Eliminate Signal Gibberish

Several steps can help maintain the integrity of measurement and control signals

By Greg Livelli,
ABB Measurement Products

DESPITE ONGOING advancements in technology, instrumenting a process still can pose technical challenges. While such projects may seem straightforward, much can go wrong. A successful installation requires:

- matching each variable to be measured with the most appropriate sensor;
- installing, calibrating and interfacing the sensor properly to the controller or recorder/indicator; and
- in some cases, conditioning, converting, compensating or mathematically manipulating the data generated by the sensor to provide meaningful information.

With this in mind, here are common-sense ideas to consider when instrumenting a process to ensure appropriate signal integrity.

SELECTING THE RIGHT SENSOR

Although it's generally obvious what quantity to measure in flow, temperature, pressure and level sensor applications, it's not always obvious which sensor technology best suits the job. A mismatch between the sensing technology and the desired measurement can lead to inaccuracies and degraded control.

Flowmeters. The great variety of flowmeter technologies available complicates the selection task. Some may work equally well in an application while others may pose problems. The technologies fall into five classifications: velocity, inferential, variable area, positive displacement and mass (Table 1).

Many kinds of flowmeters — including electromagnetic (conductive liquids only), vortex and swirl, turbine, and ultrasonic — sense a fluid's average velocity. Multiplying that velocity by the cross-sectional area of the meter or pipe gives volumetric flow rates.

When specifying velocity meters, consider the fluid's velocity profile in the pipe, which depends on

Measurement Technique		
Velocity	**Inferential (DP)**	**Other**
Electromagnetic	Orifice	Rotameter
Vortex	Venturi	Target
Swirl	Nozzle	Positive displacement
Turbine	Wedge	Coriolis (mass)
Ultrasonic	Flow tube	Thermal (mass)
Insertion	Pitot	Open channel

Table 1. Devices based on velocity, differential pressure (DP) and other technologies can measure flow.

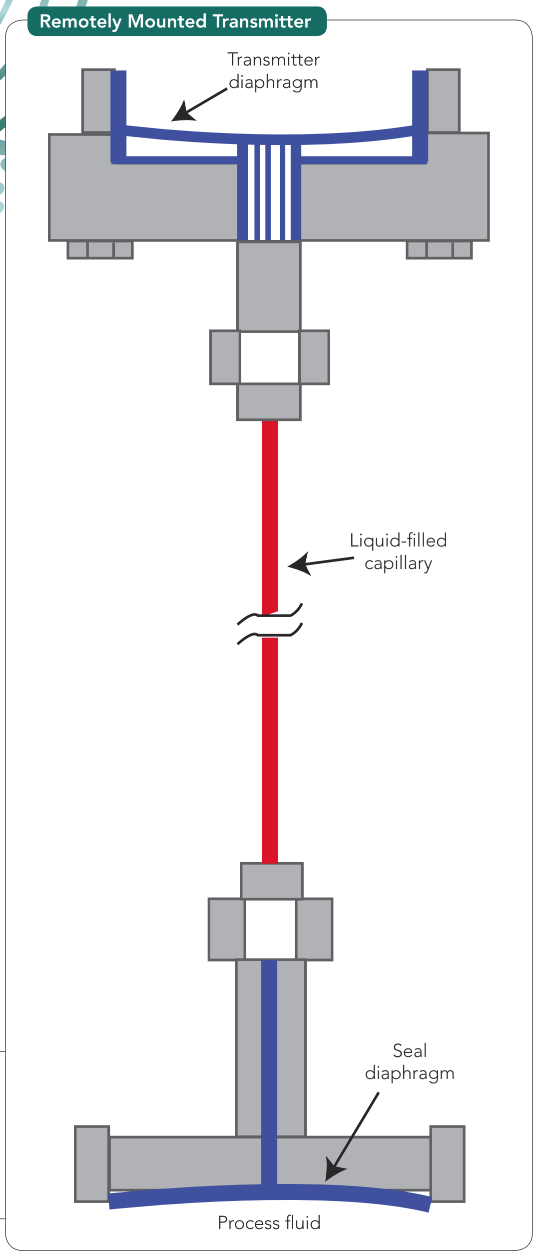

Figure 1. Impulse line transfers pressure while seal diaphragm isolates pressure transmitter diaphragm from process.

piping geometry and Reynolds number. If the flow is turbulent (Reynolds number greater than 10,000), the velocity is virtually the same at the pipe's center and inside walls. Otherwise flow velocities across the pipe cross-section differ, making the average more difficult to calculate.

