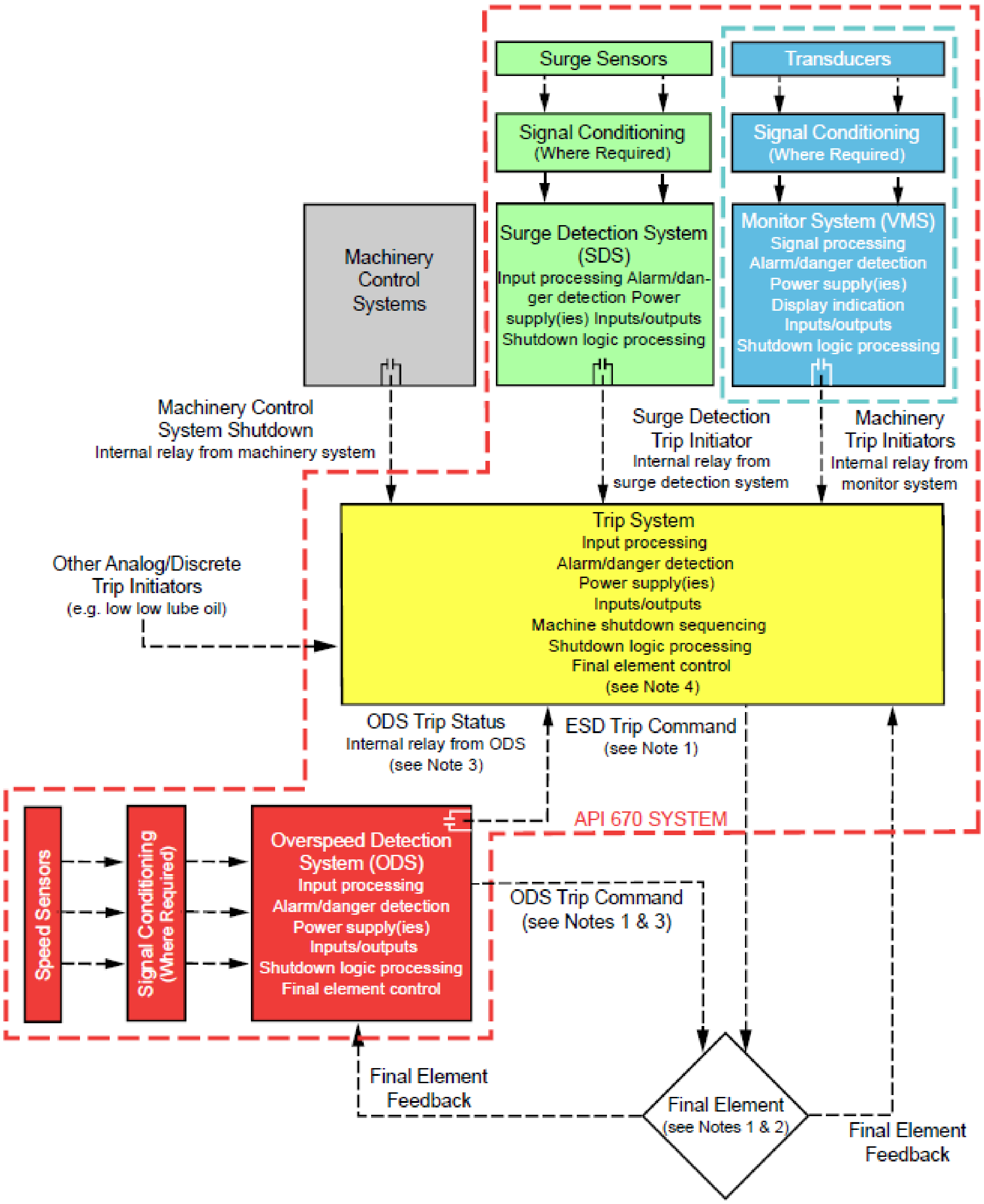
7.4.4.2.3 The trip system and the ODS shall both have direct control of the final shutdown element (see Figure 22).

7.4.4.2.4 The trip system and the ODS shall both receive final shutdown element feedback (Figure 22).

7.4.4.2.5 The trip system shall receive and process all trip initiators except overspeed.

7.4.4.2.6 The trip system shall receive the trip status signal from the overspeed system.

7.4.4.2.7 The number of inputs and outputs to/from trip system to the final element shall be based on SIL analysis in accordance with IEC 61511 and IEC 61508 guidelines.



NOTE 1 See 7.4.4.2.3
NOTE 2 See 7.4.4.2.4
NOTE 3 See 7.2.4.2
NOTE 4 See 7.4.4.2.7

Figure 22—Typical System Arrangement Using Distributed System Architecture

7.4.4.3 Integrated System

7.4.4.3.1 The vendor with unit responsibility shall define the final element interface and ODS/trip system shutdown circuit power requirements.

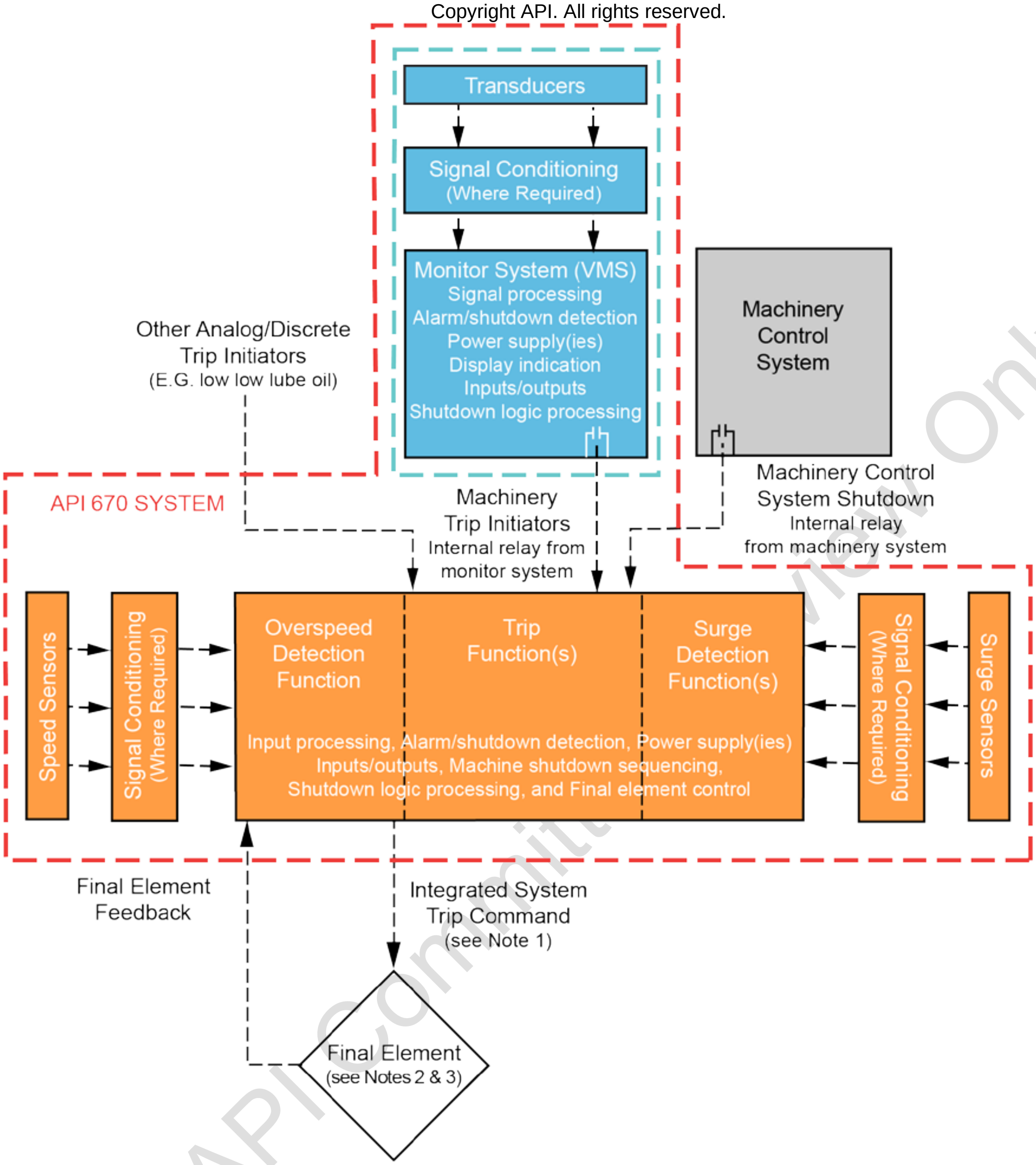
7.4.4.3.2 If redundant trip outputs to the final element are specified, careful consideration shall be given to the configuration and any online testing requirements in accordance with IEC 61508 and IEC 61511.

7.4.4.3.3 In an integrated arrangement, all trip initiators shall come into the combined ODS/trip system (see Figure 23).

7.4.4.3.4 The integrated trip system shall have direct control of the final shutdown element.

7.4.4.3.5 The combined ODS/trip system shall receive feedback directly from the final shutdown element.

7.4.4.3.6 The number of inputs and outputs to/from the trip system to the final element shall be based on SIL analysis in accordance with IEC 61511 and IEC 61508 guidelines.



NOTE 1 See 7.4.4.3.4
NOTE 2 See 7.4.4.3.5
NOTE 3 See 7.4.4.3.6

Figure 23—Typical System Arrangement Using Integrated System Architecture

7.4.5 Trip System Interface

7.4.5.1 VMS Interface Wiring

All VMS interface signals required in 6.11 and 7.1.3 shall be dry contact, direct wired to the trip system when located within the same MPS cabinet.

NOTE The intent of this requirement is to minimize the failure points that could potentially exist in multiple junction points.

7.4.5.2 VMS Trip Initiators

• If specified, connecting a series of trip relays for similar trip functions is acceptable (i.e. radial trip on compressor, radial trip on gearbox, and radial trip on driver can be connected in series for a common radial vibration trip initiator to the trip system).

7.4.5.3 Electronic ODS Interface Wiring

All ODS hardwired interface signals required in 6.11 and 7.2.4.2 shall be dry contact, direct wired to the trip system when located within the same MPS cabinet.

7.4.6 Display Indications

The trip system shall include the following display/indication functions:

a) A means of displaying all measured signals used in the trip system

• b) If specified, the corresponding alarm and trip setpoints in the trip system.

c) If the display is not integral to the hardware, then the following minimum local status indications shall be provided on the trip system hardware:

1) Power status.

2) Display digital communications link status (when using a remote display).

3) System diagnostic fault.

7.4.7 System Inputs

7.4.7.1 General System Inputs

7.4.7.1.1 The following shutdown input signals shall be included in the trip system:

a) VMS trip initiator;

b) ODS trip status, if applicable;

c) Trip initiated by machinery control;

• d) If specified, any other trip signal(s).

NOTE This is necessary to initiate the machine and process shutdown systems if the machine is manually/hydraulically shut down.

7.4.7.1.2 As a minimum, redundant trip initiators shall be provided from each of the following systems:

a) VMS,

b) machine control system.

7.4.7.1.2.1 These shutdown command signals shall be performed via mechanical or solid-state relays and shall utilize a fail-safe de-energized to shut down.

7.4.7.1.2.2 The trip logic solver shall use a one-out-of-two or two-out-of-three voting logic to determine an input shutdown command.

7.4.7.1.2.3 Mechanical relays shall be the epoxy sealed electromechanical type.

• **7.4.7.1.2.4** If specified, hermetically sealed electromechanical type relays shall be provided.

7.4.7.1.2.5 All mechanical relays shall be double-pole, double-throw type with electrically isolated contacts, and all contacts shall be available for wiring.

• **7.4.7.1.2.6** If specified, solid state relays shall be provided. The solid-state relay's leakage current shall be below that of the trip logic solver input channel's de-energized threshold level to ensure an accurate trip initiation.

7.4.7.2 Inputs from Final Trip Element and Interposing Circuits

7.4.7.2.1 The safe position indication signal from the final trip element shall be used by the logic solver to monitor the system's total shutdown circuit response time.

7.4.7.2.2 This safe position indication signal shall indicate that the machine's input energy source has been removed (e.g. valve closed, breaker open).

7.4.7.2.3 Safe position indication signals from final shutdown elements shall be performed via limit switches and shall utilize an energize-when-safe action.

7.4.7.2.4 The limit switches used shall be the epoxy sealed electromechanical type.

• **7.4.7.2.5** If specified, hermetically sealed electromechanical type limit switches shall be provided.

• **7.4.7.2.6** If specified, an analog signal indicating final shutdown element position using a linear variable differential transformer or similar shall be monitored for safe position indication.

• **7.4.7.2.7** If specified, a feedback signal indicating associated interposing relays or shutdown solenoid position shall be monitored/accepted by the trip system to indicate proper action and response time of the solenoid assembly and associated circuit.

7.4.8 System Outputs

7.4.8.1 Trip System Output to Final Trip Element

7.4.8.1.1 The trip output signal(s) shall be performed via solid state or mechanical relays with a fail-safe de-energize action to open on trip.

7.4.8.1.2 Mechanical relays shall be the epoxy sealed electromechanical type.

• **7.4.8.1.3** If specified, hermetically sealed electromechanical type relays shall be provided.

7.4.8.1.4 All mechanical relays shall be single-pole, double-throw type with electrically isolated contacts.

• **7.4.8.1.5** If specified, double-pole, double-throw type relays with electrically isolated contacts shall be provided with all contacts available for wiring.

•

7.4.8.1.6 If specified, single-pole, single-throw type relays with electrically isolated contacts shall be provided with all contacts available for wiring.

7.4.8.2 System Fault Relay

A system diagnostic fault relay shall be available for indication of trip system internal faults.

8 Inspection, Testing, and Preparation for Shipment

8.1 General

8.1.1 After advance notification of the MPS vendor(s) by the purchaser, the purchaser's representative shall have entry to all vendors' and subvendors' plant(s) where manufacturing, testing, or inspection of the equipment is in progress.

8.1.2 The MPS vendor(s) shall notify subvendor(s) of the purchaser's inspection and testing requirements.

8.1.3 The MPS vendor(s) shall provide sufficient advance notice to the purchaser before conducting any inspection that the purchaser has specified to be witnessed or observed.

• **8.1.4** The purchaser will specify the extent of participation in inspection and testing (including shop testing and inspection) and the amount of advance notification required.

8.1.5 **Eq**uipment for the specified inspection and tests shall be provided by the MPS vendor(s).

8.1.6 The purchaser's representative shall have access to the MPS vendor's quality control program for review.

8.2 Inspection

8.2.1 The MPS vendor(s) shall keep the following data available in electronic format for examination by the purchaser or his/her representative upon request:

a) purchase specifications for all major items on bills of materials,

b) test and calibration data to verify that the requirements of the specification have been met.

• **8.2.2** The purchaser shall specify the period of retention.

8.3 Testing

8.3.1 General

8.3.1.1 Equipment shall be tested in accordance with 8.3.2.

8.3.1.2 The MPS vendor shall notify the purchaser not less than ten working days before the date the equipment will be ready for testing.

8.3.2 Machinery Protection System Vendor Testing

8.3.2.1 The MPS vendor(s) shall individually bench test each component of the MPS to ensure compliance with the accuracy requirements of Table 1.

• **8.3.2.2** If specified, a factory acceptance test of the MPS shall be conducted and mutually agreed upon by the MPS vendor and the owner.

8.3.2.3 The MPS vendor shall have test documentation and certification available for inspection by the purchaser.

8.4 Preparation for Shipment

8.4.1 The MPS vendor(s) shall provide the purchaser with the necessary storage instructions.

8.4.2 The equipment shall be prepared for shipment after all testing and inspections have been completed and the equipment has been released by the purchaser.

8.4.3 The equipment shall be identified with item, revision, and serial numbers.

8.4.4 Material shipped separately shall be identified with securely affixed, corrosion-resistant metal tags indicating the item and serial number of the equipment for which it is intended. Where the equipment does not provide sufficient room for attachment of metal tags, a mutually agreed upon means for indicating item and serial number shall be used.

8.4.5 Crated equipment shall be shipped with duplicate packing lists, one on the inside and one on the outside of the shipping container.

8.4.6 One copy of the manufacturer's standard installation instructions shall be packed and shipped with the equipment.

• **8.4.7** The purchaser shall specify to the vendor any specialized requirements for packing, sealing, marking, and/or storage of the equipment.

8.5 Mechanical Running Test

Transducer systems of the same type and manufacturer as those purchased for the installation shall be in use during the factory mechanical running test of monitored equipment.

8.6 Field Testing

8.6.1 All features of the system specified in Sections 7, 8, or 9 shall be functionally tested by the construction agency (see Annex F).

8.6.1.1 Results shall be documented in accordance with 9.3.

8.6.1.2 The construction agency shall verify that the alert and trip setpoints are adjusted to the values agreed upon by the purchaser.

• **8.6.2** If specified, each transducer in the monitoring system shall be tested in the field to verify calibration in the testing temperature range (see 6.1).

8.6.2.1 These tests shall be conducted in accordance with 8.6.2 through 8.6.6 by the construction agency using the actual monitoring system components to be installed on the machine.

8.6.2.2 Results shall be documented in accordance with 9.3.

NOTE Figure 24 and Figure 25 illustrate typical overall system functions.

8.6.3 For proximity probe transducer systems, a graph of the gap (a minimum of 10 points in either micrometers or mils) versus the transducer's output voltage shall be provided by the construction agency and supplied to the owner (see Figure 26).

8.6.3.1 This procedure shall be performed in accordance with the requirements of the MPS vendor (see Annex G).

● **8.6.3.2** If specified, verification of the scale factor to the installed target surface shall be performed.

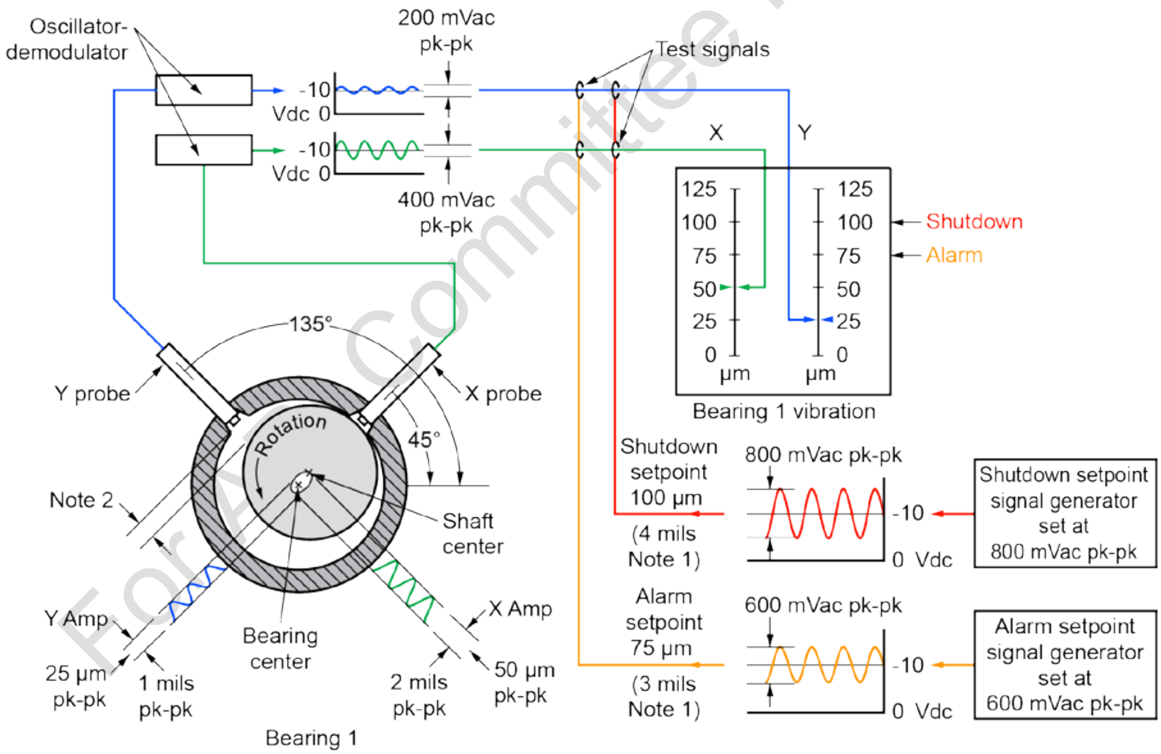
8.6.4 Temperature monitors shall be tested by substitution of the job temperature sensor with an appropriate sensor simulator. A minimum of three points (20 %, 50 %, and 80 % of span) shall be simulated and the monitor readings recorded.

● **8.6.5** If specified for casing vibration systems, a shaker simultaneously exciting the job accelerometer and a calibrated reference accelerometer shall be used for testing.

8.6.5.1 Accelerometers and piezo-velocity sensors shall be tested over the frequency and amplitude ranges listed in Table 4 and Table 5.

8.6.5.2 The VMS shall be tested to full-scale amplitude by electronic simulation.

8.6.6 Tachometer and electronic ODS shall be tested to full-scale range by electronic simulation.



NOTE 1 The example shown is for illustration only and does not necessarily represent any actual condition or machine.

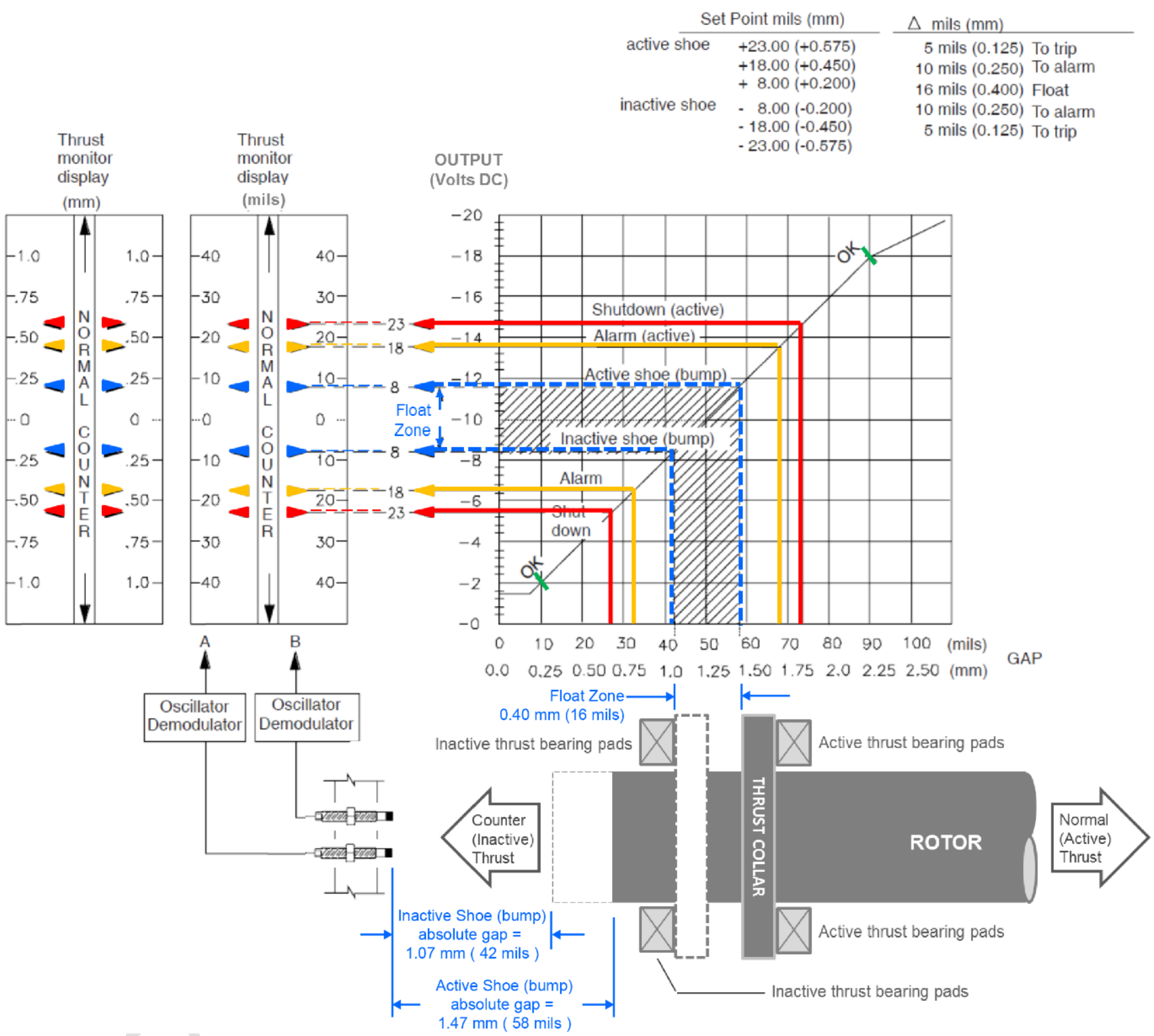
NOTE 2 Probe cold gap setting is typically 1250 µm (50 mils), which corresponds to approximately 10 Vdc.

Figure 24—Calibration of Radial Monitor and Setpoint for Alarm and Shutdown

8.6.7 The construction agency shall perform a field test of the entire MPS to verify operation to design specification requirements.

8.6.7.1 This test shall include system performance and functionality of its integration with other control, automation, and information systems.

8.6.7.2 Details of this test shall be mutually agreed upon by the construction agency and the owner. Results shall be documented in accordance with 9.3.

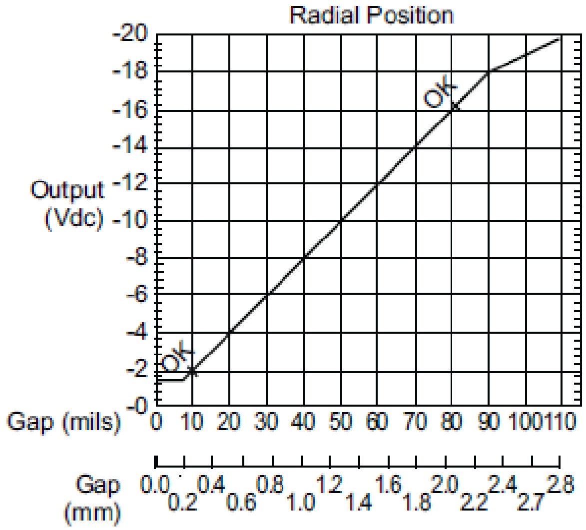


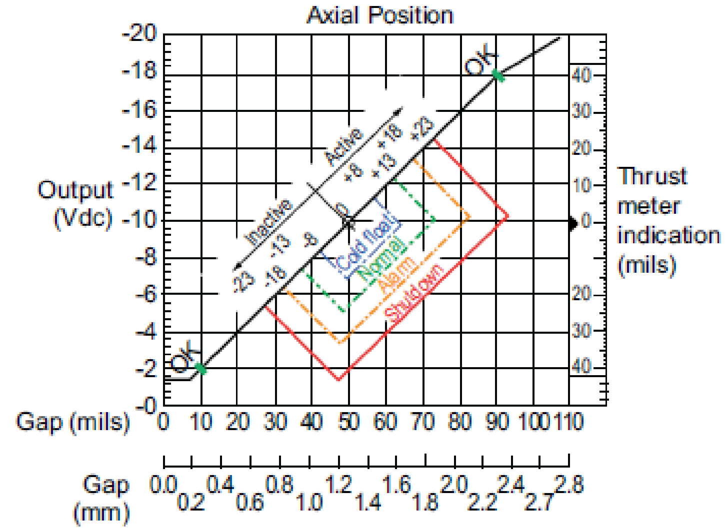
NOTE 1 The monitor system is calibrated for 7.87 mV/µm (200 mV/mil) and has a cold float zone of 0.40 mm (16 mils). The monitor's range is from +1 mm to -1 mm (+40 mils to -40 mils). The calibration procedure consists of the following steps:

(1) verifying the calibration curve
(2) bumping the shaft to the active shoe
(3) adjusting the probe for a meter indication of 0.2 mm (8 mils) (a transducer output of approximately 11.6 Vdc),
(4) bumping the float to confirm the thrust
(5) setting the alarm and shutdown points.

NOTE 2 The example shown is for illustration purposes only and does not necessarily represent any actual condition or machine.

Figure 25—Calibration of Axial Position (Thrust) Monitor





Calibration gap (mils)		Output (Vdc)	
10	____	-2.0	____
20	____	-4.0	____
30	____	-6.0	____
40	____	-8.0	____
50	____	-10.0	____
60	____	-12.0	____
70	____	-14.0	____
80	____	-16.0	____
90	____	-18.0	____

Machine tag number: ____________
Probe tag number: ____________
Probe serial number: ____________
Model: ________ Length: ________
Extension cable number: ____________
Probe resistance (ohm): ____________
Probe and cable resistance (ohm): ______
Oscillator - demodulator:
Type/serial number: ____________
Supply voltage: ____________
Cold gap set: ____________
Alarm set point: ____________
Shutdown set point: ____________
Date: ________

Output (Vdc)		Meter indication
-2.0	____	-40
-4.0	____	-30
-6.0	____	-20
-8.0	____	-10
-10.0	____	0
-12.0	____	+10
-14.0	____	+20
-16.0	____	+30
-18.0	____	+40

Machine tag number: ____________
Probe tag number: ____________
Probe serial number: ____________
Model: ________ Length: ________
Extension cable number: ____________
Probe resistance (ohm): ____________
Probe and cable resistance (ohm): ______
Oscillator - demodulator:
Type/serial number: ____________
Supply voltage: ____________
Cold gap set: ____________
Alarm set point: ____________
Shutdown set point: ____________
Date: ________

NOTE Referenced to 200 millivolts

Figure 26—Typical Field Calibration Graph for Radial and Axial Position (Gap)

Table 4—Accelerometer and Piezo-Velocity Transducer Test Points (SI)

Frequency Hz	Acceleration		Velocity	
	m/s^2 peak	m/s^2 rms	mm/s peak	mm/s rms
10 [a]	4.9	3.46	25.4	18.0
20	9.8	6.93	50.8	35.9
50	9.8	6.93	38.1	25.5
100 [a]	9.8	6.93	25.4	18.0
159.15 [b]	9.8	6.93	25.4	18.0
200	9.8	6.93	25.4	18.0
500	9.8	6.93	25.4	18.0
1,000 [a]	9.8	6.93	7.62	5.39
1,000	19.6	13.9	12.7	8.98
2,000	39.2	27.7	3.05	2.16
5,000 [a]	39.2	27.7	-	-
10,000	39.2	27.7	-	-

NOTE All values are based on sinusoidal waveforms.

[a] These values are required test points.

[b] At 159.15 Hz, 1 m/s^2 acceleration produces same signal amplitude as 1 mm/s velocity (crossover frequency).

Table 5— Seismic Transducer Test Points (USC Units)

Frequency Hz	Acceleration		Velocity	
	g peak	g rms	IPS peak	IPS rms
10 [a]	0.50	0.35	1.00	0.71
20	1.00	0.71	2.00	1.41
50	1.00	0.71	1.50	1.06
61.44 [b]	1.00	0.71	1.00	0.71
100 [a]	1.00	0.71	1.00	0.71
20	1.00	0.71	1.00	0.71
50	1.00	0.71	1.00	0.71
1000 [a]	1.00	0.71	0.30	0.21
1,000	2.00	1.41	0.50	0.35
2,000	4.00	2.83	0.12	0.09
5,000 [a]	4.00	2.83	-	-
10,000	4.00	2.83	-	-

NOTE All values are based on sinusoidal waveforms.

[a] These values are required test points.

[b] At 61.44 Hz, 1 g acceleration produces the same signal as 1 IPS velocity (crossover frequency).

9 Vendor's Data

9.1 General

9.1.1 The information required in this section shall be furnished by the machinery vendor with unit responsibility or by the responsible agency specified in Annex B.

9.1.1.1 The machinery vendor shall complete and forward the Vendor Drawing and Data Requirements Form to the address or addresses noted on the inquiry or order (see Annex G).

9.1.1.2 This form shall detail the schedule for transmission of drawings, curves, and data as agreed to at the time of the order, as well as the number and type of copies required by the purchaser.

9.1.2 The data shall be identified on transmittal (cover) letters and in title blocks or title pages with the following information:

a) the purchaser/owner's corporate name;

b) the job/project number;

c) the equipment item or tag number and service name;

d) the purchase order number;

e) any other identification specified in the inquiry or purchase order;

f) the machinery vendor's identifying proposal number, shop order number, serial number, or other reference required to identify return correspondence completely.

9.1.3 A coordination meeting covering the API 670 MPS shall be held (preferably at the entity holding unit responsibility for the entire machinery train in the case of new machines) within four to six weeks after the purchase commitment.

9.1.4 The machinery vendor having unit responsibility will prepare and distribute an agenda prior to this meeting that, as a minimum, shall include review of the following items relative to the API 670 MPS:

a) the purchase order, scope of supply, unit responsibility, and subvendor's items;

b) the datasheets;

c) applicable specifications and previously agreed-upon exceptions;

d) schedules for transmittal of data, production, and testing;

e) the quality assurance program and procedures;

f) inspection, expediting, and testing;

g) schematics and bills of material;

h) the physical orientation of the rotating equipment with relation to the API 670 system components;

i) other technical items.

9.1.5 If SIL ratings for protection loops are required, the expected SIL rating shall be stated in the RFQ to allow the vendor to quote appropriate equipment.

9.2 Proposals

9.2.1 General

9.2.1.1 The machinery vendor shall forward the original proposal and the specified number of copies to the addressee noted in the inquiry documents.

9.2.1.2 As a minimum, the proposal shall include the data identified in 9.2.2 and 9.2.3, as well as a specific statement that the system and all its components are in strict accordance with this standard. If the system and components are not in strict accordance, the machinery vendor shall include a list that details and explains each deviation.

9.2.1.3 The machinery vendor shall provide details to enable the purchaser to evaluate any proposed alternative designs. All correspondence shall be clearly identified in accordance with 9.1.2.

9.2.2 Drawings

9.2.2.1 The drawings indicated on the Vendor Drawing and Data Requirements Form shall be included in the proposal (see Annex G). As a minimum, the following data shall be furnished:

a) general arrangement or outline drawing for each monitoring system, including overall dimensions, installation details, and maintenance clearance dimensions;

b) schematics of all control and electrical systems with bills of materials shall be included.

9.2.2.2 If typical drawings, schematics, and bills of materials are used, they shall be marked up to reflect the actual equipment and scope proposed and shall have the same specific project information as noted in 9.1.4 a) to 9.1.4 i).

9.2.3 Technical Data

The following data shall be included in the proposal.

a) The purchaser's datasheets, with complete machinery vendor's information entered thereon and literature to fully describe details of the offering.

b) The Vendor Drawing and Data Requirements Form, indicating the schedule according to which the machinery vendor agrees to transmit all the data specified as part of the contract (see Annex G).

c) A schedule for shipment of the equipment, in weeks after receipt of the order.

d) A list of spare parts recommended for start-up and normal maintenance purposes.

e) A list of the special tools furnished for maintenance. The machinery vendor shall identify any metric items included in the offering.

f) A statement of any special weather protection and winterization required for start-up, operation, and periods of idleness under the site conditions specified. The statement shall show the protection to be furnished by the purchaser, as well as that included in the machinery vendor's scope of supply.

g) A description of any special requirements specified in the purchaser's inquiry.

h) A description of how the system meets specified area classification requirements, as discussed in 6.8.1.

i) Any special requirements or restrictions necessary to protect the integrity of the MPS.

j) Any component designed for finite life in 6.16.1.

k) Any scheduled maintenance practice or inspection that would not meet the prescribed uninterrupted continuous operational interval of 6.16.2.

9.3 Contract Data

9.3.1 General

9.3.1.1 The contract data specified in Annex G shall be furnished by the machinery vendor or responsible agency specified in Annex B. Each drawing, bill of material, and datasheet shall have a title block in its lower right-hand corner that shows the date of certification, a reference to all identification data specified in 9.1.2, the revision number and date, and the title.

9.3.1.2 The purchaser shall promptly review the machinery vendor's data when he/she receives them; however, this review shall not constitute permission to deviate from any requirements in the order unless specifically agreed upon in writing. After the data have been reviewed, the machinery vendor shall furnish certified copies in the quantity specified.

9.3.2 Drawings

The drawings furnished shall contain sufficient information so that with the drawings and the manuals specified in 9.3.5, the construction agency or owner can properly install, operate, and maintain the ordered equipment. Drawings shall be clearly legible, shall be identified in accordance with 9.3.1.1, and shall be in accordance with ASME Y14.2M. As a minimum, each drawing shall include the details for that drawing listed in Annex G.

9.3.3 Technical Data

The data shall be submitted in accordance with Annex G and identified in accordance with 9.3.1.1. Any comments on the drawings or revisions of specifications that necessitate a change in the data shall be noted by the machinery vendor. These notations will result in the purchaser's issue of completed, corrected datasheets as part of the order specifications.

9.3.4 Parts Lists and Recommended Spares

9.3.4.1 The machinery vendor shall submit complete parts lists for all equipment and accessories supplied and shall include the following:

a) the manufacturer's unique part numbers, materials of construction, and delivery times;

b) materials identified as specified in Section 6 through Section 10;

c) each part completely identified and shown on cross-sectional or assembly-style drawings so that the purchaser may determine the interchangeability of the part with other equipment;

d) parts that have been modified from standard dimensions or finish to satisfy specific performance requirements shall be uniquely identified by part number for interchangeability and future duplication purposes;

e) standard purchased items identified by the original manufacturer's name and part number.

9.3.4.2 The machinery vendor shall indicate on the above parts lists which parts are recommended spares for start-up and which parts are recommended for normal maintenance [see 9.2.3 d)]. The machinery vendor shall forward the lists to the purchaser promptly after receipt of the reviewed drawings and in time to permit order and start- up. The transmittal letter shall be identified with the data specified in 9.1.2.

9.3.5 Installation, Operation, Maintenance, and Technical Data Manuals

9.3.5.1 General

The machinery vendor shall provide sufficient written instructions and a list of all drawings to enable the purchaser and the owner to correctly install, operate, and maintain all of the equipment ordered. This information shall be compiled in a manual or manuals with a cover sheet that contains all reference-identifying data specified in 9.1.2, an index sheet that contains section titles, and a complete list of referenced and enclosed drawings by title and drawing number. The manual shall be prepared for the specified installation; a typical manual is not acceptable.

9.3.5.2 Installation Manual

Any special information required for proper installation design that is not on the drawings shall be compiled in a manual that is separate from the operating and maintenance instructions. This manual shall be forwarded at a time that is mutually agreed upon in the order or at the time of the final issue of prints. The manual shall contain information such as special calibration procedures and all other installation design data.

9.3.5.3 Operating and Maintenance Manual

The manual containing operating and maintenance data shall be forwarded no more than two weeks after all of the specified tests have been successfully completed. This manual shall include a section that provides special instructions for operation at specified extreme environmental conditions, such as temperatures. As a minimum, the manual shall also include all of the data listed in Annex G.

9.3.5.4 Technical Data Manual

● If specified, the vendor with unit responsibility shall provide the purchaser with a technical data manual within 30 days of completion of shop testing (see Annex G for detail requirements).

