Chin. J. Chem. Eng., **15**(2) 281—285 (2007)
RESEARCH NOTES

Wet Gas Meter Development Based on Slotted Orifice Couple and Neural Network Techniques*

GENG Yanfeng(耿艳峰), ZHENG Jinwu(郑金吾), SHI Tianming(石天明) and SHI Gang(石岗)**
Department of Automation, China University of Petroleum, Dongying 257061, China

Abstract A slotted orifice has many superiorities over a standard orifice. For single-phase flow measurement, its flow coefficient is insensitive to the upstream velocity profile. For two phase flow measurement, various characteristics of its differential pressure (DP) are stable and closely correlated with the mass flow rate of gas and liquid. The complex relationships between the signal features and the two-phase flow rate are established through the use of a back propagation (BP) neural network. Experiments were carried out in the horizontal tubes with 50mm inner diameter, operated with water flow rate in the range of $0.2\mathrm{m^3 \cdot h^{-1}}$ to $4\mathrm{m^3 \cdot h^{-1}}$, gas flow rate in the range of $100\mathrm{m^3 \cdot h^{-1}}$ to $1000\mathrm{m^3 \cdot h^{-1}}$, and pressure at 400kPa and 850kPa respectively, where the temperature is ambient temperature. This article includes the principle of wet gas meter development, the experimental matrix, the signal processing techniques and the achieved results. On the basis of the results it is suggested that the slotted orifice couple with a trained neural network may provide a simple but efficient solution to the wet gas meter development.
Keywords wet gas meter, two-phase flow, slotted orifice, neural network, wavelet analysis, principal component analysis

1 INTRODUCTION

Wet gas is the terminology for a well stream where the gas volume fraction (GVF) is greater than 90% and mostly above 95%, but less than 100%, at the metering condition. These streams always appear as gas-liquid two-phase flow with low liquid fractions. Both standard multiphase meters and dry gas flow meters cannot operate satisfactorily on wet gas[1,2].

Currently, some well-known companies have developed their wet gas meters (WGM), such as Agar, Solartron, PECO, TEA, FRAMO, and so on. At 90% confidence level, the measurement uncertainties of these products for gas and liquid flow rates are within ±10%, but when the flow conditions are changed, the uncertainties would be far beyond this limit. Until now no meter has yet proven itself to be capable of metering wet gas flow to the accuracy desired by industry. The development and improvement of WGM is therefore a key requirement to the natural gas industry[2].

The slotted orifice was put forward and studied as a single phase flow sensor by Morrison[3], and its flow coefficient is insensitive to the upstream velocity profile. Some throttling devices such as Venturi tubes, nozzle, and V-cone also have this quality, but compared with the slotted orifice, they are more complex and expensive. Hence the slotted orifice is chosen for the WGM's flow sensor, and based on the multiple measurement principle the slotted orifice couple is selected as the methodology to determine GVF of wet gas flow.

The simulations of the slotted orifice dynamics and the metering characteristics for single-phase flow have been discussed in Ref.[3], and the metering characteristics for air/water two phase flow discussed in Refs.[4—6]. This article mainly focuses on the principle of WGM development, metering algorithm development, and some results.

The authors believe that all previous effort in this field was limited by the characteristics of the flow sensors and the conventional signal process means. In a conventional signal processing, the amplitude variation of different flow sensors was detected and simply treated. As the measured signal often depends on the inhomogeneous distribution of gas and liquid in the pipe line and the interactions between them, which often vary unpredictably, the measured signals show many random features. The varying parts or AC parts of measured signals were not utilized efficiently and even filtered out as noise. This phenomenon partly accounts for the limited success achieved by the conventional methods in dealing with two-phase flow measurement. The authors think that by applying an entirely new approach to this long standing industrial problem, such as soft-sensing based signal processing techniques, might be a better way forward. To this goal, various features of the measured signal have been elaborately extracted; the relationships between these features and the gas and liquid flow rate were established through the use of a BP network. The trained BP network is applied as the metering algorithm for WGM.

2 PRINCIPLE OF WGM DEVELOPMENT

2.1 Multiple measurement principle

All of the existing online multiphase meters are based on the multiple measurement principle or a combination of different flow sensors. Suppose S_1 and S_2 are the measured outputs of two different flow sensors, for single phase flow measurement, they are monodrome and monofonic functions of the single phase flow rate. But for two-phase flow measurement,

Received 2006-03-08, accepted 2006-09-15.
* Supported by the National Natural Science Foundation of China (No.60672003) and Shandong Key Technology R&D Program (2004GG2205016).
** To whom correspondence should be addressed. E-mail: gengyf@hdpu.edu.cn

they are functions of both gas flow rate Q_g and liquid flow rate Q_L as shown in Eqs.(1) and (2), where f_1 and f_2 represent the forms of two functions.

