ON THE METROLOGICAL PERFORMANCES OF DIFFERENTIAL FLOW METERS

Mohamed Aichouni [1], Mohamed Othman Al Nais [1] and Boualem Laribi [2]

1: PhD, Assistant Professors, College of Technology at Hail, Kingdom of Saudi Arabia
2: Lecturer, PhD Candidate ,University of Sciences and Technology at Algiers, Algeria.

Email: aichouni@hotmail.com

ABSTRACT

Accuracy and precision of flow meters are the most important metrological parameters in most industries dealing with increasingly expensive fluids (water, natural gas and petroleum). The accuracy of these devices depends mainly on their position in a pipe network. Pipe fittings such as valves, bends and other fixtures generate turbulence and swirl and distort the flow distribution in the pipe. The paper presents results of an experimental investigation on the effects of non-standards operating conditions (swirling flows generated by a double bend out of plane) on the accuracy of the orifice flow meter. The results showed that the error caused by such non-standards operating conditions can be very important and is well beyond the error limit tolerated by international standards.

Keywords: *Metering error, Accuracy, Orifice Flow meters, Fully developed flow, Pipe flow, Double bend, International Standards ISO.*

الملخص

يرتكز الاقتصاد العالمي المعاصر على تداول موائع صناعية مثل الغاز الطبيعي, البترول و الماء.نظرا للأسعار المتزايدة في الأسواق العالمية لهذه المواد فأنه من الضروري قياس بدقة متناهية الكميات و الأحجام (التدفق) المتداولة . تعتبر دقة أجهزة قياس التدفق من العوامل الأساسية في العديد من الصناعات التي تنتج هذه الموائع. عند استخدام هذه الأجهزة لقياس التدفق في الأنابيب الصناعية و حسب المواصفات الدولية يلزم مراعاة أن يسبق الجهاز طول مستقيم كاف لضمان انتظام السريان. تؤدي تجهيزات الأنابيب كالأكواع و المحابس الى اضطرابات حادة و حدوث حركات دوامية في السريان مما يؤثر سلبا على دقة قراءة الجهاز و قياس تدفق المائع.

خلال هذا البحث نقدم نتائج معملية لدراسة أثر التواء و اضطراب السريان الناتج عن كوع مزدوج على دقة قياس جهاز التدفق ذو فوهة. النتائج المتحصل عليها تؤكد بأن نسبة الخطأ المترتبة عن هذه الحالة تفوق نسبة الخطأ المسموح بها في اطار المواصفات القياسية الدولية.

1. INTRODUCTION

Our interest in measurements of fluid flow is timeless. Knowledge of the direction and the velocity of air flow was essential information for ancient navigators, and the ability to measure water flow was necessary for the fair distribution of water through aqueducts of early communities such as the Sumerians around 5000 years BC. Modern industries such as food, water, power, chemical and petrochemical industries are based on the use and the transformation of fluids with increasingly rising prices. Fluids such as water, petrol and natural gas play an essential role from a technological and economical stand points. These fluids contribute significantly in the economies of many countries. Billions of Dollars come annually from fluids trade and commerce between suppliers and consumers. It is obvious that the transferred quantities and volumes of these fluids must be measured with high accuracy and as precise as possible in order to preserve economical interests and avoid important losses. Accuracy and precision of flow meters are the most important metrological parameters in most industries dealing with increasingly expensive fluids. The accuracy of these devices depends not only on their construction and method of operation but also on their position in a pipe network. Valves, bends and other fixtures generate turbulence and swirl and distort the flow distribution in the pipe. This disturbance can significantly alter the measurements made by flow meters downstream of these fittings.

