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Intelligent calibration technique using optimized fuzzy logic controller for ultrasonic flow sensor

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ABSTRACT

In this paper an intelligent flow measurement technique is designed by ultrasonic transducers with the help of optimized Fuzzy Logic controller.The main objectives of the present work is to make the intelligent flow measurement technique adaptive to variations in pipe diameter,liquid density& liquid temperature & make a linear relationship between input & output parameter.The output of an ultrasonic flow transducer is frequency which is converted to voltage by using the signal conditioning circuit. For calibration purpose an optimum Fuzzy logic controller is placed instead of conventional calibration circuit and it is test & trained for various values of pipe diameter,liquid density ,liquid temperature & signal conditioning output.The proposed technique is then subjected to the practical data for validation which is done with the help of actual flowrate & output of the intelligent technique.

Keywords: Ultrasonic Flow Transducer, Flow Measurement, Sensor Modelling, Fuzzy Logic Controller, Optimization.

1. INTRODUCTION

Flow meter is an instrument which is used to measure the mass, volumetric, linear & non linear flow of gas or liquid flowing through the pipe or tube. Ultrasonics flowmeter worked by the generating different frequency with respect to different flowrates. Among all different types of non contact type flow sensor ultrasonic flow sensor is preferable for the industry due to its higher degree of resolution. But one of the major drawbacks of the ultrasonic flow sensor is nonlinear characteristics which make this sensor restricted. There are a number of reviews on ultrasonic flow meter reveals the different methods for calibration. To produce the linear output for the variation to flow rate &calibration purpose a microcontroller based ultrasonic flow sensor implemented in [1]. Using several analog circuits the Calibration of the flow meter is discussed in [2, 4, 8, 9, 11]. Calibration of the capacitive flow sensor using analog circuit is reported in [5]. Linearization of sensors output over a certain range is done by using neural network is reported in [15-17].Various types of mathematical modelling and calibration of flow meter is discussed in [10]. Linearization of Ultrasonic flow meter optimization technique is reported in [14]. For linearization output of ultrasonic flow meter is carried by hardwired analog design in [12,13,16]. How the liquid temperature and density are effect the linearization of flow measurement are discussed in [16-18], and effect of physical dimensions of flow meter is also reported in[18]. There are several techniques are stated above which reveals how to overcome the restriction from nonlinear response characteristics of the ultrasonic flow meter but most of these are complex, less resolution and time consuming. Calibration methods are limited due to effect of variations in liquid temperature, density, and dimension of the pipe is considered in [6, 14] by optimized ANN.

2. ULTRASONIC FLOW METER

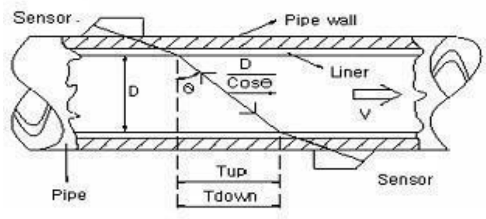

Figure 1. Arrangement of ultrasonic flow meter

Ultrasonic flow meters (UFM) are a one type of non contact type flow widely used to measure liquid flow. It is not limited to clean liquids but able to measure accurately the flow of slurries and impure liquids. Ultrasonic flow meters is one of the most accurate types of meters used to measure flow in pipes. Figure 1 shows the arrangement of basic ultrasonic flow meter where either side of the pipe sending and receiving transducers are mounted. The receiving transducer received the ultrasonic signal transmitted by the transmitting transducer with an inclined angle from one side of the pipe. The receiving transducer counting the two different time with respect to the direction of the flow are named as forward direction time & reverse direction time respectively. The difference between this two times (transit times) is proportional to flow rate in a pipe.

Table 1. Input data for fuzzy logic models

Voltages at the input of ANN with	0lpm	50lpm	100lpm	......	550lpm	600lpm
D=15,t=20°C, ρ=0.995	282	278	277	......	258	255
D=20,t=20°C, ρ=0.995	275	273	269	......	252	249
D=25,t=20°C, ρ=0.995	258	263	262	......	232	228
D=15,t=25°C, ρ=0.996	248	244	241	......	225	220
D=20,t=25°C, ρ=0.996	258	255	251	......	243	238
D=25,t=25°C, ρ=0.996	271	267	265	......	248	245
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D=25,t=30°C, ρ=0.997	276	274	269	265	259	257

From the fig.1

$$T_{up}=\frac{MD/Cos\theta}{Co+VSin\theta} \quad (1)$$

$$T_{down}=\frac{MD/Cos\theta}{Co-VSin\theta} \quad (2)$$

$$\Delta T= T_{up} - T_{down} \quad (3)$$

Frequency,

$$f_{IN} = 1/\Delta T \quad (4)$$

where; M – No of times ultrasonic signal travels in forward/ backward direction

Co – Velocity of ultrasonic signal in static fluid;

