Process conductivity transmitter implementation

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ABSTRACT

We use conductivity measurements to indicate when the chemical composition of the process changes. Examples are spill monitoring or controlling concentrations of blending processes. We usually think of this measurement as a simple and easy-to-use method that requires less attention than a pH or flow control system. The quality of the measurement usually has a direct impact on mill environmental compliance (as in spill monitoring) or product quality (as in controlling white liquor strength to the digester). The importance of these measurements requires that we properly install and maintain them.

The problems that we often experience come from an incomplete understanding of the theory of the measurement method. This paper provides a better understanding of the measurement method and presents some solutions for the selection process, installation, documentation, and final calibration.

Application:

This document is a source of information to be used by process engineers and technicians to properly select and implement conductivity-sensing systems. The measurement methods covered represent the majority of available technologies.

MEASUREMENT METHOD

Introduction

CONDUCTIVITY INDICATES WHEN the chemical composition of a process changes. Examples include spill monitoring and controlling concentrations of blending processes. The measurement method's basis is the ability of the process to conduct a small electrical flow. The measurement units are microsiemens (µS/cm) or millisiemens (mS/cm) and are the reciprocal of ohms. A wire with a resistance of 1 ohm has the conductance of one siemen (1 million µS/cm or 1000 mS/cm). (The former measuring units were mhos—1 siemen equals 1 mho.)

Theory

The conducting media for wet processes are positive and negative ions. The net charge for the solution is zero, so there are always equal amounts of positive and negative ions. If we impress a minimal potential difference (voltage) between two electrodes and measure the resulting electrolytic current flow, we will find that the results would vary with various effects. The primary effects are the physical characteristics, the mobility, and the total number of ions. An atom with a nucleus that has a sharp radius does not easily lose its outer electrons. Atoms with wider radii have lower energies to maintain their electrons in their orbits. This geometric difference has a direct impact on the charge of the ion and affects its ability as a conductor. The ion's charge also plays an important role in an effect called *polarization*.

Polarization causes a reduced electrolytic current flow when a cloud of like-charged ions forms around an electrode. The cloud of ions creates an opposite charge that tends to insulate the electrodes and reduces the net current flow, thus reducing the indicated conductivity. Polarization and other external effects have an effect on ionic mobility. Higher liquid temperatures increase the mobility of ions. Ions with higher mobility indicate a higher conductivity. Increasing the total number of ions available to act as current carriers also increases the indicated conductivity. This is useful because it allows the use of conductivity sensors to monitor concentrations. Errors are introduced when the source of the increased ionic activity is not the particular chemical we are trying to monitor.

Measurement cell

The measurement cell dimensions can also make a difference. Cell dimensions include the surface area of the electrodes, the spacing between them, their orientation to one another, and their location in the sample stream.[1] As the dimensions of the cell change, the cell constant (K_c) varies as the ratio of the distance between the electrodes (l) and the cross-sectional area of the measurement volume (A), as follows:

$$K_c = l / A \qquad (1)$$

where

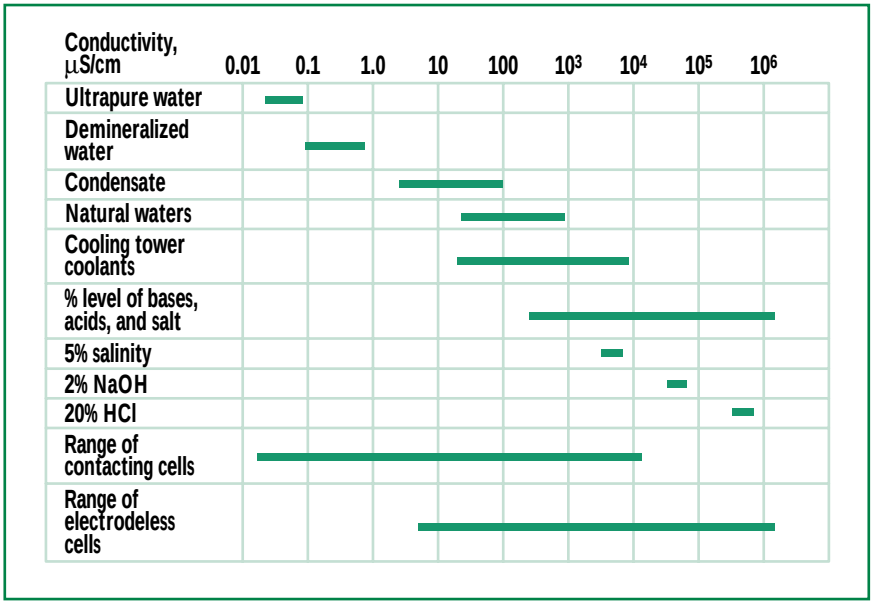
l = the distance between the electrodes, cm

