Manual of Petroleum

Measurement Standards

Chapter 5.X

Measurement of Conductive Liquids by Electromagnetic Meters

FIRST EDITION, 20XX

Introduction

This standard is applicable to the dynamic measurement of single-phase electrically conductive liquids using electromagnetic flow meters, also referred to as magmeters, eMag, or EM. While this document is specifically written for custody transfer measurement, other acceptable applications can include allocation measurement, check meter measurement, and leak detection measurement. For allocation measurement application, refer to API *MPMS* Chapter 20 for applicable guidance and considerations.

Electromagnetic flow meters use Faraday's law of electromagnetic induction to calculate velocity from an induced voltage and meter's cross-sectional area to determine volumetric flow rate when conductive liquid passes through a magnetic field, given by:

$$E = k \cdot B \cdot v \cdot D$$

$$Q = (v \cdot D)/4$$

Where:

E = Measured Voltage

k = Constant

v = Fluid Velocity

B = Electromagnetic Field Strength

Q = Volumetric Flow Rate

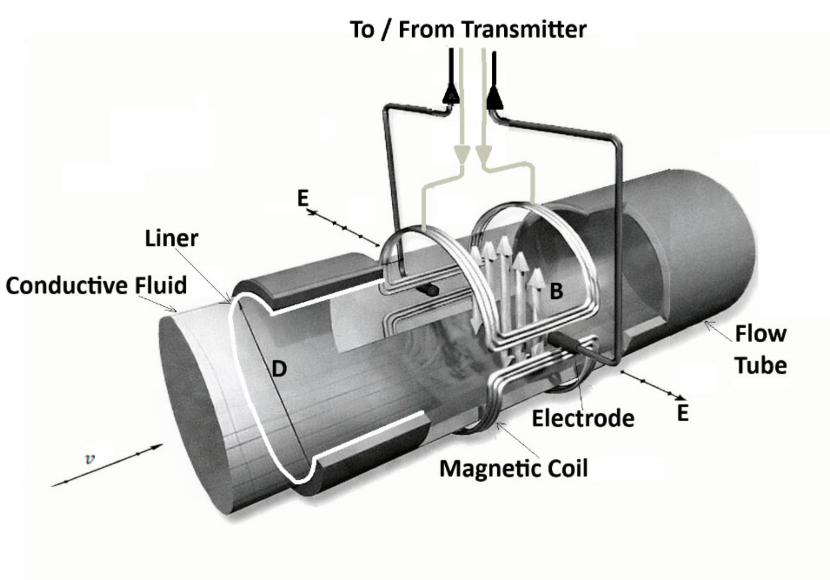

Figure 1. Electromagnetic Meter Sensor

1 Scope

This document provides guidance for the selection, installation, operation, verification, and maintenance of electromagnetic meters used for the dynamic custody transfer measurement of single-phase electrically conductive liquids, such as produced water and brine water.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the reference document (including any addenda) applies.

API *Manual of Petroleum Measurement Standards (MPMS)* Chapter 4 *Proving Systems*

IEC 61000, *Electromagnetic Compatibility*

IEC 60068, *Environmental testing - Part 1: General and guidance*

3 Terms, Definitions, Acronyms, and Symbols

3.1 Terms and Definitions

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

3.1.1 Flow Calibration

The process of using a reference standard to determine a coefficient that adjusts the output of the flow device transmitter to bring it to a value that is within the specified accuracy tolerance of the meter over a specified flow range. This process is normally conducted by the manufacturer or accredited third-party laboratory.

3.1.2 Electromagnetic meter

A type of volumetric flow meter, that generates a magnetic field perpendicular to flow to induce a voltage proportional to flow velocity, which is used to calculate flow rate according to Faraday's Law of Electromagnetic Induction. (also referred to as magmeter)

3.1.3 Meter factor (MF)

A factor used to correct the indicated volume (IV) of the meter at operating conditions to the gross volume (GV) of the meter at operating conditions.

3.1.4 Transmitter

A device that converts the signal from a sensor into a form suitable for propagating the measurement information from the site of measurement to the location where the signal is used. The signal is typically converted into a current, pulse train, or serial digital form. The sensor can be separate or can be part of the transmitter.

3.1.5 Sensor (Magmeter)

A mechanical assembly that collectively convert the physical flow of an electrically conductive fluid into an electrical signal. The mechanical assembly consists of:

a) Flow Tube: The flow tube (also referred to as meter tube or measuring tube) is the pipe section of the sensor through which the liquid flows.

b) Liner: A non-conductive material e.g., hard rubber, PTFE, or ceramic carbide which is used to isolate the meter body from the conductive fluid preventing a short circuit.
c) Electrodes: Electrodes are electrical conductors that detect a voltage that is induced in the conductive fluid as it flows through the magnetic field of a magnetic flow meter.
d) Magnetic Coil: A magnetic coil, also known as an electromagnetic coil, is a wire wound into a coil shape that creates an electromagnetic field when an electrical current passes through it. The wire coils are typically made from copper or aluminum wires.
e) Process Connections: the process connection refers to the physical interface that secures the flow meter sensor into the pipeline system. This connection is critical for maintaining a secure, leak-proof seal and ensuring proper alignment of the sensor within the flow stream,

3.1.6 Oil in Water

Small percentages of hydrocarbon by volume dispersed in water, produced water or brine.

3.1.7 Zero Stability

The deviation from a zero indication by the meter over an appreciable time when no physical flow is occurring and no output inhibiting is applied.

3.1.8 Grounding Rings

A conductive ring installed between a flowmeter flange and the adjacent pipe flange, used to provide a ground path for stray electrical signals.

3.1.9 Electrically Conductive Liquid

Liquid electrical conductivity refers to the ability of a liquid to conduct an electrical current. It is a measure of the liquid's ability to allow the flow of charged particles, such as ions, through it when an electric field is applied.

3.1.10 Electrical Conductivity Threshold

The minimum electrical conductivity range of the process fluid for a magnetic flow meter.

3.2 Acronyms and Symbols

ANSI	American National Standards Institute
ELM	Electronic Liquid Measurement
EMC	Electromagnetic Compatibility
EPA	Environmental Protection Agency
E	measured voltage
HART	Highway Addressable Remote Transducer
IEC	International Electrotechnical Commission
ISO	International Standards Organization
K	constant
MF	meter factor
NIST	National Institute of Standards and Technology
OIML	International Organization of Legal Metrology
PFA	Perfluoroalkoxy
PTFE	Polytetrafluoroethylene
SCADA	Supervisory Control and Data Acquisition
v	fluid velocity

4 Principle of Application

This document defines the application criteria for electromagnetic flow meters and outlines key considerations regarding the liquids to be measured. It also addresses the selection, installation, operation, and maintenance of electromagnetic meters in pipelines carrying electrically conductive liquids.

The electromagnetic flow meter shall be designed and constructed of materials suitable for the service conditions for which the meter is rated. The flow meter design and construction should also meet any applicable codes and regulations.

The operator should determine the expected liquid flow rates and verify that these values are within the range specified by the manufacturer. The operator should also consider the maximum velocity for piping and equipment safety (e.g., "API RP 14E Offshore Production Platform Piping Systems").

The operator is cautioned that operating electromagnetic meters at flow rates below manufacturer recommended minimum flow can incur greater measurement uncertainty.

5 Application and Meter Selection

Electromagnetic flow meters provide accurate and reliable measurement of electrically conductive liquid flow rates by utilizing the principles of electromagnetic induction. When selecting an electromagnetic flow meter, consider factors such as:

- Pipe diameter
- Upstream straight-run requirements
- Mounting orientation (vertical or horizontal)
- End connection types (e.g., flanged, threaded, socket weld, union)

Additional considerations include:

- Performance specifications (e.g., high accuracy, zero stability, strong signal-to-noise ratio, fast response),
- Output signal options (e.g., analog current, analog voltage, frequency, RS232/485, or Ethernet),
- Special features such as integrated density, level, or temperature measurement and data logging.

5.1 Selecting Meter and Accessory Equipment

Magmeters should be compatible with the following application conditions:

A. The class, type, and material of piping connections, as well as the dimensions of the equipment to be used.
B. The minimum and maximum operating flow rates.
C. The minimum and maximum operating Reynolds number.
D. The acceptable pressure-drop across the meter run. While most magmeters exhibit minimal, consideration should be given to losses introduced by the flow conditioning elements, strainers and static mixers (if applicable).
E. Compatibility of metallurgy, elastomers, coatings and other components with the process fluid.
F. The effects of erosive and/or corrosive contaminants on the meter and the quantity and size of foreign matter, including abrasive particles, which can be carried in the liquid stream.
G. The minimum and maximum ambient and process temperatures.
H. Possible depositions such as wax, asphaltenes, or other precipitants that can affect the performance of the magmeter.

I. The size and type of prover and method of proving. Unidirectional piston pipe provers with external detector switches (captive displacement prover) require special consideration to achieve repeatability.
J. Maintenance, costs, and spare parts that are needed.
K. Requirements and suitability for security sealing, auditing, and/or reporting.
L. Electrical and communication interface requirements, including power supply specifications and compatibility with signal outputs, diagnostics, alarms, and data protocols (e.g., analog current, frequency, RS232/485, Ethernet).
M. Regulatory and contractual requirements.

5.2 Sensor Considerations

When selecting an electromagnetic flow meter (magmeter), several sensor considerations are crucial to ensure accurate and reliable performance in measuring liquid flow. The sensor consists of the following components:

- Electrode
- Flow tube
- Liner
- Magnetic Coil
- Process Connections

The meter should be designed to permit easy and safe handling during transportation and installation. Hoisting eyes or clearance for lifting straps should be provided. The operator can request that the flanges directly up and downstream of the meter be dowelled to ensure exact positioning upon reassembly in the field.

5.2.1 Electrode Selection

Ensure that the electrode material is compatible with the fluid being measured. For corrosive liquids, electrodes made from materials like stainless steel, nickel alloy, or platinum is common. Some electrodes can have coatings to reduce fouling or corrosion. The shape of the electrode should also be considered during the selection phase. Some manufacturers offer a variety of different shaped electrodes for specific applications. Consult manufacturer for specific recommendations. Some electrodes are designed to be self-cleaning or have special coatings to minimize buildup and reduce maintenance needs.

5.2.2 Flow Tube Design

The flow tube (also referred to as meter tube or measuring tube) is the pipe section of the sensor through which the liquid flows. For a meter with magnetic coils mounted outside the meter tube, this would be constructed from a non-magnetic material. On designs where the magnetic coils are inside the meter tube, it can be of a magnetic material.

The inner lining of the flow tube shall be made from materials compatible with the fluid being measured, such as PTFE, PFA, polyurethane, rubber, or ceramic, to prevent corrosion, minimize abrasion and ensure durability. The flow tube should be designed to maintain a smooth, unobstructed path for the fluid to minimize turbulence and ensure accurate flow measurement. Additionally, the flow tube shall be robust enough to withstand the operating pressure and temperature conditions of the application. The design should facilitate the ease of installation and maintenance.

Ensure sufficient straight pipe lengths upstream and downstream of the flow tube. This allows for a well-developed flow profile, which is crucial for accurate flow measurement. Typical recommendations include straight lengths equivalent of 10 times the pipe diameter upstream without flow conditioner, 5 pipe diameter with a flow conditioner and 2 to 5 times the pipe diameter downstream.

The upstream and downstream flange pipe diameter shall match the flow tube process connection of the tube assembly where the magmeter will be installed. Flow tubes are typically circular in cross-section to ensure uniform flow conditions and accurate measurement. Some magmeters also come in oval or rectangular shapes for specific applications.

Consider the expected operating conditions and ensure the magmeter can measure accurately within the desired range.

5.2.2.1 Flow Tube Pressure Rating

Magmeter sensor, including flow tube(s), end connections, liners, and electrodes, shall meet the pressure code requirement for the service. This shall include the liner and electrodes in the sensor tube. The external housing around the flow tube(s) is designed to protect the sensor electronics and can fail to meet the same pressure ratings as the flow tube(s). For applications where sensors could be exposed to vacuum conditions, consult the manufacturer on the liner limitations for vacuum service. Some liner materials might not be suitable for vacuum service and could deform or fail under negative pressure.

Meters shall be manufactured to meet the pressure rating requirements of the selected connection type, including but not limited to flanged, socket weld, clamp, or threaded configurations. For flanged connections, common pipeline flange classes (e.g., ANSI Class 150, 300, 600, 900) may be used. The maximum design pressure of the meter shall be governed by the lowest-rated component among the flow tube body, connection type, electrode assemblies, and associated hardware. Designers or operators shall review all applicable codes, regulations, and site-specific requirements to determine the appropriate minimum and maximum operating pressure specifications.

Meters shall be adequately protected from excessive pressure through the proper use of pressure relief devices. Refer to API *MPMS* Chapter 5.1 for meter system pressure protection.

5.2.2.2 Flow Meter Sensor Length and Internal Diameter

Magmeters are available in a wide range of sizes to accommodate different pipe diameters. Ensure that there are no obstructions or protrusions inside the flow tube that could affect the flow profile or interfere with the magnetic field. As noted in Annex A, even relatively minor (3 mm) horizontal or vertical misalignment or obstructions can substantial accuracy deviations in the range of -0.45 % to -1.25 %.

Overall face-to-face lengths of the flow meter models, with flanges for each pressure class and pipe schedule diameter, should be readily available from the meter manufacturer. The internal diameter of the flange face (contact face) will be within the tolerances published within applicable standards (e.g., ANSI schedule).

The flow meter body inside diameter in the measurement section, as defined by the manufacturer, shall be of constant diameter to within 0.5 % of the average internal diameter of the measurement section. The operator should confirm the nominal pipe diameter of the sensor matches in the meter configuration in the transmitter.

5.2.2.3 Flow Meter Identification and Nameplate Requirements

A nameplate containing the following information should be affixed to the flow meter body:

- The manufacturer, model number, serial number and month and year manufactured
- Nominal meter size, flange class and schedule, and total weight

- Liner Maximum and minimum storage temperatures
- Body design code and material, and flange material
- Maximum and minimum operating pressure and temperature
- Maximum (Qmax) and minimum (Qmin) actual (at flowing conditions) volumetric flow rate per hour
- Direction of primary or forward flow
- Area classification

The nameplate can also include purchase order number, shop order number, or user tag number. The name plate(s) and markings shall be made of materials that will not deteriorate, fade, or peel when the meter is in an outdoor environment.

5.2.3 Performance Requirements

Accuracy and sensitivity specifications are based on the combined performance of the transmitter and sensor. Sensors and transmitter have different accuracy specifications and sensitivities regarding design and operating conditions. Accuracy and sensitivity specifications are determined by the transmitter alone or by the combined performance of the transmitter and sensor. Each component can have distinct accuracy ratings and sensitivity characteristics based on its design and operating conditions.

Check the accuracy specifications and ensure they meet your application requirements, considering factors like flow velocity, flow profiles, upstream piping and fittings (such as elbows, tees, etc.) and fluid electrical conductivity threshold; this range is typically between 3 – 5 microSiemens per centimeter (µS/cm) though exact values can vary by model, manufacturer, and application. Verify the performance of the magmeter under different flow conditions, including bidirectional flows (if applicable), to confirm compliance with accuracy requirements; see section 7.1 for Meter Validation. Consult the manufacturer for the performance envelope describing error limits throughout these conditions and consider the limits with respect to the system requirements. Flow calibration of the magmeter at accredited facilities or laboratories with standard references traceable to international or governmental agencies such as ISO and NIST can help achieve optimum meter performance and accuracy. Routinely performing in-situ proving to account for field piping conditions that cannot be replicated in a laboratory can also help achieve optimum performance and accuracy. Refer to section 8.2.3 of this document for details recommendations on flow calibration and in-situ proving of magmeters.

Deposits due to normal liquid pipeline conditions (e.g., sediment, paraffin, or traces of mill-scale, dirt or sand) can affect the meter's accuracy by reducing the meter's cross-sectional area and changing the surface roughness, thus affecting the liquid flow profile. Independent of electrodes mounting, deposits can also affect the electrode from measuring the induced voltage.

5.2.4 Meter Sensor Pressure and Temperature Compensation

Electromagnetic flowmeters manufacturers do not typically compensate for pressure and temperature effect on the meter sensor and there are no pressure or temperature compensation values published by manufacturers to compensate for their impact on measurement. Pressure or temperature could still be used to correct measured volumes back to standard conditions. Consult the manufacturer of the meter to determine if this is possible within the transmitter or to be done externally.

5.2.5 Documentation

Meter manufacturers can provide calibration certificates and other documentation for the meter, such as electrical area classification certification, pressure ratings on the meter body assembly, hydrostatic test report, and material test reports.

5.2.5.1 Documentation by Operator

Operators or users of electromagnetic flow meters should maintain specific documentation, such as installation records, calibration records, maintenance logs, baseline and operational data logs, and software and firmware updates. This documentation is to ensure the meters function correctly, maintaining accuracy, and complying with regulatory requirements and contractual agreements.

5.2.6 Bidirectional Flow

The magmeter should be capable of accurately measuring flow rates in both forward (positive) and reverse (negative) directions. This requires the flow meter to detect and process the induced voltage signal from the flowing conductive fluid regardless of the flow direction. Some applications can require frequent changes in flow direction, and the magmeter should be able to handle these variations without compromising accuracy.

If the meter is utilized in bidirectional service:

— both inlets of the meter shall conform to the upstream piping requirements.

— Meter factors, when used, should be determined for each direction.

If a meter is utilized predominantly in one flow direction over the other, temperature, pressure, or density instrumentation should be located downstream of the predominant meter.

5.2.7 Sensor Electrical Requirements

The sensor component is crucial for detecting and measuring the flow of a conductive fluid through the meter. The sensor's primary purpose is to generate a signal that corresponds to the velocity of the fluid, which is then processed by the transmitter to determine the flow rate. The strength and uniformity of the magnetic field are critical for accurate flow measurement. The sensor is designed to create a stable and consistent magnetic field that covers the entire cross-section of the flow tube. The sensor contains magnetic coils that generate a magnetic field across the flow tube. This magnetic field is essential for the operation of the electromagnetic flow meter, as it interacts with the flowing fluid to induce a voltage.

