GOOD PRACTICE GUIDE

AN INTRODUCTION TO NON-INVASIVE ULTRASONIC FLOW METERING

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This guide provides an introduction to non-invasive ultrasonic flow metering which is aimed at people who have little experience in this area. It covers the basic concepts of non-invasive ultrasonic flow metering and the advantages it offers before progressing onto the various technological options available.

The guide will then highlight the operation of these meters in non-ideal conditions that are often associated with industrial situations.

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Foreword

This document is written for those who have little experience in flow measurement but would like to increase their knowledge and understanding in non-invasive ultrasonic flow measurement devices.

This guide will describe the advantages and disadvantages of using non-invasive ultrasonic meters and discuss the main principles of operation. It will also detail a few of the most popular measurement techniques available and describe how a final result is calculated. This will assist the reader to choose which meter is the best for their use.

The best location to install the meter is discussed and steps to ensure a successful measurement will be detailed in order to give the reader confidence in using a non-invasive ultrasonic flow meter. Some common problems associated with a range of non-ideal process conditions will be addressed.

This guide should enable the reader to:

- Understand the operating principle of each non-invasive device
- Understand their capabilities
- Be able to identify good measurement locations
- Recognise any potential issues that could hinder installation
1 Introduction

1.1 What is a non-invasive meter?

In traditional flow metering, measurement often relies on causing a change in pressure or flow profile in order to derive a volumetric flowrate. For example an orifice plate restricts the diameter through which fluid can flow, typically to about 60% of its original size [1]. This restriction causes a measurable pressure drop which is related to flowrate. The technique works well but suffers from the drawback of an energy penalty caused by the pressure drop.

With the drive to utilise more efficient technologies and reduce energy losses, companies are looking towards non-intrusive and non-invasive technology to help save process costs.

The difference between invasive and non-invasive and intrusive and non-intrusive is shown in Figure 1 [2].

![Figure 1: Sensor position](image)

Invasive devices have transducers which come into contact with the flowing fluid. They are also called ‘wetted’ transducers. Non–invasive transducers do not come into contact with the fluid and are placed on the outside of the pipe. Intrusive devices protrude into the flow and distort the flow profile, as can be seen in the top two diagrams. The distortion often leads to mismeasurement by introducing asymmetry to the velocity profile.

Different devices can be intrusive but non-invasive or even invasive but non-intrusive. The ultrasonic meters discussed in this guide are both non-intrusive and non-invasive. The reason non-intrusive and especially non-invasive flow meters are so popular is because they do not protrude into the flow, do not come in to contact with fluid and do not generate any pressure losses.
1.2 Advantages

As described previously, these devices are non intrusive and therefore do not interfere with the flow profile [2]. No pressure drop is observed meaning that these devices are more cost effective to operate. They are also non-invasive which means they do not come into contact with the fluid being measured. This is very beneficial when measuring dangerous or corrosive fluids that could damage sensor heads. It also means the transducers can be used alongside heavily fouling fluids and not be affected. This extends the life of the transducers, again saving money.

There is no need to break into the pipeline to install these meters which means they can be installed without shutting down the process. This makes them ideal for use on a number of different lines for verification purposes as they are easily portable. There is no chance of leakage or contamination.

The turn down ratio is the range at which a meter can operate within its stated uncertainty levels. It is written as a ratio of the highest flow rate in its range compared to the lowest. For a more traditional flow meter such as a differential pressure meter or a turbine meter, the turndown ratio is around 10:1. A non-invasive ultrasonic meter however can have a turndown ratio of up to 400:1.

There are no moving parts associated with ultrasonic meters and hence no wear and tear. A turbine meter may have to be maintained in order to achieve peak performance but this is not the case with non-invasive technology. This low maintenance means it will continue to deliver a consistent reading for as long as transducers are working. And even if they fail then they can be easily replaced with new ones without shutting down the process.

