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# Design and analysis of flow measurement of conductive liquid and transmission via optical channel

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ABSTRACT

Measurement and transmission of flow rate of a conducting liquid through a pipe line is generally done by using electromagnetic flow meter which consists of a large electromagnet and a pair of sensing electrodes along with electronic system and involves large cost and size. In the present paper, a very simple flow sensing system for a conducting liquid is proposed and this system does not require any electromagnet and involves very low cost. Moreover in modern instrumentation system the signal transmission through optical communication system is being more preferred where the transmitted signal does not suffer from measurement error due to electromagnetic interference. So an MZI based optical communication technique has been described in the present paper. The proposed technique consists of only four insulated conducting electrodes in contact with the flowing liquid along with an electro-optic system for signal conditioning and transmission of the measured signal to a remote location. The performance of the sensor and the transmission system has been analyzed in the form of a bridge network with bridge arms represented by lumped parameter polarization impedances among the electrodes. The theoretical equations explaining the operation of the bridge network with a stabilized sinusoidal ac source and MZI based electro-optic system have been derived. A proto type unit has been designed, fabricated and its function has been studied experimentally and the experimental results are reported in the paper. A very good linear characteristic under streamline condition of the proposed unit has been observed with very good repeatability and very small uncertainty of measurement. The graphical abstract is shown below.

## 1. Introduction

Flow measurement of a conducting liquid is very important in various process industries specially in chemical industry. Electromagnetic flow meter is most widely used for measurement of flow rate of a conducting liquid through a pipe line. This consists of a large electromagnet with a pair of insulated conducting electrodes with conducting surface in contact with the flowing liquid. The electrodes are placed in diametrically opposite location in a flow head pipe line through proper insulation in the magnetic field of the electromagnet perpendicular to the longitudinal axis of the pipe line. When the conducting liquid flows in contact with the electrodes surface in a pipe line fully filled with the flowing liquid, an emf is induced between the electrodes which are linearly related with flow rate. Thus the electromagnetic flow meter has a good linear characteristic with better sensitivity and repeatability but is very costly and has large size and weight mainly due to heavier electromagnet placed in the flow rate surrounding the flow head pipe line. This flow meter is very suitable for measurement of conducting liquid in fully filled condition in a pipe line at any location. There may be various other conventional techniques [1–4] of measurement of flow rate of a conducting liquid through a pipe line such as obstruction technique, turbine technique, non-contact ultrasonic technique, vortex sensing technique, coriolis force type technique, anemometric technique etc. These techniques are suitable for both conducting and non-conducting liquids. The techniques like coriolis force type, anemometric type etc are used for mass flow rate measurement and others are used for volume flow rate measurement in a pipe line. In conventional analog instrumentation system, flow rate is converted into voltage signal by using various types of sensors, transducers and signal conditioners to drive a local indicator in the range 1–5 V dc and this voltage signal is then converted into current signal in the range 4–20 mA to transmit the measured signal to a remote receiver. In the modern instrumentation system, the measured signal is transmitted through optical medium since optical system does not suffer from measurement error due to electromagnetic interference by using an electro-optic technique [5,6]. Since flow rate measurement is an essential measurement in any process plant, so various works on the design and development on new or modified techniques of

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**Nomenclature**

*Symbols explanations*

| | |
|---|---|
| IC1, IC2 | Instrumentation amplifier1,2 |
| IC3 | Operational amplifier |
| $Z_{cal}$ | Total change in impedance of the electrode due to polarization |
| $R_{actual}$ | Actual resistance of the electrode |
| $Q$ | Liquid flow rate in liter per minute (LPM) |
| L | The electrode length used in MZI |
| $\Delta n$ | Change in the refractive index |
| E | Electric field (volt/meter) |
| $\Delta\phi$ | Change in the phase of light |
| $\lambda$ | Wavelength of the propagating light |
| $d$ | Separation between the two electrode used in the MZI |
| $V_s$ | Supply Voltage in volt |
| $V_0$ | Applied potential to the electrode of the MZI |
| $A$ | Amplitude of the light wave |
| I | Modulated intensity of the light |
| P | Normalized power of the light |
| MZI | Mach–Zehnder interferometer |
| $K_1$ & $K_2$ | Constant terms |

measurement eliminating the limitations of the conventional techniques are still being continued by various groups of workers.