The electrodes measure the signal voltage, between μV and mV depending on the flowrate, induced by the magnetic coils in the process liquid. Then, the signal voltage is forwarded to a signal converter, which primarily converts the induced signal voltage into a standard electrical signal. The electrodes are in direct contact with the process liquid; therefore, operators should select electrodes made from materials that ensure durability and compatibility with the fluid and operating conditions. Common electrode materials include stainless steel, nickel alloy, and platinum.

Consider the number of electrodes and their positioning within the flow tube. Multiple electrode pairs can improve measurement accuracy, especially in varying flow conditions or varying flow profile. The electrode configuration and placement within the flow tube should allow for accurate measurement of the induced voltage signal in both flow directions.

The described sensor process for the magnetic coil to generate the magnetic field and electrode to sense signal voltage is high power demand process requiring continuous, uninterrupted generator or commercial power to maintain custody transfer accuracy, and real-time data transmission to meet API *MPMS* Chapter 21.2 recommendations. Even though an electromagnetic meter can be installed with a solar panel and battery combination, this is not recommended for custody transfer because it requires the meter to conserve power by reporting measurement readings on an interrupted basis.

5.2.8 Crosstalk

In the context of electromagnetic flow meters (magmeters), "crosstalk" refers to an undesired interference or signal contamination that can occur between multiple sensors in close proximity. This interference can lead to inaccuracies in flow measurement.

Consult the meter manufacturer for proper multiple sensors installation.

Strong electromagnetic fields can cause signal coupling between adjacent sensors. Improper shielding, grounding, or both can lead to inaccuracies in flow measurement. Use grounding rings around the flow tube to minimize electrical noise and interference from external electromagnetic fields. These rings help to maintain a stable electrical environment for the electrodes.

Manufacturers employ various techniques to mitigate crosstalk and minimize its impact on measurement accuracy:

- Electrode Design: Optimizing the design and placement of electrodes within the flow tube to reduce interference.
- Signal Processing: Advanced signal processing algorithms are used to differentiate and filter out unwanted signals caused by crosstalk.
- Calibration: Proper calibration procedures are employed to account for any residual crosstalk effects and ensure accurate measurement.

5.2.9 Cavitation

Cavitation occurs when pressure drops below the vapor pressure of the fluid, causing vapor bubbles to form and collapse violently, leading to localized shock waves and erosion. Cavitation can affect electromagnetic flow meters (magmeters) in several ways, potentially impacting their performance and accuracy. Cavitation bubbles, which form and collapse within the fluid, can create noise and disturbances in the flow. Since magmeters rely on the electrical conductivity of the fluid to measure flow, these fluctuations can interfere with the accuracy of the induced voltage signal detected by the electrodes.

In severe cases, cavitation can cause erosion or damage to the flow tube material, particularly if the flow meter is not designed to handle such conditions. This erosion can alter the geometry of the flow tube, affecting the flow profile and potentially leading to further inaccuracies in flow measurement.

Continuous or severe cavitation can degrade the overall performance of the magmeter over time. It can lead to increased maintenance requirements, reduced calibration intervals, or even necessitate premature replacement of the flow meter components.

Cavitation can induce flow instability, causing variations in flow velocity and turbulence within the flow tube. This instability can further complicate accurate measurement by the magmeter.

To mitigate the effects of cavitation on electromagnetic flow meters, implement measures to control flow conditions and reduce the occurrence of cavitation, such as adjusting valve positions to increase back pressure, or modifying pipe geometries to reduce pressure drops. Avoid sharp bends or obstructions that promote cavitation. Ensure downstream pressure recovers gradually to prevent bubble collapse. Choose flow meter materials that are resistant to cavitation erosion, especially in applications where cavitation is expected to occur. Employ advanced signal processing techniques within the magmeter electronics to filter out high-frequency noise and distinguish genuine flow-induced signals from cavitation-induced noise. Regularly monitor the magmeter performance and fluid conditions to detect signs of cavitation early.

5.2.10 Flashing

Flashing occurs when a liquid rapidly changes phase from liquid to vapor due to a decrease in pressure below liquid vapor pressure, but unlike cavitation, the pressure does not recover so the liquid remains in vapor form or partially vaporized. This phase change can significantly alter the electrical conductivity of the fluid passing through the magmeter. Changes in electrical conductivity caused by flashing can lead to inaccuracies in the induced voltage signal detected by the electrodes.

Similar to cavitation, flashing can generate high-frequency noise within the flow stream. This noise can interfere with the electromagnetic signal detection process, leading to measurement errors or inaccuracies. The magmeter can interpret these noise signals as flow-induced signals, thus providing incorrect flow rate readings. The formation of vapor bubbles during flashing can introduce noise and fluctuations in the flow stream. These fluctuations can manifest as variations in the induced voltage signal detected by the magmeter electrodes. This signal instability can result in erratic readings or fluctuations in the flow measurement, impacting the overall accuracy of the magmeter.

In some cases, flashing can cause erosion or damage to the flow tube material, particularly if the magmeter is not designed to handle such conditions. This erosion can alter the internal geometry of the flow tube, affecting the flow profile and potentially leading to further inaccuracies in flow measurement.

To mitigate the effects of flashing on electromagnetic flow meters, implement measures to control pressure conditions upstream of the magmeter to prevent or minimize flashing. This can involve adjusting valve positions, installing back pressure valves, or modifying piping configurations to reduce pressure drops and avoid vapor formation.

5.3 Transmitter Considerations

5.3.1 Transmitter Requirements

The transmitter is a critical component that includes power supplies, microcomputers, and signal processing unit (SPU). It can be housed in one or more enclosures, and it can be mounted locally or remotely to the meter site. Protect the transmitter from dust, debris, and corrosive substances. Minimize exposure to strong electromagnetic (EMI) fields (e.g., near power lines or heavy machinery). EMI can disrupt the induced voltage signal and affect accuracy. Prevent excessive vibrations or movement that could impact sensor stability.

The transmitter works in conjunction with the meter sensor to perform several key functions:

5.3.1.1 Signal Processing

The sensor component of the flow meter generates a small voltage signal when a conductive fluid flows through the magnetic field created within the meter. This voltage is proportional to the flow rate of the fluid. However, this signal is often very weak and needs to be amplified and processed to be useful. The transmitter takes this raw signal from the sensor, amplifies it, and processes it to filter out noise and other interference. It then converts the analog signal into a digital form that can be further analyzed and interpreted.

5.3.1.2 Flow Rate Calculation

After processing the signal, the transmitter calculates the flow rate of the fluid based on the voltage generated by the sensor. This calculation considers factors such as the cross-sectional area of the pipe and fluid velocity.

5.3.1.3 Data Conversion and Display

The transmitter converts the calculated flow rate into standardized units (e.g., liters per second, gallons per minute, or barrels per hour) and displays it on a local interface or screen. It can also convert the data into formats suitable for output to other systems, such as a control room or a SCADA (Supervisory Control and Data Acquisition) system.

5.3.1.4 Communication

The transmitter often includes communication capabilities to transmit the flow data to remote monitoring systems, control systems, or data loggers. This can be done through various communication protocols and output signals such as Modbus, HART, Profibus, pulses or frequency, 4-20 mA current loops, or a combination thereof.

5.3.1.4.1 Output Signal Specifications

The transmitter should be equipped with one or more the following outputs:

- Serial data interface, e.g., RS-232, RS-485 or equivalent
- programmable frequency outputs representing flow rate at line conditions
- Discrete digital status indicator
- Analog current loop (4-20 mA, DC)
- Ethernet
- A read-only serial port
- Additional frequency output
- Additional digital status outputs

The analog flow-rate signal should be scalable up to 120 % of the meter's maximum flowrate, Q_{max}. An analog current loop (4-20mA, DC) output should not be used for custody transfer due to the possibility of increased uncertainty (refer to API *MPMS* Chapter 4.2 section on Pulse Stability).

A low flow cutoff function should be provided that sets the flow-rate output to zero when the indicated flow rate is below a user specified minimum value.

The manufacturer should provide a selection to make the frequency output go to zero, maximum meter flow rate, or to a user-selected value when the maximum meter capacity, or maximum calibrated flow rate, is exceeded.

Two separate flow-rate outputs and a directional state output or serial data values should be provided for bidirectional applications. Also, to facilitate the separate accumulation of volumes, two registers for reverse and forward flow should be provided.

All outputs shall be isolated from ground and have the necessary voltage protection to meet the electronics design testing requirements of Annex C.

5.3.1.5 Diagnostics and Alarms

Many modern electromagnetic flow meter transmitters include diagnostic functions that monitor the health and status of the flow meter system. They can detect issues such as sensor malfunction, empty pipe conditions, or wiring problems, and alert operators through alarms or error codes.

5.3.1.6 Power Supply

The transmitter typically provides power to the sensor. It can be powered by an external power source or, in some cases, by a battery, depending on the application and the specific flow meter design.

Consider the power requirements for the sensor and transmitter; the transmitter should have a stable and reliable power supply, whether from an external source, such as a power grid, or an internal battery for remote or portable applications. Since the electrical signals of the magmeters are at relatively low power levels, care should be taken to avoid interference generated from nearby electrical equipment and wiring. Manufacturers employ various materials and methods to provide shielding against EMI. Cable jackets, rubber, plastic, and other exposed parts shall be resistant to ultraviolet light, oil, and grease.

Poorly designed cathodic protection and grounding systems can be sources of potential interference with the magmeter signals.

5.3.2 Frequency Output to Tertiary Devices

When an electromagnetic flow meter provides a frequency output to tertiary devices such as a computational device, there are several key requirements that have to be met to ensure accurate, reliable, and compatible data transmission. The frequency output shall be proportional to the flow rate within the specified range of the flow meter. The flow meter's transmitter should be capable of generating a frequency signal that accurately reflects the flow rate across its entire operating range. The transmitter should allow for the configuration of the frequency output signal to match the specific requirements of the tertiary device. This might include adjusting the pulse rate or scaling the frequency output to correspond to different flow ranges. The output frequency typically ranges from a few hertz (Hz) to several kilohertz (kHz), depending on the flow rate and the specific design of the flow meter. Common ranges are 0 to 10 kHz or 0 to 5 kHz.

The frequency output has to be stable and precise, without fluctuations or noise, to ensure the flow computer receives accurate data for flow rate calculations (Refer to API *MPMS* Chapter 4.2 section on Pulse Stability and API *MPMS* Chapter 5.5). The signal should have minimal distortion or interference to prevent erroneous readings or data corruption when transmitted to a tertiary device or computational device. The flow meter's transmitter should generate a frequency output in the form of a pulse signal (square wave or similar) that is compatible with the input requirements of the flow computer or tertiary device. The frequency output signal shall have appropriate voltage levels (e.g., 0-5V, or 0-24V) that are compatible with the input specifications of the connected flow computer. Parameters such as pulse width, frequency scaling factors, and output format should be adjustable to ensure accurate data transmission and compatibility with various types of flow computers.

The frequency output signal can require electrical isolation to prevent interference or potential grounding issues between the flow meter and the flow computer. The system should include surge protection to safeguard against voltage spikes or electrical surges that could damage the flow meter, transmitter, or flow computer. The flow meter's transmitter shall be adequately powered to maintain consistent frequency output, especially if the frequency signal is being transmitted over long distances or if the signal is used to drive multiple devices. In cases where the flow meter or transmitter is battery-powered or used in remote locations, the frequency output should be designed to minimize power consumption.

When transmitting the frequency signal over long distances, proper cable length, selection (e.g., shielded twisted pair) and signal conditioning (e.g., repeaters) should be used to maintain signal integrity. The frequency output and the associated equipment shall comply with relevant industry standards for electromagnetic compatibility (EMC), safety, and performance. This ensures that the system functions reliably in various industrial environments and does not interfere with other equipment. The transmitter should include features for monitoring the frequency output signal for abnormalities or faults. Any issues detected, such as signal loss or distortion, should trigger alarms or notifications to the operator.

5.3.3 Low-flow Cutoff

Low-flow cutoff refers to a feature in electromagnetic flow meters that suppresses flow-rate output when the measured flow falls below a predefined threshold considered too low for reliable measurement. At very low flow rates, the induced voltage signal generated by the fluid movement can become weak and more susceptible to electrical noise or external disturbances. This can result in unstable or inaccurate readings. The low-flow cutoff function is designed to minimize the impact of such low-level signals by setting the output to zero or disregarding values below the user-specified minimum threshold. This threshold is typically configurable and helps ensure that only valid flow data is transmitted to downstream systems.

Low-flow or no-flow cutoffs can be programmed in the transmitter or the tertiary device. These values inhibit flow totalization for very low-flow or true no-flow conditions that can occur.

5.3.4 Electromagnetic Meter Zero Stability

Zero stability in an electromagnetic flow meter refers to how well the meter can maintain consistent reading when there is no flow. It is a crucial factor in determining the meter's overall measurement accuracy; a consistent stability close to zero value under no flow conditions means the meter will not drift significantly from its zero point even under changing conditions.

Meter Zero Stability and Low Flow Cutoff are related concepts in electromagnetic flow meters, but they address different aspects of meter performance. While they address different aspects, meter zero stability ensures that the magmeter can accurately detect and maintain a stable zero flow signal. This stability is crucial because it establishes the baseline from which flow measurements are calculated, even when flow rates are minimal. Together, these features ensure that the magmeter provides reliable and accurate flow measurements across its entire operating range, including conditions where flow rates are near zero or fluctuating within very low ranges.

5.3.5 Meter Firmware and Software

Device firmware responsible for the control and operation of the magmeter shall be stored in nonvolatile memory. All flow-calculation constants and the operator-entered parameters shall also be stored in nonvolatile memory.

The manufacturer shall maintain and publish a record of all firmware revisions, including:

- Revision number
- Date of revision
- Explanation of firmware modifications, additions, and the reason for any changes
- Explanation of any metrological effects
- Applicable meter models
- Circuit board revisions for which the firmware is applicable

The firmware revision number, revision date, serial number and/or checksum(s) shall be available and capable of being displayed by the meter or interface device, for example:

- Local display
- Flow computer
- Operator software interface

6 Installation

6.1 Piping

6.1.1 Meter bypass / Isolation Valves / Proving connections

Consideration should be given to installing a bypass around the metering package to maintain continuous flow during maintenance and inspection activities. It is recommended that the bypass includes double block and bleed features.

Isolation valves should also be installed upstream and downstream of the meter run to accommodate for isolation of flow and meter removal. Isolation valves should be the same ANSI rate as other process connections or pipe specification.

If in-situ proving of the electromagnetic flow meter is required, a prover valve manifold shall be provided. The prover valve manifold shall be designed in accordance with API *MPMS* Chapter 4. For additional information on proving systems, refer to API *MPMS* Chapter 4.

In locations where in-situ proving is not possible, a spacer should be installed to allow for removal of the meter for off-site bench proving. Additionally, upon reinstallation this space will allow for effective liner protector installation and bolt up without damaging the liner of the electromagnetic flow meter.

6.2 Mounting

Manufacturer's recommendations should be followed for proper mounting of the sensor. In general, mounting should include proper support of adjoining piping, concentric alignment of the sensor with inlet and outlet piping, and appropriate sensor orientation. The meter run design shall ensure that each meter is liquid filled under all operating conditions. However, care should be taken to ensure that the measurement electrodes are not located on the top or bottom of the pipe to minimize the effects of gases or sediment (includes sand and other particulates that could be present in produced water). Placement of the meter(s) at high points in the system should be avoided. Magmeters can be installed in different positions or planes. The meter's installation orientation should be in accordance with the manufacturers' recommendation. Refer to Annex E for procedures on proper piping and fitting location to consider for magmeter installation.

Each type of electromagnetic flow meter sensor requires a type of gasket or sealant at each end of the sensor and process connection. These gaskets or sealants shall be compatible with the process fluid and operating conditions. Avoid using metallic or spiral-wound gaskets, these gaskets can harm the sensor's liner face. Lining protectors shall be installed with spiral wound or metallic gaskets.

Use caution when installing, tightening, or torquing the sensor and process connections. Various sensor linings and process connections require specific torque values and techniques specified by the manufacturer. For all sensor installations, both sides of the sensor shall be tightened evenly (i.e., do not tighten either connection end until both connections ends are first snug). Alternating between tightening on the upstream and downstream process connections can prevent potential damage to the liner and ensure the alignment of the sensor and the adjoining piping. Note that certain meter liner material without liner protection should be installed within hours to prevent liner swelling. Consult the meter manufacturer for specific re-installation time frame.

6.2.1 Flow Direction

Operator shall verify that the electromagnetic flow meter is configured to match the required flow direction or directions of the application. The meter body's flow arrow shall align with the intended flow direction unless the meter is being used in a bidirectional application. Operators should confirm that any associated flow computational devices are configured correctly to register flow for the selected direction(s). Manufacturer guidance should be consulted to ensure proper configuration.

6.2.2 Electrode Orientation

It is best practice to orient the electrodes so that the path line between them is within 45 degrees of the horizontal plane to avoid adverse effects of occasional gaps in the process fluid (e.g., slugs or bubbles); refer to Appendix E for more information. In vertical installations, the flow should be upwards to prevent vapor pockets from accumulating on the sensor body or electrodes and the effects of cascading flow.

6.2.3 Transmitter Orientation

It is recommended that the transmitter is mounted such that it can be easily accessed to attach communications equipment, view displays, and use associated keypads. The meter pulse output signal is from the transmitter, not from the sensor. For applications using a remote-mounted transmitter, it is recommended that the transmitter be installed as close as practical to the proving computer to minimize signal degradation and ensure reliable transmission of the pulse output, particularly in setups involving portable provers.

Installing displays in the direct sunlight should be avoided if possible. Some transmitters have the option to rotate the display to facilitate local meter reading.

6.2.4 Environmental Considerations

It is essential to consider environmental factors to ensure accurate operation and reliability. Application conditions shall be compatible with the manufacturer's specified operating temperature range. In applications when the ambient temperature can be outside of the manufacturer's recommended temperature range, consideration should be given to providing shelter, insulation, heating and/or cooling for the metering tube assembly. This includes, but is not limited to, the upstream piping spool(s), magmeter sensor, the downstream piping spool(s), and all secondary measurement equipment. Providing properly sized shelter, insulation, heating and/or cooling should ensure that the meter is operating within the manufacturer's stated temperature limits and minimize liquid temperature stratification.