Inferential flowmeters — including differential pressure (DP) flowmeters (the most widely used) such as orifice plates, wedges, venturis, nozzles, flow tubes and pitot tubes — use another measurement (e.g., pressure) that has widely accepted correlations to calculate flow rate. For DP meters, the flow calculation depends on the square root of the measured DP, the fluid density, pipe cross-sectional area, the area through the restriction, and a coefficient that's specific to the device.

A variable area meter or rotameter is simple and inexpensive. It consists of a float within a tapered tube. The float's position is a balance between the upward flow rate and gravity forces acting on it. But its accuracy (±2% of full scale) is relatively low and depends on precise knowledge of the fluid and process. It's also susceptible to vibration and plugging by solids.

Positive displacement meters capture a specific volume of fluid and pass it to the outlet, providing true volumetric flow rates without calculations. They require no power, handle high pressures and provide excellent accuracies. However, they're often expensive and can't deal with multiphase fluids.

Flowmeters based on the Coriolis effect emerged in the 1970s. Steady improvements in technology and pricing since then have greatly increased their acceptance. No other flow instrument is more versatile and capable. Besides measuring mass flow rate, they can provide simultaneous outputs for volumetric flow rate, total flow, density, temperature and percent concentration. They're unaffected by flow profiles or viscosity.

Temperature sensors. For process plants, this generally involves selecting between a thermocouple and a resistance temperature detector (RTD); both yield voltages that infer temperature. A thermocouple consists of two dissimilar metal wires joined together at one end. The voltage between the unjoined ends varies with the temperature of the joint. An RTD usually comprises a wire-wound rod or thin-film metals through which a current is passed. The resistance the current encounters varies with the temperature of the metal, usually platinum.

Thermocouples as a class have a wider operating range. They can measure temperatures up to 1,800°C (3,272°F). Most wire-wound RTDs measure temperatures below 500°C (932°F) while thin-film models usually are restricted to below 200°C.

Thermocouples generally are cheaper though less accurate than RTDs. If an application doesn't require particularly tight temperature control, an inexpensive thermocouple and a well-tuned control loop should do the trick. But for processes that only will work correctly at highly specific temperatures, pay for the greater accuracy an RTD affords. The cost of scrapping a batch of ruined products would eventually dwarf any savings in equipment.

A fast sensor also can be worth the extra cost. If

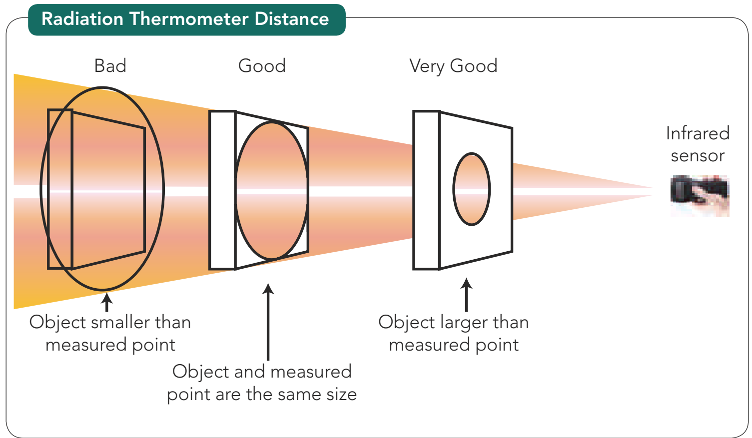

Figure 2. Accurate measurement of an object's temperature requires excluding radiation from the surroundings.

a process requires a rapid succession of heating and cooling cycles, the temperature sensor must be able to generate a reading before it's too late to be of any use. Thermocouples tend to respond faster than RTDs.

In situations where thermocouples and RTDs are impractical or conditions too harsh, sensors that detect infrared radiation from a surface may work. You aim these radiation thermometers at a surface from a distance. Major factors affecting accuracy include the surface emissivity as well as water vapor, dust, smoke and suspended matter in the space between the sensor and the measured surface.

Pressure and level transmitters. Process plants essentially have standardized on DP transmitters with internal diaphragms. These sensor/transmitters can measure absolute, differential and gage pressures, and infer liquid tank levels and flow rates.