Because of the technical and economical importance of accurate flow metering, a considerable research effort has been devoted to study the effects of flow meter operational conditions upon their accuracy and metrological performances. In the recent years, concentrated research work in USA at the National Institute of Standards and Technologies (NIST) and the Gas Research Institute (GRI) (Mattingly and [Yeh, 1991], [Yeh and Mattingly, 1996], [Morrison et al. 1992], [Morrow et al. 1991, 1997], [Brennan et al. 1991], in the United Kingdom (at the National Engineering Laboratory NEL) (Reader-[Harris and Keegans 1986], [Reader Harris, 2000] and [Laws and Ouazzane, 1994], in Germany [Merzkirch and Kalkuhler, 1998] and [Zimmermann, 1999] and in France (CERT) [Gajan et al.,1991] has been devoted to study experimentally and computationally the installation effects upon industrial flow meters. Annually, experts discuss the problem of metering errors and their economical and technological impacts at technical meetings and conferences organised by the American Society of Mechanical Engineers (ASME) in USA and the National Engineering Laboratory in the United Kingdom. In early research work [Aichouni et al. ,1996, 1998, 2000] and [Laribi and Aichouni, 2001] investigated experimentally and numerically the installation effects upon Venturi tube and orifice flow meters. The major conclusions reported that significant errors can be registered if the flow meter is working under abnormal flow conditions. It is also concluded that more experimental and numerical research effort is still needed to improve industrial flow metering performances.

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The performance of a flow meter is sensitive to the appearance of a tangential velocity component or swirl, in the flow. In piping systems, swirl may be generated when the flow passes two consecutive 90° elbows out of plane. An important parameter for the performance of the flow meter is the strength of the swirl. Consequently, comprehension of the decay process of swirl may lead to a better design of flow metering station. The present paper describes results of an experimental investigation on the decay of swirling pipe flow and its effect on orifice meter performance.

2. EXPERIMENTAL FACILITY AND PROCEDURE

The basic experimental facility is presented in figure 1. It consists of a long Plexiglas pipe with 100 mm inner diameter. The air flow was powered by a motor driving a centrifugal fan. The air enters the pipe through a nozzle then flows through a straight pipe of 11 pipe diameters length which is followed by the a 90° double bend out of planes. The double bend represents the source of the flow disturbance.

A reference orifice meter is installed 97 pipe diameter downstream where the flow is fully developed. The tested orifice meter was first installed at 1.5D downstream of the double bend and then moved at different locations downstream. The orifice plates studied were of standard geometry and had pressure tappings one D upstream and D/2 downstream, where D is the inner pipe diameter. The static pressure (upstream and downstream of the meter) was measured by four pressure tappings connected to a multitube manometer. The opening diameters d of the orifices used are 50, 62 and 70 mm, so the respective ratios of the opening diameter to the pipe diameter, d/D, were β=0.5, 0.62 and 0.70. Only results for β=0.7 are presented in this paper for space considerations.

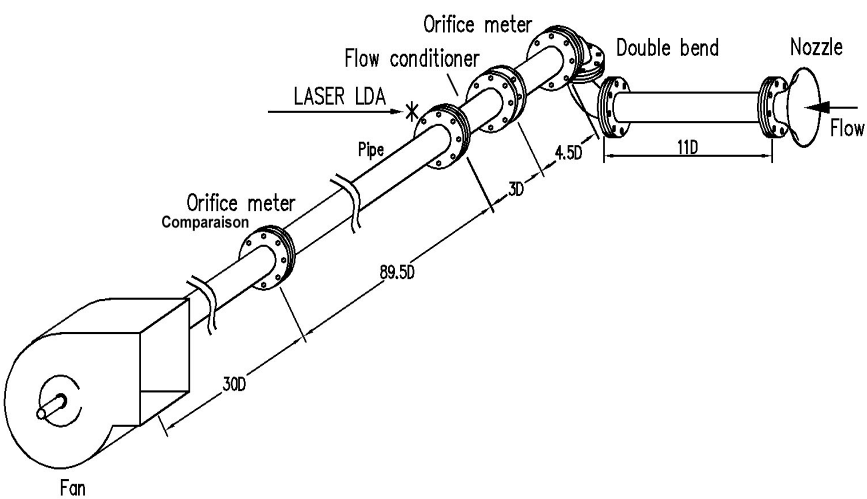

Figure 1. Experimental facility

The mean and the fluctuating components of the velocity downstream the two elbows were measured using a two component Laser Doppler Anemometer. For measurement with LDA the air flow was seeded with smoke. Tests have been done at Reynolds number ranging from 3 $x10^4$ to $11x10^4$. Profiles of the mean velocity and the axial turbulence intensity have been measured at different axial stations downstream of the double bend. Swirl angle was determined at every station from the measured axial and radial velocity components according to:

$$A = arctg\left(\frac{v}{u}\right) \tag{1}$$

At the last measuring station the flow is fully developed. This is checked by comparing the axial mean velocity profile measured at that station and the $(1/7)^{th}$ power law profile for a Reynolds number of 4.4 $x10^4$. Figure 2 shows the comparison where it is clearly shown the agreement between the two profiles. It was concluded that the experimental procedure is effective to investigate the flow development downstream a two double bend out of plane and its effects upon the metrological performance of the orifice flow meter.

3. RESULTS AND DISCUSSION

The purpose of the experimental programme was twofold: First to study the decay process of highly swirling flow generated by a typical industrial piping element (a double bend out of plane) in a circular pipe and second to evaluate the effect of such a distortion on the accuracy of the orifice flow meter.

The first part of the programme was dedicated to study the decay process of a highly swirling pipe flow. The radial distribution of the axial mean velocity profile U/U_{max}, the axial turbulence intensity $I_x(\%)$ and the swirl number measured at axial stations z/D=0.8, 6, 9, 14 and 22 are presented and compared to their fully developed values in figure 3. The figure shows that the double bend in two different planes generates a high distortion in terms of mean flow and its turbulent structure and swirl which take long downstream length to decay towards its fully developed condition. At distance of 22 pipe diameters from the disturbance source the flow is far to be considered fully developed. It is important to note here that the standards ISO 5167 (1991) specify such a distance between this disturbance and orifice flow meter. This would suggest that the lengths specified by the standards are not sufficient to guarantee the fully developed flow condition. It is obvious that any flow meter operating under this condition would register a measuring error that should be quantified.

The metering error under the disturbed flow condition (double bend out of plane) was determined as follows:

The true flow rate was measured from the reference flow meter placed at the fully developed flow condition (at 97 pipe diameter from the flow disturbance). Then the tested flow meter was

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placed at different axial stations from the double bend and the corresponding flow rate was measured. The flow rate error and the discharge coefficient shift were determined to see the effect of the meter location on the accuracy of measured flow rate. The discharge coefficient was determined as the ratio of the measured flow rate to the true flow rate. The percentage shift in the discharge coefficient was determined from the relationship :

$$\Delta C_d = \left(\frac{C_{d0} - C_d}{C_{d0}} \right) x100 \qquad (2)$$

Where C_{d0} represents the discharge coefficient measured under standards conditions (fully developed flow condition) and C_d being the discharge coefficient measured under non-standards operating conditions.

The variation of the discharge coefficient error ΔCd (%) is presented in figure 4. This figure shows that ΔCd decreases progressively from higher values (2.2%) when the meter is place at near distances from the double bend to lower values at further downstream stations. Beyond 50 pipe diameters, the measuring error is within the tolerated limits by the international standards (ISO 5167 and AGA 3). The general trend of the figure is that the Cd shift is much higher for lower Reynolds number and tends to decrease as the Reynolds number increase. This observation holds for the four measured stations z/D=10, 30, 50 and 70. It has to be noted here that the spacer between the elbows is about one diameter; This would produce an intense single eddy swirl that decays slowly in the downstream direction and would take much more length to reach the fully developed flow condition as suggested by Morrow (1997). The higher values f the discharge coefficient shift obtained at axial stations z/D = 10, 30 and 50 downstream of the two elbows indicate clearly the effect of the swirl on the meter performance.

