SELECTING PRESSURE TRANSMITTERS TO IMPROVE CENTRIFUGAL COMPRESSOR SAFETY & EFFICIENCY

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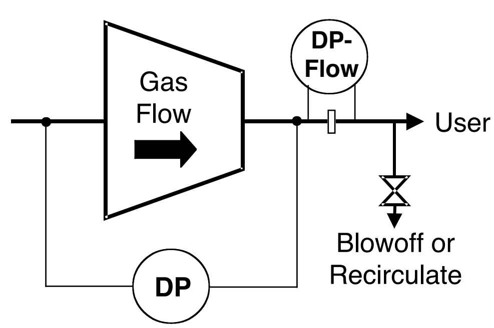
ABSTRACT

Centrifugal compressors are widely used in the process and oil & gas industries. Correct transmitter selection is critical for these applications – in particular, anti-surge and throughput control. Unfortunately, many user practices are based not on quantifiable engineering methodologies, but on experience valid more than a decade ago, but now obsolete. The objective is to allow the user to improve on the all-too-common "surge-plus-10%" rule, substituting rigorous methodologies to quantify application requirements and system performance. The paper will explain how transmitter performance – especially response time and installed repeatability – affects compressor safety. Then, methodologies and tools will be presented which allow users to quickly and reliably estimate these parameters, allowing the user to minimize unnecessary energy cost, without increasing safety risk.

INTRODUCTION

"Surge" is caused when the flow through a compressor is decreased to the point that momentary flow reversals occur. Surge is evidenced by vibration and pulsation, and if unchecked can cause severe compressor damage. As shown in Figure 1, if surge is detected, the surge control system will increase flow through the compressor, by quickly opening the blowoff valve for environmentally benign or low value gases, or the recirculation valve for hazardous or valuable gases.[1]

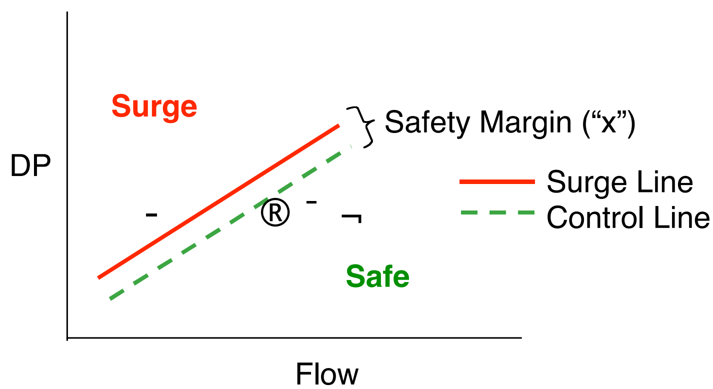
Figure 1
Surge Control Schematic



Even if surge is detected quickly, the relatively slow response time of the blowoff or recirculation valve causes the compressor to continue to operate in the surge condition for some period of time. Frequent cycling of the control system in and out of surge can cause output pressure variation, compressor wear, and poor efficiency.

Although systems which detect "incipient surge" based on either rising temperature or instability of the flow and pressure measurements have been designed, each must be custom-designed to a certain machine and compression system. Worse, these systems tend to be safe and reliable only over the range of test conditions.[2] As result, most users operate off the compressor's "surge line". As shown in Figure 2, the surge line is the minimum flow necessary, for each given pressure, to avoid surge. Points on the surge line – which may of course be a "curve" - are typically determined experimentally. If the compressor is operating safety (1), and flow suddenly decreases, the compressor can move into a surge condition (2), unless the blowoff valve is opened, and flow increased (3). While too little blowoff can result in surge, too much blowoff (4) wastes fuel, since the compressor energy is vented into the atmosphere. Even if the gas is re-circulated, the energy added during compression must be removed by cooling, otherwise the compressor will overheat.

Figure 2
Compressor
Anti-Surge
Control



Ideally, the user should operate as close to surge as possible, without actually entering surge - most users operate at "surge+x%. While a smaller "x" yields better efficiency, a larger "x" reduces risk of surge. Many users assign a fixed value[3] to x – for example, 10%. However, it should be possible to optimize this value based on:

- Response time of the valve, measurement and control system, relative to the surge time of the compressor
- Uncertainties in the pressure and differential pressure measurements
- Stability of the compressor loading (but this is often not known at commissioning)

