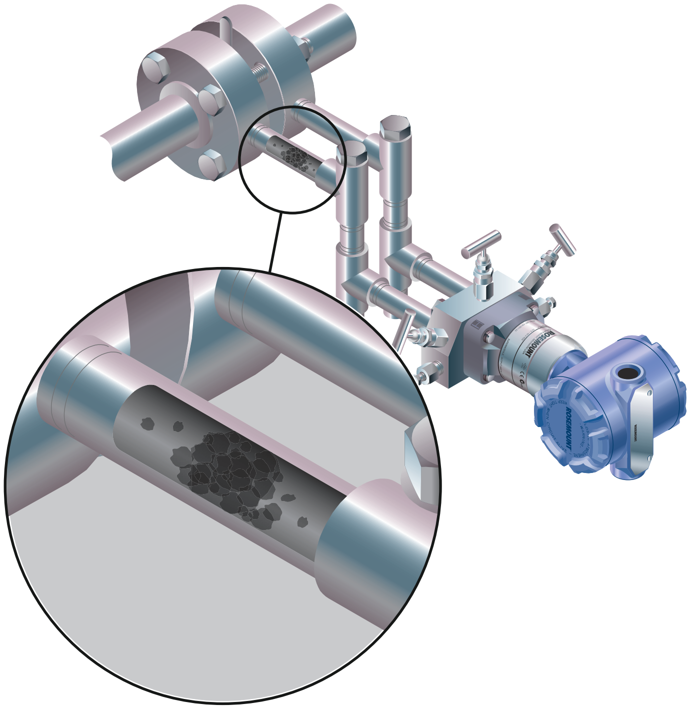
Plugged Impulse Line Detection

Using Statistical Processing Technology

1.0 Introduction

Pressure transmitters are used in pressure, level, and flow measurement applications. Regardless of application, the transmitter is rarely connected directly to the pipe or vessel. Small diameter tubes or pipes commonly called impulse lines are used to transmit the pressure signal from the process to the transmitter. In some applications, these impulse lines can become plugged with solids or frozen fluid in cold environments, effectively blocking the pressure signals (Figure 1). One survey in Europe estimated that 60 percent of heat trace systems are not working properly.[1] The user typically does not know that the blockage has occurred. Because the pressure at the time of the plug is trapped, the transmitter may continue to provide the same signal as before the plug. Only after the actual process changes and the pressure transmitter's output remains the same may someone recognize that plugging has occurred. This is a typical problem for pressure measurement, and users recognize the need for a plugged impulse line diagnostic for this condition.

Figure 1. Basics of Plugged Impulse Lines



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[1] *Daiber and Hughes, cited in NEL Flow Programme Paper:* Guide to Impulse Lines for DP Flowmeters.

Emerson™ has developed a unique patented technology that provides a means for early detection of abnormal situations in a process environment, including plugged impulse lines. The technology is based on the premise that virtually all dynamic processes have a unique noise or variation signature when operating normally, and that changes in these signatures may signal that a significant change in the process, process equipment, or transmitter installation will occur or has occurred. For example, the noise source may be equipment in the process such as pumps or agitators, or the natural variation in the DP value caused by turbulent flow, or a combination of both.

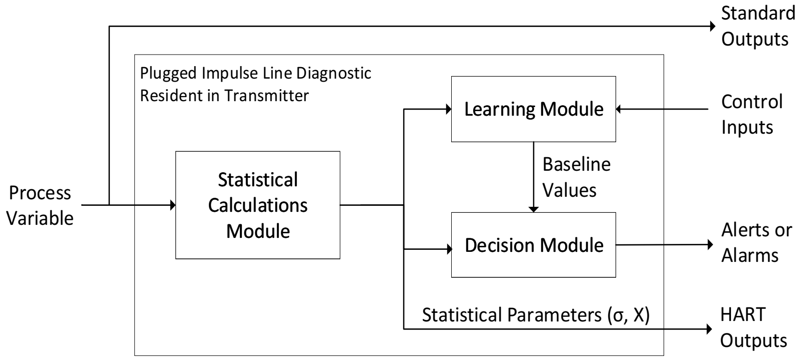
The sensing of the unique signature begins with the combination of a high speed sensing device such as the Rosemount™ 3051S Pressure Transmitter, with patented software resident in a HART® Advanced Diagnostics or FOUNDATION™ Fieldbus Feature Board to compute statistical parameters that characterize and quantify the noise or variation. These statistical parameters are the mean, standard deviation, and coefficient of variation (ratio of standard deviation to mean) of the input pressure. Filtering capability is provided to separate slow changes in the process due to setpoint changes from the process noise or variation of interest. The transmitter can make the statistical parameters available to the host system via HART or Fieldbus communications as non-primary variables. The transmitter also has internal software that can be used to baseline the process noise or signature via a learning process. Once the learning process is completed, the device itself can detect significant changes in the noise or variation, and communicate an alarm via the 4 – 20 mA output or alert via HART or FOUNDATION Fieldbus.

