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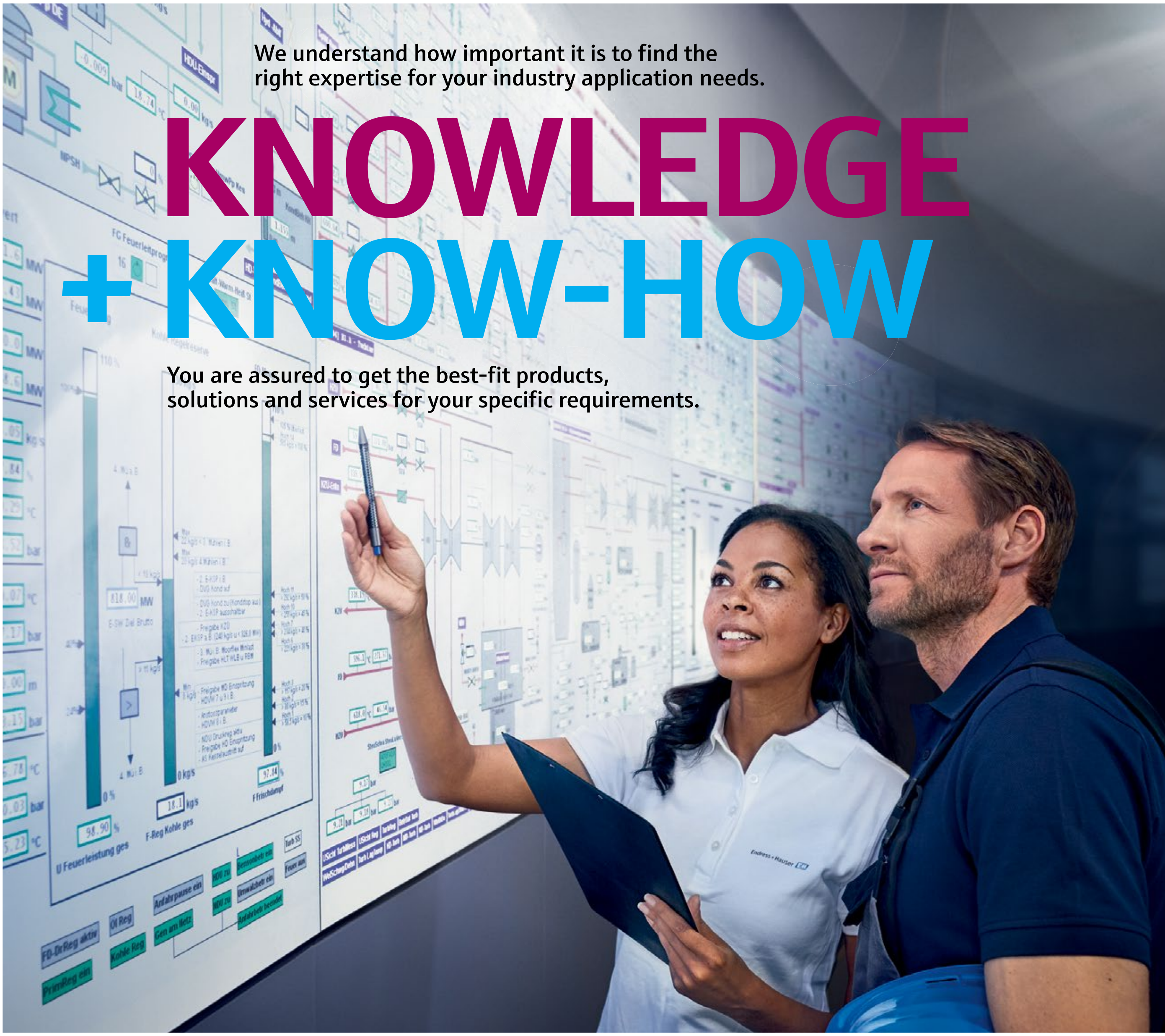

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TABLE OF CONTENTS

AD INDEX

Neglect Level Control at Your Peril

Be on the lookout for reset mode tuning issues

By Cecil L. Smith, Cecil L. Smith, Inc.

The level in a process vessel often isn't viewed as a critical variable to control. Especially in surge vessels, controller performance typically is considered satisfactory if no high- or low-level trips occur. Vessel level's effect on the corporate bottom line usually is nil. So, it's easy to see why vessel level controls receive little attention.

However, neglecting level control carries definite risks. Indeed, loss of level control has contributed to three major industrial accidents (see: "Don't Underestimate Overfilling's Risks, https://bit.ly/3iULirM).

Processes consist of a collection of unit operations. The various flow streams that interconnect these unit operations propagate variance from one to the next. This variance ideally should diminish as it spreads but the nature of some unit operations actually amplifies it.