D – Pipe diameter; v – Velocity of fluid

The velocity of ultrasonic signal depends on density of liquid which is given by

$$Co=\sqrt{\frac{k}{\rho}} \quad (5)$$

k – bulk modulus and ρ – Density of liquid

Effect of temperature on density & atmospheric pressure is given by

$$\rho_1=\left[\frac{\rho 0}{1+\alpha(t1-t0)}\right]/\left[1-\frac{(Pt1-Pt0)}{E}\right] \quad (6)$$

where;

ρ_1 – specific density of liquid at temperature t_1

ρ_0 - specific 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 liquid ;α – temperature coefficient of liquid.

The output of UFM is frequency which applied into the signal conditioning followed by the frequency to voltage converter to produce the voltage.

Table 2. Output of the proposed technique for various input condition

Actual flow rate	diameter	Density	temperature	Input of the fuzzy (mv)	Measured output flow	% error
50	13.6	0.999	34.7	282	47	6.38
50	19.9	0.996	32.5	272	52	-3.84
50	20	0.996	33	268	49	-2.04
100	21.8	0.998	32	265	97	3.092
100	21.8	0.998	32	263	105	4.76
150	22.3	0.997	32.3	284	145	3.44
150	22.3	0.997	33	284	149	0.067
150	22.3	0.997	32.5	278	154	-2.59
200	19.9	0.996	31.5	253	201	-0.049
200	22.5	0.996	31.5	271	196	2.04
250	20.0	0.997	31.3	258	246	1.62
250	19.9	0.997	31.2	244	250	0.00
300	28.8	0.995	23.9	300	300	0.00
350	16.8	0.995	27.3	247	348	0.057
350	21.2	0.998	27.8	252	356	-0.0168
400	21.2	0.997	30	255	400	0.00
450	21.5	0.998	28.8	244	457	-1.53
450	20.6	0.998	28.8	245	446	0.0896
500	20.6	0.998	29	242	500	0.00
500	20.8	0.996	24.5	210	503	-0.0596

3. DATA CONVERSION SECTION

Block diagram Figure.2 represent the flow measurement technique using ultrasonic flow meter.From Eq.4 it is seen that Ultrasonic flow meter produce frequency after sensing the flow rate.Later on the output of ultrasonic flow meter that is the frequency is converting into active signal voltage by using LM2917 series f-V converter.The available calibration circuits are designed to map the flow rate corresponding to voltage output of F-V converter.

$$V_{OUT} = f_{IN} * R * C * V_{CC} \quad (7)$$

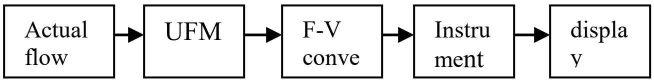

Figure 2. Block diagram of available flow measurement technique

4. PROBLEM STATEMENT

These conventional calibration techniques is found two drawbacks 1)it is time consuming processes and 2) whenever any one of the system parameter (pipe diameter, liquid density or liquid temperature) is changed then further recalibration is needed so it restrict full scale of input range. To overcome these limitation an intelligence system is in cooperate with the ultrasonic flow sensor to produce the linear output over the full scale of the input and make the system more adaptive in nature during the variation in pipe diameter, liquid density & liquid temperature. Here optimized fuzzy logic controller used as a intelligence system along with ultrasonic flow sensor. The designed optimized fuzzy logic model having the following properties:1) adaptive to variation in diameter of the pipe 2) adaptive to variation in liquid density 3) adaptive to variations in liquid temperature &4) outputs follows a linear relation with the input flow rate.

5. PROBLEM SOLUTION

The drawbacks of the conventional calibration circuit is replaced by the optimized fuzzy logic controller which is shown in figure7.The input parameters of the fuzzy logic controller are output of the f-V converter,actual temperature of flow under measure, knowing values of pipe diameter & liquid density. Fuzzy logic controller designed in such a way to produce flow rate and is displayed using a display.