Testing at Emerson and other sites indicates that this technology can detect plugged impulse lines. Plugging effectively disconnects the transmitter from the process, changing the noise pattern received by the transmitter. As the diagnostic detects changes in noise patterns, and there are multiple sources of noise in a given process, many factors can come into play. These factors play a large role in determining the success of diagnosing a plugged impulse line. The objective of this paper is to acquaint users with the basics of plugged impulse lines and the Plugged Impulse Line diagnostic, the positive and negative factors for successful plugged line detection, and the dos and don’ts of installing pressure transmitters and configuring and operating the Plugged Impulse Line diagnostic.

2.0 Plugged Impulse Line Diagnostic Operation

A block diagram of the Plugged Impulse Line diagnostic is shown in Figure 2.

Figure 2. Plugged Impulse Line Block Diagram

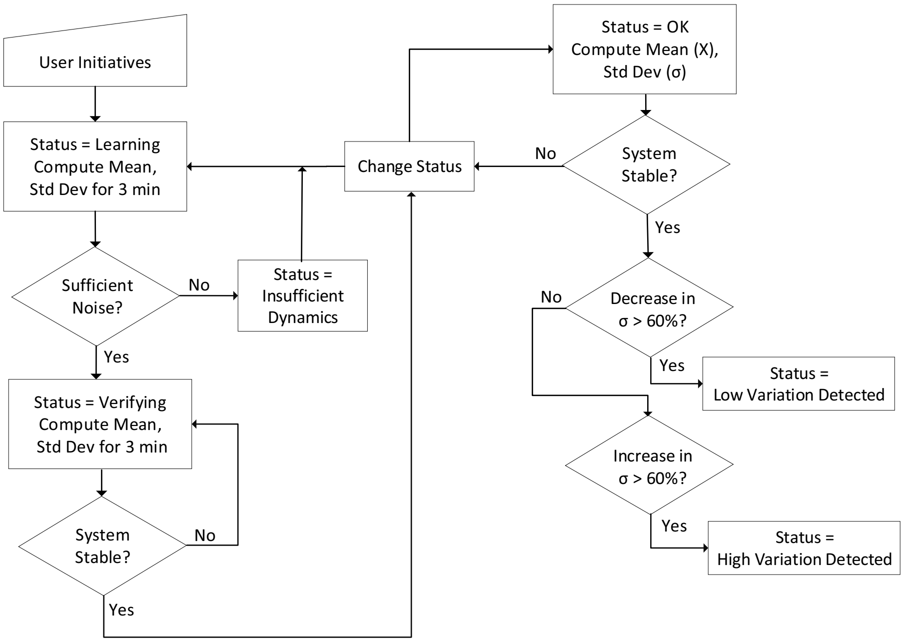


The pressure process variable is input to a Statistical Calculations Module. There, basic high pass filtering is performed on the pressure signal. The coefficient of variation is calculated from the ratio of standard deviation to mean. The mean (or average) is calculated on the unfiltered pressure signal, and the standard deviation is calculated from the filtered pressure signal. These statistical values are available to the user via HART or FOUNDATION Fieldbus on handheld communication devices like the Trex™ or asset management software such as (among others) Emerson's AMS Device Manager. The values can also be assigned as non-primary variables from the device for communication to the user through other tools like the Rosemount 333 HART Tri-loop™.