Annex A Machinery Protection System Datasheets
(informative)

Machinery Protection System Datasheets

American Petroleum Institute

API 670 MACHINERY PROTECTION SYSTEMS DATASHEET U.S. CUSTOMARY UNITS

JOB NO.		ITEM/TAG NO.	
PURCHASE ORDER NO.			
SPECIFICATION NO.			
REVISION NO.		DATE	
PAGE 1 OF		BY	

Revision

APPLICABLE TO: ○ PROPOSAL ○ PURCHASE ○ AS BUILT DATE ____ REVISION ____
FOR ____ UNIT ____
SITE ____
SERVICE ____
INSTRUMENT MANUFACTURER ____
NOTE: ○ INDICATES INFORMATION TO BE COMPLETED BY PURCHASER ☐ BY MACHINERY VENDOR
◙ BY PURCHASER OR MACHINERY VENDOR

NUMBER OF:
____ PUMPS ____ ROTARY COMPRESSOR
____ STEAM TURBINES ____ GEAR UNITS
____ GAS TURBINES ____ ELECTRIC MOTORS
____ CENTRIFUGAL COMPRESSOR ____ OTHER (DESCRIBE) ____
____ RECIPROCATING COMPRESSOR

○ ANNEX B ____
○ FINAL INSTALLATION ____
○ MACHINERY PROTECTION SYSTEM (MPS) ____
○ SIGNAL CABLES ____
○ TRANSDUCERS & SENSORS ____
○ ANNEX F REQUIREMENTS ____

○ TRANSDUCERS / SENSORS ____

○ MACHINERY PROTECTION SYSTEMS
○ VIBRATION MONITORING SYSTEM
○ SURGE DETECTION SYSTEM
○ OVERSPEED DETECTION SYSTEM
○ TRIP SYSTEM

AMBIENT TEMP. °C OR °F ____ SUMMER MAX. ____
WINTER MIN. ____
WET BULB TEMP. °C OR °F ____
○ WINTERIZATION REQUIRED
○ TROPICALIZATION REQUIRED MONITOR SYSTEMS
○ UNUSUAL CONDITIONS ○ INDOORS (7.1.10.1)
○ DUST ○ OUTDOORS (7.1.10.1)
○ FUMES
○ OTHER (DESCRIBE)

ELECTRICAL EQUIPMENT HAZARD CLASS (6.8.1)
CLASS ____ GROUP ____ DIVISION ____
TEMPERATURE RATING (T-RATING) ____
ZONE ____ GAS GROUP ____
TEMPERATURE RATING (T-RATING) ____

OPERATING TEMPERATURE RANGE (6.1)
○ STANDARD, ALL COMPONENTS FOLLOW TABLE 1
○ NONSTANDARD REQUIREMENTS
○ PROBE & EXTENSION CABLE °C OR °F FROM ____ TO ____
○ OSCILLATOR-DEMODULATOR °C OR °F FROM ____ TO ____
○ TEMP. SENSOR & LEAD °C OR °F FROM ____ TO ____
○ MONITOR AND POWER SUPPLY °C OR °F FROM ____ TO ____
○ ACCELEROMETER °C OR °F FROM ____ TO ____
○ PIEZO VELOCITY SENSORS °C OR °F FROM ____ TO ____
○ OTHER SYSTEM COMPONENTS °C OR °F FROM ____ TO ____

OPERATING ENVIRONMENT
○ STANDARD COMPONENTS (6.4.1)
○ SPECIFIED CHEMICALS (6.4.2) ____

8 MM AND 5 MM PROXIMITY PROBE DATA (6.17.1.1)
PROBE NOMINAL SIZE
○ STANDARD 8MM (NOMINAL) PROBE (6.17.1.1.1)
○ 5 MM (NOMINAL) PROBE (6.17.1.1.3 A) OR B))
BODY MOUNT CONFIGURATION
○ STANDARD REVERSE MOUNT (6.17.1.1.1)
○ FORWARD MOUNT (6.17.1.1.2 E) OR 6.17.1.1.3 E))
THREADS
○ STANDARD 3/8"-24 UNF-2A USC (6.17.1.1.2 A) (8 MM PROBES)
○ 1/4"-28 UNF-2A USC (6.17.1.1.3 A)) (5MM PROBE ONLY)
○ M10 x 1 METRIC THREADS (6.17.1.1.2 B)) (8 MM PROBES ONLY)
○ M8 x 1 METRIC THREADS (6.17.1.1.3 A))(5 MM PROBE ONLY)
OTHER OPTIONS
○ FLEXIBLE STAINLESS STEEL ARMORING (6.18.2.1.11))
○ LENGTHS OTHER THAN 25 MM (1 in) (6.17.1.1.2 C) AND 6.17.1.1.3 C))
(FORWARD MOUNT ONLY)

11 MM PROXIMITY PROBE DATA (6.17.1.2)
○ STANDARD 1/2"-20 UNF-2A USC (6.17.1.2.1) (11 MM PROBES)
○ 5/8"-18-UNF-2A USC (6.17.1.2.3 A))
○ M14 x 1.5 METRIC THREADS (6.17.1.2.3 B))
○ M16 x 1.5 METRIC THREADS (6.17.1.2.3 C))
○ LENGTHS OTHER THAN 50 MM (2 IN) (6.17.1.2.3 D))

TARGET MATERIAL
○ STANDARD 4140 MATERIAL (6.6)
○ OTHER SHAFT MATERIAL (6.6.3) ____

American Petroleum Institute

API 670 MACHINERY PROTECTION SYSTEMS DATASHEET U.S. CUSTOMARY UNITS

JOB NO.		ITEM/TAG NO.	
PURCHASE ORDER NO.			
SPECIFICATION NO.			
REVISION NO.		DATE	
PAGE 2 OF		BY	

Revision

○ STANDARD COMPLEMENT (ANNEX H)
○ NONSTANDARD COMPLEMENT REQUIRED
PRIMARY RADIAL ____
SPARE RADIAL ____
PRIMARY AXIAL ____
SPARE AXIAL ____
PHASE REFERENCE ____
SPEED INDICATING ____
OVERSPEED SENSING ____
SPARE OVERSPEED SENSING ____
PISTON ROD MONITORING ____

○ STANDARD ARRANGEMENT (6.18.1.1)
○ DEVIATION FROM STANDARD RADIAL PROBE ARRANGEMENT
REQUIRED: (DESCRIBE) ____

○ REDUNDANT PROBES SHALL BE PROVIDED (6.18.2.1.2)

○ DRIVER (6.18.1.4.1)
○ GEARBOX (6.18.1.4.1)
○ INPUT SHAFT
○ OUTPUT SHAFT
○ DRIVEN EQUIPMENT
○ SPARE TRANSDUCER WITH SAME RELATIVE PHASE (6.18.1.4.2)
○ OTHER (DESCRIBE) ____

○ STANDARD (6.18.1.6.1)
○ STANDARD PROBE W/ MULTI-TOOTH SURFACE (6.18.1.6.2 a)
○ MAGNETIC SENSOR W/ MULTI-TOOTH SURFACE (6.18.1.6.2 b)

○ STANDARD 4.5 METER LENGTH, NONARMORED (5MM AND 8MM)
○ STANDARD 4 METER LENGTH, NONARMORED (11 MM)
○ OTHER ____

PIEZO ELECTRIC ACCELEROMETER DATA (6.17.3.1)
☒ ACCELEROMETER POWER REQ. ____ 24VDC ____ (mA)
○ SPECIAL BODY MATERIAL ____
TRANSDUCER MOUNTING:
○ ANNEX C, FIGURE: C1 ____ C2 ____ C3 ____
○ OTHER ____
○ STANDARD ACCELEROMETER MOUNTING (6.17.3.1.7)
○ ACCELEROMETER WITH THE FOLLOWING OPTIONS: (6.17.3.1)
○ M8 x 1 METRIC THREADS (6.17.3.1.10)
○ INTEGRAL STUD (6.17.3.1.1.11)
○ INTEGRAL ACCELEROMETER CABLE (6.17.3.2.7)

○ EXTENSION CABLE PROTECTION (6.18.2.3)
○ STANDARD CONDUIT ____
○ OPTIONAL WEATHERPROOF FLEXIBLE ARMOR (6.18.2.3.3)
○ NUMBER OF ACCELEROMETERS PER BEARING ____
○ NUMBER OF ACCELEROMETERS PER CASING
(E.G. GEARBOX APPLICATIONS) ____
○ NUMBER OF CHANNELS IN TRAIN ____

VELOCITY SENSOR DATA (6.17.3.3)
○ STANDARD VELOCITY SENSOR (6.17.3.3.1)
○ VELOCITY SENSOR UTILIZING MOVING-COIL INSTEAD OF
INTERNALLY INTEGRATING ACCELEROMETER (6.17.3.3.2)
○ OPTIONAL INTEGRAL STUD (6.17.3.3.12)
○ M8 x 1 METRIC THREADS (6.17.3.3.9)

TEMPERATURE SENSOR DATA (6.17.4.1)
○ SENSORS NOT REQUIRED
○ STANDARD 100-ohm, PLATINUM, THREE-LEAD RESISTANCE
TEMPERATURE DETECTOR (RTD) (6.17.4.1.1 AND 6.17.4.1.2)
○ TYPE J THERMOCOUPLE (6.17.4.1.3)
○ TYPE K THERMOCOUPLE (6.17.4.1.3)
○ TYPE N THERMOCOUPLE (6.17.4.1.3)
○ OTHER (DESCRIBE) ____
○ FLEXIBLE STAINLESS STEEL OVERBRAIDING (6.17.4.1.6)

BEARING TEMPERATURE SENSORS MOUNTING (6.18.2.4)
○ EMBEDDED SENSORS
○ SPRING-LOADED SENSORS (BAYONET TYPE) (6.18.2.4.6)
○ OTHER (DESCRIBE) ____
○ ELECTRICALLY INSULATED FROM BEARING (6.18.2.4.8)
____

American Petroleum Institute

API 670 MACHINERY PROTECTION SYSTEMS DATASHEET U.S. CUSTOMARY UNITS

JOB NO.		ITEM/TAG NO.	
PURCHASE ORDER NO.			
SPECIFICATION NO.			
REVISION NO.		DATE	
PAGE 3 OF		BY	

Revision

	MACHINERY PROTECTION SYSTEM cont.		
○ SENSORS REQUIRED	○ SHUTDOWN INDICATION CONFORM TO VOTING LOGIC (6.10.6 g)		
○ SENSORS NOT REQUIRED	○ TAMPERPROOF SHUTDOWN BYPASS W/VISIBLE INDICATOR (6.10.6 h)		
☐ SLEEVE TYPE, L/D RATIO > 0.5 (6.18.1.9.1.2 a)	○ **SINGLE CIRCUIT FAILURE INCLUDING PWR SUPPLY (6.10.7)**		
☐ SLEEVE TYPE, L/D RATIO ≤ 0.5 (6.18.1.9.1.2 b)	○ SHUTDOWN DISARM - TWO ISOLATED EXTERNAL		
☐ TILT-PAD TYPE, L/D RATIO > 0.5 (6.18.1.9.1.3 a)	ANNUNCIATOR CONTACTS (6.11.13 f)		
☐ TILT-PAD TYPE, L/D RATIO ≤ 0.5 (6.18.1.9.1.3 b)	○ PERIOD OF UNINTERRUPTED OPERATION (6.16.2) ____________		
☐ LOAD-ON PAD (6.18.1.9.1.3 c)			
☐ LOAD-BETWEEN-PADS (6.18.1.9.1.3 d)	RELAYS (6.11.5)		
☐ OTHER (DESCRIBE) ________________	○ ALARM (6.11.6) (ALERT)		
________________	○ STANDARD DE-ENERGIZED TO ALARM		
	○ OPTIONAL ENERGIZED TO ALARM		
○ **STANDARD TWO SENSORS IN ACTIVE BEARING (6.18.1.9.2.1)**	○ SHUTDOWN (6.11.6) (DANGER)		
○ **STANDARD TWO SENSORS IN INACTIVE BEARING (6.18.1.9.2.3)**	○ STANDARD DE-ENERGIZED TO SHUTDOWN		
OTHER (DESCRIBE) ________________	○ OPTIONAL ENERGIZED TO SHUTDOWN		
	○ EPOXY SEALED ELECTRO-MECHANICAL TYPE RELAYS (6.11.3)		
	○ HERMETICALLY SEALED ELECTRO-MECHANICAL TYPE RELAYS (6.11.4 a)		
SAFETY INSTRUMENTED SYSTEM (SIS)	○ SOLID STATE TYPE RELAYS (6.11.4 b)		
○ DO METHODS OF FUNCTIONAL SAFETY APPLY (6.10.1)	○ RELAYS FIELD CHANGEABLE (6.11.6)		
○ MINIMUM SIL REQUIREMENT OF MPS (IF ANY) (9.1.5) ________	○ CONTACTS RATED AT A RESISTIVE LOAD OF 5 AMPERES AT		
○ SIL CALCULATION BY VENDOR/PURCHASER/THIRD PARTY	120 VOLTS AC (6.11.11)		
RESPONSIBLE PARTY________________			
○ ADDITIONAL VENDOR DOCUMENTATION (6.10.2) ________	ADDITIONAL DISPLAY AND/OR DIGITAL OUTPUTS (6.12.3)		
○ SHORTEST PROOF TEST INTERVAL OF MPS (L 5.1.3) ________		DISPLAY	OUTPUT
○ HIGHEST ACCEPTABLE MEAN TIME TO REPAIR OF	CHANNEL ALARM STATUS (6.12.3 a)	○	○
MPS (BY PURCHASER) (L 5.3.1 H))______________	ENABLED MAINTENANCE BYPASS (6.12.3 b)	○	○
○ APPLY FUNCTIONAL SAFETY FOR ASSET LOSSES (M 2.1)			
	ALARM STORAGE FOR STORING THE TIME, DATE,	○	○
POWER SUPPLY REQUIREMENTS	AND VALUE FOR A MINIMUM OF 64 ALARMS (6.12.3 c)		
STANDARD (6.9.1)	CHANNEL VALUE ± 2% FULL SCALE RANGE	○	○
○ ______________ **VAC** ______________ **Hz**	RESOLUTION (6.12.3 d)		
OPTIONAL (6.9.2)	MEASURED VALUE AS A % OF ALARM (ALERT) AND	○	○
○ ______________ VDC	SHUTDOWN (DANGER) VALUES TO 1% RESOLUTION (6.12.3 e)		
○ REDUNDANT POWER SUPPLY REQUIRED (6.9.11)	CHANNEL STATUS; ARMED/DISARMED (6.12.3 f)	○	○
	TRANSDUCER OK LIMITS (6.12.3 g)	○	○
	HARDWARE AND SOFTWARE DIAG (6.12.3 h)	○	○
○ DIGITAL COMMUNICATIONS PORT (6.10.5 d)	COMMUNICATIONS LINK STATUS (6.12.3 i)	○	○
○ STANDARD DIGITAL OUTPUT (6.12.1)	ALARM SETPOINTS (6.12.3 j)	○	○
○ DIGITAL LINK CONTENT (6.12.3)	GAP VOLTAGE WHEN APPLICABLE (6.12.3 k)	○	○
○ CHANNEL ALARM STATUS (6.12.3 a)	TIME STAMP AND DATE FOR ALL DATA (6.12.3 l)	○	○
○ BYPASS STATUS (6.12.3 b)			
○ ALARM EVENTS (MIN. 64) (6.12.3 c)	LOG OF SYSTEM ENTRY TO INCLUDE DATE, TIME,	○	○
○ CHANNEL VALUE (6.12.3 d)	INDIVIDUAL ACCESS CODE AND RECORD OF CHANGES (6.12.3 m)		
○ MEASURED VALUE, % ALARM (6.12.3 e)	SETPOINT MULTIPLIER INVOKED (6.12.3 n)	○	○
○ CHANNEL STATUS (6.12.3 f)	OTHER (DESCRIBE) ________________		
○ TRANSDUCER OK LIMITS (6.12.3 g)	________________		
○ HW AND SW DIAGNOSTICS (6.12.3 h)			
○ COMM. LINK STATUS (6.12.3 i)			
○ ALARM SETPOINTS (6.12.3 j)			
○ GAP VOLTAGE (6.12.3 k)			
○ TIMESTAMPS (6.12.3 l)			
○ SYSTEM LOG (6.12.3 m)			
○ SETPOINT MULTIPLIER (6.12.3 n)			

American Petroleum Institute

API 670 MACHINERY PROTECTION SYSTEMS DATASHEET U.S. CUSTOMARY UNITS

JOB NO. ____ ITEM/TAG NO. ____
PURCHASE ORDER NO. ____
SPECIFICATION NO. ____
REVISION NO. ____ DATE ____
 BY ____

Revision

VIBRATION, POSITION, AND TEMPERATURE MONITORING SYSTEMS (VMS)

SIGNAL PROCESSING / OUTPUTS
- ○ INDIVIDUAL BNC CONNECTORS (7.1.1.3)
- ○ CONNECTORS OTHER THAN BNC____________ (7.1.1.3 b)
- ○ 4-20 Ma DC ANALOG OUT (7.1.1.3 c)
- ○ MONITOR MORE THAN ONE MACHINE IN SAME RACK (7.1.1.4)
- ○ DISPLAY (7.1.1.7)

RADIAL SHAFT VIBRATION & AXIAL POSITION CHANNEL (7.1.4 AND 7.1.5)

READOUT RANGE

RADIAL DISPLAY (7.1.4.1)
- ○ STANDARD 0 TO 125 MICROMETERS
- ○ STANDARD 0 TO 5 MILS
- ○ OPTIONAL 0 TO 250 MICROMETERS (7.1.4.2)
- ○ OPTIONAL 0 TO 10 MILS (7.1.4.2)

AXIAL DISPLAY
- ○ –1.0 TO +1.0 MM
- ○ –40 TO +40 MILS
- ○ OTHER (DESCRIBE)
  ____
- ○ CONTROLLED ACCESS SETPOINT MULTIPLIER FUNCTION (7.1.4.8)
  - ○ STANDARD 3X (7.1.4.8a)
  - ○ STANDARD OPTION 2X (7.1.4.8a)
- ○ STANDARD DUAL VOTING LOGIC (7.1.4.5)
- ○ SINGLE VOTING LOGIC (7.1.4.6)

CASING VIBRATION CHANNEL (7.1.7)
- ○ CASING VIBRATION NOT REQUIRED
- ○ CASING VIBRATION REQUIRED
  - NUMBER OF ACCELEROMETERS MONITORED __________
  - NUMBER OF VELOCITY SENSORS MONITORED __________
- ○ CONTROLLED ACCESS SETPOINT MULTIPLIER FUNCTION (7.1.7.4)
- ○ GEARS W/O ROLLING ELEMENT BEARINGS (7.1.7.5a)
- ○ EQUIPMENT WITH ROLLING ELEMENT BEARINGS (7.1.7.5 b)
- ○ ACCELERATION MONITORED FROM 10 HZ TO 10kHZ W/ SAME TRANSDUCER (7.1.7.5 b ii)
- ○ CASING VIBRATION MONITOR SYSTEM OPTIONS (7.1.7.6)
  - ○ MONITOR AND DISPLAY OF SINGLE CHANNEL (7.1.7.6 a)
    - ○ ACCELERATION ○ VELOCITY
  - ○ MONITOR AND DISPLAY TWO CHANNELS IN EITHER (7.1.7.6 b)
    - ○ ACCELERATION ○ VELOCITY
  - ○ MONITOR AND DISPLAY ALTERNATE FILTER OR FREQ. RANGE (7.1.7.6 c)
    - SPECIFY ______________________________
  - ○ MONITOR AND DISPLAY UNFILTERED OVERALL VIBRATION (7.1.7.6 d)
  - ○ MONITOR AND DISPLAY AMPLITUDE IN TRUE RMS (7.1.7.6 e)
  - ○ MONITOR AND DISPLAY TRUE PEAK (7.1.7.6 f)
  - ○ ALTERNATE FULL SCALE RANGES (7.1.7.6 g)
    - SPECIFY ________________
  - ○ DUAL VOTING LOGIC ("2oo2") (7.1.7.6 h)
  - ○ SINGLE VOTING LOGIC ("1oo2") (7.1.7.6 i)

TEMPERATURE MONITORING (7.1.8)

READOUT RANGE (7.1.8.1)
- ○ STANDARD 0°C TO+150°C
- ○ OPTION 32°F TO +300°F
- ○ OTHER (DESCRIBE) ______________________________

SHUTDOWN SYSTEM (7.1.8.5)
- ○ STANDARD DUAL VOTING LOGIC (7.1.8.6)
  - ○ EACH RADIAL BEARING
  - ○ ACTIVE THRUST BEARINGS
  - ○ INACTIVE THRUST BEARINGS
- ○ SINGLE CHANNEL (7.1.8.6)
  - ○ EACH RADIAL BEARING
  - ○ ACTIVE THRUST BEARINGS
  - ○ INACTIVE THRUST BEARINGS

TACHOMETER (7.1.9)
- ○ TACHOMETER NOT REQUIRED
- ○ TACHOMETER REQUIRED
- ○ ABILITY TO RECORD/STORE HIGHEST SPEED (7.1.9.1)
- ○ CONTROLLED ACCESS RESET REQUIRED (7.1.9.2)

SYSTEM WIRING & CONDUIT (6.13)

VIBRATION & POSITION SIGNAL CABLE
- ○ SINGLE CIRCUIT CABLE (ANNEX D.2)
  - ○ OPTIONAL FEP FOR SEVERE ENVIRONMENTAL USE (D.2.4.2)
- ○ MULTIPLE-CIRCUIT CABLE (ANNEX D.3)
  - ○ OPTIONAL FEP FOR SEVERE ENVIRONMENTAL USE (D.2.4.2)

TEMPERATURE SIGNAL CABLE
- ○ SINGLE CIRCUIT THERMOCOUPLE (ANNEX D.4)
  - ○ OPTIONAL FEP FOR SEVERE ENVIRONMENTAL USE (D.2.4.2)

OSCILLATOR-DEMODULAR MOUNTING BOXES
- ○ ONE PER MACHINE CASE
- ○ TWO PER MACHINE CASE
- ○ OTHER (DESCRIBE) ______________________________
  ____

SYSTEM ENCLOSURES AND ENVIRONMENTAL REQUIREMENTS (6.8)

HOUSING/MOUNTING BOX
- ○ NEMA TYPE ____________

DRY AIR PURGE REQUIREMENTS (6.8.4)
- ○ NONE REQUIRED
- ○ REQUIRED PER ISA-S12.4 & NFPA 496
  - ☐ TYPE X
  - ☐ TYPE Y
  - ☐ TYPE Z
- ○ CONFORMAL COATING ON PRINTED CIRCUIT BOARDS FOR PROTECTION (6.8.6)

American Petroleum Institute

API 670 MACHINERY PROTECTION SYSTEMS DATASHEET
U.S. CUSTOMARY UNITS

JOB NO. ____ ITEM/TAG NO. ____
PURCHASE ORDER NO. ____
SPECIFICATION NO. ____
REVISION NO. ____ DATE ____
PAGE 5 OF ____ BY ____

Revision

VENDOR'S DATA (ANNEX G)

- ○ NO. OF COPIES OF REQUIRED DOCUMENT ____
- ○ REQUIRED BY (SPECIFY DATE) ____
- ○ NO. OF PRINTS AND/OR REPRODUCIBLES REQUIRED ____
- ○ REQUIRED BY (SPECIFY DATE) ____
- ○ OTHER (DESCRIBE) ____

INSPECTION AND TESTING (8.1-8.3)

- ○ TESTING REQUIREMENTS (8.1.4) ____
- ○ PERIOD OF RETENTION (8.2.2) ____
- ○ FACTORY ACCEPTANCE TEST OF MPS (8.3.2.2)

SPECIAL PACKING, SEALING, MARKING OR STORAGE REQUIREMENTS:
DESCRIBE (8.4.7): ____

FIELD TESTING (ANNEX F)

- ○ FIELD TESTING PER (ANNEX F)
- ○ FIELD VERIFICATION OF TRANSDUCER (8.6.2)
- ○ VERIFICATION PERFORMED IN THE INSTALLED TARGET SURFACE (8.6.3.2)
- ○ OPTIONAL SHAKER TABLE CALIBRATION FOR CASING VIBRATION MEASUREMENTS (8.6.5)

CONTRACT DATA (9.3)

- ○ TECHNICAL DATA MANUAL WITHIN 30 DAYS (9.3.5.4)

SURGE DETECTION SYSTEM (7.3)

COMPRESSOR TYPE

- ○ AXIAL FLOW (7.3.1.2) NUMBER OF ____
- ○ CENTRIFUGAL (7.3.1.3) NUMBER OF ____

- ○ SIL EVALUATION REQUIRED (7.3.1.5)
- ○ SURGE DETECTION INTEGRATED WITH SURGE CONTROL (7.3.3.6)
- ○ SURGE DETECTION COMBINED WITH TRIP AND ODS (7.3.3.7)

SYSTEM OUTPUTS

- ○ STANDARD OUTPUTS
- ○ OPTIONAL FURTHER ACTIONS (7.3.4.3.2)
  - ○ OPENING OF ANTI_SURGE VALVES
  - ○ SHUTDOWN OF MAIN DRIVER
  - ○ OTHER ____
- ○ OPTIONAL FURTHER RECORDING OPTIONS (7.3.4.3.5)
  - ○ RECORDING SENSOR READINGS
  - ○ RECORING OUTPUT SIGNALS
  - ○ OTHER ____

TRIP SYSTEM REQUIREMENTS (7.4)

- ○ STANDARD SYSTEM CONFORMING TO IEC61508, IEC61511 (7.4.1.2)
  - ○ OPTIONAL SYSTEM CONFORMING TO IEC 62061, ISO 21789 AND ISO 13849 (7.4.1.3)
- ○ STANDARD DISTRIBUTED TRIP SYSTEM (7.4.1.4)
  - ○ OPTIONAL OVERSPEED INTEGRATED W/TRIP SYSTEM (7.4.4.1.3 AND 7.4.1.5)
  - ○ OPTIONAL SURGE DETECTION INTEGRATED W/TRIP SYSTEM (7.4.4.1.3 AND 7.4.1.5)
- ○ ALARM ACTIVATED WHEN IN BYPASS (7.4.3.3)
- ○ OPTIONAL REMOTE ACCESS TO TRIP SYSTEM (7.4.3.10)
- ○ STANDARD INDIVIDUAL DIRECT WIRED TO TRIP SYSTEM (7.4.5.1)
  - ○ OPTIONAL CONNECTING SIMILAR RELAYS IN SERIES (7.4.5.2)
- ○ STANDARD SIGNAL DISPLAY OPTIONS (7.4.6)
  - ○ OPTIONAL SETPOINT DISPLAY OPTIONS (7.4.6 b)
- ○ STANDARD INPUT SIGNALS (7.4.7.1)
  - ○ OTHER (7.4.7.1 d) (SPECIFY) ____
- ○ STANDARD RELAY INPUTS (7.4.7.1.2.3)
- ○ OPTIONAL HERMETICALLY SEALED ELECTROMECHANICAL RELAYS (7.4.7.1.2.4)
- ○ STANDARD INPUTS FROM FINAL SHUTDOWN ELEMENT (7.4.7.2.4)
  - ○ OPTIONAL HERMETICALLY SEALED ELECTROMECHANICAL LIMIT SWITCHES (7.4.7.2.5)
  - ○ OPTIONAL ANALOG SIGNAL USING LVDT OR SIMILAR (7.4.7.2.6)
  - ○ OPTIONAL SIGNAL INDICATION INTERPOSING RELAY OR SOLENOID POSITION(7.4.7.2.7)
- ○ STANDARD OUTPUT TO FINAL SHUTDOWN ELEMENT(7.4.8.1)
  - ○ OPTIONALHEREMETICALLY SEALED ELECTROMECHANICAL TYPE RELAYS (7.4.8.1.3)
  - ○ OPTIONAL DOUBLE-POLE, DOUBLE THROW RELAYS WITH ELECTRICALLY ISOLATED CONTACTS (7.4.8.1.5)
  - ○ OPTIONAL SINGLE-POLE, SINGLE-THROW RELAYS WITH ELECTRICALLY ISOLATED CONTACTS (7.4.8.1.6)

SAFETY CRITICAL SHUTDOWN PARAMETERS (7.4.2.2)

SPECIFY ALL SAFETY CRITICAL SHUTDOWN SIGNALS TO THE TRIP SYSTEM THAT CAN AFFECT PERSONNEL SAFETY (7.4.2.2) ____

American Petroleum Institute

API 670 MACHINERY PROTECTION SYSTEMS
OVERSPEED DATASHEET
U.S. CUSTOMARY UNITS

JOB NO.	ITEM/TAG NO.
PURCHASE ORDER NO.	
SPECIFICATION NO.	
REVISION NO.	DATE
PAGE 6 OF	BY

Revision

○ ELECTRONIC OVERSPEED DETECTION SYSTEM REQUIRED (7.2)
○ OPTIONAL OVERSPEED FOR AFD MOTORS (7.2.1.10)

OVERSPEED DETECTION SYSTEM REQUIREMENTS

○ STANDARD DISTRIBUTED OVERSPEED SYSTEM (7.2.3)
○ OPTIONAL OVERSPEED INTEGRATED W/TRIP SYSTEM (7.2.3.3)
○ OPTIONAL OVERSPEED INTEGRATED W/SURGE DETECTION (7.2.3.3)
○ STANDARD 2 OUT OF 3 VOTING LOGIC (7.2.4.1.1)
○ OPTIONAL 1 OUT OF 2 VOTING LOGIC (7.2.4.1.2)
○ OPTIONAL 1 OUT OF 1 VOTING LOGIC DEGREDATION (7.2.4.1.3)
○ STANDARD IEC61508 AND IEC61511 SYSTEM (7.2.1.2)
○ OPTIONAL SYSTEM CONFORMING TO IEC62061, ISO21789, ISO13849 (7.2.1.3)
○ ODS OF MULTIPLE MACHINES IN SINGLE ODS (7.2.3.6)

○ ODS SHALL PROVIDE DIAGNOSTIC DATA (FIRST OUT, STATUS, ETC..) (7.2.4.3.8)
○ ODS SHALL PROVIDE HIGH-SPEED DATA LOGGING (7.2.4.3.9)
○ STANDARD MANUAL TESTING
○ OPTIONAL AUTOMATIC TESTING FUNCTIONALITY
○ STANDARD RESPONSE TIME (7.2.4.4.1)
○ OPTIONAL FIELD VERIFY ACTUAL RESPONSE (7.2.4.4.4)
○ STANDARD NO FIELD REPORT
○ OPTIONAL FIELD TEST REPORT (7.2.4.4.5)
○ OTHER (EXPLAIN) ______

CUSTOMER PROFILE

○ MACHINERY VENDOR
○ OWNER
○ OTHER ______

○ SYSTEM INTEGRATION PERFORMED BY ______

MACHINE DETAILS

○ DRIVER
○ STEAM TURBINE
○ GAS TURBINE
○ TURBO EXPANDER
○ AFD MOTOR
○ OTHER ______

○ MANUFACTURER ______
○ MODEL NO. ______
○ POWER ______
○ RATED SPEED ______
○ OVERSPEED TRIP SPEED ______
○ FASTEST TIME IN WHICH MACHINE SPEED CAN DOUBLE DURING START UP ______

○ DRIVEN MACHINE
○ COMPRESSOR
PUMP
GENERATOR
OTHER ______

○ MANUFACTURER ______
MODEL NO. ______
POWER ______
RATED SPEED ______

SPEED SENSORS (6.17.2)

○ STANDARD OPTION MAGNETIC (6.17.2.2)
○ OPTIONAL POLE PIECE TYPE:
○ CYLINDRICAL
○ CONICAL
○ OPTIONAL THREAD TYPE:
○ 3/4-20 UNEF-2A
○ M16 x 1.5 METRIC
○ OTHER: ______
○ OPTIONAL HOUSING TYPE:
○ EXPLOSION PROOF WITH INTEGRAL CABLE AND CONDUIT THREADS AT INTEGRAL CABLE EXIT
○ OPTIONAL NON INTEGRAL CABLE TYPE:
○ OPTIONAL ACTIVE (EXTERNALLY POWERED) TYPE (6.17.2.4):
○ PROXIMITY PROBE ______

○ MINIMUM SPEED TO BE SENSED: 250 RPM
○ OPTIONAL MINIMUM SPEED TO BE SENSED: ______ RPM

○ TIP OR POLE PIECE DIAMETER ______
○ LINEAR RANGE (PROXIMITY PROBE ONLY) ______
○ MANUFACTURER ______
○ MODEL NO. ______

SPEED SENSING SURFACE (ANNEX J)

○ LOCATION:
○ DRIVER SIDE OF COUPLING (NOTE 3)
○ OTHER ______
○ DESIGN:
○ NON-PRECISION OR GEAR (NOTES 2 AND 4) (FIGURE J.2)
○ PRECISION (FIGURE J.3)
○ EVENTS PER REVOLUTION ______
○ DIMENSIONS (FIGURE J.2 AND FIGURE J.3):
☐ TOOTH LENGTH A = ______
○ TOOTH DEPTH B = ______
○ NOTCH LENGTH C = ______
○ TOOTH WIDTH F = ______

American Petroleum Institute

API 670 MACHINERY PROTECTION SYSTEMS
ANNEX P RECIPROCATING COMPRESSOR DATASHEET
U.S. CUSTOMARY UNITS

JOB NO.	ITEM/TAG NO.
PURCHASE ORDER NO	
SPECIFICATION NO.	
REVISION NO	DATE
PAGE 7 OF	BY

Revision

		1	2	3	4	5	6	7	8
1	THROW	1	2	3	4	5	6	7	8
2	CRANK ANGLE REFERENCE PROBES (6.18.1.5)								
3	○ SPARE TRANSDUCER WITH SAME RELATIVE PHASE (6.18.1.5.3								
4	○ MULTI-EVENT REFERENCE WITH UNIQUE EVENT (6.18.1.5.4)								
5									
6	PISTON ROD MONITORING PROBES (6.18.1.3)								
7	○ VERTICAL DIRECTION (6.18.1.3.4)								
8	○ HORIZONTAL FOR DIAGNOSTICS (6.18.1.3.12, 7.1.6.4, P.4.3.5)								
9	○ PK-PK DISPLACEMENT USED FOR TRIP (P.4.3.2)								
10	○ CABLE FEED THROUGH ASSEMBLIES SHALL BE								
11	SUPPLIED (P.4.3.6)								
12	○ ACTIVATE SHUTDOWN ON INDIVIDUAL PROBE								
13	SETPOINT (7.1.6.8)								
14	FRAME VELOCITY								
15	○ VELOCITY TRANSDUCERS SHALL BE MOUNTED HORIZONTALLY								
16	AT THE CENTERLINE OF CRANKSHAFT (P.4.4.1.2)								
17	CROSSHEAD ACCEROMETER								
18	○ ACCELEROMETER MONITORED FREQUENCY RANGE SHALL								
19	BE AS AGREED (P.4.4.2.3)								
20	HIGH PASS ___ HZ LOW PASS_____ HZ								
21	○ ACCELEROMETER SENSITIVITY SHALL BE AGREED (P.4.4.2.4)								
22	_________ MV/G								
23	CYLINDER ACCELEROMETER								
24	○ CYLINDER INTEGRATED ELECTRONIC PIEZOELECTRIC								
25	ACCELEROMETERS (P.4.4.3.1)								
26	○ ACCELEROMETER MONITORED FREQUENCY RANGE SHALL								
27	BE AS AGREED (P.4.4.3.2)								
28	HIGH PASS ___ HZ LOW PASS_____ HZ								
29	○ ACCELEROMETER SENSITIVITY SHALL BE AGREED (P.4.4.3.4)								
30	_________ MV/G								
31									
32	○ CROSSHEAD LOAD DIRECTION (UP or DOWN								
33	○ ROD LOAD DIRECTION (UP or DOWN)								
34	MASS of: LBM								
35	☐ CROSSHEAD AND CROSSHEAD PIN								
36	☐ COUNTERWEIGHT ON CROSSHEAD (if present)								
37	☐ CONNECTING ROD								
38	☐ PISTON and ROD ASSEMBLY (incl. tail rod)								
39	☐ CRANKSHAFT COUNTERWEIGHT								
40	☐ INDICATOR PORTS AVAILABLE (Y / N)								
41	☐ SUCTION VALVE UNLOADER (Y / N)								
42	MATERIAL:								
43	☐ PISTON								
44	☐ PISTON ROD								
45	☐ PISTON ROD COATING								
46	☐ MAXIMUM ALLOWABLE GAS LOAD COMP. (LBF)								
47	☐ MAXIMUM ALLOWABLE GAS LOAD TENS.. (LBF)								
48	☐ MAXIMUM ALLOWABLE ROD LOAD COMP. (LBF)								
49	☐ MAXIMUM ALLOWABLE ROD LOAD TENS. (LBF)								
50	☐ MAX. ALLOWABLE WORKING PRESS. (MAWP (PSIG)								
51	☐ MAX. ALLOWABLE WORKING TEMP. (MAWT) (°F)								
52	☐ MINIMUM ROD LOAD REVERSAL DEGREES								
53	☐ PRESS. TRANS. CAL. CERT. AVAILABLE CE / HE	/	/	/	/	/	/	/	/

American Petroleum Institute

JOB NO. ITEM/TAG NO.
PURCHASE ORDER NO.
SPECIFICATION NO.
REVISION NO. DATE
PAGE 8 OF BY

Revision

API 670 MACHINERY PROTECTION SYSTEMS
ANNEX P RECIPROCATING COMPRESSOR DATASHEET
U.S. CUSTOMARY UNITS

1 APPLICABLE TO: ◯ PROPOSALS ◯ PURCHASE ◯ AS BUILT
2 FOR/USER SITE/LOCATION SERVICE NO. REQ'D
3 OTHER:
4
5
6 SITE/LOCATION SUMMARY INFORMATION — SEE API DATASHEET SET FOR COMPLETE INFORMATION
7 ◯ INFORMATION SOURCE: DATA SHEET No. REV. DATE:
8 AMBIENT: TEMPERATURE MAX: °F MIN: °F HUMIDITY MAX: MIN: PRESSURE: PSIA
9 AREA CLASSIFICATION: ◯ CLASS: GROUP: ZONE: T CODE: ◯ NON-HAZARDOUS
10 ◯ WINTERIZATION REQUIRED UNUSUAL CONDITIONS:
11 OTHER:
12 DRIVER SUMMARY INFORMATION (EACH MACHINE) — SEE API DATASHEET SET FOR COMPLETE INFORMATION
13 ◯ INFORMATION SOURCE:DRIVER DATA SHEET No. REV. DATE:
14 ◯ MANUFACTURER: MODEL NUMBER SERIAL NUMBER YEAR:
15 ◯ NAMEPLATE POWER RATING: kW DIRECTION OF ROTATION TAG NUMBER
16 ◯ SPEED (RPM): ◯IND. ◯SYNCH. ◯ OTHER ◯ FIXED ◯ VARIABLE T0
17 ◯ TYPE: ◯ INDUCTION MOTOR ◯SYNCHRONOUS MOTOR ◯ TURBINE ◯ ENGINE ◯ OTHER
18 ◯ STANDARD: ◯ API 541 ◯ API 547 ◯ API 546 ◯ API OTHER
19 ◯ FOR MOTORS: No. of IND. ROTOR SLOTS: No. of STATOR SLOTS:
20 ◯ BEARING TYPE: No. of BEARINGS: COUPLING TYPE:
21 OTHER:
22 COMPRESSOR SUMMARY INFORMATION (EACH MACHINE) — SEE API 618 DATASHEET SET FOR COMPLETE INFORMATION
23 ◯ INFORMATION SOURCE:COMPR. DATA SHEET No REV. DATE:
24 ◯ MANUFACTURER: MODEL NUMBER SERIAL NUMBER YEAR:
25 ◯ NOMINAL FRAME RATING BkW @ RATED RPM of DIRECTION OF ROTATION TAG NUMBER
26 ◯ BEARING TYPE: No. of BEARINGS:
27 ◯ COMPR.THROWS: TOTAL No No. WITH CYLS. No. PRESSURE STAGES: No. of SERVICES:
28 ◯ CAPACITY CONTROL ◯PART LOAD COND. ◯START-UP ONLY ◯BOTH ◯FIXED VOLUME POCK ◯SUCTION VALVE UNLOADERS
29 OTHER:
30 GAS ANALYSIS AT OPERATING CONDITIONS - MOLE % (BY VOLUME) ONLY
31 NOTE: IF WATER VAPOR AND/OR CHLORIDES ARE PRESENT, EVEN MINUTE TRACES, IN THE GAS BEING COMPRESSED, IT MUST BE INCLUDED

32	SERVICE OR ITEM NO.										
33	STAGE										
34		M.W.									
35	AIR	28.966									
36	OXYGEN	32.000									
37	NITROGEN	28.016									
38	WATER VAPOR	18.016									
39	CARBON MONOXIDE	28.010									
40	CARBON DIOXIDE	44.010									
41	HYDROGEN SULFIDE	34.076									
42	HYDROGEN	2.016									
43	METHANE	16.042									
44	ETHYLENE	28.052									
45	ETHANE	30.068									
46	PROPYLENE	42.078									
47	PROPANE	44.094									
48	I-BUTANE	58.120									
49	n-BUTANE	58.120									
50	I-PENTANE	72.146									
51	n-PENTANE	72.146									
52	HEXANE PLUS										
53	AMMONIA	17.031									
54	HYDROGEN CHLORIDE	36.461									
55	CHLORINE	70.914									
56	CHLORIDES - TRACES										
57											
58											
59	CALCULATED MOL WT.										
60	Cp/Cv (K) @ 65° F or ______° C or F										

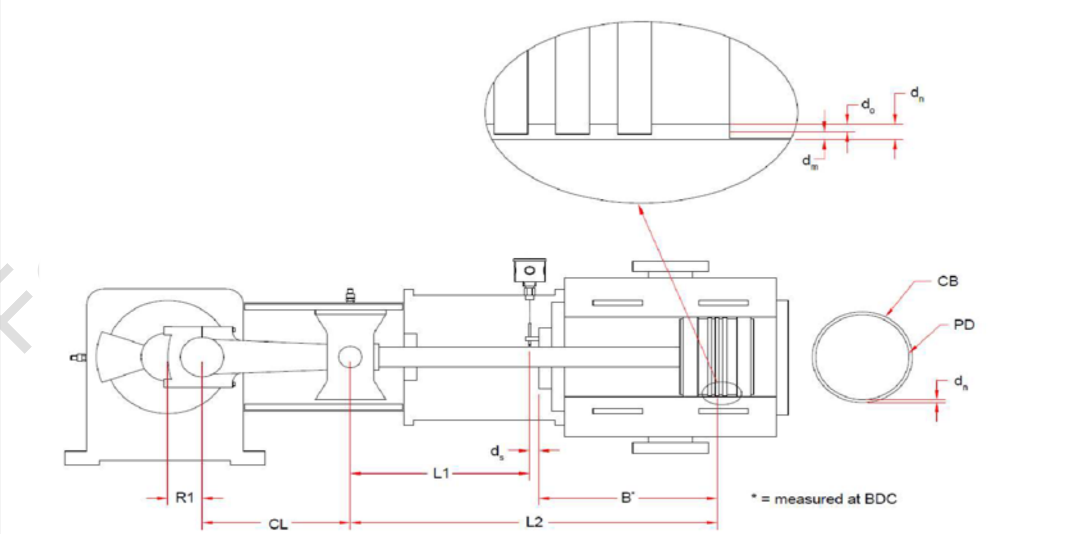
American Petroleum Institute

API 670 MACHINERY PROTECTION SYSTEMS
ANNEX P RECIPROCATING COMPRESSOR DATASHEET
U.S. CUSTOMARY UNITS

JOB NO. ____ ITEM/TAG NO. ____
PURCHASE ORDER NO. ____
SPECIFICATION NO. ____
REVISION NO. ____ DATE ____
 BY ____

Revision

		Item	Unit	1	2	3	4	5	6	7	8
1	○	THROW (REFERENCE FROM) ○ NDE ○ CPLG END		1	2	3	4	5	6	7	8
2	○	SERVICE OR ITEM NO.									
3	○	REFERENCE THROW									
4	○	CRANKSHAFT WEB ANGLE/PHASING (FROM REF. CYLINDER)									
5	○	STAGE									
6	○	SUCTION PRESSURE @ CYL FLANGE	(PSIG)								
7	○	SUCTION TEMPERATURE	(°F)								
8	○	SUCTION DESIGN FLOW	(LB/HR)								
9	○	DISCHARGE PRESSURE @ CYL FLANGE	(PSIG)								
10	○	DISCHARGE TEMPERATURE	(°F)								
11	○	DISCHARGE DESIGN FLOW	(LB/HR)								
12	○	FLOW	(LB/HR)								
13	○	No. of SUCTON VALVES - HE/CE		/	/	/	/	/	/	/	/
14	○	No. of DISCHARGE VALVES - HE/CE		/	/	/	/	/	/	/	/
15	○	CLEARANCE VOLUME - HE (%)									
16	○	CLEARANCE VOLUME - CE (%)									
17	○	POCKET CLEARANCE ADDED (%)									
18	○	SINGLE / DOUBLE ACTING (SA / DA)									
19	○	TRIGGER ANGLE									
20	○	DIMENSION:	(IN)								
21	○	CYLINDER BORE DIAMETER (CB)									
22	○	PACKING to MIDDLE OF PISTON @ BDC (B)									
23	○	PACKING to SENSORS (d_s)									
24	○	STROKE LENGTH (2 X R1)									
25	○	CONNECTING ROD LENGTH (CL)									
26	○	PROBE POSITION (L1)									
27	○	PISTON ROD LENGTH (L2)									
28	○	PISTON DIAMETER (PD)									
29	○	PISTON ROD DIAMETER (PRD)									
30	○	TAIL ROD DIAMETER (IF PRESENT)									
31	○	CROSSHEAD CLEARANCE TOP									
32	○	PISTON CLEARANCE TOP									
33	○	PISTON CLEARANCE BOTTOM NEW (d_n)									
34	○	MINIMUM PISTON BOTTOM CLEARANCE ALLOLWED (d_o)									
35	○	MAX ALLOWED RIDER BAND WEAR (d_m)									
36											



American Petroleum Institute

API 670 MACHINERY PROTECTION SYSTEMS
ANNEX P RECIPROCATING COMPRESSOR DATASHEET
U.S. CUSTOMARY UNITS

JOB NO. ITEM/TAG NO.
PURCHASE ORDER NO
SPECIFICATION NO.
REVISION NO DATE
 BY

Revision

		1	2	3	4	5	6	7	8	
1	THROW	1	2	3	4	5	6	7	8	
2	TEMPERATURES									
3	MAIN BEARINGS (P.4.5.3.1)									
4	○ SINGLE ELEMENT THERMOCOUPLE (P.4.5.1.1)									
5	○ SINGLE ELEMENT RTD (P.4.5.1.1)									
6	○ DUAL ELEMENT THERMOCOUPLES (P.4.5.1.2)									
7	○ DUAL ELEMENT RTD (P.4.5.1.2)									
8	CROSSHEAD GUIDE (P.4.5.3.2)									
9	○ SINGLE ELEMENT THERMOCOUPLE (P.4.5.1.1)									
10	○ SINGLE ELEMENT RTD (P.4.5.1.1)									
11	○ DUAL ELEMENT THERMOCOUPLES (P.4.5.1.2)									
12	○ DUAL ELEMENT RTD (P.4.5.1.2)									
13	PISTON ROD PACKING CASE VENT LINE (P.4.5.4.1)									
14	○ SINGLE ELEMENT THERMOCOUPLE (P.4.5.1.1)									
15	○ SINGLE ELEMENT RTD (P.4.5.1.1)									
16	○ DUAL ELEMENT THERMOCOUPLES (P.4.5.1.2)									
17	○ DUAL ELEMENT RTD (P.4.5.1.2)									
18	PISTON ROD PACKING CASE (P.4.5.5.1)									
19	○ SINGLE ELEMENT THERMOCOUPLE (P.4.5.1.1)									
20	○ SINGLE ELEMENT RTD (P.4.5.1.1)									
21	○ DUAL ELEMENT THERMOCOUPLES (P.4.5.1.2)									
22	○ DUAL ELEMENT RTD (P.4.5.1.2)									
23	VALVE/VALVE COVERS (P.4.5.6.1)									
24	○ SINGLE ELEMENT THERMOCOUPLE (P.4.5.1.1)									
25	○ SINGLE ELEMENT RTD (P.4.5.1.1)									
26	○ DUAL ELEMENT THERMOCOUPLES (P.4.5.1.2)									
27	○ DUAL ELEMENT RTD (P.4.5.1.2)									
28	CYLINDER COOLING JACKET (P.4.5.7.1)									
29	○ SINGLE ELEMENT THERMOCOUPLE (P.4.5.1.1)									
30	○ SINGLE ELEMENT RTD (P.4.5.1.1)									
31	○ DUAL ELEMENT THERMOCOUPLES (P.4.5.1.2)									
32	○ DUAL ELEMENT RTD (P.4.5.1.2)									
33	PROCESS GAS STREAM SUCTION (P.4.5.8.1)									
34	○ SINGLE ELEMENT THERMOCOUPLE (P.4.5.1.1)									
35	○ SINGLE ELEMENT RTD (P.4.5.1.1)									
36	○ DUAL ELEMENT THERMOCOUPLES (P.4.5.1.2)									
37	○ DUAL ELEMENT RTD (P.4.5.1.2)									
38	PROCESS GAS STREAM DISCHARGE (P.4.5.8.2)									
39	○ SINGLE ELEMENT THERMOCOUPLE (P.4.5.1.1)									
40	○ SINGLE ELEMENT RTD (P.4.5.1.1)									
41	○ DUAL ELEMENT THERMOCOUPLES (P.4.5.1.2)									
42	○ DUAL ELEMENT RTD (P.4.5.1.2)									
43										
44	RUNNING GEAR TEMPERATURES									
45	CRANK PIN JOURNAL BEARINGS (P.4.5.2)									
46	○ EUTECTIC TEMPERATURE DEVICES (P.4.5.2.1)									
47	○ WIRELESS (RADAR) TEMPERATURE SENSORS (P.4.5.2.1)									
48	CROSSHEAD PIN BUSHING (P.4.5.2)									
49	○ EUTECTIC TEMPERATURE DEVICES (P.4.5.2.1)									
50	○ WIRELESS (RADAR) TEMPERATURE SENSORS (P.4.5.2.1)									
51	CROSSHEAD SHOE(S) (P.4.5.2)									
52	○ EUTECTIC TEMPERATURE DEVICES (P.4.5.2.1)									
53	○ WIRELESS (RADAR) TEMPERATURE SENSORS (P.4.5.2.1)									
54										

Annex B Typical Responsibility Matrix Worksheet
(informative)

Typical Responsibility Matrix Worksheet [a]

JOB NO.__________________ITEM NO. ___________
PURCHASE ORDER NO._____DATE _______________
REQUISITION NO.___________DATE _______________
INQUIRY NO._______________DATE _______________
PAGE______OF _____ BY _____________________

FOR ___________________________________ REVISION _____________________________________
SITE ___________________________________ UNIT _______________________________________
SERVICE _______________________________ NO. REQUIRED _________________________________

Responsibility	Machinery Protection System Vendor	Machinery Vendor [b]	Construction Agency	Owner	Other (Specify: ___________)
Project coordination (see 9.1.3)					
System design					
Instrument purchase					
Panel design and assembly					
Grounding plan (see 6.14)					
Supply of drawing and data per Annex G					
Installation on machinery train					
Mechanical running test with contract instrumentation (see 8.5)					
Factory acceptance test (see 8.3.2.2)					
System integration verification [c]					
Field test (see 8.6)					

Discussion:

[a] The purpose of this form is to assist in project coordination. It should be completed by the purchaser by placing an “X” in the appropriate boxes to indicate responsibility for each function (see Section 4).

