Flow & Level

Advanced Tools
Simplify Instrument Maintenance

Wireless Level Tracking Propels Brewer’s Success

Back to Basics: Radiometric Level and Density Measurement

The Excitation Frequency of Magnetic Flowmeters
Introduction

The process automation industry is a bastion of innovation today. From digitalization to new instrumentation, measurement techniques and data collection efforts, these innovations have driven many organizations to take on ambitious new projects, and streamline the day-to-day operations in their facility. This is especially true when it comes to level and flow measurement, as remote calibration, connected instrumentation and mountains of collected data make the workplace simpler and safer for today’s engineers and technicians.

Given these rapid advances, the International Society of Automation (ISA) introduces the inaugural issue of InTech Focus. This in-depth e-resource is designed to inform automation professionals of the innovations and strategies needed to thrive in tomorrow’s industry, and make the most out of their flow and level instrumentation. From real-world case studies to strategic maintenance tips and expert analysis of the new tools, InTech Focus is instrumental for Process professionals to safely and efficiently enhance the value of their organizations.
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In many process plants, maintenance of instrumentation (Figure 1) falls into one of two categories. The first is “too little, too late,” where instrumentation fails due to a lack of preventive maintenance, often shutting down processes. The second category is “too much maintenance,” where companies remove, calibrate, clean and service instrumentation that doesn’t need it, at a high cost for parts, labor and equipment downtime.

Some instrument vendors now offer capabilities and services to help end users manage maintenance through on-line diagnostics, asset management, proper scheduling of maintenance tasks, and automatic alerts when problems come up.

Hardware and software developments make preventive maintenance easier, lower costs, reduce parts inventories, and prevent unexpected equipment failures.

By Jon Dietz, Endress+Hauser
This article describes how end users can exploit these technologies to simplify maintenance, lower costs, reduce parts inventories, and prevent unexpected equipment failures.

**Instrumentation that Diagnoses Itself**

Smart flowmeters and other process instruments have been available for years in “smart” versions, providing vital information for maintenance. For example, 4-20mA HART devices have been available since the 1980s. HART superimposes 35-40 digital parameters onto the 4-20mA signal, which can include device status, diagnostic alerts, configuration parameters, and so on. Fieldbus instruments provide much of the same information through various protocols such as EtherNet/IP and Profibus PA.

Unfortunately, over 60% of instruments are used only to measure the primary process variable, with the status and diagnostic data ignored by the control system. Maintenance technicians often have to access the data with handheld devices that plug into the flowmeter. A lack of understanding, training and useful software to process the data might account for maintenance departments not taking advantage of this capability.

Instrument suppliers recognized the problem and have gone to great lengths to equip flowmeters and other devices with on-board diagnostics, status information and other secondary device parameters that are needed by maintenance people—and they’ve provided the software needed to make all this data easily accessible and usable.

For example, flowmeters from Endress+Hauser are typically equipped with Heartbeat Technology, which provides a wealth of status and diagnostic information, and performs vital functions such as condition monitoring and insitu-verification.

Condition monitoring recognizes if the measurement performance or the integrity of the flowmeter are impaired. The monitoring values are transmitted to an external condition monitoring system, such as Endress+Hauser’s PC-based FieldCare software. FieldCare can be used to recognize trends in the secondary measured values, and to evaluate relationships among individual parameters.

Legal requirements may call for flowmeters or other instruments to be verified calibrated periodically. This is normally done by removing the flowmeter from the process, taking it to a flow lab or calibration rig, and quantitatively comparing it to a traceable standard.

With modern instruments, the flowmeter’s transmitter electronics continuously run a qualitative assessment so all relevant components which influence the device function and integrity are checked. This confirms and can document by verification that none of the meter components have drifted outside original calibration tolerances. If the flowmeter calibration frequency can be extended, this represents a tremendous savings in labor and process down time.

More details can be found in the Flow Control article, “How Flowmeters Perform Self-Verification” (https://www.flowcontrolnetwork.com/how-flowmeters-perform-self-verification/).

