Main Index

North Sea
FLOW
Measurement Workshop
1995

Paper 22:

PERFORMANCE TEST OF A 6 PATH USM

5.5

Authors:
Asle Lygre, Atle A. Johannessen, Christian Michelsen Research AS, Norway
Eivind Dykesteen, Rune Norheim, Fluenta AS, Norway

Organiser:
Norwegian Society of Chartered Engineers
Norwegian Society for Oil and Gas Measurement
Co-organiser:
National Engineering Laboratory, UK

PERFORMANCE TESTS OF A 6-PATH USM

by
Asle Lygre (CMR[1]), Eivind Dykesteen (Fluenta[2])
Atle A. Johannessen (CMR) and Rune Norheim (Fluenta)

ABSTRACT

A new 6-path ultrasonic gas flow meter has been developed. A 300 mm (12") version of the meter has been tested at Statoil's calibration facility K-Lab, in Norway and the test results are presented. Tests have been carried out at ideal conditions over the velocity range 0.4 to 9 m/s at pressures between 20 and 100 bar. Installation tests 10D and 5D downstream of a double S-bend (four 90° bend in the same plane) were also carried out. At ideal conditions the deviation lies within ±0.5% for all pressures between 20 and 100 bar over the velocity range 0.4 to 9 m/s at 37 °C. The deviation lies within ±0.7% at 5D and 10D over the velocity range 0.4 to 9 m/s at 37 °C and 60 bar.

INTRODUCTION

This paper presents the tests results of a new 6-path ultrasonic gas flow meter. The new meter represents a further development of the 5-path FMU 700 [1]. Based on the test results of the 5-path meter, Christian Michelsen Research in cooperation with Fluenta, developed an improved meter in the period 1993-95. The meter has been tested at K-Lab (Statoil, Norway), Lintorf (Ruhrgas, Germany) and Westerbork (Gasunie, the Netherlands). Only the tests at K-Lab are reported here, and the results from the other tests will be published later.

THE ULTRASONIC METER

In the following a brief description of the major modifications of the 5-path version described in [1] will be given. For a more general description of the flow meter technology and the capabilities of multi-path meters, we refer to [1].

The 6-path configuration

The tests of the 5-path version revealed that this meter was robust in swirling flow, e.g. generated by a double bend out of plane, whilst sensitive to cross flow encountered downstream of a single 90° bend. Examples of simple swirl and cross flow patterns are shown in Fig. 1a and 1b, respectively. When designing the 5-path meter, it was decided to apply a configuration which was robust to swirling flow. However, it turned out that the meter performance in cross flow was not acceptable for this meter, and the meter performance was also sensitive to the orientation of the acoustic paths relative to the bend.

Referring to Fig.1a it can be seen that when the acoustic paths in the upper and lower part of the pipe, are confined to the same plane, the flow velocity component along the two acoustic paths have opposite signs in swirling flow. If the swirl flow is symmetrical, perfect cancellation of the non axial flow components will occur. On the other hand, if the path configuration shown in Fig.1a is exposed to cross flow as shown in Fig.1b, the flow velocity components along the two acoustic paths will not cancel. This in fact, explains the characteristics of the performance of the 5-path configuration in swirling and cross flow situations.

Referring to Fig.1b it can be seen that when the acoustic paths in the upper and lower part of the pipe, are confined to planes which are perpendicular to each other, the flow velocity component along the two acoustic paths have opposite signs in a cross flow situation. If the cross flow is symmetrical, perfect cancellation of the non axial flow components will occur.

In the new 6-path configuration the features of the two configurations in Fig.1a and 1b are partly combined. This is carried out as illustrated in Fig.2 where the two paths in the upper part of the pipe are "doubled". In this way the non-axial flow components in the upper part of the plane (pipe) can in fact be measured. If the secondary flow pattern is symmetrical, perfect cancellation of the non axial flow components will result. This allows the meter to handle both cross flow and swirling flow.