Shelters or temperature-controlled enclosures should also be considered for magmeters located in areas subject to large cycling in ambient temperature and/or high radiant energy potential. Even if such temperature cycles are within the manufacturer's specification, over extended periods, the cycling can stress and damage the transmitter electronics. Flowing liquid temperature measurement can be influenced by radiant energy effects.

6.2.5 External Mechanical Vibration

The meter should be free from excessive vibration. External vibration sources can cause permanent mechanical damage to electronic boards and components, card cages, wiring and connectors, all of which will negatively affect magmeter performance. Magmeters should not be installed where vibration levels or frequencies might excite the resonant frequencies of SPU boards, ancillary components and sensors. Care should be taken to ensure compliance with local rules and regulations governing mechanical vibrations.

6.2.6 Electrical Noise

Electromagnetic flow meter ancillary devices, wiring integral to the meter, and conduits shall not be negatively influenced by external direct or alternating electromagnetic interferences created by, but not limited to, solenoid transients, wireless networks, 2-way radio communications and cathodic protection systems. The manufacturer shall provide to the meter operator instrument conformance related to electromagnetic radiation influences. Refer to Annex C.

6.2.7 Process Pulsation

Electromagnetic meters can be negatively influenced by different types of pulsation. Refer to API *MPMS* Chapter 6.2A for recommendations on how to mitigate pulsation.

6.3 Reference Grounding Requirements

Electromagnetic flow meters utilize a process reference ground connection to eliminate any difference in electrical potential between the meter and the process fluid. Additionally, reference grounding is essential to reduce electrical noise, ensure a consistent reference potential for the flow meter's signal voltage, and prevent drift and inconsistencies in sensor measurements. Grounding connections can be made using grounding straps, grounding rings, lining protectors, or reference electrodes. It's important to consider the impact of grounding on cathodic protection systems and to follow the manufacturer's recommendations for ground connections.

6.4 Strainers and Filtration

Magmeters have no mechanical moving parts. Strainers or other protective devices should be installed upstream of the meter to remove foreign objects that can cause measurement error. The accumulation of deposits due to mixtures of dirt, mill scale, sediment, paraffins, or a combination thereof can impact the meter's performance and should be avoided.

6.5 Air Eliminator

Air or vapor in the flowing stream will affect electromagnetic meter performance. Refer to API *MPMS* Chapter 6.1A for requirements and additional information related to air eliminators.

6.6 Temperature Devices

Temperature devices, temperature test thermowells, pressure, and density sensing devices shall be installed to accurately represent the actual metering conditions. Immediately downstream of the meter run no more than 5 pipe diameters is the preferred location. Refer to API *MPMS* Chapter 7.4 for recommendation on thermowell location and installation.

6.7 Installation & Meter Run Configuration

Different combinations of upstream fittings and valves can cause velocity profile distortions at the meter, potentially leading to measurement inaccuracies. The extent of these errors depends on the type and severity of the velocity profile distortion caused by the upstream piping arrangement and the meter's susceptibility to these distortions, which varies by meter design. Refer to Annex A for further information on upstream piping installation effect on electromagnetic meters.

While distorted velocity profiles are often mitigated using flow conditioners, certain meter designs might not require them. Manufacturers shall provide test data to the meter operator from an flow calibration laboratory demonstrating that the meter performs accurately without a flow conditioner under disturbed flow conditions.

The designer or operator of an installed metering package can choose from several configuration options. The suitability of each option for a specific meter model should be confirmed by the meter manufacturer and backed by supporting test data. This data should be obtained from an independent flow calibration laboratory, verifying that the metering package design meets the manufacturer's specification when subjected to the required flow disturbance tests in accordance with OIML R49-2.

Option 1: A conservative configuration with a flow conditioner (between spools UL1 and UL2) as shown in Figure 2:

Figure 2 – Conservative Configuration

Where:

UL1 = min. 5 ND Length

UL2 = min. 5 ND Length

DL = Variable

Option 2: Manufacturer-recommended configuration with one upstream spool and no flow conditioner as shown in Figure 3. The manufacturer should specify the length of UL1 based on independently certified test data:

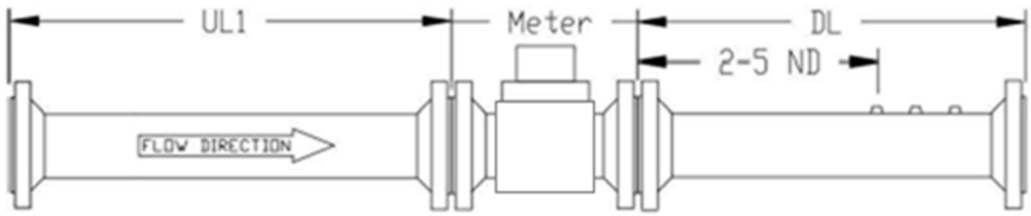

Figure 3 – Manufacturer-recommended Configuration

Where:

UL1 = Manufacturer-specified

DL = Variable

For bidirectional flow, upstream piping spool(s) and flow conditioners as applicable from Options 1, or 2 can be used on both ends of the metering package as shown in Figure 4.

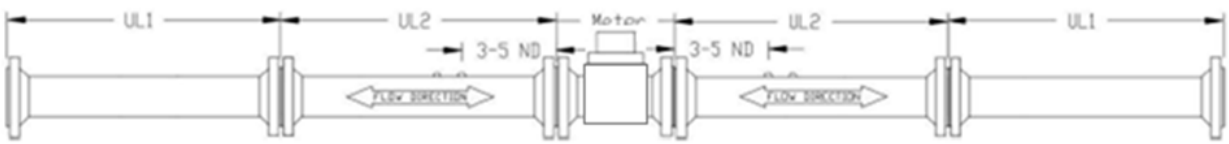

Figure 4 – Bidirectional Flow Configuration

To reduce uncertainty that can result from field installation effects, the operator might consider calibrating the metering package with the upstream and downstream piping configuration identical (size, fittings, lengths, orientation, etc.) to the planned field installation.

6.8 Meter Commissioning

6.8.1 Inspection

The meter installation should be inspected to confirm:

- Piping connections are installed in accordance with Section **Error! Reference source not found.**6.7,
- Correct installation of the sensor, transmitter, and associated wiring,
- Wiring and grounding connections are appropriately connected and tightened,
- Once filled, check process is free of leaks.
- Save meter configuration from the meter transmitter

6.8.2 Fill and Rate of Pressure Change

Sudden depressurization of the electromagnetic meter can damage the meter liner and other internal meter components. The manufacturer shall provide clear instructions for depressurization and pressurization of the meter and components during installation, start-up, maintenance, and operation. Manufacturers shall state acceptable rates of change.

6.8.3 Initial Verification / Fingerprint / Baseline

If the system includes a method for in-situ meter proving and stable process conditions have been established, it is recommended to complete an initial or first-flowmeter proving of the magnetic flow meter(s) as part of the commissioning process to establish original meter performance fingerprint or baseline to compare to future meter verification or proving and determine any deviation from original commissioning or installations. Refer to Section 7 and Section 8 for additional information on in-situ meter proving and performance criteria.

6.8.4 Configuration and Loop Checks

The flowmeter configuration and display should be set according to the operating conditions, ensuring the use of appropriate units of measure and parameter ranges.

Verify input and output signals to any peripheral devices to confirm that the loop is functioning correctly.

Meter diagnostics should be reviewed to confirm the measured values are in alignment with the manufacturer's guidance for the application. Baseline diagnostics and operating values should be captured and retained for future reference during troubleshooting and maintenance. As a final verification, testing both flow and no-flow conditions should be performed to identify any potential issues, such as incorrect alignment, obstructions, configuration, or calibration errors.

6.9 Conditions Affecting Meter Performance

Meter performance is defined by how well a metering system produces, or can be made to produce, accurate quantity measurement. See API *MPMS* Chapter 5.1 Meter Performance section for additional details.

A meter no-flow verification should be performed under non-flowing conditions per manufacturer recommendation to verify not leaking valve or liquid by-pass Very flow condition to ensure all wire and output signals and connections are terminated correctly.

7 Routine Maintenance

7.1 Confirmation of Performance

Methods for confirming the performance of magmeters vary by user, region, contract, compliance requirements, and quantities. To confirm accurate pairing of the transmitter and sensor, the calibration factor(s) in the transmitter's configuration should be verified to match the calibration factor(s) from the factory calibration certificate. Periodic visual inspection, validation, verification, use of self-monitoring, and diagnostics are recommended. Users should define their performance goals/requirements and decide the frequency and methods best suited for their application.

The following are suggested meter functionality evaluation methods:

- Magmeter Baseline / Fingerprint Diagnostic Verification
- Induced Voltage Simulation using devices traceable to a national metrology standard.
- Magmeter Validation

The following are suggested meter performance evaluation methods:

- Meter Flow Calibration
- Off-site meter proving

- In-situ meter proving (master meter, displacement, or tank)

Magmeter Validation is a process of comparing flow rates and volume totals over a defined test period between the in-service magmeter and another portable meter; refer to Annex F. The validation method is a comparative test to confirm measurement performance and to determine whether meter cleaning, or flow calibration is necessary when conventional proving is not practical. This process does not calibrate/prove the in-service magmeter. Pass/fail results of a validation will need to be determined by operator/customer agreement.

Magmeter Baseline / Fingerprint Verification is a diagnostic test of the meter's components and circuitry to ensure they are within tolerance of the baseline when the meter and transmitter left the factory or when the meter was last commissioned.

This test is performed against the sensor diagnostics available in the meter. Examples include:

- Velocity Simulation: measures actual velocity against a simulated current
- Coil Inductance: measures actual magnetic field strength against a baseline
- Coil Resistance: measures circuit resistance in the coil against a baseline
- Electrode Resistance: measures circuit resistance in the electrodes against a baseline

A baseline validation test should be performed under representative operating conditions using the actual process fluid to be measured. The pipe has to remain completely full throughout the baseline validation.

To elevate confirmation of performance confidence, it is recommended a verification should be performed with a validation test.

7.2 Internal Diagnostics for Confirming Performance of Magmeter

The magmeter hardware and software should be capable of monitoring certain parameters based on the specific application. Many of these parameters are monitored in the magmeter, and when these parameters fall outside the preset limits, a diagnostic alarm can be generated. Effective troubleshooting requires evaluating multiple diagnostic parameters in combination.

Using various methods can help to clarify the performance status of the magmeter over time and how these parameters compare to the original factory setup and the onsite start-up conditions. The complete troubleshooting process, however, requires evaluating these diagnostics parameters and process operating conditions combined. Most manufacturers of magnetic flow meters can provide device diagnostics that detect and warn of abnormal situations throughout the life of the meter. Diagnostics inform users of abnormal situations, from installation to maintenance and meter performance.

Common types of diagnostics levels to maintain accurate flow measurements:

1) **Device Level:** Looking for hardware and software faults
   a) **Diagnostic Coil Faults:** Can indicate an open, short, or other issue in the coil drive circuit anywhere from the transmitter to the magnetic coils in the sensor.
   b) **Diagnostic Output Wire Fault**: Can indicate an open or short output.
   c) **Diagnostic Electronic Temperature**: Electronics operate outside of the recommended manufacturers' temperature range.
   d) **Diagnostic Transmitter Faults**: Can indicate an issue with the transmitter hardware, software, and firmware.
   e) **4-20mA Loop Diagnostic** – Internal monitoring of the 4-20mA loop for a closed loop or possible signal overflow
   f) **Diagnostic Electrode Corrosion**: A chemical incompatibility with a product and the electrodes in the process with the magmeter.

  g) **Liquid Contact Resistance**: A non-conductive coating develops on the electrodes of the magmeter which inhibit proper functioning.
  h) **Grounding**: The meter will most likely read erratically. The signal or flow rate seen at the meter will not be consistent. A side point for the grounding and wiring between the two transmitter types is there could be a sensor connection fault if done incorrectly.

2) **Process Level Diagnostics**: Looking for process conditions which would affect measurement
  a) **Calculate Zero Level** or **Empty/Partially Filled Pipe:** At a minimum, an indication of less than full pipe of conductive liquid.
  b) **Liquid Conductivity**: An indication of the process fluid's electrical conductivity.
  c) **Process Temperature**: An indication if the "process" temperature is within range.
  d) **Air Bubbles**: An indication that process has entered multiphase.
  e) **High and Low Flow Alarms**: The measured flow rate is out of the range of user configurable set points.
  f) **Reverse flow**: An indication the flow is going in the opposite direction
  g) **High Process Noise**: An indication of electrical or process issues.
  h) **Electrode Fouling**: An indication of coating on the electrodes which can affect performance.
  i) **Flow profile**: An indication that flow profile is distorted.

3) **Performance Level Diagnostics**: Looking for meter health and/or accuracy which would affect measurement.
  a) **Meter Self-Diagnostics:** A periodic check against baseline values. Meter self-diagnostic could be done in-situ and this feature is contained in the meter. Possible checks include linearity check, accuracy check, I/O check, functioning of transmitter
  b) **Factory Fingerprints:** A comparison of existing parameters to the parameters when the magmeter was calibrated.
  c) **Liner Deformation**: An indication that physical liner can separate and affect performance.

7.3 Parts Replacement

In most cases, magnetic flow meters have limitations for field repair or parts replacement. When a diagnostic indicates an issue with the magmeter, limited number of options are available:

7.3.1 Sensor Repair or Replacement

Field repair of sensors can be limited to ground rings or the electrical connection junction box housing. In general, electrodes, liner, coils and other parts would not be field replaceable.

7.3.2 Transmitter Repair or Replacement

Magmeter manufacturers should be consulted before replacing transmitter components (e.g., electronic board stack, display or local operator interface (LOI), terminal block, covers, and mounting hardware).

If any such electronic components are changed, replacement shall not cause a change in the meter's performance greater than the manufacturer's published range of specifications of the meter. Additionally, component replacement shall not change the meter performance from the original flow calibration results by more than the long-term uncertainty of the flow calibration test facility. If the manufacturer cannot meet this requirement, flow calibration can be necessary. Refer to Section 8.2.5 on Flow Calibration.

7.4 Periodic Verification

The question of how often any electromagnetic flow meter should be verified is something typically left to the discretion of the end user. When possible, users should first establish an acceptable verification schedule based on company-specific policy, industry accepted guidelines, or any other regulations that might apply to them or their business activities. And only when warranted, following a failed Meter

Verification Diagnostic result for instance, or when required by a third-party or regulatory authority (e.g., API, EPA, or other applicable governing bodies), the meter should be sent back for complete factory evaluation and recalibration.

When abnormal flow readings, diagnostic alerts, or process inconsistencies are observed, a meter verification should be performed to assess measurement integrity. For an appropriately equipped magnetic flow meter, users can run Meter Verification Diagnostics at any time through a variety of digital communication protocols or through a local operator interface (LOI) display. However, a more practical approach is to monitor the meter's performance over time. This method provides not only a singular Pass/Fail result each time it's tested, but also a history of the meter's performance. Any sharp deviation or an abnormal trend would indicate that further investigation is needed. The ability to see deteriorating trend data can provide your maintenance staff with insight to predict when a meter might need service in the future (e.g., in known erosive/corrosive services).

8 Proving

8.1 General

Meter factor should be determined by proving the meter at stable operating conditions (i.e., essentially constant: flow rate, density, viscosity, temperature, and pressure). Refer to API *MPMS* Chapter 4 for guidance on this subject. Users typically determine the acceptable deviation limits of these operating conditions.

8.2 Proving Considerations

8.2.1 Conditions

Proving is primarily a function of regulatory and contractual requirements and typically standard company operating procedures. Proving conditions should be as close to the actual metering operation flowing conditions as practical. The essential purpose of proving is to confirm the meter's performance and accuracy at regular operating conditions.

8.2.2 Frequency of Proving

Most electromagnetic meters proving frequency should be based on meter type, operational conditions, and manufacturers' recommendations; refer to API *MPMS* Chapter 4 for guidelines. Frequency of proving guidelines is determined by individual companies' operational requirements, by mutual parties' contract agreements, or local or federal governmental agencies' regulations. When meter proving is not required by regulation, the target uncertainty of the application should be considered when specifying during design whether meter proving will be implemented at an application. Refer to API *MPMS* Chapter 4 for additional details on meter proving.

8.2.3 Proving Methods

Laboratory flow calibration and in-situ proving are two distinct processes used to ensure the accuracy and reliability of electromagnetic flow meters. Electromagnetic flow meters are typically calibrated in a controlled laboratory environment, which standard reference has been certified to a traceable to a national measurement institute (NMI), before they are put into service. Calibration ensures the meter output is accurate to the true flowrate by comparing the output against a reference standard.

Electromagnetic flow meters are typically calibrated in a controlled laboratory environment, which standard reference has been certified traceable to a national measurement institute (NMI), before they are put into service.

In-situ proving is the process of verifying the accuracy of a flow meter under actual operating conditions at the location where the meter is installed (in-situ) per one of described proving methods recommended in

API *MPMS* Chapter 4. In-situ proving is normally preferred because it verifies the meter's accuracy under actual operating conditions. However, laboratory flow calibration can help in improving the in-situ proving since the meter would be linearized at the calibration facility which helps to prove the meter faster with less proving run and passes. For this reason, it is recommended to both flow-calibrate the meter in a laboratory and perform routine in-situ proving once in service to optimize meter performance and accuracy.

8.2.4 In-situ Proving (field)

Operating conditions can affect a meter's accuracy and repeatability. In-situ proving at stable operating conditions compensates for variations in performance caused by flow rate, viscosity, density, temperature, pressure, as well as flow conditions, field piping configurations, and contaminants. API *MPMS* Chapter 4.5 can be referenced for master meter proving of an electromagnetic flow meter as a general practice, provided the additional uncertainty typically associated with master meter proving is acceptable to the parties involved.

