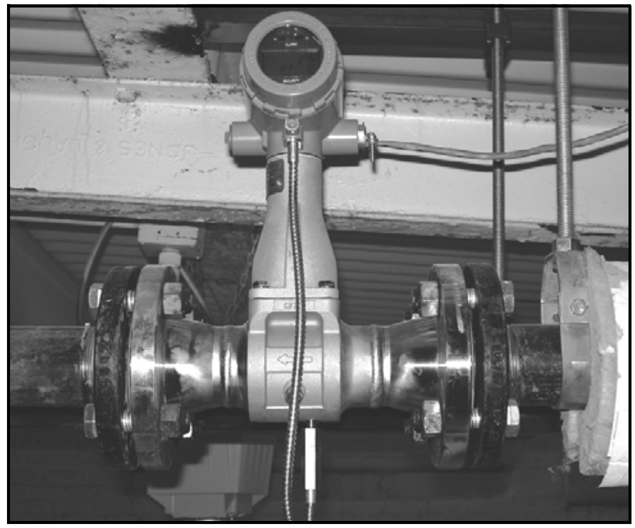
Rosemount 8800 Vortex Adaptive Digital Signal Processing

INTRODUCTION

When vortex technology was introduced, it promised to improve reliability, reduce installation costs, and provide a wide ranging flow measurement for liquids, gases, and steam with good accuracy. However, traditional vortex designs have limitations such as inherent low flow cutoff and susceptibility to inaccurate measurement from vibration.



Since it is true that the conditions in a plant environment may be quite different than the conditions under which the vortex meter is calibrated, some meters may be adversely affected by the actual process conditions. The Rosemount 8800 Vortex Flowmeter is designed to limit the effects encountered in actual installations.

The Rosemount 8800 has been designed to provide vibration immunity and the capability to measure low flow rates through a mass balanced sensing system and patented Adaptive Digital Signal Processing.

The purpose of this document is to provide a technical background for how vortex meters measure flow. It will include sections that detail how the Rosemount 8800 Vortex Flowmeter operates, including how it generates and filters a flow signal. It also provides examples for adjusting the filtering parameters and discusses the abilities to measure low flow rates and eliminate noise caused by vibration.

Contents

VORTEX FEATURES

Good Accuracy

The accuracy of the vortex flowmeter is often better than ±1% of the flow reading. For liquids, it is not uncommon to see accuracy as good as ±0.5% of flow reading. Refer to the Rosemount 8800 Series Vortex Flowmeter Product Data Sheet (00813-0100-4004) for complete accuracy specifications.

Wide Rangeability

Vortex meters can maintain a linear accuracy over a wide range of flow rates. Depending on fluid properties and process conditions, it is possible to obtain upwards of a 40:1 ratio between the maximum and minimum measurable flow rates while maintaining the same accuracy.

Wide Applicability

Vortex meters can be used to measure the flow of liquids, gases, and steam. In general, vortex meters are not affected by changes in process conditions or fluid properties.

Low Installation and Maintenance Costs

Vortex meters are easy to install, are loop powered devices, do not require field calibration, produce a minimal amount of permanent pressure loss, and have no moving parts that require routine maintenance.

ROSEMOUNT 8800 VORTEX FEATURES

Reliability

The 8800 Vortex eliminates impulse lines, ports, and gaskets to improve reliability.

Non-clog Design

The unique gasket-free construction has no ports or crevices that can clog during operation and cause a loss in flow signal.

Vibration Immunity

Mass Balancing of the sensor system and patented Adaptive Digital Signal Processing (ADSP) provide immunity from vibration causing unstable or false flow readings.

Replaceable Sensor

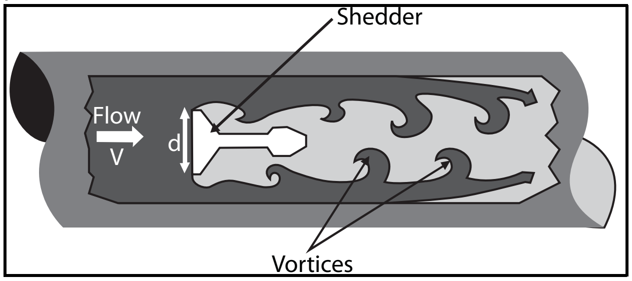
The sensor is isolated from the process and can be replaced without breaking the process seals. All line sizes use the same sensor design allowing a single spare to serve every meter.

Simplified Troubleshooting

Device diagnostics enable meter verification of the electronics and sensor with no process shutdown.

Theory of Operation

Vortex meters measure flow by using the natural phenomenon known as the von Karman Effect.



As a fluid passes by a blunt surface (Shedder), the fluid separates and forms areas of alternating differential pressure (Vortices) around the back side of the blunt surface. The frequency of the alternating vortices is linearly proportional to the velocity of the fluid.

Equation 1

$F \propto k \cdot V$

F = Frequency of Generated Vortices
V = Flow Velocity
k = Proportionality Constant

Strouhal Number

The Strouhal Number is a dimensionless number which is a function of the size and shape of the shedder. By selecting the appropriate shedder design, the Strouhal number remains constant over a wide range of Reynolds Numbers. Equation (1) can be restated using the Strouhal Number and shedder diameter.

Equation 2

$$F = \frac{St \cdot V}{d}$$

St = Strouhal Number
d = Shedder Width

Volumetric Flow Rate

To determine the volumetric flow rate through the vortex meter, the flow velocity is multiplied by the cross sectional area of the meter.

Equation 3

$Qv = V \cdot A$

Qv = Volumetric Flow Rate
A = Cross-Sectional Area

To define cross-sectional area, use the following equation.

Equation 4

$$A = \frac{\pi \cdot D^2}{4}$$

D = Inside diameter of the meter

K-Factor

The vortex K-Factor is the proportionality constant that is used to relate the measured frequency to a volumetric flow rate. The K-Factor is determined using a flow lab calibration. In the flow lab, the number of pulses from the vortex meter are counted and compared to the volume of fluid that has passed through the meter to give the K-Factor units of pulses per volume. By combining the previous equations we get the final vortex flow equation.

Equation 5

$$Qv = \frac{F \cdot (\pi \cdot D^2 / 4) \cdot d}{St}$$

The terms for area, shedder width, and Strouhal Number are then replaced by the K-Factor.

Equation 6

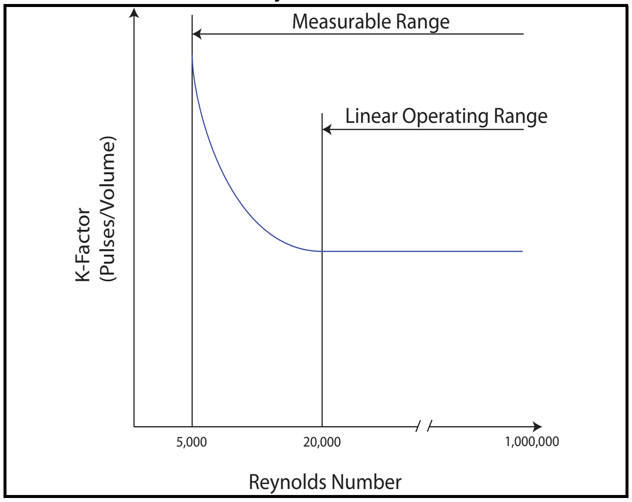
$$Qv = \frac{F}{K}$$

Once the K-Factor is known, the flow rate can be obtained by measuring the shedding frequency. The equations also show that volumetric flow rate can be obtained independently of the fluid properties such as pressure, temperature, density and viscosity. The K-factor is only dependent on meter body geometry.

Relationship between K-Factor and Reynolds Number

As it was previously stated, the Strouhal number remains constant over a wide range of Reynolds Numbers. Therefore, the K-Factor also remains constant over a wide range of Reynolds Numbers as evidenced in Equations (5) and (6). However, once Reynolds Number goes below 20,000 (15,000 for gases and steam), the K-Factor does become non-linear. The non-linearity of the relationship is dependent on the process fluid's density and viscosity.

FIGURE 1. Relationship between K-Factor and Reynolds Number



Reynolds Number

Reynolds Number is a dimensionless number that relates the ratio of inertial forces to viscous forces of a fluid and is used to define the limits of laminar and turbulent flow.

Equation 7

$$Re = \frac{\rho \cdot V \cdot D}{\mu}$$

Re = Reynolds Number
ρ = Fluid Density
V = Flow Velocity
D = Inside Diameter of Meter or Pipe
μ = Fluid Viscosity

Turbulent flow is required to generate vortices behind the shedder. Turbulent flow occurs starting at a Reynolds Number of approximately 4,000. Fully developed turbulent flow requires a Reynolds Number of about 10,000 which is a best practice lower limit for vortex flowmeters. Equation (7) shows that Reynolds Number increases as velocity increases. It also shows an increase in density will increase Reynolds Number, while an increase in viscosity will decrease Reynolds Number. Vortex flowmeters have difficulty with highly viscous fluids because flows are typically in a low Reynolds Number range.

TABLE 1. Fluid property effect on Reynolds Number

Fluid Property Change	Effect on Reynolds Number
Density Increase	Reynolds Number Increase
Density Decrease	Reynolds Number Decrease
Viscosity Increase	Reynolds Number Decrease
Viscosity Decrease	Reynolds Number Increase

Mass Flow Rate

When measuring in Mass flow units (lb/hr, kg/hr, etc.), the process fluid density must be added to the flow equation.

