CHAPTER – VII

STUDY OF A MODIFIED
ANEMOMETER TYPE FLOW METER

7.1. INTRODUCTION

Flow rate of a fluid through a pipe line is one of the most important variables that are required to be measured and controlled in a process plant in order to obtain better quality product at larger quantity with lesser cost of production. There are various effects, like the effect of energy associated with a flowing fluid through a pipeline, Doppler effect and effect of speed of the fluid suction pump on the flow rate etc. have been utilized in designing the various flow meters.

Research is still going on by several workers employing different techniques of flow measurement. Yong Yan et al.[205] have presented a method of measurement of velocity and mass flow rate of pneumatically conveyed solids using electrostatic sensing and neural network techniques. Kong Lingfu et al.[119] have designed a two-phase flow measurement system with the six-electrode probe for oil well logging. Andreas Penirschke et al.[5] have developed a mass flow meter using a cylindrical waveguide resonator. Mayela Zamora et al.[137] have described the role of the field-programmable gate array (FPGA) hardware, which is programmed using the Handel-C language, in the implementation of a “digital” Coriolis meter, which replaces the conventional analog positive feedback system used to maintain flow-tube oscillation. S.C.Bera et al.[35] have presented a novel low-cost bridge-type technique of flow measurement of a conducting liquid. Wang Fuzhong et al.[193] have designed a complete set to TMS320LF2407A DSP as the core of the ultrasonic Doppler flow measurement system, focusing on analysis of transmitter, receiver conditioning circuitry and digital part of the circuit. S.C.Bera et al.[36] have studied the effect of excitation frequency on the output of electrode polarization impedance type flow transducer. Andrew J. Skinner et al.[6] have described a null-buoyancy thermal flow sensor which is designed specifically for the measurement of very slow downward fluid flows in a vertical pipe in which a glass-rod thermistor is concentrically located.

In the anemometer type flow meter the cooling effect of a flowing fluid on a temperature sensitive constant current or a constant voltage resistance, thermistor or p-n junction diode is utilized. It has been observed that the transducer output using these flow sensors varies non-linearly with flow rate. Hence this transducer requires a linearization part in the instrumentation system. In the present paper a modified p-n junction cooling technique has been used to design a flow sensor which gives an output varying linearly with flow rate. The principle of operation of the flow sensor has been theoretically explained. The flow head with the proposed flow transducer has been fabricated and functionally tested and the experimental results are reported in the paper. From these
experimental data it has been observed that the transducer output follows a linear curve as explained theoretically.

7.2. THEOREY AND ANALYSIS

The flow head consists of a flow tube made of insulating material like PVC of suitable diameter and length with flange joints at both ends. At the middle portion of the flow tube four identical p-n junction diodes are placed in the same diametrical plane at right angle to each other. The schematic representation is shown in Fig.7.1.

Let, \( R_1 \) and \( R_2 \) is the forward and reverse resistances of a diode when there is no flow. Now forward and reverse resistance of four diodes may be assumed to form a Wheatstone bridge circuit supplied with ac voltage in which two diodes \( (D_1 & D_2) \) in one set of opposite arms are in the forward bias and the other two diodes \( (D_2 & D_4) \) in another set of opposite arms are in the reversed bias for the positive half cycle whereas for the negative half cycle, \( D_1 & D_3 \) are in the reversed biased and \( D_2 & D_4 \) are in the forward bias. Let, \( \Delta R_1 \) is the decrease in resistance of each forward biased diode and \( \Delta R_2 \) is the decrease in resistance of each reversed biased diode due to the cooling effect of the flow of fluid. Hence, at a mass flow rate \( Q \), the bridge output for identical diodes in the positive half cycle of the ac voltage is given by,

\[
V_{o+} \propto \{(R_2 + \Delta R_2)^2 - (R_1 + \Delta R_1)^2\} \tag{7.1}
\]

Where, \( V_{o+} \) is the bridge output for positive (+) half cycle.

Similarly for the negative (-) half cycle of the ac voltage the bridge output is given by,

\[
V_{o-} \propto \{(R_1 + \Delta R_1)^2 - (R_2 + \Delta R_2)^2\} \tag{7.2}
\]

Where, \( V_{o-} \) is the bridge output for negative (-) half cycle.

