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Diagnostics capabilities of FOUNDATION fieldbus pressure transmitters

Tests in an FCC unit showed both instrument and process problems could be detected

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Over the past two years, the ExxonMobil Research and Engineering group tested the self-diagnostic capabilities of pressure transmitters with FOUNDATION fieldbus (FF) capability installed on a refinery FCC unit. This project involved conducting a series of tests on the ability of the devices to diagnose plugged impulse lines.

A typical purged instrument detail for a pressure transmitter in service on an FCC unit where catalyst is present is shown in Fig. 1. Three types of problems associated with the pressure transmitters and purge systems on an FCC unit, and with the FCC process itself, can be detected with the diagnostic capabilities of fieldbus pressure transmitters:

1. Loss of a reliable signal due to a plugged pressure tap caused by catalyst restricting the outlet
2. Plugged restriction orifice or filter, resulting in diminished purge flow and possible loss in the signal sensitivity (can lead to problem 1)
3. Circulation problems caused by stick-slip flow condition in the FCC unit.

In addition to identifying process-related problems, the diagnostics capabilities of fieldbus pressure transmitters should be able to help identify conditions related to plugged impulse lines before they cause operational upsets.

Economic impact of predictive diagnostics. Advanced diagnostics technologies should help avoid unexpected process shutdowns during refinery operation. The blockage in pressure transmitters impulse lines is notorious in refinery applications, as well as many other chemical and gas applications. Though a well-experienced operator might have a feel for impulse line blockage during normal operations, it is usually well after the fact. When the impulse lines are plugged, the control system will not be getting an accurate pressure reading [pressure sensor will be reading the trapped pressure between the sensor and where the blockage is in the impulse line(s)].

Impulse line blockage can be very costly. Depending on refinery capacity, a process shutdown due to an impulse line blockage during FCC unit operation could cost as much as $1 million per day if the unit is completely shut down. Further, it might take

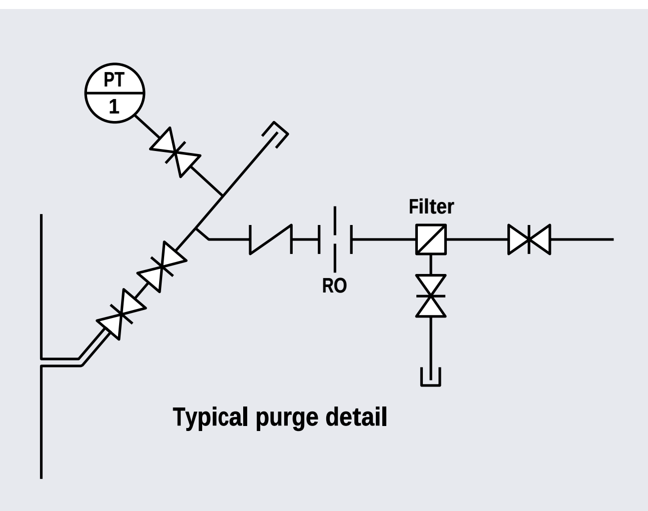

FIG. 1. Typical purge detail of a pressure transmitter on an FCC unit.

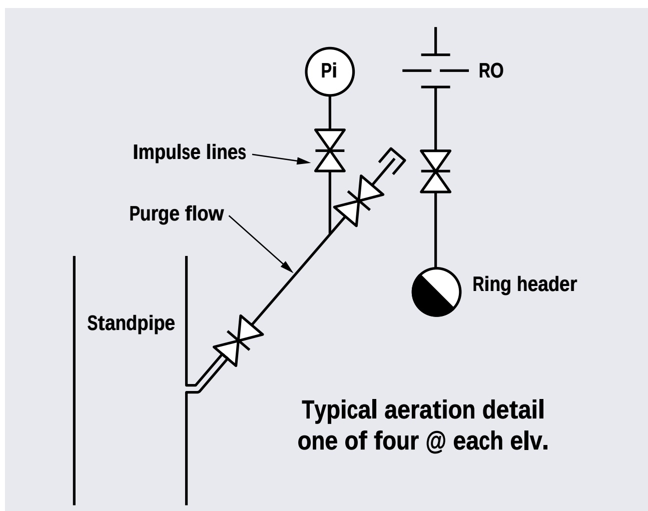

FIG. 2. Typical detail of four aeration points fed by a common header.