1.3 Transducers

The transducers are the key element in all ultrasonic technologies and non-invasive devices are no different. They utilise the piezoelectric properties of crystalline, ceramic, composite or polymer film materials which exhibit a special electromechanical quality [3]. The active element in the transducers is a polarised material which has both positive and negative charges throughout. When a current is applied across the material the positive and negative charges align with the electric field which causes the material to change in size and shape; this is called electrostriction. The effect also works in the opposite direction, where an external influence acts on the material and a current is produced. This effect is called piezoelectricity.

By utilising this phenomenon, two different transducers can send and receive ultrasonic pulses which can be used to decipher information about a flowing medium.
1.3 Transducers cont.

When a current is applied to a piezoelectric crystal the mechanical energy is produced in the form of vibrations. Tailoring the current can produce vibrations of a chosen frequency and this is the basis for all ultrasonic flow metering; including non-invasive and in-line meters. Figure 2 shows a piezoelectric crystal in operation.

![Piezoelectric Crystal Diagram](image)

Figure 2: Mechanical movement produced from an electric current in a piezoelectric crystal

1.4 Basic hardware configuration

All ultrasonic technologies follow the same basic hardware configuration for measurement. Figure 3 shows this configuration and the key components used: System Control, Excitation Electronics, Transducers, Reception Electronics, Signal Processing and Data Output [2].

![Ultrasonic Meter Configuration Diagram](image)

Figure 3: A generalised ultrasonic meter configuration

A control system is in place to ensure the process runs smoothly and the transmitted and received signals are processed properly. The control system initiates the excitation electronics to emit an ultrasonic sound wave from the transmitting transducer. The receiving transducer then detects the signal and converts the sound energy into electrical signals that are passed to the reception electronics. The signal is then processed to extract the data and an output either stores the data internally within the module memory or communicates it out in real time.
1.4 Basic hardware configuration cont.

All technologies use a similar system to this model but differ in transducer material, signal processing techniques and system control. These differences are usually proprietary to each manufacturer.

Another difference in meter configurations is with the signal emitted by the transmitting transducer. Three types of signal are mainly used and each can be of benefit in different process situations. Types of current signal include:

1. Pulse
2. Tone burst
3. Coded burst

As can be seen in Figure 3, there are distinct differences between each signal.

2 Theory of Operation

2.1 Ultrasonic methods

There are several different ways that ultrasonic signals can be utilised to calculate flow rate [2, 4]. Figure 4 shows five different non-invasive methods that can be used.

![Figure 4: Modes of ultrasonic operation](image)

Passive acoustics is a technique where the transducer simply ‘listens’ to the naturally occurring vortices or eddies in the flow. By monitoring how fast they flow by the transducer, a velocity can be derived. Beam deflection works by transmitting an ultrasonic beam across the pipe which is slightly deflected by the flow. This deflection is monitored and is directly related to the velocity of the flowing medium.

The three main types of non-invasive ultrasonic technology currently used are

- Transit time
- Doppler
- Cross correlation

These will be described in more detail later in this section.
2.2 Snell’s law

As nearly all of ultrasonic metering techniques rely heavily on knowing the angle of incidence of the ultrasonic beam, it is imperative that this value be as accurate as possible. This becomes even more important in non-invasive or externally mounted devices. As an ultrasound beam passes between two acoustically different media, the sound wave is refracted. This means the angle at which the beam was first emitted will not be the same as the angle that enters the flow. In externally mounted transducer housings there are three distinct media that the ultrasound must pass through in order to emit or receive a signal. These are shown in Figure 5.

![Figure 5: Ultrasonic beam refracting at interfaces](image)

This poses the problem of trying to match the spacing of the transducers to ensure the strongest signal is received. How do you know which angle the ultrasonic beam is propagating at? This problem can be solved by the use of Snell’s law [5] that states that the angle of incidence of the sound wave divided by the speed of sound in that medium is constant for all materials. Referring to Figure 5:

\[
\frac{\cos \alpha}{V_{o_S_1}} = \frac{\cos \beta}{V_{o_S_2}} = \frac{\cos \theta}{V_{o_S_3}}
\]

As the transducer angle, and the transducer velocity of sound \( (V_{o_S}) \) will be known, the ultrasonic beam propagation angle through the flowing fluid can be calculated. This is used to determine transducer spacing and other important configuration parameters.

