2.10 Magnetic Flowmeters


**Design Pressure**
Varies with pipe size; for a 4-in. (100-mm) unit, the maximum is 285 PSIG (20 bars); special units are available with pressure ratings up to 2500 PSIG (172 bars)

**Design Temperature**
Up to 250°F (120°C) with Teflon® liners and up to 360°F (180°C) with ceramic liners

**Materials of Construction**
Liners: ceramics, fiberglass, neoprene, polyurethane, rubber, Teflon, vitreous enamel Kynar
Electrodes: platinum, Alloy 20®, Hasselloy C, stainless steel, tantalum, titanium, tungsten carbide, Monel®, nickel, platinum-alumina ceramic

**Type of Flow Detected**
Volumetric flow of conductive liquids, including slurries and corrosive or abrasive materials

**Minimum Conductivity Required**
The majority of designs require 1 to 5 µS/cm. Some probe types require more. Special designs can operate at 0.05 or 0.1 µS/cm.

**Flow Ranges**
From 0.01 to 100,000 GPM (0.04 to 378,000 l/min)

**Size Ranges**
From 0.1 to 96 in. (2.5 mm to 2.4 m) in diameter

**Velocity Ranges**
0–0.3 to 0–30 ft/sec (0–0.1 to 0–10 m/sec)

**Power Consumption**
20 W with DC excitation, 30 W for a 2-in. (50-mm) AC and 0.3 kW for a 30-in. (760-mm) AC unit.

**Input Signals**
Voltage signal from detector proportional to flow rate; digital input 20 to 30 VDC for range switching, totalizer control, zero adjustment

**Output Signal**
4 to 20 mA DC, digital outputs for pulse outputs, multirange selection, high and low limits, empty pipe alarm, preset count, and converter failure outputs

**Communication Output**
Digital signal is superimposed on 4- to 20-mA; current signal conforms with HART protocol

**LCD Display**
Two-line, line, or dot matrix

**Surge Protection**
 Arresters are installed in the power supply and current signal output circuits

**Error (Inaccuracy)**
±1% of actual flow with pulsed DC units within a range of up to 10:1 if flow velocity exceeds 0.5 ft/sec (0.15 m/sec); ±1% to ±2% full scale with AC excitation

**Cost**
The least expensive designs are the probe versions that cost about $1500. A 1-in. (25-mm) ceramic tube unit can be obtained for under $2000. A 1-in. (25-mm) metallic wafer unit can be obtained for under $3000. An 8-in. (200-mm) flanged meter that has a Teflon liner and stainless electrodes and is provided with 4- to 20-mA DC output, grounding ring, and calibrator will cost about $8000. The scanning magmeter probe used in open-channel flow scanning costs about $10,000.

**Partial List of Suppliers**
ABB ([www.abb.com](http://www.abb.com))
AccuDyne Systems Inc.
2.10 Magnetic Flowmeters

Advanced Flow Technology Co
Arkon Flow Systems (www.arkon.co.uk)
Badger Meter Inc. (www.badgermeter.com)
Baily Controls Co.
Bopp & Reuther Heinrichs Messtechnik (www.burhm.de)
Brink HMT
Brooks Instrument Div. of Emerson (www.emersonprocess.com)
Burkert GmbH & Co. KG
Cole-Parmer Instrument Co. (www.coparmer.com) (probe)
Colorado Engineering Experimental Station
Control Warehouse
Danfoss A/S (www.danfoss.com)
Dantec Electronics
Datam Flutec
Davis Instruments
Diesel GmbH & Co.
H.R. Dulin Co.
Dynasonics Inc. (probe-type)
Electromagnetic Controls Corp.
Elis Plzen
Endress+Hauser Inc. (www.usendress.com)
Engineering Measurements Co.
EMCO (www.emcoflow.com)
Euromag (www.euromag.net)
Fischer & Porter Co.
The Foxboro Co. (www.foxboro.com)
Honeywell Industrial Control (www.honeywell.com/acs/cp)
Hangzhu Senhau Meter Factory
Instrumark International Inc.
Isco Inc. (www.isco.com)
Istec Co.
Johnson Yokogawa Corp.
K & L Research Co. (probe-type)
Krone-America Inc. (www.ka-krohne.com)
Liquid Controls Inc. (www.lcmeter.com)
Marsh-McBirney Inc. (www.marsh-mcbirney.com)
McCrometer (www.mccrometer.com)
Meter Equipment Mfg.
Metron Technology (insertion-type)
Monitek Technologies Inc. (www.monitek.com)
Montedoro Whitney
MSR Magmeter Manufacturing Ltd. (probe-type)
Nusonics Inc.
Omega Engineering Inc. (www.omega.com)
Oval Corp.
Proces-Data A/S
Rosemount Inc. (www.rosemount.com)
Sarasota Measurements & Controls
Schlumberger Industries (www.s/b.com)
Siemens AG (www.sea.siemens.com)
Signet Industrial (probe-type)
Sparling Instruments Inc. (www.sparlinginstruments.com)
Toshiba International
TSI Flow Meters Ltd. (www.tsi.ie)
Venture Measurement LLC
Wilkerson Instrument Co.
XO Technologies Inc.
Universal Flow Monitors Inc. (www.flowmeters.com)
Yamatake Co.
YCV Co.
Yokogawa Electric Corp. (www.yokogawa.co.uk)
Unlike many other types of flowmeters, magnetic flowmeters offer true noninvasive measurements. They can be constructed easily to the extent that existing pipes in a process can be configured to act as a meter by simply adding two external electrodes and a pair of suitable magnets. They measure both forward and reverse flows. They are insensitive to viscosity, density, and other flow disturbances. Electromagnetic flowmeters are linear devices that are applicable to a wide range of measurements, and they can respond rapidly to changes in the flow. In the recent years, technological refinements have resulted in more economical, accurate, and smaller instruments.

As in the case of many electrical devices, the underlying principle of the magnetic-type flowmeters is Faraday’s law of electromagnetic induction. Faraday’s law states that, when a conductor moves through a magnetic field of a given strength, a voltage is produced in the conductor that is dependent on the relative velocities between the conductor and the field. This concept is used in electric generators. Faraday foresaw the practical application of this principle to the flow measurements, since many liquids are electrical conductors to some extent. Faraday went farther and attempted to measure the flow velocity of the Thames River. The attempt failed because his instrumentation was not sensitive enough. However, about 150 years later, we successfully can build magnetic flowmeters based on Faraday’s law.