**Maintenance Management**

Modern instrumentation provides status and diagnostic information, but processing all of this data is often a problem. For example, a chemical plant in Gendorf, Germany, has more than 4,000 instruments measuring level, flow, temperature, pressure and other parameters. Having its control systems read all the diagnostic information from all 4,000 devices, analyze it for problems, and issue instructions to the maintenance department would be a daunting problem for the plant’s control system programmers. It would also burden the control system with data not relevant to its primary task, which is real-time process control.

Instead, instrument manufacturers have developed software packages that perform all those func-
tions. The packages fall into two basic categories: Instrument management programs, which analyze real-time information from instrumentation; and asset management software, which keeps track of every instrument in the plant and stores vital data, such as manuals and parts lists.

Instrument management programs perform several functions to aid maintenance departments, including:

- **Configuration**—helps maintenance configure new instrumentation during initial installation or when replacing an existing instrument.
- **Condition monitoring**—as noted above, used to analyze real-time data coming from instrumentation, look for problems, and notify the maintenance department when a device needs attention prior to failure.
- **Life cycle management**—tracks the entire life cycle of an instrument, from initial configuration to calibrations and repairs, and provides information for audits and safety regulations.

While a particular instrument manufacturer can provide information for its own instruments, what about all the other instruments in a plant from different manufacturers? Fortunately, standardization across the instrumentation industry makes that information available.

Device Description (DD), enhanced device description language (EDDL), Device Type Manager (DTM), and HART and fieldbus configuration files are available from all manufacturers, can be accessed easily from various web sites, and then loaded into the instrument management program.

Thus, a program like Endress+Hauser’s FieldCare software not only has information about its own instruments, it can support over a thousand process instruments and analyzers from other manufacturers.

### Asset Management

When a plant has thousands of instruments, keeping track of manuals, parts lists, audit reports, maintenance schedules and other information can be a nightmare. A maintenance asset management program gathers all this information, digitizes it, and makes it available to maintenance technicians via handheld devices (Figure 2).

An asset management program typically provides:

- **Instrument Manuals**—Modern manuals are available in digital form and are easily downloaded into the data base; older paper manuals can be scanned
- **Parts lists**—Like manuals, parts lists can be downloaded or scanned
- **Compliance**—The software tracks all instrument activities, including calibrations, verifications and maintenance performed to meet various industry and government regulations
- **Documentation and reports**—The software can produce audits and regulatory reports that meet government and industry standards
- **Maintenance management**—Determines when instruments need to be serviced, calibrated or verified, and notifies maintenance
- **Communications**—The software can share data with other maintenance management programs, historians, spreadsheets, etc.

Figure 2: Asset management programs provide equipment manuals, parts lists and other information to handheld devices, such as Endress+Hauser’s FieldXpert.
All this information can be kept on site or in the Cloud, where it can be accessed from a workstation (Figure 3) or a portable handheld device.

**Getting Started**

Many plants do not have sufficient information regarding their installed base of process instruments and analyzers, and over time the plants are modified and instruments change, worsening the situation.

One of the best ways to address this issue is by implementing a maintenance management program, often with the aid of a major instrument vendor. Most such vendors can come to a process plant, do an assessment of the instrumentation installed base, and make management recommendations on what needs to be done to improve the current situation.

For example, Endress+Hauser can perform an Installed Base Analysis, which consists of:

- **Instrument inventory**—Find and list all on-site devices to enable further transparency, regardless of manufacturer
- **Assess device criticality and maintainability**—Define and classify critical measuring points and its maintainability to ensure maintenance tasks can be performed easily and effectively
- **Recommend adequate maintenance strategy**—Evaluate current maintenance activities and recommend improvements to achieve a balanced maintenance program
- **Identify obsolete equipment**—Includes a migration plan to modernize the plant
- **Reduce complexity**—Includes recommendations to standardize instrumentation and minimize spare parts.

At the completion of the assessment, the instrument vendor will address its recommendations by providing key information to facilitate relevant decision making regarding the maintenance and quality improvements, obsolescence and spares management of respective installed base assets. If the plant agrees, the project begins by implementing the new maintenance program within the scope of a service agreement. The data describing each instrument is entered into the database and maintained over time to enable the user to continuously access to an up to date information at any time and from any location.

