

Proposal for the Presentation of a paper at the 2013 North Sea Flow Measurement Workshop:

**The Application of Clamp-On Ultrasonic Flowmeters in Production Monitoring**

An oral presentation.

Authors:

**Theo Warmenhoven, GDF SUEZ E&P, Nederland B.V.**

Tel: +31 223 63 96 39; theo.warmenhoven@gdfsuezep.nl

**Bernhard Funck, Flexim GmbH, Berlin, Germany**

Tel: +49 30 93 66 76 912; BFunck@flexim.de

**Peter Liptrot, Flexim GmbH, Berlin, Germany**

Tel: +49 30 93 66 76 979; PLiptrot@flexim.com

**Abstract**

Ultrasonic technologies find many applications in measurement. Transit time techniques find favour in flow measurement and are used in a variety of flowmeters. The performance of these flowmeters is now well understood, and tests of their performance in challenging applications such as wet gas have produced useful results.

Gas flow measurement offshore is typically carried out at an export metering point with well allocation according to calculation. Upstream conditions often combine the challenges of very thick-walled pipes in exotic materials with wet gas at relatively low pressures. In the last few years non-invasive (clamp-on) ultrasonic flowmeters have been installed on individual well flowlines in gas production systems on 2 offshore installations operated by GDF SUEZ E&P Nederland B.V. Reconciliation with facility sales gas metering is used to validate the wellhead measurements.

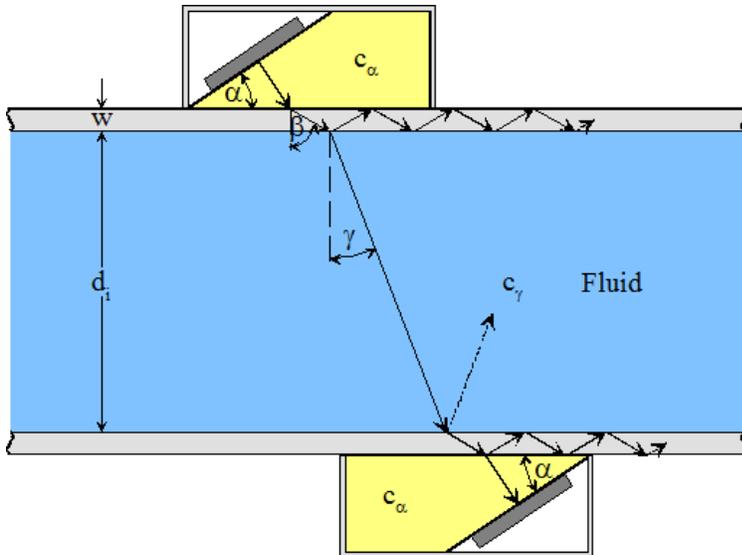
This paper considers the performance of these systems with GDF SUEZ E&P in the Dutch Sector of the North Sea. The paper presents data from the incoming flowlines to a separator and compares these with the gas measurement downstream of the separator. It also considers the operation of clamp-on ultrasonic measurement used for allocation between different gas fields supplying a single installation. Best practice for installation and operation on thick-walled DUPLEX pipes is reviewed and the reconciliation philosophy considered.

The conclusion of the paper suggests that it is feasible to deploy a measurement system giving production rates of individual wells using non-intrusive ultrasonic metering and how this system will endure deployment in offshore environments. Recommendations for measurement of wet gas and depleted wells are given and considered in the light of field experience and flow laboratory tests.

# 1 Ultrasonic Gas Measurement

Measurement of gas flow rates using ultrasonic transit time meters is an established technique. In recent years the use of non-invasive (clamp on) flow meters has gained ground. There are, of course, limitations in such measurement, which we will explore a little more.

Transit time flow measurement relies on contra-propagating transmission of sound bursts between pairs of transducers situated diagonally across the pipe. The upstream signal is delayed and the downstream signal is speeded up by the moving fluid. The difference in transit time is proportional to the flow.



**Figure 1 - Transit time measurement**

Figure 1 gives an indication of some of the challenges in clamp-on systems: the multiple reflections and refractions of the ultrasonic signal can be seen.

The actual flow rate is defined by the equation:

$$Q = K_{Re} \cdot A \cdot K_{\alpha} \frac{\Delta t}{2t_{fl}}$$

Where Q is the volumetric flow rate

$K_{Re}$  is the Reynolds number correction factor

A is the cross-sectional area of the pipe

$K_{\alpha}$  is the transducer correction factor

$\Delta t$  is the difference between upstream and downstream times of flight

$T_{fl}$  is the (average) time of flight

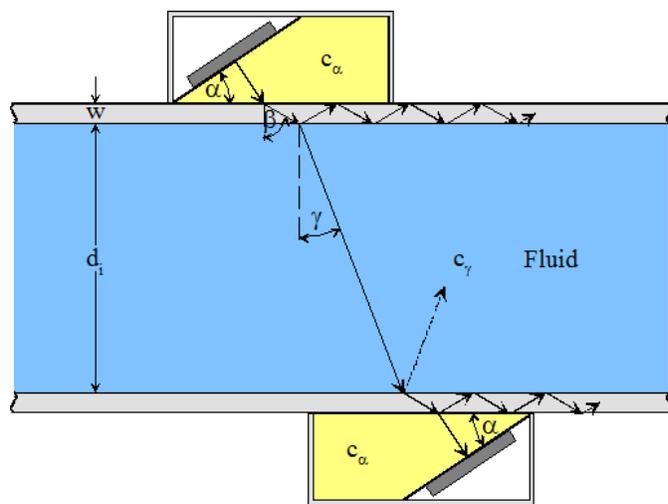
Naturally successful measurement relies on both the successful transmission of the signals and a sufficient time difference between upstream and downstream propagation times to allow an accurate calculation.

Non-invasive systems, where the transducers are external to the pipe, have been increasingly used in gas measurement applications. The advantages of such systems are clear; the installation can be carried out on existing systems without interrupting operation, and the use of such systems offers significant savings in installation and maintenance costs. The deployment of clamp on systems removes at least 2 flange (or weld) connections and removes the need for by-pass and valve systems normally required to allow maintenance of spool piece meters.

The drawbacks of clamp systems are that the propagated system must pass through two pipe walls between transducers. Signal attenuation is no longer limited to the fluid, now there are significant extra potential signal losses.

## 2 Ultrasonic Transmission

The principal challenge in clamp-on ultrasonic measurement is to align the transducers to maximize signal transmission between them. The application of Snell's law of refraction is the first consideration.



$$\frac{c_{\alpha}}{\sin \alpha} = \frac{c_{\beta}}{\sin \beta} = \frac{c_{\gamma}}{\sin \gamma}$$

**Figure 2 - Snell's law of diffraction**

The design of clamp-on flow measurement systems allows variable configurations in signal propagation, with the possibility of single or multi-path transmission. The design of most systems usually includes the transducers as separate units. In this way they can be located in different relative positions. This is useful where conditions provide strong signals and high amplitudes – increasing path numbers may be used to improve performance. Implicit in the application of Snell's law is the required spacing between transducers. The decision as to the number of paths to use is based on a number of factors, the most important of which is the likely signal losses in the transfer media, these being the pipe and the moving fluid.

The proper installation of a non-invasive system requires the detailed input of the measured fluid and pipe data to enable the correct spacing and orientation of the component parts of the system to be determined. Most manufacturers of such systems will include some functionality to estimate the signal loss in the measurement. It is important to understand the potential signal losses at each surface the ultrasonic signal will propagate across, and to understand the attenuation of the signal in the flowing fluid at the actual process conditions. If these values are understood then it is possible to estimate the number of paths which will offer the most reliable, and most accurate, measurement.

### **3 Signal Attenuation**

The principal challenge in ultrasonic systems of this nature is signal attenuation. Ultrasonic transmission is a function of acoustic impedance, which is the product of the particular materials' speed of sound and density.

#### **3.1 Acoustic impedance:**

The acoustic impedance (Z) of any material is given as the product of the density ( $\rho$ ) and the speed of sound (V) in the material.

$$Z = \rho V$$

$$\text{Internal Reflection} = \left( \frac{Z_2 - Z_1}{Z_2 + Z_1} \right)^2$$

The actual transmission rate is 1-reflection.

As may be seen, the greater the difference in acoustic impedance, the greater the transmission losses.

Early work in clamp on systems was successful in liquid measurement. Taking water as the bench mark we still see approximately 90% of the incident signal reflected as the ultrasonic pulse passes from a steel pipe wall and water. If we then consider gas measurement, even at elevated pressures, we are dealing with signal losses of above 99% across the system boundaries. (In gas measurement the difference in acoustic impedance is large, often in the magnitude of 500:1 or above).