8.2.5 Flow Calibration and Performance Requirements

Questions often arise concerning the differences between calibrating a meter in a manufacturer laboratory or third-party facility (bench) versus proving in-situ (field). These separate processes can produce different results and cannot necessarily be interchanged without realizing measurement error. Manufacturer or third-party facility flow calibration without in-situ proving the magmeter is normally not preferred because laboratory conditions do not represent the upstream piping configuration and operating conditions of the installation. Although there can be more measurement uncertainty associated with just performing flow calibration, in some situations, a laboratory calibration alone can provide the best and only alternative, for example, leak detection and pipeline segmentation applications. Refer to Annex D for further information on magmeter proving and flow calibration records.

8.2.5.1.1 Calibration Adjustment Factors

Magmeters are calibrated as part of the manufacturing process. A calibration adjustment factor (sometime also referred as calibration coefficients) determined and applied to minimize any indicated meter-bias error. The most common, industry accepted method of adjustment for linear flow meters is the use of a single adjustment factor. A calibration report is provided demonstrating performance at flow points in the magmeter range of operation. Additional flow points are provided by the manufacturer upon request. The calibration report serves as an important quality validation of the magmeter.

For a further description of calibration adjustment factor application, refer to Annex B.

8.2.5.1.2 Flow Calibration Acceptance Criteria

When flow calibrating a flow meter in a controlled laboratory environment, the acceptance criteria typically focus on key performance metrics such as linearity, repeatability, and uncertainty of the meter under test (MUT). The flow meter should be flow calibrated at an accredited facility to international standard, such as NIST, or ISO 17025. The flow meter should be flow calibrated and a report provided which demonstrates performance over the range of expected operation, if possible, which could include the minimum recommended meter flow rate (Q_{min}), maximum recommended meter flow rate (Q_{max}), and one more flow rate point between Q_{min} and Q_{max}.

After flow calibration factors have been applied to the meter configuration (As-Left), the meter should meet the following criteria over Q_{min} and Q_{max} range:

- Linearity: ± 0.2 % of the reading for the entire calibration.
- Uncertainty: ± 0.027 % for Q_{min}, Q_{max}, and all other test points in between.

For bidirectional flow calibrations, a second set of calibration adjustment factors shall be used for reverse flow.

8.2.6 Evaluation of Meter Proving Data

8.2.6.1 Repeatability

Proving run repeatability is used as an indication of whether the proving results are valid.
Some electromagnetic meters can produce a non-uniform pulse output, which can exhibit a wide span of repeatability when proved. It should be noted that proving run repeatability might not fall within the typical 5 run, +/- 0.05 % span of repeatability. However, proving runs should repeat within the guidelines of the uncertainty meter proving in accordance with API *MPMS* Chapter 4.8 and API *MPMS* Chapter 13.3.

8.2.6.2 Contributors to Increased Random Uncertainty

Proving accuracy can be affected by the delayed manufactured flow pulses from a magmeter. These delayed manufactured flow pulses can lead to a bias error in the calculated meter factor depending upon the magnitude of the flow rate change that occurs during the proving run and the duration of the prove run.

8.2.7 Reproducibility

Reproducibility is defined as the ability of a meter and prover system to reproduce results over a long period of time in service where the range of variation of pressure, temperature, flow rate, and physical properties of the metered fluid is negligibly small. A change in the meter factor greater than the user-defined limits should be considered suspect and every effort should be made to ensure that the magmeter and proving system is functioning properly. Statistical control charting of meter factors will be valuable in analyzing the reproducibility of magmeter and determining the required frequency of proving.

8.2.7.1 Reasons for non-reproducibility

If the magmeter sensor, transmitter, or Manufacturer Calibration Coefficients have changed since the last prove, especially if the Calibration Coefficients are not consistent with those provided by the manufacturer for the sensor in use, a large, unexpected variation in meter factor can occur. In this case, a careful review of the sensor serial number, the Calibration Coefficients supplied by the manufacturer for that sensor, and the Calibration Coefficients contained in the magmeter transmitter should be performed.

9 Auditing, Reporting, and Security Requirements

9.1 General

This section defines the audit trail features associated with the operation of an Electromagnetic meter to report and verify the integrity of the meter measurement. An Electromagnetic meter should be capable of establishing an audit trail by compiling and retaining sufficient data and information for the purpose of verifying periodic or batched quantities, as appropriate. Operators should note that not all electromagnetic meter manufacturers offer these audit trail features, and not all manufacturers provide full audit trail functionality; some might offer limited or no support for these features. Operators should consult with manufacturers to determine meter audit trail log capabilities. Also, some of these audit trail features could be logged on separate devices onsite or remotely.

Audit trail requirements apply only to data that affect volumetric calculations and the custody transfer quantity. The primary reason for retaining historical data is to provide support for the current and prior quantities reported by the meter for a given data retention cycle as described in API *MPMS* Chapter 21.2.

The data will provide sufficient information to apply reasonable adjustments when the electromagnetic meter:

- has stopped functioning.
- is determined to be out of tolerance
- has incorrectly recorded measurement parameters in the configuration.

The data will also allow parties with a direct interest in the measurement results to independently verify the correctness of the reported meter quantities.

9.2 Configuration Log

Those components and configuration parameters of the electromagnetic meter that affect the metrological function shall be identified and protected against unauthorized or accidental change. Authorized changes of these parameters should be stored in an audit log.

9.3 Alams and Event Log

The Electromagnetic meter shall make available alarms and event logs to indicate an alarm, event, or both. Additionally, magmeter alarms and event logs shall be viewable through the meter or system interface.

9.4 Security and Access

Configuration parameters and settings shall be secured against tampering, unauthorized changes, or undocumented changes. This can be achieved by using passwords, tamper-proof seals, locks or any other means. For magmeter connected to an ELM system, refer to API *MPMS* Chapter 21.2 for more information.

9.5 Auditing and Reporting Requirements

Auditing and reporting requirements are as follows.

a) Any and all programmable parameters, flow, and volume calculations shall be auditable.

b) The audit trail, meter configuration parameters, metrological flow calculation, calibration coefficients, firmware revision number, revision date, serial number, checksums, meter dimensions, and sampling rate, at a minimum, shall be made available to view and print.

c) API *MPMS* Chapter 21.2 fully addresses the auditing and reporting requirements of a generic electronic liquid measurement (ELM) system. The audit requirements of an ELM system using an electromagnetic meter are similar, except for the addition of specific configuration and setup parameters contained in the meter transmitter that shall be auditable and securable.

Annex A

(informative)

Installation Effects on Electromagnetic Flowmeters

This annex is a summary of the research done by PRCI on upstream piping and installation effects on electromagnetic flowmeters **(based on PRCI Report MEAS-7-02)**. This report reviews the use of electromagnetic flowmeters for the measurement of produced water, brine and fresh water in crude oil operations. The document summarizes findings from a comprehensive literature review, peer-reviewed papers, and industry standards. It identifies current best practices, and provides recommendations for selection, installation, and calibration.

This literature study, evaluates how installation affects electromagnetic flowmeters used to measure brine, produced and fresh water. With the increase in water production, the reliance on electromagnetic meters has increased, creating a need to better understand their performance, installation effects, and operational considerations.

The literature review provided the following findings:

- Electromagnetic meters are robust, but some remain sensitive to installation conditions, with upstream disturbances (e.g. elbows, reducers, partially closed valves, and misalignment) producing errors of 1% to 4% in some cases.
- Some electromagnetic flowmeters hold International Organization of Legal Metrology (OIML) R 49 Certification for Accuracy Class 1 at zero pipe diameters upstream and downstream (0D/0D) installations.
- There is limited publicly available, traceable test data confirming whether OIML R 49 0D/0D Accuracy Class 1 performance is achieved in real-world disturbed-flow conditions. The literature suggests that while some designs can maintain Class 1 accuracy, others can only reliably meet Class 2 limits when subject to common installation disturbances.
- None of the reviewed studies detailed long-term stability/drift data for electromagnetic meters.

A.1 Literature Review

This section provides a comprehensive literature review of electromagnetic flowmeters, assessing the relevance and quality of the documents. It considers whether the literature includes information on installation effects, uncertainty, and any recommendations. Sources include standards, journal articles, research, white papers, conference papers, and manufacturer publications.

A.2 Standards

The main flow standards relevant to electromagnetic flowmeters are a mixture of International Organization for Standardization (ISO) and International Organization of Legal Metrology documents:

A.2.1 ISO 20456:2017. Measurement of fluid flow in closed conduits — Guidance for the use of electromagnetic flowmeters for conductive liquids. *(International Organization for Standardization, 2017)*

This is the main international standard for electromagnetic flowmeters. It provides guidance for the use of electromagnetic flowmeters for the volumetric flow measurement of conductive liquids in closed, full pipes. The standard defines the operation principle, installation, design and practices, and calibration and verification methods.

A.2.1.1 Installation Effects

The standard recognizes typical minimum and maximum velocity ranges of 1 m/s and 10 m/s, respectively. It does not provide definitive guidance on upstream or downstream straight pipe requirements, instead deferring to manufacturer recommendations. The standard notes that flow disturbances, such as valves or elbows, can influence meter performance. It also highlights that electrode orientation should be considered if the fluid contains entrained solids or gases, ensuring that neither measuring electrode is directly impacted.

A.2.1.2 Uncertainty

The standard provides a range of conditions that should be detailed in the structured methodology for developing a complete uncertainty budget. These include ambient conditions, process conditions, and installation. However, the standard does not provide a complete uncertainty budget example.

A.2.1.3 Recommendations

Additional recommendations focus on the importance of proper installation practices. Correct grounding, accurate electrode placement, and adequate cable shielding are essential to reduce the influence of external electrical interference. The use of in-situ verification tools, such as built in diagnostics or external reference checks, is encouraged to support long term performance monitoring. All calibration procedures should be traceable to national or international standards.

A.2.3 ISO 4064-1:2014. Water Meters for Cold Potable Water and Hot Water. *(International Organization for Standardization, 2014)*

This standard is identical in content to OIML R 49-1:2024 and shares its scope and application. It is adopted widely across Europe and internationally for the certification of water meters.

A.2.4 OIML R 49-1:2024. Water Meters for Cold Potable Water and Hot Water. Part 1: Metrological and Technical Requirements. *(International Organization of Legal Metrology, 2024)*

OIML R 49-1 applies to water meters intended for cold and hot potable water. It covers both mechanical and electronic types, including electromagnetic meters. It forms the basis for type approval under legal metrology systems and is harmonised with ISO 4064-1.

A.2.4.1 Installation Effects

The standard requires manufacturers to specify the minimum upstream and downstream straight lengths needed to achieve accurate performance. Shorter runs can be permitted if the meter has been shown through testing to be insensitive to flow disturbances. Type approval testing has to cover both disturbed and undisturbed flow profiles to demonstrate compliance with the defined maximum permissible errors.

A.2.4.2 Uncertainty

Uncertainty is addressed through the specification of maximum permissible errors rather than a formal approach to uncertainty propagation. Meters are categorised into defined accuracy classes, typically Class 1, 2, or 3, based on their measured performance across the flow range. All meters have to be tested under worst case conditions to confirm suitability for legal metrology use.

A.2.4.3 Recommendations

Additional provisions require that meters operate reliably in the orientation for which they are approved, whether horizontal or vertical. The standard also includes requirements for product marking, operating environment, and periodic in-situ checks. Reverification intervals and procedures are outlined to support long term accuracy in field applications.

A.2.5 OIML R 49-2:2024. Water Meters for Cold Potable Water and Hot Water. Part 2: Metrological Controls and Test Methods. *(International Organization of Legal Metrology, 2024)*

Defines the test methods, metrological controls, and type approval processes for meters governed by Part 1. Used by test laboratories and verification bodies.

A.2.5.1 Installation Effects

The standard mandates that meters be evaluated under disturbed flow conditions using defined reference configurations. It provides guidance on how to generate asymmetric flow profiles, for example using double bends, to assess sensitivity to flow disturbances. Meter performance has to be verified at minimum, transitional, and permanent flowrates to ensure reliable operation across the full range.

A.2.5.2 Uncertainty

Uncertainty is addressed through maximum permissible error criteria using a pass or fail approaChapter The standard does not outline how to construct a complete uncertainty budget, but it does include requirements for repeatability testing and error curve analysis under a range of operating conditions.

A.2.5.3 Recommendations

The document outlines procedures for type testing, initial verification, and periodic reverification. While baseline methods are defined, more detailed installation guidance is deferred to individual manufacturer instructions.

A.2.6 Summary

Throughout the reviewed standard documents, installation effects are recognised as a key factor influencing electromagnetic meter performance. However, few provide any quantitative guidance. Most defer to manufacturers to define acceptable levels of disturbance. ISO 20456 offers the most practical and field relevant advice on piping layout, upstream fittings, and flow profile sensitivity.

Uncertainty guidance remains limited. Although accuracy classes and maximum permissible errors are clearly stated, particularly in the legal metrology (OIML), guidance for building a measurement uncertainty budget was not included. ISO 20456 is the only standard to highlight key site-specific contributors such as conductivity, entrained air, and zero drift.

All documents highlight the importance of correct installation, and periodic verification. However, few offer best practice for complex conditions. These include retrofit installations or the presence of secondary phases such as entrained gas. Such scenarios are increasingly common in upstream water measurement. Future revisions should aim to address these commonly encountered but poorly specified cases.

A.3 Journal papers & Research

The key technical literature relevant to installation effects and uncertainty in electromagnetic flowmeters includes five primary research papers and technical reports.

The selected papers span more than thirty years of research and include a mix of laboratory testing, field evaluations, and applied modelling. The most comprehensive datasets were generated by the Irrigation Training and Research Center (ITRC), whose recent work explored meter performance under shortened straight lengths, reducer fittings, and asymmetric flow conditions. Collectively, the five studies provide valuable insight into the practical limitations of electromagnetic meter installations, the variability in performance across meter designs, and the dominant role of flow profile sensitivity in driving uncertainty.

The five reviewed sources are listed below:

1. **Styles, S. et al. (2020).** Magnetic Flow Meter Testing: Flowmeter Sensitivity to Installation Effects. ITRC Report No. F 20-004
2. **Clawson, B.C. (2016).** The Effects of Upstream Straight Pipe Length on Magnetic Flow Meter Accuracy. Master's thesis, Utah State University
3. **Martim, A. et al. (2019).** Electromagnetic Flowmeter Evaluation in Real Facilities: Velocity Profiles and Error Analysis (10)
4. **Bates, C.J. (1999).** Upstream installation and misalignment effects on the performance of a modified electromagnetic flowmeter
5. **Halttunen, M. (1990).** Installation Effects on Ultrasonic and Electromagnetic Flowmeters: A Model-Based Approach

The main findings of each paper are summarised in the following sections.

A.3.1 Styles et al. (2020)

Magnetic Flow Meter Testing (ITRC Report F 20-004)

The study was conducted by the Irrigation Training and Research Center at California Polytechnic State University, funded by the U.S. Bureau of Reclamation and the California Department of Water Resources (8). It evaluated the performance of twelve electromagnetic flowmeters (4-inch and 10-inch sizes) from six different manufacturers. Conditions included baseline straight-pipe installations (10D upstream, 5D downstream), double elbows (single and perpendicular planes) at distances of 2D, 5D, and 10D upstream, throttled butterfly valves upstream at various openings, reducers, poor grounding, and electrode orientation changes. Flow velocities from 2 feet per second (fps) to 8 fps were tested. This comprehensive testing aimed to quantify the impact of common installation factors encountered in practical field conditions on the meters' accuracy.

A.3.1.1 Installation Effects

The report demonstrated that installation conditions have a substantial effect on electromagnetic meter performance. Shorter straight-pipe lengths (2 diameters upstream, 1 diameter downstream) resulted in pronounced measurement errors for half the meters tested, with errors frequently exceeding ±2% relative to baseline conditions. Although most manufacturers recommended straight-pipe lengths (typically 5 diameters to 10 diameters upstream) reduced error magnitudes, noticeable deviations persisted even at these recommended distances for certain meter models. Interestingly, disturbances involving double elbows in two perpendicular planes produced no significant additional measurement error compared to elbows in a single plane. Butterfly valves installed upstream had negligible impact until throttled beyond 50%, at which point they introduced errors exceeding 1%. See figure A14 for effect of obstructions on meter accuracy.

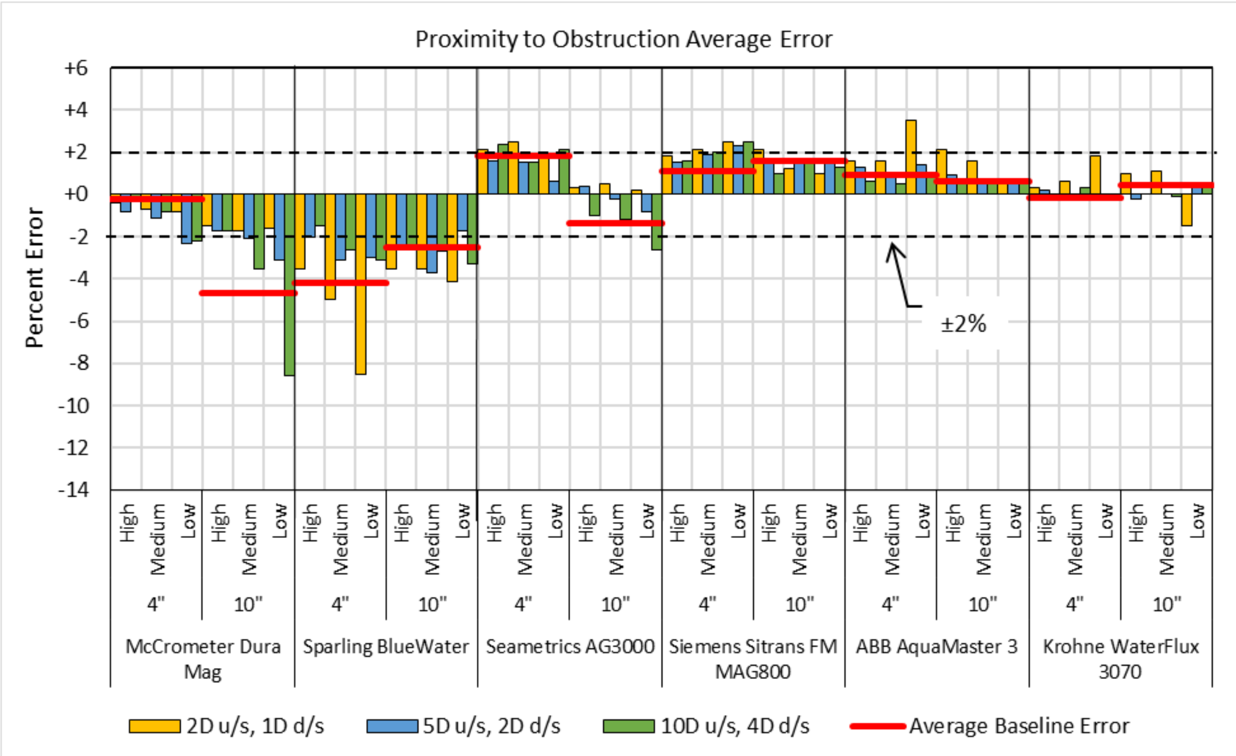

Figure A.1 – Effect of proximity of obstructions on meter accuracy

A.3.1.2 Uncertainty

While the study provided extensive repeatability and error data under each test condition, formal uncertainty budgets or expanded uncertainties were not explicitly calculated in the report. However, the report did provide a link to the flow facility measurement uncertainty analysis. The measurement uncertainty for the ITRC gravimetric tank was 0.1% at the 95% confidence interval.