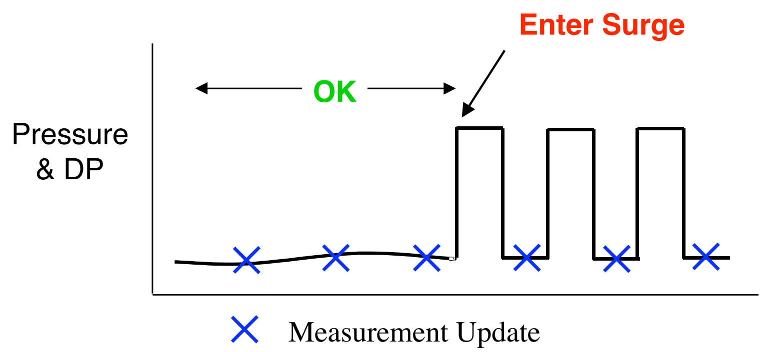
The key variables, which should be considered and quantified for pressure transmitter selection, are:

- response time, relative to compressor surge time
- pressure and differential pressure measurement uncertainty

MATCHING TRANSMITTER RESPONSE TIME TO SURGE TIME

While transmitters and control systems typically respond much more quickly than valves, it is essential that the measurement (including transmitter and controller update) be updated at least as fast as the compressor surge rate. The reason for this is illustrated in Figure 3. If the measurement does not update as fast as the compressor surges, then surges may occur *between* updates, in which case surge may persist for a several cycles before being detected, possibly leading to compressor damage. Once, however, the measurement is fast enough, further reductions in response time are not useful, since the overall system response time is limited by the valve.

Figure 3
Transmitters
Not Fast
Enough



Different compressors surge at different rates, and even the same compressor will surge at different rates in different applications. While actual surge rates are determined experimentally, generally:

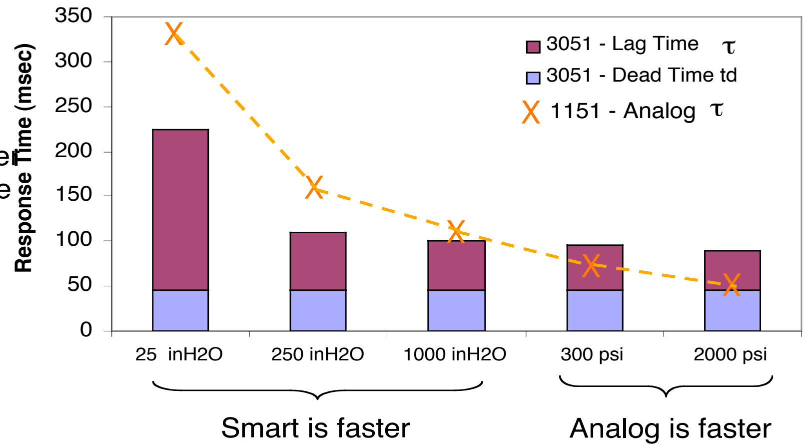
Surge time α flowrate / downstream_volume

A compressor with a very high flowrate into a small volume will surge very quickly, while one with a relatively lower flowrate into a larger volume will surge more slowly. While the relationship is not exact enough to be used for quantifying actual surge rates, it does allow users to predict whether a given compressor should surge faster in one application than in another.

Many users use vendor specifications to determine response time. It is important to understand that response time for any transmitter is dependent on the device's upper range. Transmitters designed to measure very low pressures must have very sensitive, and hence loose, diaphragms. These tend to response slowly. Transmitters designed to read high pressures have stiff diaphragms, and respond relatively more quickly.

In addition to the response time of the mechanical components (lag time = τ), a fixed response time is added by the microprocessor of a smart transmitter (dead time = t_d). This means that, all else being equal, a smart transmitter will be slower than an analog ("dumb") transmitter. However, all else is rarely equal, and it is not unusual for smart transmitters to be faster than analog. For example, Figure 4 shows response times for analog and smart transmitters from a leading pressure transmitter supplier. The smart transmitter has faster mechanical components – due to faster sensor design, stiffer diaphragms, reduced volume of oil fill, etc. At pressure ranges where the mechanical response is fast and the microprocessor update rate dominates total response time – in other words, at higher pressures – the analog transmitter is faster. However, at pressure ranges where the mechanical response is slow and dominates total response time – in other words, at lower pressures – the smart transmitter is faster. This is significant, since – if fast enough - smart transmitters can provide significant improvements in repeatability.