Control loops also can amplify variance, either through improper operating objectives or poor tuning. The flow between some unit operations depends upon a level controller's output to a final control element on a flow stream. Two factors make level loops a potential source of variance:

1. Variance in any stream in or out of a unit operation leads to variance in vessel level, to which the level controller responds by changing the flow of either an inlet or a discharge stream.
2. The inherent nature of level processes complicates controller tuning, especially for integral or reset mode. Excessive reset action (i.e., reset time

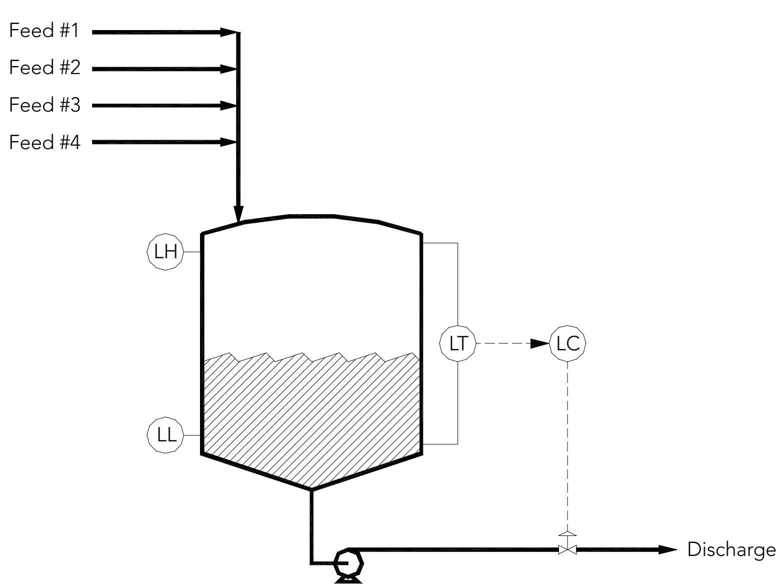
too short or reset rate too fast) results in a cycle in the flow. In the conservatively tuned level loops applied to surge vessels, the slowly responding controller produces a cycle with a period of hours. This is where level differs from other loops — reducing the controller gain or sensitivity doesn't eliminate the cycle but merely increases its period.

Figure 1 shows a vessel with four feed streams and one product stream. The level controller influences just the discharge stream. The only difference between controlling using a feed stream instead of a discharge stream is directionality (increase-increase versus increase-decrease). In Figure 1 the final control element is a valve but a pump with a variable frequency drive often is a viable, and possibly preferable, alternative.

The controller in Figure 1 translates variations in vessel level to variations in discharge valve opening and, hence, discharge flow. Maintaining level within a given proximity to its set point requires certain changes in discharge flow. Generally, the tighter the level is controlled, the larger the necessary variations in discharge flow.

Now, let's consider some characteristics of a feedback controller:

- It decreases the variance in the control error by increasing the variance in the controller output, which translates to higher variance in the flow through the final control element.



SIMPLE FEEDBACK CONTROL
Figure 1. Level controller has no way to influence any feed stream.

- It shifts variance from one variable to another; it doesn't reduce total variance.

- An improperly tuned feedback controller can significantly raise total variance.

Although instrument technicians often are responsible for tuning level controllers in a plant, propagation of variance is a process issue that's most appropriately addressed by process engineers.

INTEGRATING PROCESSES

Most level processes are integrating/ramp/non-self-regulated, the primary exception being gravity flow applications. When the level controller is on manual, with an integrating process:

- Vessel level changes at a rate proportional to the imbalance in the material balance (total flow in minus total flow out).

- Changes in level (and, thus, head) don't affect the discharge flow and, consequently, the imbalance in the material balance.

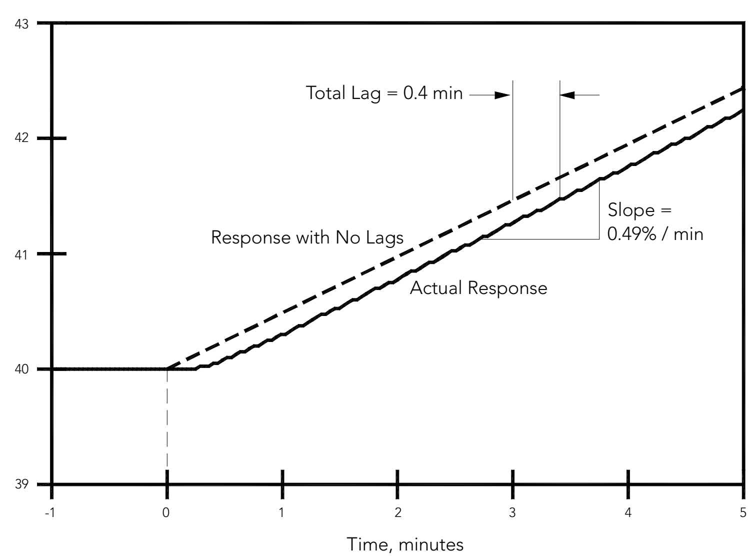
- The rate of change in level remains the same as the level increases or decreases.

When the level doesn't directly impact any flow in or out, the dynamic characteristics of the process act as an integrator. The integrator in the reset mode of a controller coupled with an integrator in the process can have adverse consequences.

Starting from an equilibrium state (total flow in equals total flow out), any upset results in a ramp change in level, hence the term "ramp process." If the upset conditions persist, the ramp continues until the level reaches a limiting condition, usually in the form of a high- or low-level process trip. When no control actions are taken, such processes don't seek an equilibrium, hence the term "non-self-regulated process."

Figure 2 illustrates the response in level to an upset to the material balance. When the material balance is closed (imbalance is zero), vessel level is constant. In Figure 2, this is the case prior to time 0. At that point the discharge valve opening is reduced by 10%, which decreases discharge flow and causes level to increase.