[b] Responsibility would normally be placed with the prime machinery vendor having unit responsibility for the entire machinery train. If responsibilities are divided among individual machinery vendors, appropriate statements should be noted above or on an attached sheet.

[c] This pertains to the digital output options (see 6.12.1 and 6.12.3) that may be integral to the machinery control system. This task is normally the responsibility of the construction agency.

NOTE Each category in the responsibility worksheet may need to be broken into subcategories to provide the level of detail needed to properly specify the installation.

Annex C Accelerometer Mounting

(normative)

Accelerometer Mounting

C.1 General

C.1.1 The accelerometer is a contact sensor (as opposed to a noncontact proximity probe) that measures the motion of the surface to which it is attached. Its many benefits include linearity over a wide frequency and dynamic range. Accelerometers have typically been used in higher frequency applications (over 1 kHz) for machinery protection and diagnostics. In order to apply the accelerometer and get reliable measurements, proper attention shall be paid to the following areas.

a) Sensor mounting configurations.

b) Frequency range of interest.

c) Amplitude range of interest.

d) Use for machine protection or for diagnostics.

e) Characteristics of the particular accelerometer under consideration.

f) Cabling and signal conditioning.

g) Environmental considerations.

C.1.2 There are many good reference sources discussing these considerations. The manufacturer of the particular accelerometer can also be consulted for answers to application questions. The primary focus of this annex is to address sensor mounting, cabling, and signal conditioning considerations for use with MPS's. Typically, accelerometers are recommended for use up to about one-third to one-half of their mounted resonant frequency. Therefore, mounting techniques can limit the useful frequency range of the accelerometer. Knowing these limitations and applying the proper technique are necessary to meet the requirements of the monitoring application. Cabling and signal conditioning can affect the accelerometer output signal and therefore are also important considerations in the overall design of the measurement system.

C.2 Accelerometer Mounts and Mounting Considerations

C.2.1 General

Since the accelerometer is a contact device, care in mounting is of particular importance because improper installation can affect the performance of the device and give unreliable and unexpected output signals.

C.2.2 Flush Mounting

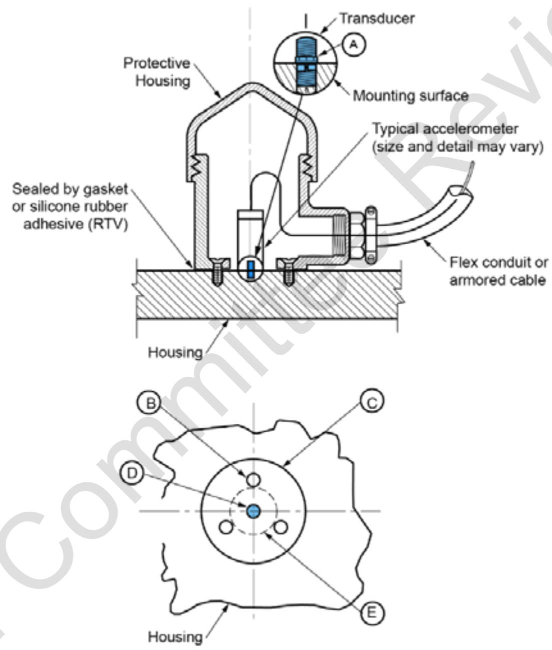
Figure C.1 shows a typical flush-mounting application allowing the accelerometer base to fully contact the mounting surface. This mounting technique is necessary for applications where frequencies above 2 kHz shall be monitored such as gear mesh frequencies on gearboxes, blade or vane passing frequencies on pumps and compressors, and rolling element bearing frequencies for predictive maintenance diagnostics. The following are offered as guidelines for proper flush mounting.

a) Requirements for the surface finish, flatness, and size of the mounting surface are as shown in Figure C.1

b) The accelerometer shall seat itself to the mounting surface over its entire base to prevent mounting-post resonance. Mounting-post resonance occurs when the accelerometer base is not flush against the mounting surface and the mounting stud becomes a structural element, lowering the mounted resonance frequency. To prevent this from occurring, the stud axis shall be perpendicular to the mounting surface and the tapped hole shall be deep enough to prevent the stud from bottoming. The mounting hole shall be perpendicular to the surface within 5° of arc or less.

c) Excessive mounting torque might distort the accelerometer case, thus affecting the accelerometer response characteristics. Too little torque will result in a loose accelerometer that can lead to large errors at higher frequencies. Manufacturer recommendations should be followed.

d) The mounting interface should be clear of any particles or debris that could prevent the accelerometer from coming down flat on the mounting surface. A thin layer of silicone grease may be applied between the accelerometer and the mounting surface to fill minute voids and improve the stiffness of the mounting.



Legend	
A	Flanged mounting stud M8x1 (¼-28 UNF)
B	M6x1(¼-20 UNC), tap 8mm (⅜ in.). deep, (full threads); three holes at 120° on a 39.7 mm [1-9/16 in.] bolt circle
C	63.5 mm (2 ½ in.) diameter spot face, surface finish (0.8 um microinches) Ra or better and surface flatness below 25 µm (0.001 in) required when accelerometer housing is used.
D	M8x1 (¼-28 UNF), tap 9mm (⅜ in). deep (full threads); one hole
E	28.6 mm (1 ⅛ in.) diameter spot face, surface finish (0.8 um or 32 microinches) Ra or better and surface flatness below 25 µm (0.001 in) required when accelerometer housing is used.
NOTE	Spot face is shown but a raised boss with proper surface is acceptable.

Figure C.1—Typical Flush-mounted Accelerometer Details

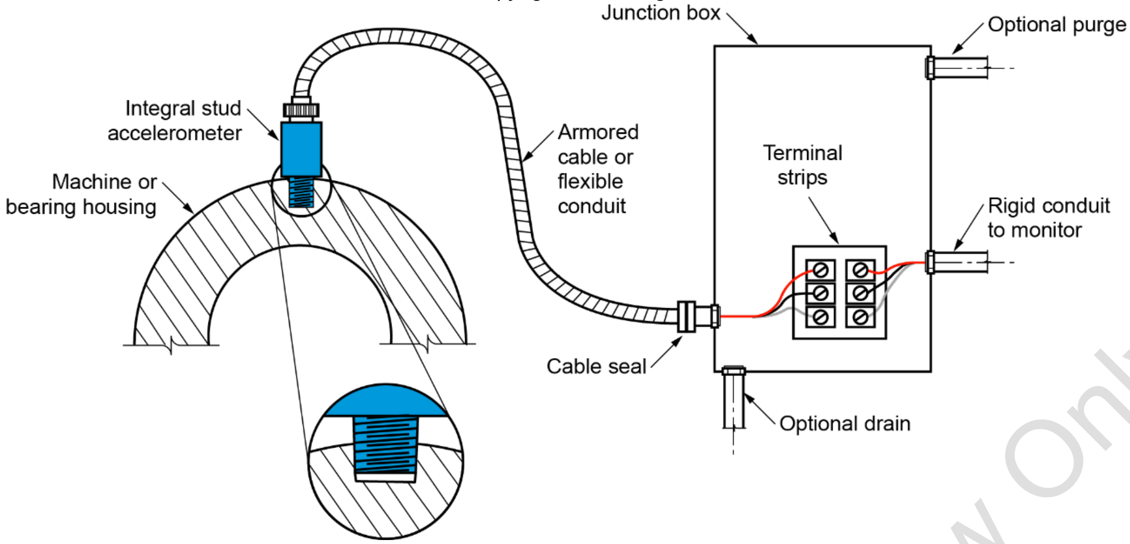


Figure C.2—Typical Nonflush-mounted Arrangement Details for Integral Stud Accelerometer

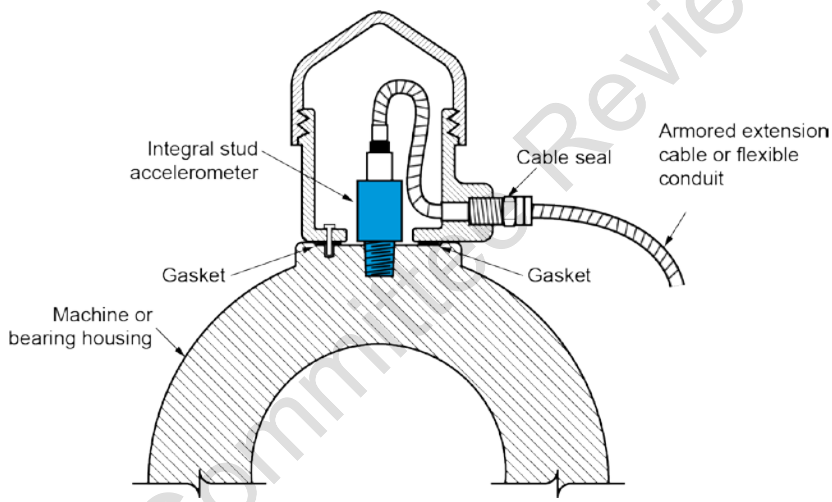


Figure C.3—Typical Nonflush-mounted Arrangement for Integral Stud Accelerometer with Protection Housing

C.2.3 Nonflush Mounting

C.2.3.1 Figure C.2 and Figure C.3 shows a nonflush-mounted accelerometer application. This mounting configuration uses tapered pipe threads. The advantage of this type of mounting configuration is that it only requires a drilled and tapped hole to be made at the measurement location for proper mounting. The accelerometer is already built onto the stud and sealed in its case. However, this type of accelerometer mount is not appropriate for applications where frequencies above 2 kHz will be monitored. This design is typically used as an optional mounting method for the standard velocity sensor of 6.17.3.3.1.

C.2.3.2 The following should be considered when using this type of accelerometer configuration for monitoring.

a) The machine point at which the accelerometer is to be mounted should be massive enough to accommodate the mass of the accelerometer without altering the response of the structure. The machines considered for permanent monitoring in this specification will typically be suitable for this method of mounting.

b) The drilled and tapped mounting hole should be perpendicular to the measurement surface within 5° of arc or less.

c) The manufacturer's torque specifications should be followed to avoid damaging the case by overtightening or affecting the frequency response through looseness. A thread-locking compound may be used.

C.2.4 Use of Adhesives and Bonding Agents

The use of bonding agents (such as bee's wax, dental cement, epoxy cement, and methyl cyanoacrylate cement) for mounting is not discussed here because these agents are not considered suitable for permanent installations.

C.2.5 Accelerometer Housings versus Unprotected Mounting

A common method of protecting the accelerometer and its connector is to mount it within a housing. Installation kits available from various sources consist of a modified electric junction box or explosion-proof housing. The housing shall be separated from the accelerometer (to prevent affecting the accelerometer's frequency response), normally by cutting a hole in the bottom of the box or housing. Installation requires care to prevent contact between the accelerometer case and its housing. The housing cover shall allow room for the proper cable bend radius, particularly important when top-mounted cable connectors are used. The box should be mounted on a relatively wide and flat surface to permit proper sealing of the base and to prevent water intrusion. See Figure C.1 for an example of an accelerometer housing.

C.3 Installation and Protection of Cables

The greatest mechanical protection of the cable can be achieved by running the cable in rigid conduit. However, maintenance requirements dictate easy removal and reinstallation of the conduit section closest to the machinery. The use of flexible conduit is not necessarily the best solution because it is not easy to remove, does not always stay in place, and often results in cable damage caused by the sharp edges of the internal reinforcing coil. Figure C.3 shows an installation example using armored cable. This type of cable is relatively flexible and can be routed next to the machinery below guards or flanges. If properly routed and securely clamped, it cannot be used as a footstep. Unlike applications using conduit, installation or removal of this type of cable does not require an electrician.

The following precautions should be evaluated.

a) If the accelerometer is left unprotected, water intrusion in the connector can be alleviated by filling the connector with a silicon grease. A commercially available silicon sealing compound or a specially designed protective boot can be used to seal the connector entry to the accelerometer.

b) The conduit or junction box shall be sealed at the cable entry point. Rubber grommets or removable, non adhesive sealants should be used.

c) The cable shall be routed to avoid excessive temperatures. Cable material limits shall be considered. As an example, PTFE-insulated cables cannot normally be used above 200 °C (400 °F).

d) Where the hazardous area classification requires it, consideration should be given to the use of barriers of the Zener type located as close as possible to the power source in a safe area. Intrinsically safe installations can be achieved by using this type of energy-limiting device. However, the MPS vendor should be consulted for overall system design considerations.

e) Avoid running the cable near sources of electromagnetic interference such as large motors or high-voltage wiring.

Annex D Signal Cable
(normative)

D.1 General

This annex provides the minimum requirements for signal cable for vibration, axial position, speed sensing, RTD's and thermocouples.

All signal cables should have mechanical support and protection such as by cable armor, conduit, or tray system. The insulation shall conform to Article 725 of NFPA 70 (*National Electrical Code*), Class 2P and withstand, with no shorts, a 1-minute test potential of 1000 Vdc plus two times the rated voltage between conductor-to-conductor and conductor-to-shield. More detailed information on signal transmission systems is available in API 552.

D.2 Shielded Single-circuit Signal Cable for Vibration, Axial Position, Speed Sensing, or RTD Transducers

D.2.1 Conductors

Shielded single-circuit cable for vibration, axial position, and speed sensing transducers shall have the following specifications:

a) Contain three twisted conductors. The conductors shall be 16 AWG to 22 AWG, or 0.336 mm^2 to 1.374 mm^2, seven-strand (minimum), Class B, concentric-lay, tinned copper wire as specified in NEMA WC 5, Part 2 (IPCEA S-61-402).

b) The lay of the conductor's twist is between be from 38 mm to 64 mm (1.5 in. to 2.5 in.).

c) The conductors shall be color-coded black, white, and red.

d) The drain wire attached to the cable shield has the same specification as the three twisted conductors.

e) Prior to installation of the cable, a green or green and yellow stripe sleeving are installed over the drain wire.

f) A heat shrink sleeve to be applied where the cable outer insulation is removed.

D.2.2 Primary Insulation

D.2.2.1 The conductors' primary insulation shall be rated for 300 V, 100 °C (200 °F) and pass the Underwriters' Laboratories VW-1 flame test**.**

D.2.2.2 The standard primary insulation shall be polyvinyl-chloride (PVC) with a thickness of 0.38 mm (15 mil).

- **D.2.2.3** If specified, fluorinated ethylene propylene (FEP) with a thickness of 0.25 mm (10 mil) will be the standard option for severe environment use.

NOTE Consideration should be given to the use of halogen-free cables in enclosed areas that are normally occupied where a fire risk could expose personnel to toxic fumes.

D.2.3 Shield

The cable shield shall be polyester/aluminum film tape with 100 % coverage and drain wire, or tinned copper wire braid with 90 % coverage. The tape shall be helically applied with a minimum of a 25 % overlap. The aluminum- coated side of the film shall be at least 0.9 µm (0.35 mil) thick and shall be in continuous contact with the drain wire, which shall be the same wire gage as the inner conductors of the cable and meet the other requirements of D.2.1. A braided shield shall have a single conductor attached to it. The single conductor shall be the same wire gage as in the inner conductors of the cable and meet the other requirements of D.2.1.

D.2.4 Overall Jacket

D.2.4.1 The cable's standard jacket shall be PVC with a nominal thickness of 0.75 mm (30 mil) and meet the other requirements of D.2.2**.**

• **D.2.4.2** If specified, FEP with a thickness of 0.25 mm (10 mil) will be the standard option for severe environment use**.**

NOTE Consideration should be given to the use of halogen free cables in enclosed areas that are normally occupied where a fire risk could expose personnel to toxic fumes.

D.3 Multiple-circuit Signal Cable (with Group Shields) for Vibration, Axial Position, Speed Sensing, or RTD Transducers

D.3.1 Conductors

Multiple-circuit cable with group shields is recommended (see Note). Multiple-circuit cable with group shields for vibration or axial position transducers shall contain three twisted conductors per group. The conductors shall be 16 AWG to 22 AWG, seven-strand, Class B, concentric-lay, tinned copper wire as specified in NEMA WC 5, Part 2 (IPCEA S-61-402). The lay of the conductors' twist shall be from 38 mm to 64 mm (1.5 in. to 2.5 in.). The conductors in each group shall be color-coded black, white, and red, and each group of three shall be identifiable by using colors or numbers.

NOTE Group shields are recommended to minimize cross talk between monitoring channels.

D.3.2 Primary Insulation

The conductors' primary insulation shall be the same as stated in D.2.2.

D.3.3 Overall Shield

The shield of each three-conductor group and the overall shield (see Note) of the multiple-circuit cable shall be polyester/aluminum-coated film or braided tinned copper. The shield specifications shall be the same as stated in D.2.3.

NOTE Overall shields are recommended to provide isolation from external noise.

D.3.4 Communications Wire

The cable shall contain a 16 AWG to 22 AWG, seven-strand, Class B, concentric-lay, copper communication wire whose insulation is 1.9 mm (75 mil) thick. The communication wire shall be coded with a color other than the group color.

D.4 Signal Cable for Thermocouples

D.4.1 Conductors

Single-circuit signal cable for thermocouples shall consist of a twisted pair of conductors. Single- or multiple-circuit cables are acceptable. The conductors shall be 16 AWG to 22 AWG solid (stranded can be used) wire, matched and calibrated as specified in ASTM E230/230M-23a. The lay of the conductors' twist shall be a maximum of 51 mm (2 in.). The conductors shall be color coded as specified in Table D.1.

D.4.2 Primary Insulation

The conductors' primary insulation shall be the same as stated in D.2.2.

D.4.3 Shield

The cable shield shall be the same as stated in D.2.3.

D.4.4 Pair Jacket

The cable's pair jacket shall have a nominal thickness of 0.9 mm (35 mil), be of the color specified in Table D.1, and meet the other requirements stated in D.2.2.

Table D.1—Color Coding for Single-circuit Thermocouple Signal Cable

Type [a]	Conductor		
	Pair Jacket	**Positive**	**Negative**
TX	Blue	Blue	Red
JX	Black	White	Red
EX	Purple	Purple	Red
KX	Yellow	Yellow	Red
SX	Green	Black	Red
BX	Gray	Gray	Red

[a] Type designations are from ASTM E230/230M-23a, Table 5.

Annex E Gearbox Casing Vibration Considerations
(normative)

E.1 General

The requirements for monitoring casing vibration on a variety of machine types are specified in 7.1.7. This annex provides additional considerations specific to gearboxes. Section 7.1.7.5 a) requires the use of a dual-path monitor for gear casing measurements. It receives its input signal from an accelerometer mounted on a gear bearing housing. This signal is divided into two separate paths in the monitor. The first path is band-pass filtered and read out directly in peak acceleration units (g's or meters per second squared). This path observes the frequencies between 1000 Hz and 10 kHz. These frequencies are associated with gear mesh and provide information on gear mesh condition. The second path is integrated to rms velocity units (inches per second or millimeters per second). This signal is band-pass filtered to observe frequencies between 10 Hz and 1000 Hz. These frequencies are associated with the vibration of the rotating elements or casing. It provides additional machine condition information to supplement a shaft vibration monitor.

E.2 Signal Detection Schemes

E.2.1 Two signal detection schemes are used simultaneously in the gearbox casing vibration monitor. They are true peak and true rms.

E.2.2 A true peak detector responds (within certain limitations of the amplifier) to excursions of the signal from zero to a maximum (or minimum). This technique is equally sensitive to both periodic and short duration (low duty cycle) vibration events in the waveform. Because gears tend to generate the short duration (spike) vibration events when malfunctioning, peak detection is the standard for monitoring gear-related activity.

E.2.3 A true rms detector responds to the total area within the vibration waveform. It is less sensitive to short duration vibration events and tends to average them out as a form of filter.

NOTE Details of the actual mathematics of rms detection are available in many texts.

E.2.4 While the standard dual-path detection scheme for gearbox casing vibration uses a combination of true peak and rms measurements, 7.1.7.6 allows the user to optionally specify both paths in either peak or rms units. Use of one technique over the other is usually determined by geographical and historical preferences.

E.2.5 Several important additional factors shall also be considered:

a) The detection circuitry in the monitor shall be consistent with the displayed units. If peak is displayed, a peak circuit detector shall be used in the monitor circuitry. Confusion occurs when an rms detector is used in the monitor and its output is scaled by 1.414 to display as peak units. This conversion is only valid for purely sinusoidal signals, which is rarely the situation except during calibration. An instrument displaying peak as 1.414 × rms may yield significantly lower values than one with a true peak detector when observing the same vibration signal. Many portable instruments use this approach, which can create confusion when comparing readings. To avoid confusion, it is recommended that peak measurements derived from rms be referred to as “derived peak” to distinguish them from “true peak” measurements.

b) Use the same units for both acceptance testing and permanent monitoring. This allows direct comparison and reduces confusion.

c) An AC voltmeter is commonly used for instrument calibration. Voltmeter calibration traceability is most common in rms terms. Calibration of a peak detecting instrument using rms × 1.414 may be utilized, but it is only valid for a pure sine wave signal.

d) Alarm limits shall reflect the units used. Use of empirically determined peak limits with an instrument using rms detection may result in machine damage. The reverse may provide unwanted alarms.

Selection of a scheme depends on experience. Companies with a database of machinery measurements and vibration limits in peak terms may not be comfortable using rms and vice versa. Each scheme can be made to work by knowledgeable people. Care and understanding shall be applied to each application to ensure that adequate machine protection is provided.

Annex F Field Testing and Documentation Requirements
(normative)

F.1 General

F.1.1 This annex outlines minimum field testing and documentation requirements for MPS components. It is intended as a convenience to the purchaser and the owner in clearly specifying the total job requirements.

F.1.2 Verification and documentation shall be submitted to the owner as follows.

a) Machinery vendors shall submit documentation at least two weeks prior to any factory mechanical testing.

b) Construction agencies shall submit documentation at least four weeks prior to machine start-up.

F.2 Tools and Instrumentation

The codes in Table F.1 are used to designate tools and instruments needed to calibrate and test various portions of the MPS.

F.3 Vendor Requirements

The purchaser shall use the form in Table F.2 to indicate the required activities and the responsible agency or vendor required to perform each specified activity.

Table F.1—Tools and Instruments Needed to Verify and Test Machinery Protection Systems

Code	Tool or Instrument	Typical Application
A	DC voltage nulling instrument	Shaft electrical and mechanical runout testing and documentation
B	Dual channel storage oscilloscope	Shaft electrical and mechanical runout testing and documentation
C	Proximity probe calibration test kit	System calibration, functional, and accuracy testing
D	Calibrated digital multimeter and frequency measuring device	System calibration, functional, and accuracy testing
E	Variable frequency waveform and pulse generator with DC offset	Simulation testing for vibration, position, tachometer, and overspeed detection channels
F	Variable amplitude and frequency shaker with calibrated reference seismic sensor providing measured amplitude from the reference sensor	Accelerometer, velocity transducer, and proximity probe system testing
G	Oscilloscope	Simulation testing for vibration, position, tachometer, and overspeed detection channels
H	Temperature sensor simulator	Simulation testing for temperature channels
J	Power supplies	System calibration, functional, and accuracy

Table F.2—Data, Drawing, and Test Worksheet

I	R	M	C	O	Activity	Tool and Instrument Codes [a] (Reference)
1					Location of rotor nodal points	[6.18.1.1.1 d) ; 6.18.1.1.1 e); Table G.2, Item 7)]
2					Electrical/mechanical runout documentation	A, B, C, D [6.18.1.1.2 d); 6.18.1.2.5; Table G.2, Item 6)
3					Calibration curve for each proximity probe transducer	C, D (8.6.3; Table G.2, Item 6)
4					Acceleration or velocity shaker test	D, E, F (8.6.5; Table G.2, Item 6)
5					System arrangement plan	(Table G.2, Item 4)
6					Monitor system calibration check	C, D, E, F, H [6.5; 8.6.2.2; Table G.2, Item 20)]
7					Recommended alarm and shutdown setpoints	(Table G.2, Item 8)
7.1					Shaft vibration	(Table G.2, Item 8)
7.2					Shaft axial position	(Table G.2, Item 8)
7.3					Radial bearing temperature	(Table G.2, Item 8)
7.4					Thrust bearing temperature	(Table G.2, Item 8)
7.5					Casing acceleration	(Table G.2, Item 8)
7.6					Casing velocity	(Table G.2, Item 8)
7.7					Piston rod monitoring	(Table G.2, Item 8)
7.8					Overspeed detection	(Table G.2, Item 8)
8					Operation for hazardous area compliance testing	(6.8.1)
9					Channel accuracy test	C, D, E, F, H (Table 1)
9.1					Radial shaft vibration	C, D, E, F (Table 1; 8.6.3)
9.2					Axial position	C, D, E (Table 1; 8.6.3)
9.3					Casing vibration	D, E, F (Table 1; 8.6.5)
9.4					Temperature	D, H (Table 1; 8.6.4)
9.5					Piston rod monitoring	C, D, E (Table 1; 8.6.3)
9.6					Overspeed detection	D, E (Table 1; 8.6.6)
10					Buffered output versus input accuracy	C, D, E, F [Table 1; 7.1.1.3 a); 8.6.2.2]
11					Power supply short-circuit test	D (6.9.4; 8.6.1)
12					Output relay tests	(8.6.1)
12.1					Circuit fault	C, D, E (7.1.1.4 a); 7.1.4.3; 7.1.5.2; 7.1.6.7; 7.1.7.3; 7.1.8.3; 7.2.4.1.6; 7.4.2.1 d); 7.4.2.5; 7.4.8.2; 8.6.1)
12.2					Shaft axial position alarm	C, D, E (6.10.6; 7.1.5.3; 8.6.1)
12.3					Shaft axial position shutdown	C, D, E (6.10.6; 7.1.5.3; 7.1.5.4; 8.6.1)
12.4					Radial shaft vibration alarm	C, D, E, F (6.10.6; 7.1.4.8; 8.6.1)
12.5					Radial shaft vibration shutdown	C, D, E, F (6.10.6; 7.1.4.5; 7.1.4.8; 8.6.1)
12.6					Casing vibration alarm	D, E, F (6.10.6; 7.1.7.4; 8.6.1)

Table F.2—Data, Drawing, and Test Worksheet (Continued)

I	R	M	C	O	Activity	Tool and Instrument Codes [a] (Reference)
12.7					Casing vibration shutdown	D, E, F (6.10.6; 7.1.7.4; 8.6.1)
12.8					Temperature alarm	D, H (6.10.6; 8.6.1)
12.9					Temperature shutdown	D, H (6.10.6; 7.1.8.5; 7.1.8.6; 8.6.1)
12.10					Piston rod monitoring alarm	C, D, E (6.10.6; 8.6.1)
12.11					Piston rod monitoring shutdown	C, D, E (6.10.6; 7.1.6.8; 8.6.1)
12.12					Overspeed detection alarm	D, E, G (0; 7.2.4.1.6; 8.6.1)
12.13					Overspeed detection shutdown	D, E, G (7.2.4.1.5; 7.2.4.1.6; 8.6.1)
13					System shutdown disarm test	C, D, E (6.11.13; 8.6.1)
14					Communication interface functional test	C, D, E, F, G, H (6.12; 6.10.8 b); 8.6.1)
14.1					Analog 4 mA to 20 mA outputs	C, D, E, F, H (7.1.1.3 c); 8.6.1)
14.2					Digital communications port	(6.12; 6.10.8 b); 8.6.1)
15					First out alarm and shutdown test	C, E, F, H (6.10.6 k); 8.6.1)
16					Circuit fault functional test	C, D, E (6.10.5 b); 6.10.5 c); 8.6.1)
17					Shutdown system functional test	E, F, H (6.10.6; 6.10.8 d); 6.10.8 e); 8.6.1)
18					Individual channel shutdown disarm test	C, D, E, F (6.10.6 f); 8.6.1)
19					Voting logic tests	(8.6.1)
19.1					Shaft axial position	D, E (7.1.5.4;7.1.5.5; 8.6.1)
19.2					Radial shaft vibration	D, E, F (7.1.4.5; 8.6.1)
19.3					Casing vibration	D, E, F (6.10.6; 8.6.1)
19.4					Temperature	D, H (7.1.8.5; 7.1.8.6; 8.6.1)
19.5					Piston rod monitoring	D, E (7.1.6.8; 8.6.1)
19.6					Overspeed detection	D, E (7.2.4.1; 7.2.4.2; 8.6.1)
20					Casing vibration filter cutoff frequency	D, E, F (7.1.7.2; 7.1.7.5; 7.1.7.6 c) 8.6.1)
21					Temperature sensor downscale failure verification test	(7.1.8.3; 8.6.1)
22					System wiring signal loss test	D, E, G (8.6.1)
23					Wiring connection verification test	(8.6.1)
24					Radio transmission RFI verification test	(6.8.5)
25					System integration test	C, D, E, F, G (8.6.7)
26					Final system arrangement plan	(9.2.2; Table G.2, Item 1)

Directions:
I—Activity item number.
R—An X in this box indicates a required activity to be performed by the machinery protection system vendor.
M—An X in this box indicates a required activity to be performed by the machinery vendor.
C—An X in this box indicates a required activity to be performed by the construction agency.
O—An X in this box indicates a required activity to be performed by other agency (specify agency).

[a] Tool and instrument codes are listed in Table F.1.

Annex G Vendor Drawing and Data Requirements
(informative)

For purposes of illustration, Table G.1 includes a typical major milestone timeline.

Table G.2 is a sample distribution record (schedule). The listed drawing and data types are required; however, the manufacturers may use different names for the same drawing. The items in the description column should be modified in the early stages of the order using the drawing names supplied by the manufacturer.

Table G.1—Typical Milestone Timeline

Milestone	Reference	Typical Schedule	Activity
T1			Initial specification and request for quotation
T2			Proposal
T3			Contract
T3.1	9.1.3	Four to six weeks after T3	Coordination meeting, covering the machinery protection system, involving vendor with unit responsibility, purchaser, and machinery protection system vendor
A	8.6, Figure 24, Figure 25, 9.2.2, 9.2.3	Six weeks after T3	Purchaser obtains and supplies to owner: setpoints, parts list and recommended spares, system arrangement plans, system schematics, and datasheets
B		Four weeks prior to T4	Construction agency obtains channel tagging requirements from owner (including content, location, material, and method of attachment) and forwards the data to the machinery protection system vendor
T4			Machinery protection system vendor shipping date
A	9.3.5.2, 9.3.5.4	Five days after T4	Machinery protection system vendor supplies standard manuals
B	Annex H	Before machining	Purchaser obtains from machinery vendor and supplies to owner the location of rotor nodal points
C	Annex F	Two weeks prior to T5	Machinery vendor supplies verification and documentation data
D	Annex F, 8.6, Figure 26, Table 4, Table 5	Before T5	Machinery vendor supplies to purchaser calibration data on each transducer
E	Applicable API standard for each machine class	Before T5	Machinery vendor supplies to purchaser runout data on each probe location on each shaft.
T5			Machine shop test date
T6			Machine shipping date
A	Annex F, Figure 26, 8.6	Four weeks prior to T7	Purchaser forwards contract data to owner
B	Annex F, 8.6, Figure 26, Table 4, Table 5	Four weeks prior to T7	Purchaser forwards calibration data on each transducer to owner
C	Applicable API standard for each machine class	Four weeks prior to T7	Purchaser forwards runout data for each transducer to owner
T7			Functional test
A	9.3.5.4	Four weeks after T7	Construction agency provides purchaser technical data manual
B	9.3.4.2	Before T8	Reviewed spare parts list is given to purchaser with time enough to purchase and receive spares for field start-up
C	Annex F	Four weeks prior to T8	Construction agency supplies verification and documentation data
T8			Field start-up

NOTE This table is typical of projects for which the machinery vendor is unit responsible and hence procures the complete machinery vibration protection system. With the widespread use of DCS's in the industry, more and more machinery protection systems are being installed in local equipment rooms and central control rooms, rather than local to the machine train. For these types of projects, the engineering contractor often assumes responsibility for all aspects of the machinery protection system supply including: procuring the protection monitor panels, coordinating the transducer supply from the machinery protection system vendor to the machinery vendor, and coordinating any required third-party system integration testing

Table G.2—Sample Distribution Record (Schedule)

CONTRACT DRAWING AND DATA REQUIREMENTS

JOB NO.____________ ITEM NO. ____________
PURCHASE ORDER NO.______ DATE ____________
REQUISITION NO.________ DATE ____________
INQUIRY NO.__________ DATE ____________
PAGE______OF _____ BY ____________

FOR ____________ REVISION ____________
SITE ____________ UNIT ____________
SERVICE ____________ NO. REQUIRED ____________

Responsible Agency [a] (Annex B)

Proposal [b] Bidder to furnish_____copies of data for all items indicated by an X.

Review [c] Vendor to furnish_____copies and_____transparencies of drawings and data indicated.

Final [c] Vendor to furnish_____copies and_____transparencies of drawings and data indicated.

Vendor to furnish_____operating and maintenance manuals.

DISTRIBUTION RECORD
to vendor
from vendor

Final—Received from vendor
Due from vendor [d]
Review—Returned
Review—Received from vendor
Review—Due from vendor [d]

				DESCRIPTION					
				1. Certified general arrangement or outline drawing and list of connections (9.2.2)					
				2. Cross-sectional drawings and bill of materials (9.2.2)					
				3. Control and electrical system schematics and bills of materials (9.2.2)					
				4. Electrical and instrumentation system arrangement plans (9.2.2)					
				5. Grounding plan (6.14)					
				6. Calibration curves (8.6.3, 8.6.5)					
				7. Rotor nodal point analysis data (6.18.1.1.1)					
				8. Recommended alarm and shutdown setpoints (8.6.1.2 and Figure 24)					
				9. Datasheets (9.2.3, 9.3.3)					
				10. Dimensions and data (9.2.2)					
				11. Installation manual (9.3.5.2)					
				12. Operating and maintenance manual (9.3.5.3)					
				13. Parts list and recommended spares (9.2.3, 9.3.4)					
				14. Engineering, fabrication, and delivery schedule (progress reports) (8.1.2, 8.1.3)					
				15. List of drawings and data (9.3)					
				16. Shipping list (9.3)					
				17. Special weather protection and winterization requirements (9.2.3)					
				18. Special system integrity protection requirements (9.2.3)					
				19. List of special tools furnished for maintenance (9.2.3)					
				20. Technical data manual (9.3.5.4)					
				21. Material safety data sheets					

[a] 1. Machinery protection system vendor; 2. Machinery vendor; 3. Construction agency; 4. Owner; 5. Other (____________).
[b] Proposal drawings and data do not have to be certified or as-built.
[c] Purchaser will indicate in this column the time frame for submission of materials using the nomenclature given at the end of this form.
[d] Bidder to complete these two columns to reflect his/her actual distribution schedule and include this form with his/her proposal.

Notes:

1. Send all drawings and data to ____

2. All drawings and data to show project, appropriation, purchase order, and item numbers in Addition to the plant location and unit. In addition to the copies specified above, one set of the Drawings/ instructions necessary for field installation to be forwarded with the shipment.

Nomenclature:

_________S—number of weeks prior to shipment.

_________F—number of weeks after firm order.

_________D—number of weeks after receipt of approved drawings.

Vendor ____

Date_________________________Vendor Reference

_____________________________ Signature _________________________________

(Signature acknowledges receipt of all instructions)

Table G.2 Description

1) Certified general arrangement outline drawing and list of connections, including the following:
   a) size, rating, and location of all customer connections;
   b) approximate overall handling weights;
   c) overall dimensions;
   d) dimensions of mounting plates and locations of bolt holes for hardware installation;
   e) maintenance and disassembly clearances;
   f) list of reference drawings.
2) Cross-sectional drawings and bill of materials, including the following:
   a) machine-mounted sensors and probe holders;
   b) vendor-supplied extension cables and connectors;
   c) monitor rack assemblies;
   d) list of reference drawings.

3) Control and electrical system schematics and wiring diagrams and bills of materials for all systems. Schematics to show all adjustment points for alarm and shutdown limits (setpoints).

4) Electrical and Instrumentation arrangement plans for all systems (see Annex H for typical arrangement plans). The following information to be provided for all system parts:

   a) description,

   b) MPS vendor part number,

   c) MPS vendor name.

5) System grounding plan.

6) Calibration curves including the following.

   a) Calibration curves for each shaft radial vibration transducer, casing vibration transducer, shaft axial position transducer, bearing temperature transducer, piston rod drop transducer and machine overspeed transducer showing sensor linearity within specified tolerances (see 8.6.3.2 and Figure 26). The MPS vendor's serial/ model number for all transducers, and the target material used for calibrating shaft radial vibration transducers and shaft axial position transducers to be included on the calibration data.

   b) Electrical and mechanical runout test data at sensor mounting locations for shaft radial vibration proximity transducers. The runout data to be phase related to the permanent or temporary once-per-revolution marker.

7) Rotor nodal analysis data showing the location of the predicted nodal points relative to the bearing centerlines and the radial shaft vibration probes.

8) Alarm and shutdown setpoints for radial shaft vibration, casing vibration, shaft axial position, bearing temperature, piston rod drop, and machine overspeed as recommended by the machinery vendor. The limits to be stated in terms of the monitor display (e.g. unfiltered mils peak-to-peak, g peak, or inches per second peak).

9) Datasheets.

10) Dimensions (including nominal dimensions with design tolerances) and data for the following parts:

    a) special transducers,

    b) special mounting fixtures.

11) Installation manual describing the following:

    a) storage procedure,

    b) mounting details,

    c) wiring connections,

    d) installation and calibration instructions,

    e) datasheets,

   f) special weather protection and winterization requirements,

   g) special system integrity protection requirements.

12) Operating and maintenance manual including the following:

   a) wiring connections,

   b) installation and calibration instructions,

   c) special weather protection and winterization requirements,

   d) board level troubleshooting instructions,

   e) basic operation details,

   f) alarm and shutdown setpoint adjustments,

   g) system bypass operation.

13) Parts list and recommended spares with stocking level recommendations.

14) Progress report and delivery schedule, including vendor buyouts and milestones.

15) List of all vendor drawings and data, including titles, drawing/document numbers, schedule for transmission, and latest revision number and dates.

16) Shipping list, including all major components that will ship separately.

17) Statement of any special weather protection and winterization required for start-up, operation, and idleness.

18) Special requirements or restrictions necessary to protect the integrity of the MPS.

19) List of special tools furnished for maintenance. Any metric items to be identified.

20) Technical data manual, including the following:

   a) storage procedures;

   b) calibration data, per Item 6) above;

   c) drawings, in accordance with 9.2.2, 9.2.3;

   d) tagging information;

   e) spare parts list, in accordance with Item 13) above;

   f) utility data (power source and purge requirements);

   g) MPS field test documentation, including: installation and calibration details, curves and data, rotor mechanical and electrical runouts, and recommended alarm and shutdown setpoints;

h) rotor nodal points, in accordance with Item 7) above;

i) as-built datasheets, per Item 9) above;

j) MPS integration test results.

21) Safety Data Sheet (OSHA Form 20), as applicable.

Annex H Typical VMS Arrangement Plans

(informative)

H.1 Purpose

This annex presents typical system arrangements for machinery with hydrodynamic bearings including a turbine (Figure H.1), a double-helical gear (Figure H.2), a centrifugal compressor or pump (Figure H.3), and an electric motor (Figure H.4). A typical arrangement for a pump with rolling element bearings is included as Figure H.5. Figure H.6 shows a typical arrangement for a horizontal reciprocating compressor.

H.2 Scope

As a minimum, the arrangement plan furnished for each machinery train (see Table G.2) shall illustrate the following items on the typical system arrangements.

a) The position of each probe in relation to the machine bearing.