Equation 8

$Qm = Qv \cdot \rho$

Qm = Mass Flow Rate

In most cases, the vortex flowmeter will use a fixed process density for this calculation. However, there are also designs that allow for a dynamically compensated density based on process pressure and/or temperature measurements.

Base/Standard Volumetric Flow Rate

When measuring in Base/Standard flow units (SCFM, NCMH), the ratio of the process density at actual and base/standard conditions is used to convert the actual volumetric flow to base/standard volumetric flow.

Equation 9

$Qb = Qv \cdot \rho r$

Qb = Base Volumetric Flow Rate
ρr = Density Ratio

Equation 10

Density Ratio = $\rho a / \rho b$

ρa = Density at Actual (Flowing) Conditions
ρb = Density at Base/Standard Conditions

The ideal gas law can also be used to calculate the density ratio.

Equation 11

$$\text{Density Ratio} = \frac{Tb \cdot Pf \cdot Zb}{Tf \cdot Pb \cdot Zf}$$

Tb = Absolute Temperature at Base/Standard Conditions
Pb = Absolute Pressure at Base/Standard Conditions
Zb = Compressibility at Base/Standard Conditions
Tf = Absolute Temperature at Actual (Flowing) Conditions
Pf = Absolute Pressure at Actual (Flowing) Conditions
Zf = Compressibility at Actual (Flowing) Conditions

Vortex Signal Amplitude/Strength

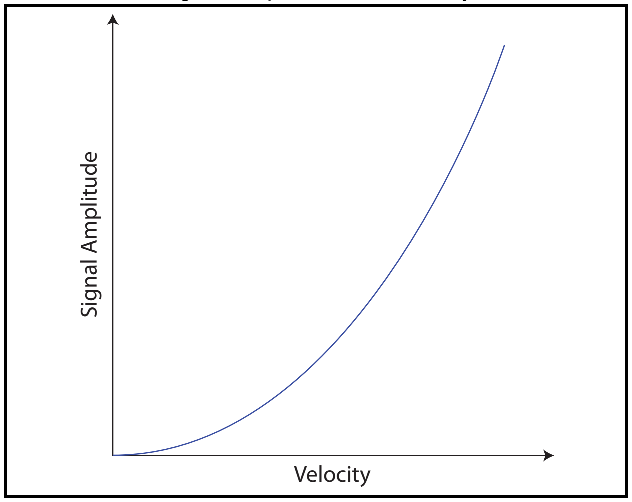
It was previously stated that vortex flowmeters require turbulent flow, and therefore a minimum Reynolds Number, for generating vortices. Another requirement is a minimum amount of signal amplitude or strength to be able to measure the flow signal. The vortex signal amplitude/strength is proportional to the process density and velocity.

Equation 12

$$SA \; \alpha \; \rho V^2$$

SA = Vortex Signal Amplitude (Strength)

FIGURE 2. Relationship Between Signal Amplitude and Velocity



The vortices must be able to transfer enough force or energy to the sensor for it to measure their generated frequency. The term of ρV^2 in Equation (12) is actually a measure of energy in the flow stream as it relates to kinetic energy.

Equation 13

$$Ek = \tfrac{1}{2} \cdot m \cdot V^2$$

Ek = Kinetic Energy

m = Mass

Higher density fluids have more inherent energy and as velocity increases, the vortex signal strength increases exponentially. Therefore, problems with measuring flow rates can arise with low density fluids or low velocity flows. All vortex meters will have an associated minimum velocity limit based on this minimum signal amplitude requirement.

Equation 14

$$Vmin = \sqrt{(SS)/\rho}$$

Vmin = Minimum Measurable Velocity
SS = Sensor Sensitivity Factor

Equation (14) shows an example for how the minimum measurable velocity based on vortex signal amplitude is typically specified. The Sensor Sensitivity Factor will vary by manufacturer, and is usually empirically derived.

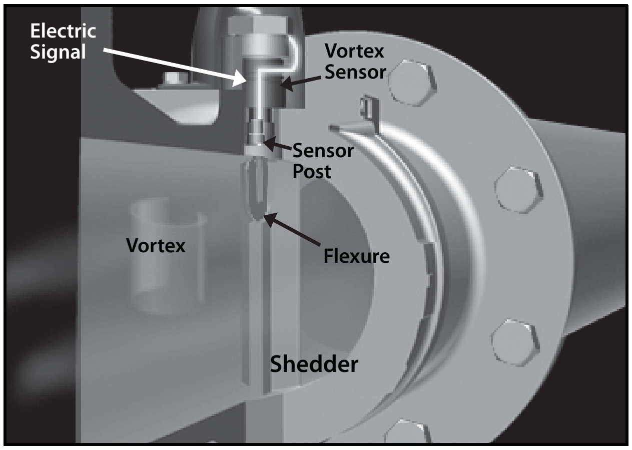
Summary of Theory

Vortex flowmeters use the von Karman Effect to measure flow. Vortices are generated at a frequency that is proportional to velocity. A K-Factor is used to convert frequency into a flow rate. For vortices to be created and measured as flow they require a minimum Reynolds Number and Signal Amplitude.

Rosemount 8800 Method of Operation

This section will address how the Rosemount 8800 Vortex Flowmeter generates a signal and produces a flow output.

Vortex Signal Generation

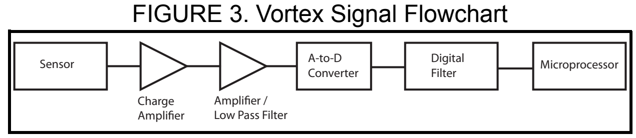


As the process fluid flows past the shedder, it separates and vortices are generated alternatively on each side of the shedder. When a vortex is generated it creates an area of low pressure on one side of the shedder. The low pressure zone causes the flexure in the shedder to move. The flexing motion is transferred to the sensor post which is outside the flow line. The sensor post motion creates a force on the vortex sensor which contains a piezoelectric element. The force on the piezoelectric element causes it to transduce the mechanical energy to an electric signal. The electric signal is transferred to the electronics for signal processing. The electronics measures the frequency of the electric signal being generated and uses the K-Factor to convert the measured frequency into a flow rate.

Vortex Signal Processing

The Rosemount 8800 electronics receive the vortex signal from the sensor, amplify it, digitize it, and pass the data to the digital signal processor (DSP). The DSP filters the data and computes the frequency of the signal. The frequency result is then passed to the microprocessor where the flow rate is computed. Figure 2 shows a block diagram of the measurement electronics.

FIGURE 3. Vortex Signal Flowchart



Amplification and Pre-Filtering

The raw signal from the sensor is amplified and pre-filtered to remove out-of-band noise. The pre-filter also provides anti-aliasing of high-frequency noise and the removal of resonant frequency noise.

Analog-to-Digital Conversion

A Sigma-Delta analog-to-digital converter samples and digitizes the conditioned signal received from the amplifier/pre-filter stage. The digitized signal passes through an isolation transformer into the digital signal processor.

Digital Signal Processor

Data samples from the A-to-D Converter are passed to the Digital Filter or Digital Signal Processing (DSP). The DSP runs the data through a series of low pass and high pass digital filters and extracts frequency information from the data.

Microprocessor

Vortex frequency information is passed from the DSP to the system microprocessor. The microprocessor uses this information to compute the exact vortex frequency and the flow rate. Additionally, the microprocessor configures and/or controls the operation of the A-to-D Converter, DSP, 4–20 mA analog output, pulse output, HART and fieldbus communication, and display.

Compensated K-Factor

The Rosemount 8800 uses a compensated K-Factor for converting frequency to flow rate per Equation 6 on page 3. A reference K-Factor for each meter is determined during a flow lab calibration procedure. The compensated K-Factor is an adjusted reference K-Factor that accounts for installation condition differences between the flow lab and actual process, such as temperature and mating pipe I.D.

DIGITAL FILTERING

At the heart of the Rosemount 8800 is a programmable digital bandpass filter. The bandpass is achieved by cascading individual low pass and high pass filter stages. Filter programming is facilitated through the microprocessor. The microprocessor adjusts the corner frequencies of the bandpass by changing the low pass corner frequency and the high pass corner frequency. These corner frequencies are tailored to typical applications according to line size and service type (liquid or gas) and are preset when the instrument is powered.

FIGURE 4. Digital Filtering Band

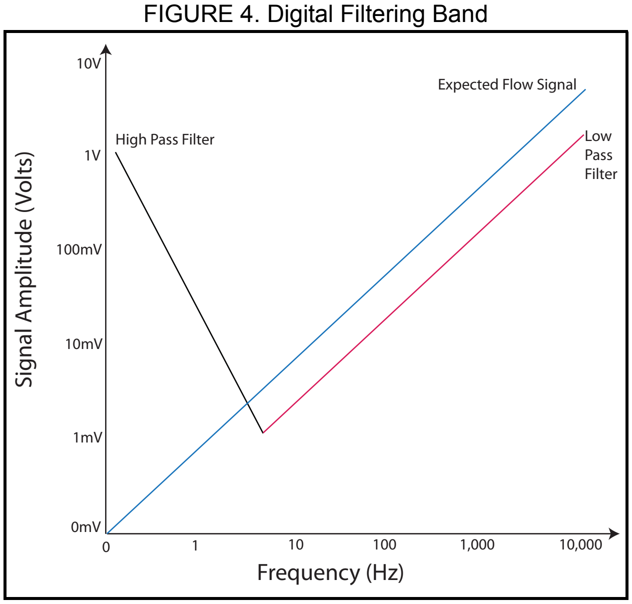


Figure 4 illustrates the placement of the Low Pass and High Pass Filters in relation to the expected flow signal. The flow signal must be inside the “V” created by the Low Pass and High Pass Filters to be measured as flow.

