INSTRUMENTATION

How to Obtain Useful Information from Instrumentation

ISSUE

Select the right technology and design an effective system for the best results.

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As industrial technology changes and production goals grow more demanding, electronic sensors and control systems are becoming more prominent. In many cases, parameters previously unmonitored are now being observed with electronic sensors. Poorly planned or improperly executed sensing and control platforms result in lost efficiency and lower production and profits. Whether sensing systems are installed for automation, predictive maintenance or remote indication, a thorough understanding of instrumentation is necessary.

Selecting the Right Technology

Every sensor has at least one input, one or more processing steps, and at least one output. End users must understand how any sensing method fits within this model when deciding what parameters to monitor and how to monitor them.

The most expensive, highly sophisticated sensor or instrument can still report erroneous or false information if the instrument was not installed correctly, the technology is not being applied correctly or the output is not being interpreted correctly by the computer system or end user.

Sensors have many levels of sophistication. This section includes a generalized method for categorizing the available sensor technologies. This set of descriptions may assist a system integrator or designer in his/her work or help end users select the most appropriate instrumentation for their systems.

Typical examples of mechanical measurement devices include spring scales to measure weight, expandable bellows type pressure gauges, bimetallic coil temperature indicators, liquid filled thermometers and valve position indicators. Mechanical measurement instrumentation:

- Depends on a mechanical response to the input
- Requires no external energy source
- Mechanical and usually visual output

- Difficult to connect the output with other systems

- May or may not compensate for external influences—for example, temperature and gravity
- Often difficult or impossible to calibrate
- Susceptible to friction and backlash/hysteresis

Electrical measurement instrumentation with analog output includes resistance temperature detectors (RTDs), thermocouples, linear potentiometers, hall-effect sensors and strain gauges. This equipment:

- Relies on some form of transducer to convert the process input into an electrical signal

- Requires external energy to extract the data
- Has an electrical signal output that represents the measured parameter, typically conditioned and amplified from the transducer output
- Is susceptible to power supply fluctuations, ground loop issues or electrical interference that may deteriorate the dependability of the output signal
- Relies on a separate electrical device to convert the sensor's electrical signal to a human readable or digitized value
- Does not provide local indication of the measured parameter
- Usually impervious to gravitational orientation and often compensates for other

- Standard electrical signal ranges make interfacing with other systems simple
- May or may not be easy to calibrate

Electrical measurement devices that provide digital output include laser tachometers, photo-interrupters, time-of-flight-based distance measurement and hall-effect gear tooth speed sensors. They may have the following characteristics:

- Usually non-contact
- Rely on definite signal measurement with the parameter in one of several discrete states at the point of measurement
- Susceptible to contamination based on technology
- Susceptible to external influence
- May or may not incorporate local digital processing
- Fast response

- Virtually immune to power supply influences or electrical noise

Electrical with hybrid analog and digital elements include digital pressure gauges, digital multi-meters and infrared temperature measurement. Most digital sensors fall into this category with these pros and cons:

- Uses the same transducers as the electrical analog sensors but the transducer output is digitized locally
- Usually incorporates an internal digital processor
- Calibration, compensation, and response usually field-programmable
- Includes a local, human readable indication; more sophisticated units include a local display
- Can be connected to an industrial network for reliable remote indications and local analog or pulse outputs for automated controls
- Less susceptible to electrical noise, power supply instability and environmental influences
- Finite resolution because of digitization
- Durability and reliability suffer because of increased complexity

Table 1. Typical pump system measurements		
General	**Pump**	**Motor**
Torque	Fluid flow	Voltage
Speed	Fluid temperature (inlet and outlet)	Current
Vibration	Lube oil temperature	Power
	Bearing temperatures	Winding temperatures
	Lube oil flow	Bearing temperatures
		Cooling air flow
		Cooling air temperature (inlet and outlet)

Pump Power Measurements

Consider a simple pumping application that uses a high-pressure, quintuplex piston pump coupled to an electric motor. Even this simple example provides multiple physical parameters that could be measured (see Table 1).

Depending on the application, some of these measurements may be more important to monitor than others, but the inter-relationships between the measurements can be interesting. For example, if the variable frequency drive's internal calculations are considered, the following independent methods to measure the system's power and efficiency are available:

- Drive-calculated electrical power
- Electrical power measured at the motor (using voltage and current)
- Mechanical power at the motor/pump shaft coupling using speed and torque
- Fluid power at the discharge using pressure, temperature and flow

Ideally, the calculated power from the drive should be equal to the motor's electrical power, but the drive power calculation has inaccuracies based solely on how and where it is measured internal to the drive. Additionally, losses in the output drive stages, output reactors or bus-work or voltage drop in the cables account for power that the drive delivers that the motor never receives. These losses and inaccuracies combined should be less than 1 percent. However, on a machine of this size, that equates to more than 15 kilowatts (kW) of non-linear inaccuracy.

In direct-current circuits, electrical power is voltage multiplied by current. In 3-phase, alternating-current circuits, the electrical power calculation is more complicated (see Equation 1).