Since \( \Delta R_2 \) is very small,

\[
\frac{\delta V_{o+}}{\delta (\Delta R_1)} = -2(R_1 + \Delta R_1) \tag{7.3}
\]
and \( \frac{\delta V_o}{\delta (\Delta R_i)} = +2(R_i+\Delta R_i) \)  

(7.4)

Hence, there exists a linear region between the characteristics of \( V_o+ \) and \( V_o- \) drawn against \( \Delta R_i \). Let for a flow rate \( Q \),

\[
V_o+ \propto (V_o - \delta V) \quad \text{and} \quad V_o- \propto (V_o + \delta V)
\]

(7.5)

So,

\[
(V_o+ + V_o-) \propto 2V_o
\]

(7.6)

Where, \( V_o \) is the bridge output voltage in the linear characteristics between \( V_o+ \) and \( V_o- \).

Hence bridge output voltage will linearly vary with \( \Delta R_i \) which is again linearly related with \( \Delta Q \) in the streamline condition and non-linearly related with \( \Delta Q \) in the turbulent condition, where \( \Delta Q \) is the change in mass flow rate of the fluid which produces the change in forward resistance of a diode by \( \Delta R_i \).

### 7.3. DESIGN

For flow sensor the p-n junction diode should have a metallic-dissipating surface. In order to obtain that for the present work four metal cap transistors like SL100 with emitter and base short circuited are used as the sensing diodes. The fluid is selected to be tap water. The flow tube is selected to be a PVC tube of 25mm internal diameter and length 50cm. At the middle part of this tube four transistors are mounted on the same diametrical planes at the top, bottom, left side and right side positions 90° apart so that the top surface of the each transistor is just in contact with the liquid and provides little obstruction to the flow of the fluid. The rest part of each transistor is insulated from the fluid by adhesive like Araldite. The flow tube is mounted horizontally so that it is always filled with the water. The signal conditioner circuit is designed by using OP07 based circuit according to the following block diagram representation shown in Figure 7.2. The flow is indicated in a PC based flow indicator designed by using LabVIEW 7.0 software from National Instruments.

![Fig.7.2: Block diagram representation of modified anemometric flow meter](image_url)
In Fig.7.3 the diode bridge transducer is excited by sinusoidal ac voltage of magnitude 1.5V with frequency 500 Hz obtained from a stabilized oscillator (Make M/S Aplab limited, India). The unbalanced bridge output due to change in liquid flow rate is fed to precision instrumentation amplifier IC1 (Burr brown INA101KP). The gain of the amplifier can be set to desired value by the trimpot R1. The amplified ac voltage then made to dc voltage by precision rectifier using IC2, D5, D6, R3 and C3. The resistors R3 and C3 are acting as filter circuit of the rectifier block.

A part of this filter circuit is selected by the potentiometer R4 in order to change the span or scale length of the whole signal conditioner circuit. Any dc offset voltage present in this selected signal at zero flow condition can be nullified by the zero adjustment potentiometer R5 in the differential amplifier circuit consisting of IC3. The OPAMP IC4 is acting as dc output signal buffer. The entire circuit is calibrated to produce output signal 1-5 volt dc against the flow rate 1 to 10 LPM through the pipeline.

This output voltage from IC4 is then fed to analog opto-isolator circuit consisting of OPAMPS IC5, IC6 and other resistors R11, R12, R13, R14, R15, and R17. The resistor shown as R16 is a light dependent resistor (LDR) and D7 is a light emitting diode (LED) which are responsible for basic opto-isolation. The LED is placed in front of LDR so that light emitted from LED falls on the working surface of LDR and accordingly the resistance of LDR changes. The unit is encapsulated in a closed chamber so that no ambient light can interfere their operation. The theoretical analysis of the analog opto-isolator are described as follows. The opto-isolator circuit is calibrated to give linear output in the range 1-5V dc for input in the same range.

In Fig.7.3 R16 denotes the value of resistance of light dependent resistor (LDR), D7 denotes light emitting diode (LED), Vf denotes the input analog signal to opto-coupler circuit obtained from output of zero and span adjustment circuit, Vz denotes a zero adjustment signal provided with the help of potentiometer R13, IC5 is acting as a summing operational amplifier and IC6 is the gain adjustment operational amplifier at the final output with feedback resistance R17.