A = the cross-sectional area of the measurement volume, cm^2

K_c = the cell factor, cm^{-1}.

The variance is the cell factor. A cell factor of 1.00 cm^{-1} is a cube-shaped measurement volume with two flat electrodes that are 1 cm^2 and separated by 1 cm. Manufacturers can vary the cell factor to change

[1] Anon. in *Theory and Application of Electrolytic Conductivity Measurement* (TI-612-112), The Foxboro Co., 1987, pp. 2–8.



1. Conductivity measurement ranges

Cell constant, (K_c), cm^{-1}	Optimum conductivity range, µS/cm
0.01	0.055–20
0.10	0.5–200
1.00	10–2,000
10.00	100–20,000
100.00	1,000–200,000
Electrodeless	50–10^6

I. Recommended cell constants vs. conductivity

the sensitivity of the measurement cell for various applications. By increasing the measurement volume cross-sectional area or decreasing the distance between the electrodes, the measurement becomes more sensitive. The cell dimensions can also reduce the effects of polarization by limiting the electrolytic current flow. This occurs by allowing unobstructed process flow into the measuring volume, moving the electrodes closer together (thus increasing the electrolytic current) and using ac instead of dc drive voltages. The cell factor changes with the number of electrodes. Some measurement cells use four electrodes wired in a Wheatstone bridge. This configuration helps to limit the effects in the standard configuration. In most cases, the number of electrodes is transparent to the user, and their use is not difficult to implement.

Temperature effects

Temperature has a direct and large effect on conductivity. All conductivity measurements are referenced to a standard temperature, usually 25°C. For a stable chemical process, temperature alone can account for a large change in measured vs. actual conductivity. The amount of change depends on the major chemical involved. To correct for this error, newer transmitters incorporate temperature compensation curves, either as a lookup table or as an internal gain function. Although there are many exceptions, the following gives a rough guide to "average" temperature compensation constants:[2]

Acids: 1.0–1.6%/°C
Bases: 1.8–2.2%/°C
Salts: 2.2–3.0%/°C
Water: 5.0–5.2%/°C

Depending on the type of acid, the indicated conductivity (without temperature compensation) will rise 1.0–1.6% for every degree that the process increases above 25°C. This means that, unless we use accurate temperature compensation, the conductivity reading will be in error by 5 to 8% for a 5°C change in temperature.

Basic configuration

Conductivity measurement elements come in two basic configurations. *Direct-contact* elements have electrodes that contact the process directly. The other style consists of two toroidal coils that use the process as the core of a transformer. *Toroidal*, electrodeless, or noncontacting elements are insulated from the process with a plastic covering. Electrodeless elements have two major benefits: They are less sensitive to coatings, and they are useful at much higher conductivities. Direct-contact elements are more sensitive at low conductivities, less than 1000 µS, and electrodeless elements are used at much higher conductivities (to 1000 mS). The sensitivities of both styles overlap in the ranges between 10 µS and 100 mS.