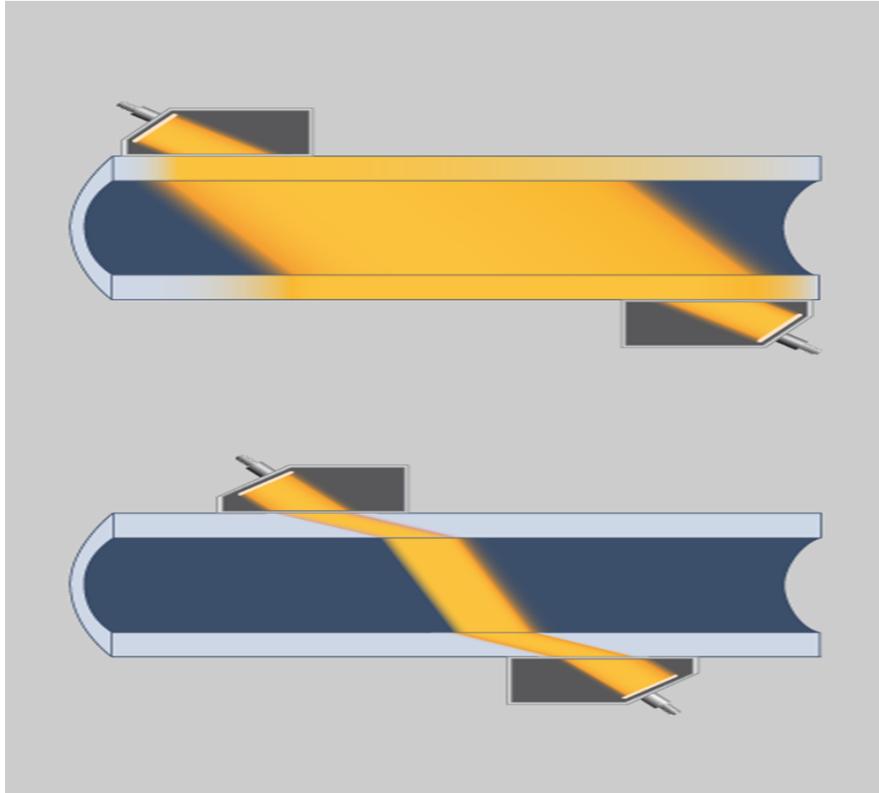
Insertion losses are such that current test experience indicates that 10-15bar -dependent on pipe geometry (principally wall thickness), fluid composition and process conditions- is the low pressure threshold for reliable measurement.

### **4 Wave Propagation**

Clamp on systems have benefited from the use of lamb waves. In the application of this means of wave propagation the transducer is designed so that the pipe wall is caused to resonate. In this way more energy may be transmitted into the fluid.

This method has many useful applications but is limited to a narrow band of applications dictated by matching the pipe wall thickness with the transducer frequency.

Outside of the application envelope of Lamb wave systems, the traditional technique of shear wave propagation is best deployed. This elastic wave is perhaps the best method of transmitting ultrasonic pulses, and finds widespread use in many applications. It is the only technique which is applicable to thick walled pipes.

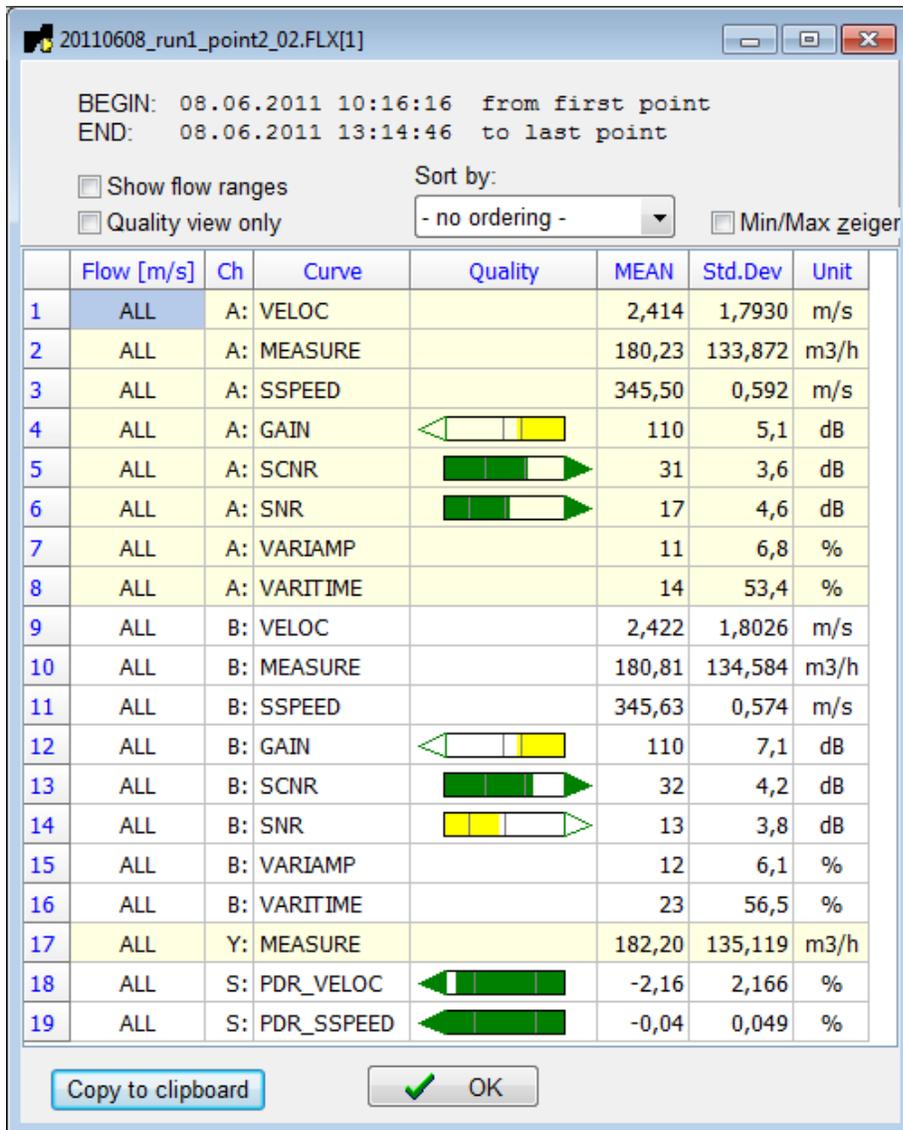


**Figure 3 - Lamb wave propagation (top) and shear wave propagation: both in single path configurations**

With the transducers of non-invasive systems separated by pipe walls, the signal losses are such that the systems run with amplifier gains rather higher than is sometimes expected. In gas systems gains of between 80dB and 100dB are typical.