As noted above, the software may already have most of the data needed, such as DD and DTM files, manuals, etc. In some cases, old manuals and parts lists may have to be found and scanned in. Eventually, the data base will be populated.
A wastewater treatment plant in Thun, Switzerland (Figure 4) had Endress+Hauser conduct an IBA, and then installed W@M Life Cycle Management software.

Once the data had been recorded, a connection was established to the control system. The visualization program allows the plant to quickly identify a measuring device needing attention. The necessary information can then be quickly accessed, including the right operating manuals, ordering information, maintenance reports, software drivers and spare parts.

The chemical plant mentioned above also conducted an IBA and adopted such a program to maintain its 4,000 instruments. In the old days, documents such as calibration reports had to be scanned and filed manually. Today, this information is available whenever and wherever it is needed. The plant is now able to identify every one of its devices and react quickly in the event of a malfunction.

**Summary**

Modern instrumentation and related maintenance strategies are making it much easier for process plants to perform preventive maintenance, eliminate process shutdowns from failed instruments, and save time and money by avoiding unnecessary maintenance activities.

Initial implementation of an instrumentation management system can be a daunting task, but instrument vendors can provide assistance as required.

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Wireless Level Tracking Propels Brewer’s Success

By Michael Koppelman

The growth of craft brewing has changed the whole American beer paradigm by separating the market from the traditional “big three.” From 2004 to 2015, annual craft beer and ale production industry-wide grew fivefold to 25 million barrels, while sales of traditional brews declined.

Craft brewing was born of a do-it-yourself (DIY) countercultural mentality that pushed the boundaries of style, brand, and quality beyond accepted norms. Many of the people making craft beer are not process engineers, but instead come from a variety of careers and are looking for a different path. Most have a keen entrepreneurial spirit, an independent streak, and a love of the art of brewing. They come to craft brewing with different motivations, and think differently than many of their counterparts in other industries.

At Badger Hill (figure 1), we enjoy craft brewing because we manufacture fun, making a product that is not a commodity. Our customers want us to be craftspeople—innovative and different—which is exactly what we want to be as a company. Our people understand this, and we are always looking for new ways to improve.

But, craft brewers are also manufacturers. We know we need to deliver product reliably enough to be financially sustainable, which means dealing with many of the same problems as more traditional
manufacturers. The expression of the craft and the capital to innovate is made possible through good manufacturing processes. Customers expect consistency, and operations must comply with appropriate regulations. We need to learn from other companies, so we can focus on new problems rather than ones already solved.

This desire for continuous improvement has been a core tenet at Badger Hill since the beginning. Each improvement extends our vision, exposing us to new technologies and applications. When we stir in DIY and Internet of Things (IoT) applications with these technologies, interesting things start to happen.

Some may find it daunting to take risks and experiment with the new IoT and wireless automation technologies, but it is possible to start small and succeed. The sensors and transmitters gathering operational data are the starting point. These technologies are scalable, making it easy to start small and grow.

**Rolling our own data historian**

Badger Hill does not have a traditional supervisory automation system or a process data historian. Like many craft brewers, ours is largely a manual operation with basic programmable logic controllers driving motors, valves, and pumps—and only a modest amount of instrumentation. When we installed the first wireless pressure transmitter, our initial step was to figure out the best way to extract data and post it to the cloud for analysis and archiving.

This meant getting to know Modbus, an amazingly forward-thinking protocol given its age, which was not familiar to us. Two wires provide remote data access and automation for dozens of devices. It can also be extended transparently over TCP/IP. Our first tests did just that using an industrial wireless gateway that bundled all of the transmitters into a single virtual Modbus network.

As our first experiment, we installed a pressure transmitter on our cold-liquor tank (a brewing water storage tank) to measure the differential pressure (DP) level and post it to the cloud. Given the low cost of cloud storage, we started gathering data continuously.

The data is requested by a simple Modbus master hosted on a $20 Arduino-like chip called a Particle Photon. It reads the response and posts it to a cloud-based database using a RESTful interface over HTTP.

