Expertise in Turbomachinery Controls

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Rapid Response

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For Surge Control	5 samples a second is too low a sampling rate for an adequate Surge Control Response to the antisurge valve.	Not applicable, since a sampling rate of 5 samples a second is too low.
	20 samples a second is an adequate sampling rate for Surge Control.	Transmitter time constant must be less than 200 milliseconds.
For Surge Detection	5 samples a second is too low a sampling rate for reliable Surge Detection based on flow dP signal rate of drop approach.	Transmitter time constant must be less than 200 milliseconds in order for the actual drop in the flow signal exceed the surge detection threshold for each surge cycle.
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Author: Medhat Zaghloul

Flow (dP) Transmitter Speed Of Response To Meet API 670 5th Edition Requirements.

The new API Standard 670, that covers Machinery Protection Systems, was updated in the 5th edition in November 2014 to include a section on surge detection for centrifugal and axial compressors. Moreover, in the standard's informative Annex K, there is a well-written distinction between an antisurge control system and a surge detection system.

One common aspect of both the surge control and surge detection applications is the selection of the differential pressure transmitters used to provide the compressor flow signal, and which must have a sufficiently fast response. In some cases, the two systems (surge detection and surge control) may share the same transmitter signals.

This article analyzes a typical behavior of the differential pressure transmitter signal from a flow measuring device during compressor surge and derives practical guidelines for selecting adequate transmitter dynamic response characteristics.

Antisurge Control System

API mandates the installation of an antisurge control system on all axial compressors and most centrifugal compressors. The main function of the antisurge system is to reduce the possibility of machinery damage due to surge events.

Most modern antisurge control systems incorporate a proximity-to-surge calculation algorithm that uses a variety of process variable transmitters around a compressor stage and produces a measure of where the operating point lies with reference to the Surge Control Line.

If the operating point approaches or crosses the Surge Control Line, the antisurge control system is usually designed to modulate (open) an appropriately sized and located antisurge valve that either recycles gas around the compressor stage or blows it off to the atmosphere.

When the compressor stage's operating point moves back to the right of the Surge Control Line the antisurge control system is usually designed to allow the antisurge valve to be ramped closed in order to eliminate the energy waste due to unnecessary recycle or blow-off.

In order to reduce energy costs associated with recycle and blow-off (when it becomes necessary), the owners/operators of turbocompressors should demand that the antisurge control system include provisions to keep the Surge Control Margin as small as is required while still ensuring adequate protection against surging.

Surge Detection System

In the event that the antisurge control system fails to protect the compressor from surging, API mandates that an independent surge detection system be installed for all axial compressors and, if specified, be installed for centrifugal compressors.

In contrast to an antisurge control system (where the proximity-to-surge is usually the main variable that is calculated), a surge detection system, according to the API standard article 9.4.1.1.1, "shall be capable of detecting each surge cycle".

In article 9.4.3.1, the new API standard mandates that an alarm output shall be generated whenever a surge (cycle) is detected.

Optionally, and if specified, the surge detection system may be required, as per article 9.4.3.2, to initiate further actions, such as the fast opening of the antisurge valve modulated by the surge control system, or the shutdown of the main driver. These "further actions" should be initiated after a specified number of surge cycles have been detected within a user-defined time window.

The Flow Transmitter

In both the antisurge control and surge detection systems, the signal that represents volumetric flow through the compressor plays a very important role. The purpose of this article is to discuss various aspects of this signal, as generated by modern digital transmitters.

Figure 1 shows an analog recording of the differential pressure (dP) signal from a flow measuring device during surge, covering a period of about 4 seconds in which two surge cycles occur.

The analog recoding shows that the dP signal drops from about 71.2% of span (or 0.712 normalized) to zero in about 67 ms, i.e an equivalent drop of approx. 106% per 100ms (or 1.06 normalized).
Let us assume that any sudden drop in the flow signal of more than 20% per 100 ms (or 0.20 normalized per 100 ms) is the threshold value used to deduce that a surge event is happening. This is shown as the red lines in Figure 1. This setting should provide the logic solver, for surge detection purposes, with a sufficient margin so as not to produce spurious surge events, which could cause nuisance trips of the compressor train.