The use of advanced diagnostic provides the opportunity to review system performance, and can often provide an indication of how an installation may be improved.

Most manufacturers will provide a diagnostic report which indicates meter performance.



**Figure 4 - typical diagnostics panel**

When considering Figure 4 the importance of recorded diagnostic values becomes clear. Perhaps the most important diagnostic value is the measured speed of sound (SOS). This is an immediate indicator of the fidelity of the installation, and is the first thing to consider before making further assessments. As discussed, measurement is only possible with a clear received signal. The signal-to-noise ratio (SNR) and derivatives thereof are measured and –if above certain thresholds- are the principal determination of a successful, and potentially stable, measurement.

Usually internal performance measures, such as gain (or it's reciprocal, amplitude) and functions relating to measurement stability are also indicated. From these data the overall measurement quality and reliability may be assessed.

Typically arrival signal waveforms (“snapshots”) are recorded.

## 5 Installation Considerations - Geometry

When applying external transducers to a pipe it may be seen that they must always be installed at a tangent to the pipe. Thus the measurement paths are always diametric. This is the case irrespective of path numbers.

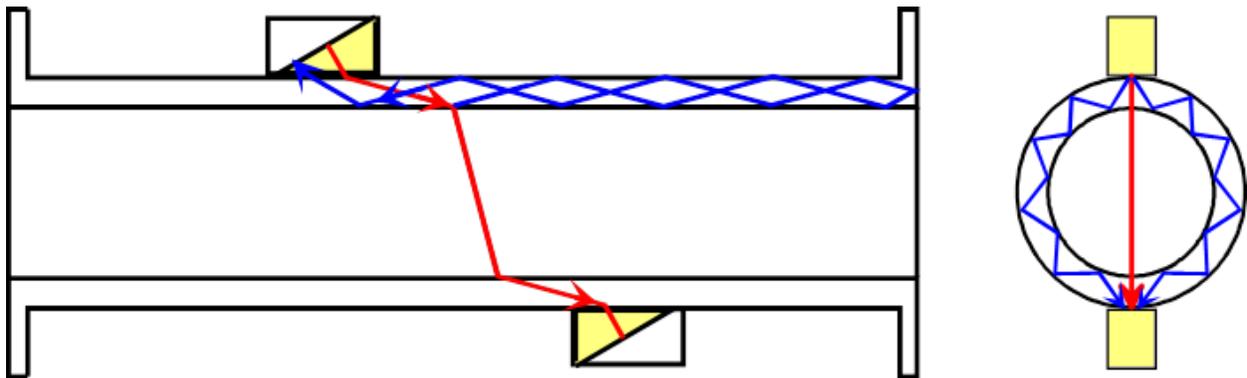


Figure 5 - diametric measurement of single-path installation

Often additional pairs of transducers are applied to the same measuring point to improve system performance. In single phase flow the traditional approach with a second channel is mount the 2 pairs of transducers such that the measurement paths are perpendicular.

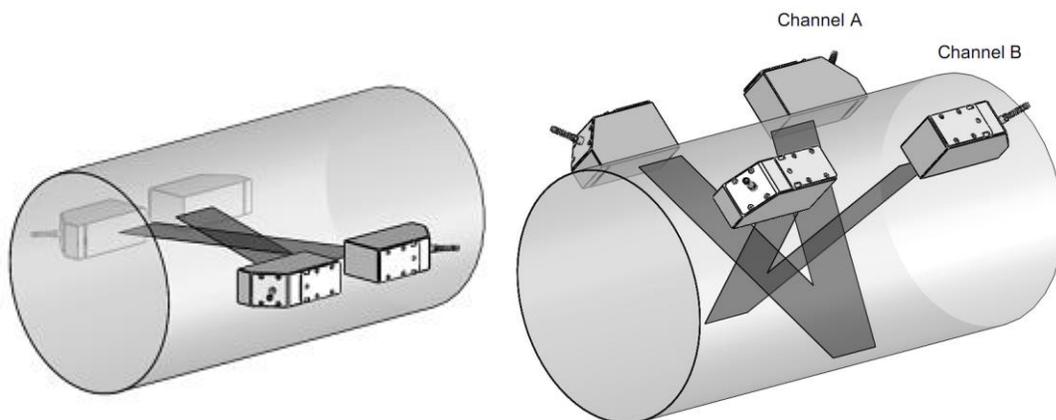


Figure 6 - dual pair installations: x-formation and perpendicular paths

Nevertheless the measurement is inferential and can be relied upon only if the flow is fully developed and free of swirl and cross flow components. Often the installation configuration is dictated by pipe surface conditions or geometric and flow conditions. Meter paths should never be in the same plane as upstream bends and elbows.