![Figure 1: Badger Hill’s people come from a variety of backgrounds, but are all committed to creating innovative products for beer lovers to enjoy.](image-url)
For data analytics, we have pretty graphs on the Internet, and we can download the data for analysis. In the future, we would like to tap into the big data capabilities of companies like Google or Amazon. New companies, such as Initial State and Meshify, also exist with this type of application in mind.

We also have Modbus capabilities in our temperature controllers, brewhouse, keg filler, canning line, and centrifuge. We are slowly bringing more data sources into our analysis. Security is and should be a concern, but the cloud is no worse, and probably better, than what can generally be achieved in-house by companies like ours.

**Inferring information from data**

The interesting part is seeing what information can be inferred from all the data. What can you learn if you are willing to spend some time looking at the data? Inference provides information on behavior, which can relate to a person or a process, and generates four main benefits for Badger Hill:

- self-documents human activities by capturing indications of process steps
- creates information useful for training by illustrating current versus ideal practices
- provides secondary and tertiary information on top of primary functions, useful for risk management
- shows where efficiency can be improved through long-term analysis

What does this all mean in actual practice? How did we recognize the potential, and how have we realized these benefits?

**More than just level**

The first use of the pressure transmitter was as a DP level instrument on the cold-liquor tank, which is the initial stage for the fresh water to be used for a new batch. In the initial data (figure 2), there was normal data scatter, but in some areas, it was much more pronounced. While this might have been written off as an instrument malfunction, we realized that these areas coincided with feeding steam into the hot-liquor tank heat exchanger.

**Figure 2**: The scattering in the continuous level plot of the cold-liquor tank showed a steam flow problem in the hot-liquor tank. This was one of the first recognitions of the information available through inference from data collected by a Rosemount 3051 wireless pressure transmitter.
The cold- and hot-liquor tanks are next to each other and have interconnecting pipes. Heating water in the hot-liquor tank involves feeding steam through a heat exchanger immersed in the water. If too much steam is being fed into the heat exchanger, steam bubbles form in the water, which shake the tank and rattle the piping. This shows up on the pressure transmitter mounted on the cold-liquor tank. So, from this scatter we were able to infer that the steam regulation to the hot-liquor tank heat exchanger was set incorrectly.

This was an interesting realization, but it became clear that much more was possible when looking at more complex operations (figure 3). The process of starting a new batch of beer in the hot-liquor tank follows a set series of steps outlined in the recipe. Usually we try to make two batches, one after the other, over 20 to 25 hours to use energy more efficiently. The hot- and cold-liquor tanks interact as water needs to be heated, and the first batch is cooled by transferring its heat to the second batch. The graph shows the levels on both tanks superimposed with the same time scale. It is easy to see the changes as liquid moves between the two tanks. By following the profile, it is possible to see each step in the process and identify changes. So how do we use this information?

These profiles document each step and put the process in a form suitable for comparing it to similar batches. This provides 90 percent of the information we were recording manually, and provides it in greater detail. When we lay profiles from multiple brewing days on top of each other (figure 4), we can see a high degree of consistency with these manual processes. This suggests we have a good recipe, and our brewers know what they are doing. It also shows us that the process does not need to be adjusted on the fly, which gives us a basis for plans to automate the process. This allows us to build our craft brewers’ know-how into our automation.
We manage risk by watching the process in real time. If any values diverge from recognized norms, we know something is going wrong with the batch.

We can use this information for training as we look at the characteristics of the most effective batches and most effective brewers. Positive deviations from normal operations can be captured and analyzed, so we can duplicate improvements.

Making this kind of thing happen is not complex or expensive. It is the result of several technological approaches working together:

- continuously logging critical process variables, with perpetual data retention using the cloud
- data collection and reporting using small, cheap, replaceable devices with powerful capabilities
- strategically placed process instruments
- the ability to recognize when useful information can be inferred from all the data

The lesson for process engineers is that you should not be afraid of looking for valid inferences. These are not guesses if they are informed by the data. Data, by itself, does not help. Information comes from understanding the data and seeing what it is telling you. Insight comes from understanding the information, and using it to improve what you are doing to gain competitive advantage.