2.3 Transit time

This is the most common type of clamp on technology and can be used for both gases and liquids. The principle is based on the time difference it takes for an ultrasonic pulse to travel a defined distance both with and against flow. The difference is directly related to the velocity of the flow and is to some extent analogous to a boat crossing a river. If the boat is travelling with the current then it will be helped across to some degree by the flowing fluid but the opposite is true when travelling against the current.
2.3 Transit time cont.

This means that time taken for an ultrasonic beam to travel across a pipe is not only dependent on the $V_o S$ in that medium but also on the velocity of the actual flowing fluid itself. The equations below show how a velocity can be derived from transit time measurements.

![Figure 6a: Oppositely placed transducers](image1)

![Figure 6b: Adjacently placed transducers](image2)

Figure 6a is normally referred to as direct mode i.e. the ultrasonic beam only makes one traverse across the pipe. Figure 6b is normally referred to as reflect mode as two traverses are required [6]. A stronger signal is achieved in direct mode but reflect mode is more accurate. Only direct mode shall be considered in more detail. As shown in Figure 6a transducer A transmits an ultrasonic pulse across a pipeline at an angle, $\theta$, which is received by transducer B. As the $V_o S$ for the flowing medium and the length the ultrasound travels are both known a simple equation can be used to calculate the time taken for the ultrasonic signal to reach the receiving transducer. This is also known as the time of flight of the ultrasonic signal [6, 7].

$$t_{ab} = \frac{L}{V_o S + V_f \cos\theta}$$

Where $t_{ab}$ is the time taken to for the ultrasound to go from transducer A to transducer B, $L$ is the distance travelled by the ultrasound, $V_o S$ is the velocity of sound in the fluid, $V_f$ is the fluid velocity and $\theta$ is the angle the ultrasound propagates through the fluid.
2.3 Transit time cont.

Transducer B now emits an ultrasonic pulse that travels across the pipe line to be received by transducer A. Again the time of flight can be found by using the following equation.

\[ t_{ba} = \frac{L}{V_0 \cos \theta - V_f \cos \theta} \]

Where \( t_{ba} \) is the time taken for the ultrasound to go from transducer B to transducer A. Notice, the fluid velocity is acting against the ultrasonic signal as it is travelling against the flow. Both waveforms are shown in Figure 7.

\[ \Delta t \]

Figure 7: Transit time waveforms

To get the transit time difference, \( \Delta t \), between these two waveforms, one traverse time is simply subtracted from the other one.

\[ \Delta t = t_{ba} - t_{ab} = \frac{L}{V_0 \cos \theta - V_f \cos \theta} - \frac{L}{V_0 \cos \theta + V_f \cos \theta} \]

Combining and rearranging for \( V_f \) gives:

\[ V_f = \frac{L \cdot t}{2 \cos \theta t_{ab} t_{ba}} \]

It is important to note that the equation to calculate velocity is independent of the \( V_0 \) of the fluid and that the only measurement taken is time. To calculate the volumetric flowrate, this velocity is simply multiplied by the cross sectional area of the pipe. The equation below shows the calculation for volumetric flowrate:

\[ Q_f = \frac{\pi d^2}{4} V_f \]

\[ Q_f = \frac{\pi d^2 L \cdot t}{8 \cos \theta t_{ab} t_{ba}} \]

This equation assumes the velocity recorded for the ultrasonic path is representative of the entire pipe cross section. This may not be the case however due to non-uniform flow profiles and flow disturbances. To correct for these conditions, profile correction factors and multiple paths can be used.
2.4 Doppler