The experimental results showed that installation-induced hydraulic disturbances introduced both systematic bias and increased variability. Errors were most pronounced at low flow velocities (around 2 fps and below), while inadequate upstream straight length elevated measurement uncertainty across most meters. Grounding effects were minimal at medium to high velocities, although ungrounded configurations showed small but measurable errors at lower velocities.

A.3.1.3 Recommendations

Styles et al. recommended adhering to manufacturers' minimum straight-pipe guidelines to reduce installation errors. However, persistent errors even at recommended lengths highlight the need for independent verification under realistic conditions. The authors emphasized evaluating performance with upstream disturbances such as reducers, elbows, and partially closed valves, and recommended comprehensive manufacturer guidance on electrode orientation and grounding to improve measurement reliability.

A.3.2 Clawson (2016)

The Effects of Upstream Straight Pipe Length on Magnetic Flow Meter Accuracy

This thesis investigated the influence of upstream straight pipe length on the accuracy of electromagnetic flowmeters in closed conduit water systems (9). Eleven 10-inch meters were tested to determine how variations in upstream straight pipe length between a single 90° short-radius elbow and the meter affected accuracy. The testing involved two phases: Phase I compared baseline performance with long upstream pipe lengths (over 40 diameters) against shortened lengths (3 diameters); Phase II tested four selected meters at multiple upstream pipe lengths (0D, 1D, 3D, 5D, and 10D). The study assessed whether manufacturer accuracy specifications could realistically be met under practical installation scenarios.

A.3.2.1 Installation Effects

The research clearly demonstrated that reducing upstream straight pipe length below recommended guidelines significantly compromised accuracy. See Figure A.2. Few met the manufacturer's specification for accuracy, even when installed in line with the prescribed requirements. In Phase I, most meters failed to meet their specified accuracy limits at the tested length of three pipe diameters downstream from an elbow. Accuracy deviations were commonly within ±1% relative to the baseline performance, but certain meters showed errors beyond this range.

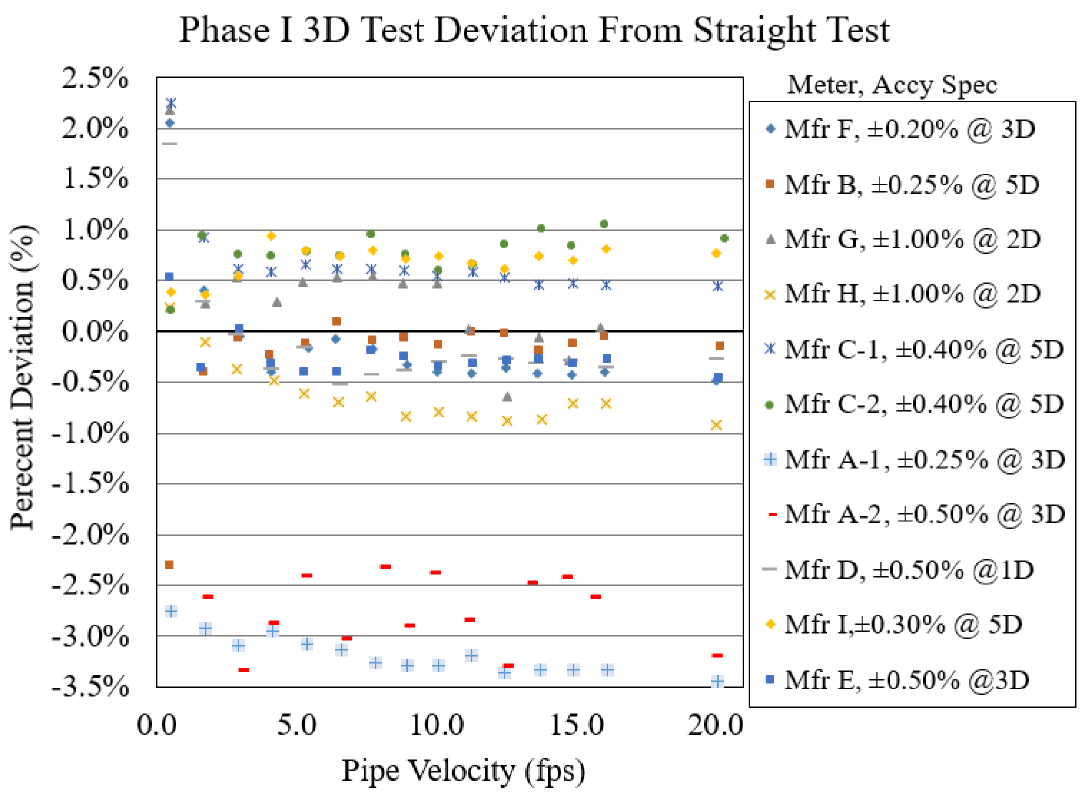

Figure A.2 – Phase I measurement deviations observed at 3D straight pipe length compared to baseline accuracy across all tested meters

Phase II provided a more detailed picture by evaluating multiple pipe lengths (0D, 1D, 3D, 5D, and 10D). It showed a clear trend as straight pipe lengths decreased, measurement errors typically increased. Some meters exhibited deviations of ±3% at 0D installations, while others maintained acceptable accuracy even with shorter pipe lengths, highlighting substantial variability in meter performance depending on specific model and manufacturer design.

A.3.2.2 Uncertainty

Formal uncertainty budgets and expanded uncertainties were not documented within the report. The gravimetric reference tank uncertainty was quoted between 0.12% and 0.14%, and is assumed to represent a 95% confidence level.

Repeatability tests at various flow velocities showed clear trends. In general, reduced upstream pipe length increased both systematic bias and random variability. Standard deviations and maximum observed deviations were calculated for all meter installations and showed significant spread, with errors frequently exceeding manufacturer specifications under shorter pipe conditions. Repeatability deteriorated markedly as upstream length decreased, highlighting the increased measurement instability introduced by elbow proximity and disturbed flow profiles.

A.3.2.3 Recommendations

The study strongly recommended adhering strictly to manufacturer-recommended straight pipe lengths whenever possible. It suggested that installing meters closer than recommended upstream distances significantly increases measurement error and reduces repeatability. Clawson emphasized the need for post-factory calibration of meters to match actual installation conditions, particularly in constrained installations where recommended upstream lengths are impractical. Additionally, it was recommended that manufacturers clearly document expected performance under disturbed flow conditions rather than relying exclusively on idealized, laboratory-calibrated accuracy claims. Further research into meter orientation, double elbows, varying pipe sizes, and alternative electrode configurations was proposed to fully understand the impact of common field installation variables on electromagnetic flowmeter accuracy.

A.3.3 Martim et al. (2019)

Electromagnetic Flowmeter Evaluation in Real Facilities: Velocity Profiles and Error Analysis

Martim et al. (10) investigated the accuracy and reliability of a 4-inch (100 mm) electromagnetic flowmeter installed under non-ideal, realistic field conditions. The purpose was specifically to examine the errors introduced by deviations from standard upstream straight pipe length recommendations in practical installations, typical of real-world water supply scenarios. Four test conditions were assessed: standard straight-pipe installation (baseline), downstream of a single short-radius 90° elbow, downstream of two orthogonal short-radius 90° elbows, and downstream of a gate valve set to openings of 100% and 50%. Velocity profiles were measured using a Pitot tube in controlled laboratory tests at the University of Campinas (FEC-Unicamp), Brazil, to directly evaluate how distorted velocity profiles affected flowmeter accuracy.

A.3.3.1 Installation Effects

The study clearly demonstrated significant flowmeter accuracy degradation resulting from disturbed upstream conditions. Under ideal conditions (60 diameters straight pipe upstream), the velocity profiles were fully developed and symmetric, resulting in negligible deviations (0.08%). However, introducing an upstream single elbow (installed 2 pipe diameters upstream of the flowmeter) created an asymmetric velocity profile and increased the measurement deviation to 0.74%. Interestingly, the configuration involving two orthogonally arranged 90° elbows led to a distorted but more complex "S-shaped" velocity profile and surprisingly showed slightly lower measurement deviations (0.45%), potentially due to vorticity interactions partially cancelling each other out, and reducing the swirl. The most significant measurement errors occurred downstream of a partially closed gate valve (50% open), reaching deviations as high as -2.05%.

A.3.3.2 Uncertainty

While detailed expanded uncertainty budgets were not calculated, the authors carefully reported the relative uncertainties of the Venturi meter used as the reference. Relative uncertainties ranged between approximately 0.27% and 0.74%, depending on the tested configuration and flow condition. Repeatability data clearly illustrated increased measurement variability and uncertainty under distorted flow conditions compared to baseline conditions, demonstrating both systematic bias and random error increases associated with disturbed velocity profiles.

A.3.3.3 Recommendations

Martim et al. advocated evaluation and field validation where possible, especially in constrained installations. The authors highlighted that even common fittings like elbows and partially closed valves could significantly distort velocity profiles, leading to errors that, although modest (below 3%), could still be critical for precise flow accounting applications. They further recommended additional research into the relative positioning of electrode planes and fittings to better understand and potentially minimize errors associated with disturbed flow.

A.3.4 Bates (1999)

Upstream Installation and Misalignment Effects on the Performance of a Modified Electromagnetic Flowmeter

Bates (11) investigated the effects of upstream installation conditions and misalignment on the accuracy and performance of a modified Danfoss DN50 electromagnetic flowmeter. The flowmeter was tested under controlled laboratory conditions, specifically addressing real-world installation variations commonly encountered in industry. The study explored three distinct pipe diameters upstream of 1.77-inches, 2-inches, and 2.17-inches (45 mm, 50 mm, and 55 mm) respectively, and examined misalignment scenarios by introducing a 0.12-inch (3 mm) offset vertically and horizontally. Velocity profiles were measured using Laser Doppler Anemometry (LDA), allowing detailed analysis of flow disturbances resulting from these varying installation configurations. The goal was to quantify and understand the practical implications of installation-induced deviations from ideal flow conditions on electromagnetic flowmeter accuracy.

A.3.4.1 Installation Effects

Significant accuracy deviations were observed due to upstream diameter changes and misalignment. For the concentric (aligned) configurations, the maximum errors recorded ranged from approximately -0.45% to -1.25%, with the greatest errors seen at lower flowrates and with the smaller upstream pipe diameter (1.77-inches). Misalignment significantly exacerbated these errors; notably, the horizontal misalignment scenario (0.12-inches offset) with a smaller upstream pipe (1.77-inches) consistently produced errors greater than 1% in magnitude. Flow measurements under vertical misalignment were comparatively less affected but still showed increased error compared to aligned configurations. The flow disturbances induced by these misalignments were characterized by highly asymmetric velocity profiles, increased turbulence, and occasional local flow instabilities, which directly impacted the meter's accuracy.

A.3.4.2 Uncertainty

Although Bates did not explicitly calculate expanded uncertainties or formal uncertainty budgets, the study provided comprehensive data on measurement variability and systematic biases under various configurations.

A.3.4.3 Recommendations

The study highlighted that even relatively minor (0.12-inches) horizontal or vertical misalignments can cause substantial accuracy deviations, particularly when accompanied by upstream pipe diameter differences beyond recommended limits. It did not provide recommendations for installation requirements.

A.3.5 Halttunen (1990)

Installation Effects on Ultrasonic and Electromagnetic Flowmeters: A Model-Based Approach

Halttunen's paper presented a combined computational and experimental approach to assessing installation effects on ultrasonic and electromagnetic flowmeters (12). Conducted collaboratively between the National Institute of Standards and Technology (NIST) in the USA and Tampere University of Technology in Finland, the research specifically addressed common disturbances introduced by single-elbow and double-elbow out-of-plane configurations. The study utilized Computational Fluid Dynamics (CFD) modeling paired with flowmeter modeling to analyze how distorted flow velocity profiles affect measurement accuracy. The electromagnetic flowmeters tested were commercial, pulse-magnetized types ranging from 2-inches (50 mm) to 16-inches (400 mm) diameter.

A.3.5.1 Installation Effects

The research clearly showed significant measurement errors due to upstream disturbances. The electromagnetic flowmeters generally exhibited, deviations of up to ~2% were observed depending on the type and orientation of the disturbance, but substantial variations between different commercial electromagnetic meter models were observed. Meter orientation relative to flow disturbances significantly impacted performance, with certain orientations reducing measurement error.

A.3.5.2 Uncertainty

Halttunen's study did not explicitly present formal expanded uncertainty budgets, but uncertainties associated with velocity measurements (±1%) and volume flow measurements (±0.2%) were detailed. Repeated experimental measurements confirmed increased variability and systematic biases when meters were exposed to disturbed flow profiles. Computed models demonstrated variability due to flow distortion effects, including significant sensitivity to reference velocity profile assumptions. Although quantitative uncertainty propagation was not the study's central focus, results highlighted disturbed flow conditions as a key source of uncertainty in practical meter installations, significantly affecting repeatability and reliability of measurements.

A.3.5.3 Recommendations

The paper recommended the use of CFD in conjunction with experimental work to identify and mitigate potential flow profile issues.

A.4 Summary

Across the five reviewed studies, installation conditions were consistently shown to have a significant impact on electromagnetic flowmeter accuracy. Short upstream straight lengths, elbows, reducers, partially closed valves, and pipe misalignment all produced measurable flow disturbances, leading to meter errors typically in the range of around 1% up to more than 4% in the most severe cases. Styles et al. (8) and Clawson (9) demonstrated that deviations from manufacturer-recommended straight lengths could noticeably reduce accuracy, with some meter designs still showing large biases even when installed in line with the stated guidelines. Martim et al. (10) and Bates (11) reinforced this by showing that realistic, non-ideal configurations such as diameter changes, misalignment, and throttled valves generated asymmetric or unstable velocity profiles that translated directly into meter error. Halttunen (12) highlighted pronounced sensitivity differences between designs, showing that electrode configuration and orientation relative to the disturbance could influence the error magnitude.

Uncertainty analysis was limited across the studies. Most mentions of uncertainty studies focused on bias and repeatability. Clawson (9) and Styles et al. (8) reported reduced repeatability at short straight lengths and under disturbed flow, while Martim et al. (10) demonstrated that asymmetric velocity profiles increased uncertainty relative to baseline. Bates (11) showed that unstable profiles and large velocity gradients were key contributors to uncertainty, and Halttunen (12) indicated through modelling and tests that sensitivity to asymmetric profiles was a major source of error for certain designs.

The findings collectively point to the need for strict adherence to manufacturer guidelines for straight-pipe lengths and installation alignment, while recognising that even compliant installations can still suffer from significant profile distortion. All authors recommend either pre-installation laboratory or CFD assessment and post-installation field verification under site-specific conditions. Manufacturers are encouraged to provide clear performance data for disturbed conditions rather than only ideal test setups. Greater emphasis in guidance documents on common non-ideal installation scenarios would help to improve measurement reliability in practice.

A.5 Recommendations

The following sub-sections provide recommendations for selection, installation, and calibration methodology for electromagnetic flowmeters. These recommendations are formed from a combination of the literature review and TÜV SÜD UK's flow measurement experience with electromagnetic flowmeters. They have been written in a style consistent with API *MPMS* standards.

A.5.1 Selection

The selection of an electromagnetic flowmeter should be based on the characteristics of the fluid, the process conditions, the required accuracy, and the installation environment. The following factors should be considered during the selection process:

A.5.1.1 Fluid Conductivity

The fluid should have a minimum electrical conductivity of 5 micro siemens per centimeter. Fluids with lower conductivity are not suitable for measurement with electromagnetic technology.

A.5.1.2 Pipe Size and Flow Range

The selected meter size should be matched to the expected operating flow range. A target liquid velocity between 3.3 feet per second (1 m/s) and 19.7 feet per second (6 m/s) is recommended to optimise performance and minimise low velocity errors.

A.5.1.3 Accuracy Requirements

The meter should have a certified accuracy that meets the requirements of the intended application. Depending on the application, this could be similar to OIML R 49 Accuracy Class 1 or 2 which ranges from between ± 1% and ± 5% of reading depending on flow and temperature ranges.

A.5.1.4 Power Supply and Signal Output

The meter should be compatible with the site power supply and communication systems, such as 4–20 milliampere, Modbus, or HART protocols. Digital out devices generally provide better accuracy due to the limitation of 4-20 mA scaling techniques and logging frequency.

A.5.1.5 Environmental Conditions

The meter should be rated for the environmental conditions at the installation location, including ingress protection (IP), pressure class, and operating temperature range.

A.5.1.6 Certifications

For regulated applications, the meter should have relevant approvals such as OIML R 49 or Measuring Instruments Directive (MID). OIML R 49 defines two accuracy classes for water meters: Class 1, which allows tighter maximum permissible errors, and Class 2, which allows slightly higher tolerances (3).

Where OIML R 49 Class 1 or Class 2 certification has been granted for zero upstream and downstream straight lengths, the user should recognize that certification testing conditions might not reflect all field disturbances. Meters should be evaluated as part of a performance assessment program at a traceable, accredited flow laboratory, and calibration under realistic installation conditions should be considered where prior testing does not include the intended installation configuration.

