Vortex Meters for Gas and Liquid Measurement

Prepared by:

Curtis Gulaga

CB Engineering Calgary
Ph: 403-259-6220
Fax: 403-259-3377
Email: cgulaga@cbeng.com

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1.0 Introduction

Vortex meters have proven to be repeatable, accurate and reliable flow meters for both liquid, steam, and gas measurement applications. They provide turn down ratios as high as 30:1, lower pressure drops then that of orifice or turbine meters, and no moving parts resulting in calculated mean time between failures (MTBF) exceeding 200 years. Recent advances in technology have dramatically improved meter performance, including those applications with inherent noise, making the vortex meter a viable choice for industry, and one of the fastest growing meter technologies in the world.

2.0 Vortex Meter Theory of Operation

A bluff body submerged in a flowing fluid sheds the boundary layer from its surface and generates alternating whirl vortices in the backward stream called the Karman vortex street. An example of this is wind blowing across a flagpole causing the flag to flutter. This is attributed to Karman vortices. In the case of a vortex meter, the bluff body is the shedder bar, and has typically been the shape of a square, rectangle, T, or trapezoid. The frequency of the vortices is directly proportional to the flowing velocity and demonstrated with the following formula;

$$\text{Vortex frequency (f)} = \frac{\text{Strouhal number (St) x Flow velocity (v)}}{\text{Vortex shedder width (d)}}$$

Strouhal number is defined as the ratio between the vortex interval and vortex shedder width. In most cases, a vortex interval is approximately 6 times the vortex shedder width while the Strouhal number is it's reciprocal value equal to 0.17. The Strouhal number remains constant when Reynolds number (Re) is within a certain range. Reynolds number is defined as the relationship between fluid velocity, viscosity, and specific gravity as shown in the following formulas for liquids and gases, and illustrates the state of flow;

Equation for Liquids: $$Re = \frac{\text{3160 x flow rate x Specific Gravity}}{\text{Viscosity x Pipe ID}}$$

Equation for gas and steam: $$Re=\frac{\text{6.316 (Flow Rate)}}{\text{Viscosity X Pipe ID}}$$

Example 1: Effect of change in Velocity (flowrate).

$$Rd = \frac{3160\ (10\ gpm)\ (1)}{(1\ inches)(0.95\ cp)} \qquad Rd = \frac{3160\ (200\ gpm)\ (1)}{(2.01\ inches)(0.95\ cp)}$$

Rd = 16,548 Rd = 330,976

Example 2: Effect of change in Viscosity.

$$Rd = \frac{3160\ (200\ gpm)\ (1)}{(2.01\ inches)(5.0\ cp)} \qquad Rd = \frac{3160\ (200\ gpm)\ (1)}{(2.01\ inches)(0.95\ cp)}$$

Rd = 62,885 Rd = 330,976

Testing has shown that linearity, low Reynolds number limitation, and sensitivity to velocity profile can vary with bluff body shape and size. For the majority of manufacturers, the Strouhal number (St) is constant when Reynolds number (Re) is between 20000 and 70000000. Therefore, as long as Re. falls within this range, the vortex frequency is not affected by change in fluid viscosity, density, temperature or pressure, unlike many other meter technologies.

The relationship between vortex frequency and fluid velocity is expressed as:

(1) $St = f * (d/v)$

Equation (1) can be rearranged as:
(2) $v = (f*d)/St$

Since volumetric flow rate Q is defined as the product of the average fluid velocity and the cross sectional area available for flow:

(3) $Q = A*v = (A*f*d*B)/St$

Where B is the blockage factor and is defined as the full bore area of the pipe less the blockage area of the bluff body, divided by the full bore area of the pipe. Equation (3) can be written as:

(4) $Q=f*K$

Where K is defined as the meter coefficient, and can be defined as pulses per unit volume.

3.0 Proving and Calibration

In non-corrosive and non-abrasive service, the meter's internal geometry, and in turn the meter's K-factor can be expected to remain constant for the life of the meter. To verify that the K factor has not shifted, one could obtain the shedder bar width and meter bore diameter at the time of manufacture. The user could remove the meter at any time, or based on some regular inspection schedule, and measure these dimensions with a micrometer. If they agree with the measurements made when the meter was originally calibrated, the meter's K-factor should be unchanged and there is no need to proceed with recalibration thereby eliminating costly meter proving and flow testing. Measurement Canada approval for natural gas has been obtained by some manufacturers.

