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APPLICATION RULES FOR VORTEX SHEDDING FLOWMETERS, MAKING A SELECTION EASY

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1 SUMMARY AND CONCLUSIONS

Since the early nineties vortex shedding flowmeters are used in the process industry as a cost effective alternative or replacement for orifice flowmeters, with the aim to have an improved performing flowmeter at a lower operating cost Often performance was not as successful as targeted for. Incorrect application of vortex flowmeters resulted in a number of cases in plant start-up difficulties, resulting in e.g. extra costs to rectify the situation and deferred production. Examples of this were situations whereby the Reynolds number or flow velocity was too low, flashing/cavitation of liquids occurred or fluid pulsation or external induced mechanical vibration levels were too high. Moreover the up- and downstream pipe configuration or positioning errors at installation affected the meter factor. Concluding one can say, wrong selections were made because of limited application and engineering knowledge in relation to the behaviour of vortex flowmeters.

To develop more knowledge about the behaviour of vortex flowmeters, members of WIB The International Instrument Users Association and the Flow Centre of TNO TPD jointly developed application guidelines for vortex flow meters. The project started in 1985 with flow profile investigations, followed by the evaluation of a variety of makes of vortex flowmeters (Yokogawa, Fisher-Rosemount, Emco, Endress+Hauser, ABB Automation and Foxboro) on meter performances and the determination of the behaviour of vortex flowmeter on vibrating and pulsating flow services. Finally, based on these results and with the “lessons learned” from a number of multinational petro-chemical companies, all members of WIB, the guidelines were developed in 1999. It is believed that those application guidelines would improve the engineering process of vortex flow meters in projects, in the majority of cases done by 3rd party engineering contractors.

This application guideline is used by Shell in the continuous feedback process to improve its Design & Engineering Standards, and as Best Practice guide for its operating companies and 3rd party engineering contractors in the selection process of vortex flowmeters. Over recent years application of vortex flow meters in Shell’s oil, gas and liquefied natural gas projects is an accepted practice. However, key to a fit-for-purpose performance of vortex flowmeters is sound application engineering. There is positive evidence now, that by taking in account the operating data, operating cases and the application environment, the vortex flow meter is now successfully applied in Shell’s process installations.

2 INTRODUCTION

In the refining and petrochemical processes, the orifice plate is traditionally the workhorse for flow measurements. Much knowledge exists about the performance, design and engineering aspects of orifice type flow measurements. Even to date revisions are still made to the well-known standard for orifice type flowmeters: ISO-5167. The existence of this standard, is for many plant owners reason enough to specify those meters.

Since 1990, there is a clear trend in new projects of Shell and other multinational companies to shift away from differential pressure type measurements, towards in-line flow measurements. Particularly the vortex flowmeter, an inherently simple and robust device, has become a popular replacement of the differential pressure devices for both liquid and gas applications, because of:

- low cost;
- good rangeability;
- adequate accuracy;
- 2 - wire implementation (no external power required).

Executing major capital projects for Shell, engineering contractors take care of the engineering and selection of flowmeters. Generally, they treat them as bulk commodities, by applying general engineering rules on them. Soon however, it became evident, that the application of vortex flowmeters is not that straightforward.

In a number of Shell projects, during initial start-up, mal-performing vortex flowmeters caused serious delays during start-up. Main problems were found in oversized meters and wrong meter applications, in fact a result of insufficient application engineering efforts and application expertise and often insufficient recognition of the need for proper commissioning.

It is evident that high replacement costs and deferred production made in-line measurement, in particular vortex flowmeters, not very popular with management of those operating companies.

From an industry perspective, there was a requirement for more knowledge about the application of vortex flowmeters. Vendors and engineering contractors could not adequately provide this support, sometimes as a result of overriding commercial reasons. So, WIB The International Instrumentation User Association, of which many multinational companies in the process industry are members, recognised this need and started a research program to evaluate the overall performance of vortex flowmeters. The Flow Centre of TNO TPD (Delft, The Netherlands) executed this program. Ultimately, making use of the deliverables of the evaluation, with input from member companies, WIB produced an Application Guideline for vortex flowmeters [1],[2],[3].

3 A BUSINESS CASE

In the period between 1990 and 1995, Shell undertook three major refinery projects in which vortex flowmeters were specified as the main choice for flow monitoring, control and safeguarding. With respect to this choice of instrumentation, these projects were not immediately successful.

What were the main phenomena found:

- Limited rangeability, as low as 2 : 1 (i.e. alarms/trip settings below low flow cut-out) found on a substantial part of the meters;
- Some meters showed loss of signal (i.e. occasional spiking);
- Some meter showed fluctuating signals.