All examples we'll discuss pertain to a straight-walled vessel containing a constant density liquid, hence the ramp has a constant slope as in Figure 2. We'll express the



MATERIAL BALANCE UPSET

Figure 2. A 10% decrease in control valve opening causes a reverse-acting response.

level as a percentage of the level measurement span. The response in Figure 2 is for a 12,000-L vessel. The average flow through the vessel is 200 L/min, giving a residence time of 60 min or 1 hr.

A simple characterization of a level process relies on two parameters whose value can be readily obtained from the response in Figure 2:

Process gain, K_F. This is the effect of a 10% change in the controller output on the slope of the ramp. From Figure 2, a 10% reduction in the controller output causes the slope of the ramp to change from zero to 0.49%/min. So:

K_F = (0.49 %/min)/10% = 0.049 (%/min)/%

A decrease leads to an increase in level, so the process is reverse acting.

Process lag, θ. The material balance suggests the ramp should commence immediately, as indicated by the dashed line in Figure 2. Instead, the slope changes gradually from zero to 0.49 %/min. By the time the slope reaches 0.49 %/min, the actual response lags by 0.4 min.

The process lag shown by the ramp in Figure 2 includes the following:

Control valve lag. A digital system can change its output by 10% very quickly but all final control elements exhibit some lag in responding to a change in their input signal. Rarely are the response characteristics of the final control element well known.

Measurement device lag. This depends on the measurement technology employed and, sometimes, on how the device is installed. Rarely is this lag quantified.

Smoothing of the process variable. When smoothing is applied either within the measurement device or the control system, quantitative values are available. However, with some level measurement technologies, smoothing can be applied externally.

The lag observed in Figure 2 is roughly the sum of these lags. The combined effect often is approximated by a transportation lag or dead time. In the simple approximations of the dynamics of a level process, the process lag θ is considered to be entirely transportation lag.

Unfortunately, for many level loops, conducting a test such as in Figure 2 is impractical due to the presence of noise on the measured level value and variability in the feed flow to the vessel.

Testing procedures are available to determine K_F and θ in face of both measurement noise and flow upsets. One approach is to use a pseudo-random binary signal (PRBS) for the output to the control element.

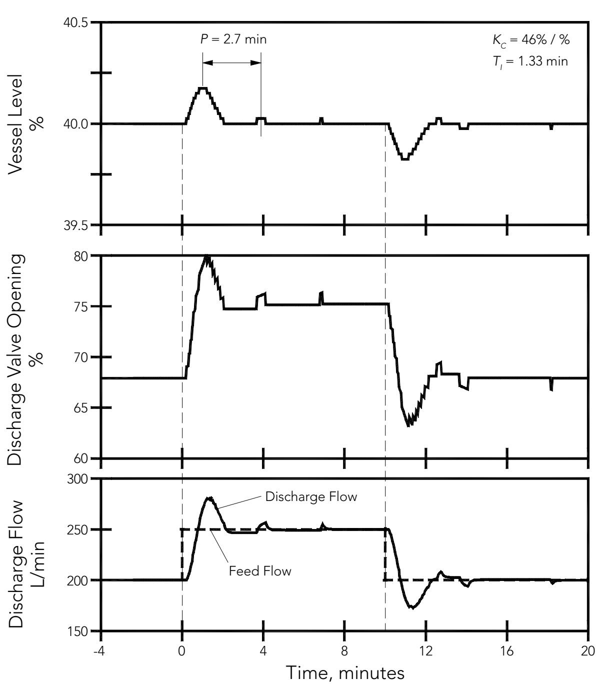
Model predictive control technology relies on such tests to find process characteristics. However, such tests are long-duration (days) and difficult to justify for level control applications.

TUNING EQUATIONS

When a proportional-integral (PI) controller is employed, the relationships between the tuning coefficients and the process characteristics are:

Controller gain, K_C: inversely proportional to the process gain K_F; inversely proportional to the lag θ.

Reset time, T_I: not affected by K_F; directly proportional to θ.



FEED FLOW INCREASE
Figure 3. A 10-min 50-L/min increase in one feed causes abrupt changes in discharge flow.

Especially for large tanks with long residence times, tuning equations often suggest unreasonably large values for K_C. Most tuning relationships link the product $K_F K_C$ (the loop gain) to the process dynamics. The large value for K_C results from two factors:

1. For responsive processes, the tuning equations suggest a large value for $K_F K_C$. For a vessel with a residence time of 1 hr, a lag of 0.4 min is trivial.