NOTE
The expected flow signal is linear because the two axes are shown in log-log form.

FIGURE 5. Flow Signal Measurement and Noise Rejection

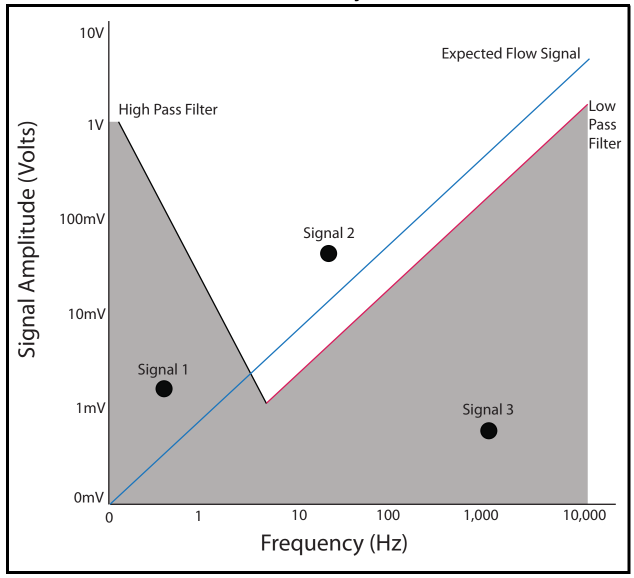


Figure 5 illustrates how the filters work to measure the flow signal (Signal 2) and reject noise signals (Signal 1 and Signal 3). Only signals in the non-shaded region will be accepted as flow signals. Signals in the shaded region will be rejected as noise.

Low Pass Filter

Normally the low pass filter corner frequency remains fixed during operation. It is preset such that the filtered vortex signal remains at a relatively constant level throughout the flow range for the application. The filter achieves this by providing a $1/f^2$ roll-off to counteract the vortex amplitude-velocity characteristic. (Recall that the signal amplitude is proportional to the square of the velocity or frequency. See “Vortex Signal Amplitude/Strength” on page 5). While the resultant vortex signal amplitude is constant, noise is attenuated by the $1/f^2$ filter roll-off.

High Pass Filter

The high pass filter is dynamically adjusted to adapt the bandpass filter to the vortex frequency. As the flow rate changes the corresponding vortex frequency changes. The digital filter is automatically adjusted during operation to track the change. This feature – sometimes referred to as adaptive digital filtering or filter tracking – maintains the vortex signal strength while minimizing noise.

FIGURE 6. Adaptive High Pass Filter

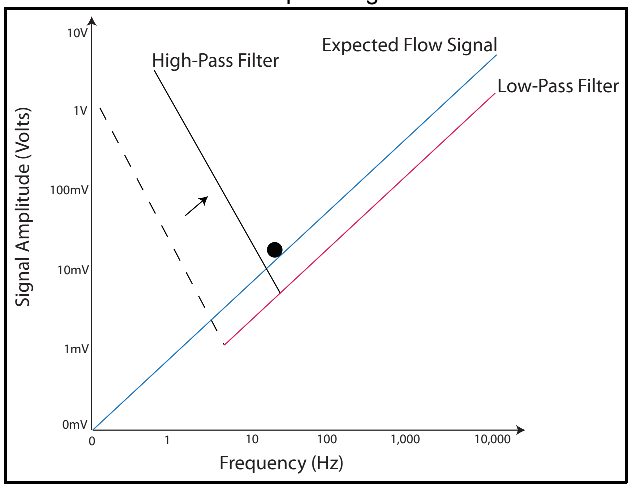


Figure 6 illustrates the high pass filter tracking the actual flow signal.

FIGURE 7. Adaptive High Pass Filter

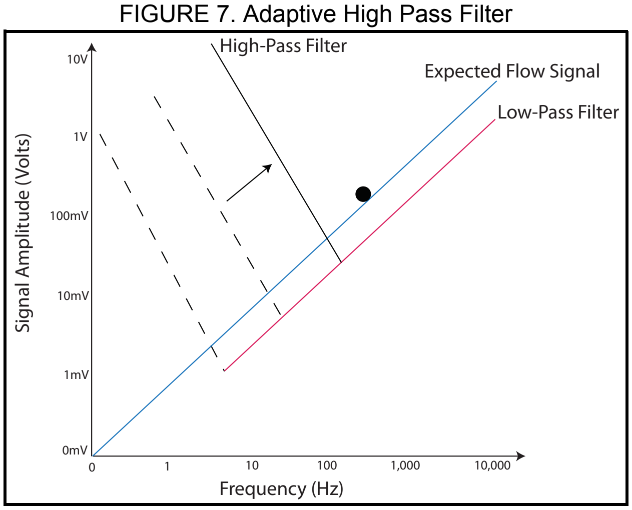
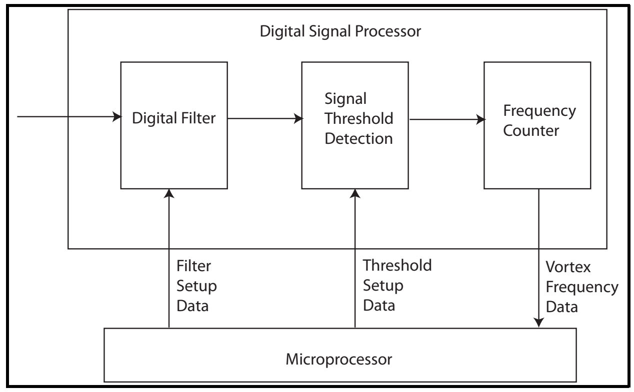


Figure 7 illustrates the high pass filter continuing to track the actual flow signal as it increases.

Signal-Threshold Detection

After the DSP has filtered the vortex signal, the data is sent to the signal detection and frequency measurement sections (both contained in the DSP). Figure 8 illustrates the data flow within the DSP.

FIGURE 8. DSP Data Flow



Signal-threshold detection is carried out via comparison of the digital filter outputs to the trigger level. This section facilitates rejection of sub-threshold noise and acceptance of the above-threshold signal.

Thus, the incoming vortex signal must be of sufficient amplitude to “pierce” the trigger level; noise components must be sufficiently filtered (attenuated) to fall beneath the trigger level. The threshold detector is commonly called a Schmitt Trigger. Figure 9 illustrates the algorithm.

FIGURE 9. Threshold Detection (Schmitt Trigger) Flowchart

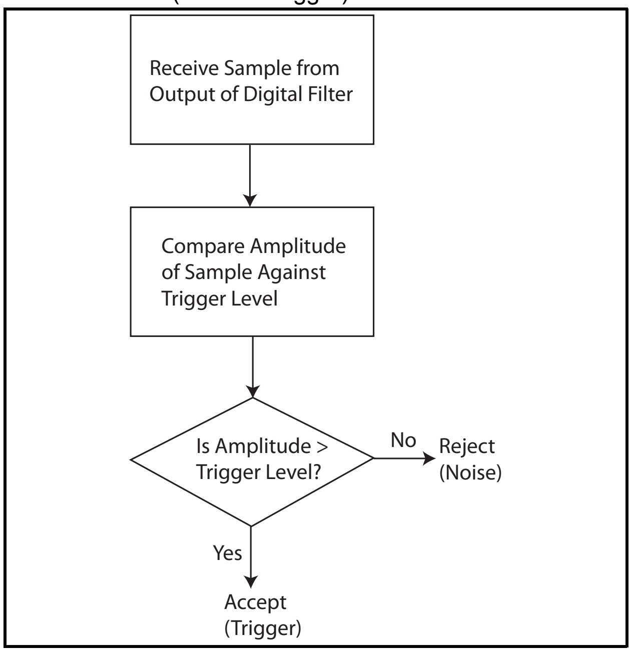


FIGURE 10. Noisy Vortex Signal and Trigger Level

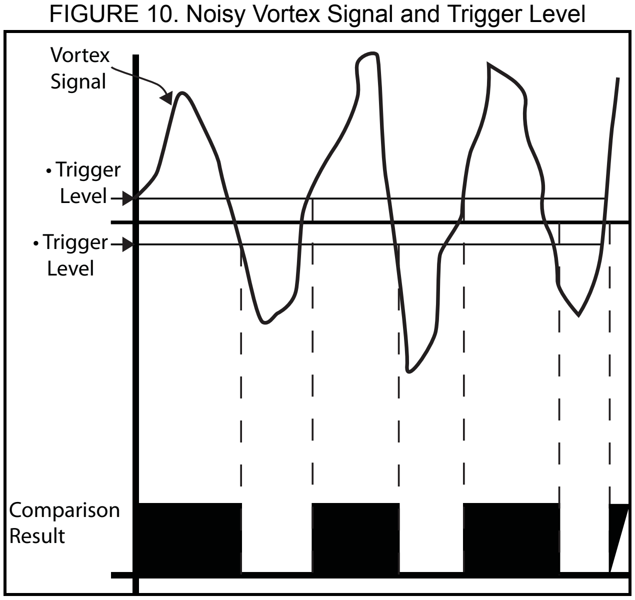


Figure 10 shows a noisy vortex signal superimposed on the threshold limit or trigger level.