ABOUT THE AUTHOR

Michael Koppelman, former head brewer, is currently the CTO of Badger Hill Brewing in Shakopee, Minn. He is responsible for the technical aspects of brewing the company’s craft beer, and for other aspects of the company’s operation. Koppelman holds a BS in astrophysics from the University of Minnesota Twin Cities, and a BA in music from the Berklee College of Music in Boston.
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Radiometric or gamma level/density instruments are most often used in applications where other measuring techniques fail due to extreme temperatures or pressures, toxic media, complex geometries of vessels or pipes with difficult installation requirements, high viscosities, changing fluid behaviors, or abrasive or corrosive properties of the process media.

Because a radiometric measuring system is a noninvasive measuring technique (i.e., the emitter and detector are mounted external to the process), the behavior of a medium inside a vessel can be precisely observed with equipment fitted outside the vessel (figure 1).

A very simple installation is shown in figure 1. Because there is an agitator inside the vessel, installing a level measuring device inside the tank, such as an ultrasonic or guided radar instrument, may not be suitable. Depending on the conditions inside the vessel, the medium may vaporize, or the rotating agitator might cause a vortex at the surface of the fluid. These conditions may interfere with other types of level measuring devices, which are installed inside the vessel walls. With radiometric measurement, it is possible to detect all medium conditions.

Benefits of using radiometric include:
- noncontact and noninvasive measuring
- guaranteed process safety due to being outside the process vessel
- precise and repeatable measurement for level, density, and interface applications
- safe and easy to install
- reliable measuring equipment
Radioactivity basics
Radioactivity can be roughly classified into three types, each emitted by the decay of the radioactive isotope:

- **alpha radiation**: particle radiation in the form of a helium nucleon (alpha particle)
- **beta radiation**: elemental particle radiation in the form of electrons and/or positrons (beta particle)
- **gamma radiation**: high-energy electromagnetic waves similar to radio waves and light

With radiometric level and density measurement, only gamma radiation is used. Alpha and beta radiation are not strong enough to penetrate solid material, but the high energy and high-frequency wavelength of gamma waves radiate through material in the beam’s path.

When a gamma ray passes through matter, the absorption rate is proportional to the thickness of the layer, the density of the material, the absorption cross section of the material, and the energy of the wave. Thus, absorption and energy are the main factors that influence the size of the required source and the quality of radiometric measurement.

Typical industrial isotopes used in radiometric applications are cesium-137 (Cs-137) and cobalt-60 (Co-60). The two isotopes differ in their physical attributes, with cesium having a longer half-life but lower emitted gamma radiation energy. Cobalt-60 has a shorter half-life with higher energy.

Half-life is the length of time that it takes for the source to decay until it reaches half of the activity generated by the original isotope. The half-life of Cs-137 is 30.17 years, and Co-60 is 5.2 years. Typically, Cs-137 is used in industrial applications, because it requires less maintenance (i.e., replacing the sources) and its activities or strength are sufficient for most applications. In special cases, Co-60 might be required for radiating through thick material or high-density fluids.

A formula determines the source size, taking into account anything in the beam path (vessel walls, insulation, heating coils, and obstructions) and the distance from the source to the detector. The calculation uses the following equation:

$$ P = \frac{F_a \cdot F_s \cdot F_i}{K} $$
where

\[ P = \text{the required source activity in mCi} \]

\[ K = \text{the isotope coefficient (K = 3.55 for Cs-137 and 13.2 for Co-60)} \]

\[ F_a = r^2, \text{where } r \text{ refers to the distance from the source to the detector} \]

\[ F_s = \text{absorption, depending on the density of the material and the thickness of the material in the beam path} \]

\[ F_i = \text{the sensitivity of the detector} \]

Today, such calculations are done in a software program, which takes all the guesswork out of the sizing (figure 2). Most manufacturers have a sizing program. The program can calculate the size of the source and the exposure rate at the source holder and the detector—and use these calculations to estimate the accuracy of the application. All sizing is based on “as low as reasonably achievable” (ALARA) guidelines. That is, the size of the source is limited to the smallest size required to make the required measurement.

