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A Smart Flow Measurement System Adaptive to Different Variation Using Ultrasonic Flowmeter

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***Abstract*- This Paper Explain the Design of a Smart Flow measurement Technique using Ultrasonic Flow Meter for custody transfer quality. The objective of the work are; (i) to extend the linearity range of measurement to 100% of the input range, (ii) to make the measurement system adaptive to variations in pipe diameter, liquid density, and liquid temperature. An Accurate flow measurement is an essential requirement both from qualitative and economic points of view. Among the non contact type of flow measurement, ultrasonic flow measurement is widely used to measure flow, because of its advantage like high resolution and less interference of noise on output. However, non linear characteristics of Ultrasonic flow meters have restricted its use. An optimal Computational Logic is considered by comparing various schemes and algorithms based on minimization of Mean Square Error and Regression close to one. The output of ultrasonic flow meter is frequency. It is converted to voltage by using a frequency to voltage converter. An optimal Computational logic block is added in cascade to frequency to voltage converter. This arrangement helps to linearise the overall system for 100% of full scale and makes it adaptive to variations in pipe diameter, liquid density, and liquid temperature. Since the proposed Smart flow measurement technique produces output which is adaptive to variations in pipe diameter, liquid density, and liquid temperature, the present technique avoids the requirement of repeated calibration every time there is change in liquid, and/or pipe diameter, and/or liquid temperature. The results show that proposed measurement technique achieves the objectives quite satisfactorily.**

Keywords*- *Computational Logic, Sensor Modeling, Ultrasonic transreceiver, Instrumentation Amplifier, Frequency to voltage converter, Ultrasonic flow meter, Calibration Scale (CS), Full Scale (FS), Temperature Compensation, Absolute Error, Mean Square Error.

I. INTRODUCTION

Flow measurement has evolved over the years in response to measure new products, measure old products with new condition of flow, and for tightened accuracy requirement as the value of the fluid is gone up. Flow measurement is the quantification of bulk fluid movement. Flow can be measured in a variety of ways, may be by contact type or non-contact type of sensor. Positive-displacement flow meters accumulate a fixed volume of fluid and then count the number of times the volume is filled to measure flow. Other indirect flow measurement methods rely on forces produced by the flowing stream as it overcomes a known constriction. Flow may be measured by measuring the velocity of fluid over a known area. Accurate flow measurement is an essential requirement both from qualitative and economic points of view. Among the non contact type of flow measurement, ultrasonic flow measurement is widely used to measure flow, because of its advantage like high resolution and less interference of noise on output. However, non linear characteristics of Ultrasonic flow meters have restricted its use.

When flowmeters accuracy is stated in % CS or % FS units, its absolute error will rise as the measured flow rate drops. If meter error is stated in % AR, the error in absolute terms stays the same at high or low flows. Because full scale (FS) is always a larger quantity than the calibrated span (CS), a sensor with a % FS performance will always have a larger error than one with the same % CS specification. Therefore, in order to compare all bids fairly, it is advisable to convert all quoted error statements into the same % AR units. It is also recommended that the user compare installations on the basis of the total error of the loop. For example, the inaccuracy of an orifice plate is stated in % AR, while the error of the associated d/p cell is in % CS or % FS. Similarly, the inaccuracy of a Coriolis meter is the sum of two errors, one given in % AR, and the other as a % FS value. Total inaccuracy is calculated by taking the root of the sum of the squares of the component inaccuracies at the desired flow rates. In well-prepared flowmeter specifications, all accuracy statements are converted into uniform % AR units and these % AR requirements are specified separately for minimum, normal, and maximum flows. All flowmeter specifications and bids should clearly state both the accuracy and the repeatability of the meter at minimum, normal, and maximum flows.

To overcome the restriction faced due to nonlinear response characteristics of the ultrasonic flow meter, several techniques have been suggested. But some of these are tedious and time consuming. Further, the process of calibration needs to be repeated or calibration circuit needs to be replaced/ tuned every time there is a change in pipe diameter or liquid density. The problem of nonlinear response characteristics of an Ultrasonic Flowmeter further aggravates when there is a change in liquid temperature, since the output of an Ultrasonic Flowmeter is dependent on temperature also.