**THEORY**

Faraday’s law states that, if a conductor of length \( l \) (m) is moving with a velocity \( v \) (m/sec) perpendicular to a magnetic field of flux density \( B \) (Tesla), a voltage \( e \) will be induced across the ends of the conductor. The value of the voltage may be expressed by

\[
e = Blv \tag{2.10(1)}
\]

Figure 2.10a shows how Faraday’s law is applied in the electromagnetic flowmeter. The magnetic field, the direction of the movement of the conductor, and the induced emf are all perpendicular to each other. The liquid is the conductor that has a length, \( D \), equivalent to the inside diameter of the flowmeter. The liquid conductor moves with an average velocity \( V \) through the magnetic field of strength \( B \). From Equation 2.11(1), the induced voltage \( e \) is

\[
e = BDV/C \tag{2.10(2)}
\]

where \( C \) is a constant to take care of the proper units.

**FIG. 2.10a**

Operational principle of electromagnetic flowmeters: Faraday’s Law states that a voltage is induced in a conductor moving in a magnetic field. In electromagnetic flowmeters, the direction of movement of conductor, the magnetic field and the induced emf are perpendicular to each other in \( X, Y \) and \( Z \) axes. Sensors \( S_1 \) and \( S_2 \) experience a virtual conductor due to liquid in the pipe.

Body; therefore, the voltage induced within the liquid is mutually perpendicular to both the velocity of the liquid and the magnetic field. The liquid can be considered as an infinite number of conductors moving through the magnetic field, with each element contributing to the voltage generated. An increase in flow rate of the liquid conductors moving through the field will result in an increase in the instantaneous value of the voltage generated. Also, each of the individual “generators” is contributing to the instantaneously generated voltage. Whether the profile is essentially square (characteristic of a turbulent velocity profile), parabolic (characteristic of a laminar velocity profile), or distorted (characteristic of poor upstream piping), the magnetic flowmeter averages the voltage contribution across the metering cross section. The sum of the instantaneous voltages generated is therefore representative of the average liquid velocity, because each increment of liquid velocity within the plane of the electrode develops a voltage proportional to its local velocity. The signal voltage generated is equal to the average velocity almost regardless of the flow profile.

Once the magnetic field is regarded to be constant, and the diameter of the pipe is fixed, the magnitude of the induced voltage will be proportional only to the velocity of the liquid [Equation 2.10(2)]. If the ends of the conductor, in this case the sensors, are connected to an external circuit, the induced voltage causes a current, \( i \), to flow that can be processed suitably as a measure of the flow rate. The resistance of the
moving conductor may be represented by \( R \) to give the terminal voltage \( v_T \) of the moving conductor as

\[
v_T = e - iR
\]

Often, magnetic flowmeters are configured to detect the volumetric flow rate by sensing the linear velocity of the liquid. The relationship between the volume of liquid \( Q \) (l/sec) and the velocity may be expressed as

\[
Q = Av
\]

Writing the area, \( A \) (m\(^2\)), of the pipe as

\[
A = \pi D^2/4
\]

gives the induced voltage as a function of the flow rate; that is,

\[
e = 4BQ/\pi D
\]

This equation indicates that, in a carefully designed flowmeter, if all other parameters are kept constant, the induced voltage is linearly proportional only to the mean value of the liquid flow. Nevertheless, a main difficulty in electromagnetic flowmeters is that the amplitude of the induced voltage may be very small relative to extraneous voltages and noise. The noise sources include the following:

- Stray voltage in the process liquid
- Capacitive coupling between signal and power circuits
- Capacitive coupling in connection leads
- Electromechanical emf induced in the electrodes and the process fluid
- Inductive coupling of the magnets within the flowmeter

**Advantages**

1. The magnetic flowmeter is totally obstructionless and has no moving parts. Pressure loss of the flowmeter is no greater than that of the same length of pipe. Pumping costs are thereby minimized.
2. Electric power requirements can be low, particularly with the pulsed DC-types. Electric power requirements as low as 15 or 20 W are not uncommon.
3. The meters are suitable for most acids, bases, waters, and aqueous solutions, because the lining materials selected are not only good electrical insulators but also are corrosion resistant. Only a small amount of electrode metal is required, and stainless steel, Alloy 20\(^\diamond\), the Hastelloy\(^\diamond\), nickel, Monel\(^\diamond\), titanium, tantalum, tungsten carbide, and even platinum are all available.
4. The meters are widely used for slurry services not only because they are obstructionless but also because some of the liners, such as polyurethane, neoprene, and rubber, have good abrasion or erosion resistance.
5. Magmeters are capable of handling extremely low flows. Their minimum size is less than 0.125 in. (3.175 mm) inside diameter. The meters are also suitable for very high-volume flow rates with sizes as large as 10 ft (3.04 m) offered.
6. The meters can be used as bidirectional meters.

**Limitations**

The meters have the following specific application limitations:

1. The meters work only with conductive fluids. Pure substances, hydrocarbons, and gases cannot be measured. Most acids, bases, water, and aqueous solutions can be measured.
2. The conventional meters are relatively heavy, especially in larger sizes. Ceramic and probe-type units are lighter.
3. Electrical installation care is essential.
4. The price of magnetic flowmeters ranges from moderate to expensive. Their corrosion resistance, abrasion resistance, and accurate performance over wide turn-down ratios can justify the cost. Ceramic and probe-type units are less expensive.
5. To periodically check the zero on AC-type magnetic flowmeters, block valves are required on either side to bring the flow to zero and keep the meter full. Cycled DC-units do not have this requirement.

6. An important limitation in electromagnetic flowmeters may be the effect of magnetohydrodynamics, which is especially prominent in fluids with magnetic properties. Hydrodynamics refers to the ability of magnetic field to modify the flow pattern. In some applications, the velocity perturbation due to magnetohydrodynamic effect may be serious enough to influence the accuracy of operations (e.g., in the case of liquid sodium and its solutions).

**TYPES OF MAGNETIC FLOWMETERS**

There are many different types of electromagnetic flowmeters, all based on Faraday’s law of induction, such as the AC, DC, dual-excited, and permanent magnet types. This section concentrates on most commonly used flowmeters: the AC, the DC and the dual-excited types. Classification due to usage is briefly explained in the subsection titled “Other Types.”

Modern magnetic flowmeters are also classified as

- Conventional flowmeters
- Smart magnetic flowmeters
- Multivariable magnetic flowmeters

Conventional flowmeters have normally have a 4- to 20-mA output. But these magnetic flowmeters are gradually being phased out because of their limited communication capabilities.