In one case problems were only found during actual start-up with hydro-carbons already in the units. When vendor representatives were consulted and problems were inventoried, the root causes could be identified.

What were the root causes:

- Meter size too large (i.e. line size)
- Incorrect piping arrangements
- Pipe vibrations
- Flow pulsations

In a joint effort of vendor / engineering contractor / own staff, replacement programs had to be initiated. The order of magnitude of the problems for these three refinery projects is represented in Table 1. Other WIB members had similar, probably less dramatic experiences.

Table 1: Replacement of Vortex Flowmeters In Refinery Projects

Project	Installed	Replaced
A	200	20
B	360	60
C	500	100

What were the consequences:

As application problems are often found during start-up, consequential losses were quite substantial in terms of deferred production replacement costs. In order to be able to progress the start-ups, a number of costly programs had to be executed to replace non-performing meters with smaller ones or alternative types. In most of the cases this also required piping modifications.

Nevertheless, it has been proven that by proper sizing, selection and installation, vortex flowmeters are a well suited alternative to orifice type installations.

What are the lessons learned:

In this type of projects, in which a large number of items have to be handled, flowmeters are treated as bulk items. General design & engineering rules are used to determine the sizing, selection and implementation aspects of flowmeters. For orifice type flow instrumentation design and installation rules are well laid down in the international standard ISO-5167. With the introduction of in-line flowmeters in projects, partially unknown territory had been entered by end-users, engineering contractors, but initially also by vendors. Although multinational companies, quickly took the lessons learned on board in their practices and standards, it was felt insufficient in-depth knowledge was available about those meters.

WIB research in relation with application guidelines

WIB The International Instrumentation Users' Association of which most oil majors are member, but also other process industries i.e. chemicals, food, water, recognised the need to start an investigation program for in-line flowmeters. With the vortex flowmeter as one of the intended workhorses for flow, a program was started to verify the specifications of those instruments. The purpose of the test was in particular to focus on application related subjects, like flow profile, temperature, vi bration, pulsation and viscosity. Those tests were performed on the makes and models as shown in Table 2.

Table 2: Makes and Models Involved With The Research Program

Make	Model	Type
ABB (F & P)	10VT1111B	Vortex shedding (DN80)
ABB (F & P)	10VT2114C	Vortex shedding (DN40)
ABB (F & P)	10VT2144C	Vortex shedding (DN100)
ABB (F & P)	10ST1101A	Swirl meter
Endress + Hauser	Prowirl 70F	Vortex shedding
EMCO	PhD	Vortex shedding
Foxboro	83 F-D	Vortex shedding
Foxboro	83 F-D	Vortex shedding (dual sensor)
Fisher-Rosemount	8800	Vortex shedding
Fisher-Rosemount	8800	Vortex shedding (dual sensor)

Make	Model	Type
Yokogawa	YF108	Vortex shedding

Making use of the individual meter evaluation results, combined with experience of WIB member flow experts, an Application Guideline for vortex flowmeters was prepared by TNO. The purpose of these guidelines was to give some rules of thumb to realise the best possible vortex flowmeter performance. However, the items mechanical integrity and long term performance aspects (e.g. fouling, erosion of the shedder bar etc) have not been covered. Regarding the mechanical integrity, the manufacturer should provide this data in particular with respect to methods for calculating fatigue stress levels and safety factors and how these are related to the relevant operational and environmental conditions.

Currently a WIB project is running to measure the effect of shedder bar erosion on the meter accuracy.

Best performance means focusing on own applications and goals

Achieving the best possible performance is a question of defining the goals (i.e. control, monitoring, safety or custody transfer) and making an inventory of the environmental, process, and installation conditions, i.e. communication, corrosiveness, vibrations, size, minimum and maximum flow, temperatures, pressures, medium, medium fouling, two phase composition, fluid pulsation, humidity and built in length. Based on this, one can choose the best suitable principle, make, type and size. Finally the detailed engineering (location, orientation, wiring) makes it complete. These application guidelines can help to make a choice whether a vortex flowmeter will match with your application or not and how to engineer it to achieve best performance. However these guidelines are not exhaustive and every application will demands its own solution.

4 OPERATING PRINCIPLE OF VORTEX SHEDDING FLOWMETERS

To understand the points of attention for vortex flowmeters, the operating principle will be explained. When a fluid flow is passing an obstacle, boundary layers of slow moving fluid are formed along the outer surfaces. If the obstacle is not streamlined or the fluid velocity is too high, the flow cannot follow the contours of the obstacle on the downstream side of the obstruction and separated layers become detached from the main fluid stream and roll over into vortices in the low pressure area behind the bluff body. The vortices are shed from alternate sides of the body, see Figure 1.