2. For large vessels, the process sensitivity K_F is small.

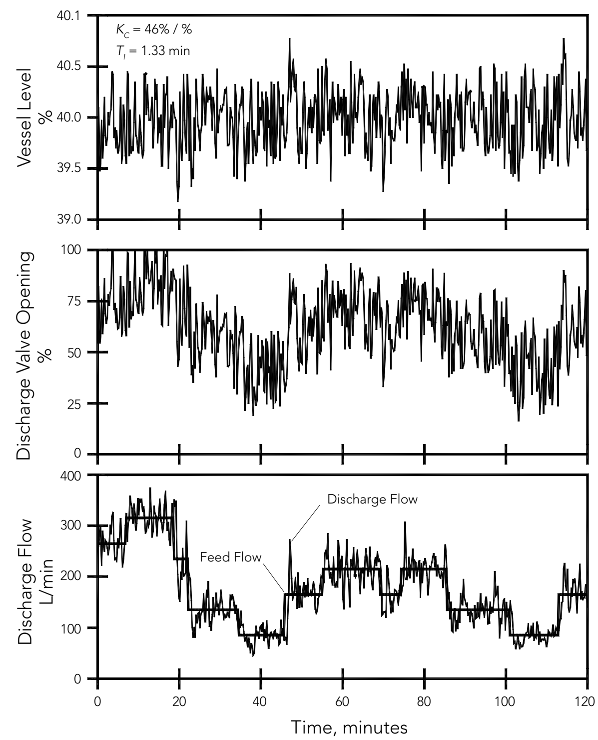
Using the Ziegler-Nichols tuning equations, the suggested values for the tuning coefficients are:

$K_C = 1/(K_F\ \theta) = 0.9/\{[0.049\ (\%/\text{min})/\%] \times (0.4\ \text{min})\} = 46\ \%/\%$

$T_I = 3.33\ \theta = 3.33 \times (0.4\ \text{min}) = 1.33\ \text{min}$

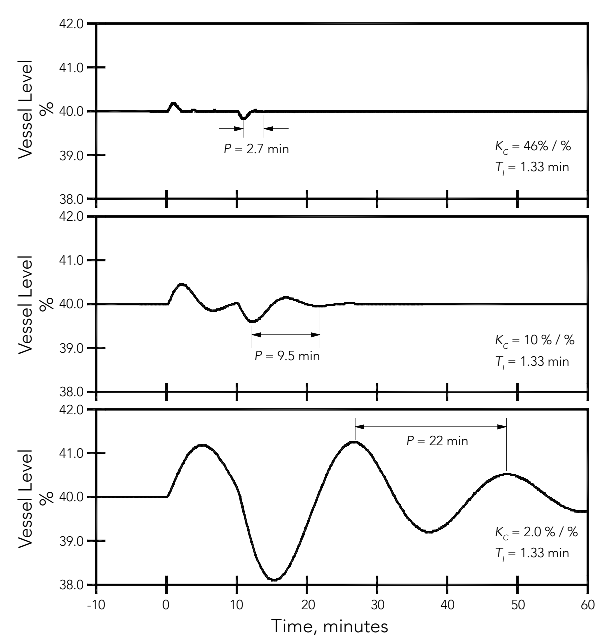
The performance objective for the Ziegler-Nichols tuning equations is a response with a quarter decay ratio, which usually provides a rapid response to a disturbance. Figure 3 presents the response to a 10-min 50-L/min increase in one feed for the level process in Figure 1. These tuning coefficients maintain the vessel level very close to its set point — the maximum level deviation is approximately 0.2%. The response period, *P*, is 2.7 min. Also note the feed flow change is translated quickly into a discharge flow change.

A controller gain of 46 %/% is unreasonable in a level controller. A high controller gain amplifies any loop imperfections, such as the consequences of a finite resolution in the measured variable. In the example here the measured level value has resolution of 1 part in 4,000 — this means that 0.025% is the smallest possible change in measured level value. Using a controller gain of 46 %/%, a change of 0.025% in vessel level alters the controller output by (0.025%) × (46 %/%) = 1.15%. This, not surprisingly, leads to the abrupt changes seen in Figure 3, especially as the vessel level approaches its set point. Between the abrupt changes, the controller output exhibits ramp changes. (The finite resolution gives a constant control error that is integrated by the reset mode.)



NOISE AND VARIABLE FEED RATE
Figure 4. While level is maintained close to target, discharge valve opening varies significantly.

Figure 4 presents the performance of the level controller with 0.5% noise on the level measurement and a varying feed rate. With the high gain, level is maintained close to its target. In addition, feed flow changes are translated quickly to discharge flow changes (which isn't necessarily beneficial). This comes at the expense of noticeable variability in the discharge valve opening and discharge flow. (The aggressive controller is amplifying the noise in the vessel level.)



REDUCED CONTROLLER GAIN
Figure 5. As gain decreases, vessel level fluctuates more widely.

When a controller is too aggressive, the customary practice is to reduce K_C. Figure 5 illustrates the effect on loop performance of decreasing the controller gain from 46 %/% to 10 %/% and finally to 2 %/%. The conventional wisdom is that reducing the controller gain has two effects:

1. The loop responds more slowly. This is clearly the case in Figure 5, with the period increasing from 2.7 min to 9.5 min and finally to 22 min.

2. Any oscillations in the response decay more rapidly. However, this isn't the case in Figure 5. For a gain of 46 %/%, the second peak in the oscillation is barely visible. For a gain of 10 %/%, the second peak is still very small compared to the first one. But for a gain of 2 %/%, the decay ratio is approximately 0.5.

With regard to the effect of the controller gain on the degree of oscillations, loops for integrating or non-self-regulated processes behave differently, especially at low K_C values. The loop contains two integrators, one in the process and one in the controller. Consider the following possibility:

- Process dynamics consist of only an integrator (no lag, $\theta = 0$).

- Controller is integral-only.