A.5.1.6 Calibration Requirements

The user should confirm that the calibration methodology is appropriate for the intended application. For OIML R 49 Class 1 or Class 2 meters, calibration under conditions representative of the intended installation should be performed if the installation design has not been included in prior certification testing or performance evaluation.

A.6 Installation

The installation process should consider available straight pipe lengths, potential upstream disturbances, and required meter orientation. Installations should also review the flow sensor certification to ensure that the intended piping orientation aligns with the conditions tested during certification.

A.6.1 General

The meter should be installed in a location where the pipe is fully filled with liquid during operation. The installation should avoid locations subject to entrained air, sediment accumulation, or excessive vibration. Electrical grounding and cable shielding should be installed in accordance with the manufacturer's recommendations.

A.6.2 Straight Pipe Length Requirements

Straight pipe lengths should be sufficient to develop a stable and symmetrical velocity profile at the meter. For general applications, a minimum of five to ten diameters of straight pipe upstream and two to five diameters downstream is recommended. For high accuracy applications, a minimum of ten diameters upstream and five diameters downstream is recommended where space permits.

Meters with valid OIML R 49 Class 1 or Class 2 certification for zero upstream and zero downstream conditions can be installed according to the certified 0D/0D lengths, without additional straight lengths. For meters without certification or for installations not covered by prior testing, mandatory minimum upstream and downstream lengths should be applied, based on aggregate testing data and expected accuracy class: less can be sufficient for Class 2 meters, more can be required for Class 1 meters.

A.6.3 Minimizing Upstream Disturbances

Disturbances such as valves and elbows can introduce flow asymmetry, swirl, or turbulence, all of which can impact meter performance. The installation should avoid placing the meter immediately downstream of disturbances such as elbows, reducers, pumps, or partially closed valves. Butterfly valves should not be installed upstream in a throttled condition greater than fifty percent open, as this can cause significant velocity profile distortion. Where disturbances cannot be avoided, the use of flow conditioners or increased straight lengths is recommended.

For meters with valid OIML R 49 Class 1 or Class 2 certification for zero upstream and downstream lengths, the guidance above may be relaxed if the installation matches the certified conditions. However, for meters without certification or for installations not covered in prior testing, mitigation of upstream disturbances is essential, and additional straight lengths or flow conditioning should be applied to ensure performance meets the intended accuracy class.

A.6.4 Orientation

Electrode orientation should follow the manufacturer's installation instructions and, where applicable, match the orientation used for OIML R 49 certification.

A.7 Calibration Methodology

Calibration ensures the meter output is accurate to the true flowrate by comparing the output against a reference standard.

Calibration frequency should be determined by the user or operator based on performance expectations, risk tolerance, and available data, in line with the applicable OIML R 49 accuracy class. The focus is to ensure that calibration methods are appropriate for the intended installation and that meters are evaluated under representative operating conditions.

A.7.1 Factory Calibration

Most electromagnetic meters are supplied with a traceable calibration certificate obtained under laboratory conditions. The calibration conditions should be reviewed to ensure that they replicate the users operating conditions.

A.7.2 Verification

Verification of meter performance can be carried out periodically using clamp-on ultrasonic meters, or routinely using manufacturer-supplied diagnostic tools. Verification systems perform electronic measurements on the sensor, transmitter, and interconnections to confirm that key parameters remain within acceptable tolerances. Ideally, these parameters are recorded during the initial manufacturer calibration, enabling direct comparison of site values against the original calibration. Where initial records are not available, verification can be undertaken against average values for flowmeters of the same manufacturer, size, and type.

Some flowmeters provide a separate verification unit that connects to the meter, while for others, this functionality is integrated into the transmitter. Electronic verification can confirm the operation and integrity of the flowmeter but cannot detect all measurement errors, particularly those caused by external influences such as upstream disturbances or insufficient fluid conductivity.

Significant deviations from expected performance should be investigated and, if necessary, the meter recalibrated.

Annex B

(informative)

Flow Meter Flow Calibration

B.1 Reasons for Calibrating Flow Meters

Flow calibration confirms that the flow meter meets the manufacturer's stated performance specifications such as, accuracy, linearity, repeatability, and stability criteria. The flow measurement accuracy specifications in Section 8 are included to permit a meter to have a maximum error, after application of any calibration factor adjustment, up to +/- 0.2% for flow rates between Qmin and Qmax. Calibration ensures the flow meter complies with relevant industry standards, certifications, and regulatory requirements. For example, flow calibration helps to certify that the flow meter meets international standards such as ISO, API, or other regulatory requirements. The initial factory flow calibration provides a baseline for the meter performance. In-situ proving validates the flowmeter performance in the in the actual operating environment

Optionally, an alternative flow calibration should be performed to obtain additional performance data and to further linearize to the flow meter output flow rate over its range. This could facilitate successful in-situ proving results faster to reduce proving time and, in some situations, reduce in-situ proving frequency where agreed upon by the operating parties.

As the following example illustrates, flow meters can operate within this allowable measurement accuracy envelope, but still produce significant and costly error in terms of measured liquid volume. One effective means of minimizing the measurement uncertainty of an flow meter is to flow calibrate the meter.

Example:

NOTE This example illustrates the different mathematical methods to linearize a flow meter. The curve on this graph has been exaggerated to show the advantages and disadvantages of each method.

An 8" nominal diameter flow meter rated for the flow capacity in Table B.1:

Table B.1 – Flow capacity

	Flow Rate	Units
Q_{max}	8,700	Bbl/h
Q_{min}	650	Bbl/h

The evaluation of this uncalibrated (no adjustment) meter at a test laboratory yields the results in Table B.2, after averaging multiple tests runs near each of the recommended nominal test rates (RNTR).

Table B.2 – Flow Calibration Data for an 8" Diameter Flow Meter

RNTR	Nominal Test (bbl/h)	Actual Test Rate - Reference (bbl/h)	Meter Reported Rate* (bbl/h)	Meter Error (%)
Qmax	8700	8694	8671	-0.26%
0.80 Qmax	6960	7012	6998	-0.20%
0.60 Qmax	5220	5262	5250	-0.23%
0.40 Qmax	3480	3500	3491	-0.25%
0.20 Qmax	1740	1751	1748	-0.16%
0.10 Qmax	1000	995	994.8	-0.02%

0.05 Qmax	435	435.5	436	0.11%

The ‘Meter Reported Rate” has been rounded to the nearest whole bbl/h. The “Flow Meter Error” is based on the values for the “Meter Reported Rate” prior to rounding and the “Actual Test Rate – Reference Meter”.

The flow calibration data from Table B.2 are plotted on Figure B.1 below. To estimate the error in volume of liquid measured by this meter, assume that, in field service, the liquid flows through the mFlow meter at a rate of 5262 bbl/h (i.e. roughly 0.6 Q_{max}). For this operating condition, the flow calibration data indicates that the meter error will be -0.23% (see Table B.2). If this flow rate is held constant for a year, the resulting measurement error is about 106,019 bbl of liquid per year.

From the example above, the magnitude and direction (i.e. overestimation or underestimation) of the measurement error of the flow meter is a function of the flow rate. That is, in this case, the flow meter underpredicts the flow rate in the middle and high end of the operational range and overpredicts on the low end of the range. Furthermore, the meter error can be substantially corrected by using the flow calibration data. The following discussion explains how test flow data can be used to minimize error.

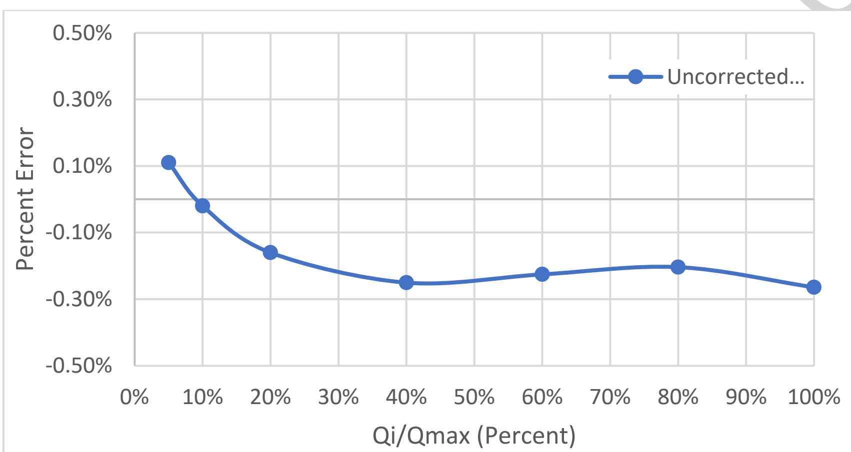

Figure B.1 Uncorrected Flow Calibration Data for an 8-nch Diameter Flow meter

Note that the individual data points in Figure B.1 represent averaged values for multiple runs near each of the recommended nominal test rates to meet an uncertainty of +/- 0.027 % for each individual data point.

B.2 Methods for Correcting an Flow Meter Flow Measurement Error

The total flow measurement error of an flow meter consists of two parts: (1) *random* (or precision) errors and (2) *systematic* (or bias) errors. Random errors can be caused by various influences on a meter’s operation. Random errors normally follow a certain statical distribution. The magnitude of the random error can usually be reduced by acquiring multiple measurement samples and then, applying accepted statical principles. Systematic errors cause repeated meter measurement readings to be in error (for some unknown reason) by roughly the same amount. Flow calibration of an flow meter can minimize the systematic error of the meter. Operational experience has shown that, in most cases, the major portion of the total flow measurement error of an uncalibrated meter results from systematic errors.

Due to matching tolerances, variations in component manufacturing processes, variations in the meter assembly process and other factors, each flow meter has its own unique operating characteristics. Thus, to minimize a particular flow meter flow measurement uncertainty, the manufacturer or operator can flow calibrate the meter and then use the calibration data to correct or compensate for the flow meter error. Residual unknown systematic errors can still exist after calibration as the result of operational or installation differences or other considerations; for this reason, in-situ proving is recommended.

An exhaustive discussion of the various meter error correction techniques is beyond the scope of this document. The designer or operator should consult with the manufacturer regarding the available options for a particular flow meter.

B.3 Flow-Weighted Mean Error (FWME) Correction

The calculation of a meter's FWME from actual flow test data is a method of calibrating a meter where only a single factor correction is applied to the meter's output. The example used in Table B.1 above will now be used to demonstrate how to calculate the FWME for a 8" diameter flow meter that has been flow calibrated under operating conditions similar to those that the meter would experience during field service. A single calibration factor F (i.e., one FWME correction factor) is determined and then applied to the test results such that the resulting FWME is equal to zero. The meter's performance, both before and after the calibration factor is applied, should be compared with the requirements specified in Section 8.2.5.

The FWME for the data set presented in Table A.1 of Section A.1 above is calculated as follows.

$$FWME = \frac{\sum_{i=1}^{n}\left(\frac{Q_i}{Q_{max}}\right)\times E_i}{\sum_{i=1}^{n}\frac{Q_i}{Q_{max}}}$$

(B.1)

Where SUM is the summation of the individual terms representing each of the test flow points, Q_i is an actual test flow rate from the reference meter, and:

> ***Q_i / Q_{max}*** is a weighting factor (*wfi*) for each test flow point, and
> E_i is the indicated flow rate error (in percent) at the actual test flow rate ***Q_i*.**

(An alternative method for computing the FWME that decreases the contribution of the highest flow rate point is to use a reduced weighting factor, such as 0.4, when $Q_i > 0.95\ Q_{max}$. The designer or the operator may also use different weighting factors, depending on whether the meter is run mostly in the lower, middle or upper range of flow.)

Applying the above equation for FWME to the test data in Table B.1 produces the results shown in Table B.2. Note that a column labeled wf_i is included in Table B.2 to show the weighting factor that is applied to each E_i value.

Table B.3 – FWME Calculation Summary

Actual Test Rate - Reference (bbl/h)	$Wf_i = Q_i/Q_{max}$	E_i (%)	Wfi*Ei (%)
8694	0.9993	-0.26%	-0.264%
7012	0.8060	-0.20%	-0.164%
5262	0.6048	-0.23%	-0.136%
3500	0.4023	-0.25%	-0.101%
1751	0.2012	-0.16%	-0.032%
875	0.1005	-0.02%	-0.002%
435.5	0.0501	0.11%	0.006%
∑ =	3.1642	∑ =	-0.694%

FWME =	-0.219%	F =	1.0022

The FWME value for the test data in Table B.3 is calculated as follows (without any calibration factor correction being applied to the data).

$$FWME = \frac{\sum_{i=1}^{n}(wf_i \times E_i)}{\sum_{i=1}^{n}(wf_i)} = \frac{-0.694\%}{3.1642} = -0.219\% \quad (B.2)$$

A single calibration factor F can now be applied to the meter output to reduce the magnitude of the measurement error. The value of F is calculated using the following equation.

$$F = \frac{100}{100 + FWME} \quad (B.3)$$

For this example, the FWME is -0.1219% and the single calibration factor is calculated to be 1.0022. By adjusting the flow meter's output by 1.0022, the resulting FWME should then equal zero. The adjusted test data are presented in Table B.3 below. In this table, each E_i has been adjusted to obtain a residual error after adjustment E_{ir1} using the following equation.

$$E_{ir1} = (E_i + 100) \times F - 100 \quad (B.4)$$

Table B.4 FWME Corrected Flow Calibration Data Summary

E_i (%)	$Wf_i = Q_i/Q_{max}$	E_{ir1} (%)	Wfi*Ei (%)
-0.26%	0.9993	-0.045%	-0.045%
-0.20%	0.8060	0.016%	0.013%
-0.23%	0.6048	-0.006%	-0.004%
-0.25%	0.4023	-0.031%	-0.012%
-0.16%	0.2012	0.060%	0.012%
-0.02%	0.1005	0.200%	0.020%
0.11%	0.0501	0.330%	0.017%
∑ =	3.1642	∑ =	0.000%

Using the adjusted data from Table B.4 to calculate FWME produces the following result:

$$FWME = \frac{0.000\%}{3.1642} = 0.000\% \quad (B.5)$$

In the following plot, the FWME corrected flow calibration data have been added to the test data presented in Figure B.1. The FWME Corrected Error (orange line) represents the meter's error after a single calibration factor of 1.0022 has been applied to the original flow calibration data.

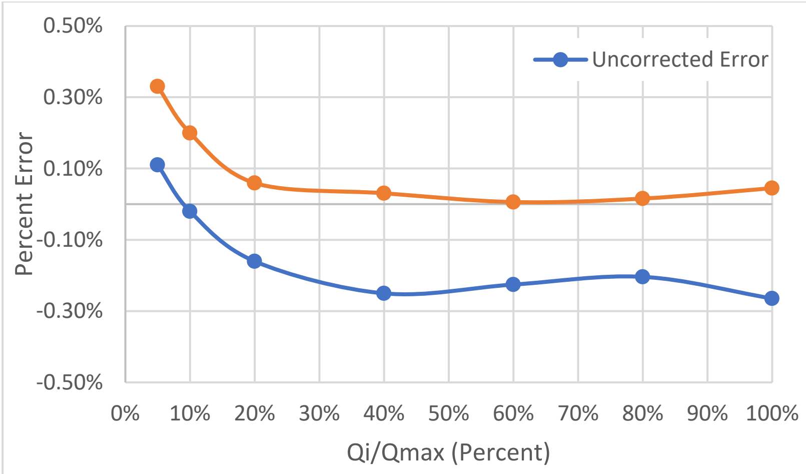

Figure B.2 Uncorrected, and FWME Corrected Flow Calibration Data

The FWME correction method is most effective at minimizing the measurement error if the flow meter measurement error (expressed in percent error) does not change over the flow range of the meter. The FWME correction shifts the Uncorrected Error curve up or down, so, ideally, if Uncorrected Error is parallel to axis X (the measurement error is the same over the flow range), then FWME Corrected Error would be zero for all flow rates. In our example, for flow rates above about 20 % of the capacity of the meter, the measurement error has been significantly reduced by applying a single FWME calibration factor. However, for flow rates below about 20 % of the meter's capacity, the single FWME calibration factor does not reduce the measurement error because the flow meter's error changes over the meter's flow range. This low flow rate performance is not uncommon and the flow meter is within the specification of the manufacturer. The operator can either accept the higher error on the low end of the meter's flow range or apply more sophisticated correction techniques to reduce the error on the low end of the meter's range. Two of these techniques are described in Sections B.4 and B.5 below.

B.4 Polynomial Algorithm Correction

Polynomial algorithms use polynomial functions for approximation of the calibration factor F over the flow meter's flow range.

$$F = a_0 + a_1 \text{ x } q + a_2 \text{ x } q^2 + \ldots + a_n \text{ x } q^n$$

Normally, third order polynomial $a_0+a_1q^1+a_2q^2$ is used that employs three parameters: a_0, a_1, and a_2.

$$F = a_0 + a_1 \text{ x } q + a_2 \text{ x } q^2 + a_3 \text{ x } q^3$$

For the test data in Table B.1, values of parameters are computed using least squares method: $a_0 = -0.0023$, $a_1 = -3*10^{-6}$, $a_2 = 6*10^{-10}$, $a_3 = -4*10^{-14}$. The adjusted flow rate Q_{adj} over the meter's range is calculated using the above parameters.

Table B.5 shows adjusted flow rates and residual errors for each test flow rate.

Table B.5 – Polynomial Corrected Flow Calibration Data Summary

Q_i Reference (bbl/h)	Qi Reported (bbl/h)	Qi Adjusted (bbl/h)	E_{ir2} (%)
8694	8671	8712	-0.202%
7012	6998	7019	-0.098%
5262	5250	5264	-0.044%
3500	3491	3500	-0.005%
1751	1748	1750	0.028%
995	994.8	995	0.007%
435.5	436	435.5	0.000%

The gray line in Figure B.3 represents polynomial corrected error. This calibration technique provides better results for low flows than FWME technique and would be useful where the operation of the system is anticipated in the lower end of the flow range. Flow weighting methods can further be used to improve polynomial corrected error in critical areas, such as in the operating flow range.