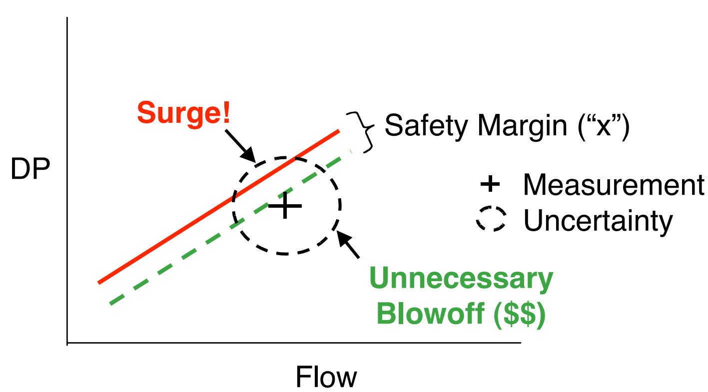
Figure 4
Transmitter Response Time (msec)



QUANTIFYING TRANSMITTER REPEATABILITY

Once the transmitter selected is fast enough to detect surge, additional improvements in response time do not provide user benefit, and the user should instead try to optimize repeatability. Returning to the surge line (originally shown in Figure 1), Figure 5 shows the impact of measurement uncertainty in pressure and differential pressure measurement. If the true flow is less than the measured flow, and the error exceeds the safety margin ("x" in surge+x% control schemes), the system will unexpectedly enter a surge condition. If, on the other hand, the true flow exceeds the measured flow, and the compressor is operating close to the surge line, the control system will call for unnecessary blowoff, wasting energy. Minimizing measurement uncertainty allows the user to operate closer to the surge line (smaller "x"), with no increase in surge risk, and reduce energy costs from unnecessary blowoff.

Figure 5
Measurement Uncertainty



How can the user determine if the uncertainty will exceed the safety margin? Consider, for example, a DP transmitter with "0.1% reference accuracy" installed on an orifice plate – will the complete measurement system provide 0.1%, 1% or 10% flow repeatability? The first step is to identify factors that will cause a transmitter to be less accurate and repeatable outside of a laboratory. For a DP transmitter, key factors include:

- **Ambient Temperature Variation**: In the vast majority of "real-world" flow measurements, the transmitter can operate at a very different ambient temperature than the one at which it was calibrated. In some outdoor applications, ambient temperatures can vary more than 50^{o}F from calibration. These variations can have a significant effect, which is easily simulated on the bench – blow warm air over a transmitter, and watch its output change.

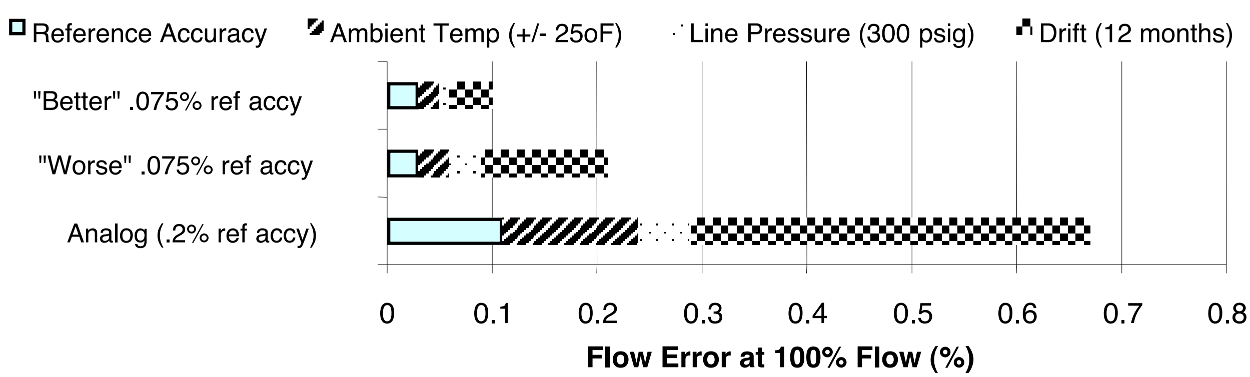
- **High Static Line Pressures**: A high line pressure – common in compressor applications – can significantly affect the DP transmitter used to infer flow. To simulate this effect on the bench, the user should apply a small DP across a transmitter. Then, add several hundred pounds of additional static pressure to *both* sides of the transmitter. In theory, the measured differential pressure should not change. In reality, it does.

- **Drift/Stability**: The output of any analog component will vary over time. As with the ambient temperature effect described above, this can affect all flow technologies. Better, smart transmitters are more stable, requiring less frequent calibration than older, analog transmitters or transducers, without any sacrifice in accuracy and repeatability.

Next, quantify the impact of these real-world conditions for the given application and transmitter of interest, using published specifications. Figure 1 shows this at 100% flow for three different transmitters:

- "Better" 0.075% smart transmitter
- "Worse" 0.075% smart transmitter
- Analog transmitter

<u>Figure 6 – Flow Error From Differential Pressure Transmitter[4]</u>



Even though the two "0.075%" transmitters have the same "reference" accuracy, the "better" transmitter is less affected by these "real-world" effects. Note also that the real-world effects for all three transmitters overwhelm their reference/laboratory accuracies.