SELECTION CRITERIA

Application

Conductivity transmitter and element selection is highly dependent on the application. The first step is to select the type of measuring cell by determining measurement range, process chemistry, and process conditions. Contacting cells have a range of approximately 0.1 µS to 10 mS, and electrodeless cells (toroidal) have a range from 10 µS to 1000 mS. Refer to **Fig. 1.**[1,2]

Figure 1 is useful in determining whether the application requires the use of a contacting measurement cell or the use of an electrodeless cell. Do not use electrodeless cells in applications below 10 µS/cm. If the measurement cell is subject to fouling, an electrodeless cell would be preferable. Measurement error caused by coatings of oil or various slurries is insignificant with electrodeless cells. Direct-contact probes suffer large errors in output from even light coats of oil.

[2]Nicholson, C. and Perko, J. in *Theory and Application of Electrolytic Conductivity Measurement*, Bailey TBI, 1987, pp. 1–8.

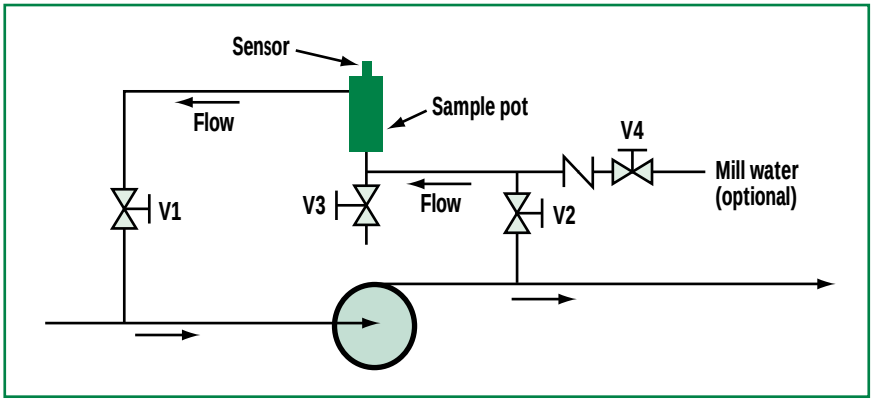
There are many uses for direct-contact probes. When an application calls for their use, the cell constant (K_c) is important in maintaining measurement sensitivity. (The importance of K_c will become less important as more of the newer digital transmitters are installed. Digital units with microprocessors adjust the drive voltage to control sensitivity.) Be sure to check for compatibility of the electrodes with the process being measured. Nickel is a common electrode material, and it should not be used for processes with a pH lower than 7. **Table I** shows recommended cell constants for various conductivity ranges.[1]

Temperature compensation

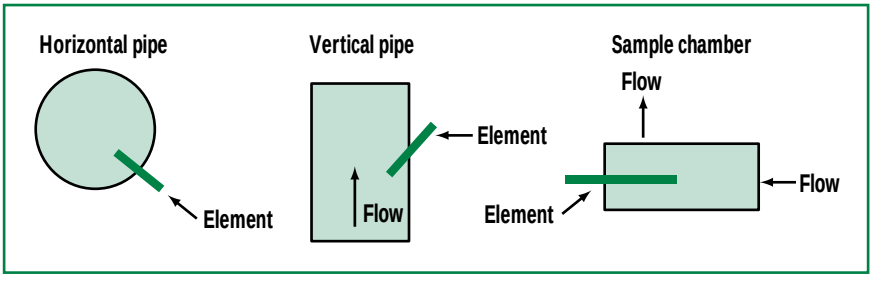
If an application is to measure the concentration of a particular chemical and display the concentration, the transmitter will need to use a temperature-compensation curve for the chemistry of interest. A number of manufacturers are developing transmitters with multiple compensation curves to match various processes. Temperature compensation alone is not enough to make these corrections. Process conductivity varies with temperature, but some chemistries are affected more than others. Some units will allow the development of custom curves. If you elect to develop your own curve, it is good practice to embed the correction in the distributed control system (DCS) rather than the transmitter so that field calibrations are less confusing.