Smart magnetic flowmeters are microprocessor-based devices, and they are capable of communicating digitally with other equipment, such as computers. The communication protocols include HART, FOUNDATION™ fieldbus (FF), Probus (PB), and serial and parallel communications. Integration of microprocessors give them additional features such as self-diagnostic and self-calibration capabilities. Table 2.10c illustrates communication features of some selected magnetic flowmeters.

Multivariable magnetic flowmeters are capable of measuring more than one process variable. For example, by measuring pressure and temperature, it is possible to calculate

---

**Table 2.10c: Communication Capabilities of Modern Magnetic Flowmeters**

<table>
<thead>
<tr>
<th>Company</th>
<th>Type</th>
<th>Excitation</th>
<th>Communication</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Smart</td>
<td>Conv</td>
<td>Multivar</td>
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<tr>
<td>ABB</td>
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<td>Advanced Flow</td>
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<tr>
<td>Yokogawa</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

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density of the flowing materials. From the density, mass flow can be determined.

**AC Magnetic Flowmeters**

In many commercial magnetic flowmeters, an alternating current of 50 or 60 Hz creates the magnetic field in coils to induce voltage in the flowing liquid. The signals generated are dependent on the velocity of liquid and flowmeter dimensions. Generally, they resemble low-level AC signals, being in the high microvolt to low millivolt ranges. A typical value of the induced emf in an AC flowmeter fixed on a 50 mm internal diameter pipe carrying 500 l/min is observed to be about 2.5 mV.

The AC excitations may be in different forms, but generally they can be categorized into two families: those using on–off excitation and those using plus–minus excitation. In either case, the principle is to take a measurement of the induced voltage when the coils are not energized and to take a second measurement when the coils are energized and the magnetic field has stabilized. Figure 2.10d shows some of the types of excitation offered by various manufacturers.

AC flowmeters operating 50, 60, or 400 Hz are readily available. In general, AC flowmeters can operate from 10 Hz to 5000 Hz. High frequencies are preferred in determining the instantaneous behavior of transients and pulsating flows. Nevertheless, in applications where extremely good conducting fluids and liquid metals are used, the frequency must be kept low to avoid skin effect. On the other hand, if the fluid is a poor conductor, the frequency must not be so high that dielectric relaxation is not instantaneous.

AC magnetic flowmeters reduce the polarization effects at the electrodes, and they are less affected by the flow profiles of the liquid in the pipe. They allow the use of high-Z<sub>a</sub> amplifiers with low drift and highpass filters to eliminate slow and spurious voltage drifts emanating mainly from thermocouple and galvanic actions. These flowmeters find many diverse applications, including measurement of blood flow in living specimens. Miniaturized sensors allow measurements on pipes and vessels as small as 2 mm dia. In these applications, the excitation frequencies are higher than industrial types—200 to 1000 Hz.

A major disadvantage of an AC flowmeter is that the powerful AC field induces spurious AC signals in the measurement circuits. This requires periodic adjustment of zero output at zero-velocity conditions, which is more frequent than in DC counterparts. Also, in some harsh industrial applications, currents in the magnetic field may vary due to voltage fluctuations and frequency variations in the power lines. The effect of fluctuations in the magnetic field may be minimized by the use of a reference voltage proportional to the strength of the magnetic field to compensate for these variations. To avoid the effects of noise and fluctuations, special cabling and calibration practices recommended by the manufacturers must be used to ensure accurate operations. Usually, the use of two conduits is required—one for signals and one for power. The cable lengths also should be set to specific levels to minimize noise and sensitivity problems.

**DC Magnetic Flowmeters**

Unlike AC magnetic flowmeters, direct current or pulsed magnetic flowmeters excite the flowing liquid with a magnetic field operating at 3 to 8 Hz. In all of the pulsed DC approaches, the concept is to take a measurement when the coils are excited and store (hold) that information, then take a second measurement of the induced voltage when the coils are not excited (Figure 2.10d). As the current to the magnet is turned on, a DC voltage is induced at the electrodes. When the current in the magnetic coils is turned off, the signal represents only the noise. The signals observed at the electrodes represent the sum of the induced voltage and the noise, as illustrated in Figure 2.10e. Subtracting the measurement of the flowmeter when no current flows through the magnet from the measurement when current flows through the magnet effectively cancels out the effect of noise.

When the magnetic field coils are energized by a normal direct current, several problems occur, such as polarization and electrochemical and electromechanical effects. Polarization is the formation of a layer of gas around the measured electrodes. Some of these problems may be overcome by

---

**TABLE**

<table>
<thead>
<tr>
<th>Voltage Drive</th>
<th>Current Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half Wave</td>
<td>Full Wave</td>
</tr>
<tr>
<td>Full Wave</td>
<td>Tri-State</td>
</tr>
</tbody>
</table>

**FIG. 2.10d**

Types of pulsed DC coil excitation.
Flow Measurement

energizing the field coils at higher frequencies. However, higher frequencies generate transformer action in the signal leads and in the fluid path. Therefore, the coils are excited by DC pulses at low repetition rates to eliminate the transformer action. In some flowmeters, by appropriate sampling and digital signal processing techniques, the zero errors and the noise can be rejected easily.

The pulsed DC-type systems establish zero during each on–off cycle. This occurs several times every second. Because zero is known, the end result is that pulsed DC systems are potential percent-of-rate systems. The AC-type systems must be periodically rezeroed by stopping flow and maintaining a full pipe so as to zero out any voltage present at that time.

The zero compensation inherent in the DC magnetic flowmeters eliminates the necessity of zero adjustment. This allows the extraction of flow signals regardless of zero shifts due to spurious noise or electrode coating. Unlike AC flowmeters, larger insulating electrode coating can be tolerated that may shift the effective conductivity significantly without affecting performance. As effective conductivity remains sufficiently high, a DC flowmeter will operate satisfactorily. Therefore, DC flowmeters are less susceptible to drifts, electrode coatings, and changes in the process conditions as compared with conventional AC flowmeters.

As a result of the slow, pulsed nature of their operations, DC magnetic flowmeters do not have good response times. However, so long as there are not rapid variations in the flow patterns, zero to full-scale response times of a few seconds do not create problems in most applications. Power requirements are also much less, because the magnet is energized only part of the time. This gives power savings of up to 75%.

If the DC current to the magnet is constant, the proportional magnetic field may be kept steady. Therefore, the amplitudes of the DC voltages generated at the electrodes will be linearly proportional to the flow. However, in practice, the current to the magnet varies slightly due to line voltage and frequency variations. As in the case of AC flowmeters, voltage and frequency variations may require the use of a reference voltage. Because the effect of noise can be eliminated more easily; the cabling requirements are not as stringent.