Measuring electrical power at the motor may be tempting in an effort to recover the lost accuracy. However, the fundamental frequency into the motor could be any frequency from near 0 to several hundred hertz (Hz), and the incoming voltage waveform is rich with harmonic content because of the pulse width modulation (PWM) switching in the drive. Specialized instrumentation is required to measure the voltages and currents in each phase accurately, measure the phase difference between voltage and current accurately, and do so over a wide frequency range.

Several power meters are available, but many are inaccurate at input frequencies other than 50/60 Hz or if the input voltage waveform is not sinusoidal.

Mechanical power at the motor output shaft is a product of the shaft speed and torque and is represented by Equation 3.

Measuring shaft speed is typically accomplished using an encoder with at least 512 pulses per revolution of resolution mounted directly to the motor shaft. Accuracy of these sensors is typically 0.25 percent or better.

Torque measurement on a continuously rotating shaft can be tricky. Because the shaft is rotating, a non-contact method is preferred. Some of the more accurate methods incorporate the torque sensor into the shaft coupling, and the torque signal is transmitted wirelessly to a stationary pickup. Torque measurements of this type are generally 0.25 percent accurate or better.

Equation 1

$$P = \sum_{n=1}^{3} \int_{0}^{T} v_n(t) i_n(t) dt$$

OR

Equation 2

$$P = \sqrt{3} \cdot V_{RMS} \cdot I_{RMS} \cdot pf$$

Where:

P	=	electrical power
n	=	phase index
t	=	time
T	=	the period of one electrical cycle
$v_n(t)$	=	instantaneous phase voltage
$i_n(t)$	=	instantaneous phase voltage
V_{RMS}	=	the root mean squared (RMS) value of voltage
I_{RMS}	=	the RMS value of current
pf	=	the power factor

Equation 3

$$P = \omega\tau; \text{ or } HP = \frac{rpm \cdot lbf \cdot ft}{5{,}252}$$

Fluid power at the pump discharge is a function of fluid flow and fluid pressure. It is represented by Equation 4.

Equation 4

$$P = Q \cdot \Delta p$$

Where:

P	=	fluid power [watts]
Q	=	volumetric flow [cubic meters per second (m^3/s)]
Δp	=	pressure rise [pascals]

Measurement of fluid pressure at the inlet and outlet will require a wide range (perhaps 0 to 15,000 psig). Since the pump is a quintuplex, piston pump, the output pressure sensor will endure fluctuations that would need to be mitigated or otherwise compensated for. Sensors are typically available with these properties with an accuracy of approximately 1 percent, but this could translate into measurement errors of up to 300 psig total. An alternative to this stacked inaccuracy possibility might be to simply measure differential pressure since that is the parameter used in the calculation anyway, provided that direct measurement of pressure is not required elsewhere.

Flow is one of the most contested measurements in industrial applications. Fundamentally, the two types of flow are volumetric flow (measured in m^3/s, gallons per minute or cubic feet per minute) and mass flow (typically measured in kilograms per second or standard cubic feet per minute). Most flow measurement technologies rely on a secondary measurement and fluid properties to calculate fluid velocity. From fluid velocity, fluid properties and internal sensor geometry, a fluid flow is calculated.

Fluid velocity multiplied by the cross-sectional area provides a volumetric flow measurement. To calculate mass flow, the fluid density must be known. In most applications, fluid density cannot be directly measured, so density is estimated based on the measured temperature and the fluid properties.

Many flow meters are susceptible to contamination or air bubbles. Accurate flow meters are available, but in practice, achieving precise measurements remains questionable in some instances.

Multiple Sensor Benefits

In some cases, investing in expensive sensing equipment may not be practical, or having a backup may be desirable. A complete understanding of the instrumentation system may allow the system designer to use instrumentation that is already available to achieve the desired monitoring.

Because of technology developments, infrared, non-contact thermal guns with laser pointers and full color thermal image screens are commonplace. Their ease of use and expense creates a perceived accuracy, and classical measurement techniques may be overlooked. All infrared temperature measurement is based on sub-optical radiation emitted by an object's surface. The object's emissivity is somewhat based on the material's composition but mainly on the surface finish. Generally, shiny surfaces have low emissivity, and dull surfaces have high emissivity. Emissivity of industrial surfaces could range from 0.03 to 0.99 (emissivity is defined from 0.0 to 1.0). The end user must enter the level of emissivity for reasonably accurate measurements. This level has a direct impact on the reported temperature. End user errors could result in discrepancies of up to 10 C.

Hand-held infrared guns have a conical shaped measurement area that extends out from the face of the unit, effectively increasing the detection area with the square of the distance. At only a few feet, small hot spots become difficult to detect. Infrared energy is still part of the electro-magnetic spectrum and can be reflected, and an operator may be unaware and wrongly assume that a reflection has a high temperature when it does not.

While infrared temperature measurement is quick and easy, its use should be limited to relative measurements only. If precision is required, RTDs or thermocouples should be used.

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