[1] Christian Michelsen Research, Fantoftvegen 38, P.O. Box 3, N-5036 Fantoft, Norway, tel. +4755574040, fax +4755574041, asle.lygre@cmr.no
[2] Fluenta a/s, Fanavegen 13, P.O.Box 265, N-5051 Nesttun, Norway, tel. +4755137510, fax +4755136878

It should be emphasized that the above analysis is very simplified and is merely included to illustrate the basic principles.

The flow computer

A new and more compact flow computer has been designed. The new computer features a non-volatile disk for storage of executable software codes and parameters for calculation of fiscal quantities. Further, the computer contains a clock with fiscal accuracy in accordance with [2]. In addition to volumetric flow rate, the computer can therefore calculate and store accumulated gas volumes. The computer supports smart transmitters based on the HART protocol, and information can be exchanged with the main data acquisition system through the Modbus protocol. Density input can also be given as a frequency signal. Mass flow rate, or accumulated mass, can accordingly be calculated according to fiscal standards. The SONFLOW software package, providing standard gas conversion codes like AGA8-85 and ISO 6976 are also implemented in the computer allowing conversion of e.g. measured volumetric flow rate to standard conditions [3].

Electronics and ultrasonic transducers

Both the electronics and the transducers of the meter have been redesigned in order to improve the reliability and stability of the meter. An important objective of the redesign has been to be able to replace transducers and/or electronics without having to repeat the zero calibration of the meter, see below. As yet, this feature has not been experimentally verified. A tool that enables replacement of the transducers without depressurizing the pipe line, has been designed. In this case the transducers will be mounted to the spool piece through double block and bleed ball valves.

Zero calibration

Prior to the calibration tests, the meter was zero calibrated at conditions close to the line conditions. All the geometrical constants were carefully measured; i.e. the angles of each transducer pair relative to a plane containing the pipe axis, the distances between the transducers in each pair and the internal diameter of the flow meter spool. All distances were measured with an uncertainty of 0.05 mm and the angles were measured with an uncertainty of 0.1 degrees.

The flow meter spool was pressurized using nitrogen and submersed in a temperature controlled bath. All transit time delays, i.e. Δt-corrections and delays of the absolute transit times, were measured at 37 °C for the pressures 20, 40, 60, 80 and 100 bar. Average transit time delays for the pressure range 20 to 100 bars were calculated and loaded in the flow computer. The same calibration parameters were used over the pressure range 20 to 100 bar. During the tests at K-Lab no other calibration constants than the zero calibration parameters established prior to the tests, were applied. The transit time delay in the cables between the CPU-unit and the meter spool is automatically accounted for, and thus the zero calibration can be carried out with a short pair of signal cables which are easy to handle.

TEST RESULTS

Test conditions

At K-Lab a bank of sonic nozzles constitutes the reference measurement system. The sonic nozzles are primary calibrated against a weighing tank. Pressure and temperature are measured in the test section close to the meter under test, and the volumetric flow rate measured by the ultrasonic meter is converted to mass flow by calculating the density using the AGA8-85 equation. The measured mass flow is then compared to the reference mass flow measured by the sonic nozzles, and the % deviation is calculated.

The tests were conducted at ideal conditions with 65D straight run of pipe upstream of the meter and with a double S-bend (four single bends in the same plane) 10 and 5D upstream of the meter. The meter was tested over the flow range 0.4 to 9 m/s at pressures between 20 and 100 bar. At K-Lab 9 m/s is the maximum velocity for a 12" meter. The cable length between the flow meter spool and the flow computer was approximately 215 m. The temperature of the surroundings varied between 10 and 25 °C in the test period. The typical gas composition of the dry natural gas at K-Lab was 82.6% (CH_4), 14% (C_2H_6), 1.1% (C_3H_8), 0.04% (iC_4H_{10}), 0.06% (nC_4H_{10}), 0.006% (C_5+), 0.8% (CO_2) and 1.3% (N_2). The tests were carried out in the period 24th of April to 23rd of June 1995.

Ideal conditions
In Fig. 3 the test results at ideal conditions are displayed. The deviation lies within ±0.5% for all pressures between 20 and 100 bar over the velocity range 0.4 to 9 m/s at 37 °C.