Frequency Measurement

The comparison result is a square-wave representation of the filtered vortex signal from which the frequency can be determined.

Frequency counters on the DSP compute the period for each cycle of the square-wave. The result, along with the number of periods counted, is sent to the microprocessor every 100 ms or one vortex cycle, whichever is greater. Using this data, the microprocessor computes the vortex frequency and the flow rate.

Adaptive Digital Signal Processing (ADSP)

The ADSP in the Rosemount 8800 is configured at the factory for optimum filtering over the range of flow for a given line size, process fluid, and process density. For most applications, these parameters should be left at the factory settings; however, some applications may require adjustment of the ADSP to increase the flow range or eliminate noise. The three user-adjustable parameters associated with the ADSP are as follows:

- Low Flow Cutoff
- Low Pass Corner Frequency
- Trigger Level

LOW FLOW CUTOFF

The low flow cutoff (LFC) defines a flow rate above which the instrument will measure the flow and below which the instrument will drop to zero flow. A finite value for low flow cutoff is required since the vortex measurement becomes impossible below certain flow velocities. The low flow cutoff sets the starting point for the adaptive High Pass filter discussed in the High Pass Filter section on page 8.

Low Flow Cutoff Deadband

The low flow cutoff also includes a deadband such that the instrument will report zero flow when the flow rate drops below the cutoff value; but, the instrument does not report the normal flow rate until that rate rises above the deadband. The deadband (also known as hysteresis) is 18% above the actual low flow cutoff value. The deadband is designed into the instrument so if the flow rate is near the low flow cutoff value, the output will not bounce back and forth between damping to zero flow and finite flow.

Low Flow Cutoff Response Type

The low flow cutoff response type defines how the output of the vortex meter will behave entering into and coming out of the Low Flow Cutoff. The options are called “damped” or “stepped” in the device. With the damped response setting, the transmitter will use zero as the starting point for outputting flow. With the stepped response setting, the transmitter will use the Low Flow Cutoff value as the starting point for outputting flow (i.e. the transmitter will never provide an output lower than the Low Flow Cutoff value).

FIGURE 11. Transmitter Output with Damped LFC Response Type Starting from No Flow

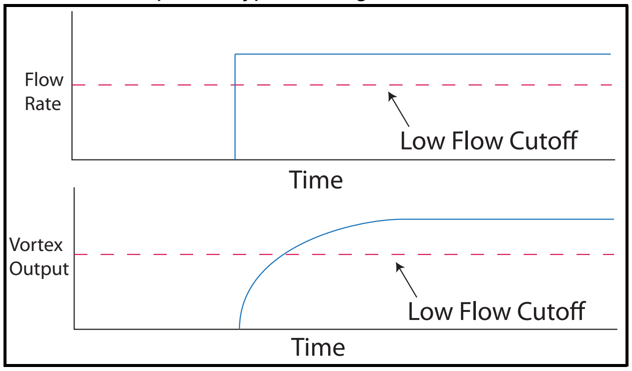


Figure 11 shows the flow rate starting at zero and then making a step change to a flow rate that is greater than the Low Flow Cutoff setting. With the LFC Response Type set to damped, the output will start at zero and ramp up to measured flow rate.

FIGURE 12. Transmitter Output with Damped LFC Response Type Going to No Flow

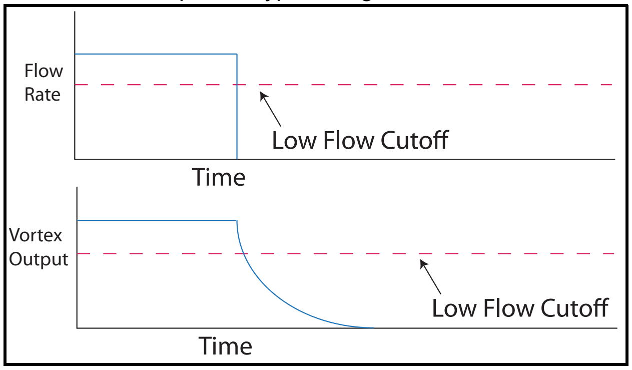


Figure 12 shows the flow rate starting at flow rate above the Low Flow Cutoff setting and then making a step change to zero flow. With the LFC Response Type set to damped, the output will ramp down to zero and there will be a period of time when the output is below the Low Flow Cutoff value.

FIGURE 13. Transmitter Output with Stepped LFC Response Type Starting from No Flow

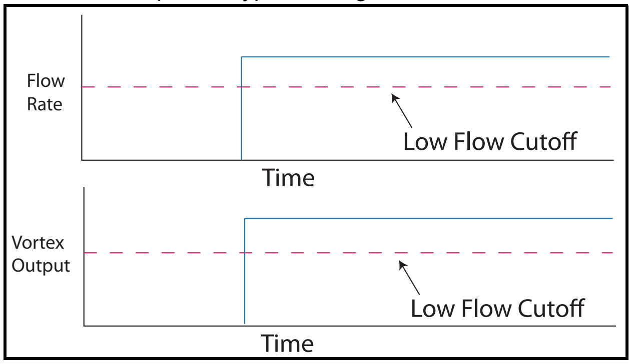


Figure 13 shows the flow rate starting at zero and then making a step change to a flow rate that is greater than the Low Flow Cutoff setting. With the LFC Response Type set to stepped, the output will jump to the measured flow rate value once the measured value is above the Low Flow Cutoff setting.

FIGURE 14. Transmitter Output with Stepped LFC Response Type Going to No Flow

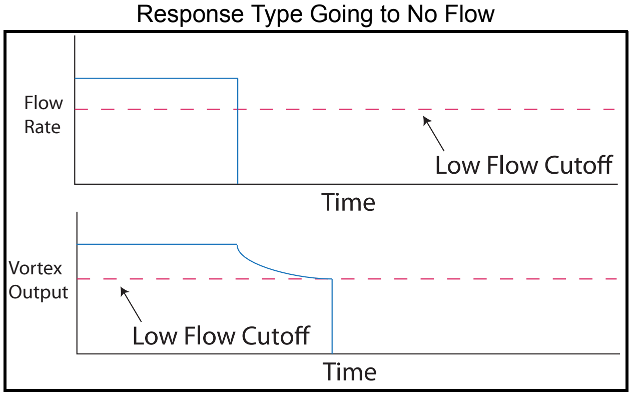


Figure 14 shows the flow rate starting at flow rate above the Low Flow Cutoff setting and then making a step change to zero flow. With the LFC Response Type set to stepped, the output will start to ramp down to zero but once it gets to the Low Flow Cutoff setting it will jump directly to a zero flow output.

LOW PASS CORNER FREQUENCY

The Low Pass Corner Frequency is the starting point for the Low Pass Filter discussed in "Low Pass Filter" on page 7. The low pass corner frequency is set at the factory to maintain a 4:1 signal-to-threshold ratio throughout the flow range based on the density that was supplied by the user. The Low Pass filter is designed to attenuate in-band and higher frequency noise components.

The Rosemount 8800 will show both the corner frequency for the low pass filter, and the minimum required density that the process fluid should have for a particular corner frequency. This makes it easy to select the low pass filter setting for a given application.

TRIGGER LEVEL

The trigger level (against which the signal amplitude is compared) is preset when the instrument is powered; it is optimized for standard applications and is determined by the line size, process fluid (liquid or gas) and density.

Trigger level is preset at approximately 25% of the expected vortex signal amplitude for a low density application. This 4:1 ratio is chosen to accommodate the amplitude modulation that normally exists in vortex signals, and to help facilitate the rejection of in-band noise.

The low pass filter keeps the vortex signal amplitude relatively constant throughout the flow range, thus maintaining the 4:1 ratio. See "Low Pass Filter" on page 7 for more information.

Signal Strength

A key measure of signal strength in the Rosemount 8800 is the signal-to-trigger ratio. The signal-to-trigger ratio is a comparison of the measured vortex signal strength and the threshold filter limit or trigger level. During normal operation the signal-to-trigger ratio should be about 4 given that the trigger level is preset at approximately 25% of the expected vortex signal strength as discussed in the previous section.

FIGURE 15. Signal-to-Trigger Ratio

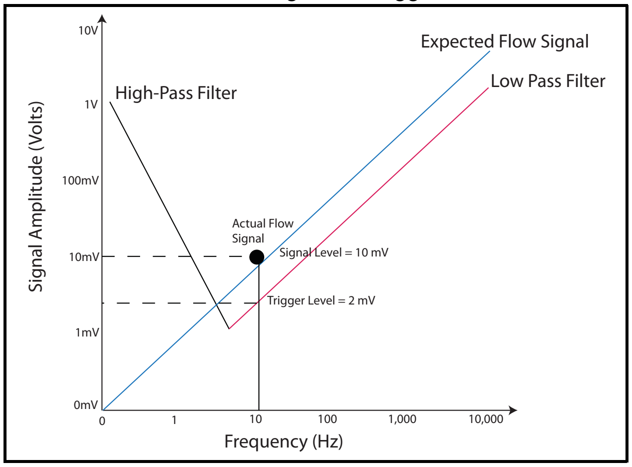


Figure 15 illustrates the signal strength measurement of signal-to-trigger ratio. In this example, the flow measurement frequency of 10 Hertz (Hz) has signal amplitude of 10 millivolts (mV). The threshold limit or trigger level of the filters at a frequency of 10 Hz is set at 2 mV. This means the signal-to-trigger ratio is 5 (10 mV÷2 mV=5).