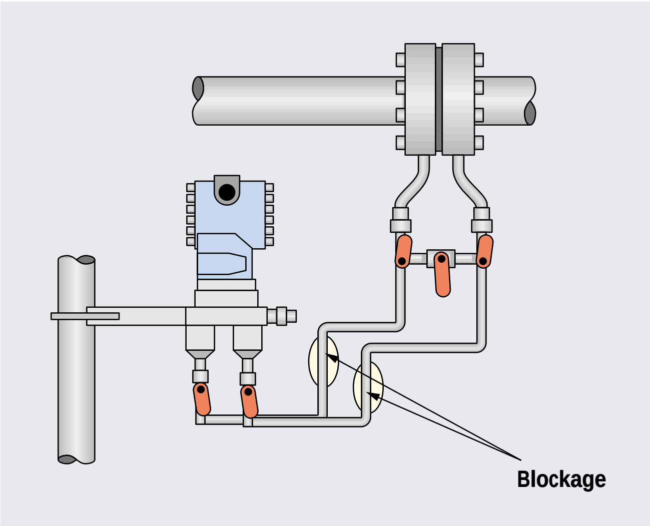

FIG. 3. When pressure transmitter impulse lines are blocked, the measurement becomes questionable.

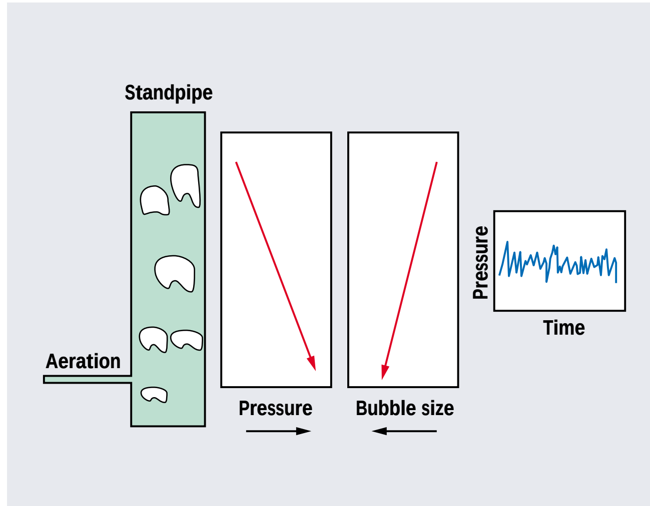

FIG. 4. Under normal conditions, gas is entrained into the standpipe and travels downward between the catalyst particles as bubbles.

up to seven days to restart the FCC unit. The FCC unit has a large impact on profits. Early detection of possible upsets, especially if shutdowns are avoided, can significantly enhance refinery profits.

With the potential economic impact in mind, ExxonMobil decided to put these new advanced diagnostics technologies to test and see where and how they might help avoid refinery production outages. ExxonMobil believes these results will be beneficial to the entire oil and gas business.

Test instrument installation. The operational FCC unit selected as the field test site is equipped with 18 levels of aeration taps on the regenerated catalyst standpipe. Fig. 2 displays a typical detail of four aeration points fed by a common ring header. Several ring headers are, in turn, connected to a single flow controller that controls total flow to the group. The restriction orifice then sets aeration flow to each point on the standpipe within a grouping. There are three flow controllers for the 18 different aeration levels forming three groups.

The upper 17 aeration levels have been equipped with pressure transmitters to aid in diagnosing flow instability problems and to help optimize the aeration distribution. These instruments are not used in any unit control or emergency shutdown system, which is the reason they were chosen for this study. The instruments are generally connected to the location occupied by the pressure indicator in Fig. 2.