As mentioned before, polarization may be a problem in DC-type flowmeters. To avoid electrolytic polarization of the electrodes, bipolar pulsed DC flowmeters are available. Also, modification of the DC flowmeters has led to the development of miniature DC magnetic flowmeters that use wafer technology for a limited range of applications. The wafer design reduces weight and power requirements.

**Dual-Frequency Excitation**

Changing the method of excitation from line frequency (AC) to low frequency (DC) provided dramatic improvements in both the accuracy and the zero stability of magnetic flowmeters. Yet it did not represent the summit in technological advancements. A limitation of low-frequency (DC) designs is their relatively low response speed (0.2 to 2 sec) and their sensitivity to measurement noise caused by slurries or low-conductivity fluids.

The idea behind dual-frequency excitation is to apply both methods and thereby benefit from the advantages of both: the zero stability of low-frequency excitation and the good noise rejection and high-speed of response of high-frequency excitation. This is achieved by exciting the magnetic field coils by a current with such a compound wave, as illustrated in Figure 2.10f. One component is a low-frequency waveform, much below 60 Hz, which guarantees good

---

**FIG. 2.10e**

Signal development of pulsed DC-type magnetic flowmeter with half-wave excitation. As shown, the magnetic field is generated by a square wave which, in function, turns the magnet “on” and “off” in equal increments. When “on,” the associated signal converter measures and stores the signal which is a composite of flow plus a variable (non-flow-related) residual voltage. During the “off” period, the converter measures the variable (non-flow-related) residual signal only. Since no field excitation is present, no flow signal will be generated. The converter then subtracts the stored residual signal from the flow developed-plus residual signal, resulting in the display of a pure flow signal.
2.10 Magnetic Flowmeters

Zero stability. The output generated by the low-frequency signal is integrated via a long time constant to provide a smooth and stable flow signal.

The high-frequency component is superimposed on the low-frequency signal to provide immunity to noise caused by low conductivity, viscosity, slurries, and electrochemical reactions. The output generated by the high-frequency component is sampled at a high frequency and is processed in a differentiating circuit having the same time constant as the integrating circuit. By adding the two signals, the result is an output that is free of "slurry" noise and has good zero stability plus good response speed.

Other Types

Classification of magnetic flowmeters varies from one manufacturer to the next. A typical classification involves several types: wafer, flange, partially filled, micro-fractional, large-size, and sanitary. There are variations in the size of detectors and other features made suitable for a specific application. For example, micro-fractional detectors are designed to measure small amounts of fluids containing substances such as chemicals. The wetted materials are made from corrosion-resistant ceramic and platinum. They are lightweight, palm-size detectors suitable for use in 2.5-mm pipes. In contrast, in large-size types, the coils are arranged to measure uneven flows, and the flowmeters are made with improved noise suppression. The size can be as large as 3000 mm (120 in.).

CONSTRUCTION OF MAGNETIC FLOWMETERS

Figure 2.10g is a cutaway view showing how the principle of electromagnetic induction is employed in a practical flowmeter. The basic element of the flowmeter is a section of nonconducting pipe such as glass-reinforced polyester or a nonmagnetic pipe section lined with an appropriate electrical conductor such as Teflon, Kynar, fiberglass, vitreous enamel, rubber, neoprene, or polyurethane, among others. On alternate sides of the pipe section are magnet coils that produce the magnetic field perpendicular to the flow of liquid through the pipe. Mounted in the pipe, but insulated from it and in contact with the liquid, is a pair of electrodes that are located at right angles both to the magnetic field and the axis of the pipe.
As the liquid passes through the pipe section, it also passes through the magnetic field set up by the magnet coils, inducing a voltage in the liquid; the amplitude of the voltage is directly proportional to the liquid velocity. This voltage is conducted by the electrodes to a separate converter that, in effect, is a precision voltmeter (electrometer) capable of accurately measuring the voltage generated and converting that voltage to the desired control signals. These may be equivalent electronic analog signals, typically 4 to 20 mA DC, or a frequency or scaled pulse output.

Most electromagnetic flowmeters are built with flanged end fittings, although the insert types are also common. Designs are available with sanitary-type fittings. In large pipe sizes, Dresser-type and Victaulic-type end connections are also widely used. Some electromagnetic flowmeters are made from replaceable flow tubes whereby the field coils are located external to the tubes. In these flowmeters, the flanges are located far apart so as to reduce their adverse effects on the accuracy of measurements; hence, they are relatively large in dimension. In others, the field coils are located closer to the flow tube or even totally integrated. In this case, the flanges could be located closer to the magnets and the electrodes, thus giving relatively smaller dimensions. On the other hand, the miniature and electrodeless magnetic flowmeters are so compact in size that face-to-face dimensions are short enough to allow them to be installed between two flanges.

The pipe between the electromagnets of a flowmeter must be made from nonmagnetic materials to allow the field to penetrate the fluid without any distortion. Therefore, the flow tubes are usually constructed of stainless steel or plastic. The use of steel is a better option, since it adds strength to the construction. Flanges are protected with appropriate liners, and they do not make contact with the process fluid.

The electrodes for the magnetic flowmeters must be selected such that they will not be coated with insulating deposits of the process liquid during long periods of operations. The electrodes are placed at positions where maximum potential differences occur. They are electrically isolated from the pipe walls by nonconductive liners to prevent short-circuiting of electrode signals. The liner also serves as protection to the flow tube to eliminate galvanic action and possible corrosion due to metal contacts. Electrodes are held in place by holders that also provide sealing. In some flowmeters, electrodes are cleaned continuously or periodically by ultrasonic or electrical means. Ultrasonics are specified for AC- and DC-type magnetic flowmeters when frequent severe insulating coating is expected on the electrodes that might cause the flowmeter to cease to operate in an anticipated manner.