When disturbed, the loop responds with a cycle of constant amplitude. Decreasing the controller gain increases the period of the cycle and its amplitude but the cycle neither grows nor decays. Any additional dynamics in the process (such as the lag exhibited in Figure 2) result in an unstable loop for all values of K_C.

For a PI controller and an integrating process, the following two observations apply:

1. At low K_C values, loop behavior approaches that of a loop with an integral-only controller. The cycles in the response have a long period and decay slowly.

2. If the reset time is less than θ, the loop is unstable for all values of K_C.

For PI control of an integrating process, continuing to reduce the controller gain results in a slowly decaying cycle with a very long period. Figure 5 clearly illustrates this behavior.

However, in practice, responses such as those in Figure 5 often are impractical to obtain for a level loop. With noise in the measured variable and frequent changes in flows in or out, the situation in Figure 4 is more typical of most level processes.

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Deftly Detect Instrument Faults

Check for some simple clues to a malfunctioning device

By Dirk Willard, Contributing Editor

Meter mayhem, I thought to myself. One magnetic flow meter showed 18 gal/min, while another read 138 gal/min. However, the magnetic flow meter monitoring the combined flow to a reactor indicated 380 gal/min. Okay, it's not a mass balance but the temperatures only were 60°F apart. The total flow should be 156 ±3 gal/min. Other flows did go into and out of the feed tank but all were for recirculation except for the one that went to the reactor. The pump for the recirculation had a design flow of 900 gal/min; some people still think you can agitate a 40,000-gal tank with a pump.

Obviously, most of the flow from the large pump went for recirculation, with only about 156 gal/min sent to the reactor. The errant measurement pointed to an instrument problem: magnetic flow meters read high when they become plugged. As I pointed out in a previous column ("Match the Flow Meter to the Service," http://bit.ly/2FOw1am), flow meters rely on inference: magmeters measure velocity for an assumed density and then infer flow rate. Plugging restricts the pipe diameter and increases the velocity, at least according to the mass flow equation: Mass = Density × Velocity × Area.

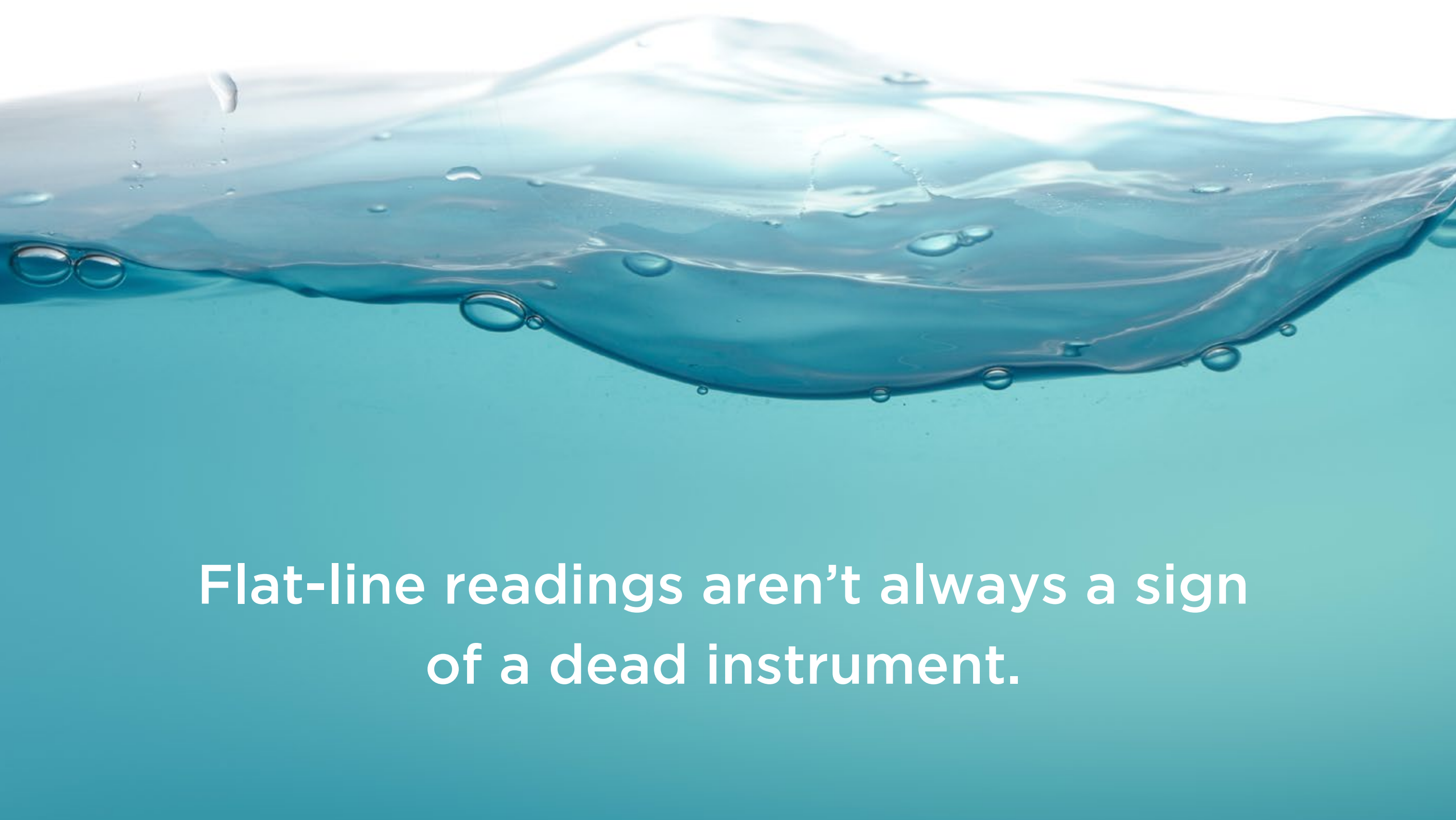
Another indication of a problem with that meter was its trend line. The trends for the 18-gal/min and 138-gal/min meters jumped around. However, the trend line for the large flow meter almost was flat. Often — but not always — that's a sign of a dead instrument. Sometimes, though, it stems from over-tuning to avoid oscillation of trend lines; that oscillation is a pulse.