Most modern flow transmitters are digital devices which produce an output value every time the actual process variable is sampled (as illustrated in Figure 2).

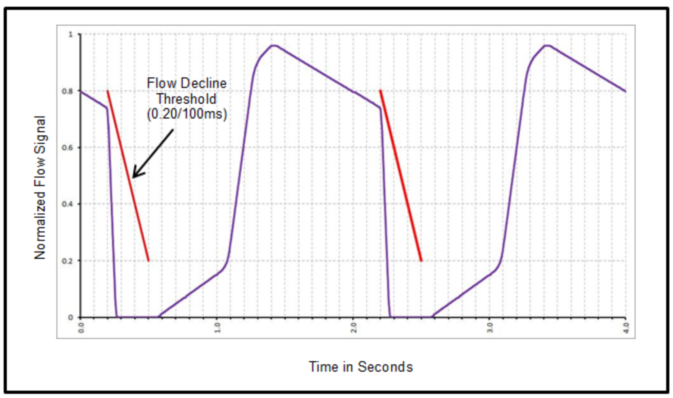

Fig. 1– Surge Analog Flow Signal Profile

The first factor we will consider in evaluating a flow transmitter that is appropriate to detect surge is the sampling rate and whether it has any significant impact on the usefulness of its digital values in terms of both Surge Control as well as Surge Detection.
Figure 2 shows the same Surge Flow signal profile, but sampled at a rate of 5 samples per second and sent as a digital signal value with no damping or dead time.
Most controllers calculate a derivative value based on several samples, and using various techniques that are well-described in literature. When the discretization of the signal approaches the useful frequency in the signal, the controller cannot accurately reconstruct the signal.

Discretization of 5 samples per second leads to a significant loss of resolution and sensitivity in the calculation of the derivative of the signal value.
Thus the system (logic solver) will not be able to detect a rate of change that is faster than that which occurs within the discretization period (which for 5 samples per second is 200 ms). In this case the system cannot detect a rate of change that is faster than 71.2% per 200 ms or 35.6% per 100 ms (0.356 normalized per 100 ms).

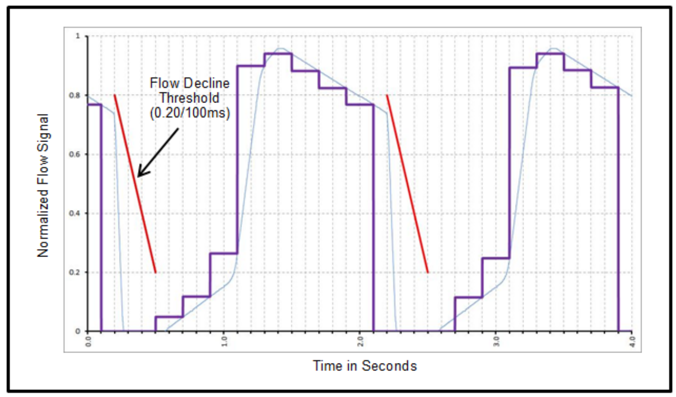

Figure 2 – Surge Digital Signal Profile (with 5 Samples per second) and no Damping

With the digital transmitters available in the marketplace that are suitable for industrial flow measurement using differential pressures, there is always some amount of signal lag. This lag is dominated by a first order lag component that renders the digital signal profile somewhat different than what is illustrated in Figure 2.

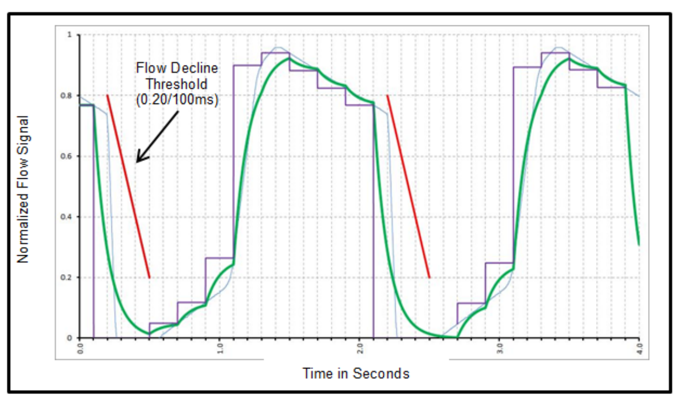

Fig. 3 – Surge Digital Signal Profile (with 5 Samples per second) and 100ms Time Constant

In Figure 3, a time constant of 100ms has been considered for the digitally sampled flow signal (also at 5 samples per second). This is illustrated by the green line.