NOTE The direction of shaft rotation does not affect the X and Y probe location. The X and Y probes are always located as defined in 6.18.1.1.1. For piston rod monitoring probes, see NOTE following 6.18.1.3.12 for probe nomenclature conventions.

b) The machine direction of active thrust (where applicable).

c) The machine direction of rotation. This shall be accomplished viewing all drivers from the outboard end and all driven machines from the driven end.

d) A complete description of the system, including the following items, as well as any other information applicable to the layout of the particular system:

   i) the number, type, and position of probes;

   ii) the type of bearings;

   iii) the clock position of radial probes, with degrees referenced to the vertical top dead center (TDC) as zero;

   iv) the clock position of piston rod monitoring probes for horizontal machines, with degrees referenced to top of cylinder with vertical top dead center as zero viewing from the crank shaft towards the cylinder.

   v) the clock position of phase reference probes, with degrees referenced to the vertical TDC as zero;

   vi) the clock position of the crank angle reference probes, with degrees referenced to the vertical TDC as zero

   vii) the location of axial probes;

   viii) the arrangement of the machine and junction boxes.

e) The layout of the radial shaft vibration, axial position, casing vibration, tachometer, overspeed detection, rod monitoring, and temperature monitors and all machine signal locations on the monitor.

f) The type of machine.

g) The owner's machine identification number.

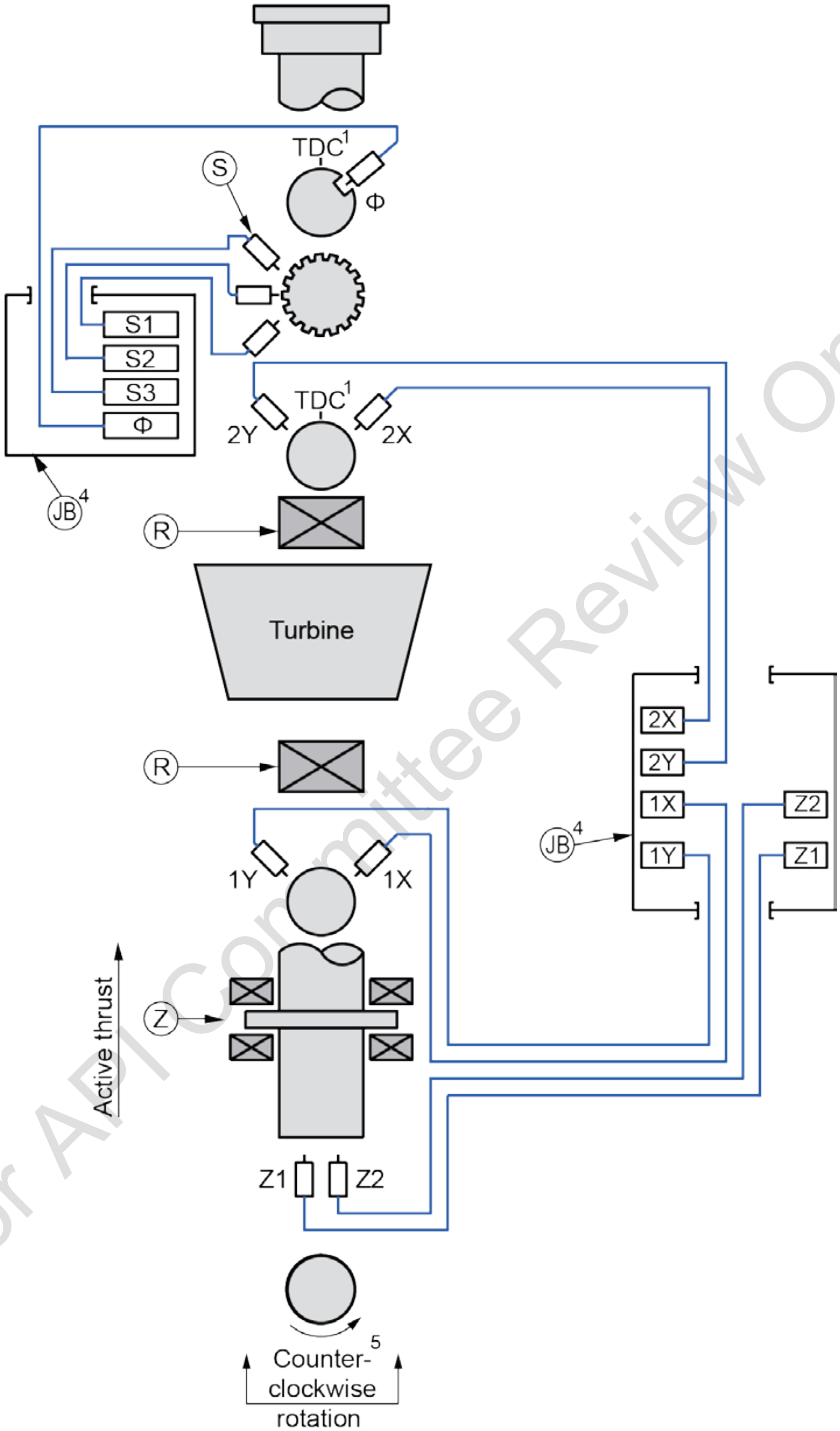


Figure H.1—Typical System Arrangement for a Turbine with Hydrodynamic Bearings

Table H.1—Probe Nomenclatures

	Overspeed detection system		
	3 Overspeed sensing channels S7 S8 S9		
Vibration, axial position, and speed monitoring[2]			
Speed and phase reference	Axial Position	Radial shaft vibration High pressure	Radial shaft vibration Low Pressure
Φ	Z1 Z2	1Y 1X	2Y 2X

Table H.2—Key and Notes for Figure H.1

KEY

Z1	Axial position probe (instrument manufacturer ID data[3])
Z2	Axial position probe (instrument manufacturer ID data[3])
2Y	Low pressure end radial vibration probe, 45° left of TDC[1] (instrument manufacturer ID data[3])
2X	Low pressure end radial vibration probe, 45° right of TDC[1] (instrument manufacturer ID data[3])
1Y	High pressure end radial vibration probe, 45° left of TDC[1] (instrument manufacturer ID data[3])
1X	High pressure end radial vibration probe, 45° right of TDC[1] (instrument manufacturer ID data[3])
Φ	Phase reference transducer, shown 45° right [location to be agreed] of TDC[1] (instrument manufacturer ID data[3])
R	Radial bearing (description)
Z	Thrust bearing (description)
JB	Junction Box
S1-S3	Overspeed Sensors

NOTE 1 TDC indicates top dead center (6.18.1.4.2).
NOTE 2 Typical temperature sensors and monitors are shown in Figure H.3.
NOTE 3 Instrument manufacturer ID data includes vendor's model and part numbers.
NOTE 4 Labels inside the junction box represent the signal conditioning interface modules to which the sensors interface.
NOTE 5 Rotation direction is to be viewed driver to driven

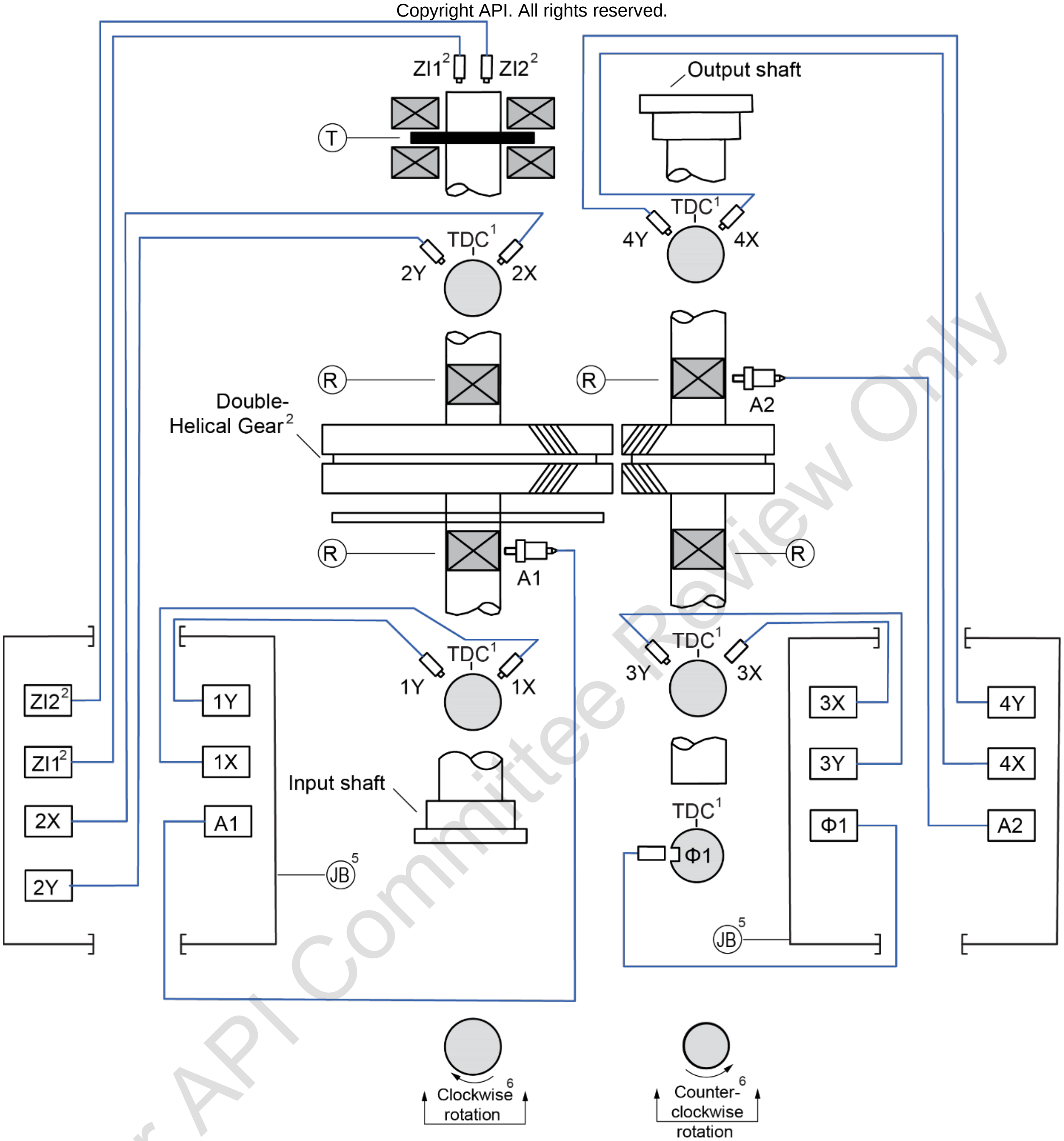


Figure H.2—Typical System Arrangement for Double-helical Gear[2]

Table H.3—Probe Nomenclatures

Vibration and axial position[3]							
Input shaft coupling end vibration	Input shaft non-coupling end vibration	Input shaft axial position	Output shaft non-coupling end vibration	Output shaft coupling end vibration	Output shaft axial position	Output shaft phase reference and speed	Case mounted accelerometers
1Y 1X	2Y 2X	ZI1 ZI2	3Y 3X	4Y 4X	ZO1 ZO2	Φ	A1 A2

Table H.4—Key and Notes for Figure H.2

KEY	
A1	Input shaft coupling end horizontal radial accelerometer 90° off TDC[1] (instrument manufacturer ID data[4])
A2	Output shaft coupling end horizontal radial accelerometer 90° off TDC[1] (instrument manufacturer ID data[4])
ZI1	Input shaft thrust bearing axial position probe #1 (instrument manufacturer ID data[4])
ZI2	Input shaft thrust bearing axial position probe #2 (instrument manufacturer ID data[4])
2Y	Input shaft blind end (non-coupling end) radial vibration probe, 45° left of TDC[1] (instrument manufacturer ID data[3])
2X	Input shaft blind end (non-coupling end) radial vibration probe, 45° right of TDC[1] (instrument manufacturer ID data[3])
1Y	Input shaft coupling end radial vibration probe, 45° left of TDC[1] (instrument manufacturer ID data[3])
1X	Input shaft coupling end radial vibration probe, 45° right of TDC[1] (instrument manufacturer ID data[3])
4Y	Output shaft coupling end radial vibration probe, 45° left of TDC[1] (instrument manufacturer ID data[3])
4X	Output shaft coupling end radial vibration probe, 45° right of TDC[1] (instrument manufacturer ID data[3])
3Y	Output shaft blind end (non-coupling end) coupling end radial vibration probe, 45° left of TDC[1] (instrument manufacturer ID data[3])
3X	Output shaft blind end (non-coupling end) radial vibration probe, 45° right of TDC[1] (instrument manufacturer ID data[3])
Φ1	Output shaft phase reference transducer, 45° right of TDC[1] (instrument manufacturer ID data[3])
ZO1	Output shaft thrust bearing axial position probe #1 (instrument manufacturer ID data[4])
ZO2	Output shaft thrust bearing axial position probe #2 (instrument manufacturer ID data[4])
R	Radial bearing (description)
ZI	Thrust bearing input shaft(description)
ZO	Thrust bearing output shaft (When present)
JB	Junction Box

NOTE 1 TDC indicates top dead center of shaft (6.18.1.4.2).
NOTE 2 For a single-helical gear a pair of axial probes should be installed at each thrust bearing.
NOTE 3 Typical temperature sensors for radial bearing and thrust bearings and monitors are shown in Figure H.3.
NOTE 4 Instrument manufacturer ID data includes vendor's model and part numbers.
NOTE 5 Labels inside the junction box represent the signal conditioning interface modules to which the sensors should interface.
NOTE 6 Rotation direction is to be viewed driver to driven

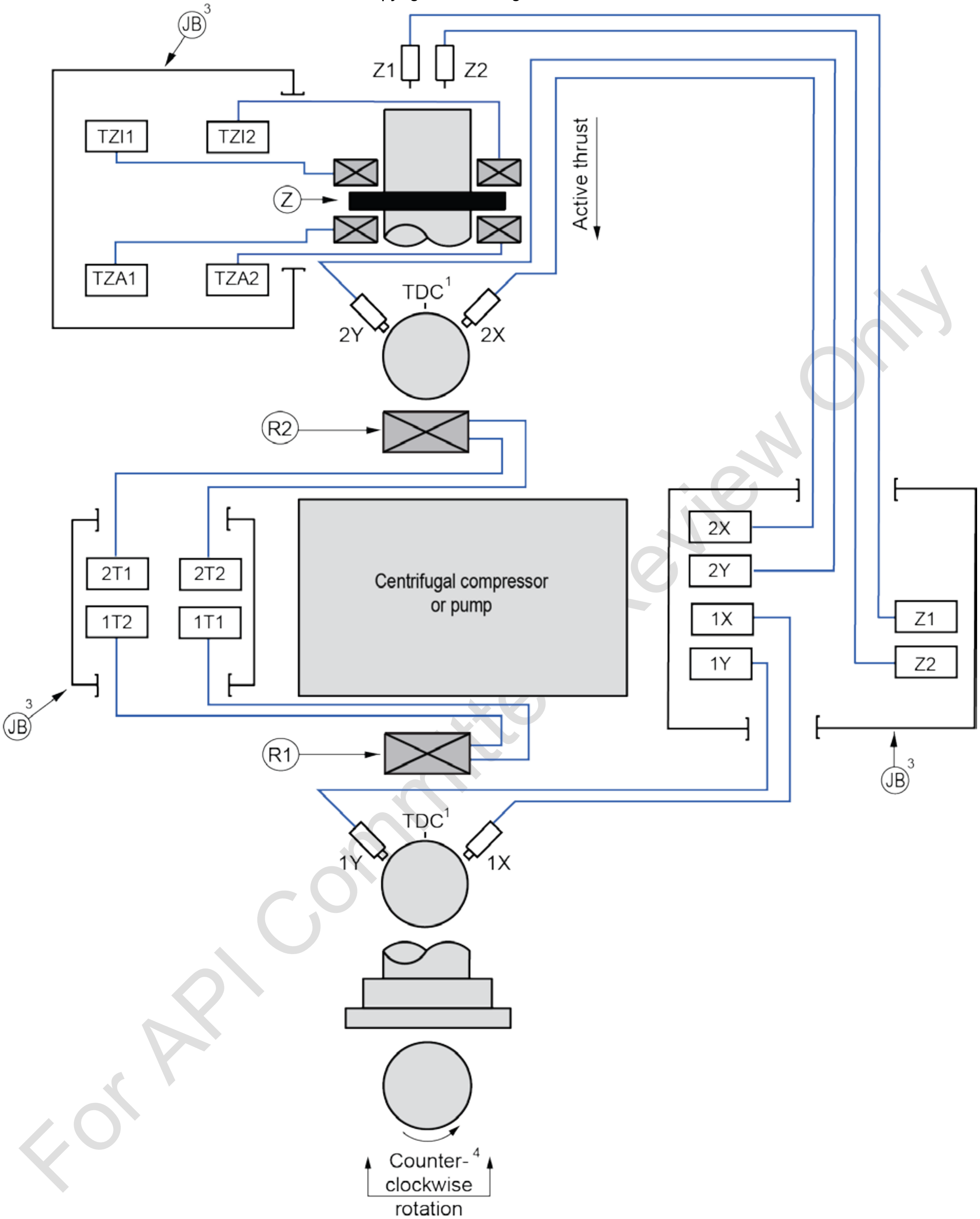


Figure H.3—Typical System Arrangement for a Centrifugal Compressor or a Pump with Hydrodynamic Bearings

Table H.5—Probe Nomenclatures

Vibration, axial position, and temperature monitoring				
Axial position	Radial shaft vibration (inboard or 1st coupling end)	Radial shaft vibration (outboard or 2nd coupling end)	Bearing temperature	Thrust temperature
Z1 Z2	1Y 1X	2Y 2X	1T1, 1T2, 2T1, 2T2	TZA11, TZA2, TZI1, TZI2

Table H.6—Key and Notes for Figure H.3

KEY	
2Y	Outboard end radial vibration probe, 45° left of TDC[1] (instrument manufacturer ID data[3])
2X	Outboard end radial vibration probe, 45° right of TDC[1] (instrument manufacturer ID data[3])
1Y	Inboard end radial vibration probe, 45° left of TDC[1] (instrument manufacturer ID data[3])
1X	Inboard end radial vibration probe, 45° right of TDC[1] (instrument manufacturer ID data[3])
Z1	Axial position probe (instrument manufacturer ID data[2])
Z2	Axial position probe (instrument manufacturer ID data[2])
R	Radial bearing (description)
Z	Thrust bearing (description)
JB	Junction Box
1T1, 1T2	Inboard end bearing temperature
2T1, 2T2	Outboard end bearing temperature
TZA1, TZA2	Active thrust pad temperatures
TZI1, TZI2	Inactive thrust pad temperatures

NOTE 1 TDC indicates top dead center (6.18.1.4.2).
NOTE 2 Instrument manufacturer ID data includes vendor's model and part numbers.
NOTE 3 Labels inside the junction box represent the signal conditioning interface module to which the sensors should interface.
NOTE 4 Rotation direction is to be viewed driver to driven

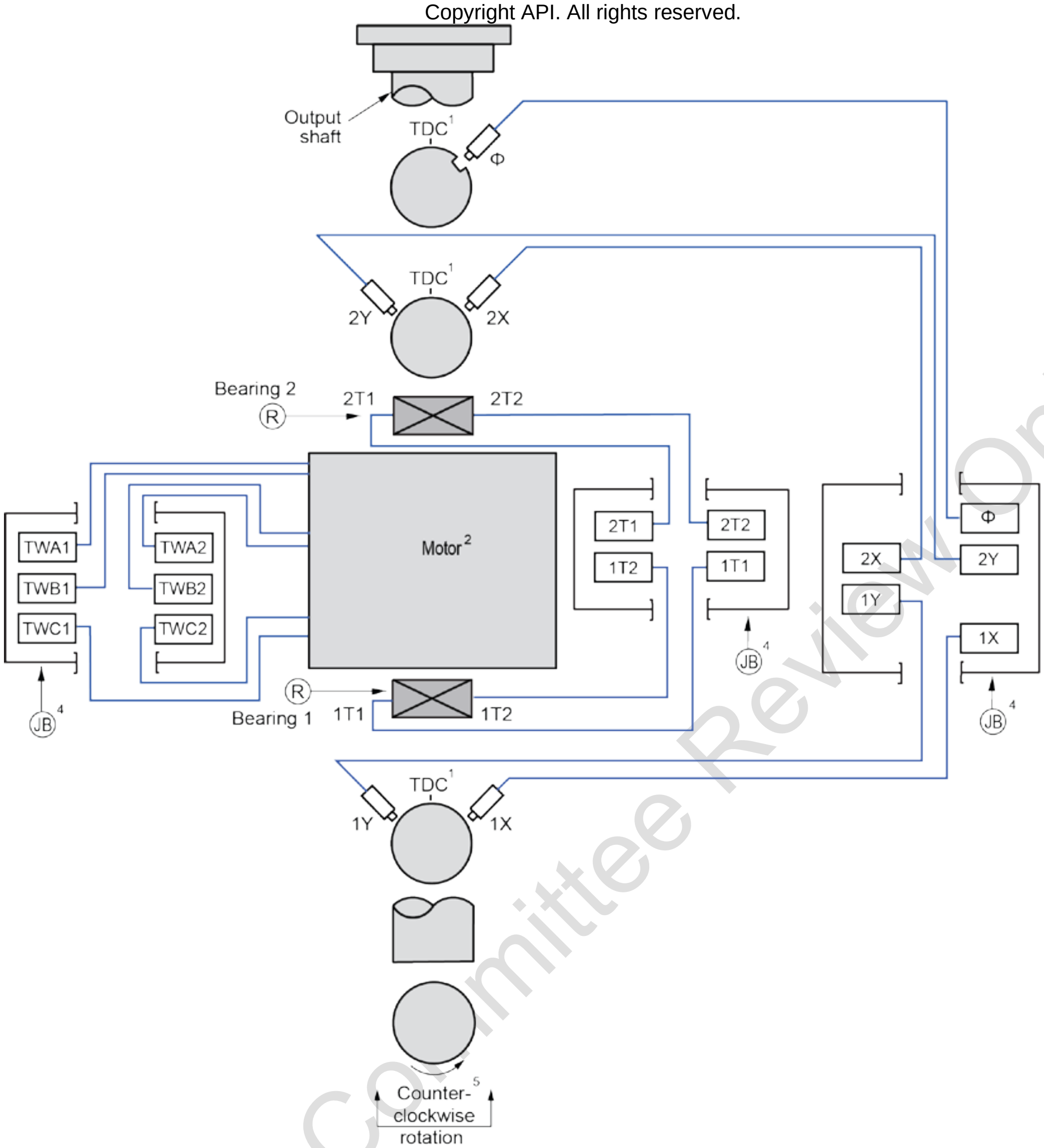


Figure H.4—Typical System Arrangement for an Electric Motor with Sleeve Bearings

Table H.7—Probe Nomenclatures

Vibration, temperature, and speed monitoring				
Speed and phase reference transducer	Radial shaft vibration (outboard)	Radial shaft vibration (inboard or coupling end)	Bearing temperature	Motor winding temperature
Φ	1Y 1X	2Y 2X	1T1, 1T2, 2T1, 2T2	TWA1, TWA2, TWB1, TWB2, TWC1, TWC2

Table H.8— Key and Notes for Figure H.4

KEY	
2Y	Low pressure end radial vibration probe, 45° left of TDC[1] (instrument manufacturer ID data[3])
2X	Low pressure end radial vibration probe, 45° right of TDC[1] (instrument manufacturer ID data[3])
1Y	High pressure end radial vibration probe, 45° left of TDC[1] (instrument manufacturer ID data[3])
1X	High pressure end radial vibration probe, 45° right of TDC[1] (instrument manufacturer ID data[3])
Φ	Phase reference transducer, 45° right of TDC[1] (instrument manufacturer ID data[3])
R	Radial bearing (description)
JB	Junction Box
1T1, 1T2	Outboard end bearing temperature
2T1, 2T2	Inboard end bearing temperature
TWA1, TWA2	Motor winding temperature (phase A)
TWB1, TWB2	Motor winding temperature (phase B)
TWC1, TWC2	Motor winding temperature (phase C)

NOTE 1 TDC indicates top dead center of shaft (6.18.1.4.2).
NOTE 2 In most cases, probe configurations for generators will be the same as shown for the motor
NOTE 3 Instrument manufacturer ID data includes vendor's model and part numbers.
NOTE 4 Labels inside the junction box represent the signal conditioning interface module to which the sensors should interface.
NOTE 5 Rotation direction is to be viewed driver to driven

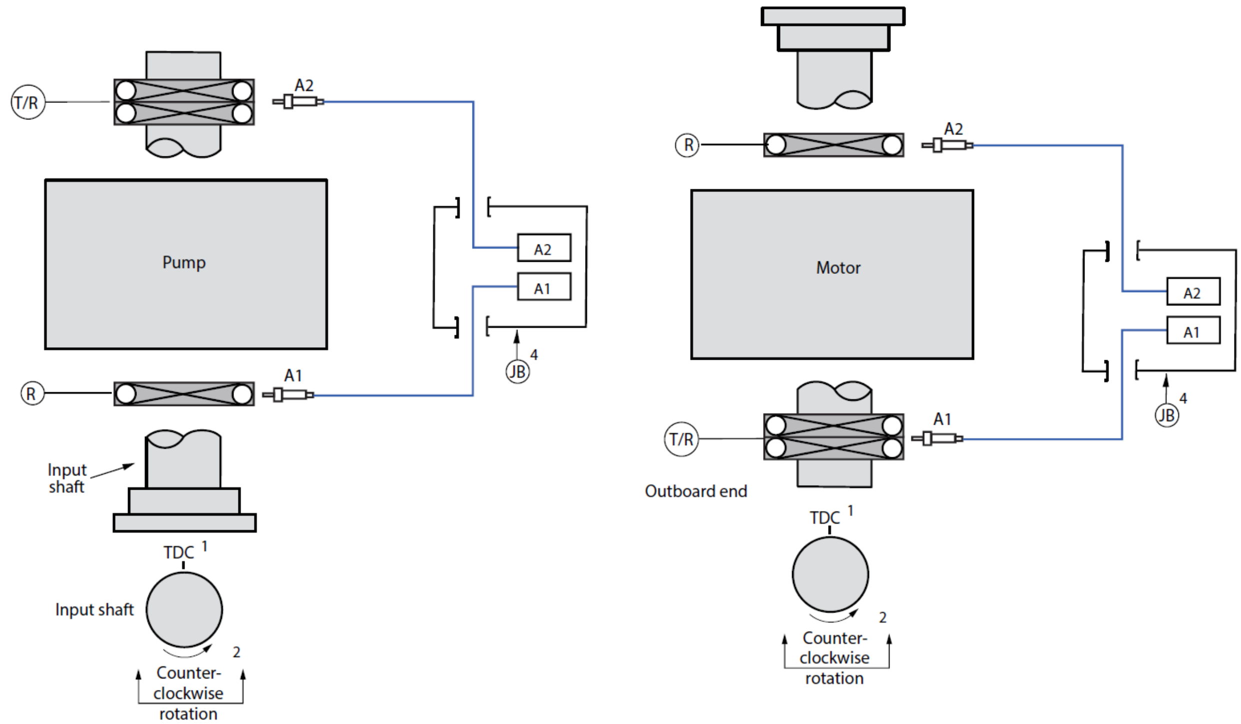


Figure H.5—Typical System Arrangement for a Pump or Motor with Rolling Element Bearings

Table H.9—Vibration Monitor

Bearing cap vibration	
Inboard end A1	Outboard end A2

Table H.10—Key and Notes for Figure H.5

A1	Inboard end radial horizontal accelerometer 90°from TDC[1] (instrument manufacturer ID data)
A2	Outboard end radial horizontal accelerometer 90°from TDC[1] (instrument manufacturer ID data)
R	Radial bearing (description)
T/R	Thrust/Radial bearing (description)
JB	Junction Box
NOTE 1	TDC indicates top dead center of shaft (6.18.1.4.2)
NOTE 2	The same arrangement would be used for a motor with roller element bearings but would be viewed from the outboard end.
NOTE 3	Instrument manufacturer ID data includes vendor’s model and part numbers.
NOTE 4	Labels inside the junction box represent the signal conditioning interface modules to which the sensors should interface.

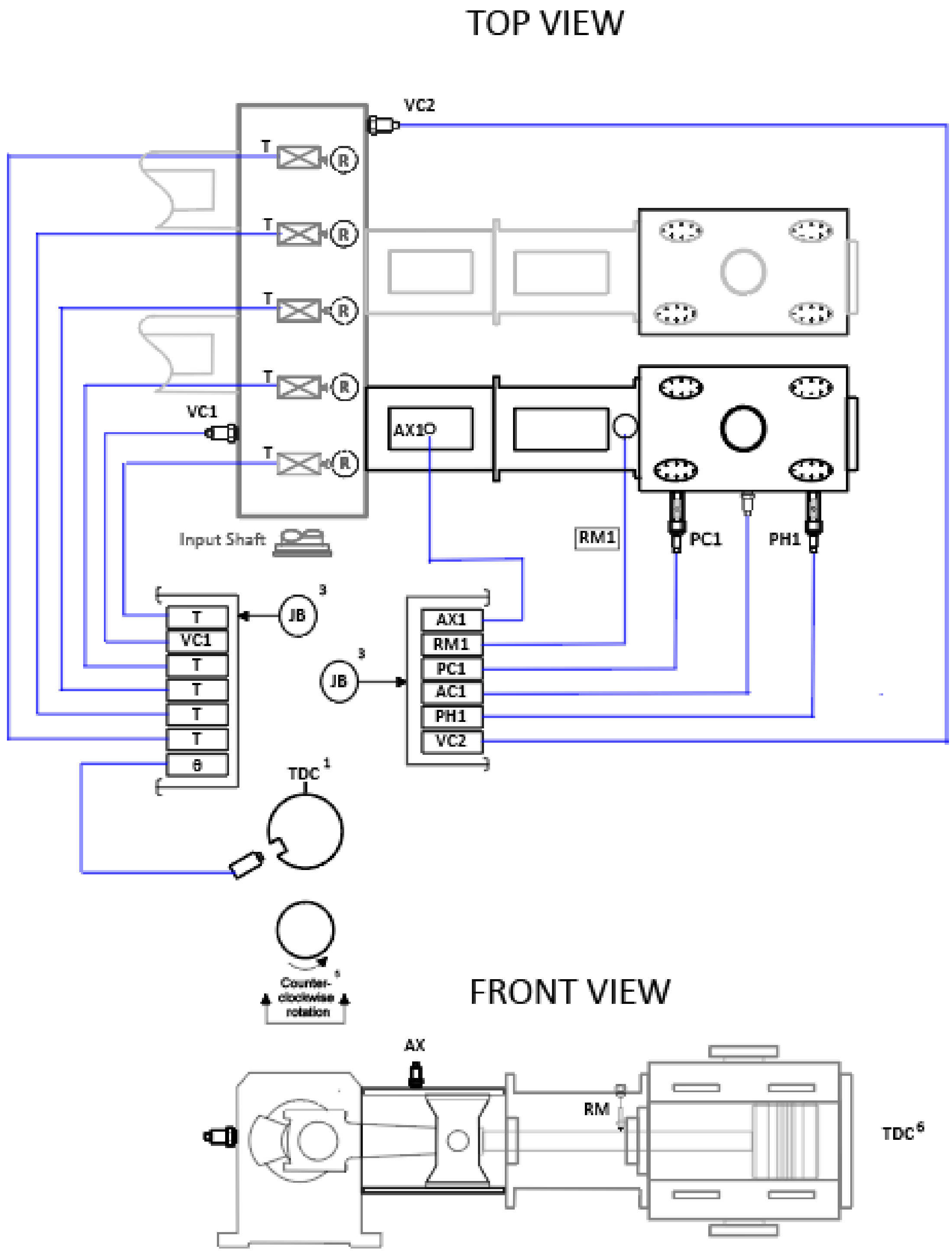


Figure H.6—Typical System Arrangement for a Reciprocating Compressor

Table H.11—Key and Notes for Figure H.6

Key	
θ	Crank angle reference transducer
R	Radial bearing (description)
JB	Junction Box
T	Main bearing temperatures
RM	Rod monitoring probes (instrument manufactured ID data[2]) per cylinder throw
PH	In-cylinder chamber head end pressure per cylinder throw
PC	In-cylinder chamber crank end pressure per cylinder throw
AX	Cross head accelerometer per cylinder throw
VC	Casing transducer (vibration) suitable for the frequency response of the machine
AC	Cylinder accelerometer per cylinder throw if agreed

NOTE 1 TDC indicates top dead center of shaft (6.18.1.5.2)
NOTE 2 Instrument manufacturer ID data includes vendor's model and part numbers
NOTE 3 Labels inside the junction box represent the signal
NOTE 4 Cylinder and bearing number convention related to specific end of the machine as agreed
NOTE 5 Rotation direction is to be viewed driver to driven
NOTE 6 Top Dead Center for each throw is its 0° crank angle value

Annex I VMS Setpoint Multiplier Considerations
(informative)

I.1 General

Setpoint multiplication is the function whereby selected channels in the monitor system have their alarm and shutdown setpoints elevated by some preset amount (usually an integer multiple such as 2 or 3; however, non-integer values are acceptable).

I.1.1 Setpoint multiplication is usually invoked by an external contact closure (such as a turbine control system relay output). However, this command could also be invoked via a digital communication link on some MPS's.

I.1.2 This annex provides an explanation of why this feature may be required on some machine types, and it also offers guidance for the proper use of this feature.

NOTE Alarm setpoints can vary depending on the strategy and requirements of various users for machinery protection. In some cases, alarm levels are established very close to the mechanical clearance limits of the machine. In these cases, setpoint multiplication should not be specified because it will result in alarm levels that exceed these mechanical clearances and will not provide adequate machinery protection.

I.2 Fundamental Rotor Response

I.2.1 General

I.2.1.1 All rotating machinery exhibits characteristic resonances at certain excitation frequencies. The most common form of excitation is the rotor's own unbalance forces occurring at the rotational speed of the machine. This discussion assumes excitation caused by these unbalance forces.

I.2.1.2 When a machine's rotational speed coincides with one of its resonances (such as during start-up or shutdown), vibration can result that is far above the levels expected at rated running speeds.

I.2.1.3 Machinery designers are generally careful to account for these resonances in their rotor dynamic designs such that the machine does not operate at or near any resonances.

I.2.2 Types of Responses at Resonance Conditions

Vibratory response at resonance conditions can be lateral (i.e. radial vibration), axial, or torsional. This standard does not address either axial vibration or torsional vibration measurements as part of the MPS. Therefore, this discussion focuses only on the lateral or radial vibration response as measured by proximity probes or by casing transducers such as accelerometers. However, care should be taken to recognize and document resonance responses other than radial vibration because they can be just as damaging to the machine.

I.2.3 Operation Above the First Critical Speed

I.2.3.1 For machines that operate at rotational speeds above their first critical, it is necessary for the machine to pass through one or more resonances as it ramps up or ramps down. Figure I.1 shows a typical radial vibration amplitude response of a machine operating above its first critical but below its second critical. The first critical occurs at the speed designated as $rpm_{critical}$ in Figure I.1. The vibration amplitude at this rotational speed is shown as $Amplitude_{critical}$. While this figure shows only the response from a single measurement location on the machine, similar graphs can be constructed for each radial vibration measurement location.

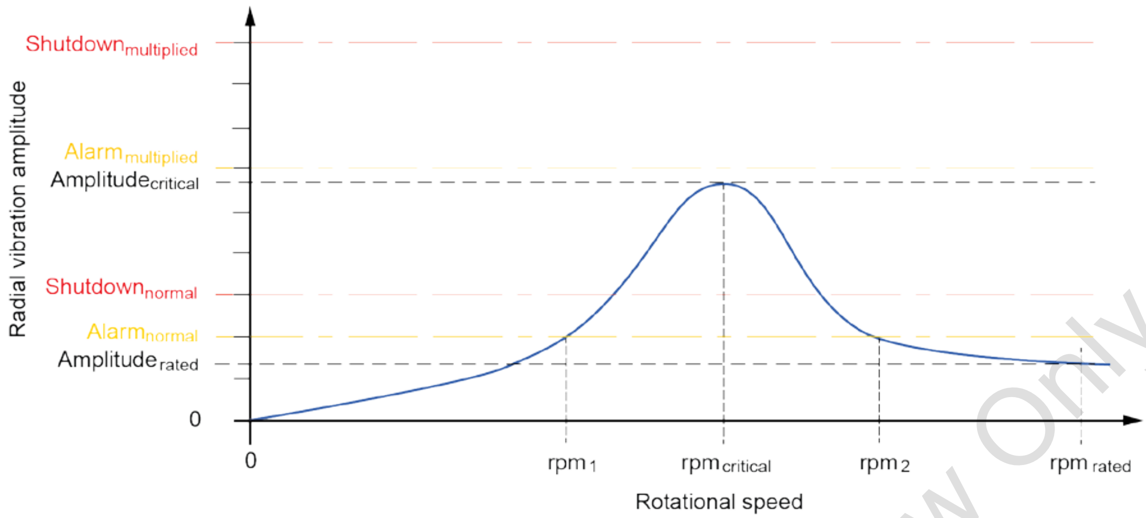


Figure I.1—Setpoint Multiplication Example

I.2.3.2 The machine's rated rotational speed is designated as rpm_{rated} and the radial vibration amplitude occurring at this speed is designated as $Amplitude_{rated}$. At this rated running speed, the vibration amplitude ($Amplitude_{rated}$) is less than the normal alarm ($Alarm_{normal}$) and shutdown ($Shutdown_{rnormal}$) setpoints.

I.3 Conditions Requiring Setpoint Multiplication

I.3.1 Notice that the machine in Figure I.1 experiences vibration amplitudes in excess of its normal alarm ($Alarm_{normal}$) and shutdown ($Shutdown_{normal}$) setpoints when it passes through its first critical. If the machine remains in this speed region ($rpm_1 \leq speed \leq rpm_2$) for a time Δt that exceeds the preset alarm delays for the channel, alarm or shutdown events will result. In the case of a shutdown event, this may actually result in the machine being shut down even though it was merely experiencing normal vibration responses as it passed through a resonance.

I.3.2 The condition defined in I.3.1 leads to the need for setpoint multiplication. As shown in Figure I.1, if the alarm ($Alarm_{normal}$) and shutdown ($Shutdown_{normal}$) setpoints are multiplied by a factor of 3 while the machine is operating between rotational speeds rpm_1 and rpm_2, the machine can pass through its first critical without encountering spurious alarms and shutdowns. In this case, the alarm and shutdown setpoints are elevated temporarily to $A_{multiplied}$ and $\lambda_{multiplied}$, respectively. The setpoints return to their normal levels when the machine is outside this speed region.

I.3.3 Thus, setpoint $0_{multiplication}$ is required when both the criteria below are met:

a) the machine experiences vibration amplitudes in excess of its shutdown or alarm setpoints as it passes through a machine resonance and this results in unwanted machine shutdown or alarms;

b) the duration of this setpoint violation exceeds the preset alarm delay times.

I.4 Alarm Suppression or Bypass Considerations

The practice of bypassing or suppressing the MPS alarms while it passes through a resonance in lieu of using properly established setpoint multiplication functions is strongly discouraged. Setpoint multiplication merely elevates the alarms—it does not suppress them. This ensures that machinery protection is provided at all rotational speeds of the machine.

I.5 Proper Applications of Setpoint Multiplication

I.5.1 General

The proper application of the setpoint multiplication function can be divided into two basic considerations.

I.5.2 Proper Identification of Applicable Channels

Each radial vibration location will typically measure a different amplitude response. Thus, the machine's characteristic response at each radial vibration measurement location should be documented over the range of rotational speeds from zero to rated speed. This information should be used in determining which channels require setpoint multiplication. Only those channels that meet the criteria of I.3.3 a) and I.3.3 b) above should be fitted with setpoint multiplication functions.

I.5.3 Proper Selection of Setpoint Multipliers

I.5.3.1 The characteristic response for each measurement location documented in I.5.2 above should also be used to establish the appropriate multiplier.

I.5.3.2 The multiplier should generally be chosen to be as small as possible while still elevating the alarm and shutdown setpoints to levels that are above the machine's characteristic response at resonance.

I.5.3.3 Provisions for setpoint multiplication by 2 or 3 are required of MPS's complying with this standard (the example contained in Figure I.1 assumes an integer multiple of 3 as can be noted by the tic marks on the vertical axis).

NOTE: When multipliers in excess of 3 are required to accommodate the machine's response at resonance(s), this can be indicative of machinery that has unacceptably large amplification factors.

I.6 Control System Interface Considerations

I.6.1 General

Typically, the machine control system will be capable of generating an output signal, such as a relay contact closure, that is wired to the MPS to invoke its setpoint multiplication function. There are three basic ways this is accomplished.

I.6.2 Absolute Speed Range Sensing

This method requires the machine control system to sense the rotational speed of the machine and activates an output any time the machine is operating at speeds between rpm_1 and rpm_2 (see Figure I.1). This is the preferred method.

I.6.3 Timer

This method can be used if the acceleration and deceleration rates of the machine are repeatable. In this case, a preset timer in the machine control system is triggered whenever the machine is accelerating through speed rpm_1 or decelerating through speed rpm_2. The machine control system simply invokes the setpoint multiplication output for a time equal to or greater than Δt (see I.3 for a discussion of Δt).

NOTE The duration Δt is dependent on the acceleration and deceleration rates governed by the machine control system. This paragraph should not be construed as permitting the machine to dwell indefinitely at or near its critical speed(s).

I.6.4 Manual Operation

This method does not rely on an automatic machinery control system. Instead, an operator manually invokes the setpoint multiplication in the MPS by a pushbutton or switch or timer as part of the machine start-up or shutdown procedure. However, this is rarely encountered because most machines are now fitted with automatic control systems capable of performing all start-up and shutdown control and sequencing without human intervention.

I.6.5 Best Practice Recommendations

The method described in I.6.2 above is encouraged as best practice when integrating the machine control system with the MPS. The manual method described in I.6.4 is least desirable because it relies on human intervention for proper machinery protection. It can result in false shutdowns or alarms if the setpoint multiplication function is not invoked. It can also lead to missed shutdowns or alarms if the setpoint multiplication function remains invoked even though the machine is operating outside the region between rpm_1 and rpm_2.

Annex J Electronic Overspeed Detection System Considerations
(normative)

J.1 General

The standard employed for the rotating machine under consideration will generally specify the allowable momentary overspeed as a percent of rated operating speed. The maximum speed attained by the rotor during an overspeed event is determined by Annex O.

J.1.1 The Electronic Overspeed Detection System shall be designed to limit maximum overshoot speed below the Maximum Allowable Momentary Rotor Overshoot Speed.

J.1.2 The electronic ODS is only one component within the entire overspeed protection system (see Figure J.1). The performance of the entire system is not limited to items discussed in this standard. Other components that are critical in determining the response of the entire system may include, but are not limited to: interposing relays, solenoids, shutdown valve(s), nonreturn valves, steam and hydraulic piping, and the entrained energy within the rotating machine itself. Collectively, these components comprise the overspeed protection system.

J.2 System Response Time

J.2.1 General

This standard requires that the electronic ODS be able to detect an overspeed event and change the state of its output relays within 40 ms when provided with an input signal frequency of at least 250 rpm. However, this response time of the detection system alone does not guarantee that the complete overspeed protection system will be suitable for a particular application. Other system dynamics need to be considered. Proper engineering judgment and system design shall be used to ensure that the complete overspeed protection system functions properly and responds fast enough to preclude the rotor speed from exceeding the maximum allowable limit. Consult Annex O as an example of how to evaluate the total system response time.