To overcome the above difficulties, a Smart flow measurement technique is proposed in this paper. The optimal Computational Logic is achieved considering different algorithms and schemes and comparing their least Mean Square Error and Regression close to one. This optimized Computational Logic is used to train the system to obtain linearity and makes the output adaptive to variations in pipe diameter, liquid density, and liquid temperature, all within a range.

Literature review suggests that several techniques are adopted to calibrate the Ultrasonic Flowmeter. In [1], linearization of Ultrasonic Flowmeter with the help of neural network algorithm is done. In [2], [4-7] calibration of flow meter using several hardware circuits is discussed. In [3] design of Ultrasonic Flowmeter is discussed in order to achieve maximum accuracy and implementation of microcontroller to linearise the output. In [8] linearization of Ultrasonic Flowmeter and making its output independent of physical parameters using Computational Logic is discussed.

II. BLOCK DIAGRAM OF THE PROPOSED SYSTEM

The project was undertaken with consideration of the prevailing methodologies and service with particular emphasis to extend the linearity range of measurement to 100% of the input range, to make the measurement system adaptive to variations in pipe diameter, liquid density, and liquid temperature and other major motivating factors being as shown in Block Diagram.

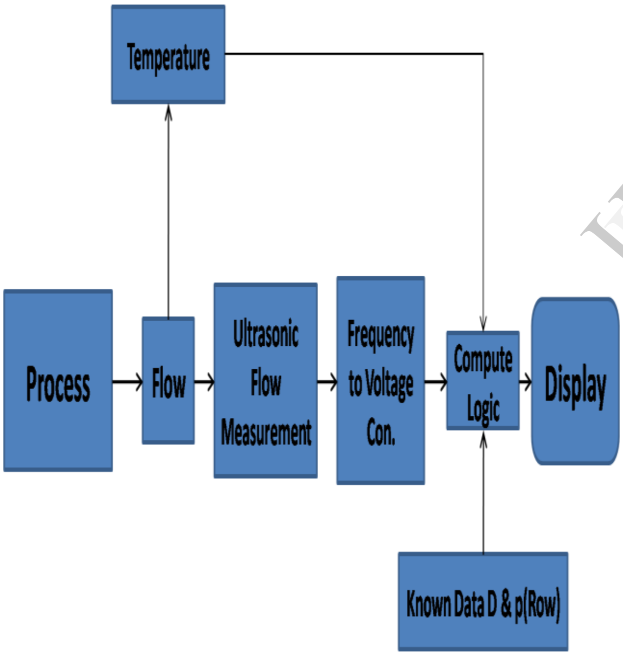

Figure.1: Block Diagram of the proposed measuring Technique.

The Block Diagram of the above Proposed Measuring System is consisting of Ultrasonic Flow Measurements, Frequency to Voltage Converter, Computational Logic Blocks.

A. Ultrasonic Flow Meter

Ultrasonic flow meters have gained a lot of attention over the past years, primarily because of their ability for measuring custody transfer of natural gas. They are replacing differential pressure and turbine flow meters in many natural gas applications. Ultrasonic Flowmeters are also widely used to measure liquid flow. This is not limited to clean liquids either. A special type of Ultrasonic Flowmeter can accurately measure the flow of slurries and liquids with many impurities

Ultrasonic flow meters are one of the most interesting types of meters used to measure flow in pipes. The most common variety, transit time, has both a sending and a receiving transducer. Figure 1 shows the arrangement of one such Ultrasonic Flowmeter. Both sending and receiving transducers are mounted on either side of the flow meter, or the pipe wall. The sending transducer sends an ultrasonic signal at an angle from one side of the pipe which is received by the receiving transducer. The flow meter measures the time that the ultrasonic signal takes to travel across the pipe in forward and reverse direction. When the signal travels along the direction of the flow, it travels more quickly compared to the condition of no flow. On the other hand, when the signal travels against the direction of flow, it slows down. The difference between the “transit times” of the two signals is proportional to flow rate [5, 10-13].