Generally, level and temperature measurements don't have a pulse. If a level measurement is leaping around on a control system faceplate, it usually indicates an electrical problem, not an instrument one. Temperature measurement coupled with flow, such as what you'd see in a furnace or vaporizer, can have a pulse; the trouble is that oscillation from the flow measurement almost certainly will overwhelm the temperature fluctuation.

An excessively high trend in temperature measurement obviously could result from a loose connection (high resistance); this applies to either thermocouples or RTDs. This probably will stand out from the background noise caused by flow measurement oscillation.

Thermocouples fail high, so do RTDs although sometimes the resistance is only somewhat higher than normal. Temperature sensor probe failures often are pretty spectacular (in the sense that high temperature may lead to fire, explosion, reactor breach, pump failure or other catastrophic and unpleasant events).

One good technique for diagnosis is to use the instrument itself. Compare the pump rates into and out of a vessel against the flow calculated from the level



Flat-line readings aren't always a sign of a dead instrument.

trend data. For example, I measured levels of 20.6% and 26.8% only a minute apart for a tank that needed 308.7 gal to alter the level 1%. So, the indicated level change would have required a flow of 1,917 gal/min — stupendously more than the 150-gal/min pump ever could provide!

This wasn't the only time a level measurement let me down. On one assignment, several hundred pounds of material seemed to appear and disappear in seconds on a faceplate in the control room. The mass measurements were made from level readings. I conducted a level measurement experiment and then looked at the trend data I downloaded: the data showed that nothing could be gleaned from any comparison until the level transmitter gain was dampened.

Diagnosing problems with control valves often isn't too difficult. Control valves are considered unreliable when they don't do what they're supposed to do. Look at the response time between the command and the response: a good valve opens quickly while a bad valve sticks, causing the controller to read the failure of the process variable (PV) to respond to change as a need to open the valve further. When the valve finally does spring open, the controller sees the change in PV and tries to crank the valve closed. Because the valve is open now, it slams closed and the process begins again. Often, an engineer will dive into this kind of problem thinking it's a tuning problem and not a hardware problem, being misled by focusing only on the controller and the measuring instrument.

As I've said before, don't believe information unless you can compare it to other data. Take the time to take the long view. ●

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Vibrating Fork Level Instruments Come of Age

Technology advancements enable self-diagnosis, remote access and improved safety

By Brent Frizzell, Endress+Hauser

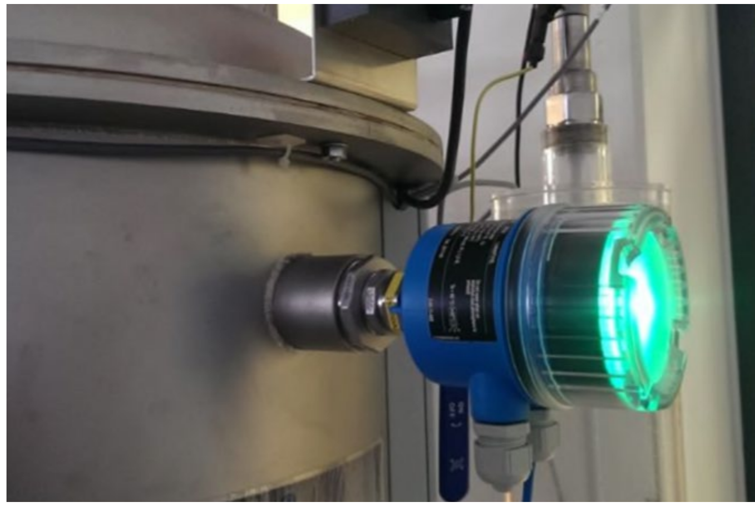
Vibrating fork level instruments — also called vibronic instruments — are widely used in the process industries. Available from multiple manufacturers, millions of these devices have been installed worldwide over the past few decades.

While the basic technology of vibronic instruments hasn't changed much over the years, today's instruments now use technological innovations to bring them into the digital age, meet the needs of Industry 4.0 and the Industrial Internet of Things (IIoT), provide diagnostics themselves and provide access from mobile devices. This article describes those developments and shows how they benefit end users.

INSIDE VIBRONIC INSTRUMENTS

Vibronic instruments consist of a transmitter and a sensor. The sensor portion of the instrument uses a tuning fork (Figure 2) that's excited at its resonant frequency by a piezoelectric crystal, with a second crystal detecting the vibration produced by the first. The frequency reduces when the fork is covered by a liquid, and this change is analyzed and translated into an on/off output signal by the instrument's transmitter.