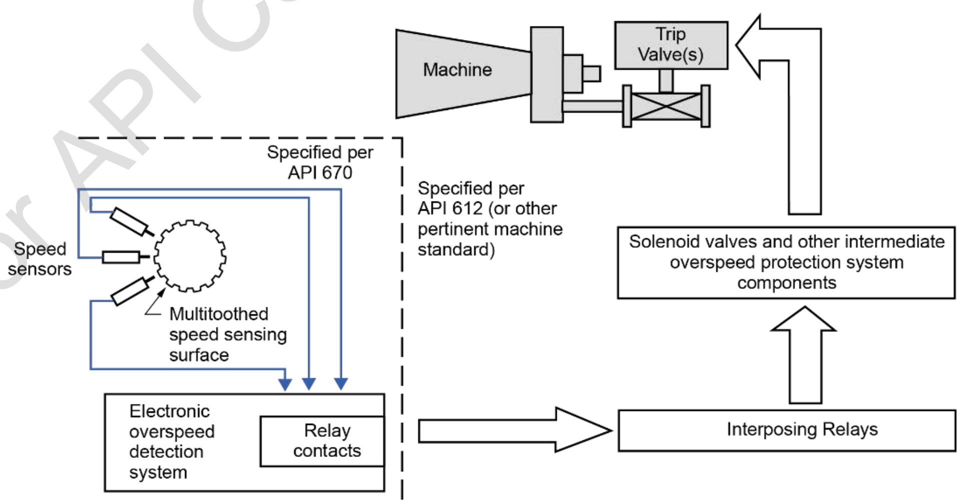
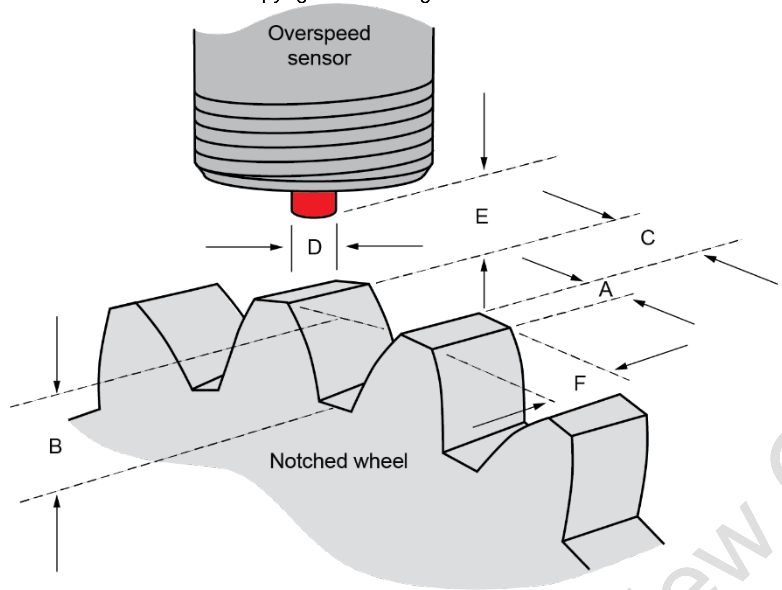


Figure J.1—Overspeed Protection System



Dimension	Description
A	Tooth length
B	Tooth depth
C	Notch length
D	Diameter of proximity probe tip or magnetic speed sensor pole piece
E	Gap
F	Tooth width

Figure J.2—Relevant Dimensions for Overspeed Sensor and Multitooth Speed Sensing Surface Application Considerations (See Table J.1)

J.2.2 Overspeed detection response time is defined as:

Overspeed detection response time = N/ $Freq_{Input}$ + L

Where:
N = Number of time intervals the system needs to qualify the overspeed condition
L = Time required for the logic solver to process the alarm condition
$Freq_{Input}$ = (EPR) * (trip speed) * (1 Minute/60 Seconds)

J.3 Speed Sensor Selection

Refer to 6.18.1.7 for speed sensor selection. Reliability of speed sensors and sensing technology must be taken into account for the SIL required.

J.4 General Considerations for Multitoothed Speed Sensing Surfaces

J.4.1 General

J.4.1.1 The speed sensing surface may be a gear, toothed wheel, evenly spaced holes in a shaft surface, or other such target that provides gap discontinuities for the speed sensors to observe. Characteristics of the sensing surface will need to be matched to the sensor type to ensure the input signal amplitude to the electronic ODS is within allowable minimum and maximum voltage limits. Figure J.2 shows the dimensions of the speed sensor and multitooth speed sensing surface that are relevant to application considerations.

J.4.1.2 The number of gap discontinuities required is a function of the speed of the machine and is determined by meeting the 40ms response time given the rotating speed of the shaft. While an Overspeed Detection System is fundamentally a fast-response system, there is no set or defined minimum events per revolution (EPR) value to achieve the required or maximum response time allowable for a given application.

J.4.1.3 There is a fundamental delay associated with receiving speed information from the notches/projections on the speed target (typically a toothed wheel or gear). The delay results from the time that elapses between the transducer observing individual timing events from the speed target. This tooth/notch detection delay time is a component of the overall response time of the Overspeed Detection System. This delay time can be significant in relation to the typical 40ms response time requirement established for many applications. Tooth/notch detection delay is governed by the Overspeed setpoint value and the Events Per Revolution for the application. For higher Overspeed setpoints, the delay decreases because at higher speeds the time delay between pulses is smaller. Similarly, for higher EPR, the time to detection decreases.

J.4.1.4 One strategy is to select an EPR value that maximizes the performance of the sensor to obtain the widest operating speed range and allow the ODS to be effective from low speeds (e.g. start-up or turning gear). The higher the EPR, the shorter the delay time in speed sensing. The maximum number of gap discontinuities is a function of the speed of the machine, the operating frequency of the sensor, and the operating frequency of the ODS sensing circuit. The following example illustrates the determination of event wheel discontinuities for a magnetic sensor.

$$Z = \frac{Freq_{max} * 60}{Range}$$

Where:
Z = number of teeth
$Freq_{max}$ = max Frequency of the sensing device in Hz
Range = Speed sensing range in rpm

Example: Trip speed of a turbine is 5620 rpm. The sensing device is able to work up to 12 kHz.
Speed range is selected to 6000 rpm

$$Z = \frac{12000 * 60}{6000}$$

$$Z = 120$$

Optimum number of teeth is 120. With 120 teeth, the full capability of the system is used. If the lowest frequency at which the system is able to detect a proper speed is 100 Hz, the lower end of the sensing range in rpm is 100 Hz * 60 / 120 = 50 rpm which is typically above turning gear speed. With 60 teeth (an often selected number), the lower end of the speed sensing range is 100 rpm and with 30 teeth, speed below 200 rpm is not properly detectable. In this example, 120 teeth compared to 60 teeth results in half the delay time to detect the overspeed.

Care should be taken to adhere to minimum feature size requirements, and minimum gap distance of the sensor. For example, on a magnetic sensor, the diametrical pitch shall be 0.4 teeth/mm [10 teeth/in] or smaller.

J.4.1.5 When designing or installing a multitoothed speed sensing surface, care should be taken to ensure that differential axial movement will not cause the speed sensing surface to move outside the transducer's range. The machine may expand or contract because of thermal conditions and normal rotor axial float. Precautions can be taken to address the expansion and contraction characteristics. The speed sensing surface should be of suitable thickness or may be located in an area not subject to excessive axial expansion or contraction of the shaft or the surface to which the speed sensor is affixed.

J.4.1.6 The reliability of the fastening system of the sensing surface to the main shaft must be taken into account. Features on the main shaft itself (e.g. once-per-turn speed event, machined feature, integral event wheel, etc.) should be used when possible.

J.4.2 Speed Sensing Surface for Magnetic Speed Sensors

J.4.2.1 When magnetic speed sensors are used, the optimum dimensions of the speed sensing surface are a function of the pole piece diameter (D). See Table J.1 for recommended dimensions when this arrangement is used. However, additional calculations are required to ensure optimum signal strength for the electronic ODS inputs. Some of these additional calculations include, but are not limited to, surface speed, gear pitch, air gap, and sensor load impedance. Consult the magnetic speed sensor manufacturer to ensure correct application guidelines are observed.

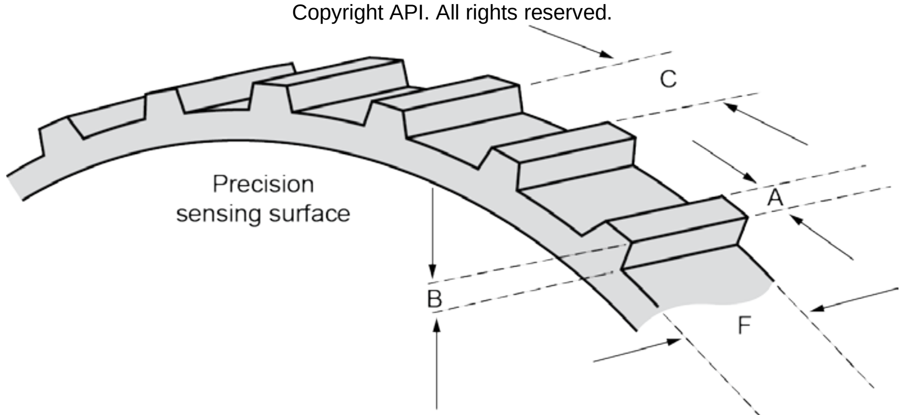
J.4.2.2 Installation considerations require a thorough understanding of the peak-to-peak vibration characteristics at the speed sensing location during both running speed and overspeed conditions. Magnetic speed sensors require a close gap, typically less than 0.51 mm (20 mil), for optimal operation. This may allow the observed speed sensing surface to contact the sensor during high radial vibration conditions, causing loss of signal and failure of the sensor. Applications in which the speed sensing surface is subject to high radial vibration amplitudes (particularly during an overspeed event) should consider the use of proximity probes as detailed in J.4.3.

NOTE Signal strength of Magnetic Speed Sensors increases with tangential velocity, decreasing gap, and the number of “teeth”. Number of teeth is determined by the maximum speed sensed at its highest sensitivity. Sensitivity increases with number of teeth and decreasing gap. Speed sensitivity should be maximized at trip speed. In cases where a single sensor cannot cover the speed range, dual range or other speed reading (e.g. once-per-turn speed sensor, secondary speed ring) can be employed (e.g. during startup or low-speed operation.)

J.4.3 Speed Sensing Surface for Proximity Probes

J.4.3.1 Angular precision (repeatability of the tooth spacing) is more important than depth precision. A precision-machined toothed wheel employs a precise tooth depth to keep a proximity probe system within its linear operating range at all times (see Figure J.1). This arrangement permits enhanced circuit fault detection and diagnostic capabilities beyond those achievable when speed sensors are used as detailed in J.1, J.4.2, and J.4.3. In addition, this arrangement is capable of providing an OK sensor indication while the machine is not running. See Table J.3 for recommended dimensions when using this arrangement.

J.4.3.2 In all cases, special care must be exercised to ensure that the probes are installed per the manufacturer’s installation tolerances. An improperly installed or aligned probe may not provide speed protection. Some commercially available probes have sensitivity to angular orientation to the sensing surface and must be installed accordingly. In some cases, this situation may detect speed at low speeds, but not be functional at higher speeds, providing a false sense of protection.



Dimension	Description
A	Tooth length
B	Tooth depth
C	Notch length
F	Tooth width

Figure J.1—Precision-machined Overspeed Sensing Surface (See Table J.3)

Table J.1—Recommended Dimensions for Speed Sensing Surface when Magnetic Speed Sensors Are Used

Dimension	Recommended
A (tooth length)	≥D
B (tooth depth)	≥C
C (notch length)	≥3D
D (diameter of pole piece)	Typically 4.749 mm (0.187 in.).
E (gap)	As close as possible. Typically 0.76 mm (30 mil) or less.
F (tooth width)	≥D

Table J.2—Recommended Dimensions for Nonprecision Speed Sensing Surface when 8mm Proximity Probe Speed Sensors Are Used (Note 1)

Dimension	Minimum	Nominal	Maximum
A (tooth length)	8 mm	Unlimited (Notes 2 and 3)	Unlimited (Notes 2 and 3)
B (tooth depth)	2 mm	Unlimited	Unlimited
C (notch length)	8 mm	Unlimited (Notes 2 and 3)	Unlimited (Notes 2 and 3)
E (gap)	0.5 mm	0.875 mm	1.25 mm
F (tooth width)	8 mm	Unlimited	Unlimited

Table J.3—Recommended Dimensions for Precision-machined Speed Sensing Surface when 8mm Proximity Probe Speed Sensors Are Used (See Note 1)

Dimension	Minimum	Nominal	Maximum
A (tooth length)	8 mm	Unlimited (Notes 2 and 3)	Unlimited (Notes 2 and 3)
B (tooth depth) (Note 4)	1 mm	1 mm	1.3 mm
C (notch length)	8 mm	Unlimited (Notes 2 and 3)	Unlimited (Notes 2 and 3)
E (gap) (Note 4)	0.5 mm	0.65 mm	0.8 mm
F (tooth width)	8 mm	Unlimited	Unlimited

NOTE 1 Table J.2 and Table J.3 assume the use of standard or standard-option proximity probes (see 6.17.1.1.2 and 6.17.1.1.3) with a linear range of at least 2.03 mm (80 mil). For applications where nonstandard probes are to be used, consult the machinery protection system vendor.

NOTE 2 Where an unlimited dimension is stated, the actual maximum limit will be determined by the overall diameter of the multitoothed speed sensing surface and the desired number of events-per-revolution.

NOTE 3 An unlimited tooth length/notch length is not intended to imply that a speed sensing surface with only a single discontinuity (i.e. tooth) is acceptable for overspeed applications. Such a design provides only a one-event-per-revolution signal and is rarely able to achieve the necessary response time required for proper machinery overspeed protection. Unlike a multitooth design, it requires multiple revolutions of the rotor to determine the change in rotor speed. The greater the number of events-per-revolution, the higher the resolution of the sampled speed signal.

NOTE 4 If dimension B + dimension E exceeds 1.8 mm (70.9 mil), the probe may indicate a NOT OK condition if the rotor stops with the probe observing a notch.

Annex K Surge Detection and Antisurge Control

(informative)

K.1 General

K.1.1 Surge is a highly transient process that creates high stresses in compressor vanes and blades, creates higher than design stresses on diaphragms, damages internal seals, and causes high impact loads on thrust bearings of centrifugal and axial flow compressors. Axial compressors have free-standing blades, and a low number of isolated surge cycles can initiate cracks. Damage to centrifugal compressors usually results from repeated high energy surge cycles over a longer period of time. High internal temperatures caused by repeated surge cycles can also lead to damage.

K.1.2 Not all surge conditions result in damage. Some aerodynamic instability can occur within the compressor and not cause damage to the compressor components. Surge detection methods should therefore focus on detecting and taking action on high energy surge cycles and not on small, harmless flow instability. High energy surge cycles are usually characterized by full flow reversal while operating outside the design envelope.

K.2 Distinctions of Surge Detection and Antisurge Control

K.2.1 To avoid damage caused by surge, an antisurge control system is used on all axial flow compressors and most centrifugal compressors. If an antisurge control system is adequately designed and maintained, machinery damage due to surge events are less likely to occur.

K.2.2 Because of compressor fouling, signal drift of analog values due to component aging, or component failures, a compressor may experience a surge event (consisting of one or more surge cycles) even when equipped with adequate antisurge control. If an antisurge control system is unable to prevent surging, then a surge detection system can be used to independently detect the surge cycles and take action to avoid severe compressor damage. These detectors should use independent sensors and independent hardware to avoid common mode failures. If the antisurge control system incorporates redundant transmitters and redundant controllers, the surge detection function may be included in the antisurge control system. Generally, using a common flow measuring element with independent transmitters is acceptable.

K.3 Description of the Surge Phenomena and Introduction to Antisurge Control

K.3.1 The onset of surge can be understood by considering a compressor operating at a fixed speed with constant inlet conditions and a discharge throttle valve. For such a system, the normal relationship between the volumetric flow measurement (Q) and the discharge pressure (P_d) is a single curve, as shown in Figure K.1. At any given time, the values of those two variables define an operating point that will fall on that performance curve unless the compressor is surging.

K.3.2 Imagine that this system is operating at steady state with a flow and pressure corresponding to point A. If the discharge throttle valve were closed slightly, the downstream system resistance would effectively increase, the flow through the compressor would decrease, and the pressure at the compressor outlet would rise.

K.3.3 If the valve is closed further in small steps, the compressor reaches point B where a further reduction in flow produces no increase in the final discharge pressure, as the operating point approaches the surge limit. Closing the valve further increases the discharge pressure above the maximum value that the compressor can sustain. At this point the flow of gas leaving the compressor has insufficient energy to enter the discharge volute. The forward flow regime through the compressor collapses, typically reversing in approximately 20 ms to 80 ms. The flow reversal through the machine and through the discharge valve causes the discharge pressure to rapidly drop and forward flow is reestablished. This is a surge cycle. If flow is reestablished and the system resistance remains elevated, then the discharge pressure will rapidly reach the unstable point B again, and the surge cycle would repeat.

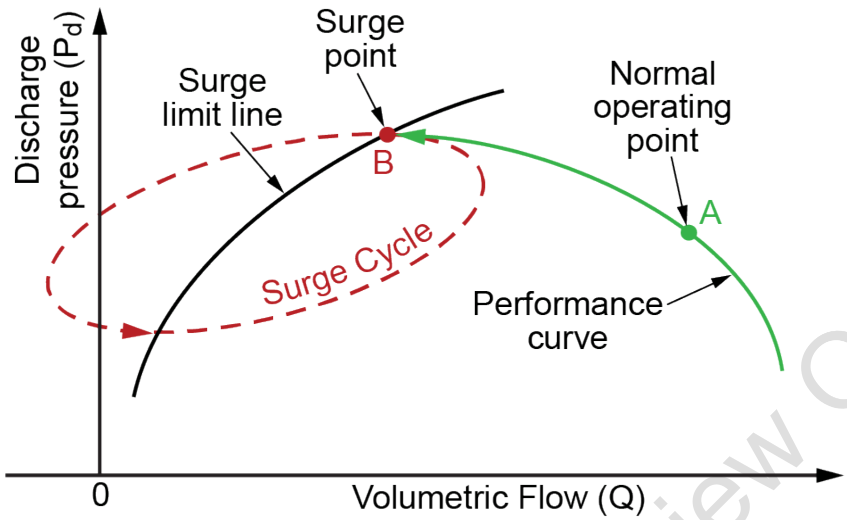


Figure K.1—Compressor Performance Limitations

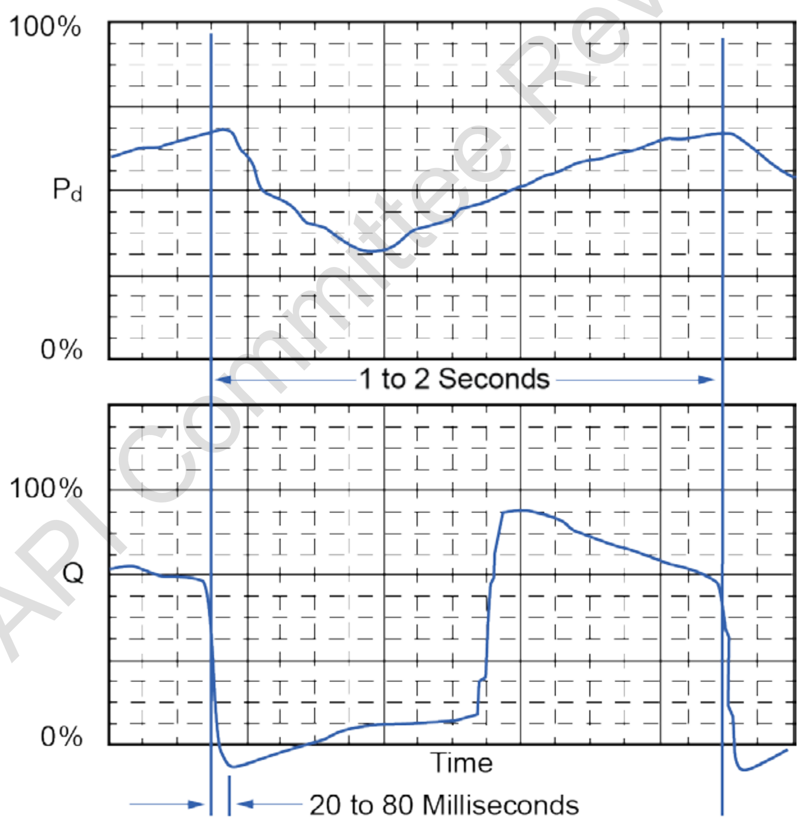


Figure K.2—Pressure and Flow Variations During a Typical Surge Cycle

K.3.4 In the example in K.3.2 and K.3.3, the surge was caused by a closing discharge valve; however, anything that increases system resistance, such as fouling of intercoolers or changes in process characteristics, can lead to surge.

K.3.5 Figure K.2 shows these fluctuations as they might be measured during an actual compressor surge. As shown, a typical surge cycle will last only 1 to 2 seconds. Depending on the application, other variables (such as speed, suction pressure, discharge temperature) may also fluctuate rapidly. The occurrence of a surge can be inferred from a rapid change in any one or more of such variables.

K.3.6 Once induced, surge can continue indefinitely until the cause is removed. In the interim, the severe oscillations of flow and pressure create heavy thrust-bearing and impeller or blade loads, vibration, and rising gas temperatures. Because of the reverse flow, the hot gas flows to the suction and is reheated in the next compression cycle. This cycle greatly increases the gas temperature. This high temperature may exceed the design limits of the compressor materials or reduce internal clearances. If more than a few cycles occur, severe compressor damage can result.

K.3.7 To prevent or stop surge, measures should immediately be taken to increase the flow through the compressor, usually by opening a valve to recycle some of the flow to the compressor inlet or (for an air compressor) to blow-off some of it to the atmosphere.

K.3.8 A system that automatically takes action to prevent surge from occurring is an antisurge control system. These systems generally utilize sensors in the process (upstream and downstream of the compressor) and logic algorithms to determine the location of the operating point relative to the theoretical (or as tested) specific compressor surge limit line. If the operating point approaches the surge limit, then the recycle or blow-off valves are opened to prevent reaching the predetermined surge point. Reference API-617 for more details.

K.3.9 If the antisurge control system fails to prevent surge for any reason (e.g. faulty or miscalibrated sensor, faulty logic solver, malfunctioning antisurge valve) then the surge detection system detects the actual surge cycles and takes independent action to prevent machine damage. Surge detection systems do not rely on determining the theoretical surge limit line or operating point locations, but instead only rely on detecting the system response to an actual surge cycle.

K.4 Considerations for Surge Detection on Centrifugal Compressors

K.4.1 Surge detection systems as defined in this annex have proven effective at reducing the risk and consequence of surge-related damage on axial compressors. Justification for surge detection systems on centrifugal compressors is application dependent. Applications that include some or all of the following risk factors may benefit from the addition of an effective surge detection system.

a) Applications where previous experience has proven the risk of surge-related damage to be unacceptable.

b) Centrifugal compressors with the following design features may be more susceptible to damage with a limited number of isolated surges:

   i) high pressures or pressure ratios,

   ii) high speed,

   iii) small internal operating clearances/tolerances,

   iv) low stability margins (long rotors),

   v) highly loaded thrust bearings.

c) If the probability of failure of the antisurge control system does not meet plant requirements for preventing machine damage.

d) If the consequence of surge-related compressor damage is unacceptable to the operator because of large production losses due to unplanned outage or performance deterioration.

e) Hazardous gas application [potential gas leaks (seal failure)].

f) Difficult location factors such as remote or unmanned operation.

K.4.2 Even if a specific surge detection system is not justified, all process plant designs that incorporate centrifugal compressors should consider the possible consequences of damage associated with compressor surge. As a minimum, this should include detection and alerting of such consequences as: gas leak detection; high or low excursions of process pressures or temperatures; abnormal rotor axial position; high bearing temperatures; or high motor currents, etc. On detection and annunciation of such conditions, the operator can take action to shut down and bring the compressor to a safe state.

K.5 Considerations for Surge Detection System Testing and Field Surge Detection Calibration

K.5.1 Surge Detection System Function Testing

K.5.1.1 The objective of function testing the surge detection system is to validate sensor and logic solver component functionality. This usually includes a demonstration that the system will reliably detect a surge cycle and take the intended action(s).

K.5.1.2 The purpose of the surge detection system test is not intended to validate the antisurge control system or other compressor protective systems.

Note Testing the surge detection system does not necessarily require exposing the machine to surge. It does test the functionality of the surge detection system and components based on the methods identified in this standard.

K.5.2 Field Surge Detection Calibration

K.5.2.1 If process variable rate-of-change methods of surge detection are used, then surge testing in the field should be used to calibrate the threshold levels that define a surge cycle on each unique system.

K.5.2.2 Duplicate machines should be individually surge tested in the field to account for installation and manufacturing differences between duplicate machines.

K.5.2.3 All other methods that demonstrate acceptable surge detection without field surge testing should be proven by successful experience and require specific purchaser approval. The purchaser may agree to OEM-recommended settings for surge detection calibration based on design models, experience, and bench testing. In these cases, the machine may not need a surge test validation in the field.

K.5.2.4 Although the objectives are different, the surge detection field calibration can coincide with the calibration of the antisurge control and other systems.

K.5.2.5 The following are prerequisites for surge testing the compressor to calibrate the surge detection system:

a) antisurge control system, VMS, and surge detection system loop functions should be function tested operational;

b) high-speed event recording and diagnostics systems should be operational and temporary instrumentation needed for surge testing available and installed.

K.5.2.6 Where possible, the antisurge control should be functionally checked and operational before starting surge testing. If antisurge controls are provided, then they are configured to allow a surge to occur by moving the antisurge setpoint or control line to approach surge, or by setting the anti-surge control line slightly below the surge line, then closing the recycle or bypass valve manually to initiate the surge.

K.5.2.7 When surge is detected, measure and record the rate of change for the surge detection variables that will be used.

K.5.2.8 For rate-of-change surge detection methods, use the measured rate of change as the basis for setting the surge detection limits.

K.5.2.9 For threshold methods, user experience, vendor experience, and recorded data, should be considered in setting the limit.

Annex L Functional Safety Methodology
(informative)

L.1 Introduction

L.1.1 The introduction of the ANSI/ISA standard S84.00.01 (Safety Instrumented Systems for the Process Industries) in 1996, followed by IEC 61508 (Functional safety of electrical/electronic/programmable electronic safety-related systems) in 1998 and the IEC 61511 (Functional safety - safety instrumented systems for the process industry sector) in 2003 have been received in the industry. These standards apply to all processes and process equipment handling hazardous materials in the oil, gas and chemicals industries, including all sorts of rotating machinery. These standards have been updated since the initial issue.

L.1.2 This annex summarizes the basic methods of functional safety. It also addresses some sector specific standards which have been derived from the IEC 61508 base standards.

L.1.3 Each human health and environmental risk in any process environment should be evaluated individually and the examples given in this annex are given for educational purposes only.

L.1.4 These methodologies are demonstrated through examples (SIS architectures) that represent possible system configurations and should not be interpreted as recommendations for system design. The user is cautioned to clearly understand the assumptions and data associated with the methodologies in this document before attempting to utilize the methods presented herein.

NOTE This text is mainly taken from ISA-TR84.00.02-2002, Part 3.

L.2 Scope

L.2.1 This annex defines the application of Functional Safety standards of machinery protection systems. It presents the basic process of implementing functional safety in this field. It demonstrates how to determine a required safety integrity level per IEC 61511 and ISO 13849 using the Risk Graph and Layer of Protection Analysis (LOPA) methods. It also gives recommendations of scaling factors for the Risk Graphs, general guidance for initiating cause rates, independent protective layers (IPL) as well as failure probabilities.

L.2.2 The user is cautioned that many different methods to identify a SIL target and verify that the selected hardware and software meets the required safety level are available. This annex only demonstrates some basic functions and is not intended to limit the user's choice in which method to follow. In case of conflicts between this annex and the applicable IEC and ISO standards, these standards supersede this annex.

L.2.3 The user is also reminded that the vendor with unit responsibility should provide all information that allows the owner to operate and maintain the safety system to meet the required safety level.

L.2.4 Two examples are included for reference (see Figure L.6 and Figure L.7). The first example shows a control system architecture which does not meet the target safety level, the second one does.

L.3 Basic Definition of Functional Safety

L.3.1 General

L.3.1.1 The Introduction of IEC 61508 provides a valuable exposure to the topic of Functional Safety and discussion of its basic features.

L.3.1.2 The scope of the standards IEC 61508/61511/62061 is limited to electric systems (E/E/and PES) whereas the ISO 13849 includes mechanical, pneumatic and hydraulic systems as well. IEC 61508/61511/62061 use the term Safety Integrity Level (SIL) for the degree of risk reduction whereas ISO 13849 uses the term performance level (PL). The SIL evaluation per IEC is done mainly by quantitative methods (calculation), whereas the ISO 13849 allows a combined quantitative/qualitative approach. Details are given below.

Table L.1— Safety Integrity Levels and Probability of Failure

Safety Integrity Level SIL as per IEC 61508	Target Range Probability of Failure on Demand Average PFD_{avg}	Probability of Dangerous Failure per Hour PFH_d	Risk Reduction Factor
1	10^{-1} to 10^{-2}	10^{-5} to 10^{-6}	10 to 100
2	10^{-2} to 10^{-3}	10^{-6} to 10^{-7}	100 to 1,000
3	10^{-3} to 10^{-4}	10^{-7} to 10^{-8}	1,000 to 10,000

NOTE For high/continuous demand applications, PFH is the equivalent probability of failure per hour. High/continuous demand is rarely seen in process applications.

L.3.1.3 This annex provides guidance on the development of the safety requirements specification necessary to achieve the required functional safety for the machinery related safety systems. Further, through examples, it provides recommendations on designing suitable protection system architecture and verification methods to ensure the design is adequate.

NOTE Text mainly taken from the introduction of IEC 61508.

L.3.2 Functional Safety in Machinery Protection Systems

L.3.2.1 Process Safety is regulated in the USA by OSHA 29 CFR 1910.119. It directs the end user to follow current standards, codes and best industry practice. OSHA has recognized ANSI/ISA- 61511 as an example of best industry practice for Safety Instrumented Systems (SIS). Machinery Safety is regulated in Europe by the Machinery Directive 2006/42/EC.

L.3.2.2 The European Machinery Directive cites IEC 62061 and ISO 13849 as harmonized standards for machine safety systems. The user should note that IEC 62061/ISO 13849 does not address the industry in which the machine will be used and recommends that relevant industry standards should also apply when reviewing the system design. Therefore, the user purchasing rotating equipment originally designed in accordance with IEC 62061 will apply IEC 61511 methodologies when using that machine in the process industry to evaluate the OEM's machinery protection system.

L.3.2.3 Safety instrumented systems are mainly used to mitigate hazards to people and the environment. Machine hazards which may harm the environment are normally linked to hazards for people. The harm which can be done to people is typically more severe than environmental harm. For this reason, this annex deals with protection of people only. It should be noted that environmental hazards should also be considered in each specific risk assessment.

L.3.2.4 The process of functional safety is the same for human health and environmental protection. However, to limit economic losses, methods other than functional safety are typically applied. Refer to Annex M for further details on designing to mitigate economic losses.

L.3.2.5 Every machine which operates in the process industry imposes hazards to people and the environment. In a risk assessment, hazards are analyzed to determine a level of risk. In some cases, safety instrumented systems are put in place to mitigate that risk. Risk is determined by the severity of the consequence of the hazard and the frequency that the unwanted event is expected to occur. The risk assessment may include consideration of independent protection layers, if present.

L.3.2.6 During the risk assessment, each hazard's risk has to be determined and compared to the tolerable risk. This risk assessment is done under the assumption that the safety instrumented system under evaluation is not present. See IEC 61511, Figure 3 (Risk Reduction: General Concepts) for examples of risk reduction.

L.3.2.7 In IEC 61508/61511, functional safety classifies the necessary degree of risk reduction into four safety integrity levels: SIL 1, SIL 2, SIL 3, and SIL 4. A SIL 1 safety system provides the least amount of risk reduction, while a SIL 4 safety system provides the highest amount of risk reduction. The probability of failure on demand (PFD) is used to describe the probability of the safety system not responding to a potentially dangerous condition. PFD_{avg} is the average probability of failure on demand and is a function of the time interval for which the equipment is tested for faults. As can be seen from Table L.1, to reduce process risk by a factor of at least 10 or up to 100, a safety system of at least SIL 1 is required. To meet SIL 1, this safety system will have a PFD_{avg} no greater than 10^{-1}. Risk reduction factors of more than 10,000 (SIL 4) are typically not seen in machinery applications.

Note For high/continuous demand applications, PFH is the equivalent probability of failure per hour. High/continuous demand is rarely seen in process applications.

L.3.2.8 The higher the safety integrity level (SIL), the higher the requirements for the safety instrumented system. The following paragraphs describe these requirements in more detail.

a) The standards for functional safety differentiate between high demand mode and low demand mode. These modes are defined as follows.

   1) Low Demand Mode—Where the frequency of demands for operation made on a safety related system is no greater than one per year.

   2) High Demand or Continuous Mode—where the frequency of demands for operation made on a safety-related system is greater than one per year.

b) Different evaluation procedures apply to these two modes. Some standards for high demand mode do not consider proof tests but give detailed instructions for diagnostic tests.

NOTE In most cases, either one of the evaluation procedures provides more or less similar results if the same risk parameters are used. If a SIS responds one or more times per years, the procedures for high demand mode may be used.

L.4 Process of Functional Safety

L.4.1 General

A life-cycle approach to Safety Instrumented systems has been adopted by standards such as ANSI/ISA 84.00.04 and IEC 61511. See IEC 615111, Figure 8 (Safety Life Cycle Phases) for the multiple stages of the SIS life-cycle. Two evaluation examples are given using Risk Graph assessment tool and SIL verification using PFD_{avg} calculation with reliability block diagrams. These examples are presented for the sake of education, noting that there are equally acceptable techniques available and that the user should be qualified in the use of these techniques.

L.4.2 Process Hazard Analysis and Risk Assessment

L.4.2.1 General

L.4.2.1.1 After the conceptual design has been completed, a Hazard Analysis and Risk Assessment should be scheduled. During this risk assessment, all hazards and risks to personnel or the environment are analyzed individually. The actual risk that is seen if no MPS exists is compared with the tolerable risk. If the actual risk is lower than the tolerable risk, the MPS does not need to be considered as a SIS**.**

L.4.2.1.2 If the actual risk (without a MPS) for personnel or environment exceeds the tolerable risk, risk reduction methods should be enforced which typically includes the installation of a MPS which functions as a SIS. The necessary degree of risk reduction should be determined in the risk assessment.

L.4.2.1.3 There are four levels of risk reduction specified in IEC 61508, 61511 and 62061, and five levels in ISO 13849. These levels are called Safety Integrity Level (SIL) in the IEC standards and Performance Level (PL) in ISO 13849. The highest level SIL 4 is typically not used in process applications.

L.4.2.1.4 The relationship between SIL and PL risk reduction factors can be seen in Table L.2.

Table L.2—Performance Level as per ISO 13849 and Safety Integrity Level as per IEC 61508/61511

Performance Level as per ISO 13849	Safety Integrity Level as per IEC 61508
A	None
B	1
C	1
D	2
E	3
NOTE Details can be found in ISO 13849-1.	

L.4.2.2 Target SIL/PL

Different methods for determination of the required Safety Integrity Level are available. Available options are the risk graph as per L.4.2.3, LOPA (layers of protection analysis) as per L.4.2.5 and the risk matrix. Other methods are used as well.

L.4.2.3 Risk Graph of IEC 61511 and VDMA 4315

L.4.2.3.1 General

L.4.2.3.1.1 A common risk assessment method among several available is the Risk Graph. The referenced standards show different Risk Graphs for personnel and environmental protection. This annex limits its consideration to personnel protection. The Risk Graph shown in Figure L.1 is specifically adapted to the requirements of turbomachinery. Details can be found in IEC 61511 and VDMA 4315-1.

L.4.2.3.1.2 The Risk Graph is used to determine the required SIL for the safety function from the four parameters:

a) severity (S) of the unwanted event;

b) occupancy rate (F) of persons in the event area,

c) possibility to avoid (AV) the impact of the unwanted event,

d) probability of the occurrence (W) of the unwanted event.

An example on how to use the Risk Graph is given in L.6.2 and L.6.4.

L.4.2.3.2 Severity or Consequence of Risk—Parameter S

4 Levels of severity are used. The range of the parameters of the Risk Graph above is defined in Table L.3.

L.4.2.3.3 Probability of Presence in the Hazardous Zone—Parameter F

Parameter F is the probability that a person is located in the hazardous area at the time when the hazardous event can occur. It encompasses the frequency of, and exposure time in, the hazardous zone (as per ISO 12100: Chapter 5.5.2.3.2, Occurrence of hazardous events) (see Table L.4).

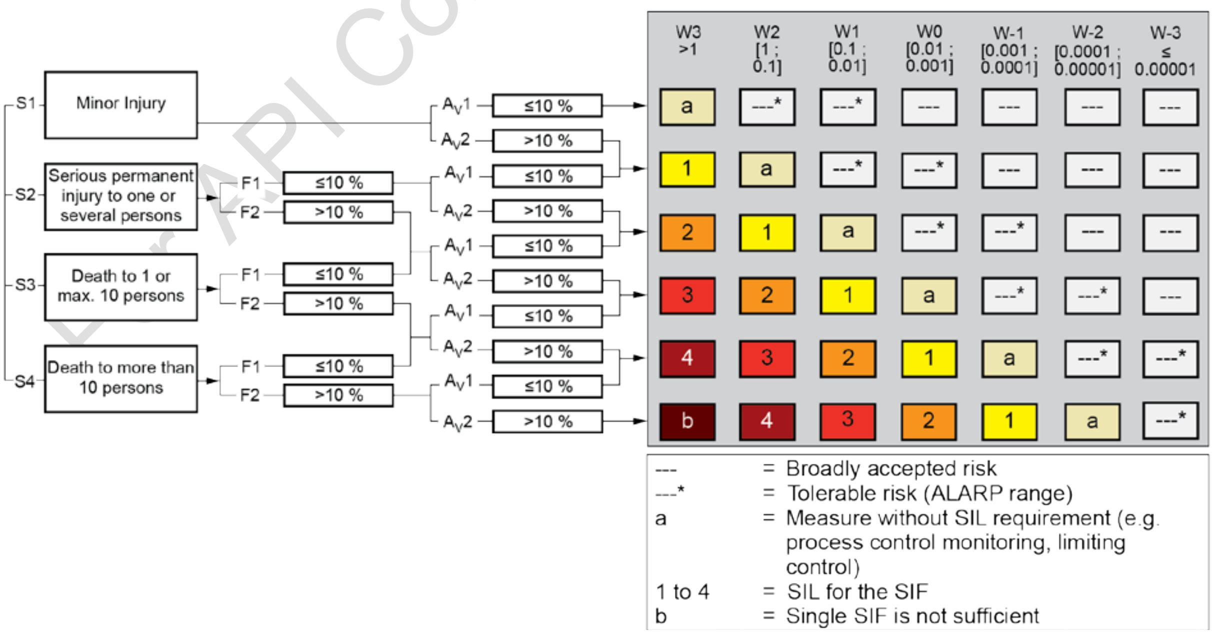


Figure L.1—Risk Graph as per VDMA 4315

Table L.3—Definition of the Range of the Parameter Severity, S

Severity or Consequence of Risk—S			
Parameter	**Definition**	**Severity-based Tolerable Accident Rate**	**Comments**
S1	Minor injury	1/100 years	Reversible injury: — first aid required — medical care required
S2	Serious or permanent injury to one or more persons	1/1,000 years	Reversible injury: — broken limbs Irreversible injury: — loss of a finger — loss of eye or arm The death of one person as a consequence of serious injury will be considered in this category
S3	Death of 1 to 10 persons	1/10,000 years	Immediate death of a person
S4	Death of more than 10 persons	1/100,000 years	Highest risk relevant to turbomachinery

Table L.4—Definition of the Range of the Parameter Probability of Presence in the Hazardous Zone—F

Probability of Presence in the Hazardous Zone—F		
Parameter	**Definition**	**Comments**
F1	≤10 %	The probability of the presence of a person in the hazardous area is ≤10 % for all possible events.
F2	>10 %	The probability of the presence of a person in the hazardous area is >10 %. Applies typically for hazards spread over a large area. (e.g. events where parts of the rotor can exit the machine). All events that will only be detected if a person enters the hazardous area have to be considered with F > 10 %. EXAMPLE Cutting jet from a high-pressure system.

L.4.2.3.4 Unavoidability Under Consideration of Vulnerability—Parameter AV

L.4.2.3.4.1 General

Even if an event happens and a person is in the hazardous area, there is still a probability that the person(s) is not exposed to injury based on the following two parameters A and V.

L.4.2.3.4.2 Parameter A: Unavoidability

When a hazardous event occurs, and a person is in the hazardous area, the person may not be able to avoid injury through his/her own actions (e.g. escaping). Parameter A (see Table L.5) is the probability that the person cannot avoid injury by his/her own action.

NOTE IEC 61508/61511 uses parameter P (probability to avoid) which is the compliment of A.

L.4.2.3.4.3 Parameter V: Vulnerability

When a hazardous event occurs while a person is present in the hazardous area, and the person is unable to escape injury though their own actions, it is still possible for the person to remain uninjured due to circumstances outside of their control. This is known as Vulnerability (see Table L.5).

EXAMPLE 1 If the vicinity of the machine is flooded with gas or steam, every person in the hazardous zone will be affected; the vulnerability would approach 1.

EXAMPLE 2 If the event is caused by a debris leaving the coupling, the likelihood of a person in the hazardous area being injured is less than in example 1, and the vulnerability will be less than 1.

From the two parameters A and V, the unavoidability AV (see Table L.6) can be calculated per the formula

$$AV = A \times V$$

Table L.5—Definition of Vulnerability V and Unavoidability A

Parameter	Definition	Character	Range
V	Vulnerability	Probability	[0…1]
A	Unavoidability	Probability	[0…1]
P	Parameter P: avoidability or probability to avoid the hazardous event (P = 1- A)	Probability	[1…0]
AV	Unavoidability considering the vulnerability	Probability	[0…1]

Table L.6—Definition of the Range of the Parameter AV (Unavoidability Considering the Vulnerability)

Unavoidability AV Under Consideration of Vulnerability—AV = A		
Parameter	**Definition**	**Comments**
AV1	≤10 %	Probability ≤10 % that a hazardous event with occupied hazardous zone will lead to injury
AV2	>10 %	Probability > 10 % that a hazardous event with occupied hazardous zone will lead to injury

L.4.2.3.4.4 Probability of the Occurrence of the Unwanted Event—Parameter W

Parameter W is the number of hazardous events per year. Its purpose is to estimate the frequency of the unwanted occurrence taking place without the addition of any safety-related systems. The assumption that the unwanted event may occur does not necessarily mean that the event actually happens.