Comparing Fig. 1 to Fig. 2, it is apparent that the arrangements are functionally the same. Gas flows associated with aeration requirements are in general much larger than those associated with instrument purge, so typically a filter is not required.

Problem theory. Line plugging has long been an issue for flow and level measurements in many process applications. Processes with dense materials such as crude oil or those in colder climates are particularly susceptible to impulse line plugging.

In a typical process, impulse line length could vary from 1 ft to more than 10 ft. Although recent close-coupled designs are intended to eliminate this problem, industry standards or the process conditions require impulse lines for flow and level measurements.

When pressure transmitter impulse lines are blocked, operators and the control system can no longer rely on the measurement since only the trapped pressure level between the sensor and the point of blockage is being measured and not the actual process pressure. Fig. 3 depicts differential pressure transmitter blockage.

Although problems 1 and 2, listed in the beginning of this article, may seem similar, the first involves standpipe pressure tap blockage, not pressure transmitter impulse line plugging.

The third problem is a process problem, and is essentially a function of catalyst circulation rate, standpipe and the fluidization properties. Under normal conditions, gas is entrained into the standpipe and travels downward between the catalyst particles (emulsion phase) as bubbles (Fig. 4). These bubbles are compressed as they travel downward, forming smaller bubbles. In addition, they will merge to form larger bubbles, which can subsequently break apart. This leads to pressure fluctuations or noise within the standpipe.

Under certain conditions (low circulation or poor catalyst fluidization properties), the catalyst will over-deaerate as the bubbles travel down the standpipe. The compression effect will then cause the bubbles to disappear. When this happens, pressure buildup along the standpipe length is no longer smooth but becomes erratic. Under severe conditions, the catalyst will bridge across the standpipe, momentarily stopping and then breaking loose again. This sudden stopping and starting of the catalyst flow is generally referred to as "stick-slip flow." It produces a very noticeable chugging noise, with pressure fluctuations that become less random but more severe (Fig. 5). If left uncorrected, this condition can result in severe damage to the standpipe system, particularly at expansion joints.

Normally, "noise" from the standpipe should be "white noise" with no distinguishable pattern as a result of the random size and population of gas bubbles in the standpipe. When the catalyst bridges, the noise becomes more regular. "Noise" at the bridging condition shows up as large pressure fluctuations to the pressure transmitters generally in use today. Detecting this condition before it becomes serious has been a costly challenge.

One goal of this field test, was to determine if the Statistical Process Monitoring diagnostic capabilities of FF pressure trans-

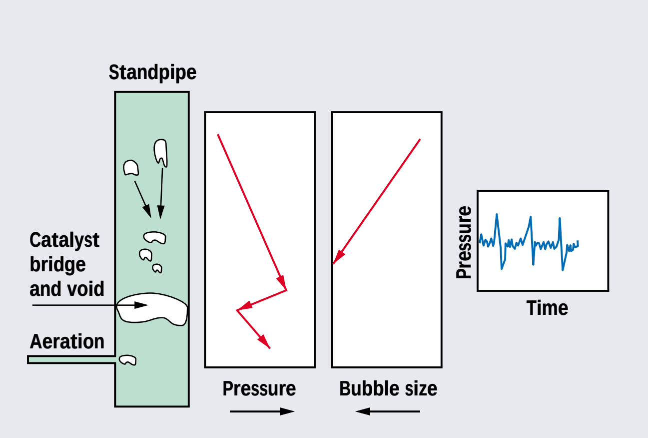

FIG. 5. Stick-slip flow produces a noticeable chugging noise with pressure fluctuations that become less random but more severe.