Vibronic instruments are well-suited for liquid level applications, including point detection at the top and bottom of tanks, certified leakage monitoring and overfill prevention, use in hazardous environments and in applications requiring safety integrity level (SIL) 2 and 3 certification. These instruments can be used in storage tanks, containers and pipes for point level detection of all types of liquids.



VIBRATING FORK POINT LEVEL INSTRUMENTS
Figure 1. Vibrating fork point level instruments are widely used in the process industries.

In the oil and gas sector, refineries rely on vibronic instruments because they are among the most reliable of measuring instruments. This allows these devices to be used in critical applications such as overfill protection and pump dry run prevention.

Unlike float switches, vibronic instruments do not require maintenance and have a long service life. In addition, most are corrosion-resistant.

Vibronic instruments are advantageous in that they are:

- *Unaffected by media.* Vibronic instruments can be used to measure the presence of liquids with viscosities up to 10,000 mm^2/s and densities greater than 0.3 g/cm^3.

- *Unaffected by media properties.* A vibronic instrument is not affected by changing flow, turbulence, gas bubbles, foam, vibration, solids content or buildup.

TUNING FORK OSCILLATION
Figure 2. The oscillation of a tuning fork instrument changes when a liquid reaches the two forks.

Early detection allows plant personnel to address issues in a proactive manner before failure occurs.

- *Easy to install and ready for use without calibration.* In most cases, a vibronic instrument works in the application without any required adjustments or calibration.

- *Wear-, tear- and maintenance-free.* A vibronic instrument has no moving parts and requires no maintenance other than periodic cleaning.

- *Self-monitoring.* New vibronic instruments are equipped with internal diagnostics and the ability to perform proof tests and verification automatically.

CHECKING FOR CORROSION

Vibronic instruments have no moving parts, so the only physical problems they might encounter are corrosion and buildup of process materials on the tuning forks.

Most vibronic instruments are available with tuning forks made of corrosion-resistant metals, such as 316/316L stainless steel, Alloy C22 and PFA coatings, but aggressive chemicals can eventually eat through even these types of materials. When tuning forks corrode, they can break off, vibrate erratically or fail completely.

Buildup of process materials on the forks also can occur, especially in processes with entrained solids, turbulence or foam. A limited amount of coating changes the probe's frequency but does not cause it to fail, i.e., a lightly coated instrument still can operate. But when buildup on the tuning forks becomes excessive, it can cause the device to fail and not detect changes in liquid level.

Modern vibronic instruments have built-in diagnostics to detect corrosion and buildup by monitoring the tuning fork's frequency. Early detection allows plant personnel to address issues in a proactive manner before failure occurs.

PROOF TESTING

A proof test confirms the SIL rating of a safety instrumented function (SIF). NAMUR provides guidelines on what proof testing is needed to meet the requirements of IEC 61508-6, B3.2.5. NAMUR Worksheet NA-106 (Issue: 2018-09-06), Annex D, typically is referenced in the process industries — such as chemical, petrochemical and oil and gas — as well as in other process plants with hazardous operations.

Point level instruments in these and other similar applications may have to be proof tested periodically to meet various safety regulations. This can pose a problem with

WIRELESS COMMUNICATIONS

Figure 3. With Bluetooth wireless communications, a technician with a handheld device can activate a proof test from up to 40 ft away from the level instrument, making it easier to perform tests on instruments installed in inaccessible locations.

older instruments as they may have to be removed from the process for testing.

Fortunately, many new vibronic level instrument can perform a proof test on demand, which complies with IEC 61511 and ISA 84 safety standards. For example, a proof test for the Endress+Hauser Liquiphant FTL51B can be activated from a control room by sending a command over a wired connection, from a mobile device via wireless Bluetooth (Figure 3) or directly at the device.

When activated, the transmitter tests the instrument's level notification and fault notification (alarm) functions. After interrupting power to the instrument supply, a test cycle is activated, which checks the instrument and electronics.

This test is approved for IEC 61508-6 and for overfill protection according to the German Water Resources Act (WHG).

VALIDATING VERIFICATION

Process manufacturing and other industrial facilities often must provide documented evidence of level instrument performance to maintain compliance with various regulatory agencies. Typical requirements are:

- Level instruments have to be verified at regular intervals.