Table L.7—Definition of the Range of the Parameter W (Probability of the Occurrence of the Unwanted Event)

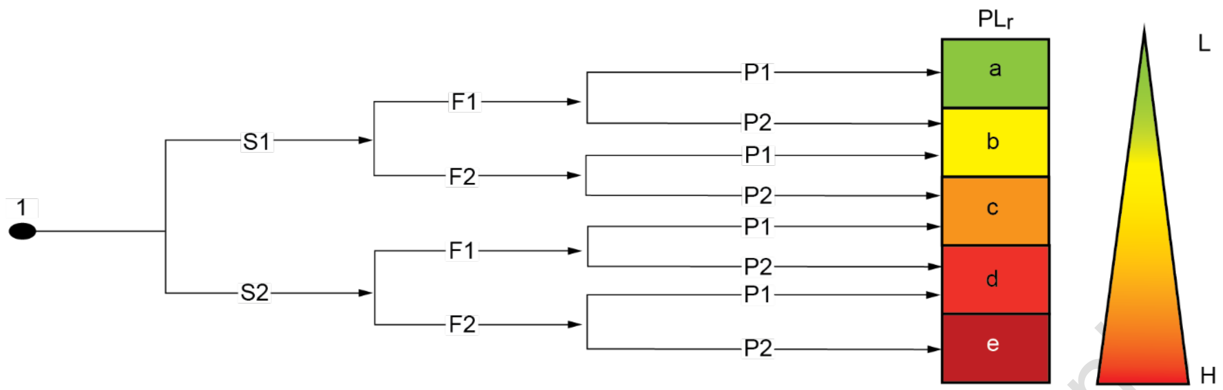
<table>
<tr><th colspan="3">Probability of the Occurrence of the Unwanted Event—W</th></tr>
<tr><th>Parameter</th><th>Definition</th><th>Comments</th></tr>
<tr><td>W3</td><td>>1 per year</td><td></td></tr>
<tr><td>W2</td><td>>1 per 10 year
≤1 per year</td><td></td></tr>
<tr><td>W1</td><td>>1 per 100 years
≤1 per 10 years</td><td></td></tr>
<tr><td>W0</td><td>>1 per 1,000 years
≤1 per 100 years</td><td rowspan="4">W0, W-1 etc. are introduced as there are hazardous situations that occur so rarely that no or only minimal risk reduction is needed, even though the severity of the harm may be high.
(Example: failure of the lubricating oil supply with standard system redundancy and reliability or embrittlement of structural parts of the gas turbine as a function of service life and low ambient temperature in combination with extreme stress such as a blade breakage)</td></tr>
<tr><td>W-1</td><td>> 1/10,000 years
≤1/1,000 years</td></tr>
<tr><td>W-2</td><td>> 1/100,000 years
≤1/10,000 years</td></tr>
<tr><td>W-3</td><td>≤ 1/100,000 years</td></tr>
</table>

L.4.2.4 Risk Graph of ISO 13849

L.4.2.4.1 The Risk Graph of ISO 13849 (see Figure L.2) looks very similar to the IEC Risk Graph. It uses the same input parameters; however, a degradation of the risk reduction in relation to the probability of the occurrence of the unwanted event (parameter W) does not exist. The parameter P (possibility of avoiding hazard or limiting harm) is used instead of parameter AV.

NOTE An example of a PL evaluation per ISO 13849 is given in L.6.3 and L.6.5.

L.4.2.4.2 ISO 13849 ignores the probability of the unwanted occurrence (W) and assumes it is high. However in turbomachinery applications, this probability is typically low. As per Table L.2 (taken from ISO 13849), a direct relationship between SIL and PL is given. For this reason, it is acceptable to use the Risk Graph (or any other method) from IEC 61508/61511 and use the evaluation method of ISO 13849, or vice-versa.



Key

1 Starting point for evaluation of safety function's contribution to risk reduction

L Low contribution to risk reduction

H High contribution to risk reduction

PL_r Required performance level

Risk Parameters

S Severity

S1 Slight (normally reversible injury)

S2 Serious (normally irreversible injury or death)

F Frequency and/or exposure to hazard

F1 Seldom-to-less-often and/or exposure time is short

F2 Frequent-to-continuous and/or exposure time is long

P Possibility of avoiding hazard or limiting harm

P1 Possible under specific conditions

P2 Scarcely possible

Figure L.2—Risk Graph as per ISO 13849

L.4.2.5 Layer of Protection Analysis of IEC 61511

L.4.2.5.1 General

Another common SIL target determination tool is Layer of Protection Analysis (LOPA). LOPA is a semi-quantitative analysis method.
The Risk Graph method as per L.4.2.3 is a suitable tool to investigate risks which are mitigated by one protection layer. This applies to most of the turbomachinery protection requirements.
In process applications, often several protection layers are in force to mitigate a single risk. For those applications, the Layer of Protection Analysis (LOPA) method is more often applied.

The LOPA method compares a calculated event likelihood with a risk target. The calculated likelihood considers the risk reduction factors of all protection layers except that of the safety instrumented function under current investigation.

Detailed information for LOPA can be found through the AIChE CCPS publications, namely:

Layer of Protection Analysis – Simplified Process Risk Assessment, ISBN: 0-8169-811-7

Guidelines for Initiating Events and Independent Protection Layers in Protection Analysis, ISBN: 978-0-470-34385-2

Guidelines for Enabling Conditions and Conditional Modifiers in Layer of Protection Analysis, ISBN:978-0-118-77783-0

L.4.2.5.2 Details of the LOPA procedure

Key parameters and methodologies used in quantitative LOPA SIL target determination include:

a) criteria for determining need for LOPA scenario analysis (i.e. Impact Event listed in Process Hazard Analysis (PHA) and associated Severity levels)
b) corporate risk targets (e.g. Target Mitigated Event Likelihood, TMEL) for each consequence severity
c) Initiating Cause and associated likelihood
d) IPLs and where applicable, enabling events and condition modifiers (CMs)
e) event likelihood

Outputs of the LOPA analysis includes:

a) SIF integrity level
b) mitigated event likelihood

Procedures on how to apply such variables and their associated data are normally documented in each company's guidance document.

L.4.2.5.2.1 Criteria for Determining the Need for LOPA

Impact events for LOPA review are normally chosen based on consequence severity in PHA study. For example, a company may perform LOPA on all "Medium" and worse safety, environmental, and commercial classifications.

L.4.2.5.2.2 Corporate Risk Targets

Before the quantitative LOPA process can be followed, a company must select their targets for each type of receptor (safety, environmental, and commercial) category. Table L.8 provides examples of Target Mitigated Event Likelihoods (TMEL) based on frequency/year for the "Medium", "Serious" and "Extensive" severity levels.

Table L.8—Examples of Risk Targets

Severity	Level	TMEL (1/yr)
S1	Medium	1.0E-03
S2	Serious	1.0E-04
S3	Extensive	1.0E-05

L.4.2.5.3 Initiating Cause Likelihood

An initiating cause could result in a hazard if not prevented or mitigated by safeguards. Examples of initiating causes common to turbomachinery equipment LOPA reviews are included in the following Table L.9:

Table L.9—Examples of Turbomachinery Initiating Causes

Initiating Cause #	Level	Frequency
1	Upstream/Downstream XV spurious closure	0.1/yr
2	Drum level control failure	0.1/yr
3	Coupling failure	0.01/yr
4	Anti-Surge control failure during process transient	0.1/yr
5	Motorized pump/compressor failure	0.1/yr
6	Manual valve inadvertently in wrong position after turnaround	0.01/yr

7	Governor or AFD speed control failure	0.1/yr

L.4.2.5.4 Independent Protection Layers (IPL), Enabling Events, and Conditional Modifiers

To prevent the hazard once an initiating cause has occurred, an IPL must be successfully applied. To distinguish them from simple safeguards like signs and warnings, the following four (4) rules must be met to be considered a true IPL:

1. specific – designed and capable of fully preventing/mitigating the risk
2. auditable – tested routinely with documented performance
3. independent – have no common mode failure attributes to the initiating cause and other IPLs
4. dependable – designed to meet a minimum probability of failure (PF) (e.g. PF≤0.1)

Common IPLs for turbomachinery are included in the following Table L.10.

Table L.10—Examples of Turbomachinery IPLs

Initiating Cause #	Level	PF
1	High level alarm and operator response	0.1
2	Basic process control loop (Anti-surge, pressure, other)	0.1
3	Mechanical overspeed trip bolt	0.1
4	Mechanical pressure relief	0.01
5	SIF (SIL1 to SIL3)	0.1 to 0.001

Additionally, some companies apply conditional modifiers to account for general conditions that the event will reach the full consequence stated in the PHA. The following Table L.11 contains a few CMs applied in turbomachinery applications.

Table L.11—Examples of Turbomachinery Conditional Modifiers

Initiating Cause #	Conditional Modifier Description	PF^{CM}
	Ignition Probability (Pi)	
1a	Ignition probability after high impact event	1.0
1b	Ignition of gas heavier than air - low impact event	0.5
1c	Ignition of gas lighter than air - low impact event	0.1
	Occupancy Modifier (Pp)	
2a	Highly occupied area - Normal operations	1.0
2b	Low occupancy area - Normal operations	0.1
2c	Documented Exclusion Zone - Plant Start-up	0.01

L.4.2.5.5 SIF Integrity Level

A SIF will be required if the current event likelihood is not less than the corporate risk target for the hazard's stated consequence level. To determine the required probability of failure dangerous on demand (PFD_{avg}) of the SIF, the event likelihood is divided by the corporate risk target.

The overall integrity level target for the SIF is based on the category in Table L.1 that meets the PFD_{avg}^{SIF}. For example, if the calculated PFD_{avg}^{SIF} is $5.4x10^{-2}$ which is less than 10^{-1}, but greater than 10^{2}, the integrity level that should be selected is SIL 2.

L.4.2.5.6 Mitigated Event Likelihood

Once the PFD_{avg}^{SIF} is available through verification calculations, the final mitigated event likelihood (MEL) can be calculated. The MEL should always be less than the TMEL to demonstrate that risk target has been achieved by the design SIF.

L.4.3 Risk Assessment by Other Methods

There are a number of other methods available for risk assessment, e.g. the Risk Matrix as per IEC 61511-3, Annex C. Details of these methods can be found in their respective standards.

L.4.4 Safety Requirement Specification

After the SIL/PL is determined, the next step in the process of functional safety is to develop a safety requirement specification (SRS). This describes all aspects of the required safety system including the test procedure for the validation test along with the acceptance criteria. Details are given in the respective standards, e.g. IEC 61511 Part 1 and 2.

L.4.5 Selection of Design and Architecture

L.4.5.1 The design process starts with the development of a system function block diagram. This is converted into a reliability block diagram by deleting all those components which are not safety relevant. Among others, the fault tree analysis as per ISA-TR84.00.02- Part 3 is an appropriate method.

L.4.5.2 For a selected SIS, the following three constraints must meet or exceed the requirements of the needed SIL level: Architectural, Systematic Capability and PFD/PFH.

L.4.5.2.1 Architectural:

This is based on hardware fault tolerance (HFT). Reference 61508-2. A higher number in HFT can compensate for a lower SFF, or vice- versa.

HFT can achieve higher SILs. The higher the SIL, the higher the required Safe failure fraction (SFF). This describes the fraction of safe and dangerous detected failures divided by all failures (including undetected).

L.4.5.2.2 Systematic Capability:

Systematic capability (SC) is a qualitative assessment of the supplier's quality management system to ensure safety equipment is designed with procedures intended to prevent systematic design errors.

It is a measure (expressed on a scale of SC 1 to SC 4) of the confidence that the systematic safety integrity of an element meets the requirements of a particular SIL. The SC level must be equal to or greater than the intend SIF's SIL level.

All components of a SIS shall be selected to meet the intended SIL resulting from the risk analysis.

Each vender of SIL assessed devices to IEC61508 will provide their component's SIL Capability limit and hardware fault tolerance requirement (which some may refer to as redundancy) based on the SIL application. (e.g. For SIL3 applications, 2 sensors may be required).

L.4.5.2.3 Probability of Failure PFD/PFH

The Probability of Failure on Demand (PFD_{avg}) of the entire loop should be lower than what is required for the SIL/ PL. The higher the SIL, the lower the acceptable PFD_{avg}. The primary contributors to the calculation are the dangerous undetected failures and the proof test interval. Reference 61508-6.

Proof test interval. During a proof test, the functionality of the SIS is verified. After a proof test, the SIS's reliability is reset to near new condition (depending on the proof test coverage). The effects of a non-perfect proof test are described in L.4.6.2 and IEC 61508-6.

If redundancy is used to improve the functional safety, care should be taken regarding common-cause failures. These are typically the most dominant factors during the SIL/PL evaluation. The probability of common- cause failures is described by the factor ß and is included in the PFD calculation.

L.4.6 Perfect and non-perfect proof test as per IEC 61508-6.

Two kinds of tests are known. Diagnostic tests are typically initiated automatically every few minutes or hours. Purpose of these diagnostic tests is to reduce the rate of undetected dangerous faults λ_{DU}. Unlike online diagnostic tests, proof tests are typically a manually initiated system test whose task is to test the λ_{DU} faults missed by the online diagnostics and prove that the protection system is in an error free status.

The supplier should provide the detailed proof test plan to achieve the estimated efficacy.

In a PFD (t) diagram like Figure L.3 or Figure L.4, λ_{DU} determines the slope of the PFD (t) curve whereas a proof test initiates the step down in the PFD (t) curve. λ_{DU} is a characteristic design figure of a given protection system whereas proof test rate and coverage are typically dictated by operational constraints.

L.4.6.1 Perfect proof test

Although unlikely in a complex system, a perfect proof test covers all dangerous failure modes and reduces PFD (t) back to zero or like new state.

Figure L.3 shows an example of the trend of PFD (t) for a perfect proof test. Shown in blue is PFD (t), in red the maximum acceptable PFD_{avg} as received from the SIL calculation (PFD_{avg_Target}) and in green the actual PFD_{avg} as per the selected design. Each proof test is able to detect all dangerous faults and brings PFD (t) down to zero. PFD_{avg} is constant during the entire lifetime of the protection system.

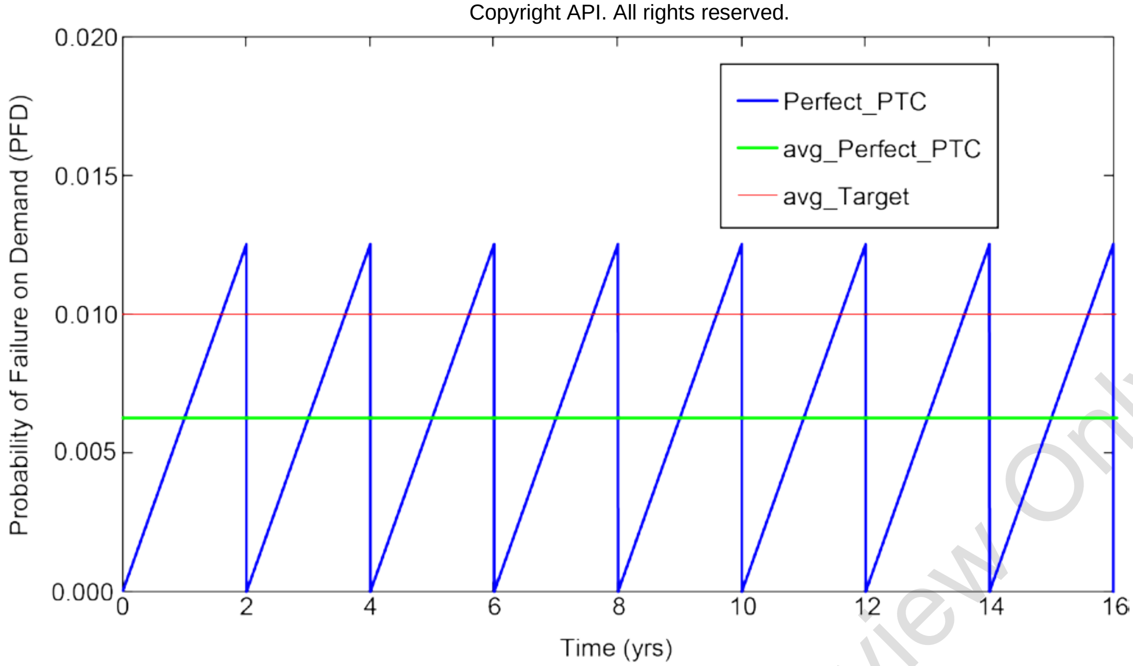


Figure L.3—Perfect Proof Test

L.4.6.2 Non-Perfect proof test

More commonly a proof test can only cover a fraction of all known dangerous failure modes and is therefore considered as a non-perfect proof test. The fraction which is covered is known as the proof test coverage (PTC). The PTC should be provided by the supplier.

Example: A partial stroke test of a valve or stroke test which does not test valve's closing speed and tightness are both considered to be non-perfect proof tests.

The effects of a non-perfect proof test are shown below in Figure L.4, which uses the same parameters from the previous example in Figure L.3, but for a non-perfect proof test with a PTC of 90%. Since each proof test can only detect 90 % of all λ_{DU} faults, the PFD_{avg} increases over time. The green curve in Figure L.4 shows this increase of PFD_{avg} due to the 10% of un-detected λ_{DU} faults.

After 10 years, the PFD_{avg} exceeds the PFD_{avg_Target}, which indicates that the system no longer meets the requirements of the specified SIL and the system either needs to be replaced or tested with a more thorough proof test.

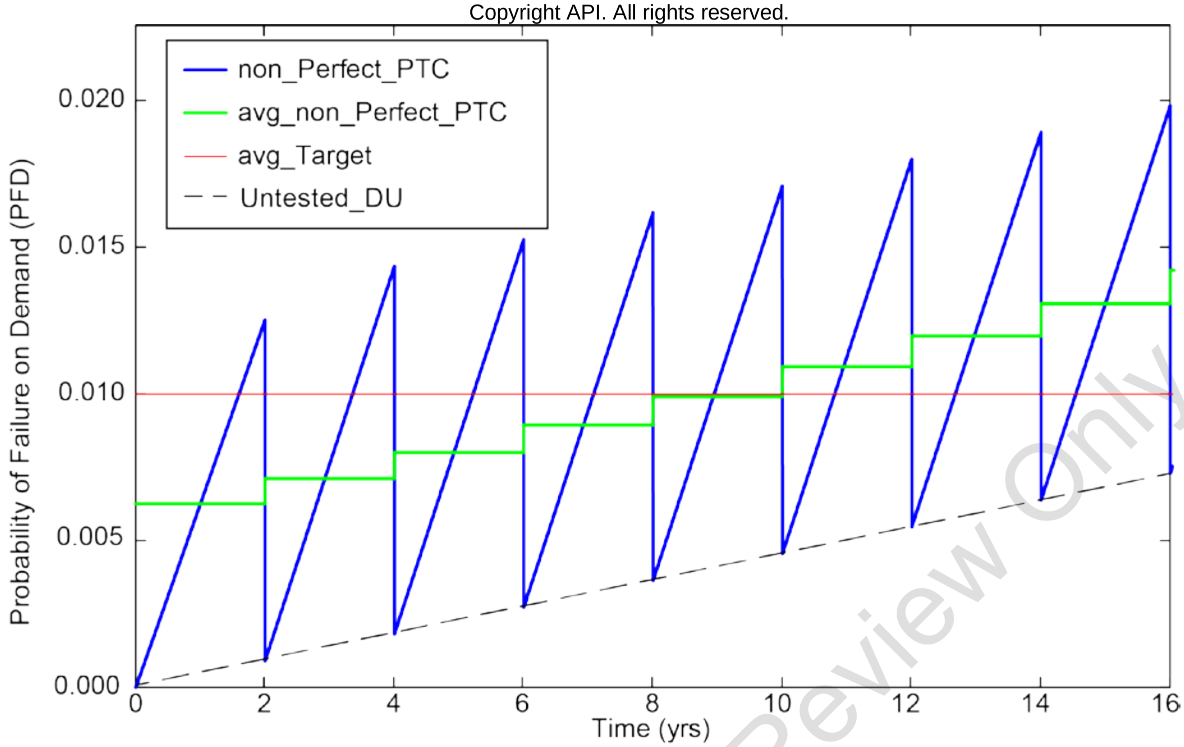


Figure L.4—Non-perfect Proof Test

More information for non-perfect proof test coverage can be found in IEC 61508-6 section B.3.2.5 which provides the formula to calculate the impact of the coverage rate on the PFD_{avg}.

If the system verification shows that the actual achieved SIL/PL is lower than the required one, any or several of the above parameters as listed in L.5.3.1 should be improved and the Safety Requirement Specification has to be changed accordingly.

L.4.7 SIL/PL Evaluation

L.4.7.1 After the SIS has been designed, the SIS should be evaluated to prove that the selected architecture along with the properties of the selected components meets the requirements stated in the safety requirement specification (SRS). There are different methods available for SIL evaluation. The most common method for complex systems is a SIL verification calculation, using different safety-specific parameters which should be made available from the component vendor or be taken from industry-accepted data bases. The basics for these calculations are given in IEC 61508 Part 6. In some applications, a method with simplified equations as per ISA-TR84.00.02- Part 2 may be used. Care should be taken that the simplifications are acceptable for the system under review.

L.4.7.2 Complex systems such as ones using programmable logic solvers should be evaluated thoroughly by either using detailed equations or a Markov analysis similar to the method described in ISA-TR84.00.02 - Part 5.

L.4.7.3 Many software packages are available to facilitate the detailed SIL verification calculations. These software packages typically use approximation techniques for obtaining the results. As with any software tool, the user is cautioned to understand the equations, mathematics, and any simplifying assumptions, restrictions, or limitations.

NOTE Above taken from ISA-TR84.00.02-, Part 3.

L.4.7.4 The selected SIS has to meet several conditions to be allowable in a distinctive SIL application:

a) The Probability of Failure on Demand (PFD_{avg}) of the entire loop should be lower than what is required for the SIL/ PL. The higher the SIL, the lower the acceptable PFD_{avg}.

b) For higher SIL, system redundancy is required. This is defined by the HFT. Refer to tables in IEC 61511.

c) Safe failure fraction (SFF) describes the fraction of safe and dangerous detected failures compared to all possible failures. The higher the SIL, the higher the required SFF. A lower number in SFF can be compensated by a higher HFT, or vice- versa.

d) Proof test interval. during a proof test, the full functionality of the SIS is verified. After a proof test, all tested components of the SIS are in as-new condition, or as close as possible to new. Refer to L.4.6.2 for non-perfect proof tests.

e) Proof Test Coverage (PTC). This parameter covers any remaining undetected dangerous failure rates which are not detected by a Proof Test.

f) Systematic Capabilities. Each component of the SIS needs to have a systematic capability which meets the respective SIL requirements (refer to L.4.5.2.2).

L.4.7.5 If redundancy is used to improve the functional safety, care should be taken regarding common-cause failures. These are typically the most dominant factors during the SIL/PL evaluation. The probability of common-cause failures is described by the factor ß.

L.4.7.6 ISO 13849 uses a slightly different semi-quantitative approach. The parameters are as follows.

a) Mean Time To Fail to dangerous condition ($MTTF_d$).

b) Diagnostic coverage is the ratio of detected dangerous failures in relation to the total number of dangerous failures (Table L.14). These are clustered into three groups (low, medium, high).

c) The system architecture of the SIS is clustered into 5 categories (B, 1, 2, 3, and 4). They differ in the diagnostic capabilities. Categories B and 1 have no diagnostics; category 4 is fully redundant with extended checks.

L.4.7.7 Figure L.5 indicates which combination of parameters is acceptable for a given PL. The higher the required risk reduction, the stronger the requirements on $MTTF_d$, diagnostic coverage, and system architecture (category).

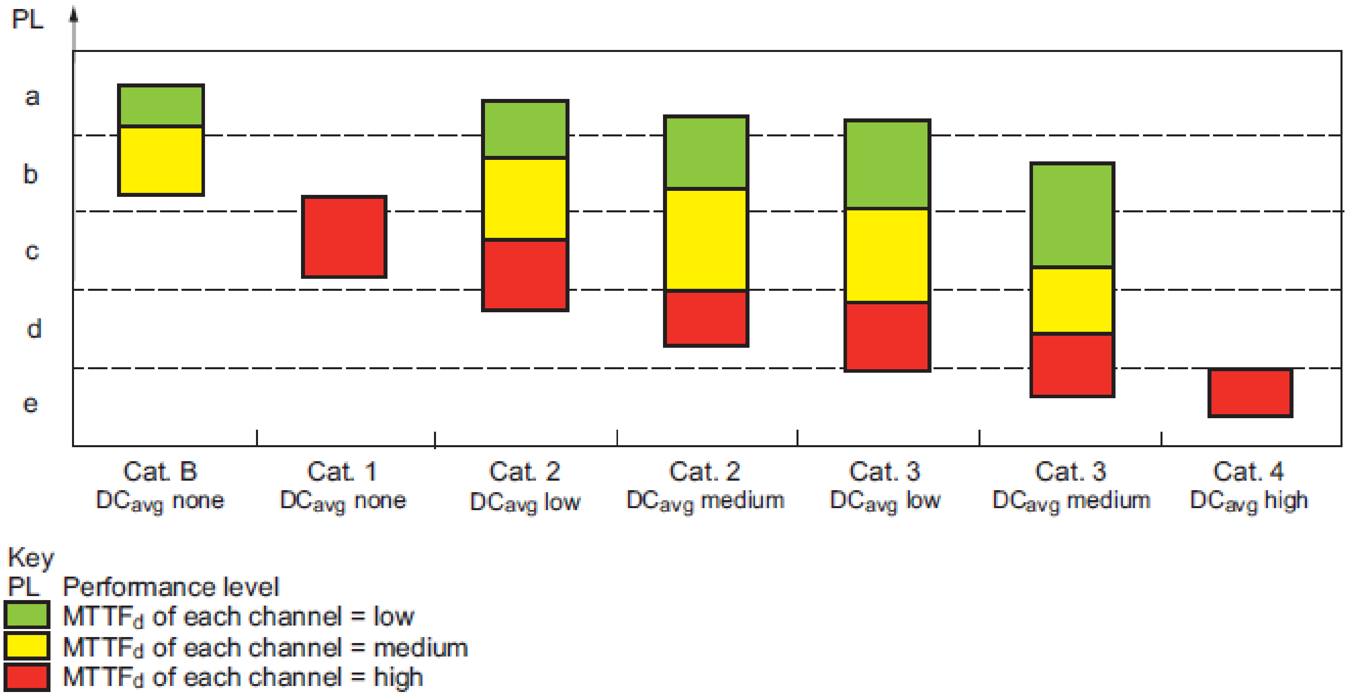


Figure L.5—Relationship Between Categories, DC_{avg}, $MTTF_d$ of Each Channel, and PL

L.4.7.8 If the achieved risk reduction factor exceeds the necessary reduction factor, the SIS may be built. If the actual risk reduction factor is lower than the required one, the system architecture and/or the component selection should be reviewed. All decided changes should to be incorporated into the SRS, and the SIL/PL evaluation process has to start again.

L.4.7.9 If the selected architecture cannot be found in the standard, the closest available standard with a lower degree of safety should be selected.

L.4.8 Verification and Validation

L.4.8.1 After each process step, the SIS should be verified against the safety requirement specification. Finally, the SIS should be tested as per the test plan and test criteria given with the safety requirement specification. If the system cannot meet the requirements, the process of functional safety shall start from the beginning with an SRS that reflects the changes.

L.4.8.2 Select components matching the blocks in functional block diagram and RBD:

a) list the available components;

b) delete those components from the list for which the equipment vendor cannot certify the suitability for the required SIL/PL;

c) if the required SIL is greater than 2, discard entries for which SIL is not certified by an organization independent of the vendor. Preferably the certificate should have been issued by a recognized certifying body;

d) have the selected vendors provide all system data as per L.5.3.1.

L.5 Responsibilities

L.5.1 End User Responsibilities

L.5.1.1 The end user has the ultimate responsibility for the safety of the plant. In his risk assessment and SIL/PL evaluation, the end user should follow IEC 61508, IEC 61511, respectively.

L.5.1.2 The RFQ should indicate any minimum architectural requirements (e.g. one-out-of-one, two-out-of-three). It is recommended the end user conduct a risk analysis to determine the required degree of risk reduction for each protection loop. This risk analysis should be done in conjunction with the machine vendor as part of their hazard and operability study and SIL reviews.

L.5.1.3 The RFQ should also indicate the shortest acceptable proof test interval for those tests which affect the process. Partial stroke tests or other proof tests which have minor or no effect on the process may be performed more frequently.

L.5.1.4 The end user will perform a SIL/PL evaluation based on the data provided by each vendor to verify that the entire loops meets all functional safety requirements.

L.5.2 Machine Vendor

L.5.2.1 Machinery safety is regulated in Europe by the Machinery Directive 2006/42/EC.

L.5.2.2 Machine protection standards such as ISO13849 (PL) and IEC 62061 (SIL) as well as IEC 61508 and 61511 are widely used by the machine manufacturers.

L.5.2.3 Based on these standards, the machinery vendor has to perform his own risk assessment which is a prerequisite for supplying a safe machine.

L.5.3 Equipment Vendor Responsibilities

L.5.3.1 The equipment vendor provides all necessary data that are required by end user and machine vendor to perform their risk assessment and SIL/PL evaluation. These are (amongst others):

a) probability of failure on demand for each subsystem (PFD_{avg}; PFH)

b) proof test interval used for data of L.5.3.1.a

c) proof test plan and proof test coverage

d) hardware fault tolerance

e) safe failure fraction (SFF)

f) undetected failure rate λ_{DU}

g) mean time to fail ($MTTF_d$)

h) mean time to repair (MTTR)

i) systematic capability

j) Component type, A (noncomplex) or B (complex)

L.5.3.2 If the risk analysis of the end user and the machine vendor comes up with different results for the required SIL/PL, then the highest SIL/PL requirement will govern.

L.6 Examples

L.6.1 General

The intention of this section is to provide a basic overview of functional safety principles rather than a user guideline for specific applications. The following examples are generic rather than specific. Two protection loops (Figure L.6 and Figure L.7) will each be evaluated and assessed using IEC 61511 and ISO 13849 to compare and contrast the techniques of each standard.

L.6.1.1 Typical Protection Loop with Single Solenoid Valve

Figure L.6 shows a typical protection loop, consisting of sensor, signal conditioner, monitor, logic solver, solenoid valve, and stop valve. The loop illustrates a one-out-of-one architecture with one sensor per plane and a simplex logic solver with a single solenoid valve. It can represent a shaft vibration protection loop, a single-channel axial displacement protection loop, a temperature protection loop with local temperature transmitter, or even a single-channel overspeed protection loop.

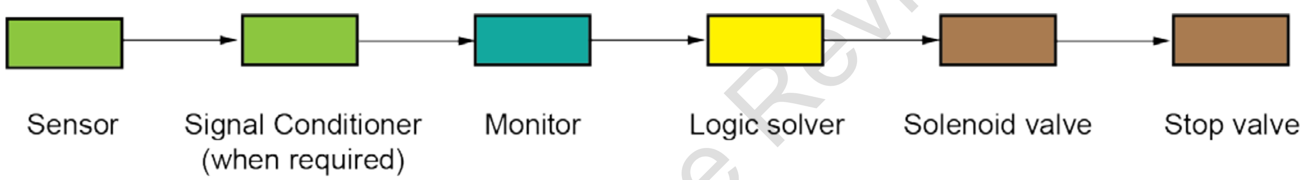


Figure L.6—Functional Block Diagram of Typical Protection Loop with a Single Solenoid Valve

L.6.1.2 Typical Protection Loop with Dual Solenoid Valve

Figure L.7 illustrates the same loop as Figure L.6 except with redundant solenoid valves.

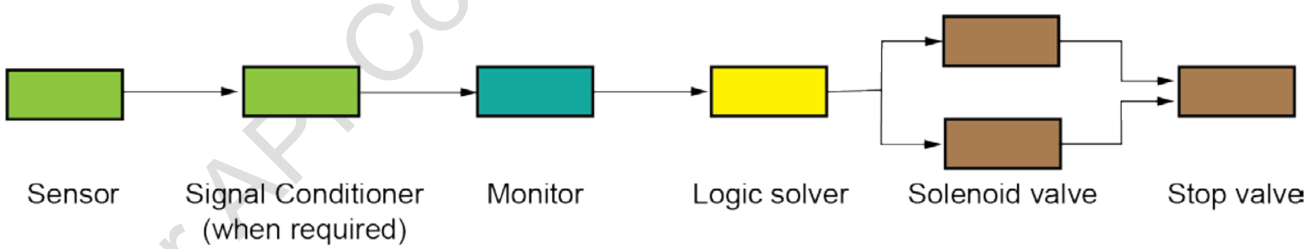


Figure L.7—Functional Block Diagram of Typical Protection Loop with a Dual Solenoid Valve

L.6.2 Example 1A—Loop Evaluation using IEC 61508, 61511, 62061 Quantitative Method

L.6.2.1 Establish SIL Requirement Using Risk Graph of IEC 61508/VDMA 4315

L.6.2.1.1 Using Risk Graph of IEC 61508/VDMA 4315

L.6.2.1.1.1 Example 1A illustrates a risk assessment of the loop in Figure L.6 made using the Risk Graph of Figure L.1. The unwanted event, for example, is serious personnel injury. Assume the following parameters have been established.

a) The severity is S2.

b) The frequency of exposure time is assumed to be more than 10 % (for more than 10 % of the total operation time, a person is located in an area where the unwanted event may harm them), thus F = F2.

c) The probability that a hazardous event will lead to harm depends largely on how the event develops. As this cannot be fully determined, a conservative assumption AV2 is made (the probability that the event may harm a person is higher than 10 %).

d) It is assumed that such an event may happen between once per year and once in 10 years. W = W2.

Therefore, using Figure L.1 and the above assumptions, SIL 2 is identified for this risk.

L.6.2.1.1.2 If the machine room is occupied only occasionally (less than 10 % of the total operation time), F can be selected to F1. This leads to SIL 1. The same applies if the probability that the unwanted event happens is less than once in ten years (W = W1).

L.6.2.2 Evaluate Loop SIL using qualitative IEC 61508 method IEC 61511

L.6.2.2.1 Data for PDF Calculation

For the loop in Figure L.6, the equipment vendor provided following data.

a) Input system:

— PFD_{avg} per probe and transducer PFD_{avg} = 2.56E-4,

— safe failure fraction, SFF = 0.65,

— Type A components (noncomplex).

b) Logic solver:

— PFD_{avg} for the monitoring system PFD_{avg} = 1.58E-3,

— PFD_{avg} for logic solver PFD_{avg} = 1.70E-4,

— safe failure fraction SFF = 0.95,

— Type B components (complex).

c) Output subsystem:

— PFD_{avg} for trip solenoid valve PFD_{avg} = 8.72E-3,

— PFD_{avg} for stop valve PFD_{avg} = 3.75E-3,

— safe failure fraction SFF = 0.62,

— Type A components (noncomplex).

d) Common data for all parts:

— hardware fault tolerance, HFT = 0,

— proof test interval, TI = 2 years,

— mean time to repair, MTTR = 8 h.

L.6.2.3 Calculation of Probability of Dangerous Failure of the Loop

The PFD_{avg} calculation provides PFD_{avg} = 1.45E-2 for the complete safety loop. This is summarized in Table L.12. This figure is higher than the acceptable 1E-2 for SIL 2 (see Table L.1). Consequently, this system may be used as SIL 1 only.

Table L.12—Table of Calculated PFD_{avg} for Example of L.8.2.2

PFD_{avg}	Device or Component
2.56E-4	Sensor and Signal Conditioner
1.58E-3	Monitor
1.70E-4	Logic Solver
8.72E-3	Solenoid Valve
3.75E-3	Stop Valve
1.45E-2	Example 1A (Overall Value)

L.6.2.4 Architectural Constraints and Systematic Capabilities of the Loop

L.6.2.4.1 Input Subsystem

The sensor and signal conditioner are both Type A components (noncomplex), so the architectural constraints according to IEC 61508-2 Table 2 allow a maximum rating of SIL 2 because SFF > 60 % at HFT = 0.

L.6.2.4.2 Logic Solver Subsystem

Monitor and logic solver are both Type B components (complex), so their architecture is evaluated according to IEC 61508-2, Table 3. SFF = 95 % and HFT = 0 allow a maximum rating of SIL 2.

L.6.2.4.3 Output Subsystem

Solenoid valve and stop valve are noncomplex Type A components. SFF = 62 % and HFT = 0 allow a maximum rating of SIL 2.

L.6.2.5 Results of the Loop Evaluation per 61508 quantitative method

The architectural constraints (SFF and HFT) for all subsystems would allow up to SIL 2. However, the probability of failure (PFD_{avg}) for the complete safety loop restricts the safety function to a maximum rating of SIL 1. The trip solenoid is the weakest item in the loop, (i.e. highest PFD_{avg}) and therefore an improvement can be made by putting two solenoids in parallel. This is discussed further in Example 1B (L.6.3).

It is assumed that all other Systematic Capability and Proof Test parameters are met.

NOTE There are different measures available to increase the degree of risk reduction, e.g. shorten the proof test interval, select components with lower probability to fail, or install redundancy.

L.6.3 Example 1B—Loop Evaluation Using ISO 13849

L.6.3.1 Establish PL Requirements Using Risk Graph of ISO 13849

L.6.3.1.1 With the same risk assessment as for the IEC Risk Graph (L.4.2.3), the ISO parameters are selected for S2, F2 and P2. The corresponding ISO Risk Graph is found in L.4.2.4. For the example under consideration, the required performance level is PL_{re}. PL_{re} is equivalent to SIL 3.

L.6.3.1.2 ISO 13849 ignores the probability of occurrence of the unwanted event (W). However, for a high probability event (W = W3), both the Risk Graphs of both standards give the same required performance (protection) level (SIL 3 and PL_{re}).

L.6.3.2 Evaluate Loop Using ISO 13849

L.6.3.2.1 Architectural Constraints of the Loop

L.6.3.2.1.1 The architecture of Figure L.7 (a simplex protection loop without any automated checking of the safety function) fits in Category 1 per Figure L.5. Per Figure L.5, PL_{re} requires Figure L.7 architecture Category 3 (full redundancy where HFT = 1 with diagnostic tests) and a high value of MTTF, i.e. > 30 years. The diagnostic coverage may be medium or high.

L.6.3.2.1.2 If the location of the machinery is occupied less than 10 % of the time, F = F1 and the required performance level is PL_{rd}. Per Figure L.7, this performance level requires either Category 2 with high MTTF or Category 3 with medium to high MTTF. The diagnostic coverage should be low to medium.

L.6.3.3 PL Evaluation as per ISO 13849

Using the previous information and the additional equipment vendor data:

a) $MTTF_d$ per sensor and signal conditioner MTTF = 39.6 years,

b) $MTTF_d$ per the monitor and logic solver MTTF = 19.5 years,

c) $MTTF_d$ per trip solenoid MTTF = 20 years. The resulting total loop MTTF is 7.9 years low. The requirements are not met.

The resulting total loop MTTF is 7.9 years while the required MTTF (Table L.13) needs to be more than 10 years for medium denotation. The requirements are not met. If the loop does not meet architectural requirements and the requirement for medium to high MTTF, then the selected SIS is not suitable to be used as a PL_{rd} or PL_{re} loop. In order to meet the MTTF, the architecture or the component selection should be revised. The SRS should also be revised and the PL_r evaluation repeated.

Table L.13—Mean Time to Dangerous Failure of Each Channel ($MTTF_d$)

$MTTF_d$	
Denotation of Each Channel	**Range of Each Channel**
Low	3 years ≤ $MTTF_d$ < 10 years
Medium	10 years ≤ $MTTF_d$ < 30 years
High	30 years ≤ $MTTF_d$ ≤ 100 years

NOTE 1 The choice of the $MTTF_d$ ranges of each channel is based on failure rates found in the field as state-of-the-art, forming a kind of logarithmic scale fitting to the logarithmic PL scale. An $MTTF_d$ value of each channel less than three years is not expected to be found for real SRP/CS since this would mean that after one year about 30 % of all systems on the market will fail and will need to be replaced. An $MTTF_d$ value of each channel greater than 100 years is not acceptable because SRP/CS for high risks should not depend on the reliability of components alone. To reinforce the SRP/CS against systematic and random failure, additional means such as redundancy and testing should be required. To be practicable, the number of ranges was restricted to three. The limitation of $MTTF_d$ of each channel value to a maximum of 100 years refers to the single channel of the SRP/CS that carries out the safety function. Higher $MTTF_d$ values can be used for single components (see Table D.1 in ISO 13849).

NOTE 2 The indicated borders of this table are assumed within an accuracy of 5 %.

Table L.14—Diagnostic Coverage

Diagnostic Coverage	
Denotation	**Range of Each Channel**
None	Diagnostic Coverage < 60 %
Low	60 % ≤ Diagnostic Coverage < 90 %
Medium	90 % ≤ Diagnostic Coverage < 99 %
High	99 % ≤ Diagnostic Coverage

NOTE 1 For SRP/CS consisting of several parts, an average value DC_{avg} for diagnostic coverage is used in Figure 5, Section 6, and E.2 of ISO 13849.
NOTE 2 The choice of the diagnostic coverage ranges is based on key values 60%, 90%, and 99 % also established in other standards (e.g. IEC 61508) dealing with diagnostic coverage of tests. Investigations show that (1 – diagnostic coverage) rather than diagnostic coverage itself is a characteristic measure for the effectiveness of the test. (1 – diagnostic coverage) for the key values 60%, 90%, and 99% forms a kind of logarithmic scale fitting to the logarithmic PL scale. A diagnostic coverage value less than 60% has only slight effect on the reliability of the tested system and is therefore called “none.” A diagnostic coverage value greater than 99% for complex systems is very hard to achieve. To be practicable, the number of ranges was restricted to four. The indicated borders of this table are assumed within an accuracy of 5 %.

L.6.4 Example 2A—Loop Evaluation using IEC 61508, 61511, 62061 quantitative method

L.6.4.1 The risk assessment for the loop (Figure L.6) shown in example 1 results in a required SIL 2 if the machinery location is frequently occupied by persons. The impact of adding a parallel solenoid valve (Figure L.7) is demonstrated in Example 2.

L.6.4.2 Using the same equipment vendor-provided data (L.6.2.2.1) used in Example 1 for the calculation of the PFD_{avg} for the loop in Figure L.7, a common cause factor ß = 0.05 (typical value) is estimated. This gives a PFD_{avg} of 6.27E-3 (Table L.15) for the loop with two parallel solenoids. This is below the required value of 1E-2; therefore the arrangement meets the required SIL 2.

L.6.4.3 Since the architectural constraints of example 1A already met the requirements of SIL 2, the higher fault tolerance in example 2A with parallel solenoids will only improve on it. Therefore, the requirements of functional safety are met.

Table L.15—Table of Calculated PFD_{avg} for Example in L.8.5

PFD_{avg}	**Device or Component**
2.56E-4	Sensor and Signal Conditioner
1.58E-3	Monitor
1.70E-4	Logic Solver
5.12E-4	Solenoid Valve, One-out-of-two Fault Tolerant
3.75E-3	Stop Valve
6.27E-3	Example 2A (Overall Value)

L.6.5 Example 2B - Loop Evaluation using ISO 13849

As already explained in L.6.3.2.1.1, a PL_{re} loop should have full redundancy (HFT = 1). For PL_{rd}, a single loop architecture with self-diagnostic feature may be used (Category 2), if MTTF is above 10 years (medium). The parallel arrangement of the two solenoid valves increases the MTTF to 12.65 years which is medium. This loop meets the requirements of PL_{rd}.

L.6.6 Proof by Reverse Consideration

L.6.6.1 The process of functional safety requires making several assumptions in regard to the consequences of an unwanted event and in regard to the probability that an unwanted event happens. It is often very difficult to determine the probability of the occurrence of the unwanted event without a MPS present (parameter W). Field experience- based data always have a MPS in place.

NOTE Risk analyses require information on how often an event happens without a protection system in place. In practice, however, all real installations are equipped with protection systems. Thus, all field-experienced based data (from events that happened) reflect installations which have a MPS in place. Overspeed analyses for example, need to estimate a figure of how often an overspeed trip event with harm to people or environment will occur if an overspeed trip system is not installed. Such an estimate is not known since all turbines in the field have an overspeed trip system installed and all experience-based data refers to installations with a MPS in place. A count of how often the MPS was activated will result in incorrect estimates as not each event which made the MPS respond would have resulted in an accident.