To achieve fully developed flow some form of flow conditioning is required. With the attraction of non-invasive systems being this very lack of any invasion of the pipework, the consideration of flow conditioning elements is undesirable. It is therefore, normal that straight runs are required.

Good practise in this respect is of course an absolute minimum of 20 diameters upstream and 5 diameters downstream. However such guidelines are unlikely to be sufficient in high velocity conditions or with large amounts of swirl. With diametric measurements, distorted velocity profiles will produce unknown uncertainties and should be avoided.

## 6 Installation Considerations – Structural Noise

The insertion losses observed contribute to significant structural born (pipe) noise. Modern DSP electronics are effective in dealing with this – measuring coherent noise- but it is usual to reduce this noise at source with mechanical damping. The application of appropriate acoustic damping materials to the pipe is desirable. Signal to noise ratios can be enhanced in the order of 5dB-10dB with appropriate damping. The structural noise increases with increasing wall thicknesses, and tends to be more significant in lower-frequency systems.

## 7 Flow Stability

In wet gas flows, low liquid contents and low gas velocities will cause the liquid to flow on the bottom of the pipe with a lower velocity than the gas. This pattern is called “stratified flow”. When the liquid content is high enough the pipe can get temporally blocked (“semi-slug flow”). With increasing gas flow velocity the pattern changes to “wavy flow”. With even higher velocity the liquid travels in a non symmetrical ring with the gas core laden with liquid droplets travelling through the centre of the pipe, which is called “annular mist flow”. In the stratified flow state it can be assumed that the meter over reads approximately corresponding to the percentage of the pipe area that is covered by the liquid. In the annular mist state the over reading should approximately correspond to the LVF. So in the mist state the error is much smaller than in the stratified state.

In the stratified flow state the amplitude of the ultrasonic signals is not affected as long as the liquid level does not reach the sound path. In the mist state the attenuation of the wave propagation increases with the LVF.

### 7.1 Definition of terms

The Liquid Volume Fraction is the ratio of the liquid flow rate to the gas flow rate.

$$LVF = \frac{\dot{Q}_l}{\dot{Q}_g + \dot{Q}_l}$$

It needs to be considered, that the velocity of the liquid flow can be much smaller than that of the gas flow. So the ratio of liquid to gas volume in the pipe can be much bigger than the LVF.

The Gas Volume Fraction is the ratio of the gas flow to the total flow rate. The relation to the LVF is:

$$GVF = 1 - LVF$$

The Lockhart-Martinelli parameter is the most useful wet gas parameter and is defined as:

$$X_{LM} = \sqrt{\frac{\text{Inertia of Liquid Flowing Alone}}{\text{Inertia of Gas Flowing Alone}}} = \frac{\dot{m}_l \sqrt{\rho_g}}{\dot{m}_g \sqrt{\rho_l}} = \frac{\dot{Q}_l \sqrt{\rho_l}}{\dot{Q}_g \sqrt{\rho_g}}$$

## 7.2 Relations between different parameters

$$X_{LM} = \frac{LVF}{1 - LVF} \sqrt{\frac{\rho_l}{\rho_g}} \quad (0.1)$$

With small LVFs the XLM number is approximately

$$X_{LM} \approx LVF \sqrt{\frac{\rho_l}{\rho_g}} \quad (0.2)$$

This shows that with constant LVF the XLM decreases with the square root of the pressure.

With consideration of the mechanical limitations of the installation, the process conditions and flow profiles, the design of an installation may be finalised.

The deployment of ultrasonic flow meters which this paper addresses is on a thick-walled DUPLEX pipe measuring wet gas from individual wells. Such an application presents a number of challenges from both process and piping perspectives.

DUPLEX piping has often been considered a difficult material in the context of ultrasonic measurement. The complex grain structure is purported to degrade ultrasonic signal transmission and is reported to provide sufficient attenuation as to make challenging applications which would otherwise be straightforward. Insertion losses will be greater with such material.

## 8 Field Experience

GDF SUEZ E&P Nederland B.V. have installed clamp on transit time meters on 2 offshore platforms in the Southern North Sea. Two meters were installed in early 2011 on platform K9-B and two meters on platform K12-C in November 2011.

The clamp on ultrasonic meters are mounted upstream of a test separator, measurement at which is by spool piece multipath ultrasonic meters. The clamps on units comprise dual channel measurement in single path X-configuration (see Figure 6). The ultrasonic transmitters are mounted in the control room and output the mean actual flow (between channels A&B) to flow computers via a pulse output. Normalized flows are calculated in the flow computers and SOS in accordance with AGA10.

Both installations included a number of interesting features.

