An Intelligent Flow Measurement Technique Using Orifice

Santhosh K. V. and B. K. Roy

Abstract—**This paper aims to design an intelligent flow measurement technique. The objectives of this work are (i) to make the overall system linear, (ii) to extend the linear range of flow measurement using orifice, (iii) to make the proposed intelligent flow measurement technique adaptive of variations in (a) pipe to orifice ratio (b) density of liquid and (c) temperature of liquid. The output of an orifice is differential pressure. It is converted to voltage by using a differential pressure sensor and additional data conversion circuit. A suitable Artificial Neural Network (ANN) block is added in cascade to data conversion unit. This arrangement helps to linearise the overall system and to extend the linear range. This arrangement further make it adaptive to variations of ratio of pipe and orifice diameters, densities of liquid and the liquid temperature. Since the proposed intelligent flow measurement technique produces output adaptive to variations of ratio of pipe and orifice diameters, densities of liquid and the liquid temperature., thus the present work avoids the requirement of repeated calibrations every time the liquid, pipe and orifice is replaced/changed.**

***Index Terms*—Artificial neural networks; Non linear estimation; Orifice; Pressure transmitters; Sensor Modelling.**

I. Introduction

Measurement of flow of liquids is a critical need in many industrial plants. In some operations, the ability to conduct accurate flow measurements is so important that it can make the difference between making a profit or taking a loss. With most liquid flow measurement instruments derives its principle from Bernoulli laws, the flow rate is determined inferentially by measuring the liquid's velocity or the change in kinetic energy. Velocity depends on the pressure differential that is forcing the liquid to flow through a pipe or conduit. Since pipe's cross-sectional area of pipe is known, the average velocity is an indication of flow rate. Orifice finds very wide applications because of its high sensitivity and ruggedness. However, the problem of offset, high non-linear response characteristics, dependence of output on the discharge coefficient, diameters of pipe and orifice, density of liquid and temperature of the liquid under measure have restricted its use and further impose some difficulties. To overcome the difficulties faced due to the nonlinear response characteristics of orifice, several techniques have been suggested, but these are tedious and time consuming. Further, the process of calibration needs to be repeated every time the diameter ratios or liquid is changed. The problem of nonlinear response characteristics of an orifice further aggravates when the temperature of liquid changes.

Manuscript received March 14, 2012; revised April 23, 2012.
K. V. Santhosh and B. K. Roy is with Department of Electrical Engineering, National Institute of Technology, Silchar, (e-mail address: kv.santhu@gmail.com).

Intelligent flow measurement technique is proposed to overcome the above difficulties using artificial neural network. This network is trained suitably to obtain linearity and make the system output adaptive to variations in ratio of diameters between pipe and orifice, liquid densities and temperatures of the liquid.

In [1], the error due to variation of diameter ratio on the flow measurement is discussed. In [2], a self validating scheme using the micro-controller is discussed for flow measurement using orifice. In [3], discussion is made on performance of the flow meter with a silicon differential micro sensor incorporated. In [4]-[6], the discussions are made on calibration procedure for linearization of orifice output using signal conditioning circuit.

The paper is organised as follows: after introduction in Section-1, a brief description on Orifice model is given in Section-2. The output of an orifice is differential pressure. A brief discussion on data conversion i.e. pressure transmitter and current to voltage converter are given in Section-3. Section-4 deals with the problem statement followed by proposed solution in Section-5. Finally, result and conclusion is given in Section-6.

II. Orifice

An orifice plate which is shown in Fig 1 is a device used for measuring volumetric flow rate. It uses the Bernoulli's principle which states that there is a relationship between the pressure of a fluid and the velocity of that fluid. When the velocity increases, the pressure decreases and vice versa. An orifice is a thin plate with a hole in middle. It is usually placed in a pipe in which fluid flows. When the fluid reaches the orifice plate, with the hole in middle, the fluid is forced to converge to go through the small hole. The point of maximum convergence actually occurs shortly downstream of the physical orifice, at the so-called vena-contracta point. As it does so, the velocity and the pressure changes. Beyond the vena-contracta, the fluid expands and the velocity and pressure changes once again. By measuring the difference in fluid pressure between the normal pipe section and at the vena-contracta, the volumetric and mass flow rates can be obtained from Bernoulli's equation [7]-[9].

$$Q = C_d . A_2 . \sqrt{\frac{1}{1-\beta^4}} . \sqrt{2(P_1 - P_2)/\rho} \quad (1)$$

where:
C_d – Discharge coefficient
A_2 – Area of the diaphragm bore
β – ratio of d_2 to d_1
P_1 – pressure at steady flow
P_2 – pressure at vena contrata
ρ – liquid density.