Keeping the flow rate and temperature constant, and varying the pressure between 20 and 100 bar results in a maximum shift of 0.5% of the deviation curve. There appears to be no systematic pressure effect e.g. in the sense constantly decreasing deviation with decreasing/increasing pressure.

The linearity over the velocity range 0.4 to 9 m/s , at constant pressure and temperature, is less than ±0.4%. In the range 1 to 9 m/s the linearity is less than ±0.3%.

The repeatability, keeping pressure, temperature and flow rate constant, appears to be of the order 0.05% over the velocity range 1 to 9 m/s.

The reproducibility of the meter was tested by repeating the flow calibration at ideal conditions (60 bar and 37°C) after a period of 7 weeks. During this period the meter was pressurized and depressurized several times and various installation tests were carried out. Over the velocity range 0.4 to 9 m/s the shift in the deviation curve was 0.25% or less, see Fig.4. No meter parts, i.e. electronics or transducers, were exchanged during this period, and the zero calibration parameters were unaltered.

Installation effects
The meter was installed 10D downstream of a double S-bend (four 90° bends lying in the same plane) and tests were carried out at three orientations of the meter; 0°, 90° clockwise (CW) and 90° counter clockwise (CCW). At the 0° orientation, the acoustic paths of the meter are perpendicular to the vertical bend plane, and at the 90° CW(CCW) the paths are lying in the bend plane. Tests were also conducted at 5D at the 0° orientation. All the tests were carried out at 60 bar over the velocity range 0.4 to 9 m/s. The deviation curves are displayed in Fig.5.

The deviation lies within ±0.7% at 5D and 10D over the velocity range 0.4 to 9 m/s at 37 °C and 60 bar.

Compared to the deviation curve at ideal conditions at 60 bar and 37 °C, the shift is maximum -0.5% and +0.7% when the meter is installed 10D downstream of the double S-bend depending on the orientation of the meter. The linearity is not affected by installing the meter 10D from the bend. At 5D and 0° orientation, the shift is maximum +0.6%, and the linearity is also increased compared to ideal conditions.

Fig. 6 shows the mean velocity and the speed of sound at 10D, 60 bar and 37 °C when the flow in the loop is reduced from 7 to 3 m/s. The step wise response of the meter to the reduced flow rate is easily depicted and the corresponding temperature effect is clearly seen as an oscillation in the speed of sound. From the measured speed of sound it is observed that stable conditions in the rig are achieved some 10 mins. after the flow rate reduction.

CONCLUSIONS
At ideal conditions the deviation lies within ±0.5%, without any flow calibration of the meter, for all pressures between 20 and 100 bar over the velocity range 0.4 to 9 m/s at 37 °C. The meter was zero calibrated prior to the installation at K-Lab, and the results indicate that a flow calibration is not necessary when the meter operates in fully developed flow.

The linearity is less than ±0.3% and the repeatability is of the order 0.05% over the velocity range 1 to 9m/s.

The meter was installed 10D and 5D downstream of a double S-bend (four single 90° bends in the same plane). The deviation lies within ±0.7% for all meter orientations (0°) at 5D and (0°, 90°CW and 90°CCW) 10D over the velocity range 0.4 to 9 m/s at 37 °C and 60 bar.

ACKNOWLEDGMENTS
The authors greatly acknowledge the support from Statoil, Norsk Hydro, Phillips Petroleum, BP and the Research Council of Norway (the KAPOF program) in the development of the new 6-path meter.

Likewise the authors highly appreciate the work of the project teams at CMR and Fluenta consisting of Per Lunde, Reidar Bø, Morten Andersen, Kjell-Eivind Frøysa, Ørjan Villanger, Hans Ingebrigtsen, Gunnar Wedvich, Svein Værholm and Sigmund Hjerman.

REFERENCES

[1] Lygre A., Folkestad T., Sakariassen R. and Aldal D. : "A new multi-path ultrasonic flow meter for gas", 10th North Sea Flow Measurement Workshop, organized by NEL, Glasgow, at Peebles Hotel Hydro, Scotland, 27-29 October 1992. CMR report no. CMR-92-A10005.