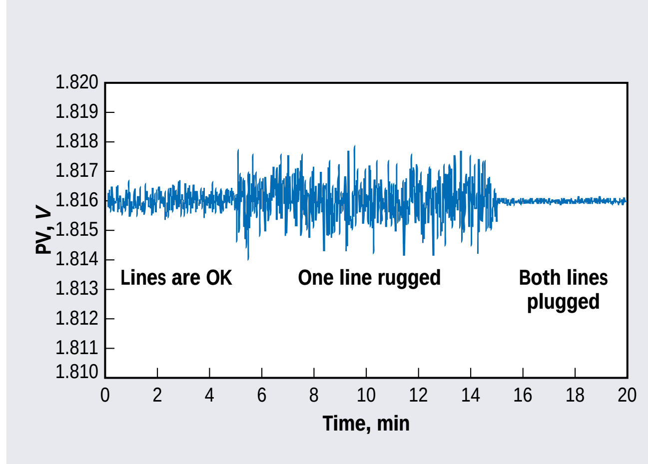

FIG. 6. Sensor output during normal and plugged impulse line conditions.

mitters could detect noise anomalies in the standpipe early enough to allow the operators to prevent the bridging condition.

Diagnostics technologies of pressure transmitters with FOUNDATION fieldbus capability.

Plugged impulse line detection. Plugged impulse line detection technology is based on an advanced pattern recognition technology with built-in intelligence to be aware of the environmental conditions of the pressure and differential pressure transmitters widely used in the process industries. Basically, the pattern recognition algorithm embedded in the pressure transmitters receives the sensor updates (update frequency varies among sensor manufacturers). The faster the response time, the more information can be captured about the process noise. This becomes important especially for differential pressure applications to differentiate a single-leg plugged condition from both legs being plugged.

In general, the measurement signal contains fluctuations superimposed on the average value of the pressure or differential pressure of the process, called process noise or signature. These fluctuations are induced by the flow and are a function of the geometric and physical properties of the system. The time domain signatures (i.e., variance and correlation) of these fluctuations do not change as long as the overall system behavior stays the same (i.e., steady-state process). In addition, these signatures are not affected significantly by small changes in the average value of the flow variables. This offers an advantage in identifying and isolating line plugging, which is part of the underlying pattern recognition technology developed to solve the problem of line plugging.

When the lines between the process and the sensor start to clog through fouling and buildup on the impulse tubing inner surfaces—or loose particles in the main flow getting trapped in the impulse lines—time and frequency domain signatures of the fluctuations start to change from their normal states. The clogging decreases or increases the effect of damping on the pressure noise of the main flow signal. As the impulse lines get clogged, measurement noise levels change. Fig. 6 displays the noise conditions of sensor outputs during normal, one line plugged and both lines plugged conditions.

Some fieldbus pressure transmitters have this diagnostics technology as part of their Advanced Diagnostics Block (ADB). Fig. 7 displays the ADB block diagram, where various function blocks such as Transducer Block (TB), Resource Block (RB) and others are displayed.

Operational details of plugged impulse line detection technology can be summarized into two distinct sections once it is properly configured, which is simply selecting a few parameters.

First is the *learning phase.* The algorithm first observes its environment, such as the process noise levels and temperature conditions. (These conditions could significantly differ from an FCC unit application in a refinery to simple drum level measurement.) At the end of this phase, the algorithm establishes the basic signature for that pressure transmitter as it is used in that process. It establishes various parameters that represent process behavior and keeps them in its memory to be used during the monitoring phase. The learning phase also has a verification phase, so that repeatability of the process behavior is established.

Second is the *monitoring phase,* where the algorithm periodically monitors the process and looks for changes in process signature. Once a change in process conditions is detected and verified, the pressure transmitter sets its alert bit to inform the operator and/or maintenance personnel, since the plugging could cause a major process upset. Fig. 8 shows a display of the fieldbus pressure transmitter status.

Statistical process monitoring. The second diagnostics feature of the fieldbus pressure transmitters is a generic process anomaly detection tool called *Statistical Process Monitoring (SPM).* Many process anomalies can be analyzed and correctly diagnosed by an expert eye or by an expert system where necessary process expertise and possible conditions and a rule-base are present.

Traditionally, fault detection has been part of the control system where analysis is done using data collected by process historians. There are various reasons for this implementation choice. Most importantly, the field devices could not handle the tasks required of fault detection methodologies. This is mainly due to the limited firmware capability of the older technologies. However, with the help of advanced silicon technology and digital fieldbus technologies, today's smart transmitters are capable of providing more information regarding the process and its conditions in addition to their traditional process variable information.