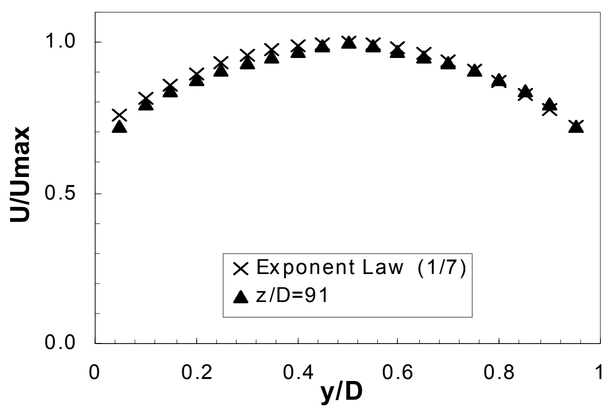

Figure 2 – Comparison of the LDA axial profile measured at 91 D downstream of the double bend with the $(1/7)^{th}$ power law profile

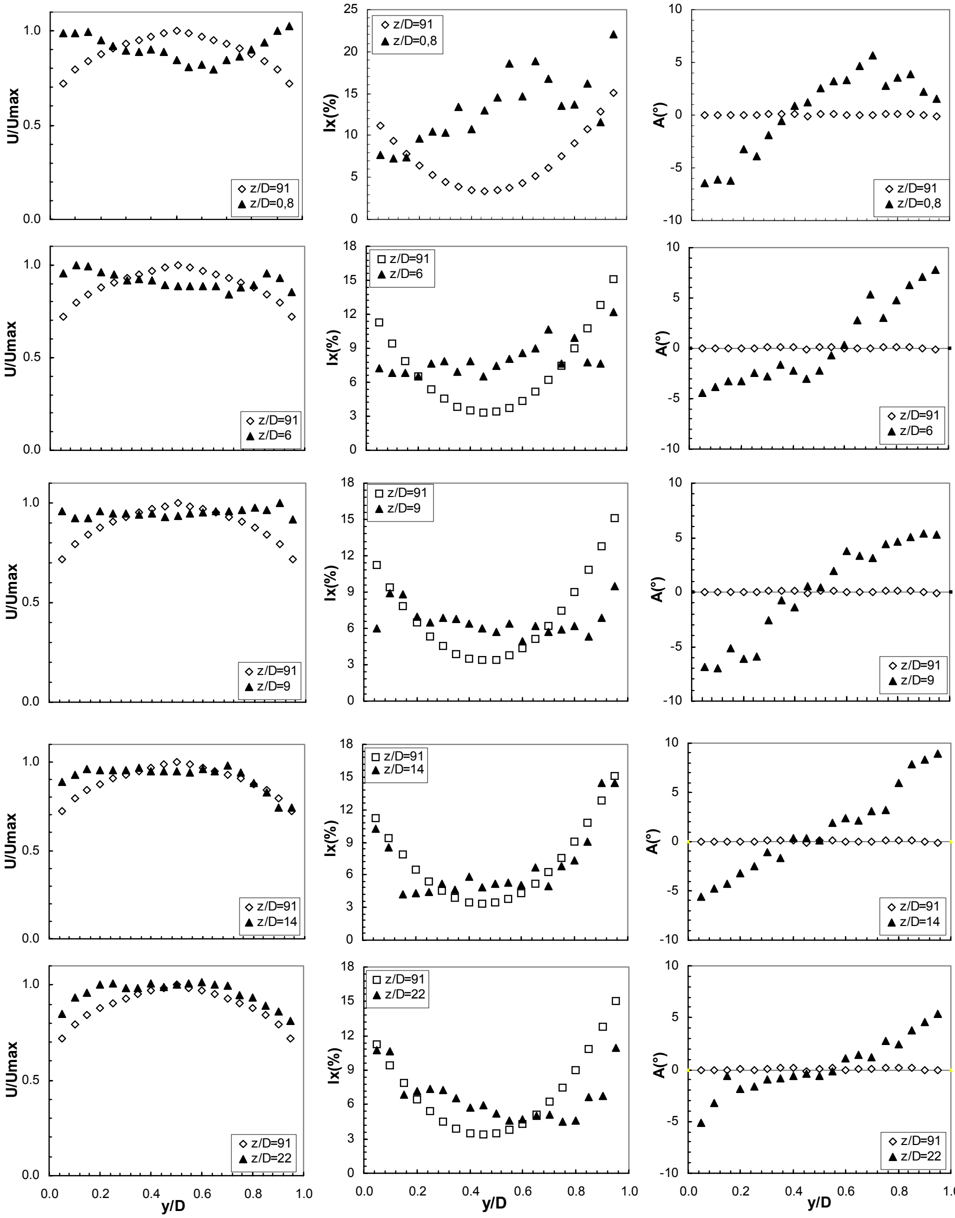

Figure 3 – Distribution of axial mean velocity, turbulence intensity and swirl angle downstream of the double bend out of plane

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4. CONCLUSIONS

The present experimental study has been devoted to investigate the decay process of a highly swirling flow in a circular pipe. The swirl was generated by a typical piping element which is a double bend in two different planes. Laser Doppler Anemometer (LDA) technique has been used to investigate the mean and turbulent flow fields. The study shows that the double bend creates a highly swirling flow which would take longer distances to decay and to develop towards the fully developed flow condition. The effect of operating flow condition can be significant on the orifice flow meter performance. It is suggested that the straight