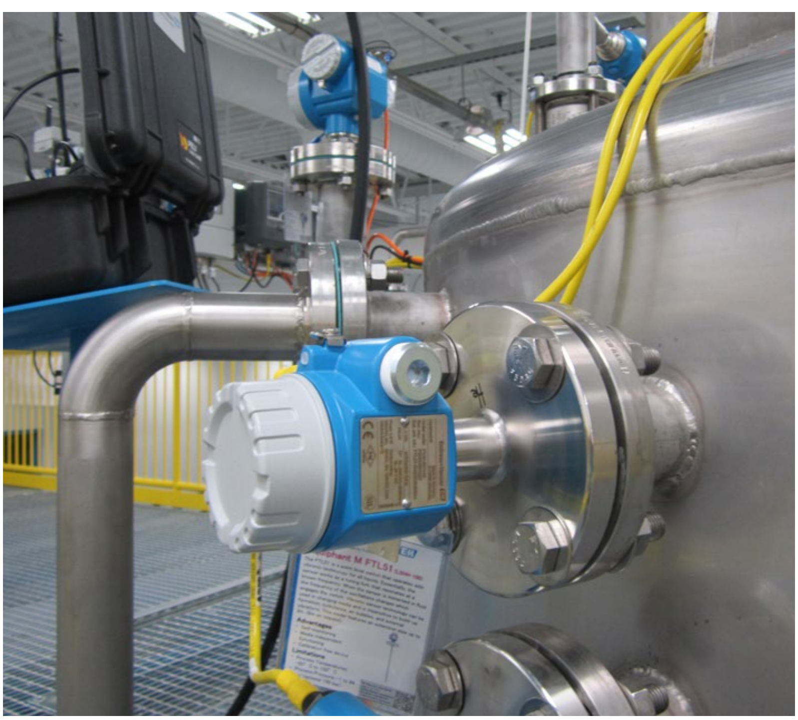
- Verification has to be performed by a qualified third party and with an accepted inspection method based on quality regulations such as ISO 9001.

- A test report needs to be provided for documented proof of verification.

The chemical and oil and gas industries have requirements for proof testing per IEC 61511, ISA 84 and other standards, while the oil and gas industry must adhere to contractual agreements between buyer and seller and comply with government agency mandates.

Most level instruments at the bottom or high point of a tank are frequently immersed in liquid and regularly activated. But some high-high level instruments (Figure 4) are seldom or never immersed in liquid, so they require periodic verification.

Regulatory requirements commonly are fulfilled by removing the level instrument, taking it to a lab and immersing it in a liquid to verify operation (commonly called a "bucket test"). Damages during transport or handling sometimes can stay undetected and lead to a situation in which a recently tested instrument is not performing per specifications. Performing verification in this manner also is costly and time-consuming and requires field work to remove and reinstall the instrument. Operator exposure to the chemical process is a safety concern.



HIGH LEVEL DETECTION
Figure 4. This high-level instrument detects a level that's too high and could cause a spill.

To address these issues, many modern vibronic instruments can perform onboard verification *in situ*. The instrument's transmitter electronics run an onboard diagnostics program, where all relevant components of the instrument are checked to confirm and document that it is still in calibration, with none of the components drifting outside of original tolerances.

For example, verification of a level instrument should include testing all electrical connections and power versus factory specifications.

Endress+Hauser's Heartbeat Technology fully complies with the requirements for traceable verification according to DIN EN ISO 9001:2008, Section 7.6 a, "Control of monitoring and measuring equipment." Upon completion of verification, the technology generates a PDF report summarizing results, which can be used to satisfy audit requirements.

MEETING IIOT DEMANDS

The demands of Industry 4.0 and IIoT are limited for point level instruments. However, predictive maintenance and process optimization software programs need data relating to instrument performance.

Most instrument manufacturers have extensive software to acquire, store and analyze data from smart devices, such as vibronic point level instruments. These software packages can analyze data from proof tests and verifications.

Mobile computers and wireless technology make it possible for a technician on the plant floor to identify a device, commission it, check the status, perform a proof test or verification and download verification documentation. Then, if the situation warrants further attention, the technician can download the relevant manuals, certificates or other documentation related to the instrument.

These types of digital capabilities allow vibronic instruments to meet Industry 4.0 and IIoT requirements.

SUMMARY

Point level instruments once led a simple life, only indicating whether a liquid was present or not. Level instruments now must conform to various safety regulations, diagnose themselves, perform self-testing and provide data for IIoT and other digital initiatives. Modern vibronic instruments are up to the task, continuing to provide reliable operation for level detection, with added functionality to meet current and future demands. ●

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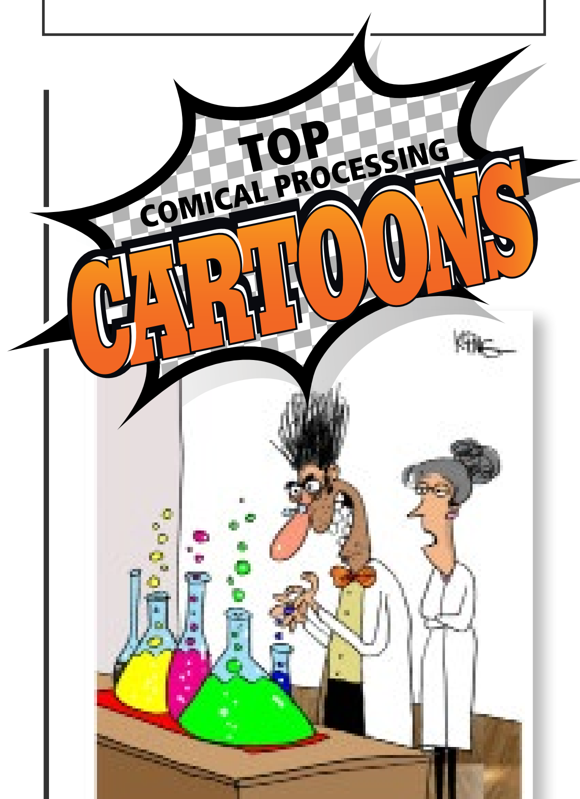

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