Process anomalies can be grouped into five categories. These

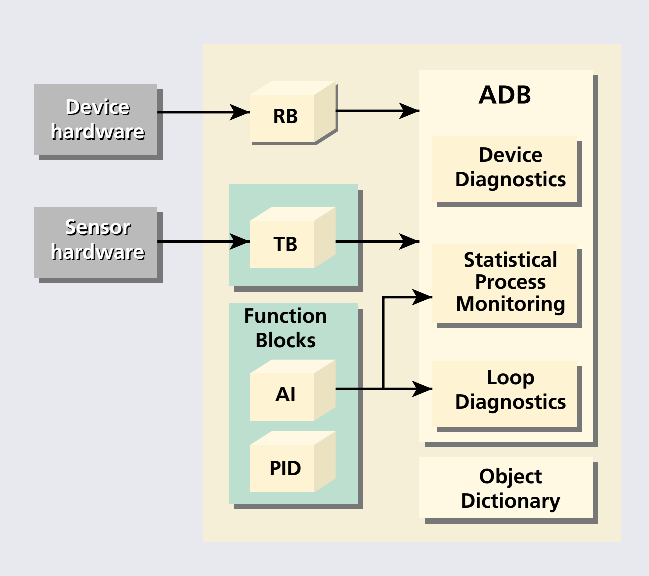

FIG. 7. Advanced diagnostic block of the fieldbus transmitter

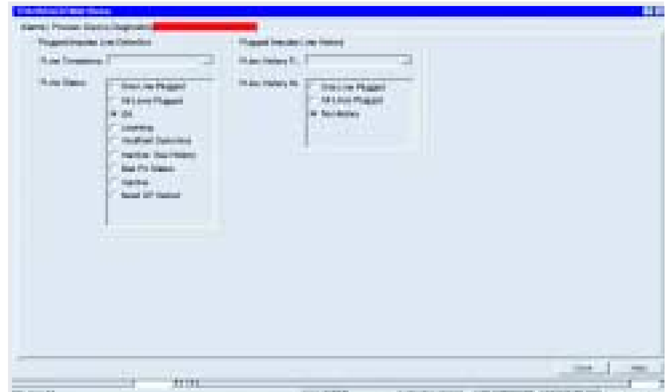

FIG. 8. Display of fieldbus pressure transmitter status.

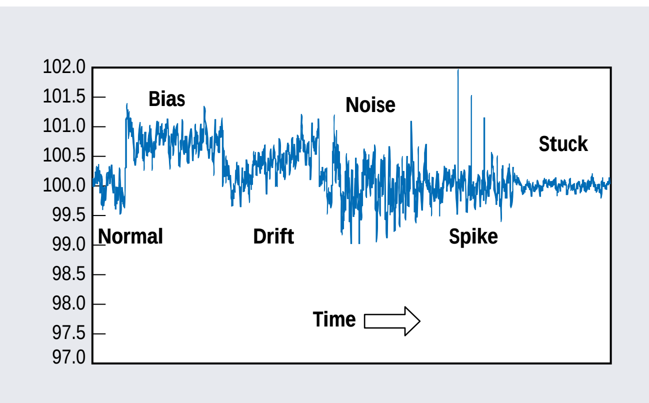

FIG. 9. Process anomalies can be categorized into five distinct classes: drift, bias, noise, spike and stuck.