ADJUSTING DIGITAL SIGNAL PROCESSING PARAMETERS

Before any adjustment of the signal processing parameters is made, the installation should be checked for other potential problems that may be unrelated to signal processing. The application should also be reviewed using the Instrument Toolkit® sizing program.

Refer to the troubleshooting section of product manual 00809-0100-4004 or 00809-0100-4772 for further details. These sections discuss symptoms, potential sources, and corrective actions for problems such as the following:

- High output (output saturation)
- Erratic output, with or without flow present
- Incorrect output (with known flow rate)
- No output or low output, with flow present
- Low total (missing pulses)
- High total (extra pulses)

Refer to the appropriate troubleshooting section if conditions such as these exist, and other potential sources have been checked such as the configuration parameters of reference K-factor, process fluid, lower and upper range values, 4–20 mA trim, pulse scaling factor, process temperature, pipe ID, etc.

Optimization Routine

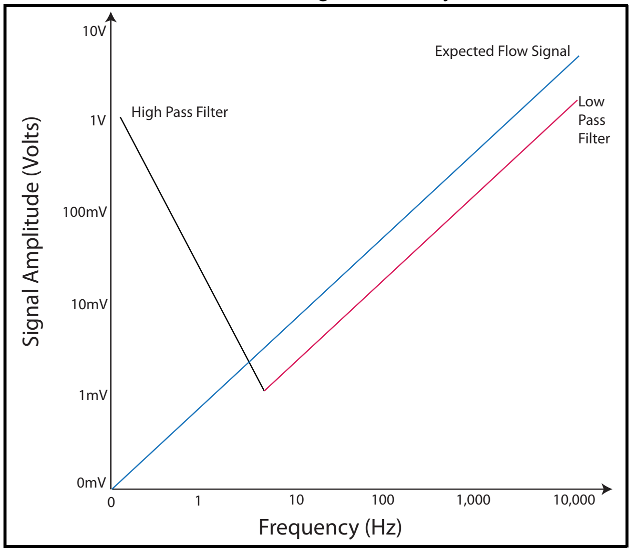
The Rosemount 8800 has an automatic function that will optimize the settings for the low flow cutoff, low pass corner frequency, and trigger level. The **Auto Adjust Filter** is the function that can be used to optimize the range of the flowmeter based on the density of the fluid. The electronics uses process density to calculate the minimum measurable flow rate, while retaining at least a 4:1 signal to trigger level ratio. This function will also reset all of the filters to optimize the flowmeter performance over the new range. If the configuration of the device has changed, this method should be executed to ensure the signal processing parameters are set to their optimum settings. To perform this function the user selects a density from a list that is closest to the actual process density without exceeding it.

All meters that are configured at the factory with a configuration data sheet (CDS) have been optimized for the density provided by the customer. When adjusting the DSP parameters in the field, the first step should be to use the optimize feature in the transmitter.

EXAMPLE 1

The following example illustrates the Auto Adjust Filter functionality.

FIGURE 16. Auto Adjust Filter Settings Based on Original Density



The actual process density was lower than originally expected. A lower process density would lead to lower signal amplitude as stated in the Vortex Signal Amplitude/Strength section.

FIGURE 17. New Expected Flow Signal with Lower Density

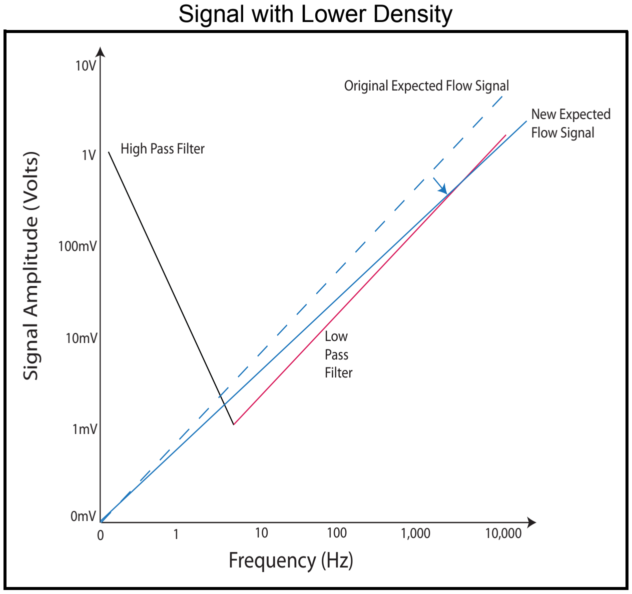


Figure 17 illustrates that if the filters are not adjusted to accommodate for the lower process density the 4:1 signal to trigger level ratio is not maintained and there is an increased possibility that flow measurement will become noisy or lost entirely.

FIGURE 18. Auto Adjust Filter Settings Based on New Density

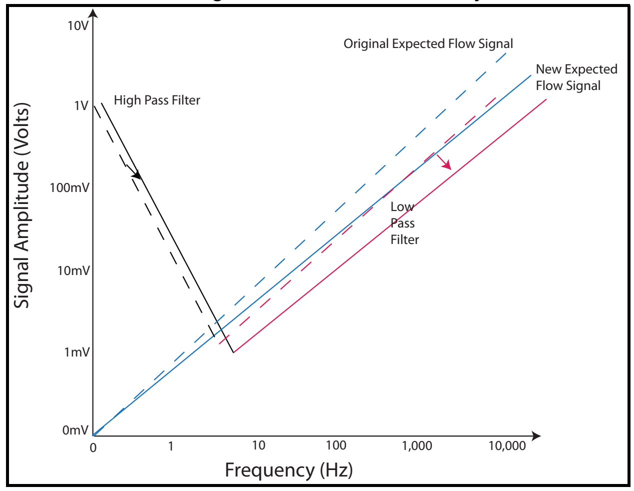


Figure 18 illustrates that the Auto Adjust Filter function has moved the filter "V" to retain at least the 4:1 signal amplitude to trigger level based on the new process density.

Low Flow Cutoff

Low flow cutoff is preset for measurement of flow over a wide range; the preset value is approximately 4% of the maximum upper range value. Some applications require adjustment of the low flow cutoff: downward in order to accommodate a slightly wider flow range or upward to further alleviate the affects of low-frequency noise.

Low flow cutoff is adjustable in approximately 18% steps. The measurement range of the Rosemount 8800 can be widened by stepping the low flow cutoff downward (providing minimum Reynolds Number and minimum ρV^2 requirements are met, where "ρ" is process density and "V" is process velocity); it can be narrowed by stepping the low flow cutoff upward. The maximum low flow cutoff must be less than the URV minus the minimum span (the minimum span for liquids is 0.5 ft/sec and 5.0 ft/sec for gases).

Movement of the low flow cutoff affects the low-frequency noise rejection on the instrument. This is because the low flow cutoff function is directly related to the high pass filter corner frequency. Downward adjustment widens the filter tracking range at the low flow end, and increases the low-frequency noise susceptibility; upward movement narrows the tracking range at the low flow end, and decreases the low frequency noise susceptibility. Therefore, dropping the low flow cutoff below the factory defaults should only be carried out if the following criteria apply:

- Minimum Reynolds Number and minimum ρV^2 requirements will be met at the new low flow cutoff value
- Low frequency noise (such as pipe vibration) is minimized

Raising the low flow cutoff above the factory defaults may be carried out if both of the following apply:

- Low frequency noise is causing false triggering (reported flow rate is higher than actual or reporting flow under no flow conditions)
- Application allows the narrower flow range that will result if the low flow cutoff is raised

Low Pass Corner Frequency

The low pass corner frequency is set at the factory by using the optimize feature of the transmitter to maintain a 4:1 signal-to-trigger ratio throughout the flow range for a density that was supplied by the user on the customer data sheet. Adjustment of the corner frequency may be necessary to improve the signal-to-noise ratio for unusually noisy applications or low density applications.

Adjustment of the low pass corner frequency can be made downward to further attenuate in-band and higher frequency noise components or upward to decrease the amount of filtering of the vortex signal. Adjustment is available in 41% frequency steps ($freq_n = 1.41 \times freq_{n-1}$). Each frequency step corresponds to a factor of two attenuation steps in signal amplitude. (Recall the relationship between frequency and amplitude. See “Vortex Signal Amplitude/Strength” on page 5.)

FIGURE 19. Low Pass Corner Frequency Adjustment

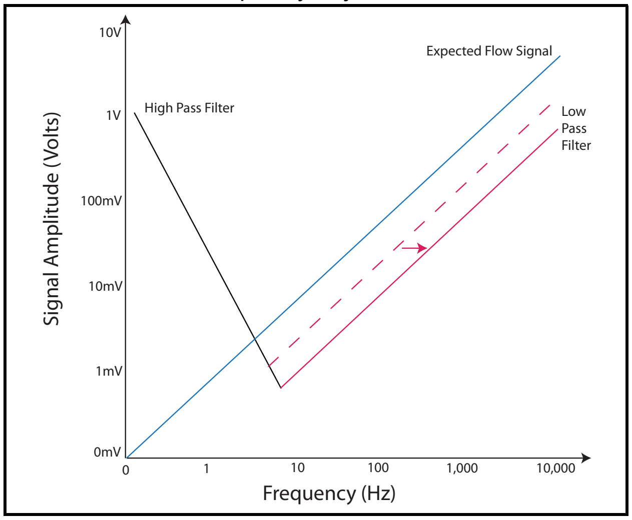


Figure 19 illustrates an increase in the Low Pass Corner Frequency. The increase shifts the Low Pass Filter to the right.

