INSTALLATION EFFECTS ON MULTI-PATH ULTRASONIC FLOW METERS: THE 'ULTRAFLOW' PROJECT

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SUMMARY

'ULTRAFLOW' was a Joint Industry Project aimed at establishing the effect of installation conditions on multi-path ultrasonic flow meters. An extensive test series was performed at 5 test facilities on 6" and 12" meters operating on natural gas at pressures from 10 to 60 bar. All test facilities and procedures are reviewed by an independent international Quality Assessment Team, comprising experts from legal metrological authorities, to ensure that the work was appropriate to support International Standards activity.
This paper is a condensed version of the projects final report describing the project and test results. The tests in ideal flow conditions pay attention to meter stability and effects of signal averaging and pressure. From the error shifts in the tests with upstream disturbances (1 or 2 bends, step changes in pipe diameter and pressure reduction) values for uncertainties due to the presence of these disturbances are proposed.

NOTATION

A, B	After, Before disturbance tests	
AV, NA	With, Without signal averaging applied	
CW, ACW	Clockwise, Anti-clockwise swirl	
CH, CV	Chords Horizontal, Chords Vertical	
D	Pipe diameter	[inch]
Di.Err.%	Shift in meter error due to a specific installation effect	[%]
Dm.Err.%	Deviation of an individual calibration from mean of all calibrations	[%]
Err.%	Meter error	[%]
r	Repeat test	
Δp	Differential Pressure	[mbar]
xD(p) (graphs)	x represents the distance between the disturbance and meter inlet and p represents the test pressure	
[a] (graphs)	indicates that tests at, or beyond that flow rate were limited by meter operation.	
[b] (graphs)	indicates that tests were limited by the test facility capacity.	

1 INTRODUCTION

Only recently, multi-path ultrasonic gas flow meters have been developed to a point where they may be considered to be a realistic alternative to orifice plate or turbine meters for high accuracy large volume gas flow measurement. In principle, upstream disturbances should have little effect upon a multi-path ultrasonic meter but there is little evidence available to quantify this. Such evidence is an important pre-requisite to the development of the installation standards.

The project 'ULTRAFLOW' was undertaken in order to address this problem and provide data on the effect of disturbances as upstream bends, swirl, step changes in pipe diameter and pressure reduction on a multi-path ultrasonic meter. The Joint Industry Project, involved 6 user companies (British Gas (BG), Gaz de France (GF), Ruhrgas (RG), Nederlandse Gasunie (GU), BP, NAM) and a meter manufacturer. The project was managed by BP and received financial support from the EC.

The objective of the project was to perform a series of tests to demonstrate the effect upon the meter of upstream disturbances like asymmetries, caused by 90° and 180° bends, swirl casued by double bends out of plane, small pipe diameter step changes and upstream pressure reduction. To be able to determine these effects, calibrations in ideal flow conditions at the appropriate pressures are performed to serve as a reference. These calibrations also serve for determination of calibration stability and pressure dependency. The overall aim of the project was to identify whether the uncertainty of the multi-path ultrasonic meter reading does not exceed 1% under defined installation conditions.

The tests were carried out on meters of nominal size 6" and 12" selected as representing a range likely to be employed in practice, and also suitable for the available test facilities. Testing was performed over a range of pressures from 10 to 60 bar. The work was carried out on 5 high pressure flow testing facilities of 4 of the participants over the period March 1993 to March 1994. Table 1 shows the agreed division of work.

TABLE 1 - DIVISION OF WORK BETWEEN LABORATORIES

			20 bar	40 bar	60 bar	10 bar	35 bar	50 bar	60 bar
TEST			12" METER			6" METER			
1. "Ideal" calibration at start and end of measurement series			BG RG GF	RG GF	BG GU	GU RG GF	GU	RG	GU
2. 90° bend Asymmetry	CH, CV	5D	BG		BG	RG		RG	
90° bend Asymmetry	CH, CV	10D	BG		BG	RG		RG	
180° bend Asymmetry	CH, CV	5D	BG		BG	RG		RG	
180° bend Asymmetry	CH, CV	10D	BG		BG	RG		RG	
3. Low Level Swirl	CH, CV	5D			GU	GU	GU		GU
Low Level Swirl	CH, CV	10D			GU	GU	GU		GU
High Level Swirl	CH, CV	5D			GU	GU	GU		GU
High Level Swirl	CH, CV	10D			GU	GU	GU		GU
4. Diameter Step	increase, decrease	0D	GF	GF		GU	GU		
Diameter Step	increase, decrease	5D	GF	GF		GU	GU		
5. Pressure Reduction	3 Δp's	5D	GF			GF			
Pressure Reduction	3 Δp's	10D	GF			GF			

A Quality Assessment Team (QAT) was set up independently of the participants in the project. The team comprised experts from PTB (Germany), NMi (the Netherlands), Ministère de l'Industrie (France) and DTI (UK) together with a representative of the ULTRAFLOW-participants. This group critically examined the installation, traceability, instrumentation, data acquisition and data acceptance criteria of each test facility, to ensure the quality of the work. The QAT reviewed each of the test facilities involved and came to the conclusion that data derived from the testing are of adequate quality for reference data to support meter standards work.