**Gamma elements**

The typical gamma level or density system consists of four parts: the radioactive source, a source holder, a detector, and the brackets to mount the components to the process vessel or pipeline. The function of the source holder (figure 3) is simply to hold the radioactive source in a safe manner. The source holder is a lead container with a slot cut to direct the gamma wave toward the process. The emission angle through the slot will normally be about 6 degrees wide and 5, 20, or 40 degrees tall. This means radiation levels are very low at the source holder unless someone is directly in the beam path.
Although not recommended, a person would have to sit on a source holder for two and a half hours to receive the same radiation dose as flying from New York to Miami in an airplane. The beam path must be shielded or screened to prevent someone from accidentally getting a finger or hand in this beam path. Per Nuclear Regulatory Commission guidelines, the source holder must have a lockable shutter mechanism to block the radiation, or a mechanism to rotate the source away from the opening. This renders the source holder safe, allowing maintenance personnel to perform work inside the vessel and to install or remove the source holder.

Detectors (figure 4) have changed much over the past few years and have become much more sensitive and responsive. The purpose of the detector is to detect and quantify the amount of radiation received. In older gamma systems, an ion chamber was typically used in density applications. Modern detectors use a scintilllator tube sensor. The scintillator tube absorbs the gamma photon and converts it into a light pulse. These light pulses create a photoelectron at the photo cathode, where they are multiplied and converted to an electrical pulse. These pulses or counts determine how much radiation is being received by the detector.

With a scintillation detector tube made of sodium iodide (NaI) crystal or PVT plastic, the energy required to make an accurate measurement is minimal. For example, an 18-inch slurry pipeline might need a 250-mCi Cs-137 source to have enough activity for the older type of ion detector to work. With a scintillation tube detector, a 30-mCi Cs-137 source handles the same application. Reduced radiation ensures the safety of people working in the area, and the detectors are much more stable even with large temperature changes. Flexible scintillation detectors offer easy installation but may not be as sensitive as rigid scintillators.

In a density application, the higher the count rates, the lower the density. In a level application, the same applies, the higher the count rate, the lower the level in the process vessel. The detector contains a transmitter that converts the count rate to a 4–20 mA HART output signal to be sent to the control or monitoring system. Profibus PA or FOUNDATION Fieldbus outputs may also be available.

With today’s more sensitive scintillator detectors, it is often possible to extend the life of a gamma sys-
tem. Old-style detectors require so much more energy, they tend to not work reliably as the source nears its half-life. A scintillator-style detector extends the life of the source, eliminating the need to purchase a new source and the cost of disposing the old source.

As discussed, radioactive sources decay at a specific rate. In older gamma systems, frequent calibration was required to compensate for the decreased source activity. Today’s detectors have built-in source decay compensation. They automatically compensate for decay, reducing calibration requirements and maintenance costs.

Some detectors use a Geiger-Mueller tube for radiation detection. These units are not as sensitive as scintillator tube detectors, but they work well for point level detection and cost less.

**Outside interference**

Radiation from external sources can be a major problem for gamma-based systems. External radiation can come from radioactive material in the process media, other gamma-emitting devices, or radiography testing. Refineries, petrochemical plants, and heavy chemical plants may do routine radiography testing of pipelines and vessels to ensure their integrity.

Every time technicians perform an x-ray of a pipe or vessel, there is a huge surge in the background radiation. The output from a gamma-based detector in the plant will most likely be affected. The increase in the background radiation is picked up by the gamma detector, causing the transmitter to report a much lower level than is actually present. This can cause major upsets in the process and may pose a safety risk.

In the past, plants would try to shield the gamma detectors or put the control loop in manual during radiography testing to avoid process upsets. Today, a gamma modulator can eliminate any issue from external radiation.