The presence of a transmitter time constant further degrades the sensitivity of the derivative calculation. It can be seen that at 5 samples per second (200 ms discretization intervals) and time constants more than 100 ms may make it impossible to distinguish between process changes and surge events.

Furthermore, these low sampling rates (long discretization intervals) and large damping time constants will also negatively affect antisurge control. The surge control algorithm will not be able to sense changes in the process variable in a timely manner, and tuning gains must be kept smaller in order to maintain stability, resulting in a slower response to surge-inducing events.

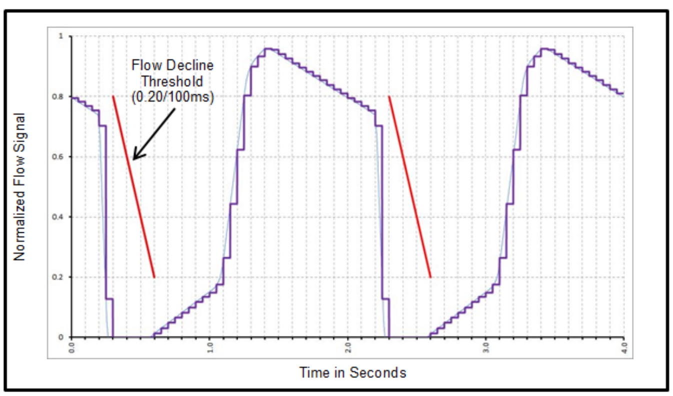

Fig. 4 – Surge Digital Signal Profile (with 20 Samples per second) and No Time Constant

In Figure 4, the sampling rate of the digital transmitter has been increased to 20 samples a second; again with no damping or dead time. As may be observed, the digital signal profile closely follows the pure analog signal shape, with more than adequate resolution, for both Surge Detection and/or Surge Control.

When the flow signal drops precipitously as the compressor's operating moves into the start of the surge cycle, the digital representation illustrated in Figure 4 produces a rate of decline which approximates the actual rate fairly well, with two samples in the steepest part of the signal profile. It could even be argued that this "pure" digital signal profile, without damping, may be used effectively in an advanced surge control algorithm as the resolution is so good.

However, an industrial transmitter will not be capable of producing such a "pure" response, and will have a time constant.

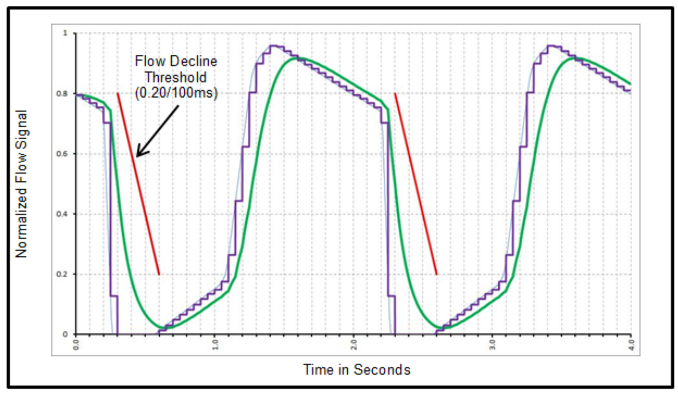

Fig. 5 – Surge Digital Signal Profile (with 20 Samples per second) and 100ms Time Constant

In Figure 5, a time constant of 100ms has been considered for the digitally sampled flow signal (still at 20 samples per second). This is illustrated by the green line.

As before in Figure 3, it is observed that while there is less-steep signal value drop during the surge cycles, it can still comfortably exceed the configured rate of signal drop that is required by the Surge Detection threshold, so this type of signal may be used for counting surge cycles.