2 DESCRIPTION OF THE METERS TESTED

The meters tested were of 6" and 12" nominal size. Maximum flow capacity was 1400 [m³/h] for the 6" meter and 5500 [m³/h] for the 12" meter (maximum mean gas velocity of 21 [m/s]). The meters comprise a spool piece housing the ultrasonic transducers which measure the gas velocity across four paths or chords arranged crosswise. Each chord has two transducers which serve alternately as transmitter and receiver to measure the transit time with and against the direction of gas flow. This permits determination of the mean gas velocity across the chord. For determination of the flow rate, the Westinghouse integration method is used.

3 PIPEWORK CONFIGURATIONS FOR TESTS

Each facility undertook tests on the meters operating in "ideal" conditions with a substantial length of straight pipework upstream and at varying pressures where appropriate. These tests were performed prior to the disturbance tests, and in most cases repeated at the conclusion of the series of disturbance tests. The following sections describe the configurations for the disturbance tests. Normally the parallel planes through the chords are oriented horizontally. In some tests, the chords have been oriented both horizontally (CH) and vertically (CV). To achieve uniform definitions, the definitions of CH and CV in this paper are related to the direction of the final bend before the meter. Note that in the case of the swirl testing the final bend was vertical, so that CH means that the chords are actually vertical, related to the earth.

3.1 Disturbances due to 90° and 180° Bends (Asymmetry)

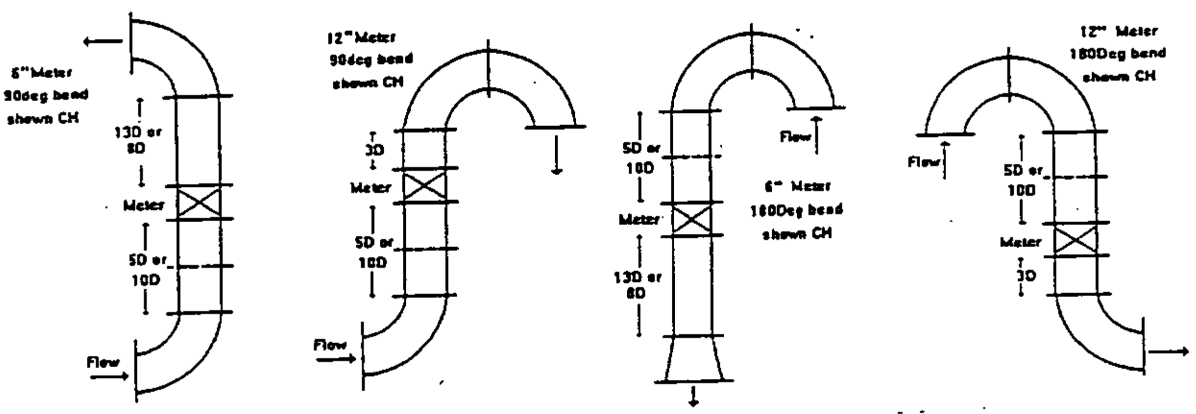

Figure 1 - 90° and 180° Bend Test Configurations

Both CH and CV tests were carried out with the meter situated 5D and 10D downstream of 90° and 180° bends. Figure 1 shows plan views of the meter installations used.

3.2 Disturbances due to Bends in Two Planes (Swirl)

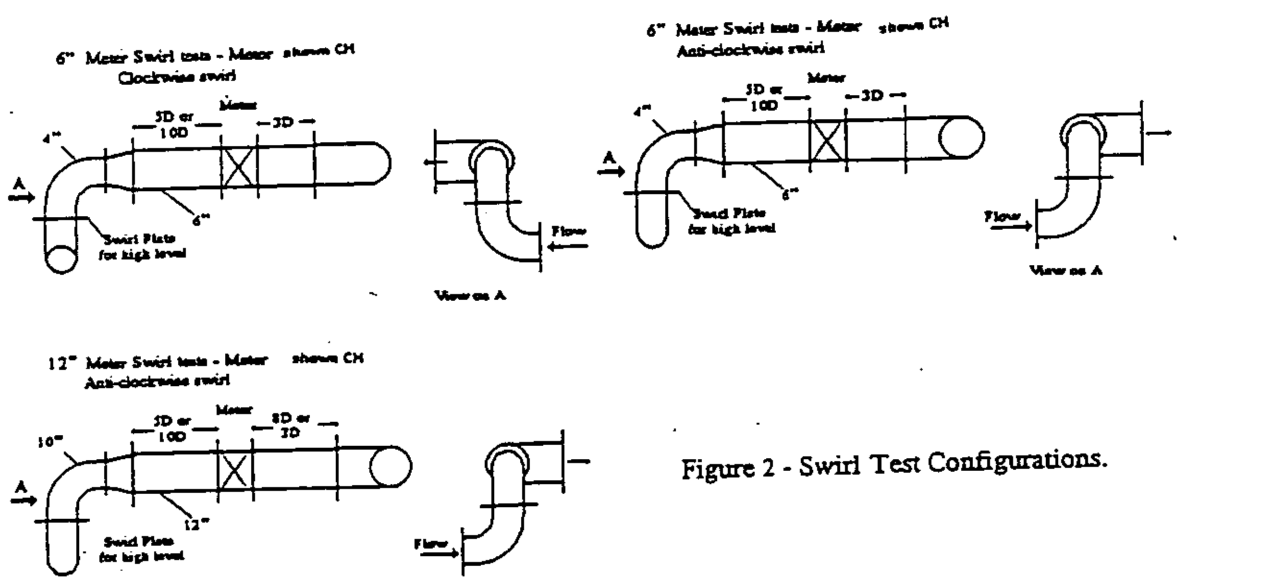

Figure 2 - Swirl Test Configurations.