A gamma modulator is mounted between the source holder and the process. It consists of two absorber rods rotating at a fixed speed directly in the gamma beam path. When the absorber rods are in
line with the gamma beam, they attenuate the gamma energy so no energy reaches the detector, and the gamma detector reads the background radiation. As the absorber rods rotate parallel to the gamma beam path, the gamma rays pass between the absorber rods and continue to the process vessel and the detector.

The detector is configured to look for this modulated gamma energy. Internally, it subtracts the background radiation reading when the modulator is in the open position (figure 5). The resultant value is thus not affected by background radiation.

Modern gamma systems for level or density measurement are reliable, accurate, and safe—and often work in level and density applications where other solutions will not. End users do need to make sure their supplier is knowledgeable about gamma licensing requirements and can provide full gamma support for your facility.

![Modulated signal](image)

![Output signal:](image)

**Figure 5: Endress+Hauser FMG60 gamma detector**

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Download Flow Energy Guide
Electromagnetic flowmeters, or as they are known by their more common name, magmeters, have become one of the most common flow metering technologies over the past 50 or more years. They are simple to operate, have no moving parts, cause no flow obstruction, and can provide a high level of accuracy and turndown ratio. The only hard-and-fast rule of application is the process liquid must be electrically conductive.

**Simple working concept**

High school physics tell us that a conductor passing through a magnetic field will generate a voltage that is proportional to the speed with which the conductor is moving. You might recognize it as Faraday’s law of magnetic induction.

In the case of a magmeter, the liquid itself is the conductor, and the magnetic field is created by coils placed around the pipe. Two electrodes placed on opposite sides of the pipe perpendicular to the liquid flow and the magnetic poles measure the induced voltage. The voltage generated is proportional to the velocity, which is then converted to a flow rate. The liquid flow, magnetic field, and line between the electrodes form the x, y, and z axes.
Figure 1 goes into more detail about the actual construction. Magmeter users appreciate how the interior surface of the device can match the upstream and downstream pipe diameter, and how there are no obstructions into the flow stream. The flowmeter itself must have an insulating lining, which can be made from rubber, Teflon, ceramic, or other materials capable of standing up to erosive or corrosive media.

Magmeters are highly scalable, running from 0.1 inch to 104 inches or more in diameter. They work well for clean fluids, such as water, acids, and caustics—or in heavy particulate applications, such as paper stock, pulp, and lime slurries. As mentioned earlier, the main requirement is the process media must have some level of conductivity, with a typical minimum range of 1 micro-Siemen (µS) to 5 µS. As long as the process meets this requirement, the meter should perform satisfactorily in the application. Most oil-based liquids are not conductive, which knocks magmeters out of many refinery applications.

The exciting part
Since their introduction in the 1950s, magmeters have evolved enormously from a technology standpoint. A typical meter from the first decade would have used AC to excite the coil, so it used the available electrical line frequency of 50 Hz or 60 Hz. Users soon found the high sampling rate this frequency offered to be particularly well suited for noisy slurry applications, and it offered fast response to changes in flow rate. However, users also noticed these AC-powered magmeters did not have a stable zero point when there was no flow. If nothing was moving in the line, the devices tended to wander. They also used a large amount of energy, with many units drawing as much as 300 W.

As magmeter technology advanced, the next generation excited the coils with pulsed square-wave DC operating around 6.25 Hz to 11 Hz. This worked well enough in most situations and delivered the
sought-after zero stability, but lower excitation frequencies could not handle noise caused by a high solids content. The low sampling rates also made them sluggish when responding to rapidly changing flow rates.

As new power supply circuits developed, instrumentation designers had more options available to try different excitation frequencies. This led to adjustable sensors where a user could choose the best frequency for the application. If the process is noisy with slurries or flow rates change rapidly, the user chooses a high frequency. For an intermittent process, such as a batch application with periods when flow stops, the user chooses the low frequency.

This approach works, but as transmitters got smarter, it was possible to incorporate circuitry capable of using both frequencies simultaneously. Dual-frequency excitation allows the transmitter to superimpose two frequencies on top of each other at the same time (figure 2). A low-frequency component of 6.25 Hz and a high-frequency component of 75 Hz work together for higher performance than either one functioning alone (figure 3).