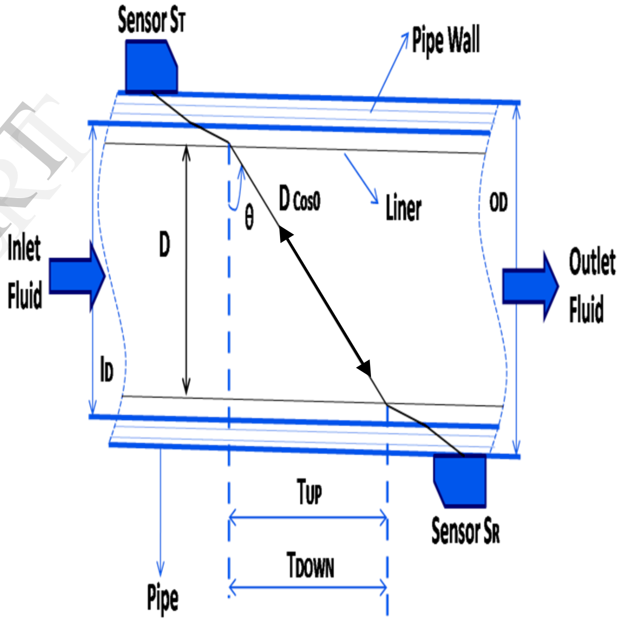

Figure.2: Ultrasonic Transreceiver.

From Figure 2, we have

$$\textbf{Tup} = \frac{M+{}^{D}/_{Cos\theta}}{Co+Vsin\theta} \tag{1}$$

$$\textbf{Tdown}=\frac{M+{}^{D}/_{Cos\theta}}{Co-Vsin\theta} \tag{2}$$

$$\mathbf{\Delta T} = \text{Tup} - \text{Tdown} \tag{3}$$

Frequency, $F_{IN} = 1/\Delta T$

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 [13] density of liquid as shown in Figure.3,

$$\sqrt{k/\rho} \qquad (4)$$

With **k** – bulk modulus and
ρ – Density of liquid

Effect of temperature on density [14-15] can be given by

$$\left[\!\left[\frac{\rho^{\circ}}{1+\alpha(t^{1}-t_{o})}\right]\!\right] \Big/ \left[\!\left[\frac{1-(Pt_{1}-Pt_{o})}{E}\right]\!\right] \qquad (5)$$

Where:-

ρ1 – specific density of liquid at temperature t1
ρ0 - specific density of liquid at temperature t0
Pt1 – pressure at temperature t1
Pt0 – pressure at temperature t0
E– Modulus of elasticity of the liquid
α – temperature coefficient of liquid

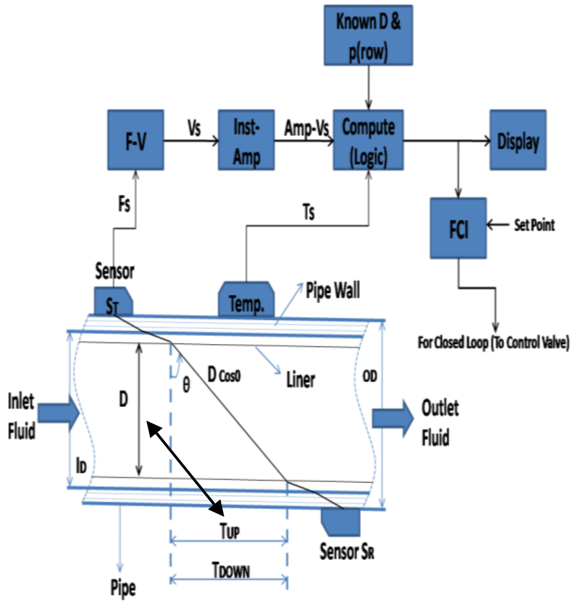

Figure.3: Ultrasonic Flowmeter with Control Arrangement.