Figure 2 shows side- and end-elevation views of the meter installations used for swirl tests, based on ISO 9951. Both CH and CV tests were carried out with the meter situated 5D and 10D downstream of pipework configured to induce swirl either CW or ACW (clockwise or anti-clockwise). Two levels of swirl were generated. "Low level swirl" was produced by two 90° bends mounted with their planes perpendicular to each other. From earlier work with this configuration, swirl angles may be estimated to be about 20. "High level swirl" was produced by addition of a half area plate between the bends causing estimated swirl angles of about 30°-40°.

3.3 Disturbances due to Steps in Pipe Diameter

5 mm Diameter step changes are assumed to be typical for tolerances in pipe wall thickness and the tests were conducted with the steps at 0D and 5D from the meter (see figure 3).

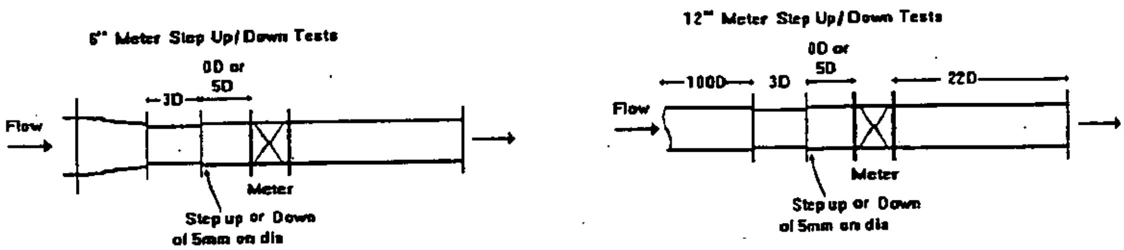

Figure 3 - Step Up and Step Down Test Configurations

3. 4 Disturbances due to Pressure Reduction Valves

The pressure reducing valve used was of a type known from previous experience to generate a combination of high level acoustic noise, profile asymmetry and swirl. The valve was placed 5D and 10D upstream of the meter. The same 4" pressure reducing valve was used with both 6" and 12" meters. Figure 4 shows a plan view of the meter installation used.

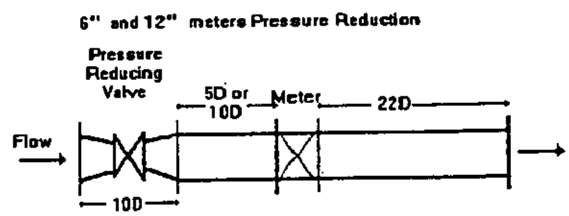

Figure 4 - Pressure Reduction Test Configuration

4 TEST RESULTS - METER OPERATING IN IDEAL FLOW CONDITIONS

Each laboratory conducted at least one but usually two ideal calibrations at each pressure to serve as a baseline for the disturbance tests. This way, a large number of ideal calibrations was obtained during a period of 12 months. It was not the aim of this project to look critically at the <u>shape</u> of the calibration curve associated with the particular meter under test. Therefore, in figure 5, the results are shown in terms of deviations from the mean of all ideal calibration curves (Dm.Err.%) against flow rate, expressed as percentage of maximum. The value of Dm.Err.% was determined at each flow rate from Dm.Err.% = Err.% - Ref.Err.%, where Err.% is the mean of data points of an individual calibration and Ref.Err.% is the mean of data points of all calibrations.

The overall spread of results between sites is within about ±0.5% over a 5:1 turndown ratio and 0.6% over a 10:1 turndown ratio. This spread includes effects of pressure (10 to 60 bar), transport between sites, meter transducer removals for inspections and transport, location of temperature thermowells at 1.5D downstream of the meter, pressure tappings at the meter body or within 3D of the meter and small differences in ideal calibration installation pipework configurations. Analysis of the data showed that tests, on the same facility and at the same pressure, before and after the disturbance tests indicated no significant calibration drift. The meters were tested over a period of 12 months without any noticeable long term deterioration in calibration or performance. No pressure dependency can be concluded from the data. From this, it is concluded that if the meter is installed in well developed flow conditions free of swirl that a meter uncertainty at the 95% confidence interval of 0.6% over a 10:1 turndown independent of pressure can be given.

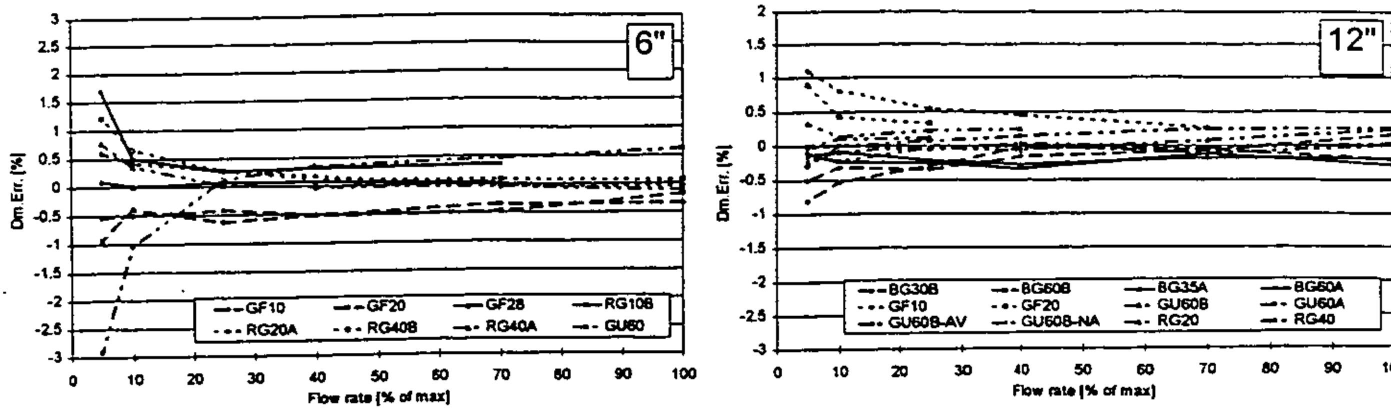

Figure 5 - Deviation of Each Individual Calibration from the Mean of Ideal Calibrations.