Versions of magnetic flowmeters are available for periodic accidental submergence and for continuous submergence in water at depths of up to 30 ft (9 m). An outgrowth of the continuous submergence design is a sampling type (pitot). The pitot-type magnetic flowmeter samples the flow velocity in large rectangular, circular, or irregularly shaped pipes or conduits. A typical design is shown in Figure 2.10h. A small magnetic flowmeter is suspended in the flow stream. The magnet coils are completely encapsulated in the liner material, allowing submersion in the liquid to be measured. The short length of the meter body and the streamlined configuration are designed to minimize the difference between the flow velocity through the meter and the velocity of the liquid passing around the meter. The velocity measurement
of the liquid through the meter is assumed to be representative of the pipe velocity. Repeatability of the system is typically 0.25 to 0.5% of full scale. As with any sampling-type flowmeter, the information from the flowmeter is representative only of the flow through the flowmeter. It is the user’s responsibility to relate that “sampled” velocity to the average velocity in the pipe, which reflects the total volumetric flow rate. When applying any sampling-type flowmeter, including the pitot-type magnetic flowmeter, substantial errors can occur in applications where the velocity profile can change due to changes in Reynolds number or due to the effects of upstream piping configuration.

Most manufacturers construct their flowmeters with coils external to the meter pipe section. Some designs place the coils within the flowmeter body, which is made from carbon steel to provide the return path for the magnetic field as in Figure 2.10i. In this design, the meters can be shorter, have reduced weight, and offer lower power consumption. The lowest power consumption is a feature of the pulsed DC design, because its coils are energized only part of the time. An additional saving with pulsed DC types is that the power factor approaches 1.

Ceramic Liners

The use of ceramic liners represents a major improvement in the design of magnetic flowmeters, because they cost less to manufacture and also provide a better meter. Ceramic materials such as Al2O3 are ideal liner materials, because their casting is inexpensive, they are electrically nonconductive, and they are abrasion- and wear-resistant. In contrast with plastic liners, they can be used on abrasive slurry services (pipelining of minerals or coal), and their inner surfaces can be scraped with wire brushes to remove hardened coatings. Ceramic units are also preferred for sanitary applications because they do not provide any cavities in which bacteria can accumulate and grow. Ceramic meters can also handle higher temperatures (360°F, 180°C) than Teflon-lined ones (250°F, 120°C). Magnetic flowmeters are velocity sensors and, to convert velocity into volumetric flow rate, the pipe cross section has to be constant. Therefore, the ceramic liners have the added advantage of expanding and contracting less with changes in temperature than do metals or plastics. Ceramic liners are also preferred by the nuclear industry because they are not affected by radiation, whereas plastics are destroyed by it.

The design of the ceramic insert-type magnetic flowmeter also eliminates the possibility of leakage around the electrodes. This perfect seal is produced by allowing a droplet of liquid platinum to sinter through the ceramic wall of the liner. Through this process, the ceramic particles and the platinum fuse into a unified whole, providing not only a perfect seal but also a permanent, rugged, and corrosion-resistant electrode. This electrode cannot move, separate, or leak.

For the reasons listed above, the ceramic insert-type magnetic flowmeter is an improvement. However, it also has some limitations. One of its limitations has to do with its brittle nature. Ceramic materials are strong in compression but should not be exposed to pipe forces that cause tension or bending. Another possible way to crack the ceramic lining is by sudden cooling. Therefore, these elements should not be exposed to downward step changes in temperature that exceed 90°F (32°C). Another limitation of the Al2O3 ceramic liner is that it cannot be used with oxidizing acid or hot, concentrated caustic applications (over 120°F, 50°C).

Probe-Type Units

The probe-type magnetic flowmeter is an “inside out” design in the sense that the excitation coil is on the inside of the probe, as shown in Figure 2.10j. As the process fluid passes through the magnetic field generated by the excitation coil inside the probe, a voltage is detected by the electrodes that are embedded in the probe. The main advantage of this design is its low cost, which is not affected by pipe size, and its retractable nature, which makes it suitable for wet-tap installations. The probe-type magmeter is also suited for the measurement of flow velocities in partially full pipes or in detecting the currents in open waters. When water flow is not constrained by a pipe, flow velocity has to be expressed as a three-dimensional vector. By inserting three magmeter probes parallel with the three axes, one can detect that vector.

The main disadvantage of the magmeter probe is that it detects the flow velocity in only a small segment of the cross-sectional area of the larger pipe. Therefore, if the flowing velocity in that location is not representative of the rest of the cross section, a substantial error can result.
APPLICATIONS OF MAGNETIC FLOWMETERS

In the applications of magnetic flowmeters, a number of considerations must be taken into account, including the following:

- Cost, simplicity, precision, and reproducibility
- Metallurgical aspects
- Velocity profiles and upstream disturbances

During the selection of electromagnetic flowmeters, the size of the required flowmeter, the process characteristics and existing structure, and the velocity constraints should be evaluated carefully to secure accurate performance over the expected range. Table 2.10k illustrates the typical sizes and capacities of most commonly available flowmeters. The full-scale velocity of the flowmeter is typically 0.3 to 10 m/sec. Some flowmeters can measure lower velocities, with somewhat poorer accuracy. Generally, employment of electromagnetic flowmeters over a velocity of 5 m/sec should be considered carefully, since erosion of the pipe and the damage to liners can be significant. In all applications, determining the size of the flowmeter is a matter of selecting the one that can handle the liquid velocities. The anticipated liquid velocity must be within the linear range of the device. The capacities of various sizes of flowmeters are given in Figure 2.10l as a typical guide for selection.

Magnetic flowmeters are the first to be considered for very corrosive applications and for applications involving measurement of abrasive and/or erosive slurries. They are widely used in pulp and paper stock measurement and other non-Newtonian applications. They can be used for very low flow rates; pipe inside diameters as small as 0.1 in. (2.5 mm) are offered that can handle flow ranges as low as 0.01 to 0.1 GPM (0.038 to 0.38 l/min). Magnetic flowmeters are also available in pipe sizes up to 120 in. (3 m).

### Table 2.10k

<table>
<thead>
<tr>
<th>Meter Size (mm)</th>
<th>Dimensions (mm)</th>
<th>Weight (kg)</th>
<th>Flow Rate (m³/h)</th>
<th>Standard Flow Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>70 × 180 × 50</td>
<td>3</td>
<td>0.191</td>
<td>0.636</td>
</tr>
<tr>
<td>25</td>
<td>80 × 170 × 65</td>
<td>3</td>
<td>0.350</td>
<td>1.770</td>
</tr>
<tr>
<td>40</td>
<td>100 × 240 × 85</td>
<td>6.5</td>
<td>1.357</td>
<td>4.525</td>
</tr>
<tr>
<td>50</td>
<td>110 × 260 × 100</td>
<td>7</td>
<td>2.120</td>
<td>7.067</td>
</tr>
<tr>
<td>80</td>
<td>110 × 280 × 125</td>
<td>8</td>
<td>5.428</td>
<td>18.10</td>
</tr>
<tr>
<td>100</td>
<td>120 × 315 × 160</td>
<td>10</td>
<td>8.482</td>
<td>28.30</td>
</tr>
<tr>
<td>150</td>
<td>230 × 390 × 215</td>
<td>22</td>
<td>19.10</td>
<td>63.61</td>
</tr>
<tr>
<td>200</td>
<td>300 × 440 × 270</td>
<td>36</td>
<td>33.90</td>
<td>113.1</td>
</tr>
</tbody>
</table>

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2.10 Magnetic Flowmeters

2.10m Magnetic flowmeter capacity nomograph.