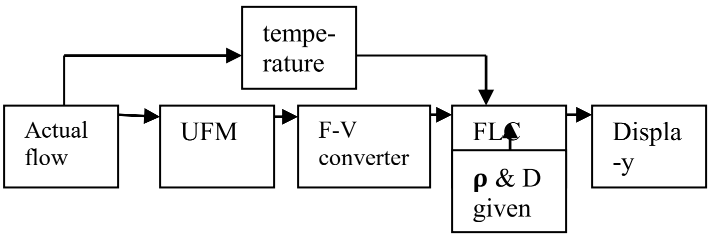

Figure 3. Block diagram of proposed flow measurement technique

This fuzzy logic controller model is designed using toolbox of MATLAB.Different combination of output voltage of a conditioning circuit, pipe diameter; liquid density & liquid temperature are used as an input parameter while respective flow rate is an output of fuzzy logic controller editor.In this paper three different fluid temperature 20℃,25℃ & 30℃, three different diameter of the pipe 15mm,20mm & 25mm ,three different liquid density 0.995kg/m3, 0.996kg/m3 & 0.997 kg/m3 are used as a secondary fuzzy infernace input while 13 different level of liquid flow rate 0lpm ,50lpm,100lpm ......600lpm are consider as a primary input of the FIS editor. The output voltage(milivolt range) which are achieved from the signal conditiong circuit from figure 2 are used as a output variable of FIS editor.The data which are help to design the fuzzy logic model are shown in Table 1.

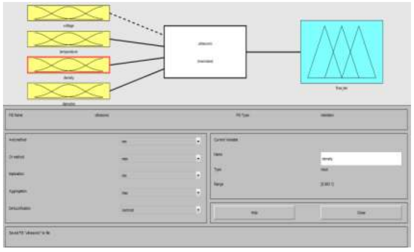

Figure 4. Fuzzy logic editor for input & output parameters

Figure 5. Fuzzy logic rules editor between input & output parameters

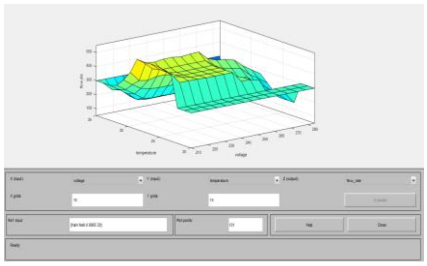

Figure 6. 3D plot for voltage, temperature & flow rate

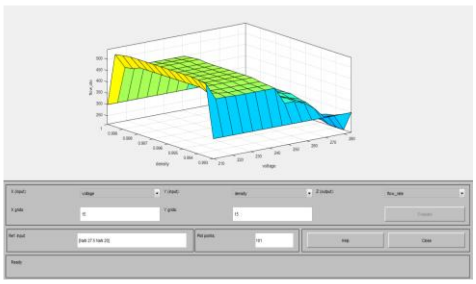

Figure 7. 3D plot for density, voltage & flow rate

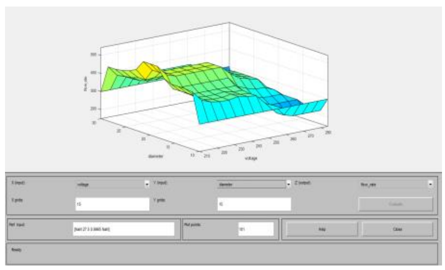

Figure 8. 3D plot for diameter, voltage & flow rate

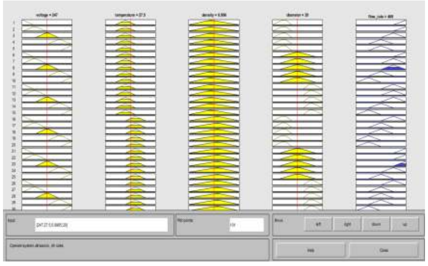

Figure 9. Rule viewer for input & output parameters

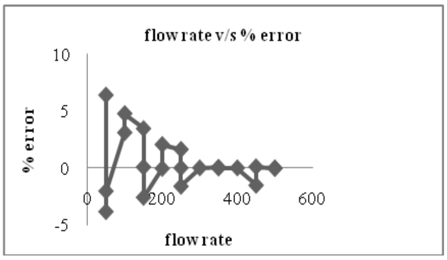

Figure 10. Error graph for the experimental result

6.CONCLUSION

Instead of the repeated calibration for adaptive of variation in liquid temperature,liquid density & pipe diameter the conventional calibration circuit is replaced by the intelligent fuzzy logic model.Available report shows that by using optimized fuzzy logic model system it produce the linear input & output charactercs over the full scale of the input range.From the Table2 it is also seen that for given input flow, pipe diameter, liquid density & temperature maximum error is 6.38% .The characteristics graph between input flow rate & % error is shown into Fig 10.Except the ANN model & fuzzy logic intelligent system the proposed flow control system can be further optimized by the ANFIS ,GA or other hybrid optimized tool.

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NOMENCLATURE

E Modulus of Elasticity of the liquid,N/m2

C_0 Velocity of ultrasonic signal in static fluid m.s-1

Greek symbols

α Temperature coefficient of liquid, /

ρ Density of liquid, Kg/m3

k bulk modulus ,N/m2