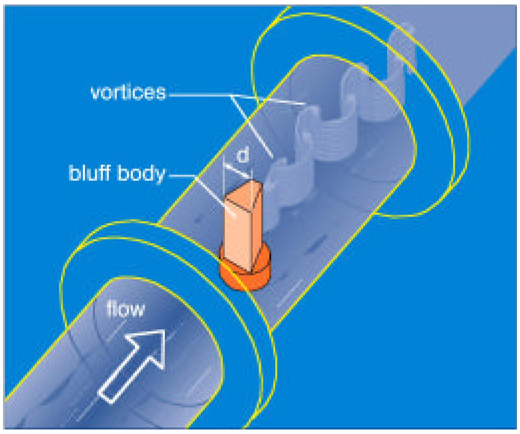


Figure 1: Scheme of measurement principle of vortex shedding flowmeters.

The frequency at which the vortices are formed is proportional to the fluid velocity over a wide range of Reynolds numbers. As a vortex sheds form one side of a bluff body the fluid velocity on that size increased and the pressure decreases; on the opposite side, a velocity decrease and pressure increase occur. The entire effect is then reversed as the next vortex is shed from the opposite side. Consequently, the velocity and pressure distribution around the bluff body change with the shedding frequency. Various methods can be used to detect either the pressure or velocity changes. The frequency at which vortices are shed is proportional to the flow velocity and inversely proportional to the diameter of the bluff-body. This can be expressed as:

$$F = St * v/d \tag{1}$$

with
- f: shedding frequency [Hz]
- St: Strouhal number [-]
- v: flow velocity past the bluff body [m/s]
- d: the diameter of the bluff body [m]

By selecting an appropriate shape, the Strouhal number can be kept constant over a wide range of Reynolds numbers. Vortex flowmeters are available for temperatures up to 773K and sizes from 15 to 300 mm (flange type).

5 APPLICATION GUIDELINES

This paper focuses on the four most important and some related selection criteria for vortex shedding flowmeters:

- Sizing (operational range and pressure drop)
- Piping effects
- Accuracy and repeatability
- Installation effects (pulsating flows and mechanical vibrations)

These items are closely related and have even an overlap. The guidelines represent the highest common factors for the different makes of flowmeters. That means that for every individual make the application guidelines could be slightly different because of differences of bluff body, sensor type and location, signal amplification and conditioning and processing. However using these guidelines will keep you at the safe side of the operational limitations.

5.1 Sizing of Vortex Shedding Flowmeters

Sizing is one of the most important issues. Choosing the correct size can avoid lots of problems. However correct sizing is a matter of balancing between:

- the operational range of the process line, e.g. minimum and maximum flows during start- up, normal operations, and extreme conditions,
- the available line pressure in relation to dynamic pressure drop and static pressure loss over the measurement section,
- the required accuracy, and
- vibration and pulsation levels and frequencies.

In the following paragraphs the above mentioned items will be deepened.

5.1.1 Operational range

In this paragraph the minimum and maximum detectable flow rates with vortex flowmeters for liquids, and gases will be discussed. Based on the many measurements some general rules of thumb are given.

Regarding the operational range of vortex flowmeters, the following statement can be made:

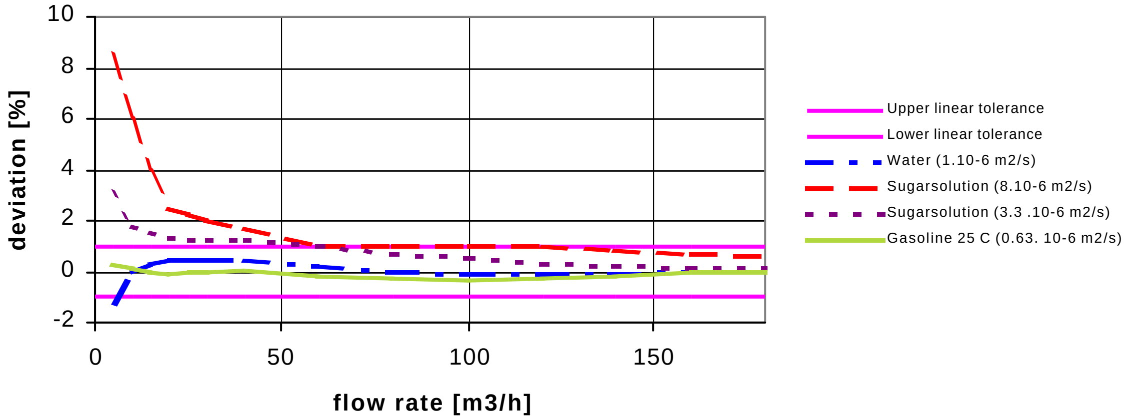
Below a pipe Reynolds number of 5,000 vortex flowmeters will not recognise a flow at all (incoherent and very small signal). The output will be zero. Between 5,000 and 20,000 the shedding frequency is non-linear with the flow rate (Equation (1) is not valid). The relationship between flow rate and frequency becomes linear when the Reynolds number exceeds 20,000 (Equation (1)). The next graphs show the sensitivity of a 3” vortex flowmeter to variations in flow rate and viscosity.