[2] Norwegian Petroleum Directorate: "Regulations relating to fiscal measurement of oil and gas", 1995, ISBN 82-7257-437-3.

[3] Institutt for Energiteknikk, K-Lab: Sales brochure, SONFLOW. IFE, Kjeller, Norway. K-lab, P.O. 308, N-5508 Haugesund, Norway.

a)

b)

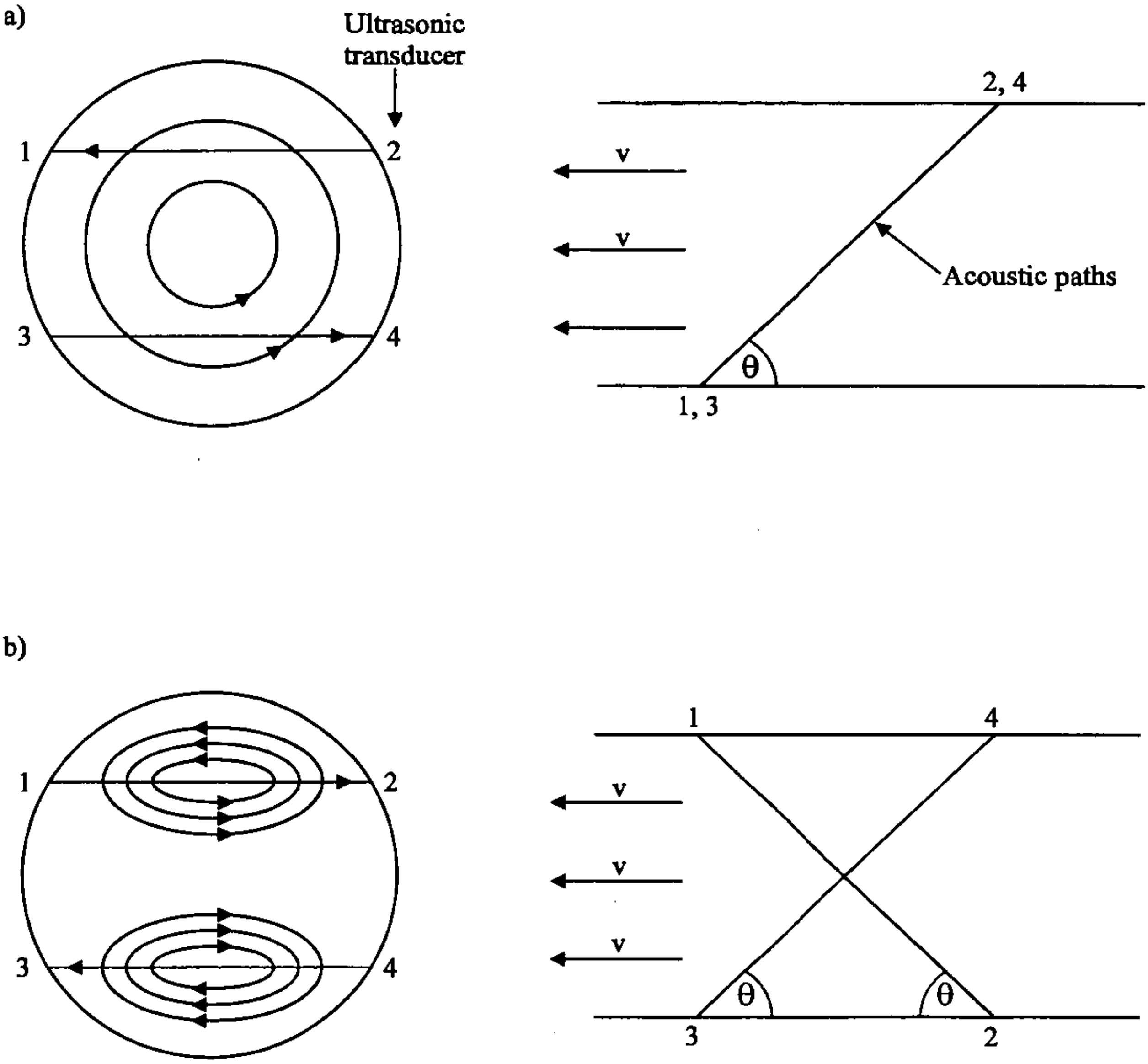

Fig. 1 **a)** Swirling flow. The flow component along path (3-4) is vcosθ - v_s, and along path (1-2) vcosθ + v_s. Accordingly cancellation is achieved when integrating (summing) the measured velocities to calculate the volumetric flow rate. v_s is the component of the secondary flow along the acoustic path. **b)** Cross flow. The flow component along path (3-4) is vcosθ + v_s, and along path (1-2) vcosθ - v_s. Accordingly cancellation is achieved when integrating (summing) the measured velocities to calculate the volumetric flow rate. v_s is the component of the secondary flow along the acoustic path.