B. *Ultrasonic Flowmeter Characteristics*

Meters are chosen for their application by their performance characteristics. The Ultrasonic Flowmeter is a high accuracy (custody transfer quality), wide flow range meter capable of high accuracy as shown in Figure.3 at high or low flow rates. Ultrasonic Flowmeters are large capacity meters for their diametric size. They are calibrated meters and commonly replace multiple parallel orifice meters with only one Ultrasonic Flowmeter. They are more tolerant to tube wall build-up than most meters. They are full-bore with no restriction. Ce Flowmeters measure very low flow rates or rates as fast as you would operate a line without causing component erosion. The meter's wet-gas performance is excellent compared to conventional high accuracy metering technologies. Ultrasonic meters operate well at high pressures. They are in operation in gas injection applications up to 10,000 PSI. The characteristics alone offer a wide choice of applications; however, it is interesting that only a few meter tube design configurations are necessary to accomplish the entire range of applications. There are numerous site configurations possible. Designers should plan site tie-ins carefully.

III. DATA CONVERSION AND AMPLIFYING UNIT

The block diagram representation of the proposed technique is given in Figure.1 & 3.

A. *Frequency to Voltage Converter*

IC LM2917 IC chip is designed specifically as a Frequency to Voltage Converter or Frequency to Voltage converter. In its use to applications Frequency to Voltage Converter IC LM2917 requires few external components. The LM2917 series is a monolithic frequency to voltage converters with high gain op amp/comparator designed to operate a relay, lamp, or other load when the input frequency reaches or exceeds a selected rate [14-15]. The op-amp/comparator is fully compatible with the sensors and has a floating transistor as its output. The collector may be taken above V_{CC} up to a maximum V_{CE} of 28V.

$$\mathbf{V_{OUT} = F_{IN} \times R \times C \times V_{CC}} \qquad (6)$$

The advantages of single chip LM2917 Frequency to Voltage Converter is able to provide instantaneous volt output o at time of frequency change 0 Hz. Very easy to apply in measuring the output frequency with the formulation of single-chip Frequency to Voltage Converter $V_{OUT} = F_{IN} \times V_{CC} \times R1 \times C1$. Then the single-chip LM2917 Frequency to Voltage Converter This configuration requires only the RC only in frequency doublings. And has an internal zener regulator to aimlessly accuracy and stability in frequency-to-voltage conversion process.

- Frequency to Voltage Converter
- Feature-owned single-chip LM2917 Frequency to Voltage Converter
- Reference to ground directly with variable reluctance
- Op-Amp / Comparator with transistor output
- 50 mA maximum output currents for application directly to the load
- Frequency doubling until low ripel
- Build in zener
- Linear output ± 0.3%

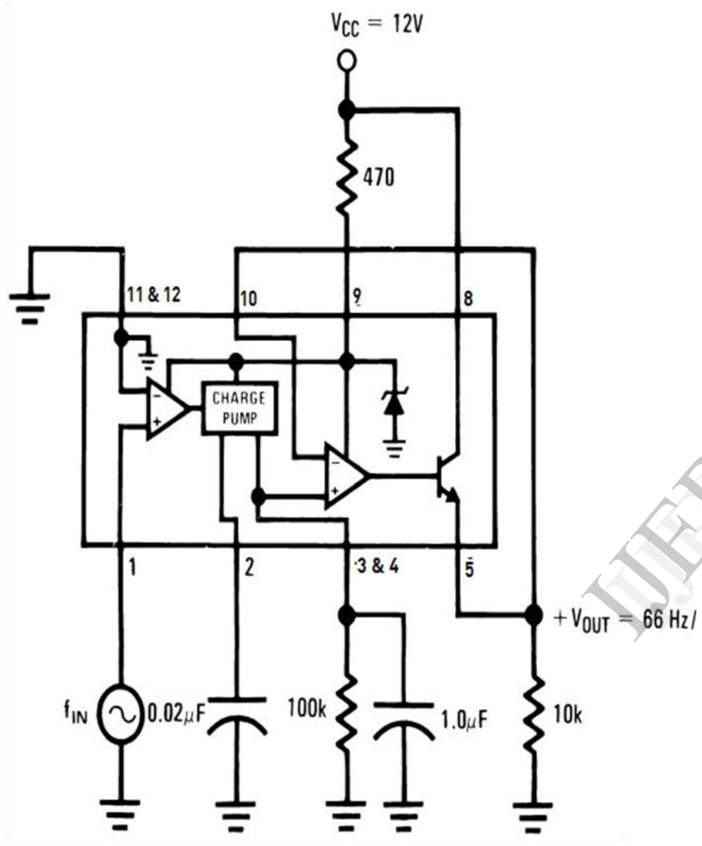

Figure.4: Circuit Diagram of Frequency to Voltage Converter IC LM2917.