The optimum operating range is different for fluids and gases. For gases there is no known upper Reynolds limit to the production of vortices. The density of the gas and the sensitivity of the sensor determine the minimum acceptable flow rate. For low flow rates and low densities the signal to noise ratio is bad, see equation 2:

$$S = C \rho v^2 \qquad (2)$$

with S: force of vortices [N]
C: constant [m^2]
ρ: density of fluid [$kg.m^{-3}$]
v: velocity of fluid [$m.s^{-1}$]

Figure 2 depicts typical deviations found on actual flow and Reynolds number for water, sugar solutions with different viscosities and gasoline.



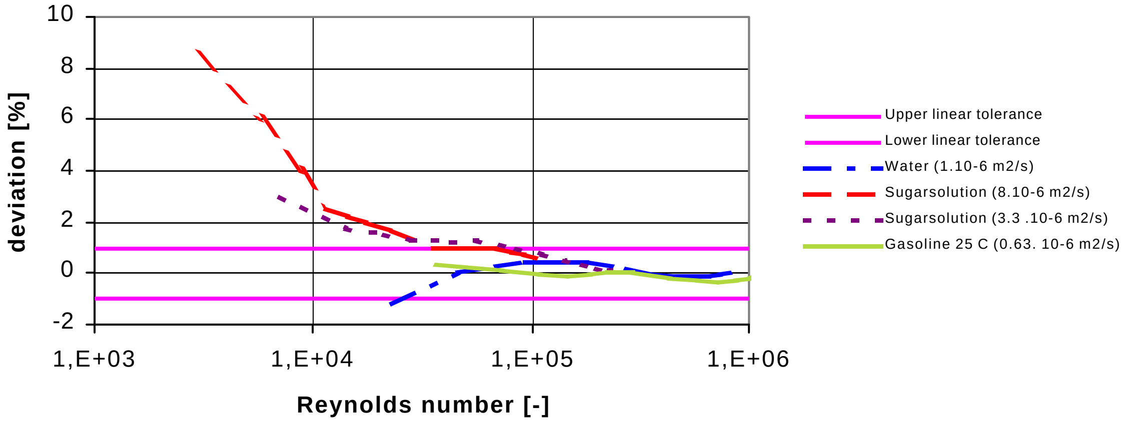


Figure 2: Operating range of 3” vortex flowmeters

For liquids, the flow range depends on the process conditions and fluid (e.g. viscosity, density, vapour pressure and line pressure). The minimum flow rate is governed by the minimum allowable Reynolds number and the minimum frequency that can be handled by the electronics. The maximum flow rate is limited by the maximum allowable meter pressure loss and the vapour pressure (see paragraph pressure drop in relation to sizing, flashing and cavitation).

According to these starting points the following application guidelines can be given:

- Pipelines are often designed so, that: the mean flow velocity for liquids lies between 1 m/s and 3 m/s, and for gases the maximum flow velocity will not exceed 30 m/s (matches well with the flowmeter operational range). As a result of this, the velocity for liquids does not match with the vortex flowmeter velocity range. To ensure that the minimum and maximum process flow rates are within the capability of the meter and sufficient turn down ratio is obtained, a size has to be selected which in most cases is smaller than the pipe line size (at the most two sizes smaller than the pipe line size).

- Besides the normal operating conditions, attention must be paid to possible extreme conditions, e.g. during start-up it is possible that the fluid viscosity is different from normal as a result of lower fluid temperatures. If so, the flowmeter may operate outside its capability.

5.1.2 Pressure Drop In Relation To Sizing, Flashing and Cavitation

The maximum flow rate for liquids is determined by the fact that sufficient line pressure has to exist to prevent flashing and cavitation. Flashing and cavitation occur when, as a result of increased flow velocity in the vortex flowmeter, the line pressure locally drops to or below the vapour pressure. Under these conditions, the flowmeter will be damaged by erosion and the output will be seriously in error. The lowest pressure point in a vortex flowmeter is at the vena contracta (dynamic pressure drop). The vena contracta is somewhere between the up- and downstream side of the bluff body, depending on the bluff body shape. This was measured during the WIB research program. At the meter outlet there is a considerable pressure recovery (as an effect of the attenuation of the vortices). The static pressure loss of a vortex flowmeter depends greatly on body geometry. The following figure shows the pressure profile along a vortex flowmeter.