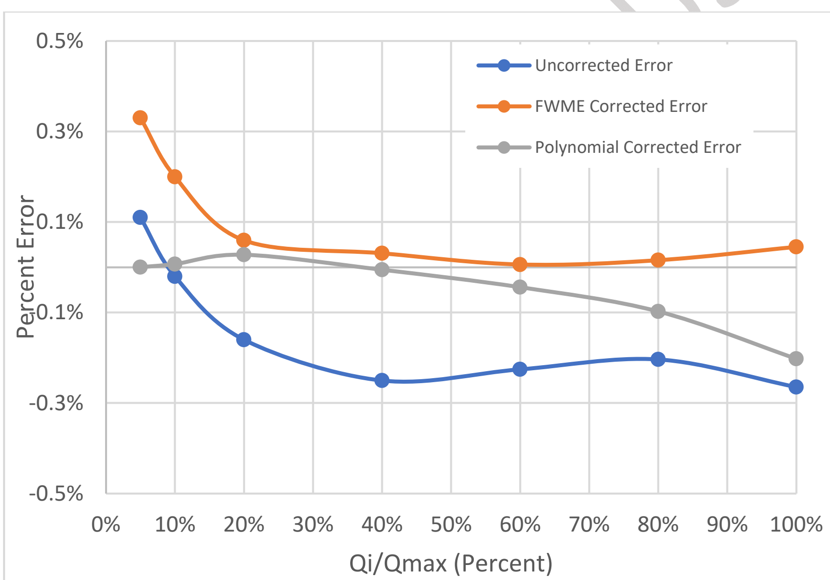

Figure B.3 Uncorrected, FWME and Polynomial Corrected Flow Calibration Data

B.5 Multi-Point/Piece-Wise Linear Interpolation

A multipoint/piece- wise linear interpolation (PWL) uses linear function for the calibration factor between adjacent test points i and i+1.

$$F = F_i(F_{i+1} - F_i) \times \frac{Q - Q_i}{Q_{i+1} - Q_i} \quad \text{(B.6)}$$

Q_i, Q_{i+1} refer to “Q_i reported” and Q refers to “Q Reference” in Table B.6.

For 7 test points specified in Table A.1, there are 6 linear functions, and each linear function has two parameters F_i and a_i specific for the flow rates between these test points. The adjusted flow rate Q_{adj} between adjacent test points I and i+1 is computed by application of the calculated calibration factor to the meter's output.

$$Q_{adj} = Q \times [F_i + a_i \times (Q - Q_i)] \tag{B.7}$$

$$where\ a_i = \frac{F_{i+1} - F_i}{Q_{i+1} - Q_i}$$

Table B.6 shows parameters F_i and a_i along with adjusted flow rate and residual error E_{ir3} for each test flow rate.

Table B.6 Multi/Point/PWL Corrected Flow Calibration Data Summary

Q_i Reference (bbl/h)	Q_i Reported (bbl/h)	F_i	a_i	Qi Adjusted (bbl/h)	E_{ir3} (%)
8694	8671	1.0027		8694	0.000%
7012	6998	1.0020	0.0000003653	7012	-0.001%
5262	5250	1.0023	-0.0000001248	5262	0.000%
3500	3491	1.0025	-0.0000001417	3500	0.000%
1751	1748	1.0016	0.0000005198	1751	0.000%
995	994.8	1.0002	0.0000018610	995	0.000%
435.5	436.0	0.9989	0.0000023283	435.5	0.000%

The marks on the zero axis in Figure B.4 represent PWL corrected error at the test flow rates. It should be mentioned that the disadvantage of the PWL technique is the fact that the measurement error of the flow calibration facility for each flow rate at the time of the flow meter calibration becomes systematic error of the meter for this flow rate.

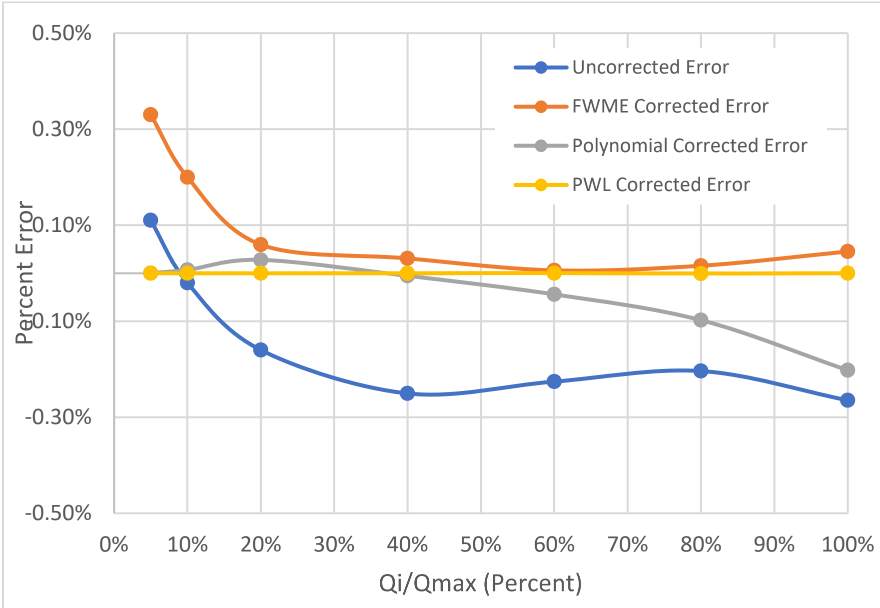

Figure B.4 Uncorrected, FWME, Polynomial, and PWL Corrected Flow Calibration Data

Annex C

(Normative)

Electronics Design Testing

The design of the Electromagnetic meter's electronics shall be tested to demonstrate that the magmeter will continue to meet the performance requirements of this document, while operating under the influences and disturbances specified in the current revisions of IEC 61000 Electromagnetic Compatibility (EMC), and IEC 60068, General requirements for measuring instruments – Environmental conditions.

For the climate conditions refer to IEC 60068-2 series on environmental testing and guidance. This class applies to instruments or parts of instruments used in open-air locations excluding those in extreme climate zones like polar and desert environments. For mechanical conditions refer to IEC 60068-2 series. This class applies to locations with significant or high levels of vibration and shock, e.g. transmitted from machines and passing vehicles in the vicinity or adjacent to heavy machines, conveyor belts, etc. For electromagnetic conditions refer to IEC 61326 series. This class applies to measuring instruments powered by the battery of a vehicle and exposed to electromagnetic disturbances, which correspond to those likely to be found in any environment not considered hazardous for general public.

These test requirements shall apply to the design of all circuit boards, electrodes, interconnecting wiring, and customer wiring terminals. The electronics shall be in operation, measuring zero flow, and remain 100 % functional during the tests. In the case of high-voltage transient and electrostatic discharge tests, the meter may temporarily stop functioning but shall automatically recover within 30 seconds.

During these tests, the magmeter electrodes may be operated in a smaller and lighter test cell (or test cells) instead of a full flow-meter body. However, the electrodes shall be measuring zero flow and be exposed to the same test conditions as other parts of the electronic system.

Annex D

(informative)

Magmeter Proving Reports, Laboratory Calibration, and Records

The data presented in this informative annex illustrates typical magmeter performance during in-situ proving or laboratory calibration. The meter brand and model have been blinded; exercise caution when interpreting the data presented in this table: this data does not indicate meter installation, meter orientation, or upstream piping design. Various meter brands are represented by letters below.

The Coriolis meters used as master meter prover meets API *MPMS* Chapter 5.6. The master meter provers in data presented in this table all meet API *MPMS* Chapter 4.5 standards for accuracy and performance. All provings were conducted for five runs and single pass.

Meter Information				Prover Information			Proving Results								
ID	Brand	Model	Nominal Size (in)	Prover Type	Meter Type	Nominal Size (in)	Meter Factor	Number of Runs	Repeatability (%)	Uncertainty (%)	Flow rate (bbl/hr)	Passed (Y/N)	Insitu/ Lab	Temperature (F)	Pressure (psig)
111111	A	1	2	Master Meter	Coriolis	3	7.2115	5	2.467	10.354	345	N	Lab	87.3	59.9
111112	F	1	2	Master Meter	Coriolis	3	0.9922	5	0.165	0.088	76	Y	Insitu	77	97.6
111113	B	1	6	Master Meter	Coriolis	3	0.9967	5	0.17	0.092	459	Y	Insitu	93.2	78
111114	F	1	3	Master Meter	Coriolis	3	0.9936	5	0.389	0.208	290	Y	Insitu	63.1	32
111115	F	1	3	Master Meter	Coriolis	3	1.0045	5	0.217	0.108	495	Y	Insitu	69.7	48.7
111116	F	1	2	Master Meter	Coriolis	3	0.9941	5	0.267	0.13	175	Y	Insitu	67.5	70.2
111117	F	1	2	Master Meter	Coriolis	3	1.0085	5	0.429	0.252	200	Y	Insitu	77.1	25.3
111118	B	1	3	Master Meter	Coriolis	3	0.9931	5	0.238	0.124	285	Y	Insitu	47.5	35
111119	F	1	2	Master Meter	Coriolis	3	1.0081	5	0.068	0.035	165	Y	Insitu	73.6	27.1
111120	B	1	3	Master Meter	Coriolis	3	0.9978	5	0.299	0.152	170	Y	Insitu	85	10.6
111121	F	1	4	Master Meter	Coriolis	3	0.9896	5	0.276	0.14	380	Y	Insitu	76.3	27.3
111122	B	1	6	Master Meter	Coriolis	3	0.9949	5	0.198	0.097	795	Y	Insitu	93.8	164.8
111123	B	1	3	Master Meter	Coriolis	3	1.0008	5	0.13	0.064	380	Y	Insitu	99.2	58.8
111124	B	1	3	Master Meter	Coriolis	3	0.999	5	0.09	0.044	135	Y	Insitu	98.8	106.9
111125	B	1	6	Master Meter	Coriolis	3	0.9925	5	0.139	0.068	675	Y	Insitu	99.7	156.7
111126	B	1	3	Master Meter	Coriolis	3	1.0027	5	0.13	0.066	400	Y	Insitu	124.3	124.3
111127	B	1	6	Master Meter	Coriolis	3	0.9882	5	0.178	0.09	700	Y	Insitu	98.8	65
111128	B	1	4	Master Meter	Coriolis	3	0.9919	5	0.089	0.053	300	Y	Insitu	96.3	202.5
111129	B	1	4	Master Meter	Coriolis	3	0.9895	5	0.148	0.079	220	Y	Insitu	99.4	197.2
111130	F	1	3	Master Meter	Coriolis	3	0.9898	5	0.391	0.211	265	Y	Insitu	59.7	96.5
111131	F	1	3	Master Meter	Coriolis	3	0.9964	5	0.077	0.042	320	Y	Insitu	72.3	76.2
111132	B	1	3	Master Meter	Coriolis	3	1.001	5	0.17	0.076	245	Y	Insitu	73.2	104.7
111133	B	1	2	Master Meter	Coriolis	3	0.9877	5	0.158	0.07	310	Y	Insitu	79.4	111.1
111134	F	1	3	Master Meter	Coriolis	3	1.002	5	0.167	0.084	360	Y	Insitu	79.3	129.4
111135	F	2	3	Master Meter	Coriolis	3	0.9881	5	0.225	0.112	420	Y	Insitu	73.3	162.9
111136	B	1	2	Master Meter	Coriolis	3	0.9992	5	0.1	0.052	165	Y	Insitu	87.7	37.7
111137	B	1	2	Master Meter	Coriolis	3	0.9791	5	0.04	0.023	260	Y	Insitu	86.5	60.7
111138	F	1	2	Master Meter	Coriolis	3	1.0037	5	0.287	0.152	160	Y	Insitu	68.3	102.7
111139	B	1	3	Master Meter	Coriolis	3	0.9975	5	0.12	0.068	500	Y	Insitu	84.3	140.9
111140	B	2	4	Master Meter	Coriolis	3	0.997	5	0.159	0.078	550	Y	Insitu	82.7	80.5
111141	F	1	3	Master Meter	Coriolis	3	0.9901	5	0.377	0.19	100	Y	Insitu	77.2	206.4

Meter Information				Prover Information			Proving Results								
ID	Brand	Model	Nominal Size (in)	Prover Type	Meter Type	Nominal Size (in)	Meter Factor	Number of Runs	Repeatability (%)	Uncertainty (%)	Flow rate (bbl/hr)	Passed (Y/N)	Insitu/ Lab	Temperature (F)	Pressure (psig)
111142	B	1	3	Master Meter	Coriolis	3	0.9976	5	0.209	0.101	235	Y	Insitu	69.5	88.1
111143	F	1	3	Master Meter	Coriolis	3	0.9963	5	0.366	0.178	360	Y	Insitu	75.3	110.6
111144	F	1	2	Master Meter	Coriolis	3	1.0109	5	0.168	0.085	165	Y	Insitu	67.3	132.6
111145	F	1	3	Master Meter	Coriolis	3	1.0111	5	0.134	0.066	290	Y	Insitu	74.1	106.6
111146	B	1	4	Master Meter	Coriolis	3	0.9964	5	6.604	3.059	200	N	Insitu	71	88.5
111147	F	2	2	Master Meter	Coriolis	2	1.0007	5	0.195	0.104	300	Y	Lab	57.3	66.5
111148	B	2	4	Master Meter	Coriolis	3	1.0002	5	0.446	0.22	300	Y	Lab	60.8	62.4
111149	B	2	4	Master Meter	Coriolis	3	1.0012	5	0.355	0.189	310	Y	Lab	58.3	61.8
111150	B	2	4	Master Meter	Coriolis	3	1	8	0.46	0.201	310	Y	Lab	59.9	61.3
111151	B	1	3	Master Meter	Coriolis	3	1.012	5	0.116	0.059	295	Y	Lab	61.7	62.8
111152	F	1		Master Meter	Coriolis	3	0.9752	5	0.415	0.2	260	Y	Insitu	117.5	136.6
111153	B	2	4	Master Meter	Coriolis	3	0.995	5	0.308	0.189	290	Y	Insitu	113.3	57
111154	B	2	6	Master Meter	Coriolis	3	0.9984	5	0.344	0.18	630	N	Insitu	118.4	104.9
111155	B	2	6	Master Meter	Coriolis	3	1.0106	5	0.313	0.15	785	N	Insitu	128.3	140.2
111156	F	1		Master Meter	Coriolis	3	0.9838	5	0.314	0.138	875	Y	Insitu	121.9	141.4
111157	B	1	3	Master Meter	Coriolis	3	0.9948	5	0.309	0.154	185	Y	Insitu	114.4	68.8
111158	B	2	2	Master Meter	Coriolis	3	1.0217	5	0.133	0.072	93	Y	Insitu	65	84.5
111159	F	1		Master Meter	Coriolis	3	0.9326	5	0.46	0.206	700	Y	Insitu	117.4	162.7
111160	F	1		Master Meter	Coriolis	3	1.0018	5	0.449	0.203	880	Y	Insitu	116.9	146.6
111161	B	2	6	Master Meter	Coriolis	3	1.0011	5	0.12	0.059	740	Y	Insitu	121.3	171.2
111162	B	1	6	Master Meter	Coriolis	3	1.0095	5	0.323	0.146	145	Y	Insitu	126.3	108.3
111163	B	2	4	Master Meter	Coriolis	3	0.9862	5	0.385	0.203	125	Y	Insitu	70.8	122.6
111163	B	1	4	Master Meter	Coriolis	3	0.9775	5	0.098	0.049	125	N	Insitu	70.5	209.7
111164	F	1		Master Meter	Coriolis	3	1.0009	5	0.17	0.087	195	Y	Insitu	64.6	47.6
111165	F	1		Master Meter	Coriolis	3	0.9921	5	0.358	0.204	300	Y	Insitu	63.3	36.4
111166	F	1		Master Meter	Coriolis	3	0.9993	5	0.391	0.222	310	Y	Insitu	70.2	87.3
111167	B	1	2	Master Meter	Coriolis	3	0.9984	5	0.13	0.069	340	Y	Insitu	64.9	64.4
111168	F	1		Master Meter	Coriolis	3	1.0051	5	0.48	0.247	79	Y	Insitu	73.3	31.2
111169	F	1		Master Meter	Coriolis	3	0.9931	5	0.125	0.056	300	Y	Insitu	67.2	49.2
111169	F	1		Master Meter	Coriolis	3	1.0031	5	0.335	0.163	60	Y	Insitu	67.7	26.3
111170	F	1		Master Meter	Coriolis	3	1.0067	5	0.274	0.135	310	Y	Insitu	68.7	43.2
111171	F	1		Master Meter	Coriolis	3	1.0079	5	0.409	0.206	190	Y	Insitu	69.4	52.5
111172	F	1		Master Meter	Coriolis	3	1.0049	5	0.479	0.243	120	Y	Insitu	62.1	178.4
111173	B	1	2	Master Meter	Coriolis	3	0.984	5	0.296	0.14	530	Y	Insitu	71.1	105.7
111174	B	1	2	Master Meter	Coriolis	3	1.0035	5	0.241	0.118	410	Y	Insitu	77.1	85.1
111175	F	1		Master Meter	Coriolis	3	1.0156	5	0.256	0.119	115	Y	Insitu	70.1	75.8
111176	B	1	3	Master Meter	Coriolis	3	1.0055	5	0.251	0.125	400	Y	Insitu	69.9	134.2
111177	B	1	3	Master Meter	Coriolis	3	0.9981	5	0.14	0.069	450	Y	Insitu	97.5	115.9
111178	A	1	2	Master Meter	Coriolis	2	0.9851	5	0.039	0.02	212	Y	Lab	93.3	3
111179	A	1	2	Master Meter	Coriolis	2	0.9919	5	0.089	0.047	210	Y	Lab	73	5.5
111180	A	1	3	Master Meter	Coriolis	2	0.9986	5	0.055	0.029	203	Y	Lab	60.3	16.5
111181	B	1	6	Master Meter	Coriolis	3	0.9999	5	0.376	0.2	420	Y	Lab	88.2	44.5
111182	B	1	6	Master Meter	Coriolis	3	0.996	5	0.404	0.214	275	Y	Lab	68.4	12
111183	B	1	2	Master Meter	Coriolis	2	0.989	5	0.05	0.024	153	Y	Lab	87.3	30.5
111183	B	1	2	Master Meter	Coriolis	2	0.9966	5	0.069	0.036	201	Y	Lab	69.3	16.2
111183	B	1	2	Master Meter	Coriolis	3	0.999	5	0.019	0.045	220	Y	Lab	62.1	63.2
111184	A	1	2	Master Meter	Coriolis	2	0.9955	5	0.044	0.025	149	Y	Lab	87.3	31.3
111185	A	1	4	Master Meter	Coriolis	3	0.9946	5	0.403	0.213	260	Y	Lab	61.8	60.8
111186	A	1	4	Master Meter	Coriolis	3	1.0029	5	0.136	0.073	261	Y	Lab	61.6	60.2
111187	A	1	4	Master Meter	Coriolis	3	0.9949	5	0.348	0.185	271	Y	Lab	63.6	60.1
111188	A	1	4	Master Meter	Coriolis	3	1.0069	5	0.366	0.196	245	Y	Lab	60.2	59.1
111189	A	1	4	Master Meter	Coriolis	3	1.0006	5	0.319	0.17	220	Y	Lab	57.8	62.1
111190	A	1	4	Master Meter	Coriolis	3	0.9963	5	0.1	0.054	450	Y	Lab	77.3	52
111191	A	1	4	Master Meter	Coriolis	3	0.997	5	0.12	0.056	447	Y	Lab	77.2	52.1
111192	B	1	2	Master Meter	Coriolis	2	0.9955	5	0.179	0.095	200	Y	Lab	60	14.2
111193	B	1	2	Master Meter	Coriolis	2	0.9999	5	0.09	0.048	200	Y	Lab	60.4	10.4
111194	B	1	2	Master Meter	Coriolis	2	0.9985	5	0.22	0.117	200	Y	Lab	60.5	11.1
111195	B	1	2	Master Meter	Coriolis	2	1.0015	5	0.175	0.093	200	Y	Lab	60.1	14.3
111196	B	1	2	Master Meter	Coriolis	2	0.9981	5	0.245	0.13	200	Y	Lab	59.9	11.1
111197	B	1	2	Master Meter	Coriolis	2	0.9988	5	0.115	0.061	200	Y	Lab	60.2	16.6
111198	B	1	2	Master Meter	Coriolis	2	0.9953	5	0.15	0.08	200	Y	Lab	60.1	14.1
111199	B	1	2	Master Meter	Coriolis	2	0.9942	5	0.04	0.021	200	Y	Lab	56.9	11.5
111200	B	1	2	Master Meter	Coriolis	2	0.9939	5	0.283	0.15	200	Y	Lab	60.3	11.6
111201	B	1	3	Master Meter	Coriolis	3	1.0029	5	0.311	0.166	250	Y	Lab	56.8	61.3
111202	B	1	3	Master Meter	Coriolis	3	0.9933	5	0.064	0.032	175	Y	Lab	89	65
111203	A	1	6	Master Meter	Coriolis	3	1.0027	10	0.392	0.091	265	Y	Lab	68.5	9.6
111204	A	1	6	Master Meter	Coriolis	3	1.0035	10	0.467	0.109	270	Y	Lab	68.6	30.5
111205	A	1	6	Master Meter	Coriolis	3	1.0027	10	0.346	0.09	275	Y	Lab	70.4	45.3
111206	A	1	8	Master Meter	Coriolis	3	0.9996	10	0.325	0.075	270	Y	Lab	68.5	37.7