B. Instrument Amplifier

A traditional method for building an instrumentation amplifier is to use three op amps and seven resistors as shown in Figure 5. This approach requires four precision matched resistors for a good common-mode rejection ratio (CMRR). Errors in matching will produce errors at the final output. An imbalance of one or two picofarads on certain nodes will drastically degrade the high frequency CMRR, a fact often overlooked. This circuit uses a monolithic difference amplifier with laser trimmed thin film resistors for the output amplifier, thereby providing good dc and ac accuracy with fewer components than the traditional approach.

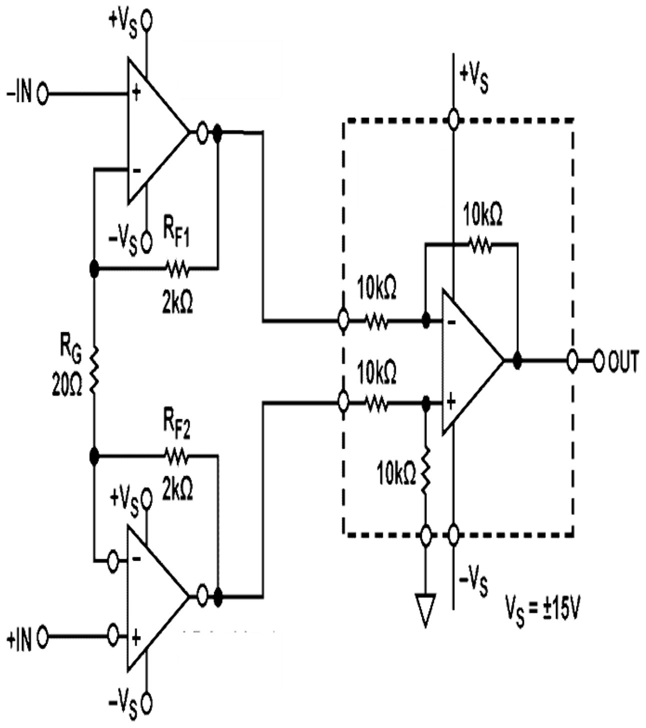

Figure.5: Circuit Diagram of Instrument Amplifier.

This circuit utilizes difference amplifier and two Non-Inverting amplifiers, which have low noise, low drift, low offset, and high speed. For high impedance sources, the Non-Inverting Amplifier is an ideal choice for the input stage amplifiers due to the extremely low input bias current of their JFET inputs.

The op amps selected for the input stage must also have low offset voltage and low offset voltage drift with temperature. They also need to have good drive characteristics. This allows the use of low value resistors to minimize resistor thermal noise. Headroom issues relating to the op amp must be considered in this circuit for proper operation.

When working with any op amp having a gain-bandwidth product greater than a few MHz, careful layout and bypassing are essential. A typical decoupling network consists of a 1 μF to 10 μF electrolytic capacitor in parallel with a 0.01 μF to 0.1 μF low inductance ceramic MLCC type.

For the lowest noise with low impedance sources only, low voltage noise is important. The Inverting Amplifier has lower noise, lower offset voltage drift, and lower supply current; but the input bias currents are much higher, and the bandwidth will be lower than that obtained with the Non-Inverting Amplifier. The measured −3 dB points are 56.6 kHz and 87.6 kHz for the Inverting Amplifier and Non-Inverting Amplifier, respectively.

With high impedance sources, the input bias current and the input noise current of a bipolar op amp can result in errors. The bias current creates an I × R drop, which will be multiplied by the overall circuit gain. This can result in several volts of offset at the output. The input noise current is also multiplied by the source impedances, creating an additional noise voltage. To avoid this, a JFET input op amp, such as the Non-Inverting Amplifier, should be used. Even though the voltage noise is slightly higher than the Inverting Amplifier, the current noise is significantly lower, resulting in lower overall noise when used with high impedance sources.