4.0 Recent Developments

To further reduce the effects of noise superimposed on the measuring signal, new technologies have been developed. They utilize advanced processing algorithms known as Spectral Signal Processing (SSP) resulting in accuracies as great as 0.75%. SSP analyzes the incoming signals and applies an intelligent amplification circuit, based on measured frequency and predicted process conditions. Start up tuning is eliminated even in noisy environments resulting in reduced maintenance time, and stable, accurate flow measurement is attainable at flow rates well below 20000 Re. Expanded diagnostic capabilities provide alarms for process anomalies like entrained gas in liquid, and optional integral RTD providing multi variable outputs, including mass measurements when using a fixed pressure input.

In addition to SSP, adaptive noise suppression (ANS) serves to provide a higher signal to noise ratio by minimizing the effects of mechanical noise. One crystal, as a function of its position, has an output with a larger noise component than signal. The second crystal, again because of its position within the shedder bar, has a greater signal component. At the same time the outputs of the two crystals are 180 degrees out of phase from each other (reverse polarity). ANS balances the noise component of the second or "noise" crystal to equal that of the "signal" crystal. The output of the two crystals is then added in a summing amplifier, and the noise component is then eliminated (due to the reverse polarity of the two crystal outputs) and what remains is noise-free signal. ANS is a dynamic process, which means ANS continuously analyzes the incoming signals and adapts to changing noise conditions to continuously provide optimum flow signals. A Spectral Adaptive Filter (SAF) is then applied that further analyzes the individual signals and applies a mathematically derived band pass filter to further enhance the vortex shedding flow frequency.

5.0 Sizing and Installation

Vortex meter equations are relatively simple when compared to those for orifice plates, but there are still rules that must be applied. Manufacturers offer free computer software for sizing, where the user enters fluid properties such as density, viscosity, and desired flow range, and the program automatically sizes the meter as per figure 1. Installation requirements are specific to the meter manufacturer and shown in figure 2 and 3.

Customer: BP | Date: 03/10/2003 | Tag #:

Fluid: | Fluid Type: Other Liquid

	Maximum	Operating	Minimum
Flow (m^3/hr):	800	600	200
Pressure (psig):	1440	800	600
Temperature (°C):	25	12	2

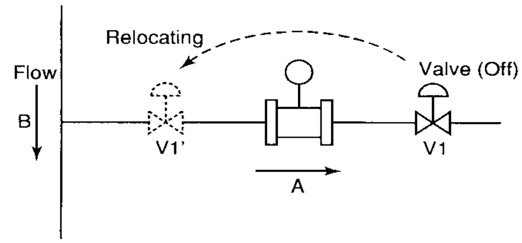
Density Kg/m^3 op: 400 | Viscosity (cp): 0.05 | Vapor Pressure (psig): 575

Model	DY080	DY100	DY150	DY200	DY250	DY300	DY400
Size (in)	3.0	4.0	6.0	8.0	10.0	12.0	16.0
Qmax (m^3/h	**{142.5}**	**{248.8}**	**{544.7}**	974.0	1506.1	2156.9	3547.2
Qlin	8.280	14.45	31.65	66.01	116.7	167.1	549.5
Qmin	8.280	14.45	31.65	66.01	116.7	167.1	**{549.5}**
Pd	197.4	64.80	13.51	4.227	1.768	0.862	0.319
Pmin (psig)	**{1482.2}**	**{899.0}**	**{642.6}**	596.1	583.8	579.3	576.6
Recommended?	**{N/R}**	**{N/R}**	**{N/R}**	Preferred	Acceptable	Acceptable	**{N/R}**
Select Meter							