Hooshm and Joorabian [7] have utilized a two dimensional mathematical model with a finite difference numerical solution approach to explain the operation of electromagnetic flow meter for a conducting liquid and a Matlab based three layer neural network technique has been used by them for accurate calibration of electromagnetic flow meter. Bera and Mandal [8] have developed a capacitance type orifice transducer for measurement of flow rate of a conducting liquid through a pipe line. In this technique they have shown that the capacitance between a metallic orifice in an insulated pipe line and a grounded metallic ring placed surrounding the pipe line near the orifice plate varies linearly with flow rate. Marick et al. [9] have described a new bourdon tube based flow measurement system where change of liquid pressure due to change of flow rate through a pipe line is taken as flow measurement parameter. This technique eliminates the limitations of obstruction type techniques of flow measurement. A polarization impedance type flow measurement technique has been described by Bera and Chakraborty [10] for measurement of flow rate of a conducting liquid through a pipe line. In this technique it has been shown that the polarization impedance among four conducting electrodes inserted into an insulating pipe line in contact with the liquid varies with flow rate. In this approach the information is only transmitted in the form of electrical signals. As the demand of high speed data transmission, it is required to transmit the data via optical channel. Zhang et al. [11] have implemented the method to find out the characterization of commercial fiber which is integrated with electro-optic modulator. Cao et al. [12] have proposed a method which is capable to electro-optic modulation in MZI by applying the small ac voltage to the coplanar electrode. Inoue et al. [13] have developed nano scale MZI to perform the electro-optic modulation which have interference length of the order of sub-micron. A lithium niobate ($LiNbO_3$) birefringent optical waveguide based electro-optic system has been developed by Gutiérrez-Martínez et al. [14] for measurement of information signal present in a multi megahertz wide band electric field. A MZI based optical switch has been designed and developed by Spickermann et al. [15] to operate a large pump. In this technique the switching energy loss in conventional electronic switch is reduced to a very small value. Kumar et al. [16] has developed flow measurement technique in which the measured information is transmitted over optical channel. An electrical resistance tomography based technique has been developed by Jia et al. [17] for the measurement of flow rate of a highly conducting liquid. An ultrasonic flow mapping technique has been developed by Franke et al. [18] for measurement of liquid metal flow. In this technique an ultrasonic pulse produced by an ultrasonic transmitter is allowed to propagate to the metallic fluid flowing through a pipe line and the flow rate is measured from the time of travel from the instant of transmission of the pulse signal and the instant of receiving the echo pulse by the same transmitter.

In any instrumentation system, the measured signal may suffer from errors due to electromagnetic interference in the communication cable during transmission of the measured signal to the remote receiver. In the present paper, an optical MZI based technique has been proposed for transmission of measured flow rate signal by an electrode polarization type flow measurement system for a conducting liquid. This transmission system will be free from error due to electromagnetic effect and will be very much effective in flammable area of a process plant. A pure optical technique used in measuring system consisting of sensor, transducer, amplifier and signal conditioner may be very much helpful in obtaining negligible measurement error. But it is difficult to design a purely optical based measurement system because of the reasons like range limitation, accuracy, durability and cost. The most practical solution may be obtained if we integrate the electrical domain system with an optical system to be used for transmission and indication through a suitable design of electro-optical converter (E-O) system. In this paper, a MZI based electro-optic flow measurement technique has been proposed. The setup is broadly divided in the two sections. First section provides the sensed output in the form of electrical domain and the second section provides the output in terms of intensity modulated optical signal using the principle of electro-optic effect. In the first section, an electrode polarization impedance type flow measurement system for a conducting liquid has been described. In this technique the flow sensor consists of four conducting electrodes inserted into the pipe line through proper insulation with the conducting surface in contact with the flowing liquid. It has been shown that the polarization impedance among this four electrodes form a bridge network supplied from a stabilized sinusoidal source and the bridge output is found to vary linearly under laminar conditions. This output of the bridge network is converted into dc signal by instrumentation amplifier, rectifier and signal conditioner in the proper range suitable for exciting the optical system. The optical system consists of a MZI system which produces light signal with intensity proportional to excitation voltage signal in the given range. The whole system is designed, developed and functionally tested experimentally. The experimental results are reported in the paper.

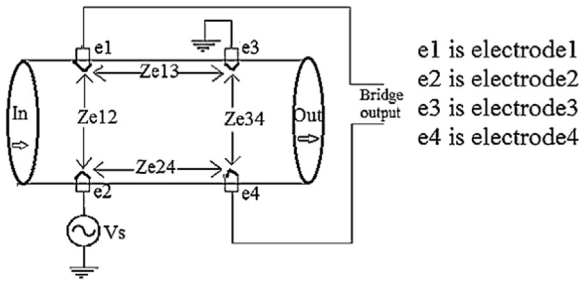


**Fig. 1.** Electrode system in flow head pipe line in the form of bridge network.