Doppler non-invasive ultrasonic flow meters are based on the well known Doppler principle and frequency shifts in the ultrasonic signal. From a stationary source, a sound wave will reach a stationary observer with the same frequency as it was emitted. Consider now a moving source and a stationary observer. As each sound wave is emitted the source moves further away meaning there is a larger distance for the next sound wave to travel before it reaches the observer. As the sound velocity will be the same, it will be the time between each wave that will increase and therefore the frequency will be shifted. The effect can be heard in everyday life by the siren of a passing emergency vehicle. The frequency of the siren is high pitch as it comes towards you but becomes lower as it passes and drives away. Figure 8 below shows the Doppler Effect schematically:

![Figure 8: The Doppler Effect](image)

In flow measurement, again two transducers are used and are often placed on the same side of the pipe. Most Doppler techniques require a small amount of gas or entrained solids in the flow in order to calculate a velocity [6]. Transducer A emits an ultrasonic beam of a known frequency. This beam reflects off either the gas bubbles or solids within the flow and is frequency shifted. Transducer B then receives the frequency shifted ultrasonic signal and by measuring the change can derive a velocity. Figure 9 shows the transducers and ultrasonic signal in operation.

![Figure 9: Doppler ultrasonic meter](image)
2.4 Doppler cont.

The velocity is directly proportional to the change in frequency and is shown below [6, 8]:

\[ \Delta f = f_t - f_r = f_t \left( \frac{v_f \cos \theta_r}{V_0 S} + \frac{v_f \cos \theta_t}{V_0 S} \right) \]

Where \( f_t \) is the transmitted frequency, \( f_r \) is the received frequency, \( v_f \) is the velocity of the reflection particle and \( \theta_t \) and \( \theta_r \) are the transmission and receiving angles of the ultrasonic signal which are predetermined by the meter manufacturer.

As the transducers are on the outside of the pipe then Snell's law can be used to make the calculation independent of fluid and wall acoustic properties.

\[ \Delta f = f_t \left( \frac{v_f \cos \alpha}{V_0 S_1} + \frac{v_f \cos \beta}{V_0 S_1} \right) \]

Where, \( \alpha \) is the transmitted beam angle in the transmitting transducer and \( \beta \) is the receiving beam angle in the receiving transducer. Manufacturers will use the same material for each transducer and therefore the \( V_0 S \) will be the same. Normally, the propagation angle of the ultrasonic beam will be set up to be the same for both transducers meaning the equation simplifies to:

\[ f = \frac{2 f_t v_f \cos \alpha}{V_0 S} \]

\[ v_f = \frac{f V_0 S}{2 f_t \cos \alpha} \]

Again, multiplying by the cross sectional area of the pipe will give volumetric flowrate.

2.5 Cross correlation

In this technique, two pairs of transducers are positioned on a pipe with both receivers and both transmitters on the same side of the pipe respectively. The transducer pairs are placed in the same plane in order to maximise the potential for correlating signals [9]. The main difference between transit time and cross correlation flow meters is that one transducer is always the transmitter and one transducer is always the receiver; they do not swap. Figure 10 shows the transducer configurations:
2.5 Cross correlation cont.

Both the upstream and downstream transducers transmit an ultrasonic pulse across the pipe that is modulated by naturally occurring eddies or vortices in the flow. The result is two very similar waveforms (Figure 11) that have distinctive peaks which are displaced by a time factor. This time factor is directly proportional to the distance between the pairs of transducers and inversely proportional to the flow velocity.

\[
\tau_m
\]

Figure 11: Cross correlation waveforms received

To calculate the time difference a mathematical cross correlation function is used.

\[
R_{xy}(l,\tau) = T \lim_{T \to \infty} \frac{1}{T} \int_0^T x(t + \tau) y(t) \, dt
\]

Where \( y(t) \) is the downstream signal (blue in Figure 11), \( x(t + \tau) \) is the upstream signal delayed by time (red in Figure 11), \( T \) is the integration time and \( l \) is the distance between the pairs of transducers.

