Innovative AC-excited magmeter benefits pulp and paper operations

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Design innovations in AC-excited magmeters offer the fast response and noise-free outputs with the zero-drift performance of pulsed DC magmeters.

The pulp and paper, metals, and mining industries hold some of the most aggressive and challenging applications for electromagnetic flowmeter (magmeter) measurement. Changing operating conditions, higher consistency and solid contents, and tighter process control are pushing the boundaries of magmeter performance.

Conventional electromagnetic flowmeters using DC excitation have been used to measure flow in these noisy and difficult applications, but they are typically saddled with long damping times to smooth their output. This results in slow response times and ultimately waste and quality issues.

Recent improvements in AC electromagnetic flowmeters can now provide these users with better performance, quicker response, and noise-free outputs not possible with DC technology. These improvements can lead to increased efficiency, improved quality, and conservation of raw materials and energy, reducing direct costs and increasing profits. The new AC magmeters can perform well in the simplest to the most extreme applications, making them a universal solution to conductive liquid flow measurement.

Reviewing electromagnetic flowmeter principles

The principle of operation for magnetic flowmeters is based on Michael Faraday’s law of electromagnetic induction. Magnetic coils are excited by an AC or DC current creating a magnetic field within a meter body through which a conductive liquid passes. This voltage is extracted through a pair of electrodes which are installed on opposite sides of the pipe. The voltage developed is proportional to the density of the magnetic field, the length of the conductor, and the velocity of the conductor moving through the field. There is nothing in the function of magnetic flowmeters that depends on pressure, temperature, density or viscosity because the magmeter develops its signal independent of these parameters.

The volumetric flow rate through the magmeter is an easily derived function of this velocity signal and the known cross-sectional area of the meter body. The raw voltage signal (on the order of micro-volts) then goes to a transmitter for processing and conversion to a signal suitable for process control or for simple totalization.

Internal noise signals accompany the raw flow velocity signal. Appropriate measures such as shielding, insulation, and capacitance neutralization can eliminate internal noise. Signals from sources external to the flowmeter (such as electrically charged fluids, large particles, and electrochemical potentials at the electrode interface) also introduce unwanted electronic noise into the system. In addition, electromagnetic fields at line frequency present in virtually all installations contribute to the external noise.
Electronic noise does not affect AC and DC excited systems in the same way. Noise effects must be considered in the context of both zero shift and flow signals respectively.

AC verses DC excitation systems

Early electromagnetic flowmeters were all excited by AC. The magmeter coils were energized by line voltage (120 VAC +/- 10%) at 60 Hz line frequency. Figure 2 shows the resulting sinusoidal (sine) waveform developed by the signal electrodes of an AC magmeter. The amplitude of the waveform varies directly as the flow rate through the magmeter.

The AC magmeter proved to be a significant advancement when compared to flow measurement by differential pressure techniques. It offered no obstruction to the flow and could measure flow rates over a much wider ranges. Additionally, in cases of rapidly changing flow conditions, and, most significantly, when the pipe became empty, the AC magmeter provided fast full-scale response time. It recovered quickly from a non-full state.

In conventional AC-excited magnetic flowmeters, the continuous alternating current in the presence of a stationary conductor (the fluid at zero flow rate) creates a varying non-flow induced voltage, which is electronic noise. Typically, noise created by fixed conductive electrode wires can be “zeroed out” by operators during start-up (or even eliminated by circuitry if the voltages are out of phase with each other). However, non-moving conductive coatings that accumulate on the electrodes during normal process conditions (after zeroing the system) often cause an apparent shift in zero in conventional AC systems.

The introduction of pulsed DC electromagnetic flowmeters went a long way towards solving the problem of maintaining a stable zero flow signal. Pulsed DC magmeters were originally energized by low voltage (~10 VDC) at 3¾ Hz. Instead of continuous power to the coils, the coils are both energized and deenergized during a voltage cycle. Figure 3 shows the square -like pulse waveform developed by the signal electrodes of a pulsed DC magmeter. During the “off” part of the cycle, any measured voltage constitutes electric noise.

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Dealing with process signal noise

Despite this advantage, pulsed DC magnetic flowmeters have often proved unsuccessful in certain applications because of process noise, which comes in two forms: 1/f noise and electrode impingement.