Location	Pipe Diameter	Wall Thickness	Pressure	$X_{LM}$
K9-B	115.2	14.2	92	0.015
K12-C	114	13.3	89	0.014

**Figure 7 - Summary of installation parameters; K9-B and K12-C**

These applications may be considered thick-walled and relatively small diameter. All pipework is Duplex, and the geometry dictates the use of shear-wave transducers. Note, however, that the pressures are high. All wells produce wet gas with Lockhart-Martinelli numbers of approximately 0.015. This suggests that, at expected velocities, the gas/liquid flows will remain homogeneous.

Previous tests in other, similar locations have suggested that the installations will be noisy and will not present fully developed flow profiles.

There was insufficient straight length on the K9-B installation to effect any measure of flow conditioning. There was, however, sufficient deck space to offer some piping modification. A large flag of piping was installed to allow appropriate straight lengths.



**Figure 8 - Flag piping on K9-B; note transducer installation and damping material**

In Figure 8 the additional piping installed by GDF SUEZ E&P Nederland B.V. can be seen. Inflow conditions of 20 diameters were made possible with this configuration.



**Figure 9 - K12-C installation -looking downstream**

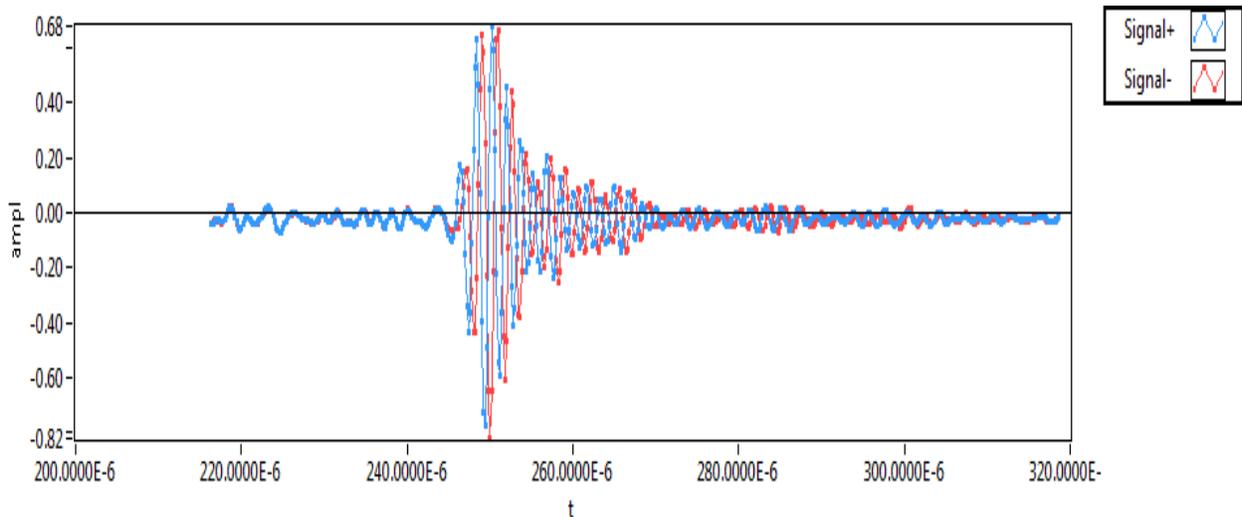
With shear wave transducers single path configuration was chosen in all cases. The orientation of the transducers was selected so that both pairs were in the horizontal plane. This orientation was selected to minimize the effects of the upstream swirl in-plane with the upstream piping.

In Figure 8 and Figure 9 the pipe damping mats can clearly be seen.

## 9 Results

The received signal waveforms (“snapshots”) indicated reasonably high fidelity measurement. The ratios of signal to coherent noise were in the order of 25dB-30dB.

A typical “snapshot” shows the measurement condition.



**Figure 10 - Snapshot (K9-B, well 5; typical)**

The snapshot in Figure 10 indicates a clear arrival signal and also some low amplitude noise before the signal arrival. This is typical of thick-walled pipes but can be seen to be a limited contributor to the noise in the SNR evaluations.

## 10 Diagnostic Review and Spotchecks

Well 6				
Ch	Feature	MEAN	Std.Dev	Unit
A:	MEASURE	132.11	1.511	m3/h
A:	SSPEED	401.81	0.058	m/s
A:	GAIN	84	0.5	dB
A:	SCNR	28	0.6	dB
A:	SNR	21	2	dB
B:	MEASURE	129.62	1.344	m3/h
B:	SSPEED	404.16	0.067	m/s
B:	GAIN	82	0	dB
B:	SCNR	22	0.3	dB
B:	SNR	22	1.2	dB

**Figure 11 - Diagnostic Panel, K9-B Well 6**

All measures in the diagnostic panels show satisfactory results.