5 TEST RESULTS - DISTURBANCE TESTS

In this section, all results are shown in terms of error shifts (Di.Err.%) due to the disturbance.The value of Di.Err.% was determined at each flow rate from Di.Err.% = Err.% - Ref.Err.%, where Err.% is the mean of data points of specific test and Ref.Err.% is the mean of data points of the ideal calibration at the same pressure at the same laboratory.

The ideal calibrations were performed mainly to serve as base line for disturbance tests. From analysis of the results of these calibrations follows that any "disturbance error" Di.Err.% in excess of ±0.2% may be regarded as a significant effect of the disturbance. At low flows (below 10% of maximum) a Di.Err.% in excess of about 0.5% is needed before it can be attributed to the disturbance. These figures are estimates based on spread in ideal calibration curves, the known repeatability of each of the test facilities[3] and the repeatability specification of the meters.
It can be noted that for a particular installation producing asymmetric flow profiles the errors are repeatable and can be considered as systematic therefore if calibrations were performed they could be calibrated out. However for the purposes of this work the errors will be viewed as an additional uncertainty which can be added to the base uncertainty observed in the ideal flow situation.

5.1 Asymmetry: 90° Bend

The results of the asymmetry tests with 90° bends are shown in figure 6.

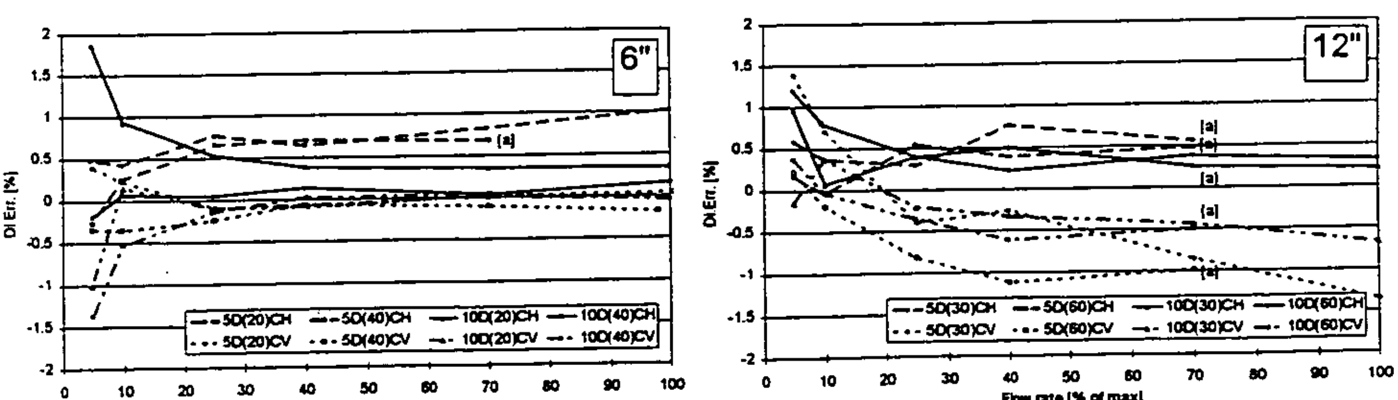

Figure 6 - Meter Downstream of a 90° Bend.

The tests show generally consistent results. There is a general reduction in error shift as the meter is moved further away from the disturbance which is indicative of the flow profile re-establishing itself. The orientation of the meter chords with respect to the plane of the bends appears to have some effect. This effect can be explained by the meter geometry employed. The plane of symmetry of the disturbance with respect to the meter chord directions will result in different measured average linear velocities for each chord which will produce differences in the way the chord arrangement cancels over- and undermeasurement of the profile due to the disturbance.

There also appears to be some differences in magnitude of the errors associated with the meter size. In general, the 6" meter displays less sensitivity to asymmetry than the 12" does. This may be due to the relative sizes of the ultrasound beams to the meter cross sections i.e. the smaller the meter the more the chord linear average velocity represents the cross sectional area it is associated with in the flow integration process.

5.2 Asymmetry: 180° Bend

The results of the asymmetry tests with a 180° bend are shown in figure 7. The results differed substantially for the 6" and 12" meters.
In this configuration there is a general reduction in error shift as the meter is moved further away from the disturbance, which is consistent with results in the 90° bend. The orientation of the meter chords with respect to the plane of the bends appears to have some effect. For the 180° bend the 6" meter tests had the final bend in the same orientation as the 90° tests and similar results are evident. However, the 12" meter 180° bend test was in the opposite direction with the result of a tendency for the error shifts to be in the opposite direction when shifting from CH to CV. This phenomena can also be explained by the meter geometry.