3 Meter Set-up

Non-invasive ultrasonic meters are extremely sensitive to any variations in propagation angles and transducer spacing. This means that during set-up, care has to be taken to ensure the measurements are as accurate as possible. The same procedures for set up can be applied to all non-invasive ultrasonic technologies as it is only the actual measurement and processing techniques that vary.
3.1 Metering location

The first step in any metering process is to select a suitable location for measurement. Ultrasonic flow meters are heavily influenced by changes in flow profile caused by flow disturbances and this has to be taken into consideration when choosing a measurement location. Each meter manufacturer has its own guidelines on what distances from a disturbance to place a meter in order to achieve a good measurement. This information can be found in manuals and technical specifications. Typical distances from a flow disturbance can be found in Table 1.

Table 1: Typical distances from a flow disturbance

<table>
<thead>
<tr>
<th>Disturbance</th>
<th>Downstream (D)</th>
<th>Upstream (D)</th>
</tr>
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<tbody>
<tr>
<td>Single elbow</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Double elbow in plane</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>Double elbow out of plane</td>
<td>40</td>
<td>5</td>
</tr>
<tr>
<td>T-piece</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td>Diffuser</td>
<td>30</td>
<td>5</td>
</tr>
<tr>
<td>Valve</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>Reducer</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Pump</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

Other key points to note when choosing a metering location are to ensure that there is no chance of:

- The pipe becoming partially or completely empty
- Material deposits on the inside diameter of the pipe interfering with the signal
- Gas bubbles interfering with the signal
- Liquid/gas accumulation

These conditions can occur when measuring flow in vertical pipes or pipe configurations that have natural low or high points that allow for liquid or gas pooling.

3.2 Pipe preparation

Once a suitable location on the pipe has been found, the pipe then has to be prepared in order to ensure a high quality signal can be sent between the transducers. As discussed, each material has different acoustic impedances which restrict the amount of sound energy that can be passed between them. In order to maximise the energy passed through the interface of the two materials a good contact has to be achieved. In normal industrial applications, there is a good chance that a pipe will exhibit some rust or have paint or scratches leaving an uneven surface. Also, with natural manufacturing processes it is likely there will be an element of roughness to the surface of the pipe.

The pipe therefore will have to be smoothed down and cleaned up. This can be done using some emery cloth and tissues. It is best to use the emery cloth in an axial motion along the pipe instead of radially around the pipe as this is parallel to the direction the ultrasound will travel. Once the rust or paint is removed and a smooth finish has been made the next step in the set-up involves taking measurements of the pipe wall thickness and diameter. This can be estimated using pipe schedule information but it is recommended to take readings at the measurement location as there can be variations in pipe wall thickness and diameter at the manufacturing stage.
3.2 Pipe preparation cont.

Normally a pi tape is used to give outside diameter but other instruments can be used as long as they are reasonably accurate. Manufacturers often sell pipe wall measurement devices alongside their meter and an average of several points around the test position should be used.

3.3 Transducer housings

Once the outside pipe diameter and wall thickness are known, they can be entered into the flow computer alongside the fluid type and temperature etc. This information is then used to calculate the transducer spacing required for measurement. If transducer housings are supplied then they should be installed on the pipe at this stage by following the manufacturer’s instruction manual. It is often recommended that two people complete the installation but it can usually be completed by one. Figure 12 shows a typical housing set up with transducers attached.

In order to combat issues such as solids formation on the bottom of the pipe or gas bubbles at the top, it is recommended to attach the housings in the horizontal position if only one pair of transducers are being used. Figure 13 shows the correct positions of transducers for a single pair of transducers in reflect mode.
3.3 Transducer housings cont.

If using two pairs of transducers however they should form an X configuration in the pipe. Two pairs of transducers will be more accurate as they can handle disturbances in the flow better. Figure 14 shows the correct installation.

![Figure 14: Transducer positions for 2 pairs of transducers](image)

To improve installation of the system, first locate and secure the transducer housings. After the transducers have been housed, tighten all the associated fasteners. Now, the housings should be in the correct place with the correct transducer spacing. The flow computer also has all the information it requires for measurement.

Carefully apply the transducer couplant gel to the middle of the transducer base in a thin, line along the length. This couplant is used to ensure reflections are not received from the pipe wall and that any imperfections in the pipe smoothness can be minimised. Insert the transducers into the housing and tighten. The couplant should spread out along the transducer base and allow for full contact with the pipe wall.

