Vortex Shedding Meters

Class # 8150

Curtis Gulaga
Business Development Manager
CB Engineering Ltd.
#20, 5920 – 11 Street S.E.
Calgary, Alberta, Canada

1.0 Introduction

Vortex meters have proven to be repeatable, accurate and reliable flow meters for liquid, steam, and gas measurement applications. They provide turn down ratios as high as 30:1, low-pressure drops and no moving parts resulting in calculated mean time between failures (MTBF) exceeding 250 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

In the case of a vortex meter, the bluff body is the shedder bar, typically shaped like a square, rectangle, T, or trapezoid as shown in figure 1, and is submerged in a flowing fluid. As the fluid passes the bluff body, alternating whirl vortices are generated in the backward stream referred to as a Karman vortex street and illustrated in Figure 2. Another example of this is wind blowing across a flagpole causing the flag to flutter. The vortex shedding phenomenon is caused by pressure or velocities fluctuations on either side of the bluff body. Frequency detection can be accomplished by using different techniques including piezoelectric, differential pressure, or capacitance, and 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) $v = (f*d)/St$

Fig 1 : Vortex Shedder Cross Sections

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

(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.

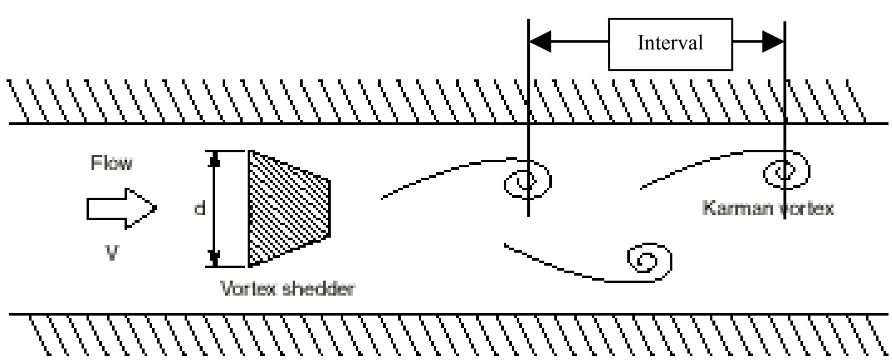
3.0 Proving and Calibration

Vortex meters are a linear device that can produce either an analog output and or a raw or scaled pulse output, with accuracy specified as a % of reading versus % of span. The number of pulses produced varies with meter size and velocity. There are no moving parts in a vortex meter, and the primary element, the vortex shedder, is not easily damaged during brief periods of mixed phase flow. Empirical data has shown that the sensitivity to maintaining sharp edges on the shedder is 10 times less then that of an orifice plate. Therefore, meter performance is virtually unaffected by thin oil coatings or slight rounding of the shedder bar. 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. 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.

4.0 Custody Transfer Measurement

Manufacturer's specified accuracy for most vortex meters is +/- 0.75% for liquids and +/- 1.0% for gas. Repeatability is generally 0.2%. Flow calibration at accredited gas laboratories has resulted in accuracy's equal to or better then 0.5% and repeatability's typically better then 0.1%. Liquid provings have resulted in accuracy's of 0.25% and repeatability's substantially better then 0.1%. The technology is not as effected by swirl, or turbulence as for an orifice meter. Test measurements show that the effects on the flow coefficient for typical pipeline conditions including bent pipe, reducer, expander, and shut off valve are 0.5% or less if the upstream straight pipe length is 10D or more. Flow conditioners will provide a pseudo-fully developed flow profile and eliminate this bias. Measurement Canada has granted approval for some manufacturers on natural gas measurement, and an API working committee is currently writing a draft standard for the technology.

Figure 2



5.0 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). 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. For some manufacturer's, flow is measurable to as low as 5000 Re, and may be referenced in the manufacturer's sizing program as a minimum flow rate versus linear flow rate, with a decrease in both accuracy and repeatability. Below 5000 Re, the digital signal, frequency and mA signals drop to zero and 4mA respectively to avoid erroneous flow measurements that may be caused by process noise, mechanical vibrations, and or electrical interference.