$$S_1 = f_1(Q_g, Q_L) \quad (1)$$

$$S_2 = f_2(Q_g, Q_L) \quad (2)$$

Theoretically, there are two unknown variables with two equations, Q_g and Q_L can be obtained. However, the real issue here is that the two functions are unknown, or at least not accurate. Actually many researchers have worked on the two equations[7], such as Murdock, Chisholm, Lin Z.H., Steven[8], and so on. To date only the main factors that effect the equations have been identified, but there is no precise equation for use. To say the least, even if the two functions were known, it would be possible that two different combinations of Q_g and Q_L could yield an identical value of S. For example, low Q_g and high Q_L may produce identical DP as high Q_L and low Q_g. The method of how to choose the real solution from the two reasonable solutions deserves further investigation. On the other hand, because of measurement error or random noise, there would very likely be either no solution or multi-solutions[9].

To deal with the strong correlations between Eqs.(1) and (2), some researchers point out that the two-flow sensor should be different. The larger the discrepancies between the two sensors, the better the solution obtained. In practice, some sensor couples have already been studied, such as orifice and pitometer[10], orifice and Venturi[7], Venturi and turbine[11], double Venturi[12], *et al.* In this study two slotted orifices with different structure parameter have been designed, and the results so far show that the design is successful.

Furthermore, if more than two equations can be obtained from different flow sensors or from one of the signal processing techniques, coordinating and compromising can be made between different equations. In other words, the best solution or the least square error solution can be obtained. Neural network techniques or data fusion of multi-sensors may be a new feasible solution for function approximation or equation solver to this problem. So there are two ways of using neural network in this study. The first one using neural network aims at representing or approximating the relationship between various characteristics of measured signals and gas-liquid flow rate, as the theoretical relationship between them cannot be acquired now. Thus optimization techniques such as dynamic programming can be used to get the final solution of gas and liquid flow rate. The second one is using neural network for mapping the measured signals and their features to gas-liquid flow rate directly. In this article only the second one is discussed.

2.2 Prototype of WGM

The prototype of WGM in this study is shown in Fig.1. It consists of seven parts. They are pressure transducer 1 (P1), differential pressure transducers 2 and 3 (DP1 and DP2), temperature transducer 4 (T1), flow sensors 5 and 6 (two slotted orifices with different beta values and different structural parameters), and the last one a LabVIEW based data acquisition system 7, which is responsible for all data sample and processing. The signals from the two flow sensors set up the two equations. To accurately convert the Q_g from metering condition to standard condition, P1 and T1 must be used. Practically pressure and temperature both play an important role in gas–liquid two-phase flow measurement. Even at the same gas–liquid mass flow rate, DP1 or DP2 have different characteristics at different pressures. Other configurations of the prototype are: the pipe diameter is 50mm. The two beta ratios are 0.75 and 0.5. The three straight pipe lines are 10D, 15D and 5D from upstream to down stream, D is the diameter of pipe line. The arrow on the pipe indicates the flow direction.

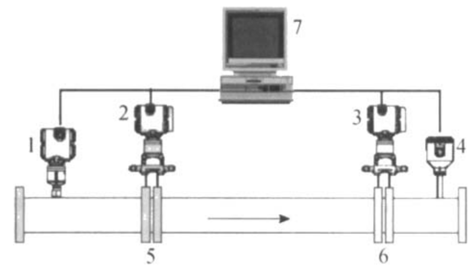

Figure 1 The prototype of wet gas meter
1—pressure transducer (P1); 2,3—differential pressure transducer (DP1, DP2); 4—temperature transducer (T1); 5, 6—two slotted orifices; 7—LabVIEW based data acquisition and processing system

2.3 Experimental matrix and method

In multiphase flow study, the experimental data distribution is often called an experimental matrix. Fig.2 shows an experimental matrix, in which x-axis and y-axis represent Q_g and GVF respectively. Every diamond point is one of the experimental points. There are 64 experimental points in Fig.2. It covers gas flow rate 100—1000$m^3 \cdot h^{-1}$ and liquid flow rate 0.2—4$m^3 \cdot h^{-1}$. The pressure is 850kPa and the temperature is ambient temperature. To find the function f in Eqs.(1) and (2), a number of experiments were carried out. All experimental points under the same Q_g form an experimental group. The experimental rig is described in Ref.[13]. During the experiments of each group, the Q_g was kept constant and the Q_L was stepped from low to high or in reverse manner, and

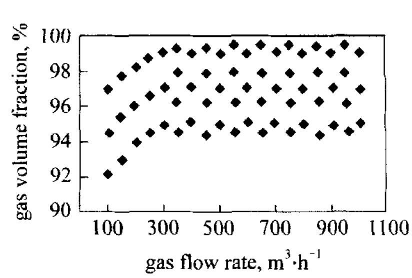

Figure 2 Experimental matrix