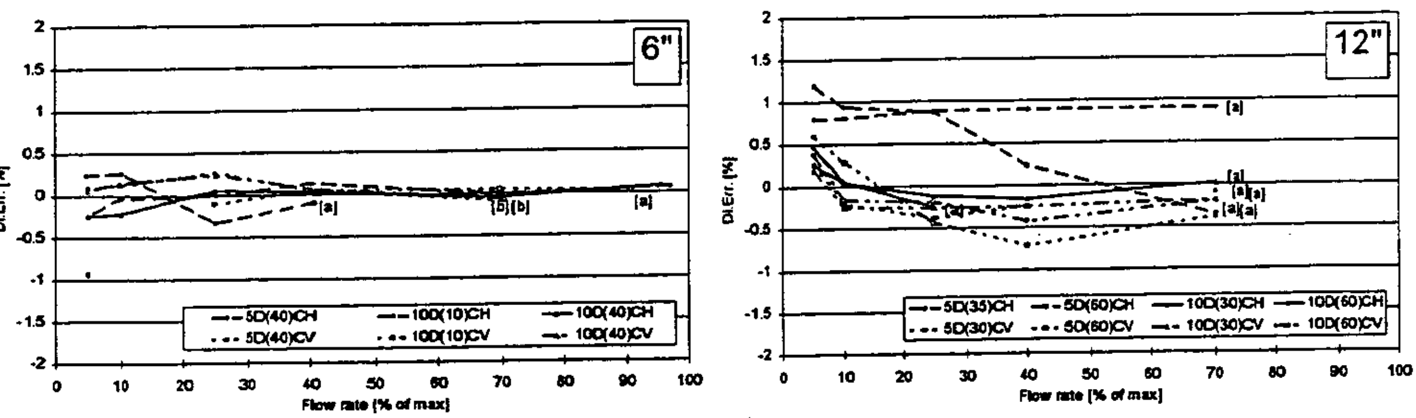

Figure 7 - Meter Downstream of a 180° Bend.

The overall error shifts due to asymmetric flow profiles are generally small regardless of meter size and orientation and with due allowance for medium term reproducibilities and day to day test site uncertainties associated with repeatabilities error shifts are generally within 1.0 % at 5D and 0.5% at 10D over a 5:1 turndown with the meter operating correctly.

5.3 Low Level Swirl Tests

The results of the meters in low level swirl are given in figures 8 (6" meter) and 9 (12" meter). The swirl appears to be rather severe. In the ISO 9951 document this low level test was intended to represent the most severe case to occur in normal pipework configurations. However, it seems it is not a realistic representation of field installation conditions.
The meter errors, especially at 5D, will be a combination of effects which confuses the issue. The flow is not only swirling, but has also asymmetry in the profile. The swirl generator is known to produce instabilities in the flow with severe turbulence, affecting the meter in both chord failures and increased fluctuations in the meter output (which necessitated repeat tests with changes made to the signal handling statistical checking). Anti-clockwise swirl results in larger error shifts than

clockwise swirl. The changes in errors between anti-clockwise and clockwise can be attributed on the meter geometry as mentioned with the asymmetry tests. The error shift generally tended to fall somewhat between the 5D and 10D tests but this was not always the case.

It is difficult to draw definite conclusions from these variable results. It is suggested that the most severe swirl from normal pipework installations may increase the uncertainty by 2.5%. No recommendations for upstream pipe lengths can reasonably be given.

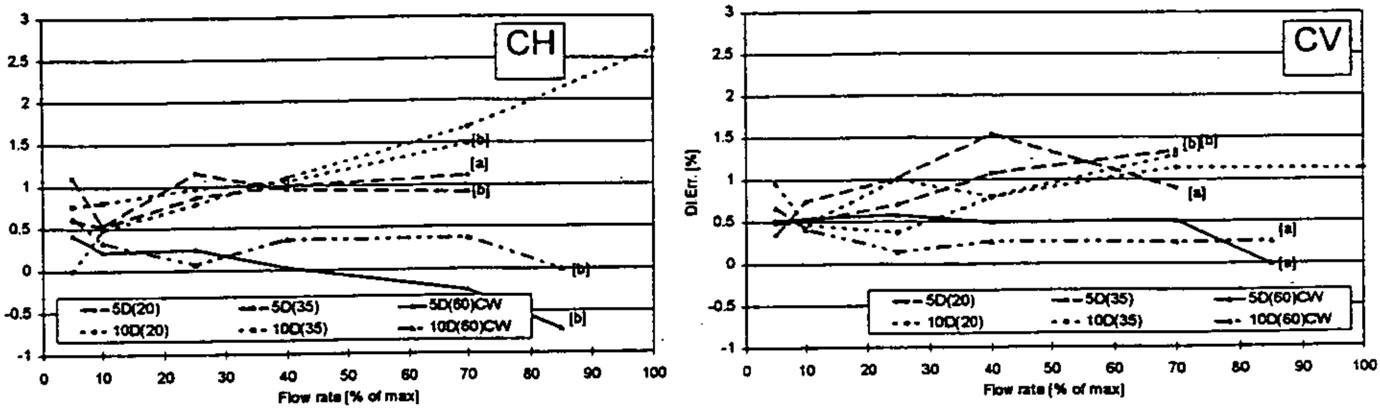

Figure 8 - 6" Meter in Low Level Swirl.