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 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. Expanded diagnostic capabilities provide alarms for process anomalies like entrained gas in liquid, or vibration, and multi variable options provide simultaneous outputs, as well as inferred mass flow rate when using either an integral RTD or pressure sensor. Steam tables are often embedded in the meter electronics and referenced with either the live temperature or pressure signal for mass measurement. With the advent of Foundation Fieldbus, all output signals may be obtained through one set of wires, otherwise known as a common bus and referenced in a math function block for providing an inferred mass output.

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 3, Compliments of Yokogawa Corporation of America

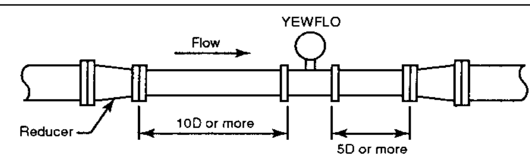
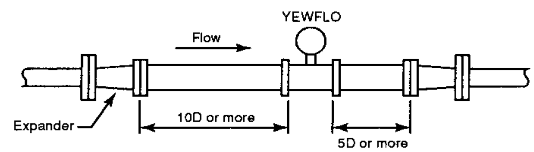
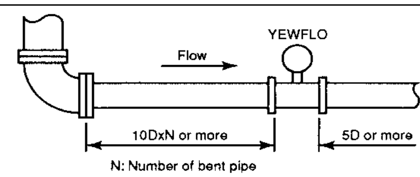
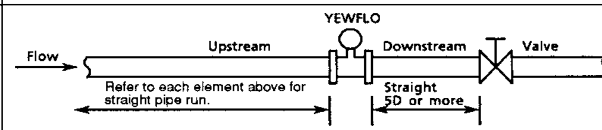
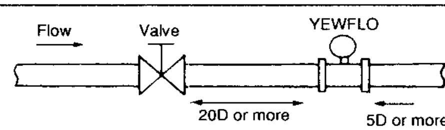
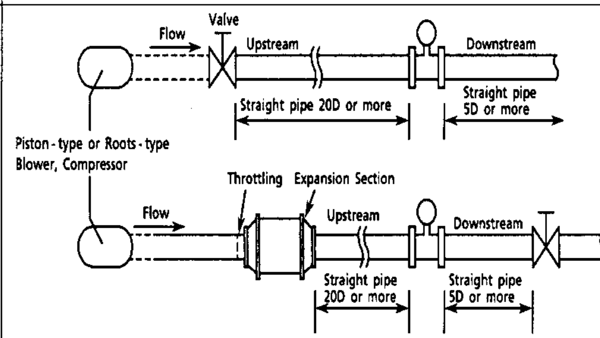
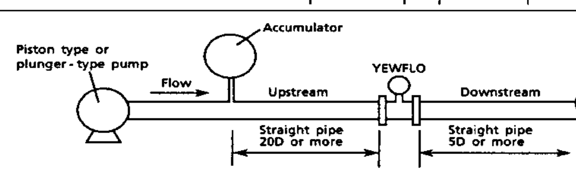
Description	Figure
Piping support: Typical vibration immunity level is 1G for normal piping condition. Piping support should be fixed in case of vibration greater than 1G.	
Installation direction: If a pipe is always filled with liquids, the pipe can be installed vertically or at inclined angle.	
Adjacent 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 4, Compliments of Yokogawa Corporation of America

6.0 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, temperature, pressure, and desired flow range, and the program automatically sizes the meter as per table 1. Note that Qmin and Qlin are based on 20000 Re, and this can be adjusted up or down in the software. Installation requirements are specific to the meter manufacturer and shown in figure 2 and 3.

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 standard 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 – 40 depending on the disturbance and manufacturer without flow conditioning. Vortex meters are versatile, capable of withstanding product viscosities as high as 30 cP, or as low as 0.01 cP for high temperature, high quality steam. Some manufacturers offer multivariable options including temperature and pressure outputs for inferred mass flow rate, and reducer style meters for easily retrofitting existing piping. 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

5. ISO/TR 12764 Measurement of Fluid Flow in Closed conduits – Flow rate measurement by means of vortex shedding flow meters inserted in circular cross – section conduits running full.