For direct pressure installations, selection largely involves choosing the right connection as well as the diaphragm material, seal and coating for protection from the process medium. Special diaphragm materials include variations of tantalum, super duplex stainless steel and high nickel alloys. Coatings that resist abrasion, hydrogen penetration, sticking and corrosion also are available.

For remotely mounted transmitters, impulse lines can transfer pressure from the process to the transmitter input ports. Some vendors offer transmitter algorithms to detect when impulse lines get plugged. Additionally, impulse lines consisting of sealed capillaries combined

Condensation Drainage

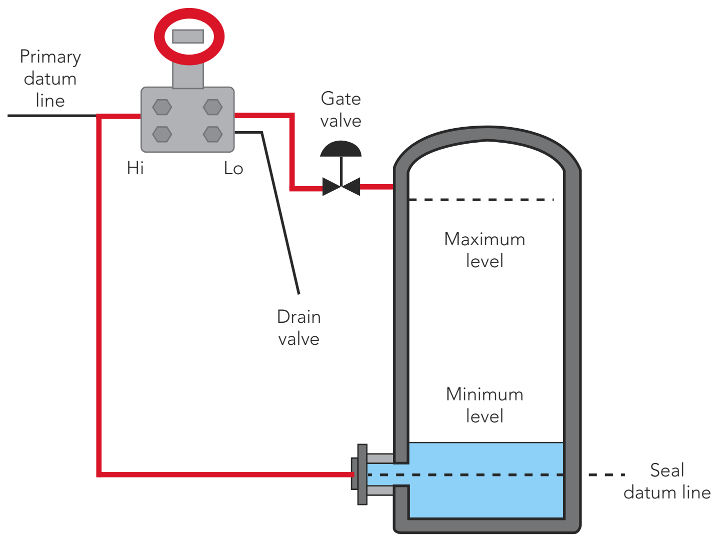

Figure 3 .Placing pressure transmitter above the closed tank lets condensation drain back into tank.

Separating Out Noise

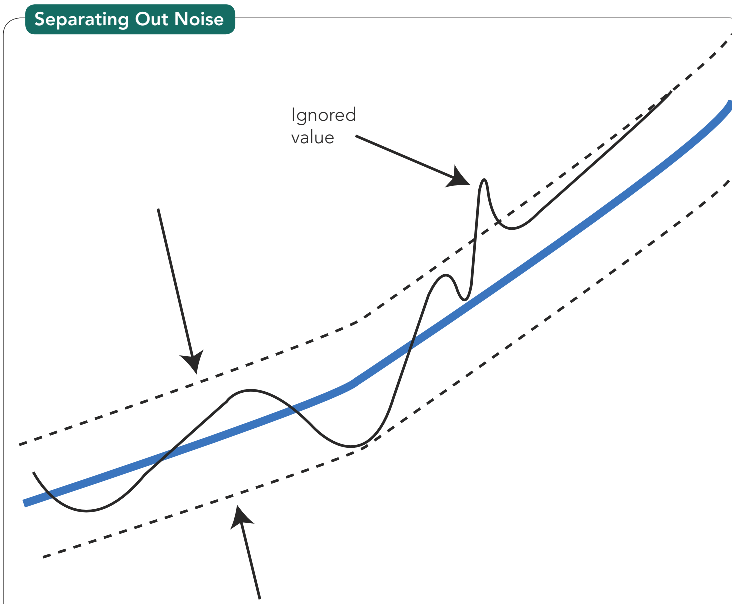

Figure 4. Digital signal processor computes moving average of signal and ignores values outside of the defined window.

with remote process seals can isolate the process medium (Figure 1).

The trick is to find the right technology for the application or to choose instruments that span a broader range of solutions.

AVOIDING INSTALLATION MISTAKES

The best sensor can yield disappointing results if improperly installed.

For example, many flowmeters require a specific length of straight pipe before and after them to provide "fully developed" flows. Nearby bends, junctions, pumps and valves in the pipeline can adversely affect their accuracy. You must pipe an electromagnetic flowmeter so it remains full at zero flow — otherwise its output can become erratic because of electrode exposure to air. You must install a rotameter vertically plumb so the float experiences the full effect of gravity.

Placement also can affect temperature sensors. Even a highly accurate RTD only detects the temperature of its immediate vicinity. So, if it's tucked into the corner of a mixing chamber and mixing is incomplete, that local reading may not represent the temperature of material elsewhere.