Figure 2.10m is a nomograph for magnetic flowmeter capacities. Magnetic flowmeters have an excellent operating range of at least 100:1. For AC types, typical inaccuracy is ±1% of full scale. To improve performance, range is usually divided into two portions and automatically switched between the two. Pulsed DC-types have typical inaccuracy of ±1% of rate applicable to a 10:1 range or ±0.5% of rate over a 2:1 or 5:1 range, and at flow rates below 10% of maximum it is on the order of ±0.1% of full scale. The converter can be set for 20 mA output at any flow between 10 and 100% of meter.
capacity and still have at least a 10:1 operating range. This ability to field set or reset the meter for the actual operating conditions provides optimal performance.

Most processes employ circular piping that adds simplicity in the construction of the system. The flowmeters connected to circular pipes give relatively better results as compared to rectangular or square-shaped pipes, and velocity profiles of the liquid are not affected by the asymmetry. However, in circular pipes, the fringing of the magnetic field may be significant, making it necessary to employ empirical calibrations.

Upstream and downstream straight piping requirements may vary from one flowmeter to another, depending on the manufacturer’s specifications. As a rule of thumb, the straight portion of the pipe should be at least 5D/2D from the electrodes and 5D/5D from the face of the flowmeter in upstream and downstream directions, respectively. For a good accuracy, the recommendations of manufacturers for piping requirements should be carefully observed. In some magnetic flowmeters, coils are used in such a way that the magnetic field is distributed in the coil to minimize the piping effect.

Magnetic flowmeters are often used to measure explosive fluids in hazardous environments. In these applications, explosion-proof housings are absolutely essential. The construction and specifications of such housings are regulated by authorities such as the European Committee for Electrotechnical Standardization (CENELEC). Usually, integral or remote electronics are offered for mounting flexibility and reliability. In many instruments, the electronic circuitry is separated from field wiring terminations by a dual-compartment housing and an integral backlight LCD design that provides an easy operator interface.

Accuracy and Calibration

The power consumption of a conventional (high-frequency AC excited) 2-in. (50-mm) flowmeter is about 30 W. For a 30-in. (76-cm) flowmeter, it is about 300 W. Low-frequency DC excitation has reduced the power consumption of some magnetic flowmeters to 20 W, regardless of meter size. The accuracy of conventional magnetic flowmeter is usually expressed as a function of full scale, typically 0.5 to 1% FS. However, DC flowmeters have a well-defined zero due to an automatic zeroing system; therefore, they have percentage rate of accuracy better than AC types (typically 0.5 to 2%).

Magnetic flowmeters do not require continuous maintenance other than periodic calibrations. Nevertheless, electrode coating, damage to the liners, and electronic failures may occur. Any modifications and repairs must be treated carefully because, when installed again, some accuracy may be lost. After each modification or repair, recalibration may be necessary.

Calibration of electromagnetic flowmeters is achieved with a magnetic flowmeter calibrator or by electronic means. The magnetic flowmeter calibrators are precision instruments that inject simulated output signals of the primary flowmeter into the transmitter. Effectively, this signal is used to check correct operation of electronic components and make adjustments to the electronic circuits. Alternatively, calibrations can also be made by injecting suitable test signals to discrete electronic components. In some cases, empirical calibrations must be performed at zero flow while the flowmeter is filled with the stationary process liquid.

Zero adjustment of AC magnetic flowmeters requires compensation for noise. If the zero adjustment is performed with a fluid other than process fluid, serious errors may result because of possible differences in conductivities. Similarly, if the electrodes are coated with an insulating substance, the effective conductivity of the electrodes may be altered, causing a calibration shift. If the coating changes with time, the flowmeter may continually require calibration for repeatable readings.

Errors in Magnetic Flowmeters

Operation of a magnetic flowmeter is generally limited by factors such as liner characteristics, pressure ratings of flanges, and temperatures of the process fluids. The maximum temperature limit is largely dependent on the liner material selection and usually is set to around 120°C. For example, the ceramic liners can withstand high temperatures but are subject to cracking subjected to sudden temperature changes in the process fluid.

For accurate measurements, magnetic flowmeters must be kept full of liquid at all times. If the liquid does not contact the electrodes, no measurements can be taken. Figure 2.10n illustrates this point. If the measurements are made in flows other than vertical, the electrodes should be located in horizontal directions to eliminate the possible adverse effect of the air bubbles, given that air bubbles tend to concentrate on the top of the liquid.

Often, the magnetic flowmeter liners are damaged by the presence of debris and solids in the process liquid. Also, the use of incompatible liquid with the liners, wear due to abrasion, and excess temperature during installations and removals can contribute to the damage of liners. The corrosion in the electrodes

---

**FIG. 2.10n**

The pipes of electromagnetic flowmeters must be full of liquid at all times for accurate measurements. If the liquid does not make full contact with electrodes the high impedance prevents the current flow hence measurements cannot be taken. Also, If the pipe is not full, even if contact is maintained between the liquid and electrodes, the empty portions of the pipe will lead to miscalculated flow rates.
may also be a contributing factor for the damage. In some cases, magnetic flowmeters may be repaired on site if severe damage occurs; in others, they must be shipped to the manufacturer for repairs. Usually, manufacturers supply spare parts for electrodes, liners, flow tubes, and electronic components.

Grease and other nonconductive electrode coatings introduce an error in the measurement, because the voltage generated by the conductive fluid is measured by the magmeter electronics as a voltage drop across its input impedance \( R_{\text{fm}} \) as in Figure 2.10o. When there is an electrically resistant coating on the electrodes, some of the voltage generated by the conductive liquid drops across the coating, and less of it remains to be detected by the input impedance. The resulting error percentage can be calculated as follows:

\[
E = 100 \frac{R_c}{R_{\text{fm}}} \left( \frac{R_{\text{fm}}}{R_c} + \frac{R_c}{R_{\text{fm}}} \right)
\]

2.10(6)

Coating resistance \( R_c \) can reach \( 10^7 \), and if the input impedance \( R_{\text{fm}} \) in similar, substantial errors will result. In some newer designs, the input impedance of the flowmeter has been increased to \( R_{\text{fm}} = 10^{11} \). Even at a coating impedance of \( R_c = 10^7 \), this limits the coating error to 0.01%. With such high-impedance electronics, the need for electrode cleaning is minimized or eliminated.