The Rosemount 8800 will show both the corner frequency for the low pass filter, and the minimum required density that the process fluid must have for a particular corner frequency. This makes it easy to select the low pass filter setting for a given application. The transmitter will also display the signal-to-trigger level ratio when fluid is flowing through the meter. This can be used to determine if the signal is not strong enough for the current low pass filter settings, or if there is enough signal to increase the level of filtering by lowering the low pass corner frequency. As mentioned previously, it is recommended to maintain a 4:1 signal-to-trigger ratio.

CAUTION
Downward adjustment of the low pass corner results in attenuation of the vortex signal, which may in turn cause the transmitter to miss pulses (and report a flow rate that is lower than actual) if the process density is not sufficiently high. Continued downward adjustment of the low pass filter could eventually reduce the signal amplitude below the trigger level, causing the output to indicate zero flow.

Trigger Level

The trigger level is preset at the factory with a value such that the nominal amplitude of the vortex signal to trigger level ratio will be approximately 4:1 for that application.

For all line sizes and service types, the trigger level is preset to a normalized index of four. This baselines an amplitude that is four times lower than the expected peak amplitude of the nominal vortex signal for that line size and service type. The baseline amplitude is compared to the filtered signal to determine acceptance or rejection. Refer to "Signal-Threshold Detection" on page 8 for details on the comparison methodology.

The trigger level can be adjusted to one of 16 possible levels. Figure 20 shows the relative amplitudes of trigger level indices 0 through 8, along with the level corresponding to the vortex signal's relative peak amplitude.

Figure 21 shows the relative amplitudes of trigger level index four, along with indices 8 through 15. Also shown is the level corresponding to the relative peak amplitude of the vortex signal.

Note that the vortex signal peaks in Figure 20 and Figure 21 correspond to the peaks that would occur for the lowest allowable density for a particular process.

The 4:1 ratio has been chosen to allow for the amplitude swings that normally occur on a vortex signal of a given frequency.

CAUTION
Unless the process is of a sufficient density, raising the trigger level may result in lost pulses and less accurate measurement. Raise the trigger level to increase noise immunity if the following criteria are met:
- Process density is sufficiently high
- Noise is causing false triggering and it cannot be alleviated by moving the low flow cutoff or the low pass filter corner

Similarly, dropping the trigger level is not advised unless the following criteria are met:
- Application results in a lower than nominal vortex signal amplitude caused by very low process density (low pressure, high temperature, and/or low molecular weight gases), and/or the application requires low velocity flow measurement
- Noise sources are minimized

FIGURE 20. Trigger Levels 0-8, Relative to 4

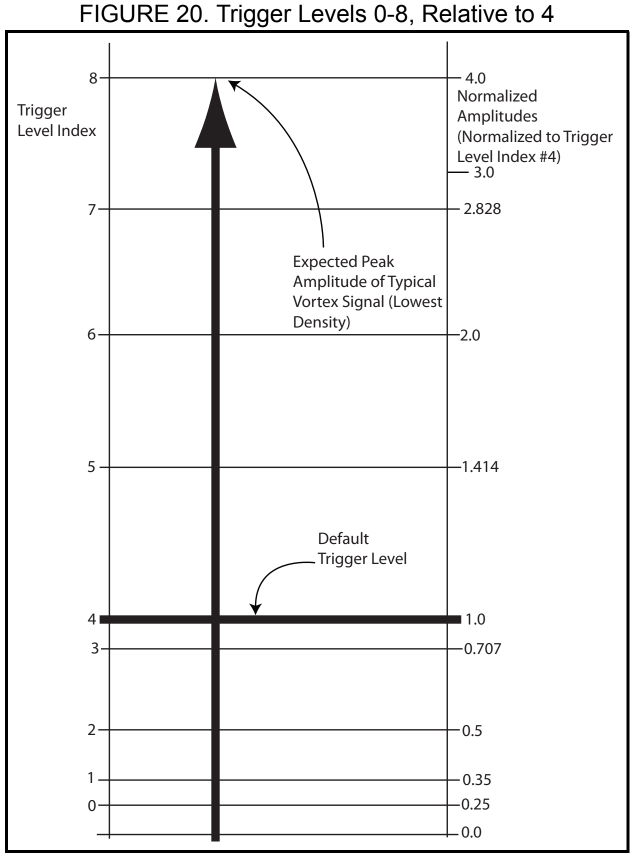
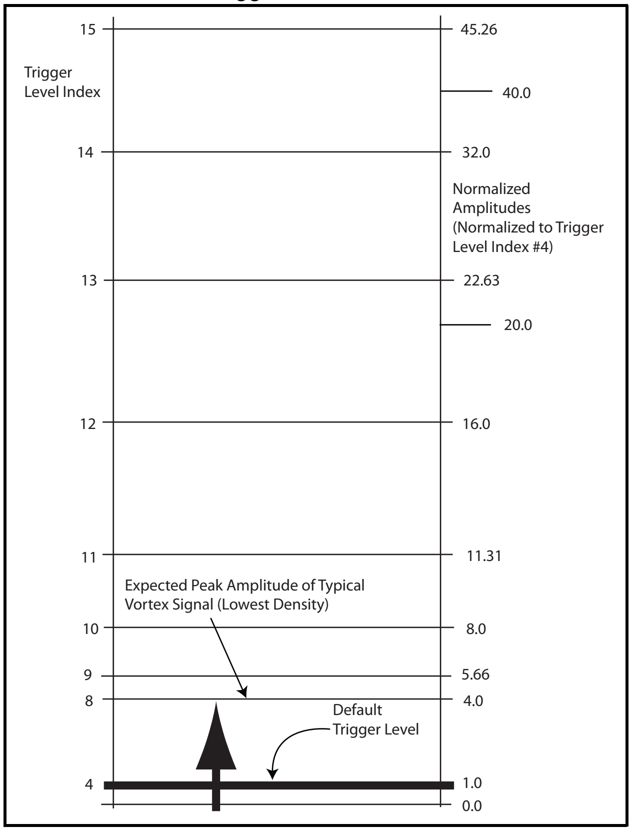


FIGURE 21. Trigger Levels 8-15, Relative to 4



Low Flow Measurement

One limitation of vortex flowmeters is the inability to measure down to zero flow. As discussed in “Theory of Operation” on page 3 vortex meters require a minimum Reynolds Number for generating vortices and minimum signal strength for the sensing element to detect flow. The relationship of Reynolds Number, signal strength, and signal filtering determines the low end measurement range of the vortex flowmeter.

LOW FLOW LIMITS

This section will define the measurable low flow limits of the Rosemount 8800 Vortex Flowmeter

Minimum Reynolds Number Limit

As previously discussed in “Reynolds Number” on page 4, the minimum Reynolds Number for generating vortices is 4,000 (turbulent flow limit). For the Rosemount 8800 we have set the minimum Reynolds Number requirement at 5,000 to provide a buffer zone above the theoretical turbulent flow range. This buffer zone ensures that turbulent flow has been achieved by the process.

ρV^2 Limit

The ρV^2 limit is another name for the signal amplitude or signal strength limit. As discussed in “Vortex Signal Amplitude/Strength” on page 5 the strength of the flow signal is dependent on process fluid density and velocity. A minimum amount of signal amplitude is required by the vortex sensor in order to measure flow. With factory default filter settings, the minimum velocity at which this occurs for the Rosemount 8800 can be expressed using the following equation:

Equation 14

$$Vmin = \sqrt{36/\rho}$$

Where Vmin is minimum velocity in units of feet per second and ρ is process fluid density in units of lb/ft3.

Or

Equation 15

$$Vmin = \sqrt{54/\rho}$$

Where Vmin is minimum velocity in units of meters per second and ρ is process fluid density in units of kg/m3.

These minimum velocity limits are based on having the factory default signal filter settings. Adjusting the filter settings can change the overall sensitivity of the system. For example using Equation 14, if the Trigger Level (see “Trigger Level” on page 11) is lowered from 4 to 3 the Sensor Sensitivity Factor (see “Equation 14” on page 5) would decrease from 36 to 26. Empirical testing has shown that the Sensor Sensitivity Factor can be as low as 9 with ideal installation conditions and proper filter adjustment.

Minimum Measurable Flow Rate

The minimum measurable flow rate is defined as the greater value of the minimum Reynolds Number and ρV^2 limits. In other words, if there is enough signal amplitude available the Rosemount 8800 can measure flow down to a Reynolds Number of 5,000. If the ρV^2 limit is determining the minimum measurable flow rate, filters settings may be adjusted to potentially provide a lower flow limit.

Minimum Measurable Flow Rate versus Minimum Accurate Flow Rate

Accuracy is a typical consideration when measuring low flow rates with a vortex flowmeter. The minimum accurate flow rate is defined as the point where the K-factor becomes non-linear. As discussed in “Relationship between K-Factor and Reynolds Number” on page 3, this occurs when Reynolds Number drops below 20,000 (15,000 in gas and steam applications). So while the vortex meter may measure down to a Reynolds Number of 5,000 it will only meet the linear accuracy specification down to a Reynolds Number of 20,000.