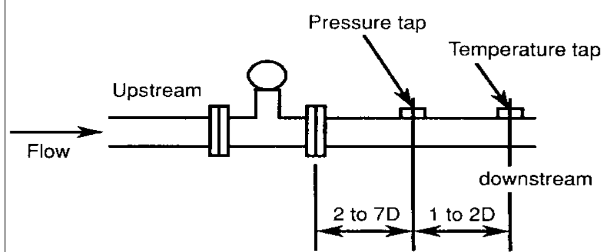
Figure 1

Description	Figure

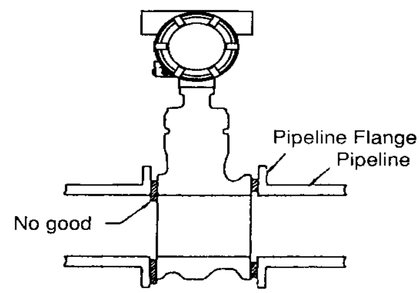
Valve positon (T-type piping exist):
If pulsating flow results from a Tee installation, install the valve upstream of the flowmeter.



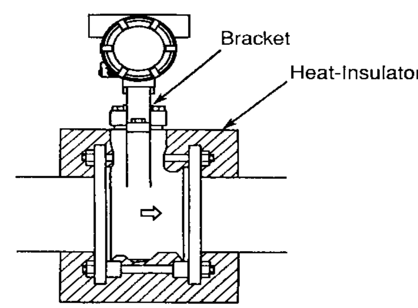
Pressure and Temperature Taps:
Pressure tap outlet: install this tap between 2D and 7D on the downstream side of a flowmeter.
Temperature tap outlet: install this on the downstream side 1D to 2D away from a pressure tap.



Mounting Gasket:
Avoid mounting gaskets which protrude into the pipe line. This may cause inaccurate readings.
Use the gaskets with bolt holes, even if YEWFLO is the wafer type.
When using a spiral gasket(without bolt holes), confirm the size with the gasket -manufacturer, as standard items may not be used for certain flange ratings.



Heat-Insulation:
When a integral-type flowmeter or a remote type detector is installed and the pipe carrying high-temperature fluids is heat-insulated, do not wrap adiabatic materials around the installation bracket of the converter.



Flushing of the pipe line:
Flush and clean scale, encrustation and sludge on the inside of pipe for newly installed pipe line and repaired pipe line before the operation. For flushing, the flow should flow through bypass-piping to avoid damaging the flowmeter. If there is no bypass-piping, install short pipe instead of the flowmeter.

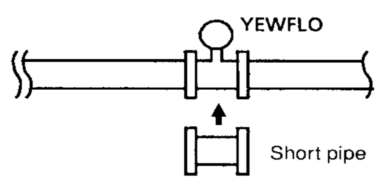


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Figure 2, Compliments of Yokogawa Corporation of America