Well 5				
Ch	Feature	MEAN	Std.Dev	Unit
A:	MEASURE	110.44	9.744	m3/h
A:	SSPEED	414.57	0.757	m/s
A:	GAIN	81	0.4	dB
A:	SCNR	23	0.6	dB
A:	SNR	24	1.2	dB
B:	MEASURE	117.15	9.747	m3/h
B:	SSPEED	408.41	0.695	m/s
B:	GAIN	80	0.5	dB
B:	SCNR	26	0.9	dB
B:	SNR	28	0.9	dB

**Figure 12 - Diagnostic Panel, K9-B Well 5**

Well 3				
Ch	Feature	MEAN	Std.Dev	Unit
A:	MEASURE	181.62	0.8	m3/h
A:	SSPEED	412.86	0.11	m/s
A:	GAIN	82	0	dB
A:	SCNR	20	0.6	dB
A:	SNR	17	1.5	dB
B:	MEASURE	165.8	0.779	m3/h
B:	SSPEED	412.13	0.107	m/s
B:	GAIN	82	0	dB
B:	SCNR	21	0.5	dB
B:	SNR	17	2.3	dB

**Figure 13 - Diagnostic Panel, K12-C Well 3**

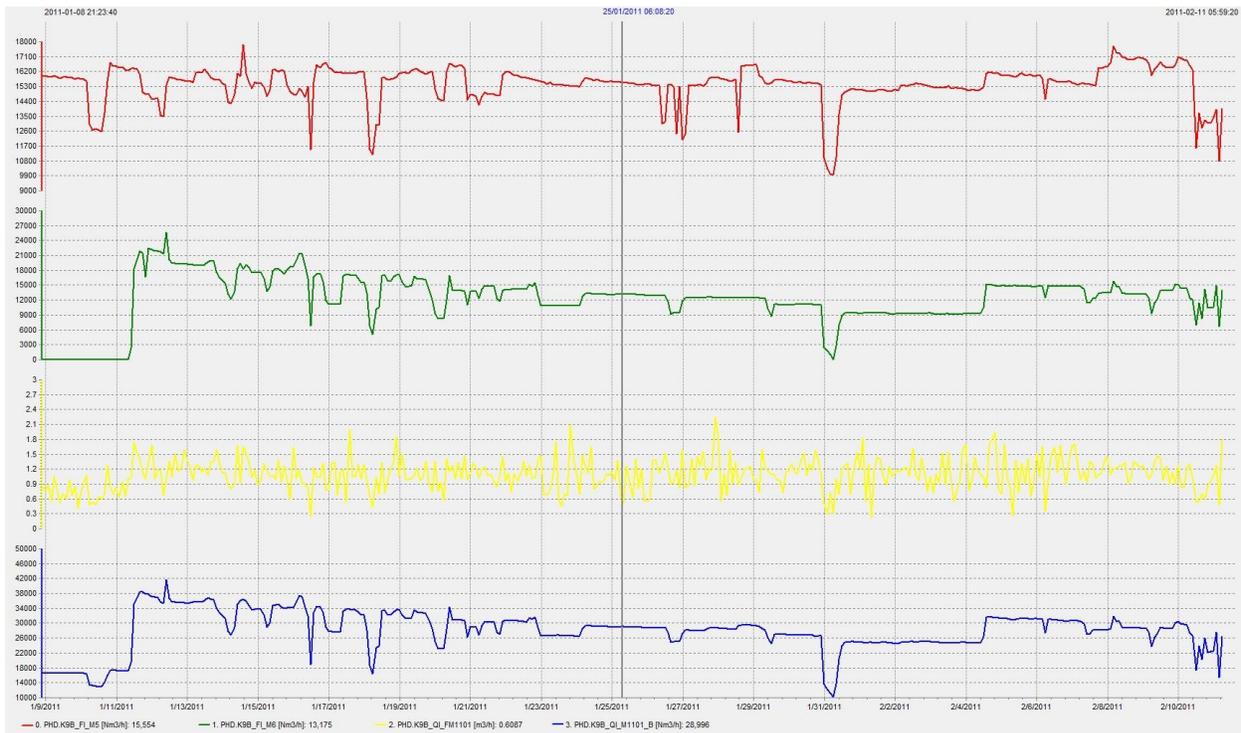
Previous research suggests a measurement error of between 2% and 4% may be expected due to the wetness of the gas. Spot checks suggested variations between the upstream clamp on systems and the separator outlet in accordance with this expectation. SOS variations indicate lack of homogeneity in the pipe.

Well	Calculated SOS	Measured SOS	
		A	B
5, t1	416.91	A	415.38
5, t1	416.91	B	415.31
5, t2	416.95	A	415.81
5, t2	416.95	B	408.59
6, t1	401.97	A	401.74
6, t1	401.97	B	404.17
6,t2	401.95	A	401.817
6,t2	401.95	B	404.09

**Figure 14 - SOS Comparisons, K9-B at times t1 and t2, 15 minutes apart**

The vicissitudes of upstream measurement do not impact the diagnostics, which remain pleasingly consistent. What may be seen is that the measured rate between channels A&B vary by up to 10%. This indicates some levels of cross flow components in the pipe (swirl). In this case the meter output is the mean of both channels, using an internal calculation channel, the value of which meets the expectations.