piping length specified by the standards ISO 5167 for an orifice meter installed downstream of two 90° elbows out of plane is not sufficient and should be increased in order to avoid unwanted metering errors.

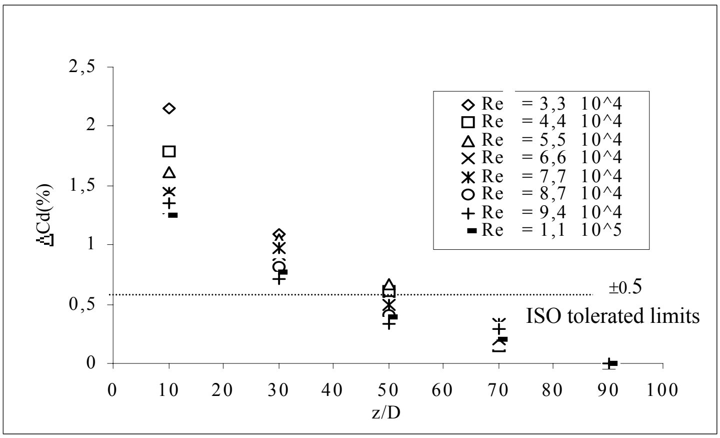

Figure 4 – Discharge Coefficient Shift for the Orifice Flow meter (β=0.7) placed at Different Locations Downstream of a 90° Double Bend out of planes

NOMENCLATURE

A	Swirl angle $A(°) = \mathrm{arctg}(V/U)$
C_d	Coefficient of discharge
ΔCd (%)	Discharge coefficient Shift
D	Internal Pipe Diameter
d	Orifice flow meter diameter
I_x (%)	Axial Turbulence Intensity $I_x = \sqrt{\overline{u'^2}} / \bar{U}_m$
Q	Discharge (Flow rate)

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R_e	Reynolds Number ($R_e = \rho\, U_m\, D / \mu$)
U, V	Axial and Radial Mean Velocity Components
U_m	Axial Average Velocity
U_{max}	Axial Maximum Velocity
U_m	Flow mean velocity
y	Radial Coordinate
z	Axial Coordinate
β	Orifice flow meter diameter ratio $\beta = d/D$
μ	Fluid absolute viscosity
ρ	Fluid density