L.6.6.2 At the end of a complex calculation process, it is good engineering practice to check whether the result is in line with field experience. This check can be used if the MPSs in use are of similar or lesser quality than those specified.

L.6.6.3 The probability of occurrence of the unwanted event W (Table L.7), multiplied by the risk reduction factor, which is determined by the SIL (Table L.1), gives the remaining probability that the unwanted event occurs even with the safety system in place. It is recommended to compare this remaining probability with actual statistics from machines in operation.

L.6.6.4 An example of the reverse consideration follows.

L.6.6.4.1 The risk analysis for shaft vibration being unacceptably high is typically classified as W1 which assumes that the unwanted event (risk of harm to a person if shaft vibration trip is not present) occurs less than once in 10 years.

L.6.6.4.2 The MPSs commonly in use are certified for SIL 1 which is equivalent to a risk reduction factor of 10 to 100 which allows that the safety function fails to stop the machine once in 10 to one of 100 cases (refer to Table L.1).

L.6.6.4.3 A machine that is protected by a MPS (per the above data) may be exposed to an unwanted event (injury or death of person) in one in 100 up to one in 1,000 years, even with the MPS in place.

L.6.6.4.4 The actual field experience with current installations shows that there is not more than one event (personal injury due to missed vibration trip) in 1000 years.

L.6.6.4.5 Therefore, this proves that the selected degree of risk reduction is adequate.

Annex M The Use of Functional Safety Methodology to reduce Economic Losses and Redundancy to avoid Spurious Shutdowns

(informative)

M.1 General

M.1.1 Functional safety is a mandatory requirement for health to personnel and the environment.

M.1.2 Annex L provides an overview to the concept of functional safety and SILs as they pertain to MPS's in regard to personnel and environmental protection. It assumes that a particular SIF is designated purely or primarily for safety-related reasons. In contrast, this annex discusses the voluntary application of SIL ratings and other methods to MPS's in order to reduce risk of equipment damage or economic losses. Such cases could be referred to as commercial integrity level (CIL) or asset integrity level (AIL) targets.

M.1.3 When evaluating methods to reduce losses, an optimum solution to meet both equipment protection and process availability, needs to be established.

M.1.3.1 Equipment protection describes the capability of a system to provide the expected degree of protection to assets.

M.1.3.2 Process availability describes the capability of a system to provide the expected degree of undisturbed process operation.

M.1.4 For Health, Safety, and Environment (HSE) risks, safety integrity always has priority. When asset losses are evaluated, an optimum between equipment protection and process availability is required as economic losses may result from failed equipment protection and/or low process availability due to spurious shutdown.

M.1.5 Section M.2 discusses the use of functional safety to avoid losses through equipment damage. Section M.3 discusses the use of redundancy to improve process availability while maintaining equipment protection.

M.1.6 Regardless of whether there are HSE-related consequences associated with a machinery failure, there will almost always be economic or asset consequences for the classes of machinery addressed by an API 670 protection system. Such economic consequences include, but are not limited to, machinery repair or replacement costs and/or lost-production costs.

M.1.7 When large enough, these costs can prompt end users to specify additional measures beyond the requirements in regard to HSE.

M.1.8 In such cases, the end user may specify the application of the process of functional safety (including SIL rating) not because they are required to do so by safety-related laws or regulations but rather as an entirely voluntary method of mitigating exposure to economic risk

M.1.9 If the voluntary application of the process of functional safety to reduce economic losses results is more severe SIL/AIL/CIL requirements than the HSE protection, the highest requirement should govern.

M.1.10 Economic losses may result from the following situations.

M.1.10.1 If a protection system fails to shut down the equipment in a dangerous condition, the following economic losses may result from this abnormal situation:

a) Cost of parts to repair or replace a damaged equipment
b) Manpower for equipment repair
c) Production losses for waiting time till repair can start
d) Lost production during repair time
e) Lost raw process material during process restart

The equipment vendor is able to deliver basic data for a) and b), the impact of c) to e) has to be determined by the equipment operator.

M.1.10.2 If the equipment is shut down without the need for a shutdown, following economic losses may result from this spurious shutdown:

a) Lost production
b) Lost raw process material during process restart

M.1.11 Economic losses resulting from spurious shutdowns and trips can be reduced by the use of redundant (e.g. fault tolerant) systems.

M.1.12 ISA TR84.00.02, Part 1 provides information to determine the false shutdown, nuisance shutdown, or spurious shutdown rate. ISA TR84.00.02, Part 2 describes method to reduce the number of spurious shutdowns to an acceptable level.

M.2 Reduction of Economic Losses through Functional Safety

M.2.1 The process of Functional Safety can be applied to avoid economic losses due to missed shutdowns. Instead of Safety Integrity Levels SIL, the terms CIL or AIL are used.

M.2.2 The process starts with a risk analysis which investigates all operational risks which may result in economic losses as per M.1.10. Next step is the application of the methods of functional safety with known techniques such as Risk Graph, LOPA or others.

M.2.3 It has to be noted that the use of functional safety for reduction of economic losses is purely voluntary and each Risk Graph needs to be calibrated individually for each application. Following Risk Graph is an example for educational purposes only.

M.2.4 The Risk Graph below is basically the same as for personal protection, see Annex L. The calibration of the severity needs to be made in asset impact instead of harm to personnel.

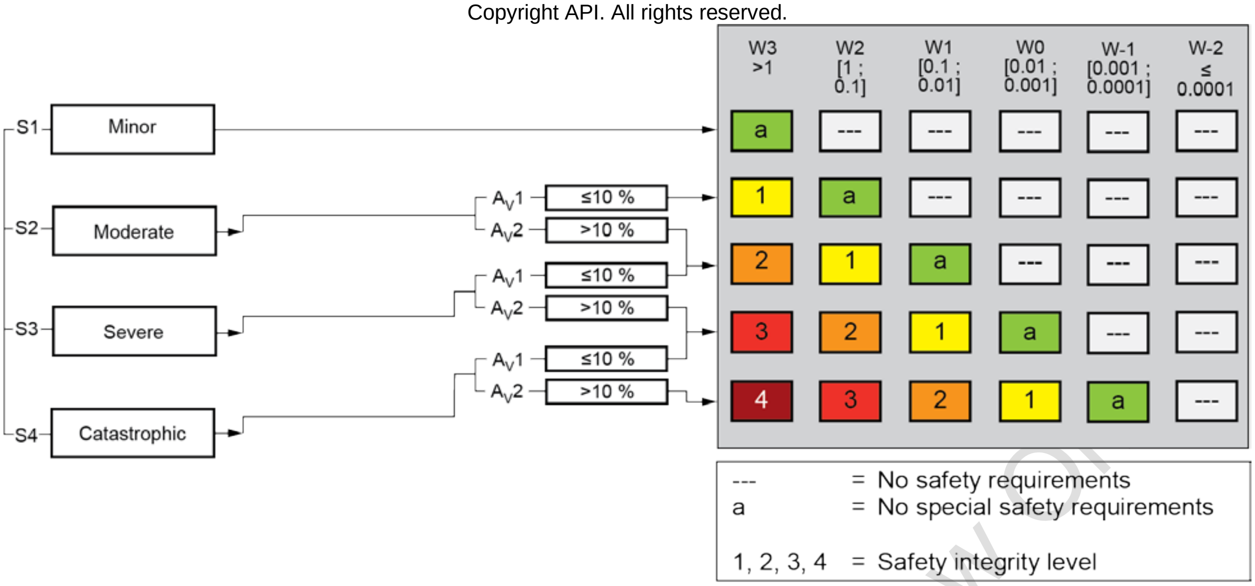


Figure M.1—Risk Graph for asset losses

M.2.4.1 The risk severity S is calibrated in generic consequences minor/moderate/severe and catastrophic. Or it may be calibrated in fiscal figures. It needs to include all economic impacts of a damaging event.

M.2.4.2 The parameter F (Frequency of Exposure) is not used for asset losses.

M.2.4.3 The parameter Av describes the avoidability of the event. A dangerous event may be avoidable e.g. by operator interaction. This parameter considers as well that not every event which may cause a heavy damage will result in asset losses. A surge of an axial compressor may result in lost blades but not every surge will result in a rotor damage.

M.2.4.4 Parameter W is the event rate. W3 is very frequent and W-2 is very rare.

M.2.4.5 It is common practice to apply the methodology of functional safety (SIL 1 to SIL 3) to the CIL 1 to 3 or AIL 1 to 3. A risk identified as CIL 2 or AIL 2 requires a protection system classified SIL 2.

M.2.4.6 Example: Surge of a critical axial flow compressor may result in blade failures which are considered to be severe. Blade failures are typically seen after several surge cycles only. Thus, parameter AV is < 10 %. Without adequate surge protection, surges may happen more often than once per year, leading to W3. As per the Risk Graph, the surge protection shall be designed equivalent to SIL 2.

M.2.4.7 The Risk Graph as per Figure M.1 may be used to evaluate risks which are reduced by either open loop or closed loop control.

M.2.5 If the voluntary application of the process of functional safety to reduce economic losses results is more severe SIL/AIL/CIL requirements than the HSE protection, the highest requirement should govern.

Note: If functional safety is not required for HSE and used to reduce asset losses only, balance between asset protection and process availability has to determine the degradation method (3-2-0 versus 3-2-1-0)

M.2.6 The purchasers should perform their own assessment and specify the required SIL/CIL/AIL for each individual protection loop. Alternatively, they may give the vendor a suitable calibration chart, risk matrix, or Risk Graph to reconsider their recommendations.

M.2.7 All steps of the risk reduction procedure should follow Annex L.

NOTE The application of the methods of functional safety on equipment damage is only required if expressively specified by the purchaser.

M.3 Reduction of Economic Losses Caused by Spurious Shutdowns

M.3.1 General

M.3.1.1 When the design of a system is focused purely on lowering the probability of missed shutdowns, it may have the undesirable effect of increasing the probability of spurious shutdowns.

Note: The term "sensor" in Section M.3 stands for all those elements in a SIS whose number can be increased, e.g. sensors, safety barriers, logic solver etc.

M.3.1.2 The common method to avoid unwanted shutdowns is to introduce additional sensors ($n > 1$) and voting schemes that improve process availability while still maintaining the required SIL. Several system architectures are available for this.

M.3.2 1-out-of-n Voting (system with highest HSE safety or highest equipment protection)

A "1-out-of-n" voting system provides the highest safety integrity and equipment protection, but the lowest plant availability. In a system with n sensors where any single sensor can shut down the machine, the probability of a missed shutdown could be lowered by simply introducing more sensors (increasing n). However, the probability of a spurious shutdown increases with each sensor added because the sensor itself may fail and falsely indicate a machinery problem when no problem actually exists. The larger the number of sensors, the more likely that any one sensor will fail in a manner that falsely indicates a machinery problem.

M.3.3 n-out-of-n Voting (system with highest process availability)

A "n-out-of-n" voting system provides the highest process availability, but the lowest safety and/or equipment protection. In such a system, the probability of spurious shutdowns can be lowered by simply introducing more and more sensors. The likelihood that all n sensors will fail and simultaneously give a so-called "false positive" indication becomes lower with each incremental sensor addition. Conversely, the probability of a missed shutdown increases with each sensor added because the sensor itself may fail and disable the safety and/or equipment protection provided by the whole assembly on this configuration.

M.3.4 m-out-of-n Voting (minimizing both missed and spurious shutdowns)

In practice, end users typically aim to minimize both missed shutdowns and spurious shutdowns as each may have associated economic related consequences. m-out-of-n voting strategies are widely used, where m is the number of sensors required to shut down and n equals the total number of sensors. Voting schemes such as 2- out-of-3 or 2-out-of-4 voting are commonly employed to balance the probabilities of spurious shutdowns against those of missed shutdowns. In those schemes, the failure of n-m sensors can be tolerated with only minimal impact on the safety integrity and/or equipment protection specified. The voting of a majority of sensors m can be trusted to most likely represent the correct status of the sensors.

Figure M.2 shows the relationship between the number of sensors, the voting scheme and the degree of protection/process availability.
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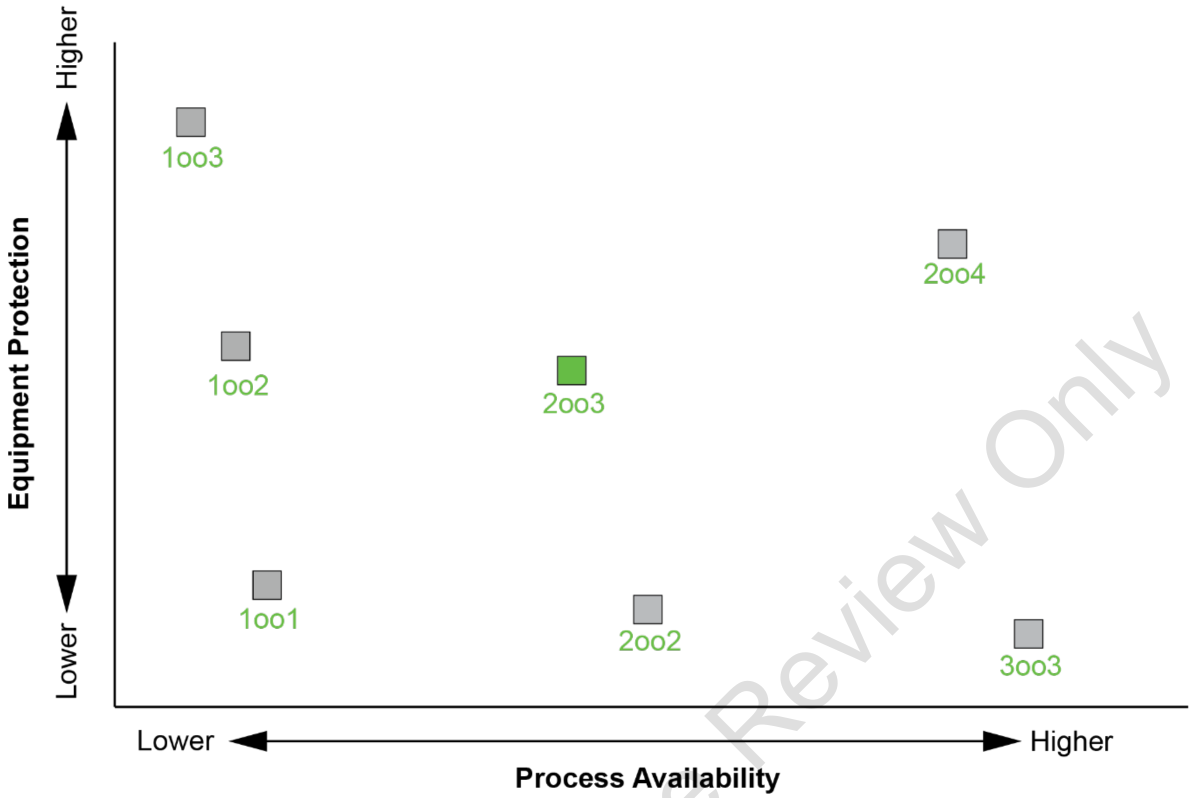


Figure M.2—Protection/Availability Matrix

M.3.5 Hot Standby

Another appropriate measure against spurious trips is Hot Standby. Hot standby is a redundant method in which one system/component runs simultaneously with an identical primary system/component. Upon detected failure of the primary system/component, the hot standby system/component immediately takes over, replacing the primary system/component. Both systems/components have identical functionality since data is mirrored in real time.

M.4 Reduction of Economic Losses by Preventive Diagnostics

M.4.1 A further method to reduce the risk of economic losses is the use of monitoring and diagnostic processes that diagnose the condition of the protection system and generate a prewarning if any monitored parameter has left the nominal working range. Such a prewarning allows the operator to service the protection system under convenient circumstances.

EXAMPLE 1 On speed sensing systems using eddy current probes, the gap between gear wheel and probe can be monitored continuously for high or low gap, with alarms generated once thresholds are exceeded.

EXAMPLE 2 The temperature of the PCB or important components on the PCB can be monitored and an alarm generated if the temperature exceeds the acceptable level.

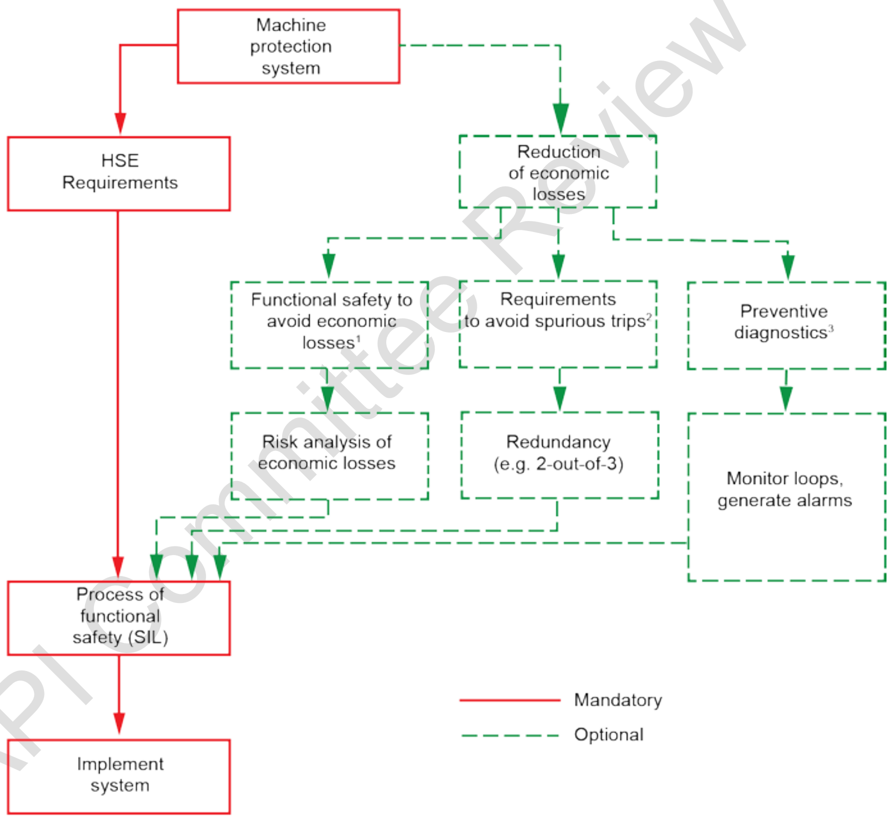
EXAMPLE 3 Current consumption of sensors or electronic components can be monitored and alarmed if too high or too low.

M.4.2 The machinery system operations manual should advise what to do once an alarm occurs.

M.5 Combining Fault Tolerance with Functional Safety for Safety Loops

M.5.1 Redundancy with *m*-out-of-*n* voting systems above or beyond the requirements of functional safety can reduce the rate of spurious shutdowns. This is voluntary whereas functional safety in regard to protection of personnel and the environment is mandatory. Therefore, any system architecture that has been selected to reduce economic losses has to be checked against the SRS for compliance with the methods of functional safety.

M.5.2 Figure M.3 describes the process. Any architectural requirement has to be considered a prerequisite to the process of functional safety. Once the SRS is finished, no design changes to the protection system are acceptable, as far as HSE is concerned.



Notes
1 Reference section M.2
2 Reference section M.3
3 Reference section M.4

Figure M.3—Process Block Diagram

Annex N Torsional Vibration Monitoring
(informative)

Torsional Vibration Monitoring

N.1 General

The purpose of this annex is to provide guidance on the selection and application of permanently installed torsional vibration monitoring systems. This annex does not address temporary torsional vibration monitoring systems.

N.2 Scope

This annex covers torsional vibration instrumentation and monitoring systems applicable to turbomachinery such as those addressed in API stand-alone equipment standards.

N.3 Sensors

N.3.1 General

Typical sensor design definitions for rotating equipment applications are in Section 6, and their applications are noted throughout the standard. However, torsional vibration monitoring uses different technologies to measure vibration. This section provides information for this unique application.

For reference Table N.1 summarizes typical temperature ranges and accuracy requirements. These sensors are discussed in more detail in subsequent sections.

Table N.1—Typical Torsional Vibration Monitoring System Accuracy Requirements

Components	Temperature		Accuracy Requirements as a Function of Temperature	
	Testing Range	Operating/ Storage Range	Within Testing Range	Outside Testing Range but Within Operating Range
Strain gauge based torsional sensors	20 °C to 30 °C (68 °F to 86 °F)	-40 °C to 125 °C (-40 °F to 257 °F)	±1.0% of Full-Scale Torque Frequency response: ±3 dB from DC to 1 kHz.	±1.5% of Full-Scale Torque Frequency response: ±3 dB from DC to 1 kHz.
Strain gauge based torsional interface modules		-40 °C to 85 °C (-40 °F to 185 °F)		
Magnetostrictive torsional vibration probe and cable	20 °C to 30 °C (68 °F to 86 °F)	–35 °C to 125 °C (–30 °F to 257 °F)	Average scale factor: ±10 % of 10 mV/MPa (68 mV/ksi) DSL: within ±20 MPa (±2.9 ksi) of the best fit straight line at a slope of 10 mV/MPa (68 mV/ksi) Frequency response: ±3 dB from DC to 1 kHz.	Average scale factor: ±15 % of 10 mV/MPa (68 mV/ksi) DSL: within ±30 MPa (±4.4 ksi) of the best fit straight line at a slope of 10 mV/MPa (68 mV/ksi) Frequency response: ±3 dB from DC to 1 kHz
Magnetostrictive torsional interface module		–35 °C to 85 °C (–30 °F to 185 °F)		
Multitooth phase transducer and cable	20 °C to 30 °C (68 °F to 86 °F)	-40°C to 130°C (-40 °F to 265 °F)	±1% of Full scale mean torque For 10% torsional vibration typically ±1% torsional amplitude. Actively temperature compensated Sample rate at full shaft speed 6kHz-10kHz giving bandwidth up to 2kHz	±1% of Full scale mean torque For 10% torsional vibration typically ±1% torsional amplitude. Actively temperature compensated Sample rate at full shaft speed 6kHz-10kHz giving bandwidth up to 2kHz
Multitooth phase shift interface module		0°C to 60°C (30 °F to 140°F)		

N.3.2 Strain Gauge Systems

Strain gauges mount directly on the rotating elements (shaft or coupling) to detect torsional strain. Typically, the signal conditioning, including power, rotor antenna and signal transmitting components, reside on the rotor. The torsional vibration signal can be wirelessly transmitted from the shaft to the receiver (stator pick up).

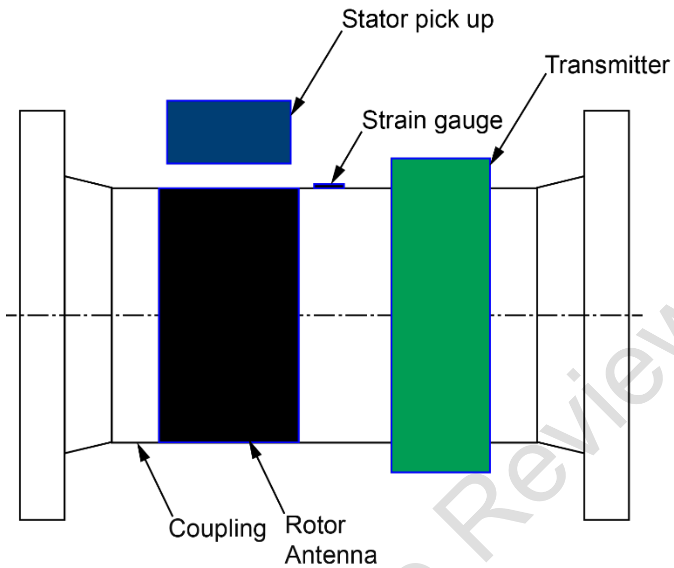


Figure N.1—Wireless strain gauge system

N.3.3 Magnetostrictive Systems

Magnetostrictive systems generate and pass a magnetic field through the target rotating elements. Torsional stress changes the magnetic properties of the target rotating element, which changes the magnetic field. The non-contacting sensors, mounted near the rotor similar to eddy current probes, detect these changes. The sensors connect to an interface module, with signal conditioning and analog amplifier, mounted away from the machine case and/or coupling guard. Two sensors at the same axial location are required to cancel run out form the signal pickup.

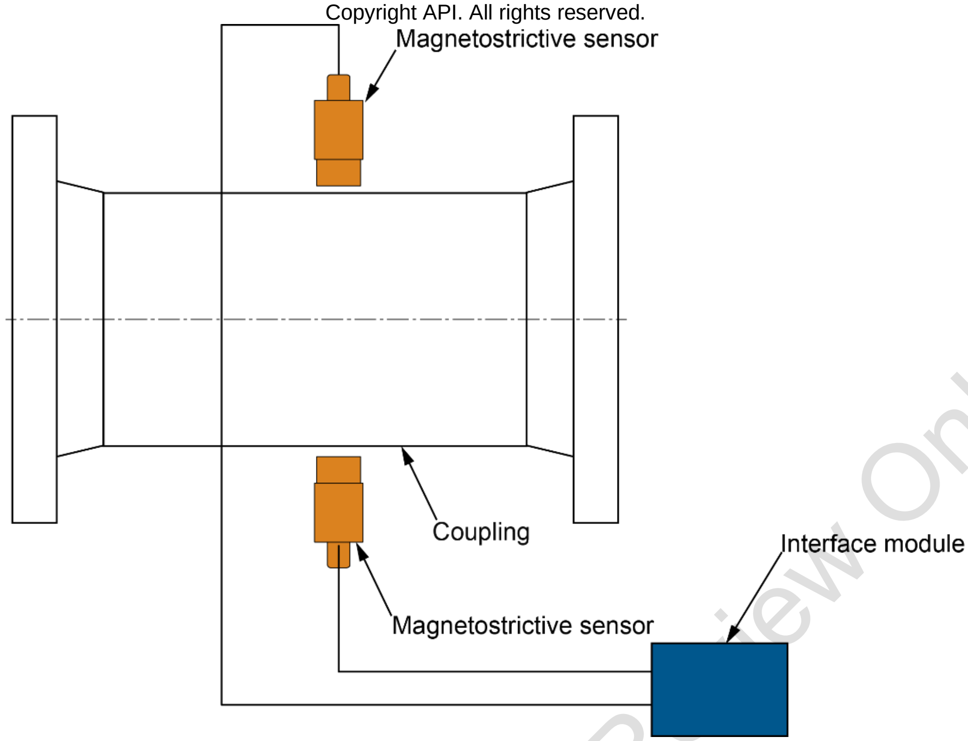


Figure N.2—Magnetostrictive system

N.3.4 Multi-Tooth Phase Shift Systems

The system consists of toothed wheels at either end of a one-piece coupling spacer shaft that generate sinusoidal voltages in pick up coils. The signal processor detects phase difference between the signals varies with the twist of the shaft, directly proportional to torque. Typical tooth number range from 100-200 with a shaft twist angle of 0.25-0.5 degrees at full torque. Shaft temperature measurement allows compensation for change of shaft modulus with temperature.

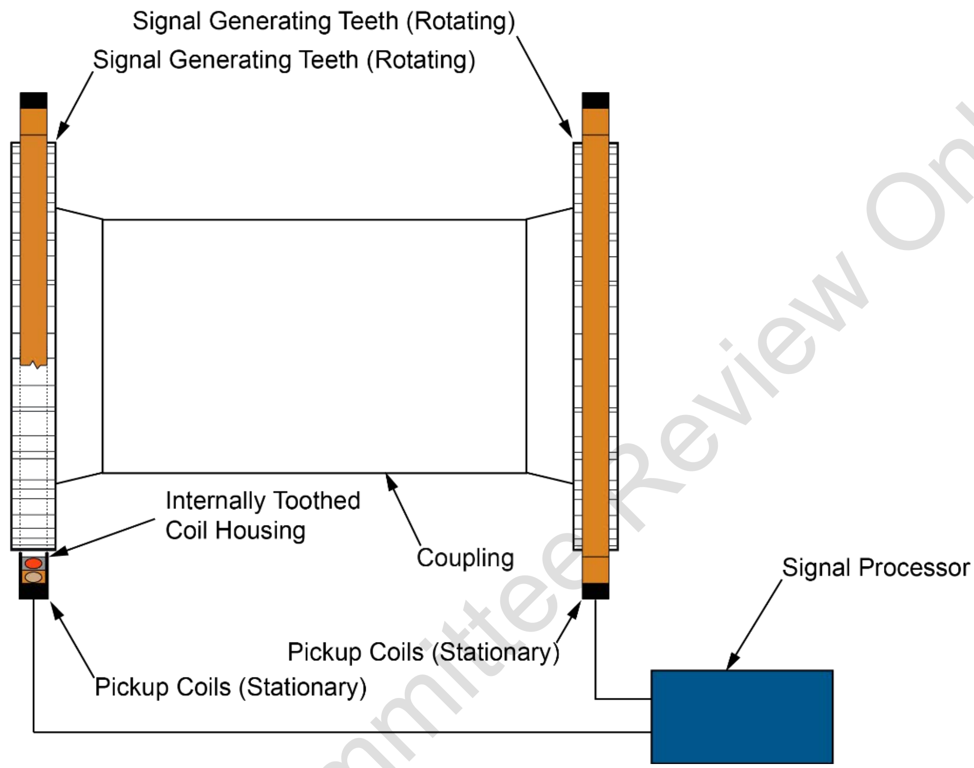


Figure N.3—Multi-Tooth Phase Shift Systems

The signal processor digitizes the pickup coil signals to produce steady state torque and speed data as well as torsional vibration transmitted through the coupling. If the operator is interested some of these systems are available with a SIL rating.

N.4 Transducer Function and Installation

For machines without prior measurements a torsional model should be generated and analysis performed to locate the rotor components that most likely have the highest stress. Refer to API-684 for a discussion on development of torsional models.

Measurements most often focus on the lowest 1-3 modes of vibration since these are the ones that are often associated with machine damage. Measurements of higher modes may require additional considerations. For example, lumped parameter models often used to estimate the resonant frequencies may not be accurate for modes with nodes away from the coupling (i.e. inside a machine case).

N.4.1 Application

Figure N. shows the mass-elastic diagram and mode shape diagram for a motor-driven compressor train. The mode shape diagrams (bottom three panes) indicate the relative angle of twist across the model elements. The higher the slope of this line, the greater the change in twist. Since shear strain and stress scale with change in angle of twist, the elements with higher slopes will provide the optimum response due to systems sensitivity to stress/strain. It is important to understand that this location may not be the same for each mode shape of the machine train. In Figure N. the element between station #3 and #4 (the low-speed coupling) has the steepest slope for the first mode. In contrast, the element between station #7 and #8 (the high-speed coupling) has the steepest slope for the second mode.

Looking at the mass elastic diagrams both the low-speed and high-speed couplings have less stiffness than the other elements in their respective systems. Couplings are often intended to limit the mechanical torque a system experiences so many times they will be the element with highest shear stresses.

Note that for the second mode, the low-speed coupling element also slopes so a system at this location may report information about the second response as well as first mode. The slope is slight compared to that in mode 1 so two planes of measurement may be required to ensure the system detects both modes.

The mounting location also varies depending on machine type. Figure N. shows the elastic diagrams and mode shape diagrams for a reciprocating engine driving a reciprocating compressor. In this example the slopes of the mode shape are approximately the same for stations #1 through #11 for the first mode. In theory any of these stations would provide a good location for strain/stress sensitive systems. Practically, mounting inside an engine crankcase adds complications so the likely best element would be between station #10 and #11. In this machine, that location also has the steepest slope for mode 2 and mode 3. For this reason, a single strain/stress sensitive system installed at this location would likely capture the response of all three modes.

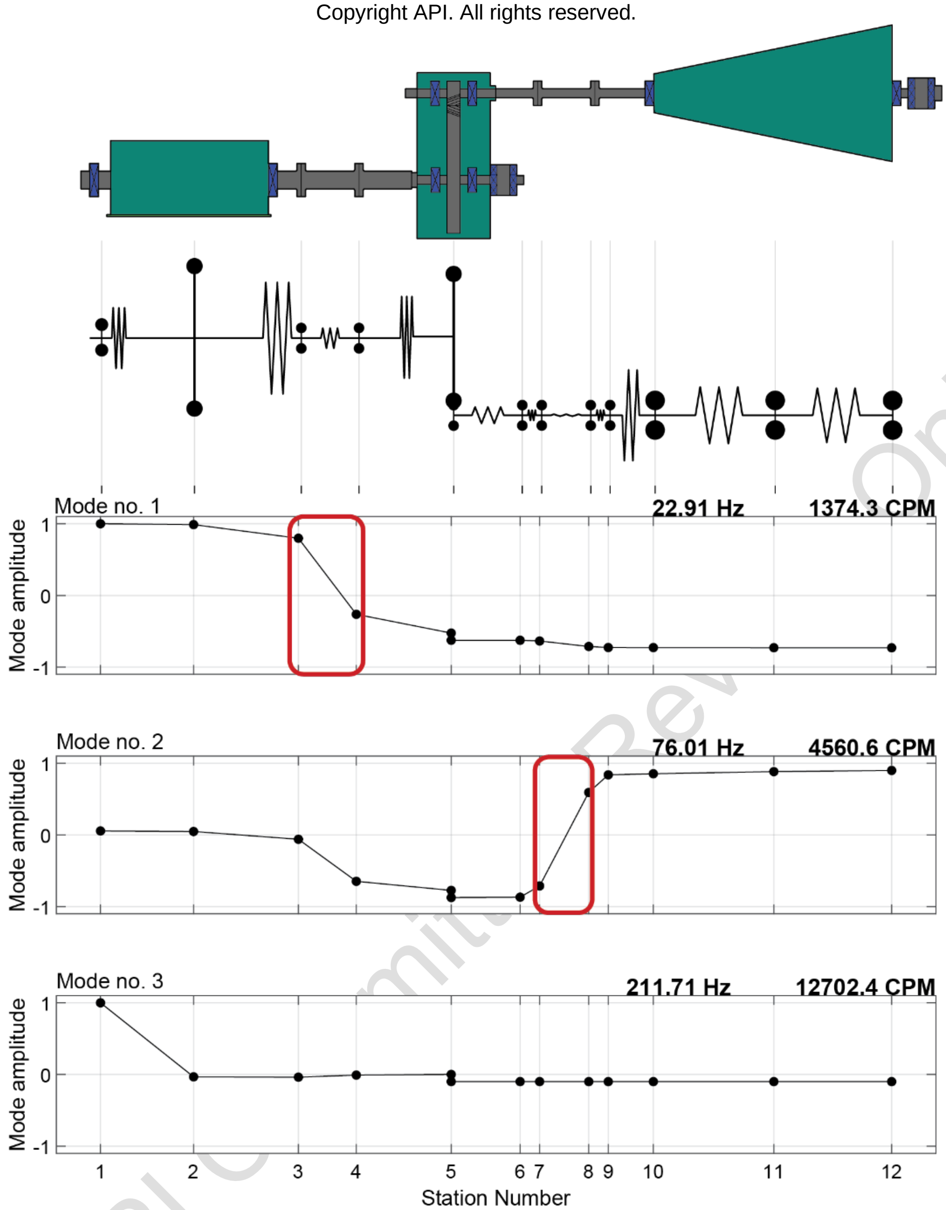


Figure N.4—Mode shape for motor-gearbox-compressor.

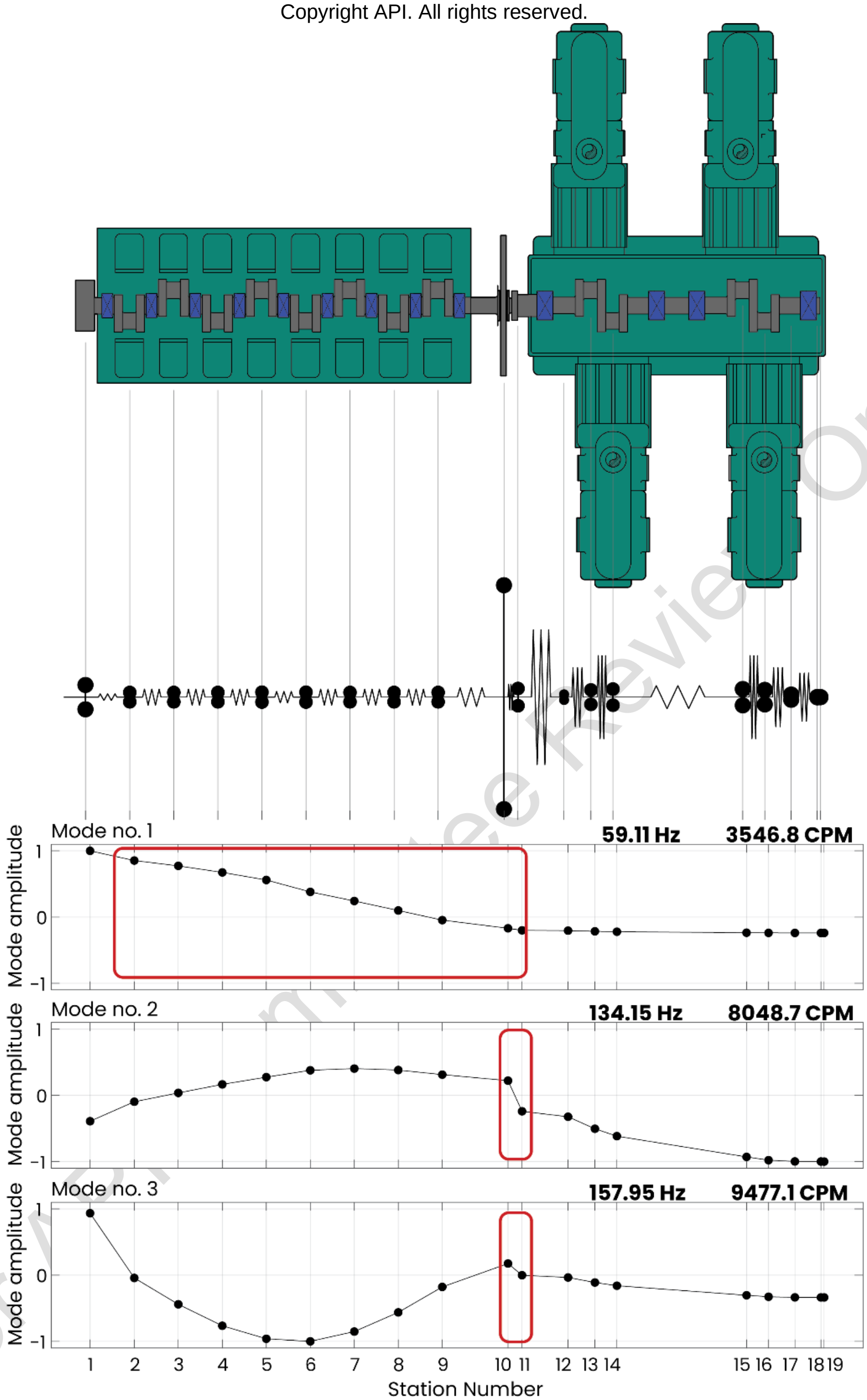


Figure N.5—Mode shape for reciprocating engine driving a reciprocating compressor.

N.4.2 Installation Arrangements

N.4.2.1 Strain Gauge Systems

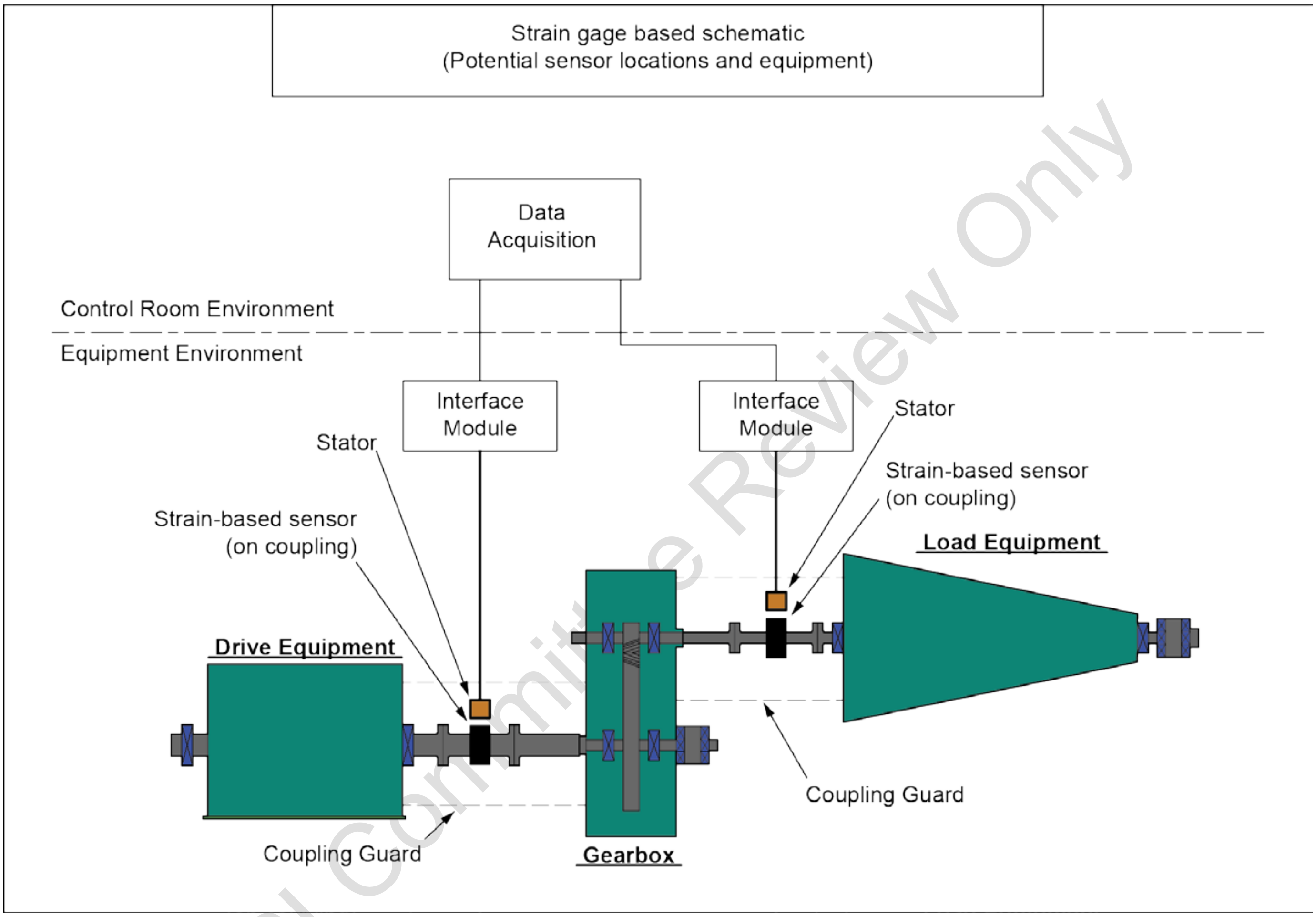


Figure N.6—Strain gauge installation arrangement.