The Plugged Impulse Line diagnostic also contains a learning module that establishes the baseline values for the process. Baseline values are established under user control at conditions considered normal for the process and installation. These baseline values are made available to a decision module that compares the baseline values to the most current values of the mean and standard deviation. Based on sensitivity values and the actions selected by the user, the Plugged Impulse Line diagnostic generates alarms or alerts when a significant change is detected in either value.

Further detail of the operation of the Plugged Impulse Line diagnostic is shown in the Figure 3 flowchart.

Figure 3. Simplified Flowchart of the Plugged Impulse Line Operation



This is a simplified version showing operation using the default values. While the diagnostic continuously calculates the mean and standard deviation values, the learning and decision modules are evaluated when the Plugged Impulse Line diagnostic algorithm is active. Once enabled, the diagnostic enters the learning/verification mode. The diagnostic calculates a baseline mean and standard deviation value over a period of time controlled by the user (Learning/Monitoring Period; default is 3 minutes). The status of the diagnostic will be "Learning". A check is performed to make sure that the process has a sufficiently high noise or variability level (above the low level of internal noise inherent in the transmitter itself). If the level is too low, the diagnostic will continue to calculate baseline values until the criteria is satisfied (or turned off). After passing this check, a second set of values is calculated over the same period of time and compared to the original set to verify that the measured process is stable and repeatable. During this period, the diagnostic's mode will change to "Verifying". If the process is stable, the diagnostic will use the last set of values as baselines and move to the "Monitoring" mode. If the process is unstable, the diagnostic will continue to verify until stability is achieved. The stability criteria are also user defined.

Once in the "Monitoring" mode, new mean and standard deviation values are continuously calculated, with new values available every second. When using mean and standard deviation as the Plugged

Impulse Line diagnostic variables, the mean value is compared to the baseline mean value. If the mean has changed by a significant amount, the diagnostic can automatically return to the Learn mode. The diagnostic does this because a significant change in mean is likely due to a change in process operation and can result in a significant change in noise level (i.e. standard deviation) as well. If the mean has not changed, the standard deviation value is compared to the baseline value. If the standard deviation has changed significantly relative to the baseline, exceeding preset threshold values, this may indicate a change has occurred in the process, equipment, or transmitter installation and a HART alert or analog alarm is generated.

For DP flow applications where the mean pressure is likely to change due to changing process operation, the recommended variable for process diagnostics is the coefficient of variation. Since the coefficient of variation is the ratio of standard deviation to mean, it represents normalized process noise values even when the mean is changing. If the coefficient of variation changes significantly relative to the baseline and exceeds sensitivity thresholds, the transmitter can generate a HART alert or analog alarm.

When a trip of the diagnostic occurs, the Plugged Line Impulse diagnostic also time stamps the event using the device's internal timer. This timer keeps track of the elapsed time since the event's occurrence, giving the user the ability to tie diagnostic indication from the Rosemount 3051S with Advanced Diagnostics to other events in the plant. The unit also uses the timer to record its total operating time.

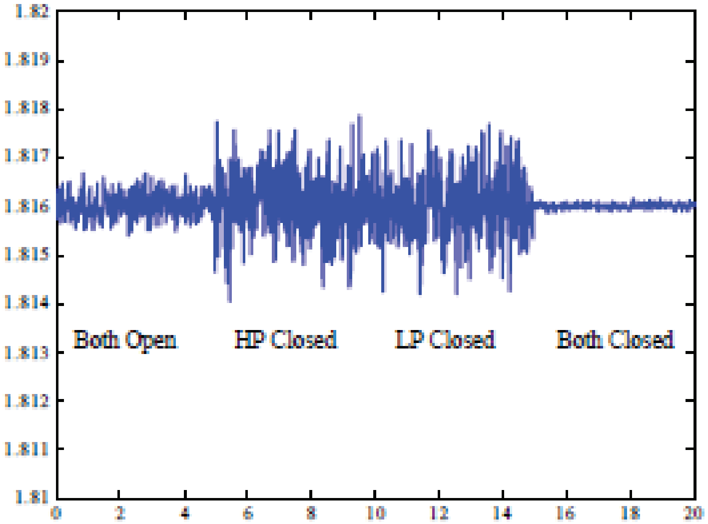
3.0 Plugged Impulse Line Physics

The physics of plugged impulse line detection begins with the fluctuations or noise present in most pressure and differential pressure (DP) signals. In the case of DP flow measurements, these fluctuations are produced by the flowing fluid and are a function of the geometric and physical properties of the system. The noise can also be produced by the pump or control system. This is also true for pressure measurements in flow applications, though the noise produced by the flow is generally less in relation to the average pressure value.