The meter’s electrodes must remain in electrical contact with the fluid being measured and should always be installed in the horizontal plane. In applications where a buildup or coating of the inside wall of the flowmeter occurs, periodic “flushing” or cleaning is recommended. Coatings can have conductivities that are the same, lower, or higher than the liquid. These effects are significantly different. Where the conductivity of the coating is essentially the same as that of the liquid, there is no effect on the accuracy of the measurement except for the effect of a reduced cross-sectional area. This can be viewed as a specific profile condition, and the meter will average the velocity to give the correct value for the particular flow rate. Fortunately, this is the most common coating condition. If the conductivity of the coating is significantly lower than that of the liquid being measured, the electrically insulating coating can disable the meter. If periodic cleaning is not possible, mechanical, ultrasonic, thermal, and other electrode cleaning techniques can be applied.

Manufacturers also offer specifically shaped protruding electrodes to take advantage of the self-cleaning effect of the flow at the electrode. If the conductivity is higher than that of the process fluid, no corrective measure is needed.

**EFFECTS OF ELECTRICAL CONDUCTIVITY OF FLUID**

For electromagnetic flowmeters to operate accurately, the process liquid must have minimum conductivity of about 1 to 5 \( \mu \)S/cm. Most common applications involve liquids whose conductivity is greater than 5 \( \mu \)S/cm. Nevertheless, for accurate operations, the requirement for the minimum conductivity of liquid can be affected by length of leads from sensors to transmitter electronics. For example, the resistance between electrodes may be approximated by \( R = 1/\delta d \), where \( \delta \) is the fluid conductivity and \( d \) is the electrode diameter. For tap water, \( \delta = 200 \) \( \mu \)S/cm, for gasoline \( \delta = 0.01 \) \( \mu \)S/cm, and for alcohol 0.2 \( \mu \)S/cm. A typical electrode with a 0.74-cm diameter in contact with tap water results in a resistance of 6756 \( \Omega \).

Application of magnetic flowmeters can be realized only with conductive liquids such as acids, bases, slurries, foods, dyes, polymer emulsions, and suitable mixtures that have conductivities greater than the minimum conductivity requirements. Generally, magnetic flowmeters are not suitable for liquids containing organic materials and hydrocarbons. As a rule of thumb, magnetic flowmeters can be applied if the process liquids constitute a minimum of about 10% conductive liquid in the mixture.

Most liquids or slurries are adequate electrical conductors to be measured by electromagnetic flowmeters. If the liquid conductivity is equal to 20 \( \mu \)S/cm or greater, most of the conventional magnetic flowmeters can be used. Special designs are available to measure the flow of liquids with threshold conductivities as low as 0.1 \( \mu \)S/cm. Some typical electrical conductivities are as shown in the following table.

<table>
<thead>
<tr>
<th>Liquid (at 25°C except where noted)</th>
<th>Conductivity, ( \mu )S/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid (up to 70% by weight)</td>
<td>250 or greater</td>
</tr>
<tr>
<td>Ammonium nitrate (up to 50% by weight)</td>
<td>360,000 or greater</td>
</tr>
<tr>
<td>Molasses (at 50°C)</td>
<td>5000</td>
</tr>
<tr>
<td>Ethyl alcohol</td>
<td>0.0013</td>
</tr>
<tr>
<td>Formic acid (all concentrations)</td>
<td>280 or greater</td>
</tr>
<tr>
<td>Glycol</td>
<td>0.3</td>
</tr>
<tr>
<td>Hydrochloric acid (up to 40% by weight)</td>
<td>400,000 or greater</td>
</tr>
<tr>
<td>Kerosene</td>
<td>0.017</td>
</tr>
<tr>
<td>Magnesium sulfate (up to 25% by weight)</td>
<td>26,000 or greater</td>
</tr>
<tr>
<td>Corn syrup</td>
<td>16</td>
</tr>
<tr>
<td>Phenol</td>
<td>0.017</td>
</tr>
<tr>
<td>Phosphoric acid (up to 87% by weight)</td>
<td>50,000 or greater</td>
</tr>
<tr>
<td>Sodium hydroxide (up to 50% by weight)</td>
<td>40,000 or greater</td>
</tr>
<tr>
<td>Sulfuric acid (up to 99.4% by weight)</td>
<td>8500 or greater</td>
</tr>
<tr>
<td>Vodka (100 proof)</td>
<td>4</td>
</tr>
<tr>
<td>Water (potable)</td>
<td>70</td>
</tr>
</tbody>
</table>
The effect of conductivity changes above the threshold conductivity may be minimal, but the effect of liquid operating temperature on the threshold conductivity should be considered. Most liquids have a positive temperature coefficient of conductivity. Liquids that are marginal at one temperature can become nonconductive enough at a lower temperature to impair metering accuracy. At a higher temperature, the same liquid may be metered with good results. There are a few liquids that have a negative temperature coefficient; these should be carefully checked for their minimum conductivity before applying magnetic flowmeters.

Magnetic flowmeters are not affected by viscosity or consistency (referring to Newtonian and non-Newtonian fluids, respectively). The changes in flow profile resulting from changes in Reynolds numbers, or from upstream piping, do not greatly affect the performance of magnetic flowmeters. The voltage generated is a summation of the incremental voltages across the entire area between the electrodes, resulting in a measure of the average fluid velocity. Nevertheless, it is recommended to install the meter with 5 diameters of straight pipe before it and 3 diameters of straight pipe following it.

**INSTALLATION**

The signal detected by magnetic flowmeter electrodes is in the high microvolt to low millivolt range. Proper electrical installation and grounding is mandatory. Individual manufacturer’s recommendations for installation are the result of extensive experience and should be scrupulously followed, as illustrated in Figure 2.10p.