Again manufacturers have different couplants and use different techniques to apply it. You should always consult the manufacturer’s instruction manual when in doubt.

3.4 Meter diagnostics

The transducer should now be installed on the pipe. Ensure all housings and transducers are tight and will not move with any pipe vibrations. The next step before taking the measurement is to ensure you have confidence in the reading. The diagnostics of the ultrasonic meter must be checked to make sure they are within the stated limits [10]. Typically the Signal to Noise Ratio (SNR) should be above a minimum of 20 but a target of 30 or 40 should be achieved [11]. The SNR is a measure of the signal strength received compared against the background (random) noise picked up. If these two values are not significantly different then a correct measurement cannot be made. SNR can be calculated by using the equation below:

\[
\text{SNR} = 20 \log \frac{\text{signal amplitude}}{\text{noise amplitude}}
\]

The VoS is an important factor in clamp-on technology. As the VoS is not measured directly but instead inferred from the transit time of the ultrasonic wave and knowledge of the distance between the transducers, it can be used as a check to see if the meter is working properly. Most meters have a built in table listing the VoS of different media and so by comparing this measured value against the value in the table, the meter can be checked to see if the values are similar [11]. If the values are different by a predetermined amount, then the diagnostics will alert the user to the problem.
4 Factors Affecting Performance

4.1 Flow profile factor

Fluids can flow along a pipe in two very distinctive ways. Which flow is present is dependent on the viscosity, density and velocity of the fluid but also on the diameter of the pipe. These parameters can be combined to form a dimensionless function called Reynolds number. It is a measure of the viscous forces against the inertial forces and depending on which one is dominant, defines the way the fluid flows along the pipe.

When viscous forces are dominant and Reynolds numbers are \(<2000\) then laminar flow is present. Laminar flow can be similar to a busy motorway; cars travel along at various speeds rarely changing their lanes. In relation to flow in a pipe, the slow lane would be at the pipe wall and fast lane in the centre.

When inertial forces are dominant and Reynolds numbers are \(>4000\) then turbulent flow is present. Turbulent flow can be similar to a flock of birds or school of fish. Whereas the collective group are all heading in the same direction, each individual will move unpredictably through the mass; veering up, down, left and right. The flow is no longer moving parallel to each other but mixing up and, as the name suggests, becoming turbulent.

With Reynolds numbers between 2000 and 4000, the flow is unclassified and either of the flows can be present or indeed a mixture of the two. This is called the transition region and it is always best to avoid measurement in this region as it is too unpredictable.

Both laminar and turbulent flows have different effects on the velocity at different points on the cross section of the pipe. Laminar flow tends towards a peaked flow profile but turbulent has a flatter profile as shown in Figure 15.

In all non-invasive ultrasonic technologies only diametric paths are used because of the position of the transducers. This means that the signal is only taking an average of the diameter of the pipe directly through the middle. When looking at the flow profile for fully developed flow this means that an ultrasonic meter will over-read the velocity of the flowing fluid [2]. Figure 15 shows the over-reads with respect to flow profile.

![Figure 15: Diametric and mean velocities for laminar and turbulent flow profiles](image-url)
4.1 Flow profile factor cont.

In the laminar region \((\text{Re} < 2000)\) a rounded or peaked profile is present with faster moving fluid in the centre. As the ultrasonic meter averages out the velocity on this diameter it has a large over-reading that is not representative of the mean velocity. The same is true for fluids in the turbulent region except that the over-read is not as high.

In order to combat this, a flow profile correction factor is introduced, \(k_h\). This correction factor is simply to correct the measured velocity to the mean flow velocity and is calculated by the following equation:

\[
k_h = \frac{v_{\text{mean}}}{v_{\text{measured}}}
\]

Typically \(k_h\) has a value of 0.76 for laminar flow and 0.94 for turbulent flow [2]. In Figure 16 the turbulent \(k_h\) factor is plotted as a function of flow velocity for three values of pipe diameter and two fluid viscosities. The functional shape is almost independent of pipe size and relatively linear with fluid velocity, except at very low values. It is also apparent that any (uncompensated) changes in viscosity can have the capacity to introduce additional errors of the order of a few tenths of a per cent.