Low Flow Cutoff

There are cases when the default low flow cutoff setting is a higher flow rate than the minimum measurable or even the minimum accurate flow rate. Default filter settings are determined using the Auto Adjust Filter function discussed in “Optimization Routine” on page 12. The default filter settings are based on empirical test data and are optimized for noise free operation. The resulting default filter settings may be conservative compared to the actual capabilities of the Rosemount 8800 Vortex. However, care should always be taken when adjusting filters to read lower flow rates as this increases the susceptibility to noise interference.

ADJUSTING FILTERS FOR LOW FLOW MEASUREMENT

This section will discuss best practices for filter adjustment when trying to read lower flow rates than the default settings will permit by working through an example.

EXAMPLE 2 PROCESS INFORMATION

(US UNITS) Process Fluid: Water

Process Fluid Density: 62.4 lb/ft3

Process Fluid Viscosity: 1.0 cP

Line Size: 2 in.

Compensated K-Factor: 36.00

Flow Range: 0 – 100 gal/min

Desired Minimum Measurable Flow Rate: 7.5 gal/min

Important Flow Rates

Reynolds Number Limit (Rd = 5,000) = 3.04 gal/min

$\rho V^2 \ \text{limit} = \sqrt{36/\rho} = \sqrt{36/62.4}$ =0.76 ft/sec = 7.94 gal/min

Minimum Measurable Flow Rate = 7.94 gal/min (greater of the two values)

Minimum Accurate Flow (Rd = 20,000) = 12.15 gal/min (linear accuracy limit)

Default Low Flow Cutoff = 5.92 Hz = 9.87 gal/min (based on optimization routine)

Situation

In this example the minimum measurable flow rate is 7.94 gal/min. If there was a strong enough signal the meter should be able to read down to 3.04 gal/min. The linear accuracy per the specification will be maintained down to 12.15 gal/min. The default low flow cutoff will be set to 9.87 gal/min from the factory. This value is higher than the calculated minimum measurable flow rate.

The user would like to measure down to 7.5 gal/min. Under the default settings this is not possible as the low flow cutoff will drop the flow reading to zero when the measurement gets below 9.87 gal/min.

Solution

To read flow down to the desired minimum flow rate the default filter settings will need to be adjusted. Before adjusting filters consider the criteria for lowering the filters.

Reducing the low flow cutoff below the factory defaults should only be carried out if the following criteria apply:

- Minimum Reynolds Number and minimum ρV^2 requirements will be met at the new low flow cutoff value
- Low frequency noise (such as pipe vibration) is minimized

Reducing the trigger level is not advised unless the following criteria are met:

- Application results in a lower than nominal vortex signal amplitude caused by very low process density (low pressure, high temperature, and/or low molecular weight gases), and/or the application requires low velocity flow measurement
- Noise sources (such as pipe vibration) are minimized

CAUTION
Notice that in both filter adjustment cases there is a consideration for noise; especially noise caused by pipe vibration. Reducing the filter levels increases the vortex meter's likelihood of reading noise. When trying to measure low flows with a vortex meter, ensure there are sufficient piping supports and the installation has been performed according to the manual.

Review the Criteria

With the default filter settings the low flow cutoff is higher than the desired minimum flow rate. To measure the desired minimum flow rate the low flow cutoff will have to be decreased.

Minimum Reynolds Number

Reynolds Number Limit (Rd = 5,000) = 3.04 gal/min, so the desired flow rate (7.5 gal/min) is greater than the minimum criterion.

ρV^2 limit = $\sqrt{36/\rho}$ = 7.94 gal/min, so the desired flow rate (7.5 gal/min) exceeds this limit. Lowering the trigger level will be required to increase the sensitivity of the meter and allow it to read to lower flow rates per the trigger level adjustment criteria.

FIGURE 22. Default Filter Settings for Example 2

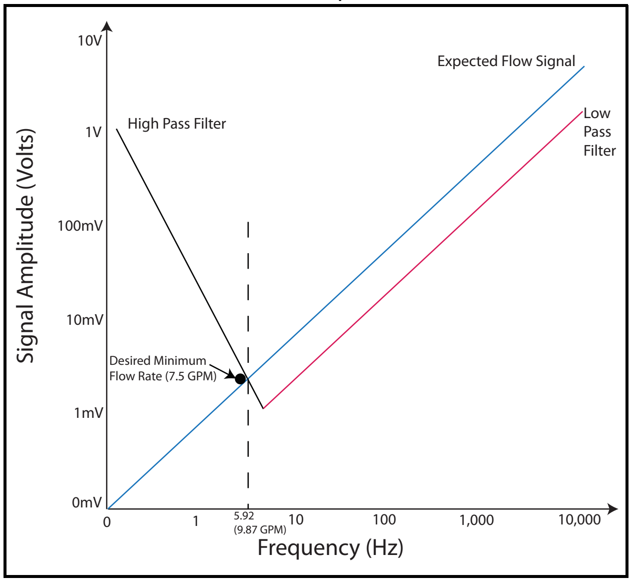


FIGURE 23. Low Flow Cutoff Adjusted Down for Example 2

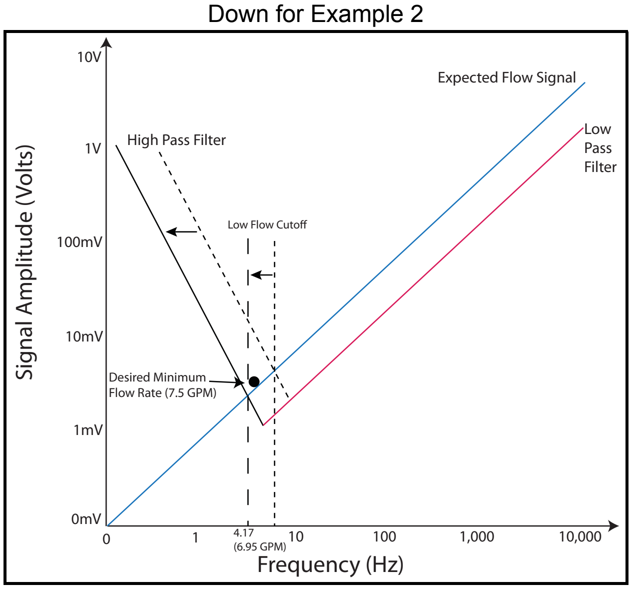


Figure 23 shows the filter settings with the low flow cutoff adjusted downward below the desired minimum flow rate. As stated in “Low Flow Cutoff” on page 13 the low flow cutoff can be adjusted in 18% steps. In this example, two steps of adjustment were required. A third step may be desired to allow for the 18% dead band around the low flow cutoff. The goal of adjusting the low flow cutoff is to allow the desired minimum flow rate to be measured without letting in additional noise.

An important rule of filter adjustment is to only adjust each filter one step at a time. After an incremental step change the unit should be observed for proper operation before continuing with another filter adjustment.

FIGURE 24. Trigger Level Adjusted Down for Example 2

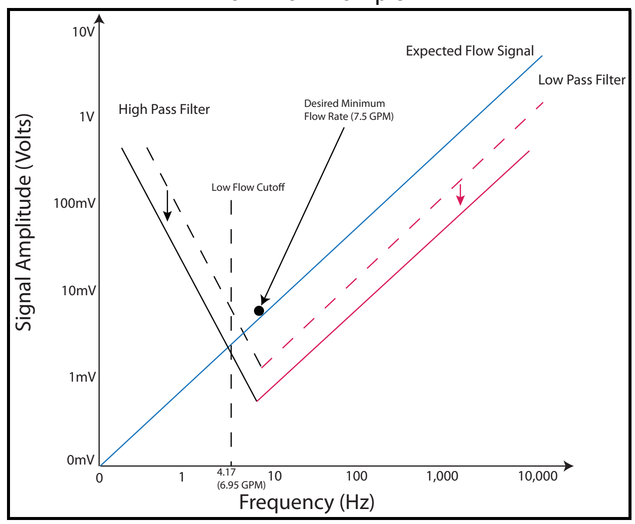


Figure 24 illustrates what happens to the filters when the trigger level is adjusted downward from 4 to 3. The system sensitivity is increased which provides a better signal-to-trigger ratio at all measurement points. See “Signal Strength” on page 12 for details. In effect, the ρV^2 limit has been reduced to $\sqrt{26/\rho}$ = 6.74 gal/min which is below the desired minimum flow rate (7.5 gal/min). The end result of adjusting the trigger level should be a signal-to-trigger ratio of 4 or greater across the entire flow range.

Summary

After analyzing the situation and reviewing the criteria for filter adjustment, the proper settings for low flow cutoff and trigger level were determined. In this example, external noise such as pipe vibration was not included. However, in real process environments it would have to be considered and filter levels could only be lowered as much as the application would allow.

Vibration

Vortex meters operate by measuring a frequency. An output with no process flow may be detected if sufficiently strong vibration is present at the same frequency range as the expected flow measurement frequency range.

The Rosemount 8800 Vortex Flowmeter design will minimize this effect, and the factory settings for signal processing are selected to eliminate these errors for most applications.

If an output error at zero flow is still detected, it can be eliminated by adjusting the low flow cutoff, trigger level, or low pass corner frequency filters.