The 1/f noise decreases with excitation frequency. More
noise occurs at low frequencies, especially at 10 Hz and less. The major problem with this process noise is that the low levels of the magnetic coil excitation result in a greater chance for disruption of the flow measurement. Figure 4 shows this 1/f noise function in graphical terms.

The magnitude of 1/f noise typically depends on the severity of conditions in a field installation. For example, in low consistency (0 to 3%) pulp stock flows, the 1/f noise increases as stock consistency increases. Also, chemical additions upstream and near a magmeter often produce 1/f noise as a function of rapidly changing fluid conductivities, which disturb the electrode interface.

The second type of process noise is a phenomenon known as electrode impingement. This is a mechanical disturbance of the electrode/electrolytic interface of the process fluid with the electrode surfaces. These disturbances cause the electrode signal to temporarily spike several times its normal magnitude. This noise is typical of heavy liquors that contain a variety of solids particles. In addition, most slurries represent a potential to display electrode impingement characteristics to various degrees.

Reducing noise content

The original pulsed DC magmeters operated at 3¾ Hz (waveform cycles of 3¾ times per second). This low frequency coil excitation produced excellent zero stability, but was susceptible to 1/f noise. In recent times, pulsed DC magmeter vendors have attempted to reduce the effect of 1/f noise by increasing the signal filter's low frequency cutoff value as well as by increasing the coil excitation frequency.

But two problems arise. First, the signal filter can also eliminate part of the live process signal being measured, adversely affecting magmeter accuracy. Second, as coil excitation frequency increases, the square waveform begins to deform, taking on some of the characteristics of the AC magmeter. The waveform begins to “droop,” becoming distorted.

Because the pulsed DC magmeter measures process noise when the coils are de-energized, a droopy waveform makes it increasingly difficult for the signal converter to accurately separate process noise from process signal. For example, a 30 Hz coil drive will experience 1% droop in the square waveform when the low frequency cut-off is 0.3 Hz, and a 10% droop if the cut-off is raised to 3 Hz. Ultimately, this can lead to pulsed DC magmeter inaccuracies and non-repeatabilities. Pulsed DC noise suppression algorithms have had limited success in reducing the problems associated with mechanical disturbances.

Process noise, because its magnitude is a relatively large portion of the pulsed DC magmeter’s flow signal, also tends to distort the flow measurement. The historic fix is to increase the damping constant until the signal converter’s analog output ceases to be erratic. Because of the resulting long response times, this fix greatly reduces the ability to control production processes by means of magmeter flow measurement. Typically, pulsed DC magmeters in these cases serve only for monitoring purposes.

The AC magmeter, on the other hand, has a high signal-to-noise ratio in noisy flow applications. The AC magmeter delivers more power to the magmeter coils, so the measured electrode signal is a higher voltage compared to a DC meter. Most specifications for power consumption call for pulsed DC magmeters 24 inches and smaller to consume no more that 23 VA, while AC magmeters of the same size consume no more than 50VA. The higher power requirements of the AC magmeter help to establish a measuring system that is much less susceptible to the ill effects of process noise.

Figure 4. Process noise diminishes with frequency, except for a spike at 60-Hz line voltage frequency.
As a result of noise issues, AC magmeters are often selected over pulsed DC magmeters on difficult, highly noisy applications. They more rapidly respond to changing flow conditions and recover more quickly from empty pipe conditions.

**Closing the gap**

Although the pulsed-DC method of magnetic field excitation predominates today, it has not replaced AC technology entirely. AC magmeters are more resistant to process generated noise created by varying fluid conductivities and slurries, making them more suitable for many demanding applications. Various innovations have reduced the functionality gap between DC and AC magnetic flowmeter, namely:

- the introduction of hard electrode tips,
- higher operating frequencies,
- microprocessor techniques in noise reduction.

But in the final analyses, conventional AC magnetic flowmeters still outperform DC designs with respect to process noise; whereas DC magnetic flowmeters are inherently better with respect to zero stability.

The FSM4000 AC magmeter from ABB contains more innovations to close the gap with pulsed DC. For example, the FSM4000 operates at an optimal 70 Hz, a frequency in the low part of the noise spectrum. Operating at this frequency eliminates virtually all need for output signal dampening used in noisy applications.