Custom compensation curves are developed by holding the transmitter temperature compensation at 25°C (either by manual compensation or by using a set resistor) and recording the indicated conductivity at various temperatures. Select a transmitter that has multiple-point curve generation. Some manufacturers offer only a two-point calibration. The two-point curves do a poor job of temperature compensation in processes that have very large temperature swings. The specification is process and chemical dependent. The test is time consuming and must be carefully monitored to ensure accuracy.

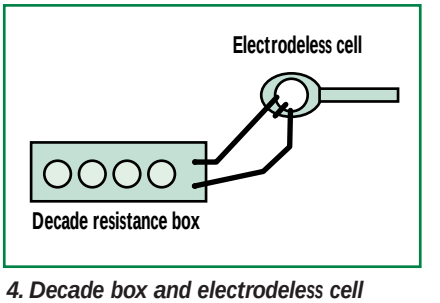
Proper temperature compensation is critical to accurate conductivity measurement. Be cautious if the manufacturer specifies that a field resistor be attached to the wiring or the back of the transmitter. The device is probably not going to have the proper temperature compensation for your process. The resistor is used for manual temperature compensation, and its value is often set to 25°C. If the element does not have its own temperature sensor, investigate mounting a separate temperature sensor and wiring it to the transmitter's input. [The same is valid for those cases where the selected element's temperature sensor does not match the transmitter's input requirements, such as resistive temperature devices (RTDs) vs. thermistors.]



2. Recommended conductivity mounting method



3. Mounting orientation of conductivity elements



4. Decade box and electrodeless cell

INSTALLATION

Mounting

Manufacturers have designed around many of the causes of polarization in conductivity elements. Their efforts can be undone by mounting the element in a stagnant sample zone. A fresh and well-agitated sample is necessary for good measurement. It is good practice to mount the element as shown in **Fig. 2.**

The sample pot's minimum measurement volume (inside) diameter should be 2.5 times the maximum element diameter (e.g., the inside diameter and inside length). Use stainless steel construction for the

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Foxboro 873EC Configuration Record

Tag#/Location:_____ **Date:**_____ **By:**_____

Symbol	Parameters & Values Accessed	Settings
CELL	Config. of Display and Analog Outputs	
Hold	Analog Output Hold	
Cd	Temperature Compensation and Damping • Damping Factor • Units of Measure • Chem. Temp. Compensation	
Hac	High Alarm Configuration • Measurement Selection • Low/High/Instrument plus Passive/Active State • % Hysteresis	
HAtt	High Alarm Trigger Time	
HAFt	Haigh Alarm Feed Time	
HAdL	High Alarm Delay Time	
LAC	Low Alarm Configuration • Measurement Selection • Low/High/Instrument plus Passive/Active State • % Hysteresis	
LAtt	Low Alarm Trigger Time	
LAFt	Low Alarm Feed Time	
LAdL	Low Alarm Delay Time	
UL	User - Defined Upper Measurement Error	
LL	User - Defined Lower Measurement Error	
UtL	User - Defined Upper Temperature Error	
LtL	User - Defined Lower Temperature Error	
HO1	100% Analog Output - Channel 1	
LO1	0% Analog Output - Channel 1	
HO2	100% Analog Output - Channel 2	
LO2	0% Analog Output - Channel 2	

Symbol	Parameters & Values Accessed	Settings
bL	Basic Setup Lock Control	
Ct	Cell Type	
FSC	Full Scale Value	
tCF1	Temperature Cell factor	
tEC1	Thermistor Temperature Elec. Cal.	
tCL1	RTD Low Temperature Elec. Cal.	
tCC1	RTD Mid. Temperature Elec. Cal.	
tCH1	RTD High Temperature Elec. Cal.	
LCC	Lock Code Change	
tCt	Custom Temp. Compensation Curve	
PCt	Custom Percent Concentration Curve	
LCO1	Analog Out 1 Elec. Lower Calibration	
HCO1	Analog Out 1 Elec. Upper Calibration	
LCO2	Analog Out 2 Elec. Lower Calibration	
HCO2	Analog Out 2 Elec. Upper Calibration	
SFt	Software Version Number	
SOH	Sales Order High	
SOL	Sales Order Low	