As the process begins to flow through the meter, most vibration effects are quickly overcome by the flow signal. At or near the minimum liquid flow rate in a normal pipe mounted installation, the maximum vibration should be 0.087-in. (2,21 mm) double amplitude displacement or 1 g acceleration, whichever is smaller. At or near the minimum gas flow rate in a normal pipe mounted installation, the maximum vibration should be 0.043-in. (1,09 mm) double amplitude displacement or ½ g acceleration, whichever is smaller.

NOTE
Adjusting the signal processing filters can affect the vortex meter's vibration immunity. The vibration specification above is based on factory default filter settings.

Pipe Vibration

Pipe vibration can be caused by a number of different things including valves, motors, pumps, rotating equipment, or other piping disturbances. Excess pipe vibration can be dangerous to the integrity of pipe, cause leaks, or damage equipment. It can also cause false indication of flow by vortex meters. Pipe vibration can occur in any direction and is typically at a frequency of less than 20 Hertz (Hz). Pipe vibration is of greatest concern when it is in the same axis as the shedder bar motion. However, if the sum of vibration is all axes is too large it can also cause false flow indication by the vortex meter. General methods of eliminating excessive vibration include piping supports or braces and rotation of the installation orientation of the vortex meter.

Mass Balancing

The first method the Rosemount 8800 Vortex uses for providing vibration immunity is mass balancing. Mass balancing is a mechanical design method in which the amount of mass around the sensing system's pivot point is equalized. This causes the sensing system's center of gravity to move together with any pipe vibration. The result is that pipe vibration alone does not trigger movement of sensing system that will cause a stress on the piezoelectric element. With no stress on the piezoelectric element, no electric signal is generated which could potentially be measured as flow.

Adaptive Digital Signal Processing

The second method the Rosemount 8800 Vortex uses for providing vibration immunity is Adaptive Digital Signal Processing (ADSP). The ADSP in the Rosemount 8800 is configured at the factory for optimum filtering over the range of flow for a given line size, service type, and process density. For most applications, these parameters should be left at the factory settings; however, some applications may require adjustment of the ADSP to eliminate noise caused by pipe vibration.

ADJUSTING FILTERS FOR RESOLVING VIBRATION ISSUES

This section will discuss best practices for filter adjustment when the vortex meter is detecting a false flow reading caused by excessive pipe vibration.

EXAMPLE 3

Process Information

(US UNITS) Process Fluid: Water
Process Fluid Density: 62.4 lb/ft^3
Process Fluid Viscosity: 1.0 cP
Line Size: 2 in.
Compensated K-Factor: 36.00
Flow Range: 0 – 100 gal/min

Important Flow Rates

Flow Indication = 12 gal/min (7.2 Hz)
Default Low Flow Cutoff = 5.92 Hz = 9.87 gal/min (based on optimization routine)
Acceptable Minimum Flow Rate = 20 gal/min

Situation

In this example the user does not have flow going through the pipe, but the vortex meter is indicating a flow of 12 gal/min (measured frequency of 7.2 Hz).

The user needs to eliminate this false indication of flow. The default filters will have to be adjusted to eliminate the vibration noise.

Solution

To eliminate the false indication of flow caused by pipe vibration the default filter settings will need to be adjusted. Before adjusting filters consider the criteria for raising the filters.

Changing the low flow cutoff response type from damped to stepped should be the first filter adjustment if both the following apply:

- The measured flow rate is less than the low flow cutoff value.
- A step change in flow output will not adversely affect the control system or process. Refer to “Low Flow Cutoff Response Type” on page 10 for more information about the possible step change in output.

Raising the low flow cutoff above the factory defaults may be carried out if both of the following apply:

- Low frequency noise is causing false triggering (reported flow rate is higher than actual or reporting flow under no flow conditions)
- Application allows the narrower flow range that will result if the low flow cutoff is raised

Unless the process is of a sufficient density, raising the trigger level may result in lost pulses and less accurate measurement. Raise the trigger level to increase noise immunity if the following criteria are met:

- Process density is sufficiently high
- Noise is causing false triggering and it cannot be alleviated by moving the low flow cutoff or the low pass filter corner

Review the Criteria

With the default filter settings there is an indication of flow under no flow conditions. To eliminate the false flow rate indication the low flow cutoff will have to be increased.

Flow Indication

Flow Indication = 12 gal/min or 7.2 Hz which is higher than the default low flow cutoff of 9.87 gal/min or 5.92 Hz.

Acceptable Minimum Flow Rate

Acceptable Minimum Flow Rate is 20 gal/min according to the user, so raising the low flow cutoff should be acceptable.

FIGURE 25. Default Filter Settings for Example 3

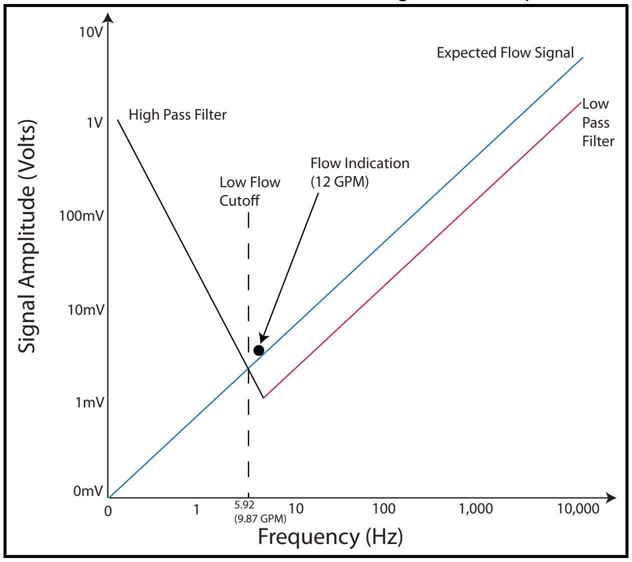


FIGURE 26. Low Flow Cutoff Adjusted Up for Example 3

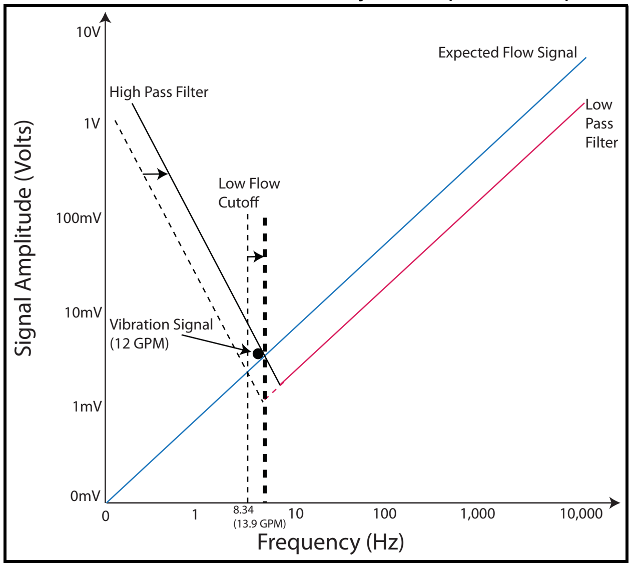


Figure 26 shows the filter settings with the low flow cutoff adjusted upward above the false flow indication. As stated in “Low Flow Cutoff” on page 17 the low flow cutoff can be adjusted in 18% steps. In this example, two steps of adjustment were required. The goal of adjusting the low flow cutoff is to eliminate the false flow indication caused by pipe vibration without cutting into the desired measurable range.

An important rule of filter adjustment is to only adjust each filter one step at a time. After an incremental step change the unit should be observed for proper operation before continuing with another filter adjustment.

In this example, the adjustment of the trigger level was not required. The low flow cutoff adjustment was enough to eliminate the false flow indication.

Summary

After analyzing the situation and reviewing the criteria for filter adjustment, the proper settings for low flow cutoff was determined. In this example, the low flow cutoff adjustment did not interfere with the operating flow range.

Reference Data

TABLE 2. Auto Adjust Filter Densities for Optimizing Signal Processing Parameters

Density Value (lb/ft^3)	Density Value (kg/m^3)
0.02	0.30
0.04	0.60
0.08	1.2
0.15	2.5
0.30	5
0.60	10
1.2	20
2.5	40
5	80
10	160
20	320
40	640
80+	1280+

TABLE 3. Typical Frequency Range by Fluid Type and Line Size

			Liquids		Gas/Steam	
Line Size (in)	Line Size (mm)	Nominal K-Factor	Minimum Shedding Frequency (Hz)	Maximum Shedding Frequency (Hz)	Minimum Shedding Frequency (Hz)	Maximum Shedding Frequency (Hz)
0.5	15	1643	25.9	648	259	6484
1	25	303.6	13.6	341	136	3408
1.5	40	78.23	8.3	207	83	2068
2	50	36.05	6.3	157	63	1571
3	80	10.79	4.1	104	41	1036
4	100	4.672	3.1	77	31	772
6	150	1.379	2.1	52	21	517
8	200	.594	1.5	39	15	386
10	250	0.285	1.0	27	10	270
12	300	0.170	1.0	22	9	220

TABLE 4. Nominal K-Factors by Line Size

Line Size (in)	Line Size (mm)	Nominal K-Factor (F/W/D Type)	Nominal K-Factor (R Type)
0.5	15	1643	-
1	25	303.6	1643
1.5	40	78.23	303.6
2	50	36.05	78.23
3	80	10.79	36.05
4	100	4.672	10.79
6	150	1.379	4.672
8	200	0.594	1.379
10	250	0.285	0.594
12	300	0.170	0.285

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