N.4.2.2 Magnetostrictive Sensor Systems

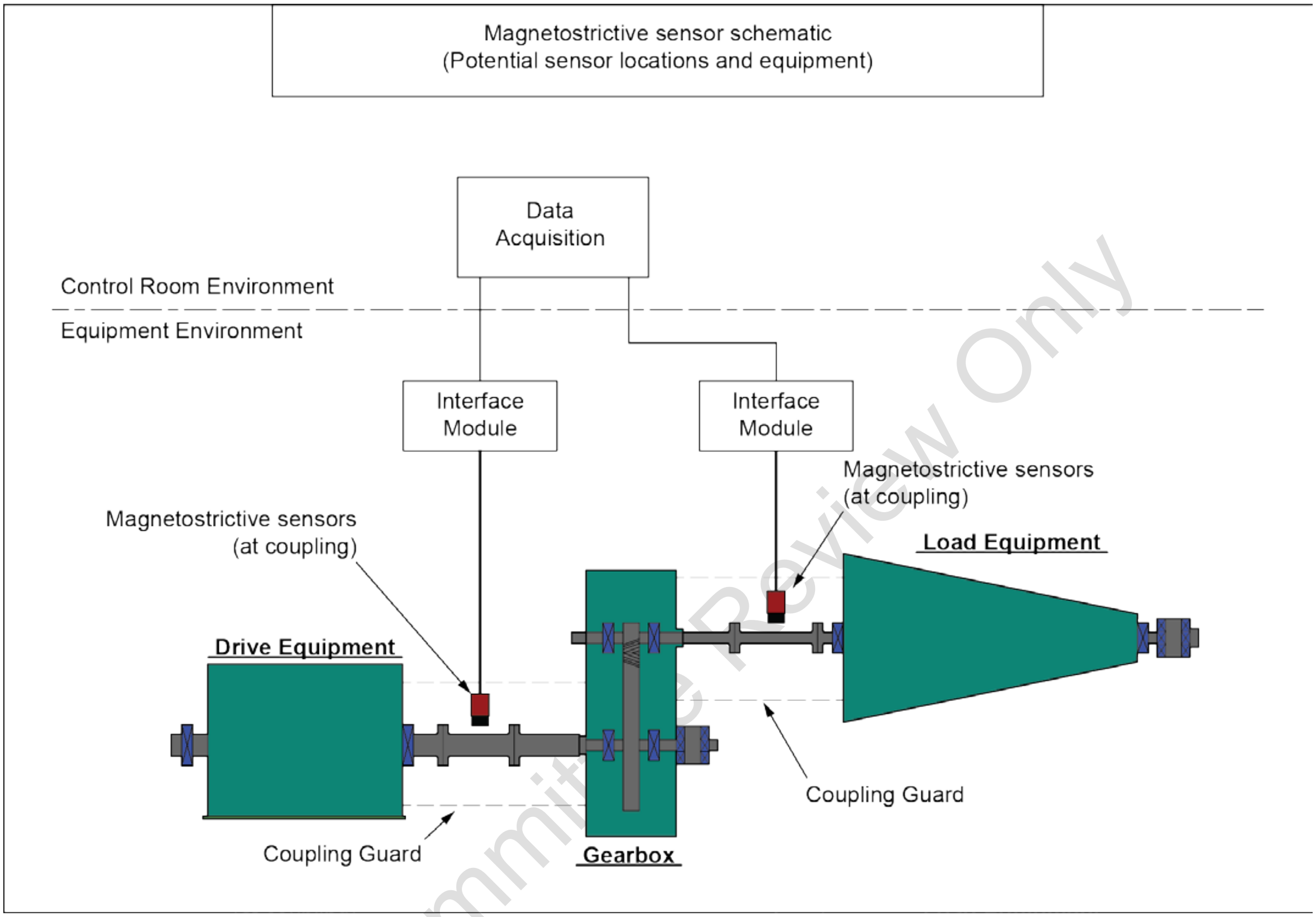


Figure N.7—Magnetostrictive system installation arrangement.

N.4.2.3 Multi-Tooth Phase Shift System

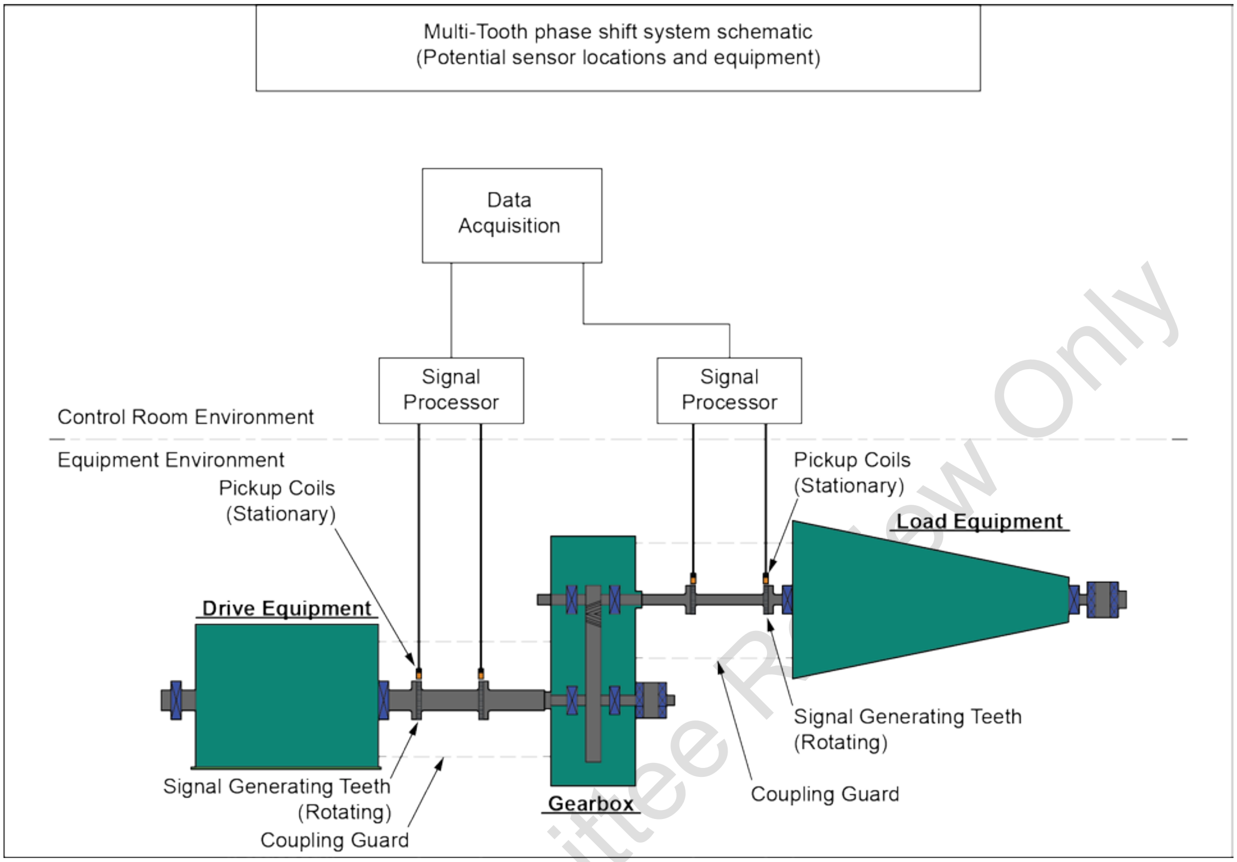


Figure N.8—Multi-tooth phase shift system installation arrangement.

N.5 Condition Monitoring

N.5.1 Torsional Vibration Monitoring

N.5.1.1 This section covers the general recommendations of torsional vibration monitoring system.

N.5.1.2 The torsional vibration measurements can be made with strain gauges, non-contacting magnetostrictive sensors, or signals from multi-toothed phase shift systems.

N.5.1.3 The recommended monitored frequency range should be from 0 to 1000 Hz or ranges agreed between vendor and purchaser.

N.5.1.4 The sensor linear range should be at least 120% of coupling maximum continuous rated torque. The coupling peak torque can be much higher and if required the linear range should be mutually agreed between vendor and purchaser.

N.5.1.5 On the monitoring system, the static torsional full-scale range (DC output) should be coupling maximum continuous rated torque. The vibratory torsional full-scale range (AC output) should setup at least 50% of maximum continuous rated torque and can be modified based on measured maximum torsional vibration response at all operating conditions. For synchronous motors or across-the-line start on induction motors, the vibratory torsional full-scale range could be higher than 50% of the maximum continuous rated torque.

N.5.1.6 Oscillatory torque should be reported as peak-to-peak N-m [in-lbs].

NOTE: The coupling spacer diameter and thickness and material property is required for the torsional strain/stress to be converted to torque.

N.5.1.7 The full-scale range should be reported as peak-to-peak MPa [ksi].

N.5.2 Torsional Natural Frequency Monitoring

The torsional natural frequency monitoring system should be fixed with at least two field-changeable bandpass filters for each torsional natural frequency. These bandpass filters should have the following characteristics:

a) The bandpass filter output should have unity gain at configured center frequency, referencing the input signal level.

b) The bandpass bandwidth should be less than 3 Hz where the cutoff frequency is at -3dB, referencing the input signal.

NOTE: Bandpass filters can be used to monitor either rotor system torsional response at specific frequencies or excitation frequencies.

Annex O Overspeed

(normative)

O.1 Calculation of the Maximum Rotor Speed During an Overspeed Trip

O.2 Scope

O.2.1 This annex shall be used if the individual API machinery standard does not address the overspeed calculation.

O.2.2 Following the initiation of a shutdown by the overspeed shutdown system, the speed of the rotor system will increase due to the following.

a) The energy input to the turbine during the signal delay time, T_s. This delay includes the response time of the electronic overspeed shutdown device as well as the response time of all the components between the electronic overspeed shutdown device and the steam, inlet, or fuel shutdown valve such as the hydraulic shutdown block, hydraulic piping runs, and solenoid valves. The maximum turbine power needs to be considered in the calculation.

b) The energy to accelerate the turbine during the stop valve(s) closing time, T_v. This power input corresponds to a certain fraction (f) of the maximum turbine power. For example, for a valve with a linear response characteristic, $f = 0.5$.

c) The energy to accelerate the turbine from any steam (or condensate that can flash to steam) or gas contained within the turbine system when the turbine is operating at maximum output. For gas turbines, the energy input from the remaining fuel between the fuel valve and the combustor. For expanders, the energy input from any residual gas contained between the stop valve and the turbine wheels when the turbine is operating at maximum output. The steam or gas will expand to the exhaust pressure. The power from this source may be partly or wholly expanded during the time the stop valve is closing or after the valve has become closed if the steam or gas is trapped in a region downstream of the stop valve such as inlet and extraction piping. It is assumed that a certain fraction of this energy is available for accelerating the rotor system.

O.2.3 The maximum speed attained by the rotor, N_{max}, may be determined by evaluating the rotor energy at the time the shutdown is initiated, then adding the energy that is applied to the rotor by the steam, gas, or fuel until the energy sources are removed and dissipated. Referring to Figure O.1, this is the starting kinetic energy at overspeed shutdown setpoint plus all the energy input to the rotor during the period between the initiation of a shutdown and the final closure of the stop valve(s). The final speed can be calculated using the peak kinetic energy and inertia of the rotor. These calculations tend to be conservative (actual excursion shall be less than the calculated excursion) because the energy consumed by the parasitic losses (bearing friction, windage) and the energy absorbed by the driven equipment (if connected) has not been subtracted from the total energy of the rotor after the trip sequence is initiated.

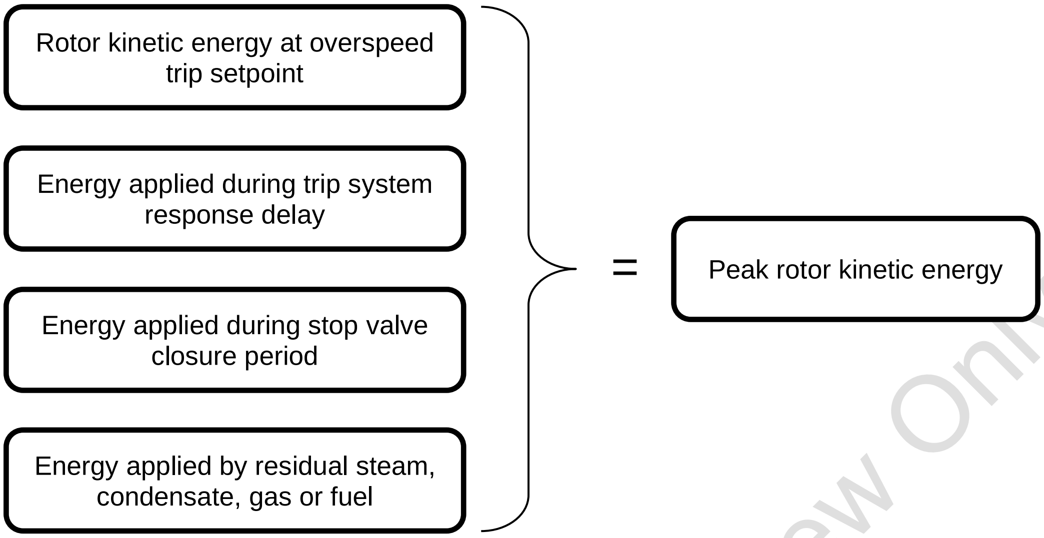


Figure O.1—The Peak Kinetic Energy of the Rotor

O.2.4 Calculations in SI Units (applies to Steam Turbine and Turboexpander, Power Recover Turbine)

O.2.4.1 The instantaneous rotor acceleration at the overspeed shutdown setting can be determined by

$$\alpha_t = k \times \frac{P_{g(max)}}{N_T \times WR^2{}_T} \text{ (rpm/s) [turbine rotor uncoupled]} \quad \text{(O.1)}$$

$$\alpha_t = k \times \frac{P_{g(max)}}{N_T \times WR^2{}_C} \text{ (rpm/s) [complete generator train]} \quad \text{(O.2)}$$

where

k is 9.1189×10^4 [rpm^2-kg-m^2/(kW-s)];

$P_{g(max)}$ is the turbine rated power (kW);

N_T is the setpoint of overspeed shutdown device (rpm);

$WR^2{}_T$ is the rotational inertia of turbine rotor (uncoupled) (kg-m^2);

$WR^2{}_C$ is the rotational inertia of the complete train (kg-m^2).

O.2.4.2 The kinetic energy of the rotor at a given speed, N, can be calculated by

$$E = k_2 \times WR^2 \times N^2 \quad \text{(kW-s)} \tag{O.3}$$

$$E_T = k_2 \times WR^2 \times {N_T}^2 \quad \text{(kW-s)} \tag{O.4}$$

$$E_T = k_2 \times {WR^2}_C \times {N_T}^2 \quad \text{(kW-s) (complete train)} \tag{O.5}$$

where

E_T is the rotor kinetic energy at overspeed shutdown setpoint;

k_2 is 5.49×10^{-6} [kW-s-min^2/(kg-m^2)].

O.2.4.3 The energy added to the rotor during the signal delay time is

$$\Delta E_s = T_s \times P_{g(max)} \quad \text{(kW-s)} \tag{O.6}$$

where

T_s is the signal time delay (seconds)—the period of time between when an overspeed shutdown condition occurred and the time the shutdown valve(s) starts to close. This time period includes sensor delays, logic solver I/O scan rate delays, logic solver program scan rate delays × 2 (this is the worst case delay), shutdown solenoid delays, and shutdown oil-header delays.

O.2.4.4 The energy added to the rotor during the closure time of the stop valve is

$$\Delta E_V = f \times T_V \times P_{g(max)} \quad \text{(kW-s)} \tag{O.7}$$

where

T_v is the closure time for stop valve (seconds)—the time which the valve needs to travel from fully open to fully closed;

f is the fraction of maximum steam flow that passes through the stop valve during closure period.

O.2.4.5 If the stop valve characteristics are linear, the energy added during the closure time of the stop valve would be half the turbine max power times the closure time. In this case, f would be 0.5. The energy added to the rotor by the expansion of steam that is trapped within the turbine is

$$\Delta E_e = k_3 \eta \left[\Sigma^{W_{1i} u_{1i}} - \Sigma^{W_{2i} u_{2i}} - \Sigma^{(W_{1i} - W_{2i}) h_{2i}} \right] \quad \text{(kW-s)} \tag{O.8}$$

where

k_3 is 1.0 kW-s/kJ;

η is the turbine efficiency;

W_{1i} is the mass of gas or steam and condensate contained within each "i" space inside the turbine when the turbine is operating at its maximum output (kg);

u_{1i} is the internal energy for each of the gas or steam W_{1i} masses, estimated at the actual pressures and temperatures that exist at the various "i" spaces when operating at maximum output (kJ);

W_{2i} is the weight of gas or steam in the "i" spaces defined for W_{1i} after expansion has ceased (kg);

u_{2i} is the internal energies for the W_{2i} masses of gas or steam in the "i" spaces after isentropic expansion (kJ);

h_{2i} is enthalpies of the W_{2i} masses of gas or steam after isentropic expansion (kJ).

O.2.4.6 The maximum kinetic energy of the rotor will be the sum of the kinetic energy at the time the overspeed shutdown system initiates a shutdown and the energy added because of time delays and entrapped gas or steam.

$$E_{max} = E_T + E_S + E_V + E_e \quad \text{(kW-s)} \tag{O.9}$$

O.2.4.7 The maximum speed attained by the rotor can be calculated using Equation (O.10) and Equation (O.11) as follows.

$$N_{max} = \sqrt{\frac{E_{max} \times 10^6}{k_2 \times WR^2{}_T}} \quad \text{(rpm) (turbine uncoupled)} \tag{O.10}$$

$$N_{max} = \sqrt{\frac{E_{max} \times 10^6}{k_2 \times WR^2{}_C}} \quad \text{(rpm) (complete train)} \tag{O.11}$$

O.3 Calculations for Generator Drive and Mechanical Drive

O.3.1 Generator Drive (Steam turbine, power in units of kW)

O.3.1.1 The instantaneous rotor acceleration at the overspeed shutdown setting can be determined by

$$\alpha_t = k \times \frac{P_{g(max)}}{N_T \times WR^2{}_T} \quad \text{(rpm/s) (turbine uncoupled)} \tag{O.12}$$

$$\alpha_t = k \times \frac{P_{g(max)}}{N_T \times WR^2{}_C} \quad \text{(rpm/s) (complete train)} \tag{O.13}$$

where

k is 2.164×10^6 rpm2-lb-ft^2/(kW-s);

$P_{g(max)}$ is the turbine rated power (kW);

N_T is the setpoint of overspeed shutdown device (rpm);

$WR^2{}_T$ is the rotational inertia of turbine rotor (uncoupled) (lb-ft^2);

WR^2_C is the rotational inertia of the complete train (lb-ft^2);

O.3.1.2 The kinetic energy of the rotor at a given speed, N, can be calculated by

$$E = k_2 \times WR^2 \times N^2 \quad \text{(kW-s)} \tag{O.14}$$

$$E_T = k_2 \times {WR^2}_T \times {N_T}^2 \quad \text{(kW-s) (turbine uncoupled)} \tag{O.15}$$

$$E_T = k_2 \times {WR^2}_C \times {N_T}^2 \quad \text{(kW-s) (complete train)} \tag{O.16}$$

where

E_T is the rotor kinetic energy at overspeed shutdown setpoint;

k_2 is 2.31 × 10^{-7} [kW-s-min^2/(lb-ft^2)].

O.3.1.3 The energy added to the rotor during the signal delay time is

$$\Delta E_s = T_s \times P_{g(max)} \quad \text{(kW-s)} \tag{O.17}$$

where

T_s is the signal time delay (seconds).

O.3.1.4 The energy added to the rotor during the closure time of the stop valve is

$$\Delta E_v = f \times T_v \times P_{g(max)} \quad \text{(kW-s)} \tag{O.18}$$

where

T_v is the closure time for stop valve (seconds);

f is the fraction of the maximum turbine output during the stop valve closure period.

Stop valves typically have characteristics that result in f being less than 1 but greater than 0.5. The stop valve manufacturer may furnish typical values of f for the valve in question.

O.3.1.5 The energy added to the rotor by the expansion of steam that is trapped within the turbine is

$$\Delta E_e = k_3 \eta \left[\Sigma^{W_{1i} u_{1i}} - \Sigma^{W_{2i} u_{2i}} - \Sigma^{(W_{1i} - W_{2i}) h_{2i}} \right] \quad \text{(kW-s)} \tag{O.19}$$

where

k_3 is 1.055 kW-s/BTU;

η is the steam turbine efficiency;

W_{1i} is the mass (lbm) of steam and condensate contained within each “i” space inside the turbine when the turbine is operating at its maximum output;

u_{1i} is the internal energy for each of the steam W_{1i} masses, estimated at the actual pressures and temperatures that exist at the various "i" spaces when operating at maximum output (BTU/lbm);

W_{2i} is the weight of steam in the "i" spaces defined for W_{1i} after expansion has ceased (lbm);

u_{2i} is the internal energies for the W_{2i} masses of steam in the "i" spaces after isentropic expansion (BTU/lbm);

h_{2i} is enthalpies of the W_{2i} masses of steam after isentropic expansion (BTU/lbm).

O.3.1.6 The maximum kinetic energy of the rotor will be the sum of the kinetic energy at the time the overspeed shutdown system initiates a shutdown and the energy added because of time delays and entrapped steam.

$$E_{max} = E_T + E_S + E_V + E_e \quad \text{(kW-s)} \tag{O.20}$$

O.3.1.7 The maximum speed attained by the rotor can be calculated using Equation (O.21) and Equation (O.22), as follows.

$$N_{max} = \sqrt{\frac{E_{max} \times 10^6}{k_2 \times WR^2{}_T}} \quad \text{(rpm) (turbine uncoupled)} \tag{O.21}$$

$$N_{max} = \sqrt{\frac{E_{max} \times 10^6}{k_2 \times WR^2{}_C}} \quad \text{(rpm) (complete train)} \tag{O.22}$$

O.3.2 Mechanical Drive (Steam turbine, power in units of HP)

O.3.2.1 The instantaneous rotor acceleration at the overspeed shutdown setting can be determined by

$$\alpha_t = k \times \frac{P_{g(max)}}{N_T \times WR^2{}_T} \quad \text{(rpm/s) (turbine uncoupled)} \tag{O.23}$$

$$\alpha_c = k \times \frac{P_{g(max)}}{N_T \times WR^2{}_C} \quad \text{(rpm/s) (complete train)} \tag{O.24}$$

where

k is 1.614×10^{-6} rpm^2-lb-ft^2/(HP-s);

$P_{g(max)}$ is the turbine rated power (HP);

N_T is the setpoint of overspeed shutdown device (rpm);

$WR^2{}_T$ is the rotational inertia of turbine (uncoupled) (lb-ft^2);

$WR^2{}_C$ is the rotational inertia of the complete train (coupled) (lb-ft^2).

O.3.2.2 The kinetic energy of the rotor at a given speed, N, can be calculated by

$$E = k \times 10^{-7} \times WR^2 \times N^2 \quad \text{(HP-s)} \tag{O.25}$$

$$E_T = k_2 \times WR^2{}_T \times N_T{}^2 \quad \text{(HP-s) (turbine uncoupled)} \tag{O.26}$$

$$E_T = k_2 \times WR^2{}_C \times N_T{}^2 \quad \text{(HP-s) (complete train)} \tag{O.27}$$

where

E_T is the rotor kinetic energy at overspeed shutdown setpoint;

k_2 is 3.10×10^{-7} [HP-s-min^2/(lb-ft^2)].

O.3.2.3 The energy added to the rotor during the signal delay time is

$$\Delta E_s = T_s \times P_{g(max)} \quad \text{(HP-s)} \tag{O.28}$$

where

T_s is the signal time delay (seconds).

O.3.2.4 The energy added to the rotor during the closure time of the stop valve is

$$\Delta E_V = f \times T_V \times P_{g(max)} \quad \text{(HP-s)} \tag{O.29}$$

where

T_v is the closure time for stop valve (seconds);

f is the fraction of maximum steam flow that passes through the stop valve during closure period.

If the stop valve characteristics are linear, the energy added during the closure time of the stop valve would be half the turbine max power times the closure time. In this case, f would be 0.5.

O.3.2.5 The energy added to the rotor by the expansion of steam that is trapped within the turbine is

$$\Delta E_e = k_3 \eta \left[\Sigma^{W_{1i} u_{1i}} - \Sigma^{W_{2i} u_{2i}} - \Sigma^{(W_{1i} - W_{2i}) h_{2i}} \right] \quad \text{(HP-s)} \tag{O.30}$$

where

k_3 is 1.415 HP-s/BTU;

η is the steam turbine efficiency;

W_{1i} is the mass of steam and condensate contained within each “i” space inside the turbine when the turbine is operating at its maximum output;

u_{1i} is the internal energy for each of the steam W_{1i} masses, estimated at the actual pressures and temperatures that exist at the various "i" spaces when operating at maximum output;

W_{2i} is the weight of steam in the "i" spaces defined for W_{1i} after expansion has ceased;

U_{2i} is the internal energies for the W_{2i} masses of steam in the "i" spaces after isentropic expansion;

h_{2i} is enthalpies of the W_{2i} masses of steam after isentropic expansion.

O.3.2.6 The maximum kinetic energy of the rotor will be the sum of the kinetic energy at the time the overspeed shutdown system initiates a shutdown and the energy added because of time delays and entrapped steam.

$$E_{max} = E_T + E_s + E_v + E_e \quad \text{(HP-s)} \tag{O.31}$$

O.3.2.7 The maximum speed attained by the rotor can be calculated using Equation (O.32) and Equation (O.33), as follows.

$$N_{max} = \sqrt{\frac{E_{max} \times 10^6}{k_2 \times WR^2{}_T}} \quad \text{(rpm) (turbine uncoupled)} \tag{O.32}$$

$$N_{max} = \sqrt{\frac{E_{max} \times 10^6}{k_2 \times WR^2{}_C}} \quad \text{(rpm) (complete train)} \tag{O.33}$$

O.3.3 Mechanical Drive (Power Recovery Turbine (PRT) or gas turbo-expander, Power in units of HP)

O.3.3.1 The OEM should provide the overspeed estimate based on their experience and design configuration. Generally, coupling failure or generator loss of load will represent the maximum overspeed case, and shall be considered for gas expander drivers.

O.3.3.2 The instantaneous rotor acceleration at the overspeed shutdown setting can be determined by

$$\alpha_t = k \times \frac{P_{g(max)}}{N_T \times WR^2{}_T} \quad \text{(rpm/s) (turbine uncoupled)} \tag{O.34}$$

$$\alpha_c = k \times \frac{P_{g(max)}}{N_T \times WR^2{}_C} \quad \text{(rpm/s) (complete train)} \tag{O.35}$$

where

k is 1.614×10^{-6} rpm²-lb-ft²/(HP-s);

$P_{g(max)}$ is the turbine rated power (HP);

N_T is the setpoint of overspeed shutdown device (rpm);

$WR^2{}_T$ is the rotational inertia of turbine (uncoupled) (lb-ft²);

$WR^2{}_C$ is the rotational inertia of the complete train (coupled) (lb-ft²).

O.3.3.3 The kinetic energy of the rotor at a given speed, N, can be calculated by

$$E = k \times 10^{-7} \times WR^2 \times N^2 \quad \text{(HP-s)} \tag{O.36}$$

$$E_T = k_2 \times WR^2{}_T \times N_T{}^2 \quad \text{(HP-s) (turbine uncoupled)} \tag{O.37}$$

$$E_T = k_2 \times WR^2{}_C \times N_T{}^2 \quad \text{(HP-s) (complete train)} \tag{O.38}$$

where

E_T is the rotor kinetic energy at overspeed shutdown setpoint;

k_2 is 3.10×10^{-7} [HP-s-min²/(lb-ft²)].

O.3.3.4 The energy added to the rotor during the signal delay time is

$$\Delta E_s = T_s \times P_{g(max)} \quad \text{(HP-s)} \tag{O.39}$$

where

T_s is the signal time delay (seconds).

O.3.3.5 The energy added to the rotor during the closure time of the gas inlet valve is

$$\Delta E_V = f \times T_V \times P_{g(max)} \quad \text{(HP-s)} \tag{O.40}$$

where

T_v is the closure time for inlet valve or guide vanes (seconds);

f is the fraction of maximum gas flow that passes through the inlet valve during closure period.

If the inlet valve characteristics are linear, the energy added during the closure time of the inlet valve would be half the turbine max power times the closure time. In this case, f would be 0.5.

O.3.3.6 The energy added to the rotor by the expansion of gas that is trapped within the turbine is

$$\Delta E_e = k_3 \eta \left[\Sigma^{W_{1i} u_{1i}} - \Sigma^{W_{2i} u_{2i}} - \Sigma^{(W_{1i} - W_{2i}) h_{2i}} \right] \quad \text{(HP-s)} \tag{O.41}$$

where

k_3 is 1.415 HP-s/BTU;

η is the expander / turbine efficiency;

W_{1i} is the mass of gas contained within each "i" space inside the turbine when the turbine is operating at its maximum output;

u_{1i} is the internal energy for each of the gas W_{1i} masses, estimated at the actual pressures and temperatures that exist at the various "i" spaces when operating at maximum output;

W_{2i} is the weight of gas in the "i" spaces defined for W_{1i} after expansion has ceased;

u_{2i} is the internal energies for the W_{2i} masses of gas in the "i" spaces after isentropic expansion;

h_{2i} is enthalpies of the W_{2i} masses of gas after isentropic expansion.

NOTE Gas constituents and properties must be obtained to estimate the internal energies and enthalpies. These are provided in the specification / data sheet for the expander / turbine. A gas properties tool, such as REFPROP from the National Institute of Standards and Technology (NIST) is also helpful.

O.3.3.7 The maximum kinetic energy of the rotor will be the sum of the kinetic energy at the time the overspeed shutdown system initiates a shutdown and the energy added because of time delays and entrapped gas.

$$E_{max} = E_T + E_s + E_v + E_e \quad \text{(HP-s)} \tag{O.42}$$

The maximum speed attained by the rotor can be calculated using Equation (O.43) and Equation (O.44), as follows

$$N_{max} = \sqrt{\frac{E_{max} \times 10^6}{k_2 \times WR^2{}_T}} \quad \text{(rpm) (turbine uncoupled)} \tag{O.43}$$

$$N_{max} = \sqrt{\frac{E_{max} \times 10^6}{k_2 \times WR^2{}_C}} \quad \text{(rpm) (complete train)} \tag{O.44}$$

O.3.4 Mechanical Drive (Gas Turbine, Power in units of HP)

O.3.4.1 The OEM should provide the overspeed estimate based on their experience and design configuration. Generally, coupling failure or generator loss of load will represent the maximum overspeed case, and shall be considered for gas turbine drivers.

O.3.4.2 The OEM shall consider the residual fuel and energy in the system to determine the maximum overspeed and specify the overspeed trip level accordingly.

O.3.4.3 The instantaneous rotor acceleration at the overspeed shutdown setting can be determined by

$$\alpha_t = k \times \frac{P_{g(max)}}{N_T \times WR^2{}_T} \quad \text{(rpm/s) (turbine uncoupled)} \tag{O.45}$$

$$\alpha_c = k \times \frac{P_{g(max)}}{N_T \times WR^2{}_C} \quad \text{(rpm/s) (complete train)} \tag{O.46}$$

where

k is 1.614×10^{-6} rpm^2-lb-ft^2/(HP-s);

$P_{g(max)}$ is the turbine rated power (HP);

N_T is the setpoint of overspeed shutdown device (rpm);

$WR^2{}_T$ is the rotational inertia of turbine (uncoupled) (lb-ft²);

$WR^2{}_C$ is the rotational inertia of the complete train (coupled) (lb-ft²).

O.3.4.4 The kinetic energy of the rotor at a given speed, N, can be calculated by

$$E = k \times 10^{-7} \times WR^2 \times N^2 \quad \text{(HP-s)} \tag{O.47}$$

$$E_T = k_2 \times WR^2{}_T \times N_T{}^2 \quad \text{(HP-s) (turbine uncoupled)} \tag{O.48}$$

$$E_T = k_2 \times WR^2{}_C \times N_T{}^2 \quad \text{(HP-s) (complete train)} \tag{O.49}$$

where

E_T is the rotor kinetic energy at overspeed shutdown setpoint;

k_2 is 3.10×10^{-7} [HP-s-min²/(lb-ft²)].

NOTE These equations are for simple gas turbines.

O.3.4.5 For more complex gas turbine arrangements, such as multiple shafts, heat extraction, and regeneration, the OEM shall provide overspeed estimates based on their unique design and engineering practices.

O.3.4.6 The energy added to the rotor during the signal delay time is

$$\Delta E_s = T_s \times P_{g(max)} \quad \text{(HP-s)} \tag{O.50}$$

where

T_s is the signal time delay (seconds).

O.3.4.7 The energy added to the rotor during the closure time of the fuel valve is

$$\Delta E_V = f \times T_V \times P_{g(max)} \quad \text{(HP-s)} \tag{O.51}$$

where

T_v is the closure time for fuel valve (seconds);

f is the fraction of maximum fuel flow that passes through the inlet valve during closure period.

If the fuel valve characteristics are linear, the energy added during the closure time of the fuel valve would be half the turbine max power times the closure time. In this case, f would be 0.5.

O.3.4.8 The energy added to the rotor by the combustion of fuel that is trapped within the turbine fuel lines is

$$\Delta E_e = LHV \times M_f + SH \quad \text{(O.52)}$$

where

LHV is the Lower Heating Value of the fuel;

M_f is the mass of the fuel in the fuel lines;

SH is the sensible heat of the fuel
$SH = M_f \left(h_T - h_{ref}\right)$
Sensible heat considers the effect of temperature on the fuel vs. standard or reference conditions.;

NOTE Fuel and gas constituents and properties must be obtained to estimate the internal energies and enthalpies. These are provided in the specification / data sheet for the expander / turbine. A gas properties tool, such as REFPROP from the National Institute of Standards and Technology (NIST) is also helpful.

O.3.4.9 The maximum kinetic energy of the rotor will be the sum of the kinetic energy at the time the overspeed shutdown system initiates a shutdown and the energy added because of time delays and entrapped gas.

$$E_{max} = E_T + E_s + E_v + E_e \ \text{(HP-s)} \quad \text{(O.53)}$$

The maximum speed attained by the rotor can be calculated using Equation (O.54) and Equation (O.55), as follows

$$N_{max} = \sqrt{\frac{E_{max} \times 10^6}{k_2 \times {WR^2}_T}} \ \text{(rpm) (turbine uncoupled)} \quad \text{(O.54)}$$

$$N_{max} = \sqrt{\frac{E_{max} \times 10^6}{k_2 \times {WR^2}_C}} \ \text{(rpm) (complete train)} \quad \text{(O.55}$$

O.3.5 Electric Adjustable Frequency Drive

O.3.5.1 A risk assessment shall be performed to determine if the risk of human error, software error, or component failure results in a risk level that is not tolerable and would require an independent overspeed detection system to mitigate.

O.3.5.2 Adjustable speed drives will not overspeed on a sudden loss of load, as the speed is a function of electrical frequency output from the driver and is independent of load. Therefore, the case of over-speeding a AFD motor from a loss of load or failed coupling is very unlikely.

O.3.5.3 It is possible that an adjustable frequency drive might be configured or fail in such a manner to increase speed, however the system is limited by the available electrical output power of the drive. An example of such a configuration is a bypass around the AFD that allows the motor to run at line frequency.

O.3.5.4 The motor electrical supply and output power limits should be considered. In many cases, the motor controller is limited in its excess power capacity and will not be capable of overspeed. In the case of a sudden loss of load, the motor driver must also experience a controller setpoint failure for overspeed to occur.

O.3.5.5 Use of “smart” motor control centers for managing motor overspeed is allowed as determined by a safety assessment and compliance to the determined safety integrity level.

O.4 Use of rotor acceleration as a proxy for overspeed.

Generally, measuring rotor acceleration is not considered robust or accurate enough to use as a safety device. Sudden changes in rotor acceleration are possible while still being well within the safe speed zone, and will likely result in false or unnecessary trips.

Annex P Reciprocating Compressor Monitoring

(Normative)

P.1 Introduction

The purpose of this document is to provide guidance in the selection and application of permanently installed on-line monitoring systems. This document does not address periodic monitoring systems.

P.2 Scope

This annex covers instruments for on-line monitoring systems applicable to reciprocating compressors addressed by API 618. Further information can be found in that document.

P.3 General

Typical sensor design definitions for centrifugal equipment applications are located in Section 6, and their applications are noted throughout the standard. However, some of these typical sensors are used in unique ways for reciprocating compressors. There are also sensors that are only used in monitoring reciprocating compressors. This section provides information for the reciprocating compressor application.

P.4 Transducer Function and Installation

P.4.1 General

This section outlines transducers for reciprocating compressor applications. Application of each arrangement is dependent on the monitoring objectives.

P.4.2 Cylinder Chamber Pressure (Selected on Datasheet)

P.4.2.1 Static pressure transmitters shall not be used for dynamic chamber pressure measurements.

P.4.2.2 Cylinder chamber pressure transducer(s) shall be installed on each compression chamber.

P.4.2.3 Cylinder chamber pressure transducer(s) shall mount to an isolation valve.

Note Typically, this is a double block and bleed isolation valve that mounts on the cylinder chamber pressure ports to have two isolation points within the same valve body.

P.4.2.4 Cylinder chamber pressure port isolation valves shall be made with materials compatible with the service and rated to meet or exceed the cylinder maximum allowable working pressure and temperature and shall have zero leakage during operation.

NOTE 1 If the cylinder does not have pressure ports, an indicator ported valve assembly can be used to provide a cylinder pressure tap.

NOTE 2 The preferred location for the indicator ported valve is the suction valve location. However, when the suction valve locations are used for capacity control devices then these may not be available for modification for an indicator port. The discharge valve assembly (one in each chamber) might then be the most available location for having a modification for an indicator port.

P.4.2.5 The indicator port connections and brackets shall be designed such that the transducer has structural bracing so it is protected from damage from accidental external impacts during maintenance action and to reduce effects of vibratory resonance.

P.4.2.6 The pressure port length and diameter shall be designed to prevent channel resonance and not exceed the temperature limits of the transducer.

P.4.2.7 The pressure transducer shall have a direct viewing straight path to the inside of the pressure chamber.

Note An isolation valve with a transducer access at right angles to the end of the valve body meets this condition.

P.4.2.8 The transducer cables shall be supported to prevent crimping of the cable which would result in poor performance of the transducer from damaged signal cabling.

P.4.2.9 The indicator valve shall be installed in a manner that allows the isolation valves to be operated without interference.

P.4.3 Piston Rod Monitoring

Piston rod monitoring is applicable for horizontal machines. It consists of the measurements of rod drop, rod position and PP displacement.

P.4.3.1 Proximity probes shall be used for piston rod monitoring.

• **P.4.3.2** If specified, PP displacement shall be used for trip.

NOTE The piston rod transducer system measures all piston rod movements. These movements are a result of not only rider band wear but can include one or more of the following:

a) mechanical rod runout due to crosshead-to-cylinder misalignment in the measurement plane,

b) rod deflection/flex, caused by forces imposed by load and process condition changes

c) cracked piston rod, loose crosshead shoes, loose connections, cracked pistons

These conditions occur in all reciprocating machines to varying extents and can potentially lead to erroneous conclusions regarding rider band wear when displayed in the average mode. In order to minimize these effects and obtain the most reliable indication of rider band wear, it is necessary to use the triggered mode. To use the triggered mode properly, find a point on the stroke where the influences of Items a) to b) are reduced. This is done through field testing during commissioning of the piston rod monitor.

P.4.3.3 Proximity probe systems shall be calibrated for the piston rod material.

P.4.3.4 The vertical proximity probe shall be mounted in the 6 o'clock or 12 o'clock position on the packing flange.

• **P.4.3.5** If specified, an additional horizontal proximity probe shall be mounted in a true horizontal position on the packing flange.

• **P.4.3.6** If specified, cable feed through assemblies shall be supplied.

P.4.3.7 Proximity probes shall be mounted at least one and one-half probe tip diameters measured from the probe tip center to the face of the packing flange (see Figure 11).

NOTE For piston rod diameters less than 3" (76mm), the horizontal probe can be offset more than 2 probe tip diameters to ensure cross talk is not an issue.

P.4.4 Vibration

P.4.4.1 Frame

P.4.4.1.1 A minimum of two velocity piezoelectric transducers, one mounted at the non-drive end and the other mounted at the drive end, shall be used to monitor frame vibration.

NOTE Mechanical vibration switches and moving coil velocity transducers are not suitable for continuous monitoring.

• **P.4.4.1.2** If specified, velocity transducers shall be mounted horizontally at the centerline of the crankshaft on the outside of the crankcase in line with a structural web/bearing saddle at each main bearing for direct transmission of vibration.

P.4.4.1.3 The monitored frequency range shall be from 1/2X running speed up to at least 20X running speed.

P.4.4.2 Crosshead

P.4.4.2.1 Integrated electronic piezoelectric accelerometer(s) shall be installed vertically on each crosshead guide.

P.4.4.2.2 Crosshead acceleration shall be used for trip and measurement units shall be 0-peak.

• **P.4.4.2.3** Monitored frequency range shall be agreed.

• **P.4.4.2.4** Accelerometer sensitivity shall be agreed.

NOTE Accelerometers can be mounted under down-running crossheads. If machine design does not allow mounting accelerometers under down-running crossheads, all accelerometers can be mounted on top.

P.4.4.3 Cylinder

• **P.4.4.3.1** If specified, cylinder integrated electronic piezoelectric accelerometers shall be provided for valve monitoring.

P.4.4.3.2 Monitored frequency range shall be agreed.

P.4.4.3.3 Quantity of sensors and mounting locations shall be agreed.

NOTE Accelerometers mounted at or near the discharge plenum can be exposed to high temperatures.

P.4.4.3.4 Accelerometer sensitivity shall be agreed.

P.4.5 Temperature

P.4.5.1 General

P.4.5.1.1 Thermocouples or RTD's shall be provided for temperature measurement for main bearings, packing, packing vent, crosshead guide, and valve covers.

• **P.4.5.1.2** If specified, dual element thermocouples or RTD's shall be provided.

P.4.5.1.3 Capillary temperature sensors shall not be used.

P.4.5.2 Crankpin Journal Bearings, Crosshead Pin Bushings, and Crosshead Shoes

• **P.4.5.2.1** If specified, crankpin journal bearings, crosshead shoes, and crosshead pin bushings shall be provided with either eutectic high temperature trip devices or wireless (radar) temperature devices.

P.4.5.2.2 Quantity of sensors and mounting locations shall be agreed.

P.4.5.3 Main Bearings and Crosshead Guides

• **P.4.5.3.1** If specified, main bearing temperature measurement devices shall be provided.

• **P.4.5.3.2** If specified, crosshead guides shall be provided with temperature measurement devices.

NOTE For optimized behavior of temperature sensor the normal running of the crosshead (uprunning or down-running) in either the upper or lower shoe can best assist in the proper location of the temperature sensor.

P.4.5.4 Valve/Valve Cover

• **P.4.5.4.1** If specified, valve/valve cover temperature measurement devices shall be provided.

P.4.5.4.2 Valve/valve cover temperature measurement device location details shall be agreed.

P.4.5.4.3 The valve cover bolts and jackscrews shall not be modified for temperature measurement devices.

P.4.5.5 Piston Rod Packing Case

• **P.4.5.5.1** If specified, a packing case temperature measurement device shall be provided.

P.4.5.5.2 Packing case temperature measurement device location details shall be agreed.

P.4.5.6 Packing Case Vent Line

• **P.4.5.6.1** If specified, a packing case vent line temperature measurement device shall be provided.

NOTE The placement of the temperature device should be as close to the packing vent discharge as practical.

P.4.5.6.2 Packing case vent line temperature measurement device location details shall be agreed.

P.4.5.7 Cylinder Cooling Jacket

• **P.4.5.7.1** If specified, cylinder cooling jacket system temperature measurement devices shall be provided.

P.4.5.8 Process Gas Stream

P.4.5.8.1 Suction gas temperature measurement devices for each cylinder shall be provided.

P.4.5.8.2 Discharge gas temperature measurement devices for each cylinder shall be provided.

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