![Figure 16: Diametric profile factor expressed as a function flow velocity](image)

4.2 Installation effects

On a calibrated flow facility, manufacturer’s claims of ± 2% uncertainty are achievable but in industrial situations non-standard conditions are usually present and therefore typical uncertainties are in the region of ± 5%. This is due to disturbances in the flow such as bends, valves and pipe sizes that all cause changes to the flow profile [12]. Examples of disturbances can be found in Figure 17.

![Figure 17: Examples of flow disturbances](image)
4.2 Installation effects cont.

Figures 18a and 18b show a computational fluid dynamic (CFD) representation of a fully developed and a highly disturbed flow profile respectively with a pair of ultrasonic transducers attached.

In a fully developed flow profile (Figure 18a) the measurement path takes account of all the velocities in the pipe from pipe wall to centre. This gives an accurate representation of the flow velocity once the flow profile correction is applied. For the disturbed flow however there is a large high velocity region on the right hand side which the measurement path barely cuts through. This means this high velocity region is not properly represented in the measured velocity and so the meter will under-read [13, 14].
4.2 Installation effects cont.

Flow profiles will all eventually become fully developed like Figure 18a but this happens over substantial settling lengths. Manufacturers will always state a required distance from a disturbance before reliable flow measurement can be achieved and wherever possible this should be adhered to. Examples have been shown previously in Table 1.

4.3 Entrained gases/solids

Another common issue with process fluids is the presence of another phase within the flow. This could be caused by either entrained solids in the system such as sand, or entrained gas from cavitation or flashing. The effect of either or both of these problems is quite similar and can cause the ultrasonic meter to over-read the fluid velocity.

As an ultrasonic meter derives the volumetric flowrate of liquid across a diameter, any value it measures will be assumed to be for a single phase fluid. In reality however, a small percentage of the flow will be either solids or gas therefore reducing the volume of liquid present. The meter will therefore misread the amount of liquid flowing through the pipe. Higher solids content or gas volume fractions (GVFs) are directly related to larger errors associated with measurement.

Another problem related to the presence of another phase is the attenuation of the ultrasonic signal. As the beam travels through the pipe it will reflect and be absorbed by the second phase [6, 15]. This reduces the strength of the signal received by the receiving transducer and therefore the signal quality. The SNR will reduce and with it any confidence in an accurate measurement. Figure 19 shows the relationship between total volume error (blue) and SNR (red) with GVF. These results are for a velocity of 5 m/s.

![Figure 19: Effect of GVF on total volume error and SNR](image)
5 Recent Advancements

In previous years it has widely been regarded that anything above 2% gas or solids in a system would cause ultrasonic flow meters to stop giving a sensible value for the flow rate but in recent years there has been an advance in technology and processing ability so that meters can still maintain a reading well over 10%.

This has provided an opportunity for non-invasive ultrasonic metering to be applied in a wider field of measurement involving 2-phase flow. Manufacturer's websites and conferences can give more information about the application range of particular devices and these should be sought for further information.

From recent work carried out at TUV NEL, the uncertainty associated with non-invasive ultrasonic flow meters after a flow disturbance has been reduced significantly. Extensive test work and CFD modelling have been used to create correction factors that can reduce errors by a several per cent in some cases. TUV NEL has also developed specific cluster configurations that use multiple paths of non-invasive flow meters to reduce the error further.

6 References

2. Training Course on Ultrasonic Meters. TUV NEL Ltd, www.tuvnel.com
6. BS 8452:2005 Use of Clamp-on (externally mounted) Transit Time Metering Techniques for Liquid Applications
11. Manufacturer Presentation, “Clamp-on Diagnostics” 2010
7 Further Reading

National Measurement System

The National Measurement System delivers world-class measurement for science and technology through these organisations