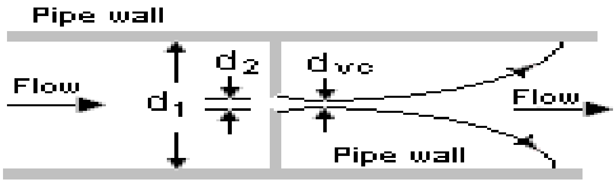

Fig. 1. Orifice diagram.

Effect of temperature on density [10]-[11] can be given by

$$\rho_1 = \left[\frac{\rho_0}{1+\alpha(t_1-t_0)}\right] / \left[1 - \frac{(P_{t_1}-P_{t_0})}{E}\right] \quad (2)$$

where: ρ_1 –density of liquid at temperature t_1
ρ_0 - density of liquid at temperature t_0
P_{t1} – pressure at temperature t_1
P_{t0} – pressure at temperature t_0
E – Modulus of Elasticity of the material
α – temperature coefficient

III. Data Conversion Unit

The block diagram representation of the proposed measuring technique is shown in Fig. 2

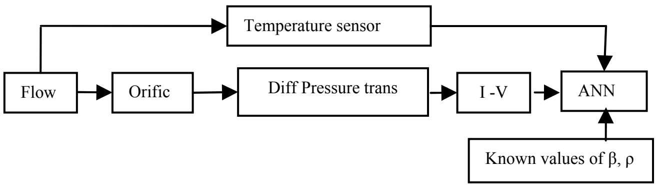

Fig. 2. Block diagram of the proposed technique.

A. Pressure Transmitter

A pressure transducer is a transducer that converts pressure into an analog electrical signal. The conversion of pressure into an electrical signal is achieved by the physical deformation of strain gages which are bonded into the diaphragm of the pressure transducer. A 4-20mA signal is produced as output [12].

B. Current to Voltage Converter

The 4mA level of signal from the transducer produces a 0V output and the 20mA level produces a 5V output. A current sense amplifier generates this analog 0V to 5V output [13].

IV. Problem Statement

In this section characteristics of orifice are simulated to understand the difficulties associated with the available measuring scheme. For this purpose, simulation is carried out with three different ratios of diameter between orifice and pipe is considered. These are $\beta_1 = 0.3$, $\beta_2 = 0.6$ and $\beta_3 = 0.9$. Three different liquid densities as $\rho_1 = 0.5$, $\rho_2 = 1.0$ and $\rho_3 = 1.5$ are chosen. Different liquid temperatures, like $t_1 = 25^oC$, $t_2 = 50^o$ C, $t_3 = 75^oC$ and $t_4 = 100^oC$ are used. The output differential pressures of orifice with respect to various values of input flows considering particular diameters of pipe and orifice, liquid density and temperature of liquid are calculated. These output pressures are used as inputs of pressure transmitter and output current are generated. Finally, voltage signals are produced using current to voltage converter (I-V). The MATLAB environment is used of and the following characteristics are simulated

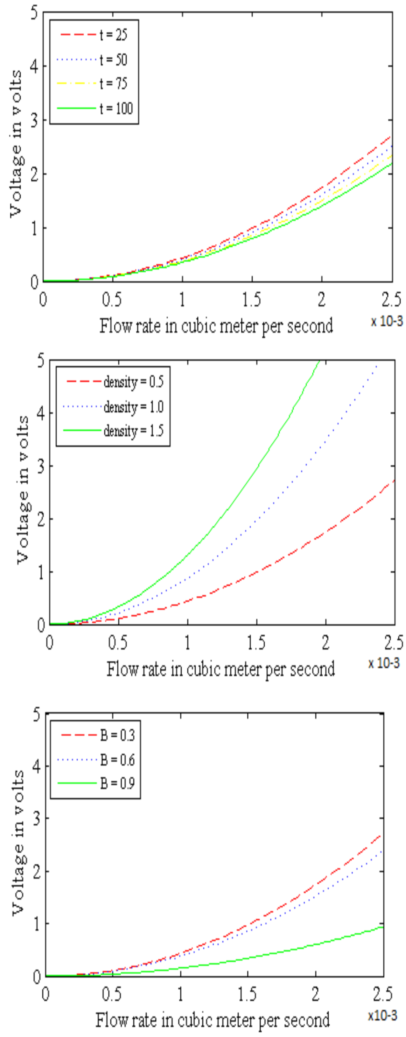

Fig. 3. Input flow Vs voltage output for variations of (a) temperatures, (b) liquid density and(c) diameter ratio.