Cell Code - Output Configuration

Digit 1	1 = (only choice)
Digit 2	0 = (only choice)
Digit 3	Output 1 Selection 1 = Conductivity 3 = Temperature 5 = Log of Conductivity
Digit 4	Output 2 Selection 1, 3, or 5 (as above)

Cd Code - Compensation and Damping

Digit 1	Digit 2	Digits 3 & 4
0 = none	0 = % Legend Disabled	99 = Special
1 = 10sec.	Use for uS & mS	00 = No Temp. Comp.
2 = 20sec.	measurements.	01 = Dilute NaCl
3 = 40sec.	1 = % Legend Enabled	02 = NaCl, dilute to 25%
		03 = Hcl, dilute to 15%
		04 = HNO_3, dilute to 10%
		05 = H_2SO_4, dilute to 25%
		06 = H_2SO_4, 93% to 99.5%
		07 = Green Liquor
		08 = H_3PO_4, dilute to 35%
		09 = Oleum, 18% to 42%
		10 - NaOH, dilute to 15%
		11 = NaOH, dilute to 20%
		12 = Black Liquor

Hold Code - Hold Analog Output

Digit 1 - Hold Select
0 = No Hold
1 = Alarms held in present state & hold output
2 = Alarms held in off state & hold output
3 = Alarms held in on state & hold output
Digits 2, 3, & 4 - Analog Output Set
Enter 000 to 100 (%) of analog value

Ct Code - Cell Type

1 = UT/LB
2 = RE/BW/EV
3 = AB
4 = SP/HP
5 = TF
6 = NL
7 = PN/PX

HAC and LAC Codes - Alarm Configuration

Digit 1 - Measurement Selection	
1 = Conductivity	
3 = Temperature	
Digit 2 - Configuration	
1 = Low/Passive	5 = Instrument/Passive
2 = Low/Active	6 = Instrument/Active
3 = High/Passive	7 = Hold/Passive
4 = High/Active	8 = Hold/Active
Digits 3 & 4 - Analog Output Set	
Enter 00 to 99 (%) of full scale	

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5. Example configuration setup sheet

Device		Interlock	Interlock	Interlock	Interlock	Interlock	Interlock	
Tag	Number	Alarm level	Alarm level	Alarm level	Alarm level	Alarm level	Alarm level	Description
CV	81 A	CAH-081 1500uS	CAH-085 1500uS	HIS-081 Accept Auto Dump				If HIS-081 in auto and either CAH-81 or CAH-85, CV-81B (Dump) opens. Once it opens, the CV-81A (Accept) closes. HIS-081 has two manual positions: 1) Accept (CV-81A open & CV-081B closed), 2) Dump (CV-81B open & CV-081A closed)
CV	81 B	CAH-081 1500uS	CAH-085 1500uS	HIS-081 Accept Auto Dump				If HIS-081 in auto and either CAH-81 or CAH-85, CV-81B (Dump) opens. Once it opens, the CV-81A (Accept) closes. HIS-081 has two manual positions: 1) Accept (CV-81A open & CV-081B closed), 2) Dump (CV-81B open & CV-081A closed)

6. Suggested interlock sheet layout

sample pot, valves, and tubing. Half-inch diameter stainless steel tubing is adequate for all of the tubing and fittings unless the process being monitored requires larger diameters. The small sample line valves can be ball valves. In Fig. 2, V2 (the pump outlet) should be one-quarter to one-half open, and V1 (the pump inlet) should be fully open. V3 can be used by operators to draw a sample for lab testing. Mill water can flow through the sample pot by closing V2 and opening V4. This is not an absolute check for zero but should be adequate to check the instrument's operation. (Most mill water is in the 10–50-µS range.)