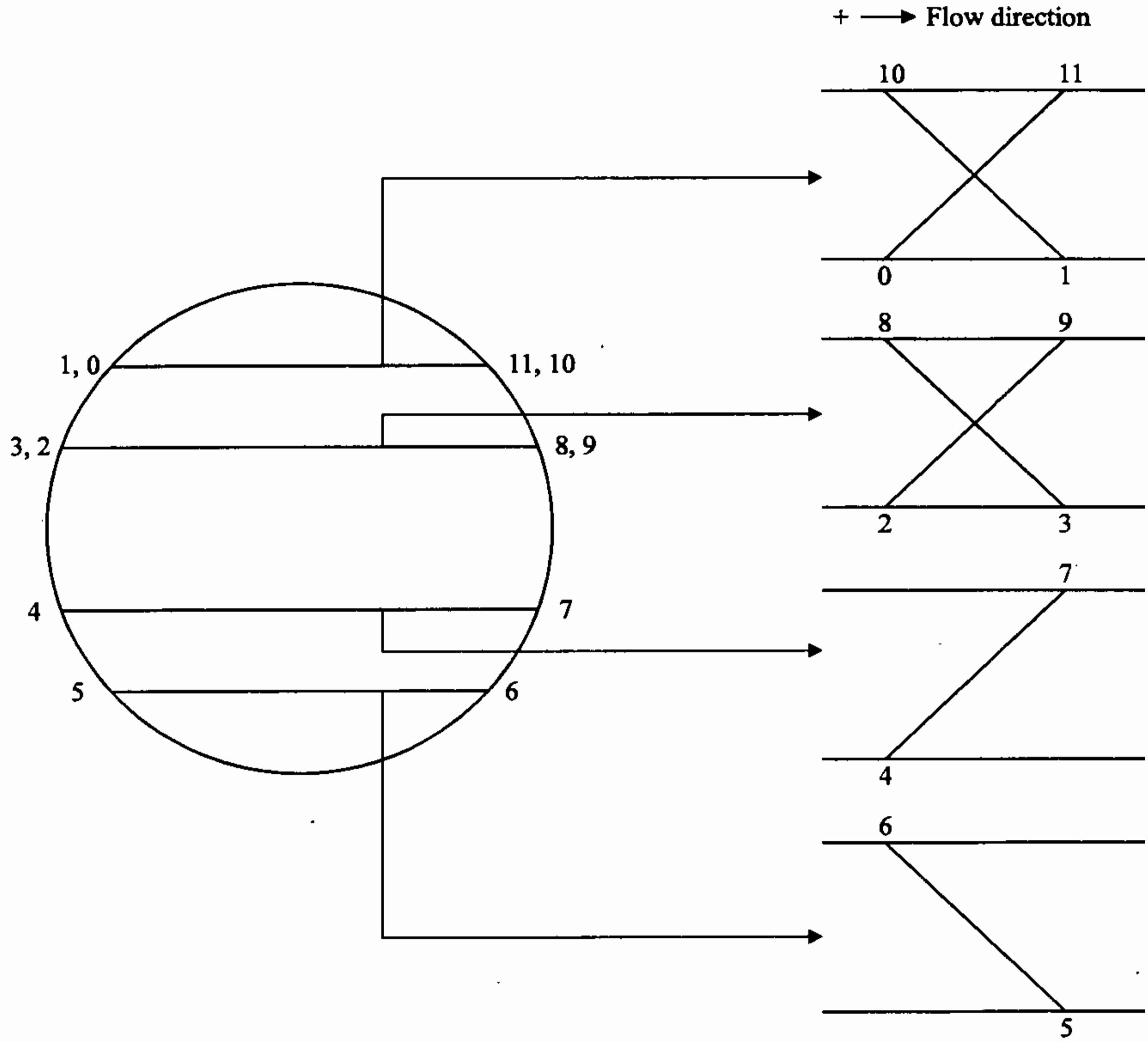

Fig. 2 The configuration of the 6 acoustic paths in the FMU 700.

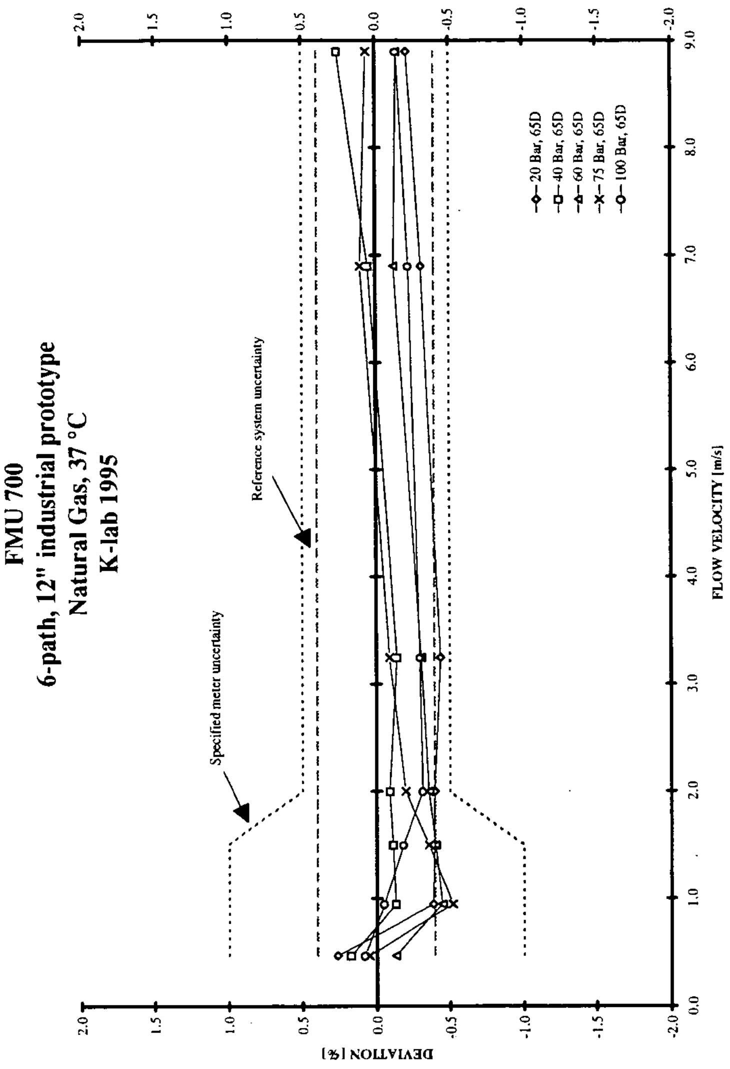

Fig. 3 Observed deviation at ideal conditions at K-Lab with 65D straight inlet length upstream of the 6 path ultrasonic flow meter. The tests were carried out at 37 °C for pressures in the range 20 to 100 bar over the velocity rang 0.4 to 9 m/s. Each mark on the curves represents the average deviation of 2 to 5 consecutive measurements averaged over 300 seconds.