As Figure 5 and Figure 6 show, the Inverting Amplifier is the proper choice with low source impedances, and the Non-Inverting Amplifier is better with higher source impedances. There is a trade-off: the input capacitance of JFET op amps is higher than bipolar op amps, so the RC time constant must be considered.

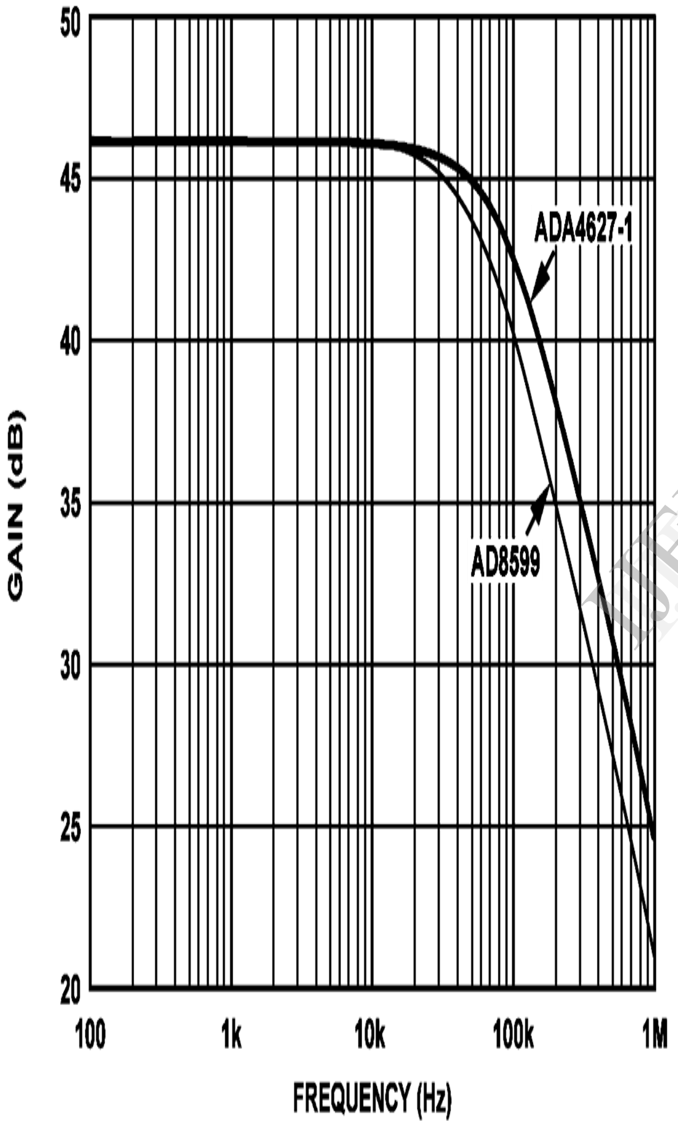

Figure.6: Graph between Gain and Frequency

IV. RESULTS AND CONCLUSIONS

The output voltage of data conversion and Amplifying unit for a particular flow, pipe diameter, liquid density, and liquid temperature is stored as a row of input data. Various such combinations of input flow, pipe diameter, liquid density, liquid temperature, and their corresponding voltages at the output of data conversion and Amplifying unit are used to form the other rows of input data. The output of the Computational logic Block is the target matrix consisting of data having a linear relation with the flow and adaptive to variations in pipe diameter, liquid density, and liquid temperature.

Mean Squared Error is the average squared difference between outputs and targets. Lower value of MSE is better. Zero means no error. Regression measures the correlation between output and target. Regression equal to 1 means a close relationship and 0 means a random relationship.