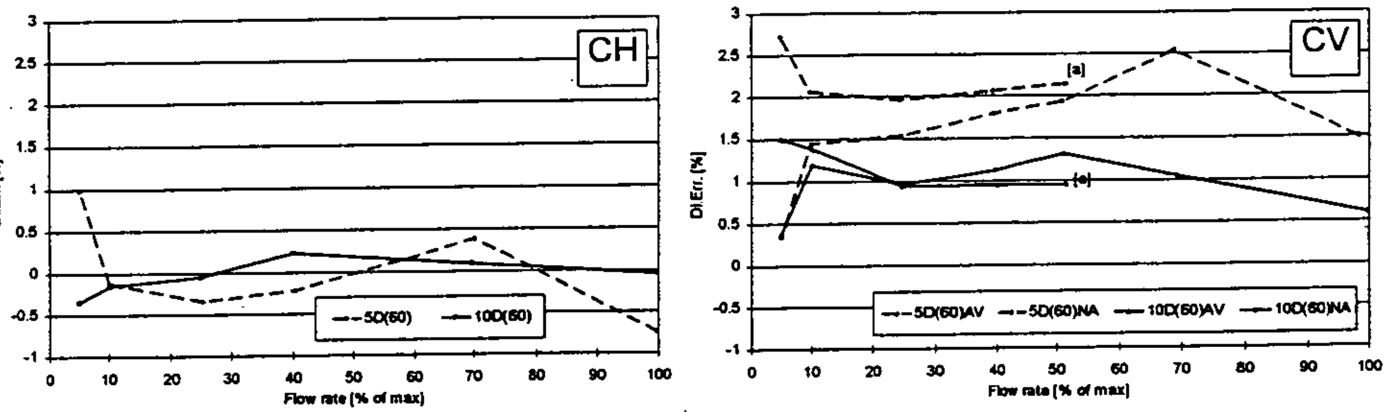

Figure 9 - 12" Meter in Low Level Swirl.

5.4 High Level Swirl Tests

The results of the tests in high level swirl are given in figures 10 (6" meter) and 11 (12" meter).

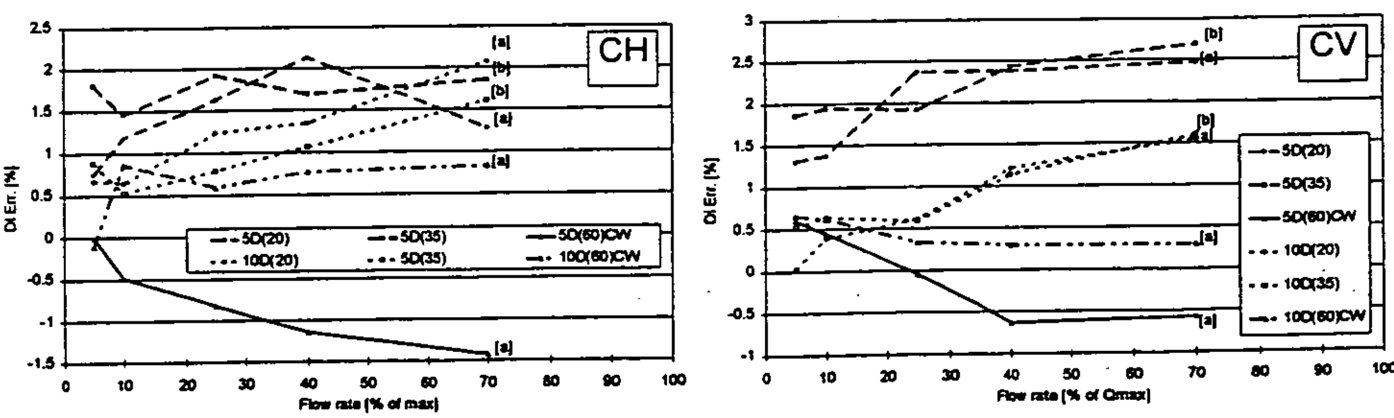

Figure 10 - 6" Meter in High Level Swirl.

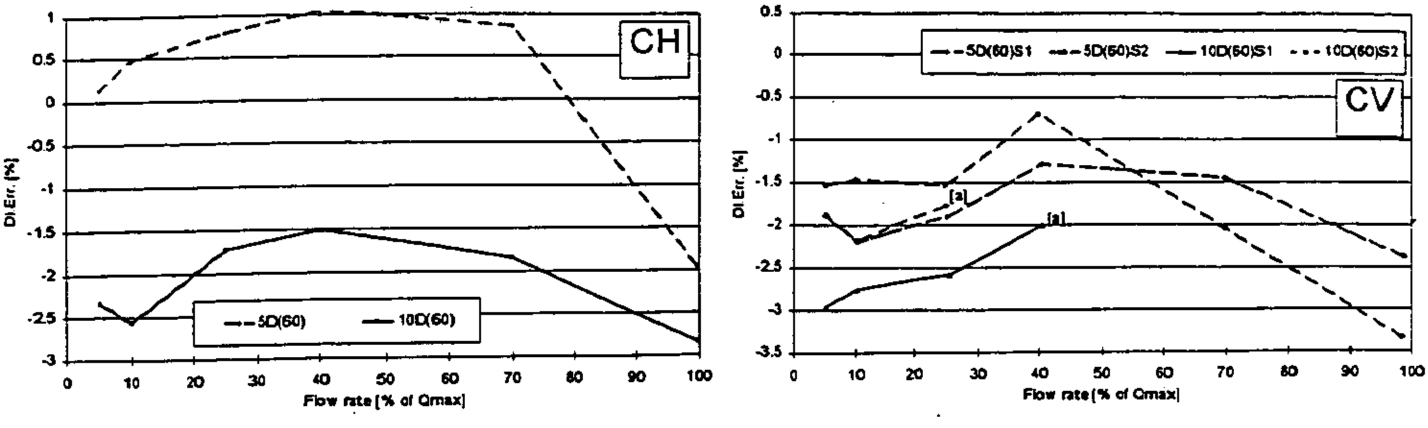

Figure 11 - 12" Meter in High Level Swirl.