Alternating-current-type magnetic flowmeters occasionally shift their no-flow indication after some operating time, requiring a zero reset. One of the most important installation considerations with electromagnetic flowmeters is a proper bonding of the flowmeter to the adjacent piping to minimize zero shifts. The intent of this bonding, or jumpering, is to prevent stray currents from passing through the flowmeter near the electrodes. Magnetic flowmeters are lined with an electrically insulating material; generally, this lining covers the flange face of the meter, making the meter an electrical discontinuity in the system. The flange bolts should not be used for bonding, given that rust, corrosion, paint, and other insulating materials can create an insulating barrier between the bolts and the flanges. Manufacturers supply, and insist on, the installation of copper braid jumpers from the meter flange to the pipe flange at either end of the flowmeter. The jumpers provide a continuous path for the stray currents, which guarantees a more stable zero. It is also essential to install a ground strap to a grounded piece of structural steel, a grounding rod, or a conductive cold water pipe.

We can eliminate the above-described installation process, which involves labor-intensive drilling, tapping, and strapping of adjacent pipe flanges in metallic pipes or the installation of expensive grounding rings in lined or nonconductive pipes, if the magmeter is provided with built-in grounding electrodes. When installing the flowmeter, the grounding electrode must always be at the bottom and must be connected to the third-wire ground of the power input.
The conservative installation of magnetic flowmeters requires 3 to 5 diameters of straight pipe, the same size as the flowmeter, to be installed upstream from the meter, plus 2 or 3 diameters downstream. Meters can be installed in horizontal pipelines, vertical pipelines, or sloping lines. It is essential to keep the electrodes in the horizontal plane to ensure uninterrupted contact with the liquid or slurry being metered. In gravity-feed systems, the meter must be kept continually full; therefore, the meter should be installed in a "low point" in horizontal lines or, preferably, in a vertical upflow line.

SIGNAL CONSIDERATIONS AND DEMODULATION TECHNIQUES

Each magnetic flowmeter requires electronics to convert the electrode output into a standardized analog or digital signal. The electronics can be mounted locally, directly on the flowmeter, or remotely. Integral mounting simplifies the installation, reduces cost, and eliminates the noise and other problems associated with the transmission of a low-level signal over a relatively long distance. The advantages of remote mounting include the reduced headroom requirement for the meter, accessibility, operator convenience, and the distancing of the sensitive electronics from the high-temperature or otherwise undesirable environment of the flowmeter. If shielded, twisted wires are used, the electronics can be 200 ft (67 m) from the meter.

The housings of the electronics can be designed for indoor or outdoor use and for general-purpose or hazardous environments. The converters can serve several flowmeters simultaneously and provide for interfacing with computers. The displays can provide flow rate or total flow indication. "Smart" magmeters provide the added features of self-diagnostic and detection of coil/converter/metering tube failure or of empty pipe, as well as switching, alarming, flow integration, and preset batching functions. They can also detect pipe blockage; signal erroneous settings; or change the range, engineering units, damping times (63% response time settable from 0.1 to 100 sec), or even the flow direction of metering.

Magnetic flowmeters are essentially four-wire devices that require an external power source for operations. Particularly in AC magnetic flowmeters, the high-voltage power cables and low-voltage signal cables must run separately, preferably in different conduits. In contrast, for DC magnetic flowmeters, the power and signal cables can be run in one conduit. This is because, in DC-type magnetic flowmeters, the voltage and the frequency of excitation of the electromagnets are much lower. Some manufacturers supply special cables along with their flowmeters.

Despite beliefs to the contrary, magnetic flowmeters demonstrate a certain degree of sensitivity to flow profiles. Another important aspect is the effect of turbulence. Unfortunately, there is very little information available on the behavior of turbulent flows when they are in transverse magnetic fields. Figure 2.10q shows an example of flow profile in which the velocity profile perturbed. The fluid is being retarded near the center of the channel and accelerated at the top and bottom near the electrodes.

In AC flowmeters, the electrode signals may be amplified much more readily as compared with their DC counterparts. That is why AC flowmeters have been used successfully to measure very low flow rates as well as the flow of very weakly conducting fluids. Nevertheless, AC flowmeters tend to be more complicated, bulky, and expensive, and they require electromagnets with laminated yokes along with stabilized power supplies. In some magnetic flowmeters, it is feasible to obtain sufficiently large flow signal outputs without the use of yoke by means of producing magnetic fields by naked coils. In this case, the transformer action to the connecting leads may be reduced considerably.

One of the main drawbacks of AC-type flowmeters is that it is difficult to separate the signals caused by transformer action from the useful signals. The separation of the two signals is achieved by exploiting the fact that the flow-dependent signal and the transformer signal are in quadrature. That is, the useful signal is proportional to the field strength, and the transformer action is proportional to the time derivative of the field strength. The total voltage \( v_T \) can be expressed as

\[ v_T = v_F + v_i = V_F \sin(\omega t) + V_i \cos(\omega t) \tag{2.107} \]

where \( v_F \) is the induced voltage due to liquid flow, and \( v_i \) is the voltage due to transformer action on wires, and so on.
Phase-sensitive demodulation techniques can be employed to eliminate the transformer action voltage. The coil magnetizing current, $i_m = I_m \sin(\omega t)$, is sensed and multiplied with the total voltage $v_T$ giving

\[ v_T i_m = [V_f \sin(\omega t) + V_i \cos(\omega t)] I_m \sin(\omega t) \quad 2.10(8) \]

Integration of Equation 2.11(8) over one period between 0 and $2\pi$ eliminates the transformer voltage, yielding only the voltage that is proportional to the flow.

\[ V_f = V_f I_m \pi \quad 2.10(9) \]

where $V_f$ is the voltage after integration. This voltage is proportional to the induced voltage modified by constants $I_m$ and $\pi$.

In reality, this situation can be much more complicated because of phase shift due to eddy currents in nearby solids and conductors. Other reasons for complexity may be the result of harmonics because of nonlinearities such as hysteresis, or caused by capacitive pickup.

Particularly in AC flowmeters, if the flowmeter is not grounded carefully relative to the potential of the fluid in the pipe, then the flowmeter electrodes may be exposed to excessive common-mode voltages that can severely limit the accuracy. In some cases, excessive ground potential can damage the electronics, because the least-resistance path to the ground for any stray voltage in the liquid would be via the electrodes.

Some commercial magnetic flowmeters have been developed that can operate on sawtooth or square waveforms. Standardized magnetic flowmeters and calibration data still do not exist, and manufacturers use their own particular design of flow channels, electromagnets, coils, and signal processors. Most manufacturers provide their own calibration data.

Bibliography


Kuroki, Y. et al., Viscous flow measurement using electromagnetic flowmeter, ISA/93 Technical Conference, Chicago, IL, 1993.
VanLark, F., Application limits of electromagnetic flowmeters, in Proc. ISA/92 Conference, Houston, TX, 1992.