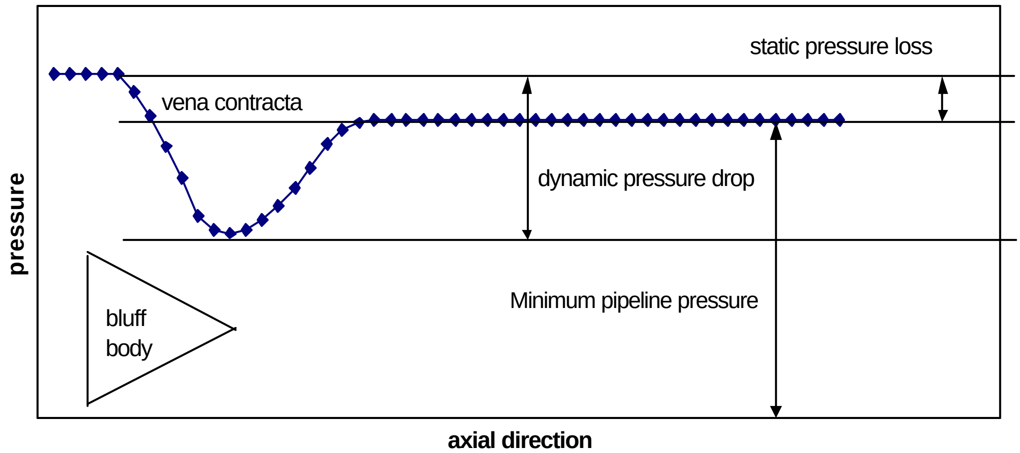


Figure 3: Pressure changes across the bluff body

A rule of thumb for the minimum acceptable line pressure (P) at 5D downstream the flowmeter, to avoid flashing and cavitation and guarantee that the pressure at the vena contracta will be larger than the vapour pressure, is:

$$P = 2.7 * dP + 1.3 * Pv \qquad (3)$$

with P: minimum pipe pressure [bar abs.]
dP: pressure drop across the flowmeter [bar]
Pv: liquid vapour pressure at operating conditions [bar abs.]

The pressure drop Pv depends on the size of the flowmeter. A smaller pipe will result into larger pressure drops across the meter section, e.g. for a 2 line sizes reduced flowmeter section, the pressure loss across that section of line becomes 4 times higher. This means that optimising the flowmeter for the operating range (often choosing a smaller line size) will result into larger pressure drops and so to an increased cavitation chance.

A rule of thumb related to the pressure drop is: Control valves installed in series with a vortex flowmeter should be installed downstream of the flowmeter, in order to maintain the highest possible pressure in the flowmeter.

5.2 Accuracy / Repeatability

The manufacturer's published meter performance specification is generally based upon stipulated installation and operating conditions and water calibration curves (typical values for water < 0,75% and for gases < 1 %). It is no guarantee that the same performance will be achieved at site under actual operating conditions, e.g. pipe work can cause non-linearity and nominal meter shifts. Moreover, for gas and steam applications where the same water curve can be used, it is important that the meter curves are related to a well-defined pressure reference point (P_R-point), otherwise differences in meter curves will occur.

To achieve the highest accuracy, the vortex flowmeter should be calibrated in the actual process fluid it is intended for together with its measuring section. The measuring section consists of actual upstream and downstream piping attached to the flowmeter with if applicable measurement points for reference pressure and temperature. After calibration the measuring section can be installed without any loss of accuracy provided parts are not disassembled. Further improvement can be realised by curve linearisation.

In many applications, repeatability (long-term repeatability) is more important than accuracy, e.g. in a flow control loop (stable and repetitive reading). Typical repeatability values for vortex flowmeters are ≤0,2% for liquids and ≤0,1% for gases.

5.3 Pipe Configuration

Upstream pipe configurations like piping elbows, reducers, expanders, gaskets, piping bore mis-match and control valves and misalignment can cause significant shifts in meter performance compared to those for ideal conditions. Reasons for the shift can be explained in most cases by changes in the mean axial velocity profiles and swirl. The length of upstream pipe work required, to ensure satisfactory approach conditions, depends on the specific design of the meter, type of upstream disturbance present and the level of accuracy required. The following table shows the effects of disturbed velocity profiles at the entrance of the vortex flowmeter with respect to the ideal situation (upstream straight pipe is 70D) on the nominal meter factor. The shifts presented in the table are based on a comparative investigation on 3" vortex meters of different designs.