If the element mounts directly into the process, the mounting location should be far enough downstream to ensure good mixing and low turbulence. Too much turbulence or cavitation can also cause problems, such as noisy signals or damage to the element. If the process is flashing at the measurement point, as with steam condensates, move the element to a point with a lower pressure drop and/or a higher process pressure. It is also good practice to use extraction valves and elements so that the element can be removed while the process is pressurized.

Do not mount direct-contact elements on the top or bottom of a pipe. At the top of the pipe, the element can be dry and not in the process due to a trapped air bubble. An element mounted at the bottom of a pipe is often fouled by collected mud, particulate, etc. The best mounting positions are shown in **Fig. 3.**[1]

All interconnecting wiring from the transmitter to the element and to the DCS should be routed in conduit at the transmitter location. Field radios have a bad habit of interfering with the operation of these devices. Specify that installers provide enough conduit so that the element can be removed from the process without rewiring the element. Attempt to keep sensor wiring isolated from ac power sources. Motors switching on and off, lighting circuits, and anticorrosion systems can all affect the performance of this type of sensor. Choosing an electrodeless element is effective when you need to isolate the measurement from the process stream.

It is best to install a field-mounted power switch at the transmitter. This allows field technicians to easily and quickly remove power for servicing the transmitter.

High-consistency stock (8–15% Cs) conductivity is difficult to measure. Some success has been made by measuring the filtrate's conductivity. This is done by using a four-electrode direct-contact element. The element is mounted into the side of the piping, and the insertion depth of the element is limited to 0.125 in. (±0.031 in.). This places the measurement zone in the filtrate layer between the pulp plug and the inside surface of the pipe. This method requires the use of an easily removed element because of the high amount of preventative maintenance required. The element must often be removed on a biweekly basis for cleaning and calibration.

We have had some success in using the mounting method shown in Fig. 2 on pulp stock consistencies below 5% Cs. The recirculation piping around the pump needs to be about a 4-in. pipe and has a susceptibility to pluggage during shutdowns if not flushed thoroughly. Direct insertion into the pipe is not recommended, because pulp stock tends to build up on the probe tip. As the stock builds up and sloughs off, the conductivity output varies. If the element extends too far into the pipe, there is also a chance that the probe will break off during system startup as a plug of dewatered stock hits it.

Temperature compensation

Nearly all conductivity elements allow temperature compensation. Where the temperature sensor is a part of the element, specify that the element is oriented so that the temperature sensor is facing the upstream side.

Preventative maintenance

Conductivity sensors normally require quick and easy access to perform calibration checks, preventative maintenance, and general maintenance. Many of the suggestions listed

KEYWORDS
Calibration, conductivity, electrodes, electrolytes, electrolytic cells, ionic mobility, measuring instruments, sensors, temperature, trouble shooting.

previously are based on this need. It is important to make access to the sensing element and the front and back of the transmitter an important part of the installation design.

CALIBRATION

General

Calibration for any conductivity measurement requires a good understanding of how the device makes its measurement and how the manufacturer wants its device calibrated. Treat the information that follows as general guidelines.

Standard solutions used for calibrations are very susceptible to exposure to air. The standard conductivity decreases in poorly sealed containers. Never use old solutions. Freshly made solution provides better results. Standard solution conductivity is referenced to 25°C. That means that the conductivity listed on the container is accurate at 25°C only. Use temperature compensation (the preferred method) or correct for the difference when doing the calibration (use manual temperature compensation). (Most off-the-shelf solutions have a compensation curve listed on the original container.) Another source of error that can occur when using standard solutions is contamination. Before placing an element in fresh solution, make sure it is clean and dry.

Air makes a reliable zero reference as long as the electrodes are dry. This is true for either the direct-contact– or electrodeless-type elements. The electrodeless element is affected by any conducting medium within two element diameters (that is, pipe walls).