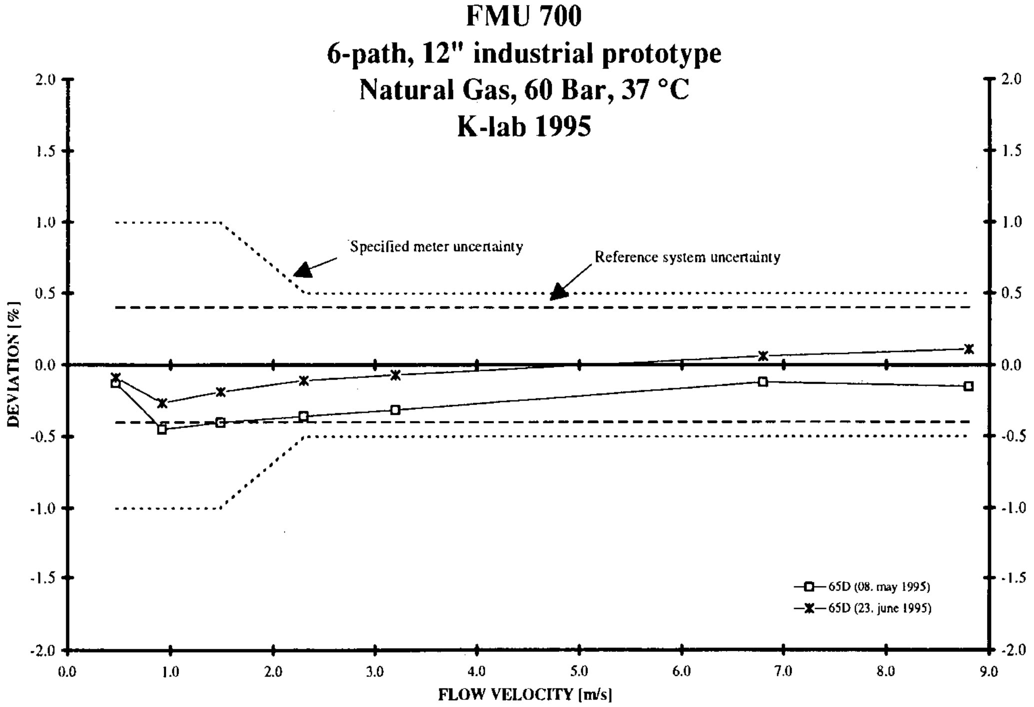

Fig. 4 Reproducibility test of the 6 path ultrasonic flow meter. Two tests at ideal conditions at 60 bar and 37 °C were carried out. The tests were spaced 7 weeks in time.