For high level swirl it is even more difficult to propose an additional uncertainty than it was for low level. The half area plate not only enhances the swirl, but also very strongly the asymmetries, instabilities and turbulence. The instabilities caused severe signal handling problems. The high level swirl test results differed considerably between the 6" and 12" meters. The error shifts were both positive and negative and in the range ±3%. The error shift tended to fall between the 5D and 10D tests but this was not always the case, and there is a definite switch between CV and CH error directions. Since intention of the ISO test for high level swirl was to represent a pressure regulator these results should be compared with those for the pressure reducer. If this is done it is seen that in general terms the results are similar.

5.5 Diameter Step Up and Down

The results of these tests are given in figure 12 for both the 6" and 12" meters. For a step up or step down of 5mm in pipe diameter at the meter inlet, or at 5D upstream no additional uncertainty is added. Over 10:1 turndown all test results were within the area of medium term reproducibility and no significant error shifts could be measured.

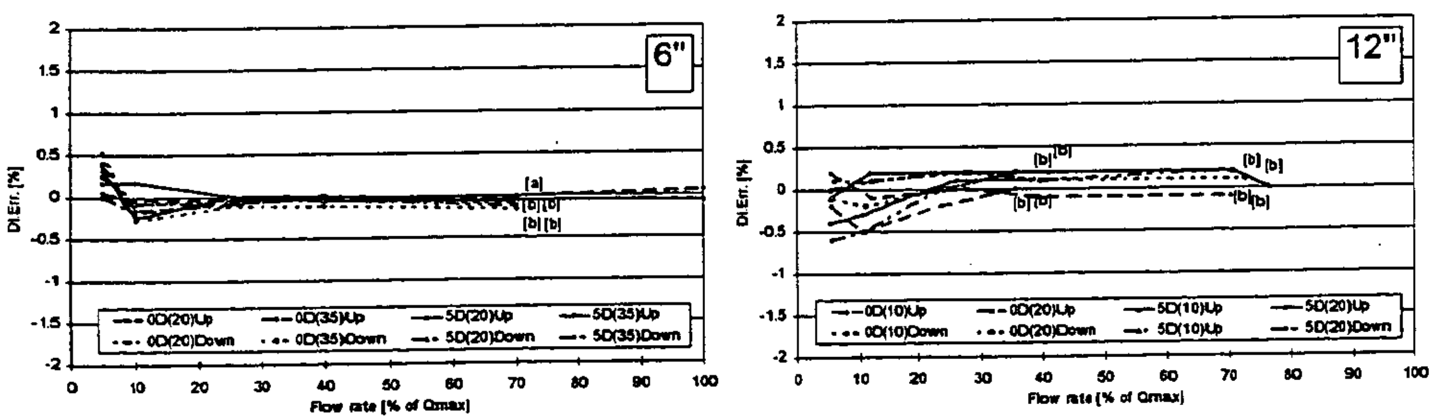

Figure 12 - Meter with Step Up or Down.

5.6 Pressure Reduction Tests

The results of the meters placed downstream of a 4" pressure reducer are given in figure 13. The pressure reducer subjects the meter to swirl, asymmetry and ultrasonic noise. The pressure reducer tests were curtailed because the meters would not operate correctly with a pressure reduction in excess of 2 bar. Only low level pressure reduction tests at 900 mbar could be completed and even then special filtering techniques were needed for the meter to handle the signal.

The 6" meter was much more seriously effected than the 12" meter, which may well have been due to the fact that the same size pressure reducing valve was used. At present it must be suggested that the meters should not be installed in close proximity to any substantial pressure reduction. If this is essential then for a limited pressure reduction an additional uncertainty of perhaps 2% is introduced.

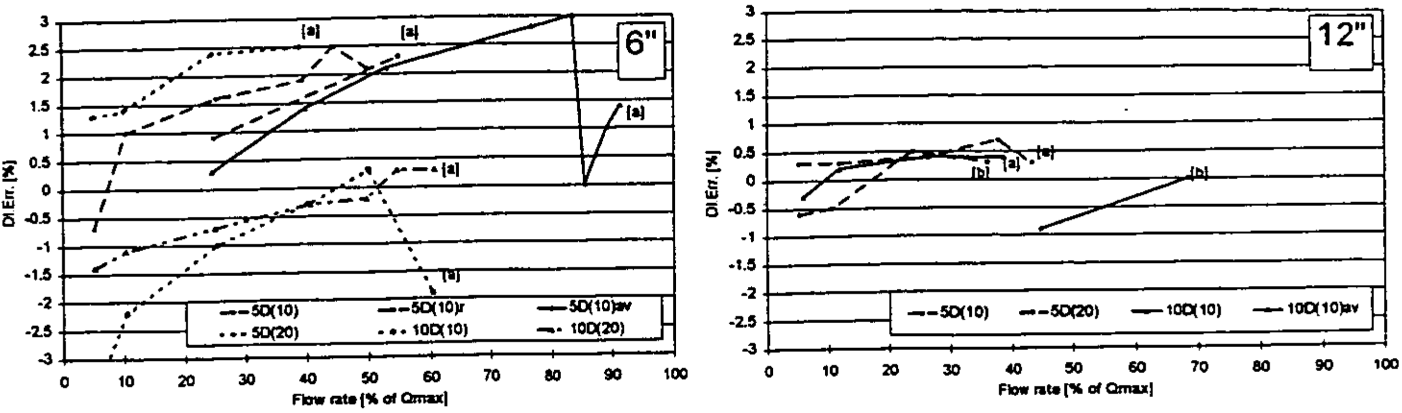

Figure 13 - Meter with 900 mbar Pressure Reduction.