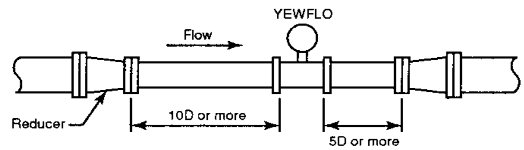
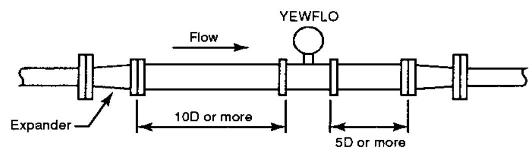
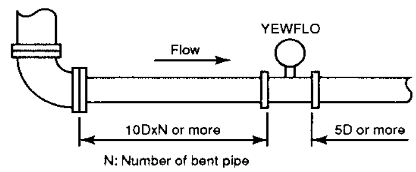
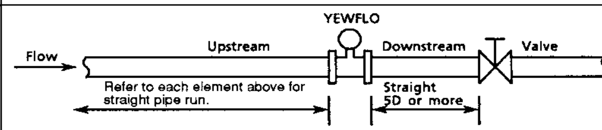
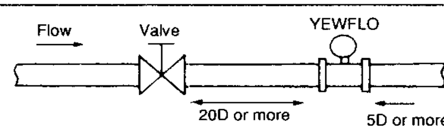
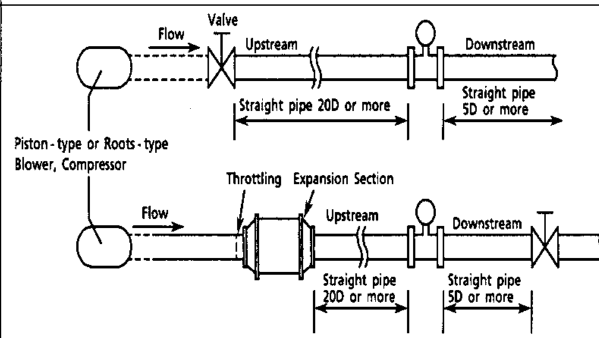
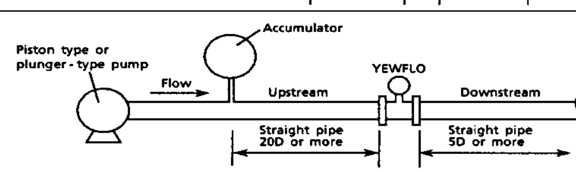
Description	Figure
Piping support: Typical vibration immunity level is 1G for normal piping condition. Piping support should be fixed in case of vibration greater than 1G.	
Installation direction: If a pipe is always filled with liquids, the pipe can be installed vertically or at inclined angle.	
Adjacent pipes: The process pipline inner diameter should be larger than the YEWFLO inner diameter. Use the following adjacent pipe. Nominal size .5 to 2 in. (15 to 50mm) : Sch 40 or less. Nominal size 3 to 12 in. (80 to 300mm) : Sch 80 or less.	
Reducer pipe: Ensure the upstream straight pipe length is 10D or more, and the downstream straight pipe length is 5D or more for reducer pipe. (D: nominal YEWFLO diameter)	
Expander pipe: Ensure the upstream straight pipe length is 10D or more, and the downstream straight pipe length is 5D or more for expander pipe.	
Bent pipe and straight pipe length: Ensure the upstream straight pipe length is 10D or more, and the downstream straight pipe length is 5D or more for bent pipe.	
Valve position and straight pipe length: ■ Upstream straight run requirement is dependent upon configuration, such as upstream valves, expansions, elbows, etc. 5D or more for downstream pipe runs. ■ In case the valve has to be installed upstream of the flowmeter, ensure the upstream straight pipe length is 20D or more, and the downstream straight pipe length is 5D or more.	 
Fluid pulsation: For a gas line which uses a position-type or roots-type blower compressor or a high-pressure liquid line (about 1MPa or more) which uses piston-type or plunger-type pump, fluid pulsations may be produced. In these case, install valve on the upstream side of YEWFLO. For fluid vibration, put a vibration damping device such as throttling plate or expansion section on the upstream side of YEWFLO.	
Piston-type or plunger pump: Install the accumulator on the upstream side of YEWFLO to reduce fluid vibrations.	

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Figure 3, Compliments of Yokogawa Corporation of America

6.0 Conclusion

Vortex meters are unaffected by process changes in viscosity, density, temperature, and pressure when operated with in their linear range, which can be as great as 30:1. Advanced processing algorithms and adaptive noise suppression practically eliminate noise and vibration superimposed on the measuring signal making accuracies of 1.0% for gas and 0.75% for liquids easily attainable. Meter sizes range from ½" to 16", and require upstream pipe diameters ranging from only 10 – 30 pipe diameters depending on the disturbance and manufacturer. Vortex meters are versatile, capable of withstanding product viscosities as high as 30 cP, or as low as 0.01 cP for high temperature steam. Some manufacturers offer multivariable options including temperature and pressure outputs with on board steam tables for mass flow rate calculation. Caution is advised in continuous on/off applications, as the meter will not detect flow below 5000 Re which would be equivalent to it's minimum detectable flow rate.

7.0 References

1. Yokogawa Corporation of America – Vortex Meter General Specifications 01F06A00-01E and 01F02B04-00E.

2. American Petroleum Institute – Measurement of Fluid Flow in Pipes Using Vortex Flow Meters, ASME/ANSI MFC-6M-1987

3. Measurement Canada – Notice of Approval AG-0395 Rev 1.

4. Flow Measurement Engineering Handbook – R.W. Miller