Table 3.: Effect of upstream disturbance on nominal meter factor

Disturbances	Location of upstream disturbance		
	5D upstream of vortex flowmeter	**10D upstream of vortex flowmeter**	**40D upstream of vortex flowmeter**
90° elbow		Minimum: +0,4% Maximum: +1%	Minimum: <0,1% Maximum: +0,4%
Two 90° bends out of plane		Minimum: +0,2%	Minimum: <0,1%

		Maximum: -0,6% +0,7%	Maximum: +1%
Reducer	minimum: -0,2% maximum: +1,4%	Minimum: -0,1% Maximum: +1%	

To minimise the pipe configuration effect the following should be observed.

- The effects caused by a asymmetrical velocity profiles (90° elbow) and swirl (two 90° elbows out of plane) can be reduced by installing an upstream straightener and de-swirler respectively.
- Upstream straight lengths required for line size and reduced size vortex flowmeters must be at least 15D. In case of a swirl upstream of the vortex flowmeter the upstream straight pipe length should be increased to 30D.
- Downstream disturbances (control valve etc.) have to be installed at least 5D from the flowmeter.

5.4 Mechanical Vibration and Flow Pulsation

Pulsating flows and mechanical vibrations in pipe systems mainly originates from fluid machinery, such as compressors or pumps in systems. Moreover they can be the result of a leaking valve and slugging fluids. In the following figure, pulsation sources with an indication of their frequency and amplitude ranges will be given. For vibrations, the sources and frequencies are also valid.

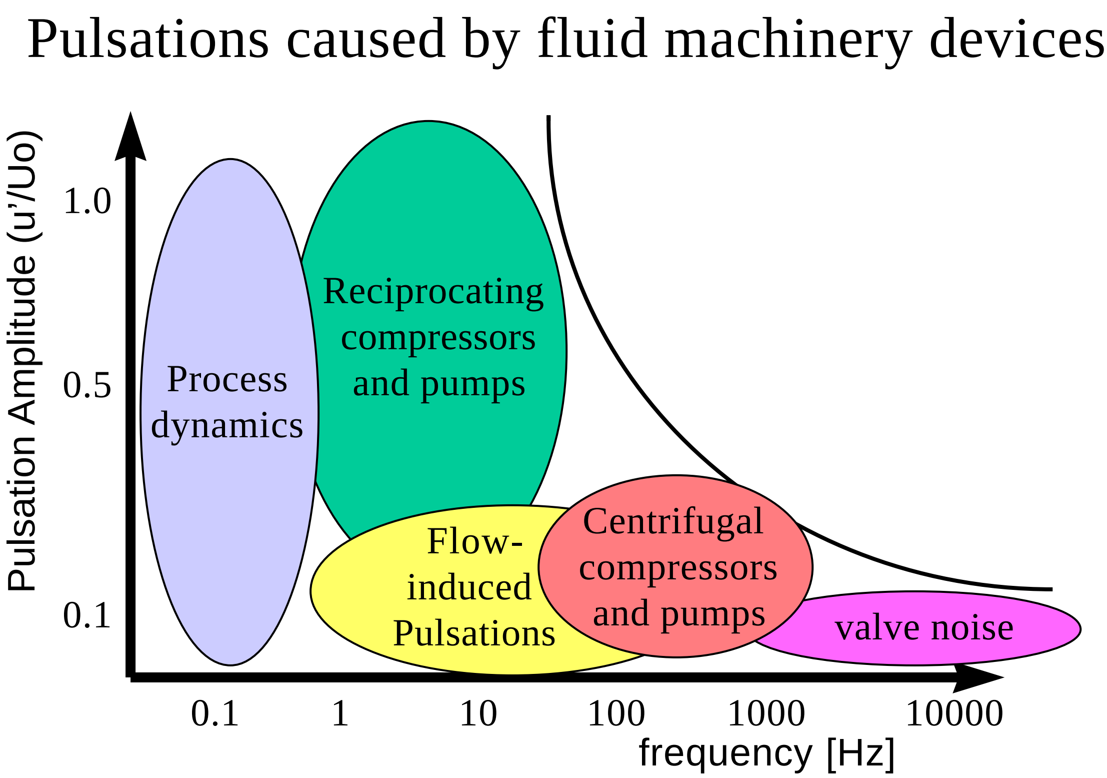


Figure 4: Relation between pulsation sources and frequency and amplitude

5.4.1 Mechanical vibration

Most of the measurement principles detecting vortices are also picking up mechanical vibrations [5], especially when the vibration levels are above 0,25 g. Below 0,25 g the vibration component within the sensor signal is often not detectable. This can have the following two effects: either the instrument is detecting a flow rate that is directly induced by the vibration frequency, or the output is related to a weighing of the vortex shedding and vibration frequency. Either effects can cause significant errors. The vibration effect will become smaller when the density and/or flow rate increase (improved signal to noise ratio).