<table>
<thead>
<tr>
<th>Excitation Method</th>
<th>AC Power</th>
<th>Pulsed DC</th>
<th>Dual Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave Form</td>
<td>![Waveform]</td>
<td>![Pulsed Waveform]</td>
<td>![Dual Frequency Waveform]</td>
</tr>
<tr>
<td>Excitation Frequency</td>
<td>50Hz</td>
<td>6.25 to 10Hz</td>
<td>6.25 Hz &amp; 75Hz</td>
</tr>
</tbody>
</table>

Figure 2: Creating a waveform with characteristics of both AC and DC allows a magmeter to use the advantages of both.

<table>
<thead>
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<tr>
<td>Excitation Frequency</td>
<td>50Hz</td>
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<td>6.25 Hz &amp; 75Hz</td>
</tr>
<tr>
<td>Response Time</td>
<td>Fast</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Zero Point Stability</td>
<td>Stable</td>
<td>Stable</td>
<td>Stable</td>
</tr>
<tr>
<td>Immunity Against Process generated Noise</td>
<td>Strong</td>
<td>Weak</td>
<td>Strong</td>
</tr>
</tbody>
</table>

Figure 3: Dual-frequency sensors deliver performance advantages without requiring a user to choose one or the other or to switch at various points.

Reducing power consumption

Early magmeters needed a powerful magnetic field to create a signal strong enough to be measured accurately and linearized enough to provide a reliable and accurate flow reading. This is why early units drew so much power. With improvements in transmitter designs, it became possible to scale everything down, even while improving performance.
Units that once drew 300 W can now operate with 10 W to 15 W. Naturally, the physical size of a sensor has a major influence on power consumption; a 36-inch sensor requires more power to maintain a magnetic field than a 4-inch sensor. Some designs go even further with power reduction, to the point where two-wire, loop-powered designs are available in sensor sizes up to 8 inches. Bear in mind, when only 0.3 W is available (0.1 percent of what earlier units often needed), there is some compromise in performance.

Nonetheless, being able to replace other loop-powered flowmeters with a magmeter offers compelling advantages. Differential pressure and mechanical flowmeters are still very common, but obstructions in the flow path can cause clogging and pressure loss. Having the free flow of a magmeter without needing to update wiring is very attractive.

These low-power units have some limitations. Check with your supplier, but they typically require relatively high conductivity (10 µS to 20 µS) for the process liquid and a slight reduction in accuracy. Four-wire magmeters are usually capable of accuracies of ±0.2 percent to ±0.5 percent of flow rate. Loop-powered magmeters usually start at ±0.5 percent of flow. Moreover, four-wire units have a higher effective turndown ratio, handling liquid velocities ranging from 0.33 feet per second (fps) to 33 fps.

**Simple installation requirements**

Magmeters have few installation constraints, but observing them goes a long way toward ensuring the best possible performance. First and foremost is keeping the pipe full of liquid. If long horizontal runs accumulate slugs of air, this will cause inaccurate readings. Keep the sensor at a low point in the piping, or better yet, install it in a vertical section with flow going up.

Second, like most flowmeter designs, having straight pipe upstream and downstream from the sensor reduces turbulence and provides more accurate readings. The flow profile through a pipe is never entirely uniform, but reducing turbulence keeps it more predictable. Having at least five diameters of straight pipe upstream and at least two diameters downstream will be a major help. Having longer straight runs is even better.

No single flowmeter technology is truly universal. Every flow instrument has its limitations, so every application has to be evaluated carefully to ensure the appropriate process requirements are met. Magmeters are particularly well suited to situations with difficult liquids or where solids tend to cause clogging, so make sure they are in your application toolbox.

**ABOUT THE AUTHOR**

Scott Stewart, has been a senior product consultant with Yokogawa Corporation for 11 years, part of a 25-year career in industrial automation. Prior experience includes 10 years with Magnel International as a level and flow specialist in the southeast U.S. He graduated from Texas State University with a degree in marketing. Stewart is currently training for the Ride the Rockies Bicycle Tour in Colorado and likes to tinker with classic automobiles.
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