With radiation thermometers, you must place the sensor at a distance where only radiation from the surface to be measured enters the lens (Figure 2). Otherwise the sensor also sees radiation from the surroundings.

Applications often employ a DP transmitter and an impulse line consisting of an isolating seal and liquid-filled capillary to measure the level of harsh liquid chemicals in tanks. If the tank is open or vented, the low-pressure transmitter port is left open, and a single impulse line from near the tank bottom connects to the high-pressure port. You can place the transmitter at any level and correct the head effect of the liquid in the capillary by the zero adjustment.

However, if the tank is closed, a second impulse line must connect to the top of the tank to cancel out vessel pressure. If that line also is a filled capillary with a remote isolating seal, the transmitter's best location is near the tank's mid-section. This location provides uniform distribution of temperature across the lengths of the two capillaries.

With a plain impulse line (no isolating seal) from the tank top, ensure condensate doesn't enter the transmitter body, which would cause measurement error. One way is to place the transmitter above the tank so any condensate flows back into it (Figure 3). For a transmitter at a lower location, fill the impulse line from the tank top with a suitable liquid of higher specific gravity to maintain a constant pressure on the low-pressure transmitter port.

Sensor location can adversely affect controller performance. Recall that a PID (proportional-integral-derivative) controller looks at the difference between the sensor signal and its setpoint. After a process event, the controller first changes the output proportionally to minimize the difference. If the difference persists, the integral (reset) component comes into play, gradually attempting to equalize the sensor signal and the setpoint.

Poor control can result if a sensor is installed too far from the associated actuator or thermal element. A distant sensor may not be able to measure the effects of the control element's last action in time for the controller to make an intelligent decision about what to do next. A case in point is a pH sensor located far from where alkali or acidic dosing to maintain the desired pH takes place.

Sensors often require protection from the environment or the process. Proper material selection and liners help flowmeters withstand corrosive and abrasive fluids. Thermowells protect temperature sensors from the process. Liquid-filled impulse lines with remote isolating seals safeguard pressure sensor diaphragms.

Housings can protect outdoor instruments, which can take quite a beating from rain, snow, hail and falling ice. Such instruments can fail slowly over time unless enclosed in appropriate housings. You should configure the housing so it doesn't affect the sensor reading. For example, a housing for a temperature sensor shouldn't act as a heat sink, lowering the sensor's reading. Conversely, if a housing has fins to draw heat from an enclosed sensor during warm weather, you should mount the fins vertically. Otherwise, warm air won't be able to rise away from the housing.

DEALING WITH SIGNAL NOISE

Proper grounding of electrical signals is important. Signals often are referenced to a ground potential. Undesirable electrical ground loops occur when an extraneous current flows through the instrumentation wiring between two points that are supposed to be at the same voltage but aren't. The resulting

WHAT ABOUT WIRELESS NETWORK INTERFERENCE?

Chemical plants are showing increasing interest in wireless measurement and control. After all, wireless devices dramatically reduce costs in wiring engineering, installation and maintenance while offering increased data gathering flexibility. Once plants install a wireless system, they can easily modify it, adding or deleting measuring points.

However, processing sites often have dense infrastructures, vehicle movement, large electrical equipment, and numerous sources of electromagnetic interference and radio frequency interference (RFI), including from other radio communication systems. Modern wireless networks for measurement and control must incorporate multiple capabilities to overcome possible communication interference.

The U.S. Federal Communications Commission permits use of the industrial, scientific and medical bands (902–928 MHz, 2.4–2.4835 GHz, 5.725–5.85 GHz) at power levels up to 1 W without end-user licenses. Spread spectrum radio transmissions operating at these frequencies have distinct advantages regarding immunity to noise and interference.

Two common methods used in these bands are frequency hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS).

FHSS radio systems quickly hop through multiple frequency channels. The transmitters and receivers are synchronized. FHSS specifies a particular time slot and frequency for each transmission. This scheme anticipates competition with other radio systems and RFI from other sources. For example, if one frequency is affected or blacklisted in an FHSS system, the data switch to a clear channel.

DSSS radio systems spread a narrow frequency source by integrating it with a pseudo-random noise signal. The digital bits of the noise signal occur at a higher frequency than the original signal, spreading it into a wider band. The synchronized receiver processes the signal with the same pseudo-random sequence, reconstructing the original data. The technique adds redundancy to the original signal, permitting the receiver to recover data damaged during the transmission.