## 11 Performance Review, K9-B

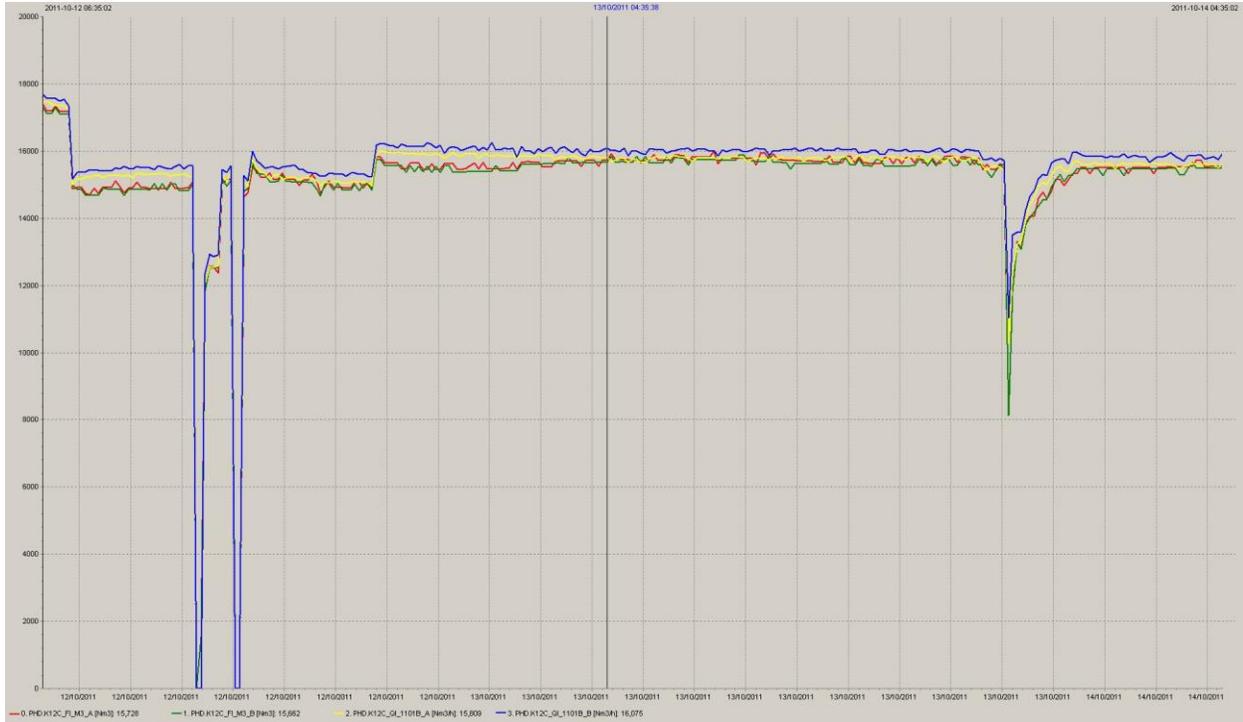


**Figure 15 - Outputs of clampon ultrasonic flow meters and the test separator, K9-B**

Figure 15 shows the 2 separate wells (5&6, in red and green respectively) against the outputs from the separator (liquid in yellow and gas in blue). The graph traces these flows over a period of 1 month in

September 2011. The deviation between the 2 clamp on measurements combined and the measurement downstream of the separator was within 2%.

## 12 Performance Review, K12-C



**Figure 16 – Respective measurement of the clamp-on meters and downstream meters, K12-C**

This shows the well's main & back up gas measurement ( in red and green respectively) against the main & Back up gas measurements downstream the separator (in yellow and blue).

On K12-C just one well was originally commissioned. Original spot checks comparing the 2 channels for this measurement gave agreements of SOS to within 0.2% but a deviation in flow rate of 4%. The combined flow rate (the average of A & B) was within 3.5% of the reference.

Longer term measurements show the deviation between channels to decrease to within 2%. Agreement with the separate reference remains between 2% and 4%. The measurements and agreement with the reference remain stable.



**Figure 17 - Outputs of clamp on ultrasonic meter (well 4) and reference meter, K12-C**

With the additional well on line (well 4) the performance was also studied over time. Deviation between the clamp on device and the separator reference was less than 2%.

## 13 Conclusion

The field installation of clamp on ultrasonic flow measurement systems for well flow line measurement has been shown to provide consistent measurement to within limits of 2% - 4% deviation between the actual measured flow and the reference.

If the specific conditions of the installation, pipework, materials and so-on are considered along with the process conditions, the expectations of measurement uncertainty in wet gas measurement can be met or improved upon.

## 14 References

[1] M. Panicke, B. Funck. Diagnose und Bewertung von Ultraschall-Clamp-on-Messungen. 4. Kötter Workshop Gasmengenmessung, 2008

[2] D. W. Spitzer (editor) Flow Measurement Practical Guides for Measurement and Control, Instrument Society of America 1991

[3] J. Lansing, The Benefits of a Fully Self Diagnosing Gas Ultrasonic Meter, 8<sup>th</sup> South East Asia Hydrocarbon Flow Measurement Workshop 2009