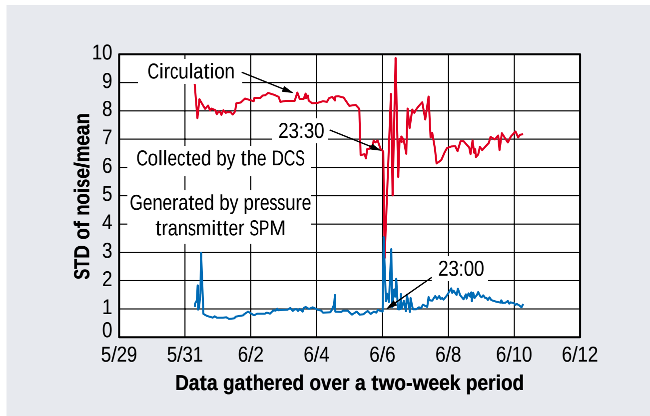

FIG. 10. Historian and SPM data collected from the transmitter during a catalyst upset.

are common for all sensor types and processes: pressure, temperature, flow, level and others. Using advanced pattern recognition and statistical analysis methods, fieldbus transmitters and smart valves can now detect drift, bias, noise, spike and stuck behaviors of each process where:

- Drift: sensor/process output changes gradually
- Bias: sensor/process output shows a level change
- Noise: dynamic variation in the sensor/process output is increased
- Spike: sensor/process output is momentarily very high or low
- Stuck: dynamic variation in the sensor/process output is decreased.

Fig. 9 illustrates these anomalies along with normal behavior.

The approach and key features of the developed local anomaly detection technology that make it applicable to a broad range of industrial processes are:

- ▶ No redundancy in the measurement system is assumed
- ▶ No mathematical model of the process is necessary
- ▶ No mathematical model of the sensor is required.

Field test results.

Test condition 1: Plugged impulse line detection. Unit testing was broken into two days. On day one, the plugged tap and loss of purge scenarios were tested (problems 1 and 2). On day two, the circulation problem was tested. Prior to starting the test, each instrument was calibrated to establish new baseline values for the diagnostics analysis, and both plugged line diagnostics and SPM features of the transmitters were initialized to learn the process and establish the base-line process patterns.

To test the built-in impulse line blockage diagnostics feature of the fieldbus pressure transmitter, root valves of the installation were used to create impulse line blockage.

The fieldbus pressure transmitter successfully detected every test scenario.

Test condition 2: Loss of purge flow detection. This was tested by closing the purge source valve. (It was expected that either the built-in impulse line plugging detection feature or the statistical data collected at the fieldbus transmitter via SPM would provide sufficient data to observe the blocking.) Test results indicated that both diagnostics features were successfully indicating the loss of flow condition.

Test condition 3: Circulation problems within FCC unit. The internal diagnostic technology of the fieldbus pressure transmitter tested, namely SPM technology, continuously samples the process signal from the sensor at high frequencies and performs

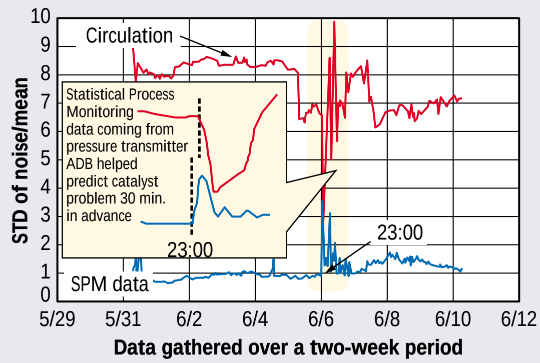

FIG. 11. The transmitter diagnostic data detected the catalyst upset 30 min. in advance.

additional calculations on it. The transmitter calculates the mean value of the signal and how that changes with time. It also calculates the standard deviation in the noise from the process signal. The standard deviation calculation should allow us to detect a change in the white noise characteristic long before transition into stick-slip flow. This will allow operations to take corrective actions before circulation problems develop.

Fig. 10 displays the data collected with the historian as well as the fieldbus pressure transmitter's ADB for a period of two weeks during which a catalyst upset occurred. Fig. 11 highlights the data collected from the transmitter, where the upset during the operation was detected 30 minutes in advance. It was expected at the beginning of the test period that this type of data from the fieldbus pressure transmitter would indicate such process upsets in advance so that necessary measures could be taken to avoid process shutdowns. The next stages of the research program will integrate this type of data with operational procedures to improve the operators' ability to respond to catalyst upsets. **HP**

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