Annex E

(Informative)

Electromagnetic Meters Installation Guidelines

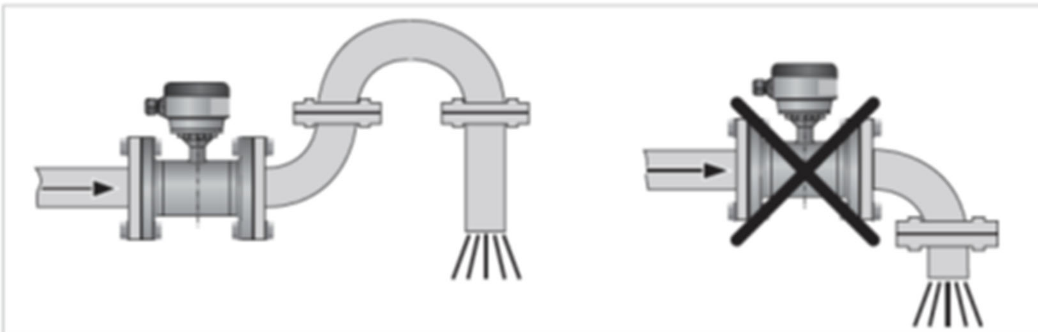

Figure E.1: Installation in front of an open discharge

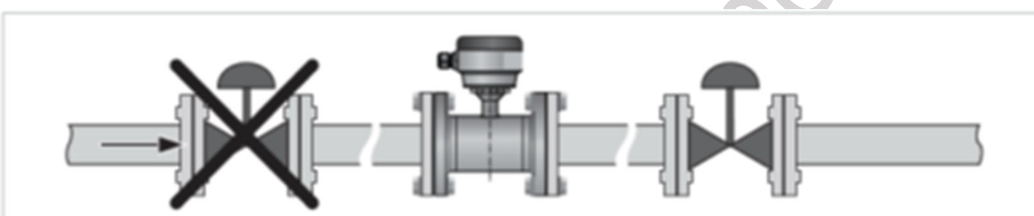

Figure E.2: Installation in front of a control valve

Figure E.3: Installation behind a pump

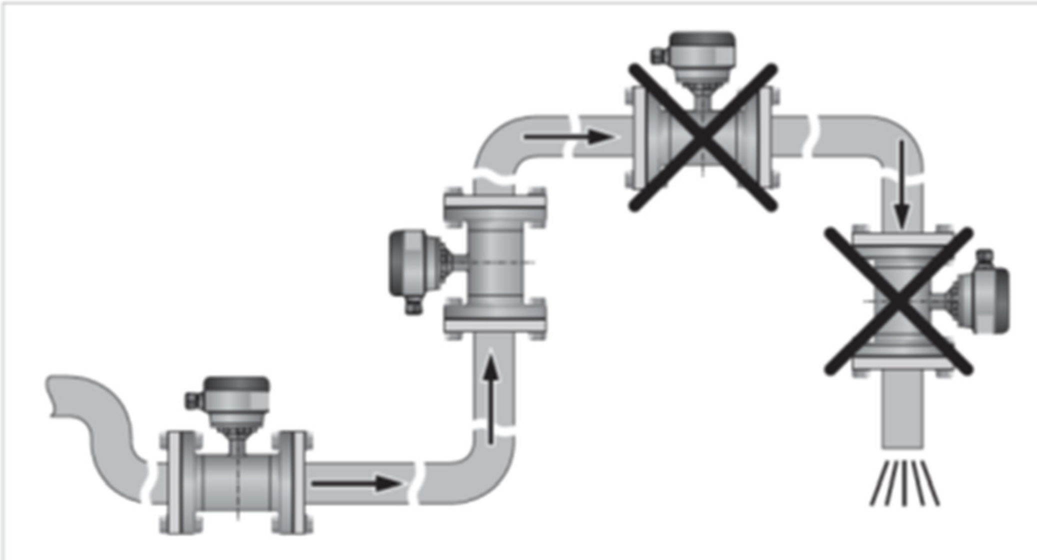

Figure E.4: Installation in bending pipes (90 degrees)

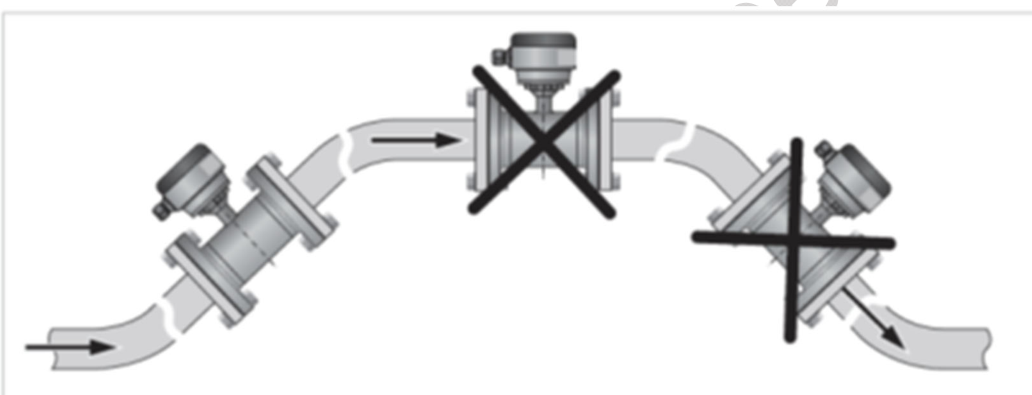

Figure E.5: Installation in bending pipes (45 degrees)

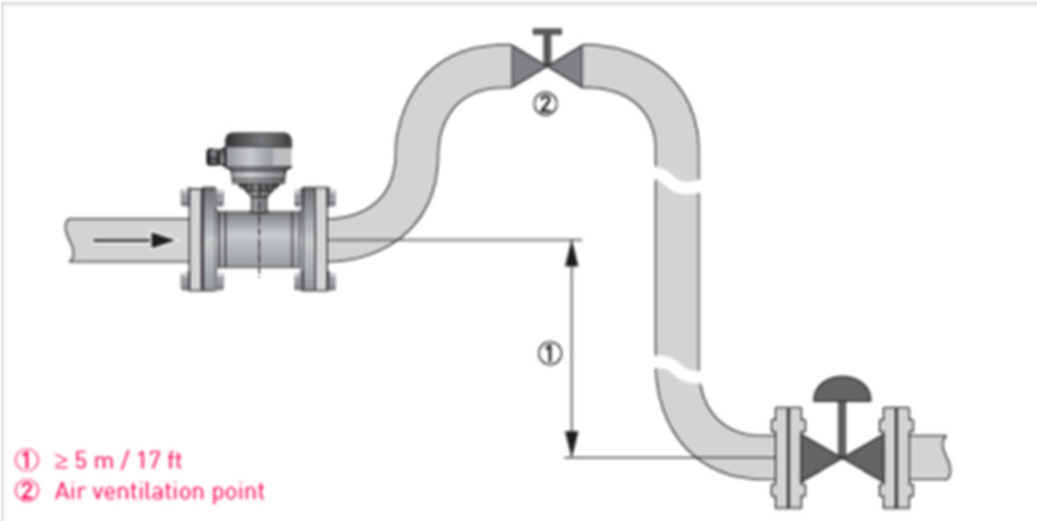

Figure E.6: Air Venting

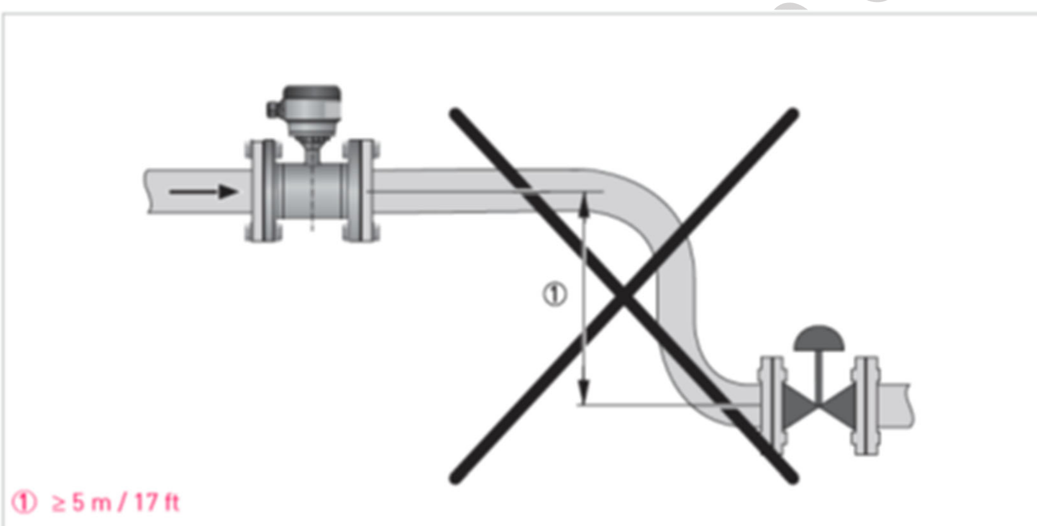

Figure E.7: Vacuum

Annex F

(informative)

Electromagnetic Meter Validation Method Using Transit-Time Clamp-On Ultrasonic Meters

F.1 General

Magmeter Validation is a process of comparing flow rates and volume totals over a defined test period between the in-situ magmeter and another portable meter. This informative annex outlines a recommended procedure to perform magmeter Validation in the field using transit time Clamp-on Ultrasonic meters; however, other metering technology could be applied with this method.

NOTE Meter Validation is a diagnostic tool used to troubleshoot electromagnetic meter, and it is not intended to calculate a meter factor for volume adjustment; meter factor is calculated through Meter Proving techniques described in API *MPMS* Chapter 4.

F.2 Test Preparation

F.2.1 Recommended Equipment

- Portable ultrasonic flow meter or equivalent
- Transducer set appropriate for pipe size and fluid type
- Pipe surface preparation tools (grinder or sandpaper, rags, cleaning solvent)
- Coupling gel or mounting rails with dry coupling pads (pads optional)
- Measuring tape, caliper, & level (to verify OD and wall thickness) **Wall thickness probe recommended.**
- Tools & equipment for "as-found / as-left" documentation (e.g., camera, laptop)
- Other equipment to be used for the collection of opening and closing volume totals

F.2.2 Safety

- PPE: gloves, safety glasses, FR clothing, H2S monitor if applicable
- Follow company and site safety requirements.
- Ensure line pressure and fluid type are confirmed before work.
- Be aware of hot surfaces or extreme ambient temperatures.

F.2.3 Preparation

- Ensure clamp on ultrasonic meter is functioning properly, configured correctly, and in working order. Pay careful attention to fluid type, fluid quality (i.e. oil in water, sediment, etc.), pipe size, pipe material, and wall thickness.
- Review site P&IDs. Take a picture of the complete meter run as is, if possible.
- Confirm, or note, whether the magmeter is installed in accordance with manufacturer's recommendations, including upstream and downstream meter run lengths

- Reference for manufacturer requirements for installation and operation of portable ultrasonic flow meter
- When possible, ensure there are no obstructions, piping modifications, or other disturbances between the location of the clamp-on ultrasonic transducers and the in-situ magmeter.
- Clean pipe surface thoroughly at mounting location. Grind/sand down paint, rust, or scale to bare metal or smooth surface and wipe clean and dry.
- For convenience, mark placement of transducers for future validations.

F.3 Test Procedure

F.3.1 Setup

- Configure clamp on ultrasonic meter in accordance with the manufacturer's recommendations for the meter and process fluid under test; note any differences outside of manufacturer recommendations.
- Mount transducers in accordance with the clamp on ultrasonic meter manufacture's recommendation. Pay careful attention to distance and level of transducers, pipe material and size, and an orientation to ensure liquid is flowing against the pipe wall.
- When possible, mount the clamp-on transducers as close as possible upstream to the magmeter under test.
- Verify signal strength meets the minimum recommendation of the clamp on ultrasonic meter manufacturer. Adjust transducers as needed to meet, or exceed, minimum requirements.

F.3.2 Data Collection

- Once clamp on ultrasonic meter begins to register flowrate, monitor flowrate to identify if stable flowrate is present with both meters. Note any flowrate inconsistencies.
- When ready, record opening totalizer and begin test. Document instantaneous flowrate and diagnostics, if available. Monitor data for duration of test; test should be performed for a consistent amount of time, or volume, for each run.
- For purposes of repeatability, a minimum of three tests should be performed at a similar time or volume, and process conditions (temperature, pressure, flowrate).
- Results of each test should be documented and compared between the clamp-on ultrasonic and the in-service meter, documenting the variance in volume and percentage.

F.4 Data Review and Acceptance Criteria

- Ensure placement and location of transducers match the data input to clamp-on ultrasonic system.
- Review all site-specific data and verify information is correct (e.g. location, station, pipe data).

- Ensure all information is recorded accurately for proper calculation of results.
- Clamp-on ultrasonic meter results should be within agreed upon percentage difference from the meter under test. Previously noted differences, or out of tolerance configurations, should be considered in the results.
- A variance outside of agreed upon differences should require further troubleshooting, removal from service to be cleaned, or sent to a qualified facility for re-calibration. Common acceptable differences are normally within 3 % - 5 %.

Bibliography

[1] API *Manual of Petroleum Measurement Standards (MPMS)* Chapter 4.2*, Displacement Meters*

[2] API *Manual of Petroleum Measurement Standards (MPMS)* Chapter 4.5*, Master Meter Provers*

[3] API *Manual of Petroleum Measurement Standards (MPMS)* Chapter 4.5*, Operation of Proving Systems*

[4] API *Manual of Petroleum Measurement Standards (MPMS)* Chapter 5.1*, General Considerations for Measurement by Meters*

[5] API *Manual of Petroleum Measurement Standards (MPMS)* Chapter 5.5, *Fidelity and Security of Flow Measurement Pulsed-Data Transmission Systems*

[6] API *Manual of Petroleum Measurement Standards (MPMS)* Chapter 5.6*, Measurement of Liquid Hydrocarbons by Coriolis Meters*

[7] API *Manual of Petroleum Measurement Standards (MPMS)* Chapter 6.1A, *Metering Assemblies – General Considerations*

[8] API *Manual of Petroleum Measurement Standards (MPMS)* Chapter 6.2A, *Metering Assemblies – Loading-Rack and Tank-Truck Metering Systems*

[9] API *Manual of Petroleum Measurement Standards (MPMS)* Chapter 7.4, *Dynamic Temperature Measurement*

[10] API *MPMS* Chapter 20 (all sections), *Allocation Measurement*

[11] API *MPMS* Chapter 21.2, *Electronic Liquid Measurement*

[12] API RP 14E – *Recommended Practice for Design & Installation of Offshore Production Platform Piping Systems*

[13] Code of Federal Regulations, Title 49, Section 195, *Transportation of Hazardous Liquids by Pipeline: Minimum Federal Safety Standards*

[14] ISO 17025, *Testing and calibration laboratories*

[15] IEC 61326, *Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 1: General requirements*

[16] OIML R49-2, *Water meters for cold potable water and hot water. Part 2: Test methods*