Fig. 3 shows the variations of voltages with changes in input flow rates considering different values of liquid density, diameter ratio and temperature. It has been observed from the above graphs that the relation between input flow rate and voltage output has a non linear relation. Datasheet of orifice suggests that the input range of 10% to 60% of full scale is used in practice as linear range. The output voltage also varies with the change in liquid densities, diameter ratios and temperatures. These are the reasons which have made the user to go for repeated calibration techniques using some circuits. These conventional techniques have drawbacks that this time consuming and need to be calibrated every time an orifice plate is changed in the system, variation of liquid temperature and the use is restricted only to a portion of full scale.

To overcome these drawbacks, this paper makes an attempt to design a flow measurement technique incorporating intelligence to produce linear output and to make the system adaptive of variations in diameter ratios, discharge coefficients, liquid densities and temperatures of liquid using the concept of artificial neural network.

V. Problem Solution

The drawbacks discussed in earlier section are overcomed by introducing an ANN model after current to voltage converter. This model is designed using the neural network toolbox of MATLAB.

The first step in developing a neural network is to create a database. The output voltages of data conversion circuit for the changes in flow rates, diameter ratios, liquid densities and temperatures are stored in one matrix which forms the input data matrix for the ANN model. The output data matrix would be the target matrix consisting of data having a linear relation with the flow rate and adaptive of variation in all other parameters.

Back Propagation neural network (BP) trained by Ant Colony Optimization (ACO) [14]-[17] is used here with 2 hidden layers. The hidden layers consist of 8 and 9 neurons respectively. With the help of simulated data, the neural network is trained. To satisfy the linearity property between input flow rate and output of ANN model, the linear target graph is considered, as shown in Fig 4(a).

TABLE I: Summarizes the Require Data for Training

OPTIMIZED PARAMETERS OF THE NEURAL NETWORKS MODEL					
Database		Training base (60%)		90	
		Validation base (20%)		30	
		Test base (20%)		30	
No of neurons in		1st layer		8	
		2nd layer		9	
Transfer function of		1st layer		tansig	
		2nd layer		tansig	
		Output layer		linear	
Input		Flow	Dia ratio	density	Temp
	min	$0\ m^3/s$	0.3	0.5	0° C
	max	$2.5\times 10^{-3}\ m^3/s$	0.9	1.5	100° C
MSE		5.83×10^{-4}			
R		0.999875			

VI. Results and Conclusion

The proposed ANN is trained, validated and tested with the simulated data. Once the training is over. The proposed measurement technique as shown in Fig.2 is subjected to various test inputs corresponding to different flow rates at a particular discharge coefficient, liquid density, diameter ratio, and temperature of liquid all within the specified range. For testing purposes, the range of flow rate is considered from 0 to 2.5 $\times 10^{-3}$ m^3/s, the range of diameter ratio is 0.3 to 0.9, range of liquid density from 0.5 to 1.5 and temperature ranges from 0^oC to 100^oC. The outputs of proposed system with ANN are noted corresponding to various input flow rates at different values of discharge coefficients, diameter rates, liquid densities and temperatures. The input output result is plotted and is shown in Fig 4(b). The output graph is matching the target graph as shown in Fig 4(a).

It is evident from the Fig 4(b), that the proposed measurement system discussed has gained intelligence. It has increased the linearity range of the proposed flow measurement. The output is made adaptive of variations in the discharge coefficients, diameter ratios, liquid densities and temperatures. Thus if the liquid under measure is varied, and/or diameter of the pipe, and/or diameter of orifice is replaced by different values, the system does not require any calibration. Similarly, if there is a change in environment conditions like change in temperature, the system need not be calibrated to give the accurate reading.