Pressure level measurements may have noise if the tank or vessel has a source of agitation. The noise signatures do not change as long as the system is unchanged. In addition, these noise signatures are not affected significantly by small changes in the average value of the flow rate or pressure. These signatures provide the opportunity to identify a plugged impulse line. When the lines between the process and the transmitter start to plug through fouling and build-up on the inner surfaces of the impulse tubing or loose particles in the main flow getting trapped in the impulse lines, the time and frequency domain signatures of the noise start to change from their normal states. In the simpler case of a pressure measurement, the plug effectively disconnects the pressure transmitter from the process. While the average value may remain the same, the transmitter no longer receives the noise signal from the process and the noise signal decreases significantly. The same is true for a DP transmitter when both impulse lines are plugged.

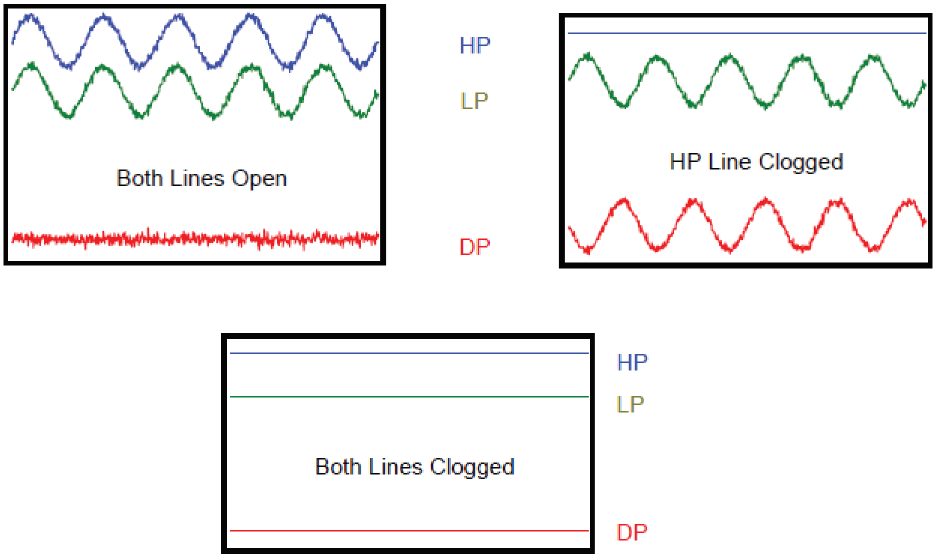
The case of the differential pressure measurement in a flow application with a single line plugged is more complicated, and the behavior of the transmitter may vary depending on a number of factors. First the basics: a differential pressure transmitter in a flow application is equipped with two impulse lines, one on the high pressure side (HP) and one on the low pressure side (LP) of the primary element. Understanding the results of a single plugged line requires understanding of what happens to the individual pressure signals on the HP and LP sides of the primary element. Common mode noise is generated by the primary element and the pumping system as depicted in Figure 4.

Figure 4. Differential Pressure Signals Under Different Plugging Conditions



When both lines are open, the differential pressure sensor subtracts the LP from the HP. When one of the lines are plugged (either LP or HP), the common mode cancellation no longer occurs. Therefore there is an increase in the noise of the DP signal. See Figure 5.

Figure 5. Differential Pressure (DP) Signals Under Different Plugged Conditions



However, there is a combination of factors that may affect the output of the DP transmitter under single plugged line conditions. If the impulse line is filled with an incompressible fluid, no air is present in the impulse line or the transmitter body, and the plug is formed by rigid material, the noise or fluctuation will decrease. This is because the combination of the above effectively "stiffens" the hydraulic system formed by the DP sensor and the plugged impulse line.

The Plugged Impulse Line diagnostic can detect these changes in the noise levels through the operation described in the previous section.