5.7 Meter Signal Handling Techniques

In many of the disturbance tests results could not be obtained at high flow due to excessive chord fails on the meters. These can be alleviated, however, by appropriate setting of the meter averaging or statistical acceptance limits, at the expense of longer up-date times or larger variations in output. The results indicate that these do not influence the "ideal" calibration of the meter, although perhaps this does need to be more convincingly demonstrated in the highly disturbed flows, such as swirl or pressure reduction.

6 PROPOSAL OF ADDITIONAL UNCERTAINTIES DUE TO DISTURBANCES

The additional uncertainties proposed in the previous chapter are summarized in table 2. All figures are given in percentages. Overall figures represent uncertainties required if meter orientation is not defined as part of the installation requirement.

TABLE 2 -
SUMMARY OF PROPOSED ADDITIONAL UNCERTANTIES DUE TO DISTURBANCES

	90° Bend		180° Bend		LL Swirl		HL Swirl		Diam. Step		Press.Red.	
	5D	10D	5D	10D	5D	10D	5D	10D	0D	5D	5D	10D
6" CH	1.0	0.5	1.0	0.5	1.0	2.5	2.0	2.0	0.0	0.0	3.0	2.0
6" CV	0.5	0.5	0.5	0.5	1.5	1.5	2.5	1.5	NT	NT	NT	NT
12" CH	1.0	0.5	1.0	0.5	1.0	0.5	2.0	2.5	0.0	0.0	0.5	1.0
12" CV	1.5	0.5	1.0	0.5	2.5	1.5	3.5	3.0	NT	NT	NT	NT
Overall	1.5	0.5	1.0	0.5	2.5	2.5	3.5	3.0	0.0	0.0	3.0	2.0

7 CONCLUSIONS

Ultrasonic meters can be installed in well developed flow conditions in the absence of swirl and provide meter uncertainties of 0.6% without recourse to reference calibration methods. All that is required is accurate determination of meter dimensions and setting of meter zero under no flow conditions. From the results, additional uncertainties are proposed to be used for standardization work in case the meter is to be installed in non-ideal conditions. There may be advantages gained in defining meter orientation but this cannot be certain.

- The diameter step tests have shown that ultrasonic meters are insensitive to small changes in upstream pipe diameters such as that which would be experienced from use of standard scheduled pipe and installation of full bore ball or plug valves immediately adjacent to the meter.
- For the disturbance tests of asymmetry, swirl and pressure reduction the results at 5D all are at or exceed 1% additional uncertainty. It is not recommended that ultrasonic meters are installed with only 5D of straight pipe from the disturbing pipe configurations.
- If ultrasonic meters are placed with 10D of straight pipe after a bend in a single plane (90° or 180°) an additional uncertainty of 0.5% must be added to the base calibration uncertainty.
- From present results conclusions on swirl cannot be clearly drawn. If the meters are installed 10D from the disturbance an additional uncertainty of 2.5% is proposed which places the meter outside the usual custody transfer accuracy requirements.
- Installing ultrasonic meters downstream of pressure reduction stations is not recommended without provisions to eliminate noise and other disturbances. Where valves are producing low pressure reduction (< 1 bar) the meters can operate but with no additional flow conditioning an additional uncertainty of 2% is indicated with the disturbance 10D from the meter.

The test programme has demonstrated that the meter geometry and integration techniques also play an important role in the meter response to particular disturbances. **The above conclusions may therefore not be fully representative for other meter types. Any conclusions apply specifically to 4 path meters, with criss-cross chord arrangements using the Westinghouse integration method.**

8 FUTURE WORK

- The swirl tests seem to be more severe than that found in actual practice. Testing of more realistic swirl conditions like headers and extension of the upstream pipe straight lengths is recommended because the results indicate that these might result in the required uncertainty being maintained below the 1% limit. Also the benefits of flow straighteners should be investigated. Suggested spacings are 0D, 5D and 10D.
- The pressure reduction tests highlighted the problem of ultrasonic noise and demonstrated a need to address methods of reducing this if ultrasonic meters are to operate successfully downstream of pressure reducing valves. Like swirl the pressure reduction tests need also to establish acceptable upstream lengths to maintain uncertainty within the 1% limit.
- The programme was limited to a single meter type and it is apparent from the results that meter geometry and integration technique plays a role in response to disturbances. It is important that future programmes look at different meter types. These should be backed up by theoretical and practical work on profile effects to help predict meter performance and understand the results.
- There does appear to be a need for work on optimisation of the meter signal processing for different disturbed conditions. There may be a need to indicate a possible down-rating of the meter capacity in disturbed conditions.

ACKNOWLEDGEMENTS

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