Preinstallation

Before installing the transmitter and element, these items should be checked on a calibration bench. The measurement components should be wired and powered. The temperature-compensation circuit calibration should be checked first by replacing the temperature sensor with a resistance decade box (±0.01 ohm accuracy minimum). After checking and calibrating the temperature circuits, attach the decade resistance box to the conductivity element. Direct-contact cells can be checked by attaching the resistance wiring directly to the exposed electrodes. Run a wire through the opening on electrodeless cells. In either case, the temperature compensation circuit should be manually set to 25°C. The transmitter should indicate the conductivity that is appropriate for the resistance value [conductivity = (1/resistance value) x cell factor]. Greater resolution is obtained by running multiple wire turns through the electrodeless cell's opening [conductivity = (1/resistance) x cell factor x $(\text{turns})^2$]. See **Fig. 4** for decade box wiring. Enter the setup data now if the transmitter is a digital device. Once the unit is checked and operable, it can be installed.

Installation

Very high conductivities, above 20,000 µS, should be rechecked with a decade resistance box before installing the element into the process piping. Lower conductivities can be checked with standard solutions (see the previous warnings about standard solutions). This preliminary calibration serves two purposes. First, it checks the installation and allows the checking of any switching valves and associated system equipment. Second, it provides a calibration prior to startup.

Standardization

None of the calibration and setup work that is completed corrects for any variance that the sensor may see that is due to the physical installation. Mounting-induced bias is a common installation-induced measurement error in electrodeless cells. If the measuring element is in close proximity to electrical fields or conductive material (pipe walls), the conductivity measurement will have an offset from the bench calibration. This last calibration step is normally completed after startup and when the process has leveled out. A sample is drawn from the process, and the transmitter reading is recorded. The sample is measured with a conductivity standard meter, and the transmitter's reading is corrected to the standard value. This last step corrects for a majority of the installation-related errors.

DOCUMENTATION

Mounting method

It is very common for most instruments to be mounted field run. (Drawing and engineering costs to completely document an installation are very high. The transmitter and element mounting locations are only generally noted. Conduit runs and actual mounting positions are determined by the field installers.) The conductivity transmitter's mounting position is not important to the transmitter, but access by field technicians to both the front and back of the instrument is important. Also specify how and where the conduit will be run. (See "INSTALLATION–Mounting.")

Setup sheets

Figure 5 is an example of a configuration setup sheet for the Foxboro 873EC conductivity transmitters. The setup sheets are important because there is no other way to easily document the internal configurations on digital transmitters. In most cases, the alarm setups are not critical to the operation of the control system, because you usually control all alarming through the DCS. By documenting the setups, you can eliminate con-

fusion in the field when the transmitters flash alarm signals. You can also use the alarm settings to help troubleshoot process problems. They are also a good way to ensure that all transmitters are set up in the same way and have the proper calibration configuration.

Loop sheets

Loop sheets should include all DCS alarm levels, transmitter calibrations (zero and full-scale), and complete model numbers for both the transmitter and element. If a configuration sheet is not used, some of the important configuration data should also be included (e.g., the internal setup data) in the transmitter.

Process and instrumentation drawings

In addition to the typical process interconnections, alarm levels used for interlocks should be included in the interlock notes. If space is limited, reference a separate interlock sheet (as described in the next section).

Interlock sheet

An interlock sheet is useful for training and future troubleshooting efforts by field technicians. The list should be organized by tag numbers, alarm levels, and resulting control action. An example is shown in **Fig. 6.**

Calibration and preventative maintenance standard operating procedures (PM SOP)

Calibration and PM SOPs help round out the documentation. The SOP should be written by the people who will be using it (field technicians). The completed SOP should include a recommended PM schedule. We recommend that you gather data on each process and set the final PM schedule to match. A good starting place for most processes is to check each individual transmitter's operation on a weekly basis. TJ

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