4.0 Plugged Line Detection Factors

The factors that may play a significant role in a successful or unsuccessful detection of a plugged impulse line can be separated into positive factors and negative factors, with the former increasing the chances of success and the latter decreasing the chances of success. Within each list, some factors are more important than others as indicated by the relative position on the list. If an application has some negative factors that does not mean that it is not a good candidate for the diagnostic. The diagnostic may require more time and effort to set up and test and the chances of success may be reduced. Each factor pair will be discussed.

4.1 Ability to Test In-Situ

The single most important positive factor is the ability to test the diagnostic in-situ. Virtually all DP flow and most pressure measurement installations include a root or manifold valve for maintenance purposes. By closing the valve, preferable the one(s) closest to the process to most accurately replicate a plug, the user can note the response of the diagnostic and the change in the standard deviation value and adjust the sensitivity or operation accordingly.

4.2 Stable, In-Control Process

A process that is not stable or in no or poor control may be a poor candidate for the Plugged Impulse Line diagnostic. As explained earlier, the diagnostic baselines the process under conditions considered to be normal. If the process is unstable, the diagnostic will be unable to develop a representative baseline value. The diagnostic may remain in the learning/verifying mode. If the process is stable long enough to establish a baseline, an unstable process may result in frequent relearning/verifications and/or false trips of the diagnostic.

4.3 Well Vented Installation

This is an issue for liquid applications. Testing indicates that even small amounts of air trapped in the impulse line or the pressure transmitter can have a significant effect on the operation of the diagnostic. The small amount of air can dampen the pressure noise signal as received by the transmitter. This is particularly true for DP devices in single line plugging situations and GP/AP devices in high pressure/low noise applications. See the next section and the "Impulse Line Length" for further explanation. Liquid DP flow applications require elimination of all the air to insure the most accurate measurement.

4.4 DP Flow and Low GP / AP vs. High GP / AP Measurements

This is best described as a noise to signal ratio issue and is primarily an issue for detection of plugged lines for high GP/AP measurements. Regardless of the line pressure, flow generated noise tends to be about the same level. This is particularly true for liquid flows. If the line pressure is high and the flow noise is very low by comparison, there may not be enough noise in the measurement to detect the decrease brought on by a plugged impulse line. The low noise condition is further enhanced by the presence of air in the impulse lines and transmitter if a liquid application. The Plugged Impulse Line diagnostic will alert the user to this condition during the learning mode by indicating "Insufficient Variation" status.

4.5 Flow vs. Level Applications

As previously described, flow applications naturally generate noise. Level applications without a source of agitation have very little or no noise, therefore making it difficult or impossible to detect a reduction in noise from the plugged impulse line. Noise sources include agitators, constant flow in and out of the tank maintaining a fairly consistent level, or bubblers.

4.6 Impulse Line Length

Long impulse lines potentially create problems in two areas. First, they are more likely to generate resonances that can create competing pressure noise signals with the process generated noise. When plugging occurs, the resonant generated noise is still present, and the transmitter does not detect a significant change in noise level, and the plugged condition is undetected. The formula that describes the resonant frequency is:

$$fn = (2n-1)*C/4L$$ (2)

where:
fn is the resonant frequency,
n is the mode number,
C is the speed of sound in the fluid, and
L is the impulse length in meters.

A 10 meter impulse line filled with water could generate resonant noise at 37 Hz, above the frequency response range of a typical Rosemount pressure transmitter. This same impulse line filled with air will have a resonance of 8.7 Hz, within the range. Proper support of the impulse line effectively reduces the length, increasing the resonant frequency.

Second, long impulse lines can create a mechanical low pass filter that dampens the noise signal received by the transmitter.

The response time of an impulse line can be modeled as a simple RC circuit with a cut- off frequency defined by:

$$\tau = RC \text{ and } \tau = 1/2\pi f_c$$
$$R = 8\nu L/\pi r^4$$
$$C = \Delta\text{Volume}/\Delta\text{Pressure}$$

where:
f_c is the cut-off frequency
ν is the viscosity in centipoises,
L is the impulse line length in meters
r is the radius of the impulse line.

The "C" formula shows the strong influence of air trapped in a liquid filled impulse line, or an impulse line with air only.