Based on this, the following mechanical vibration related application guidelines can be derived:

- Install a vortex flowmeter at a location where vibration levels are below 0.25 g.
- Support/clamp upstream and downstream pipe at both ends of the flowmeter.
- Use the possible means incorporated in the embedded software of the transmitter to set trigger level, filters and noise reduction.
- Increase the low flow cut-off (below which the output is driven to 4 mA and zero pulses/s) within the embedded software of the transmitter to eliminate undesirable output at no flow conditions.
- Select a size that differs from the selected one. When the relevant vibration frequencies are in the lower part of the operating range of the flowmeter choose a reduced size (the operating frequency range of the vortex meter will be higher) and the other way around.

However, increasing the low flow cut off or the flowmeter size is influencing the flowmeter rangeability. Moreover, a reduced size will give larger pressure drops, resulting in an increased chance of cavitation. With a larger size on the contrary, the rangeability requirement can be beyond the flowmeter capability.

5.4.2 Pulsating flows

Pulsating flows affect the vortex shedding downstream of the bluff body. In the presence of pulsating flows, the sensor signal of the vortex flowmeter becomes irregular and contains additional frequency components. Due to the regular pulse output, the vortex frequency measurement and thus the output reading may be in error [4]. This can already occur at very low flow pulsation amplitudes, e.g. 3%. The following effects of pulsating flows on the vortex flowmeter output can be discriminated (see Figure 5):

- in the neighbourhood of even multiples of half the pulsation frequency (f_p), the vortex shedding frequency (f_v) will lock with this frequency:

  at: $f_v/f_p \cong \frac{1}{2}$ $\quad f_v = \frac{1}{2} \cdot f_p$
  at: $f_v/f_p \cong 1$ $\quad f_v = f_p$
  at: $f_v/f_p \cong 1\frac{1}{2}$ $\quad f_v = 1\frac{1}{2} \cdot f_p$
  at: $f_v/f_p \cong 2$ $\quad f_v = 2 \cdot f_p$
  and so on

- between these frequencies the shedding frequency is still affected by the pulsations,
- when the vortex frequency is larger than four times or smaller than half (in some cases a quarter) of the pulsation frequency, the errors in reading will be within 2%, even at large amplitudes of the flow pulsation.

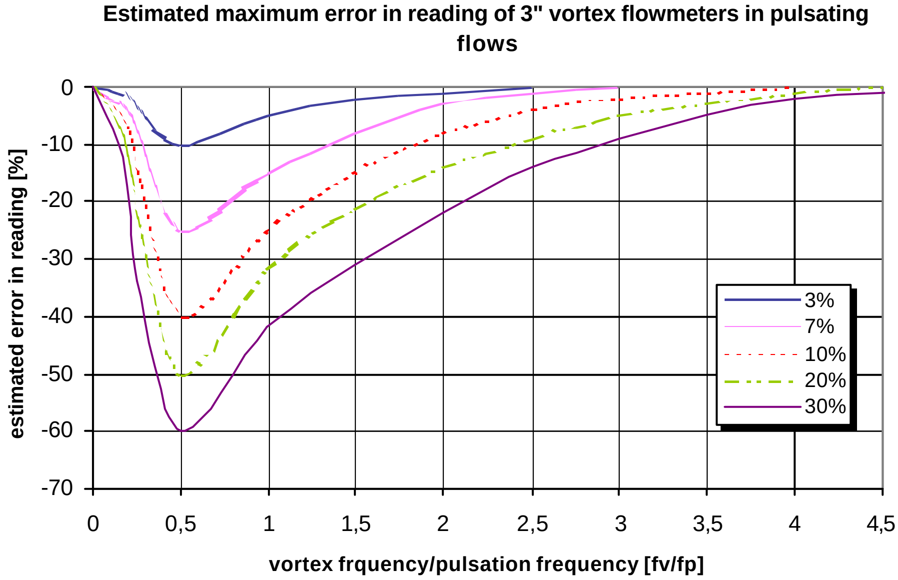


Figure 5: Estimated maximum errors in reading of 3" vortex flowmeters in pulsating flows

This results in the next applications guidelines:

- avoid pulsating flows, and
- when the pulsation frequency is within the operating vortex frequency range, a size up or down may be selected.

Knowing beforehand what the pulsation frequency will be can improve the instrument engineering. Similar considerations as for mechanical vibrations should be taken in account in increasing or decreasing the meter size.

5.5 General Guidelines Using Vortex Flowmeters

Next to the four discussed items, more guidelines have been defined, regarding flanges, temperature effects, gas, liquid and steam practice, installation, erosion, and dual bluff body or dual sensor/transmitter vortex flowmeters. In the next table some points of interest are summarised.