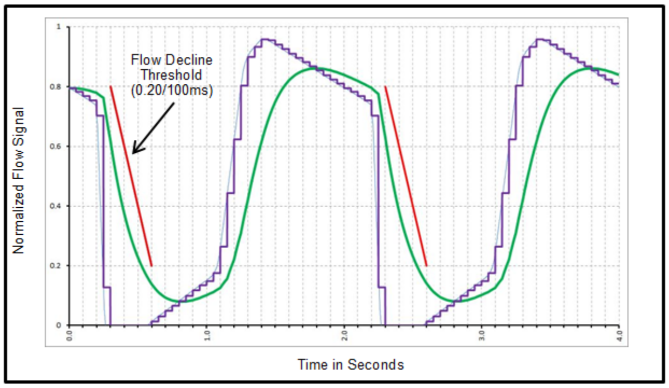

Fig. 6 – Surge Digital Signal Profile (with 20 Samples per second) and 200 ms Time Constant

In Figure 6, a time constant of 200ms has been considered for the digitally sampled flow signal (still at 20 samples per second).

This appears to constitute the limit so as to exceed the configured rate of signal drop that is required by the Surge Detection threshold.

Conclusion

The conclusions that may be drawn can be summarized as follows:

	Transmitter Sampling Rate	Transmitter Time Constant
For Surge Control	5 samples a second is too low a sampling rate for an adequate Surge Control Response to the antisurge valve.	Not applicable, since a sampling rate of 5 samples a second is too low.
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It is therefore recommended that the flow transmitter sampling rate be 20 samples a second or more, and its time constant be 200 milliseconds of less.

Time Constant Differences between the API Spec and Transmitter Specifications

In paragraph 9.4.4.3, note 2 in the API 670, 5th edition text it is mentioned that "for the purpose of this section, response time means that 90% of the process step change is recognized by the device, as listed by the manufacturer". The standard then goes on to state that "engineering experience indicates that (transmitter) response times of 200 ms are adequate" ... for the surge detection function.

Transmitter manufacturers however are much more used to declaring the speed of response of their devices using the standard 1st-order lag response concept of "time constant".

The time constant (or Tau - τ) is the time needed for a 1st order lag response to reach 63.2% of its final value in response to a step change. This is illustrated in Figure 7.

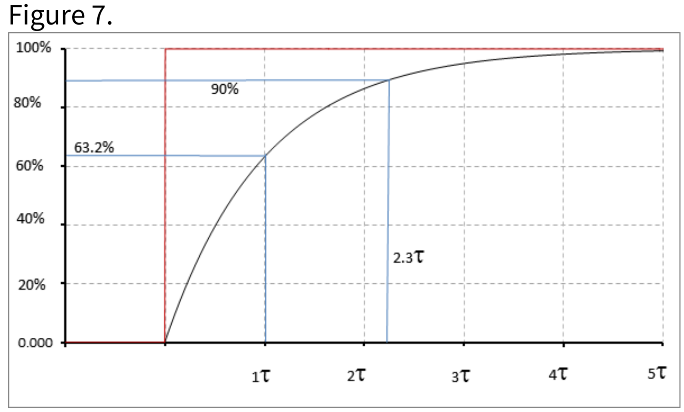

Fig. 7 – Difference Between 1st Order Lag Time Constant and API 670 Response Time

Thus, the "response time to reach 90% of a step input change" as per the API standard, would be equivalent to a time constant of approx. 2.3 Tau or a transmitter time constant of approximately 200/2.3 = 87ms.
In the authors experience this time constant (Tau) of 87ms is not achievable with most transmitters available commercially, especially if the time constant

includes the "dead-time" or pure time delay characteristic that is present in almost all transmitters. Many manufacturers specify the transmitter's response time, which includes the transmitter dead time and the time constant. A transmitter response time of 200 ms or less is considered by the author as adequate for both surge control and surge detection.

About The Author:

Medhat Zaghloul is CCC's Regional Technology Manager for the Europe, Middle East and Africa Regions with Compressor Controls Corporation (CCC), based in the Abu Dhabi Office. Medhat joined CCC in 1993 and has over 38 years of experience in the oil and gas industry with 15 years specific to the instrumentation and controls for the petrochemical industry. He is responsible for the development of technical solutions and control applications and providing technical guidance and support. Mr. Zaghloul holds a B.Sc. in Electrical Engineering from the Cairo Institute of Technology in Egypt (now Helwan University).