Both potential issues indicate the value of short impulse lines. One installation best practice for DP flow measurements is the use of the Rosemount 405 series of integrated compact orifice meters with the 3051S Pressure Transmitter. These integrated DP flow measurement systems provide perhaps the shortest practical impulse line length possible while significantly reducing overall installation cost and improved performance. They can be specified as a complete DP flow meter.

4.7 Liquid vs. Gas / Steam Flow Applications

In general, liquids generate and transmit noise signals better than gases and steam. Therefore, the reductions (or increase) in the noise levels under plugged conditions is less. More time may be required to properly adjust the Plugged Impulse Line diagnostic to detect plugged conditions, particularly single plugging, in a gas or steam flow application.

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4.8 Low Beta vs. High Beta Primary Elements

Dual and single line plugging can be detected for high beta (0.65 and greater) primary elements, including annubars. In general, these devices generate lower common noise signals than the lower beta primary elements. Extra time may be required to properly adjust the Plugged Impulse Line diagnostic to detect plugged conditions, particularly single line plugs.

Note
The Plugged Impulse Line diagnostic capability in the Rosemount 3051S Pressure Transmitter with Advanced Diagnostics calculates and detects significant changes in statistical parameters derived from the input pressure signal. These statistical parameters relate to the variability of and the noise signals present in the pressure signal. It is difficult to predict specifically which noise sources may be present in a given pressure measurement application, the specific influence of those noise sources on the statistical parameters, and the expected changes in the noise sources at any time. Therefore, Rosemount cannot absolutely warrant or guarantee that the diagnostic will accurately detect each specific condition under all circumstances.

4.9 Configuring the Plugged Impulse Line Diagnostic

A complete description of the Plugged Impulse Line diagnostic parameters is provided in the respective instruction manuals for the Rosemount 3051S. For the HART version, the recommended settings are the same as the default values. These parameters are located in the configuration guided setup and on the "Baseline Configuration" screen. The settings are listed below in Table 1.

Table 1: Recommended Initial Settings for Plugged Impulse Line Diagnostic

Parameter	Recommended Initial Setting
SPM Mode	On
SPM Variable	Stdev&Mean (pressure and DP level applications) Coefficient of Variation (DP flow applications)
Lean Monitoring Period	3 minutes
Sensitivity	Medium
Action	Alert Unlatched

5.0 Troubleshooting the Plugged Impulse Line Diagnostic

A complete troubleshooting guide is provided in the Rosemount 3051S Pressure Transmitter reference manual. Relevant sections have been replicated here for eliminating false trips and non-detection of plugged impulse lines. Remember that events other than plugged impulse lines can cause significant changes in noise patterns.

Table 2: Plugged Impulse Line Diagnostic Issues and Actions

Plugged Impulse Line Diagnostic Issue	Action
Diagnostic algorithm status indicates insufficient dynamics and will not leave learning or verifying mode	Process is very low noise. Turn off insufficient dynamics check (Learning screen). Technology algorithm will be unable to detect a significant decrease in noise level.
Diagnostic algorithm will not leave verifying mode	Process is unstable. Increase learning sensitivity checks (Learning screen). If this does not correct the issue, increase the learning verification period to match or exceed the cycle time of the instability of the process. If maximum time does not correct the problem, process is not a candidate for Plugged Impulse Line diagnostic. Correct stability issue or turn off diagnostic.
Diagnostic does not detect a known condition	With the condition present, but the process operating, go to the status or review screen and note the current statistical values and compare to the baseline and threshold values. Adjust the sensitivity threshold values until a trip of the diagnostic occurs.
Diagnostic indicates “High Variation Detected” when no diagnostic event has occurred	The most likely cause of this is a fast change in the value of the process variable. Direction of the change is not important. Increase the learning/monitoring period to better filter out increases in standard deviation.

6.0 Conclusion

Detection of plugged impulse lines is important for many pressure measurements. Emerson has developed a patented and unique statistical processing technology that can be used to detect plugged impulse lines in a variety of pressure applications. This technology is resident in HART and FOUNDATION Fieldbus versions of the Rosemount 3051S Pressure Transmitter with Advanced Diagnostics, and can provide early warning of process, equipment and installation problems. This is accomplished by using statistical techniques to characterize the process signal and noting changes in the process signal characteristics.

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