REFERENCES

1. Aichouni, M. Mous, M., Benchicou, S, Mouaici, M, Belghit, M. and Mechmeche, M, 'How flow meter condition affects measurements accuracy', Proceeding of the 7th International Symposium on Flow Modelling and Turbulence Measurements, Tainan, Taiwan, October 5 – 7, 1998.
2. Aichouni, M., Laribi, B., Retiel, N., Houat, S., Nehari, D. and Benchicou S., 2000, 'Experimental investigation of the installation effects on the Venturi flowmeter performance', 2000 ASME Fluids Engineering Conference, Boston, USA, June 11-15.
3. Aichouni, M., Laws, EM and Ouazzane, AK, 1996, 'Experimental study of the effects of upstream flow condition upon venturi flow meter performance', In *Flow Modelling and Turbulence Measurements VI,* Ed. Chen, CJ et al., Balkema, Rotterdam.
4. Brennan, J.A., Sindt, C.F., Lewis, M.A., and Scott, J.L.,1991, 'Choosing flow conditioners and their Location for Orifice Flow Measurement'. *Flow Measurement and Instrumentation*, Vol. 2, Number 1, pp. 40-44.
5. Gajan, P,. Hebrard, P., Millan, P. and Giovanni, A. , 1991, 'Basic study of flow metering of fluids in pipes containing an orifice plate'. *Gas Research Institute Report*.
6. ISO 5167, 1991, 'Measurement of fluid flow by means of orifice plates, nozzles and Venturi tubes inserted in circular cross section conduits running full', the International Standards Organization.
7. Laribi, B. , Aichouni, M, 2001, 'Experimental study of the decay of swirling turbulent pipe flow and its effect on the orifice meter performance', 2001 ASME Fluids Engineering Conference, New Orleans, USA, May 29 – June 1.
8. Laws, E. M., Ouazzane, A. K., 1994, 'Compact installations for differential flow meters'. *Flow Measurement and Instrumentation*., Vol. 5 No. 2, pp. 79-85.
9. Mattingly, G.E., and Yeh, T.T, 1991, 'Effects of Pipe Elbows and Tube bundles on Selected Types of flowmeters'. *Flow Measurement and Instrumentation*, Vol. 2 (1), pp.4-13.
10. Merzkirch, W. and Kalkühler, K. 1998,'Velocity and turbulence measurements in the flow downstream of flow conditioners', Advances in Fluid Mechanics and Turbo machinery, eds. H.J. Rath, C. Egbers, pp. 125-135, Springer-Verlag, Berlin.

11. Morrison, G.L, DeOtte, R.E., Beam, E.J, 1992, 'Installation effects upon orifice flow meters'. *71st Annual Gas Processors Association Convention*, Anaheim, CA, March 16-18.
12. Morrison, G.L., Panak, D.L., and DeOtte, R.E., 1992, 'Numerical study of the effects of upstream flow condition upon orifice flow meter performance'. *ASME 11th International Conference on Offshore Mechanics and Arctics Engineering*, Calgary, Alberta, Canada, June 7-11.
13. Morrow, T.B, 1997, 'Orifice meter installation effects : Research update for A=29Dmeter tubes', AA operations Conference, Nashville, Tennessee, May 1997.
14. Morrow, T.B, Park, J.T., and McKee, R.J, 1991, 'Determination of Installation Effects for a 100 mm Orifice Meter Using a Sliding Vane Technique'. *Flow Measurement and Instrumentation*, Vol. 2, Number 1, pp. 14-20.
15. Presented at the 6th International Symposium on Flow Modelling and Turbulence Measurements, FAMU/FSU, Tallahassee, Florida, USA, 8-10 September, 1996.
16. Reader Harris, 2000, 'NEL - Flow Programme www.flowprogramme.co.uk'.
17. Reader Harris, M.J, and Keegans, W, 1986, 'Comparison of computational and LDV measurements of flow through orifice and perforated plates, and computation of the effect of rough pipe work on orifice plates'. *International Symposium on Fluid Flow Measurements*, November 16-18.
18. Yeh, T.T and Mattingly, G.E, 1996, 'Flow meter installation effects due to a generic header', NIST Technical note 1419.
19. Zimmermann, H, 1999, 'Examination of disturbed pipe flow and its effects one flow measurement using orifice plates', *Flow Measurement and Instrumentation* ,vol 10, pp 223-240.

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