Table 4: Errors due to process and piping induced disturbances.

Item	Liquid service	Gas/steam service
Calibration with water Uncertainty of calibration	0.2 %	
Calibration over Reynolds number range Uncertainty of calibration	0.2 %	0.3 %
Temperature effect on geometry: for stainless steel	-0.05 % / 10 K	-0.05 % / 10 K
Viscosity effect: from 0.4 to 8 cSt.	+/- 1 %	
Viscosity effect: from 2.6 to 10.2 cSt.		+/- 1 %
Effect of reference pressure point (Pr-point)		+/- 1.5 %
Long term stability	< +/- 0.2 %	< +/- 0.2 %
Effect of upstream disturbances at 15 D	+/- 1 %	+/- 1 %
Effect of upstream disturbances at 30 D	+/- 0.25 %	+/- 0.25 %
Non linearity of meter curve over operating range	+/- 0.5 %	+/- 1 %

6 APPLICATION GUIDELINES IN PRACTICE

The value of an application guideline.

In Shell, there is a general trend to move away from company specific standards towards industry standards (i.e. ISO, IEC, API etc). In this respect, WIB the International Instrument Users' Association plays a unique role, that it traditionally provides independent evaluations and verifications of instrumentation and system specifications. Now, derived from those evaluations, for the first time an application guideline bundles the knowledge obtained through those evaluations with the expertise available with that of its member companies. As such the application guideline does provide high value information, based on testing and user feedback, for inclusion in Shell's system of Design & Engineering Practices (DEP's) on field instrumentation. The feedback obtained through successful practices and "lessons learned" from projects complement this process of continuous learning and feedback.

Shell DEP's are in turn used by operating companies and engineering contractors in providing guidance in design, engineering and construction of its operating facilities and new projects.

Application engineering of vortex flow meters.

The selection of an instrument for a specific application is an iterative process, carried out as a joint effort of a process technologist and an instrument engineer. It is important to record the selection process for auditing purposes and future reference.

The selection process should involve the following steps:

1. Identify all operating cases, such as normal operation at minimum, normal and maximum flow, alternative operating modes, start-up, commissioning and emergency operation.
2. Determine the operating window by collecting all relevant process data for each operating case, including fluid data (i.e. properties, erosiveness, solids etc.), operating data and application aspects (i.e. pulsating, uni-directional, backflow risk etc.)
3. Collect data regarding the operating environment of the instrument. This should include the following aspects i.e. location, accessibility, electrical safety, authority requirements.

In order to work efficiently, engineers require simple guidelines for making fit-for-purpose designs and selection of flow meters in process installations, nevertheless they have to take in account the above steps.

Assuming a vortex flow meter would satisfy the requirements, the degrees of freedom for selecting a vortex flow meter are limited. The size of the meter determines the upper range limit, while the minimum measurable flow is determined by the minimum Reynolds number for liquids and the minimum detectable flow at the given density for gases.

At first selection, the meter with the most optimal rangeability is usually selected. Practically this will result in a meter one to two sizes smaller then the line size.

Subsequently, the first parameter to be checked is the resulting differential pressure at operating flow. Other factors to be checked are:

- any possibility of cavitation
- will alarm and trip values be at least 10 - 15% above the minimum measurable flow

In balancing meter rangeability with resulting pressure loss, the most optimum meter will be selected.

Generally in continuous processes flow pulsation and line vibration are hard to predict. It should be noted that the vortex shedding frequencies for liquid flowmeters can be low. Some typical frequency values for meter sizes in liquid applications are:

DN50:	7 - 100 Hz
DN80	2 - 32 Hz
DN100	1 - 14 Hz
DN150	0.5 - 4 Hz

Pipe vibrations at those frequencies will occur and should have a decremental effect on the accuracy. Practically these can be prevented by simple supporting. In case this is not possible, a different meter size shall be selected, in order to increase or decrease the vortex shedding frequencies.

Other piping effects can be prevented by applying the practical rules of the application guideline of straight lengths. In particular the use of concentric reducers is highly recommended to minimise asymmetry of flow profiles as a result of piping bends. Eccentric reducers, liked by piping designers, shall not be used to reduce piping size around vortex flowmeters.

Ultimately it requires checking whether high flows as a result of an emergency operation (i.e. depressuring) may damage the meter internals. This is, however, rarely a problem, as practical restriction of process piping will limit the flow sufficiently.

From the above it can be concluded that any change in meter size has a number of resulting consequences in rangeability, pressure loss, frequency range. If the above described balancing checks are not made, it is clear that the application of vortex flow meters may lead to failures.

By applying the above rules, there is much evidence now, that the vortex flowmeter is a fit-for-purpose flowmeter, which is a worthy alternative for a orifice installation.

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