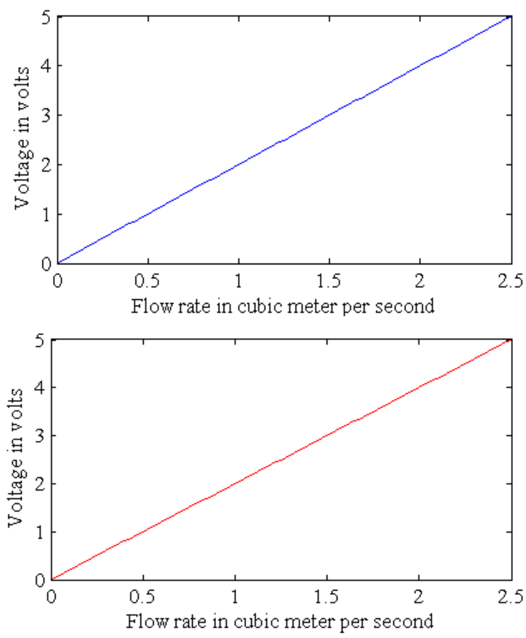

Fig. 4. (a) Target graph, (b) Output graph.

The proposed measurement technique appears to be better in comparison to the mentioned reported works. In comparison to [1], present work avoids the process of choosing the location of orifice meter based on flow. In [2] the process of calibration is to be repeated every time the parameters change which is not necessary in the proposed technique discussed in the present paper. In [3] on varying the flow parameters and temperature the system produces erroneous result which is overcomed in the proposed technique. Paper [4]-[6] discusses techniques where calibration need to be repeated every time a parameter changes. Some time, the calibration circuit itself may need to be replaced which is a time consuming and a tedious procedure, which is avoided in the proposed technique. The proposed technique uses the full scale of input range which is not the case in the above reported works.

References

[1] J. A. Brennan, C. F. Sindt, M. A. Lewis, and J. L. Scott, "Choosing flow conditioners and their location for orifice flow measurement," *Flow Measurement Instrumentation*, Butterworth-Heinemann Ltd, vol. 2, pp. 40-44, January 1991.

[2] J. Q. Zhang, Y. Yan, "A self validating differential pressure flow sensor," *IEEE Instrumentation and Measurement Technology conference*, Budapest, May 2001.

[3] H. Krassow, F. Campabadal, E. Lora-Tamayo, "The smart-orifice meter: a mini head meter for volume flow Measurement," *Flow Measurement Instrumentation*, Butterworth-Heinemann Ltd, vol 10, pp. 109-115, January 1991.

[4] J. E. Lawley, Orifice meter calibration, 57th International School of Hydrocarbon Measurement, document ID: 16233, 1982.

[5] J. J. S. Shen and V. C. Ting, "Velocity profile measurement in a orifice meter calibration system for natural gas," *61th International School of Hydrocarbon Measurement,* document ID: 4774, 1986.

[6] B. T. Arnberg and C. L. Britten, "Calibration of orifice meter assembly," *Colorado Engineering Experiment Station Inc*, Document ID: DA27169, 1971.
[7] E. O. Doebelin, Measurement Systems - Application and Design. Tata McGraw Hill publishing company, 5th edition, 2003.
[8] White paper, *Emerson Process Management,* Daniel Measurement and Control, Inc.
[9] B. G. Liptak, *Instrument Engineers Handbook: Process Measurement and Analysis,* 4th Edition, CRC Press, June 2003.
[10] R. J. Plaza. Sink or Swim: The Effects of Temperature on Liquid Density and Buoyancy. California state science fair, 2006.
[11] Density of Fluids-Changing Pressure and Temperature, The Engineering toolbox 2008.
[12] Rosemount 3051 datasheets, 2006.
[13] R. F. Coughlin and F. F. Driscoll, *Operational amplifiers & linear integrated circuits,* Prentice Hall, 1998.
[14] F. Roger, Practical methods of optimization, 2nd Edition, John Wiley & Sons, New York, ISBN 978-0-471-91547-8, 1987.
[15] J.-B. Li and Y.-K. Chung, "A Novel Back propagation Neural Network Training Algorithm Designed by an Ant Colony Optimization," IEEE/PES Transmission and Distribution Conference & Exhibition: Asia and Pacific Dalian, China 2005
[16] L. Bianchi, L. M. Gambardella, M. Dorigo, An ant colony optimization approach to the probabilistic travelling salesman problem. Proc. of PPSN-VII, International Conference on Parallel Problem Solving from Nature, Lecture Notes in Computer Science, Springer Verlag, Berlin, Germany, 2002.
[17] S. Russell and P. Norvig, *Artificial Intelligence A Modern Approach, Pearson publication*, 3rd edition 2010.