In addition, the FSM4000 eliminates zero-shift through use of a field search coil, which allows the processor to subtract electronic noise signal from the aggregate of the noise and flow signal. To accomplish this, the signal and reference values are stored after filtering, and are available in their respective results buffer at a sample rate of 4kHz. The 71.43Hz magnetic field excitation frequency is a multiple of the sampling frequency. As a result, the number of measured values per period has an integer value, producing exactly 56 samples per excitation period.

In this way, exactly one period of the measured signal can be stored in the respective results buffers. To determine the measured flowrate, the ratio of the signal to reference must be known. For this purpose, the areas of the signal and reference are integrated and inserted in the ratio computation. The start signal for the calculation of the flowrate is the zero crossing of the reference - easily determined by waiting for the change in the sign of the measured values sent.

The system determines the phase shift between the signal and the reference by examining the zero crossing of the signal and reference using samples and partial samples. The phase shift constitutes the zero adjustment for the flowrate measurements, enhancing zero stability.

The result is a magmeter with faster dynamic response, yielding tighter accuracies and higher signal-to-noise ratios.

**Digital Signal Processing**

Advances in digital signal processing (DSP) have made it easier for users to develop data acquisition systems (signal converters) and analysis systems. The term DSP is misleading because it is usually associated with Fast Fourier Transforms, digital filters, and spectrum analysis. DSP, however, involves processing of an analog signal in the digital domain. Real-world signals, such as voltages, pressures, and temperatures are converted to their digital equivalents for processing by the digital microprocessor.

Digital Signal Processing relies more heavily on the soft
ware processing of signals in the digital mode rather than using analog hardware and filtering to do the job. Processing a digital signal offers more alternatives, and software is much more flexible than hardware. These benefits lead to more effective methods of separating the real signal from the process noise. Tangible advantages include: improved measurements in applications involving vibration, hydraulic noise, and temperature fluctuation.

As with any electromagnetic flowmeter, unwanted frequency signals can be generated caused by hydraulic noise and line noise. DSP provides faster A/D conversions for the sensor signal, providing a greater number of sample points compared to prior technologies. Digital filters, with sharp drop-offs, eliminate signal frequencies created by hydraulic noise and line noise that are outside the targeted measurement range. Advanced filtering techniques, such as automatic filter adaptation and frequency weighting, further allow the processor to accurately extract the flow signal from a potentially noisy sensor signal. By employing the power of the DSP Converter, improvements are made to zero stability, low flow performance, and measurement accuracy over a wide range of conditions.

Independent tests confirm performance

The Herty Foundation (Savannah, GA) performed independent tests of the ABB FSM4000 flowmeter. The foundation ran several tests against competing electromagnetic flowmeters in the pulp and paper industry.

To duplicate actual mill conditions near the short circulation piping of the headbox, the measured flow had a 3.6% consistency with and without injection of about 5% entrained air. The charts indicate flow variation for various signal dampening values. Lower dampening values improve response time. Smaller flow variations indicate steady readings with good noise rejection.

The performance of the FSM4000 flowmeter (AC 70 Hz) for the entrained air case was outstanding. Herty’s decision to induce entrained air at the rate of 5% adds a real-world element to the tests. Many stock streams, despite the best efforts of process system designers and pulp and paper mill operators, often contain this disruptive condition. Causes for entrained air include atmospheric washers and screens along with pump cavitation and other conditions.

![Figure 6. Under typical pulp and paper conditions, the ABB FSM4000 magmeter greatly outperformed competing DC- and AC-excited flowmeters.](image)

Entrained air is essentially noise to the flowmeter and constitutes a major contributor to inaccurate control. Having an excitation frequency near 70 Hz, the FSM4000 operates away from the normal background noise of 60 Hz line frequency as well as outside the area where noise is prevalent in typical DC and high signal DC electromagnetic flowmeters. This design innovation minimizes the presence of environmental noise during signal conversion.

Additionally, with asynchronous synthesized coil excitation, the signal processor rejects all signals that do not fit within the expected signal envelope. This mode of operation greatly improves rejection of noise caused by trapped air and particles.
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