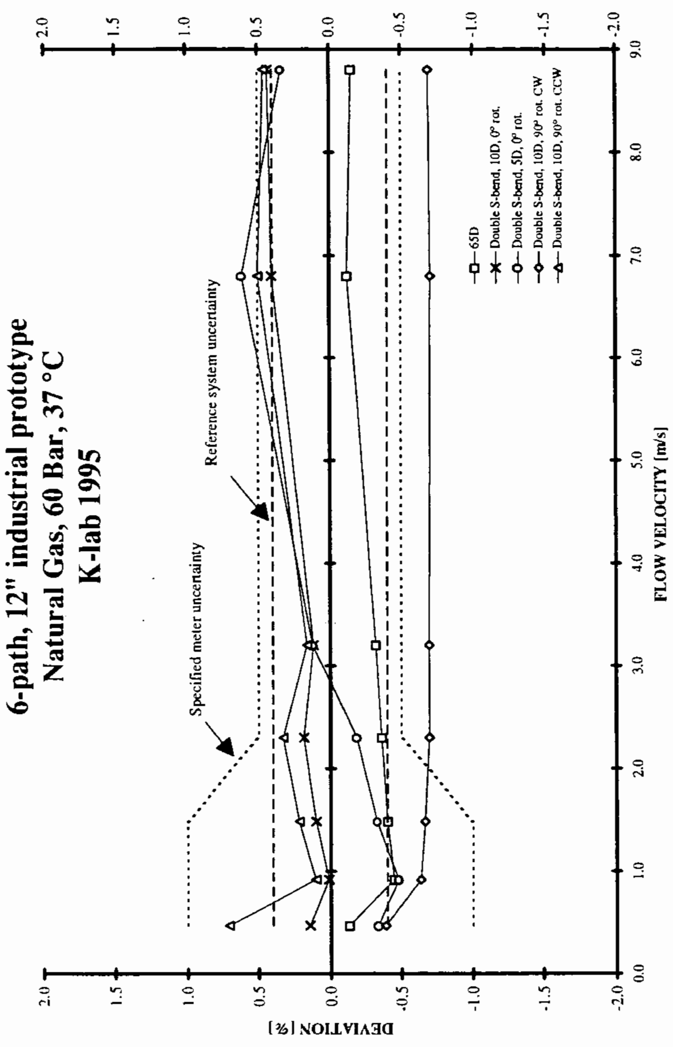

Fig. 5 Observed deviation 5 and 10D downstream of a vertical double S-bend in the same plane (four bends in the same plane). At the 0° orientation, the acoustic paths are horizontal, i.e. perpendicular to the bend plane. At the 90° CW and CCW orientations, the acoustic paths are confined to the bend plane. The tests were carried out at 60 bar and 37 °C. Each mark on the curves represents the average deviation of 2 to 5 consecutive measurements averaged over 300 seconds.

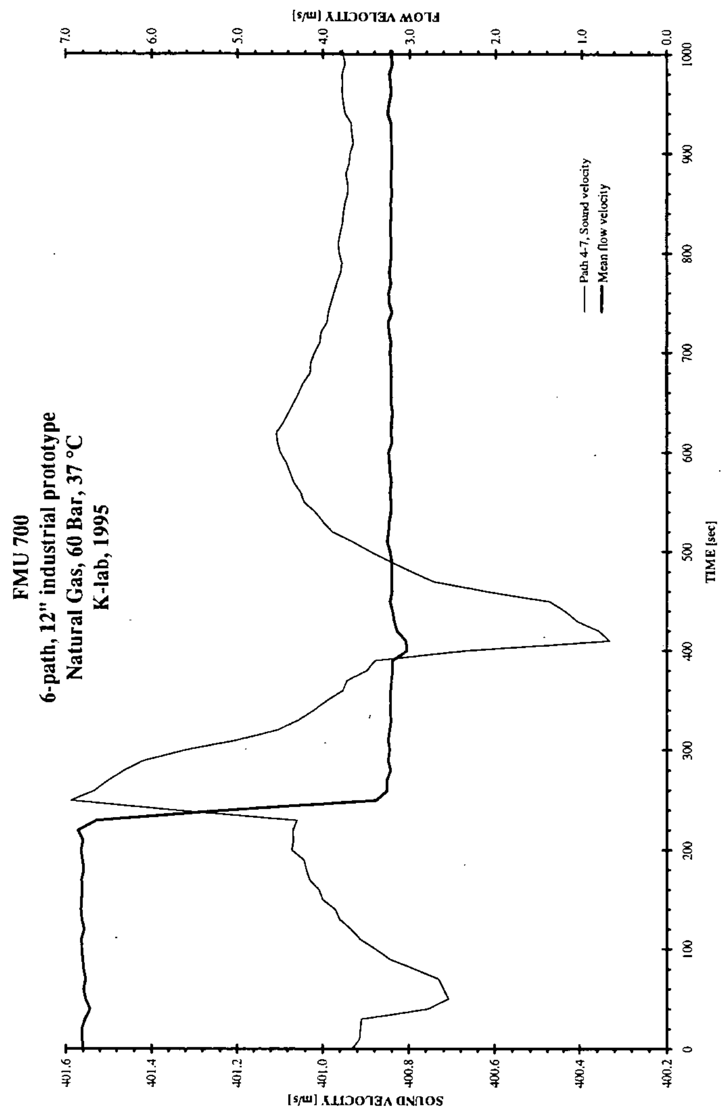

Fig. 6 Response of the 6 path ultrasonic flow meter when the flow was reduced from 7 to 3 m/s at K-Lab. The test was carried out at 60 bar and 37 °C when the meter was installed 10D downstream of the double S-bend.