Additional techniques such as data checksums and redundant mesh routing further improve immunity to interference. The cyclic redundancy check (CRC), commonly used with data sent over wire, offers a unique digital signature to data. CRC ensures the data received are identical to the data sent. If the data don't match, the receiver automatically requests a repeat transmission. With redundant mesh routing, the network automatically reroutes transmission to unobstructed pathways whenever interference or other obstacles hinder communications.

Plants also can use antenna design to improve signal integrity. High-gain directional antennas can provide radio communications at long distances through a crowded chemical plant. Conversely, a low-gain antenna can keep radio signals from straying unwanted distances. Radio communications needn't be line of sight but objects in the path may attenuate the signal, so receiver sensitivity can become an important factor.

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electrical interference can cause random fluctuations in sensor output and even may damage the sensor. You must ground all instruments together at one master grounding point or to a grounding grid spread throughout the plant. Isolation techniques such as transformers and fiber optic communications can minimize grounding problems.

Electromagnetic and radio frequencies are common in plants that use walkie-talkies, pagers and wireless networks. Interference from these sources can adversely affect sensor signals. Interference also results whenever a current changes dramatically, such as when relay contacts engage or static voltage discharges, generating a spark.

Replacing electromechanical equipment with solid-state devices will eliminate arc-generated interference. Alternatively, simply relocating switch boxes and relays to instrument-free areas of the plant may suffice. Passive shielding of a source also is a solution.

PID controllers tuned to provide appreciable derivative action are particularly susceptible to the effects of measurement noise. They tend to react aggressively to every blip in the measurement signal to quickly suppress deviations from the setpoint. If a blip turns out to be nothing but noise, the controller will take unwarranted corrective actions and make matters worse.

Many modern digital instruments come with built-in digital signal processors and filters. These instruments replace complex analog components like oscillators, mixers and filters with mathematical operations executed inside a digital signal processor (DSP). Such a DSP (similar to a processor inside a personal computer but designed for specific "number crunching" applications) can perform complex operations at blazing speed. Recent advancements in DSP techniques can help greatly in separating extraneous noise from measurement signals.

Compared to analog hardware, a DSP offers more alternatives and much greater flexibility. These benefits lead to more effective methods of separating a real signal from process noise. Tangible advantages include: improved measurements in applications involving vibration, hydraulic noise and temperature fluctuation.

A DSP provides faster analog/digital conversion of a sensor signal, so it can handle a greater number of sample points in a given time than prior technologies. Digital filters with sharp drop-offs eliminate signal frequencies created by hydraulic and line noise that are outside the targeted measurement range. Advanced filtering techniques such as automatic filter adaptation and frequency weighting give a processor further capabilities to accurately extract the signal from a potentially noisy process signal.

Powerful digital signal processing techniques for separating signal from noise include:

- *Moving average*. The user defines a band of measurement values. The DSP maintains a moving average of the incoming data values over a selectable window size. Values that fall outside the band are ignored and replaced by the average value (Figure 4). The instrument registers the number of error measurements. If the error total exceeds 50% of the window size, the measurement value is held. If the hold time setting is surpassed, the procedure resets, a new average value is calculated, and the window shifts accordingly.
- *Signal reset*. The user defines upper and lower signal thresholds. If five signal measurements exceed a threshold, the signal holds its value for a defined time (1.5 sec. or 0.5 sec.). This technique eliminates voltage spikes for which continuous feedback to the controller can't compensate.
- *Prefilter*. When considerable noise affects an input signal, the user can turn on a narrow frequency "notch" filter ahead of the main filter and select the width of the notch (in 0.15-Hz to 68-Hz increments). The narrower bandwidths provide higher noise reduction but require greater processing time, and vice versa. Signal processing in the prefilter takes half the time required in the main filter. So, prefiltering suits processes requiring fast response times such as many batches.

It generally is more cost-effective in the long run to install sensors correctly and minimize the sources of interference than to rely strictly on mathematics to separate data from noise. When constructing a control loop, apply data filters in the final stages of the project just before the loop tuning. ●

GREG LIVELLI is marketing manager for ABB Measurement Products, Warminster, Pa. E-mail him at greg.livelli@us.abb.com.