It is subjected to various test inputs corresponding to different pipe diameters, liquid densities, and temperatures of liquid, all within the respective specified ranges. For testing purposes, the range of flow is considered from 0.0 to 0.0025m³/s, range of pipe diameter is 4 inches to 12 inches, range of liquid density is 1500 to 2500 Kg/m³, and liquid temperature is 25 to 75 Celsius. The flow measured by the proposed technique corresponding to sample test inputs are tabulated in Table 1. It shows that the actual flow rates and the measured flow rates by the proposed technique are same.

Actual flow in m³/s	D in inc.	P in Kg/M³	T in °C	Data Conv. & Amp. O/p in V	Comp. Logic O/p in V.	Measured flow in M³/s
0.0005	8	2000	36	3.0953	1.0	0.0005
0.0005	12	2500	72	4.0326	1.0	0.0005
0.0010	6	2100	38	0.0277	2.0	0.0010
0.0010	4	1900	42	1.7406	2.0	0.0010
0.0020	10	1750	36	1.2186	4.0	0.0020
0.0020	6	2450	54	0.0514	4.0	0.0020
0.0025	5.1	2300	38	0.4743	5.0	0.0025
0.0025	8.8	2200	71	0.5734	5.0	0.0025

Table.1: Result of Measuring System using Ultrasonic Flowmeter.

V. REFERENCES

[1]. T. T. Yeh, P. I. Espina and S. A. Osella, "An Intelligent Ultrasonic Flow Meter for Improved Flow Measurement and Flow Calibration Facility", Proc. IEEE Conf. On Instrument and Measurement Technology, Budapest, Hungary, (2001), pp. 1741-1746.

[2]. O. Keitmann-Curdes and B. Funck, "A new calibration method for ultrasonic clamp-on transducers", IEEE Symposium on Ultrasonic's, Berlin, (2008), pp. 517-520.

[3]. Ch. Buess, "Transit-Time Ultrasonic Airflow Meter for Medical Application", Thesis, Swiss Federal Institute of Technology, (1988).

[4]. Santhosh KV and BK Roy, "An Intelligent Flow Measuring Scheme Using Ultrasonic Flowmeter", 31st International Conference on Modelling, Identification and Control (2012) April, Thailand.

[5]. J. Yang and H. Jiao, "Design of Multi-channel Ultrasonic Flowmeter based on ARM", Proc. IEEE Conf. on Electrical and Control Engineering, Yichang, China, (2010), pp. 758-761.

[6]. E. Aziz, Z. Kanev, M. Barboucha, R. Maimouni and M. Staroswiecki, "An ultrasonic flowmeter designed according to smart sensors concept", Proc. IEEE 8th Mediterranean Electro technical conference, France, (1996), pp. 1371-1374.

[7]. L. Guowei and C. Wuchang, "The Measurement Technology of Flow Rate and Instrument", China Machine Press, (2002) June.

[8]. P. I. Espina, P. I. Rothfleisch, T. T. Yeh and S. A. Osella, "Telemetrology and advanced ultrasonic flow metering", Proc. of the 4th International Symposium on Fluid Flow Measurement, Denver, USA, (1999).

[9]. L. C. Lynnworth, "Ultrasonic measurements for process control", Academic Press, San Diego, CA, (1989).

[10]. L. Z. Yang, Z. Zhang and Dongsheng, "The Experiment Study of Ultrasonic Flowmeter Precision", Journal of Xi'an University of Technology, vol. 22, no. 1, (2006), pp. 70-72 .

[11]. J. Yoder, "Many Paths to Successful Flow Measurement", Flow Control Network, (2006) February.

[12]. R. J. Plaza, "Sink or Swim: The Effects of Temperature on Liquid Density and Buoyancy", California state science fair, (2006).

[13]. B. G. Liptak, "Instrument Engineers' Handbook: Process Measurement and Analysis", 4th Edition, CRC Press, (2003) June.

[14]. D. Karaboga, "An idea based on honey bee swarm for numerical optimization", Technical report-tr06, Erciyes university, engineering faculty, computer engineering department (2005).

[15]. F. M. Dias, A. Antunes, J. Vieira and A. M. Mota, "Implementing the Levenberg-Marquardt Algorithm On-line: a sliding window approach with early stopping", Int. Conf. Proc. IFAC, USA, (2004).

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