While these errors may seem small at 100% flow, since the errors are fixed over the entire transmitter range, and DP α flow^2, small errors at 100% - and small differences in transmitter accuracy - are **magnified** at lower flowrates, as seen in Figure 7.

Figure 7 – Flow Error From Differential Pressure Transmitter

Flowrate (scfm)	DP	"Better" .075%	"Worse" .075%	Analog
1000	100	0.09%	0.21%	0.65%
750	50	0.16%	0.38%	1.16%
500	25	0.37%	0.85%	2.60%
250	6.25	**1.46%**	**3.40%**	**10.20%**

Conclusions from this typical application:

- Compressor flow measurements are of greatest importance at low flows, where surge can occur. At a flow of 25%, the analog transmitter contributes **10%** repeatability.

- The "reference accuracy" of a transmitter is not useful for predicting installed repeatability. From Figure 2, when installed the two "0.075%" transmitters differ by nearly 2% at a flow of 25%.

- The user can control some of the factors affecting installed repeatability. For example, more frequent calibration or calibration to a higher DP range will improve repeatability. However, both will increase operating costs. An obvious corollary is that better transmitters can be calibrated less frequently – reducing maintenance cost – and/or calibrated to a higher DP – reducing energy costs – yet still provide acceptable repeatability.

The user benefit of reduced uncertainty is a smaller "x" in "surge+x%" control systems. Consider a given compressor in a given application in which x=10% provides acceptable surge risk, when using an analog transmitter with repeatability=10% at surge flow. If that transmitter is upgraded to a smart transmitter with repeatability=1.5%, it should be possible to operate with x=5%, for example, with no increase in surge risk. This will significantly reduce unnecessary blowoff and recirculation, and reduce energy cost.

As shown in Figure 8, software tools are available that allow users to quantify installed repeatability for specific transmitters in user-defined application conditions.

Figure 8 – Software Tool Predicts Installed Repeatability[5]

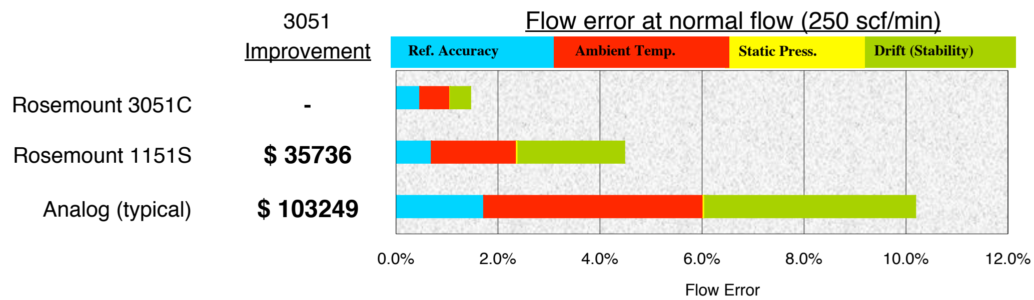
Total Probable Flow Error Due to DP Transmitter

does not include effect of process pressure/temperature variation or primary element

Fluid / Service:	Natural Gas to Boiler #1		
Transmitter Calibrated Span:	0 - 100 in H20	Maximum Flow:	1000 scf/min
Ambient Temp. Variation:	50 deg F	Normal Flow:	250 scf/min
Static Line Pressure:	300 psig	Value of Fluid:	.009 $ / scf
Calibration Frequency:	12 months		

DP Transmitter	DP Transmitter flow error at normal flow (250 scf/min)		
	Flow Error	Annual Value of Flow Error	3051 Improvement*
Rosemount 3051C	1.46%	$ 17285	-
Rosemount 1151S	4.48%	$ 53021	$ 35736
Analog (typical)	10.19%	$ 120534	$ 103249

*Annual Reduced flow uncertainty (accuracy/repeatability)



CONCLUSION – BEST PRACTICES

For best safety and efficiency, users should:

- Select transmitters which, under the application conditions specified, respond at least as quickly as the compressor surge time. However, once the transmitters are "fast enough", additional improvements do not provide additional value.

- Calculate and optimize installed repeatability, under the specified application conditions. This should allow the user to minimize unnecessary blowoff and/or recirculation, with no added surge risk, and/or to reduce maintenance and energy costs.

REFERENCES

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3. White, M.H., "Surge Control for Centrifugal Compressors", *Chemical Engineering*, Dec. 1992.

4. Menezes, M., "Calculating & Optimizing Repeatability of Natural Gas Flow Measurements", *Pipeline & Gas Journal*, July 2001.

5. The TPFE.xls spreadsheet calculates the repeatability/uncertainty contribution of the DP transmitter under user-specified application conditions, and is pre-loaded with performance specifications for a wide variety of transmitters from leading suppliers. See www.Rosemount.com to obtain a copy.