The basic principle in this technique lies in the fact that when an analog dc current is passed through a light emitting diode in the forward biased condition, the intensity or power of light emitted from the LED is linearly related with the dc current passing through it and when this light is incident on a light dependent resistor the resistance of LDR decreases with the increase of intensity or power of the incident light. Hence the resistance of LDR unit will decrease with increase of the DC current passing through LED. Let for an input voltage Vf and zero adjustment voltage Vz, the voltage drop across
LED be $V_{LED}$. So for the series resistance $R_2$ the DC current assign through LED is given by the following equation (7.7)

$$I = \frac{(V_i + V_z - V_{LED})}{R_{15}} \quad (7.7)$$

Now the light power $P_l$ emitted by LED is directly proportional[57] to current. $P_l \propto I$

$$P_l = K_1 \frac{(V_i + V_z - V_{LED})}{R_{15}} \quad (7.8)$$

where $K_1$ is a proportionality constant. Now one terminal of LDR is connected to $-V$ volts potential terminal of stabilized dc source and the other terminal is at virtual ground potential. Here in physical circuit the value of negative voltage applied to terminal of LDR is 15V. Hence if $I_d$ be the current through LDR in the dark condition, and $I_{ph}$ be the current in the lighted condition then the resistance of the LDR is given by the following equation (7.9).

$$R_{16} = \frac{V}{I_d + I_{ph}} \quad (7.9)$$

In the dark region, $I_{ph}$ is 0 and $I_d$ is very small. So the value of $R_{16}$ is very high in the dark region. Now, let in the lighted region the incident power $P_{inc}$ on the LDR surface is proportional to the developed power $P_L$ by LDR. Hence,

$$P_{inc} \propto P_L \quad \text{or} \quad P_{inc} = K_2 P_L \quad (7.10)$$

Where $K_2$ is the constant of proportionality.

Now, current $I_{ph}$ produced by incident photons in the LDR material is given by

$$I_{ph} = \frac{qP_{inc}}{h \nu} \quad (7.11)$$

Where $q$ is the electronic charge, $\eta$ is the quantum efficiency of generation electron hole pairs by the incident photons, $h$ is the plank’s constant and $\nu$ is the frequency of the emitted light by LDR. Combining the equations (7.8), (7.9), (7.10) and (7.11) we get,

$$R_{16} = \frac{V}{I_d + \frac{q \eta K_1 K_2 (V_i + V_z - V_{LED})}{R_{15} h \nu}} \quad (7.12)$$

Hence the output voltage signal $V_o$ in the LDR circuit is given by,

$$V_o = R_{17} \frac{V}{R_{16}} \quad (7.13)$$

or $V_o = R_{17} \frac{V}{I_d + \frac{q \eta K_1 K_2 (V_i + V_z - V_{LED})}{R_{15} h \nu}} \quad (7.14)$

Thus the isolated output voltage is linearly related with the input voltage since all the other parameters in the above equation (7.14) are almost constants. Hence $V_o = V_i$ when the following equation (7.15) is satisfied.

$$V_i \left(\frac{1}{R_{17}} \right) - \frac{q \eta K_1 K_2 h \nu}{R_{15} h \nu} = \frac{q \eta K_1 K_2 (V_i + V_z - V_{LED})}{R_{15} h \nu} + I_d \quad (7.15)$$

This condition can be achieved by adjusting the zero adjustment voltage $V_z$ and the gain adjustment feedback resistance $R_{17}$ by trial and error technique. Thus the output isolated voltage following the input voltage can be produced.

The output of this opto-isolator circuit is sent to PC through DAS card. A virtual flow indicator is designed in PC using LabVIEW software. The snapshot of the design of the
flow indicator is shown in Fig.7.4. In this figure data section of the DAQ assistant block receives the on-line data in volts from opto-isolator through a channel selected in this block. The snapshot of the corresponding PC based display unit is shown in Fig.7.5.

Fig.7.4: Snapshot of the design of the LabVIEW based virtual flow indicator

Fig.7.5: Snapshot of the display unit of the LabVIEW based virtual flow indicator
This voltage signal is converted into flow signal in LPM by using conventional $y = mx+c$ equation where $x$ denotes the input voltage signal and $y$ denotes flow signal in LPM. Here for flow signal from 1-10 LPM the opto-isolator output is 1-5V which is digitally viewed in virtual digital indicator in 'Input' icon block. So relation between $y$ and $x$ is given by

$$\frac{y-1}{x-1} = \frac{10-1}{5-1}$$

or $y = 2.25x - 1.25$

Thus $m = 2.25$ and $c = -1.25$

This mathematical operation is implemented in different blocks as shown in Fig.7.4.

### 7.4 EXPERIMENT RESULTS

Experiment is performed to find the static characteristics of the flow transducer, hardware circuit and the whole PC based flow indicator. The experimental set-up was made as shown as Fig.7.6(a) and Fig.7.6(b).

In the experimental set-up the flow of tap water through flow tube was increased in steps by adjusting the manual valve $V$ and by noting the reading of the rotameter connected in the set-up as shown in Fig.7.6. In each step, the actual flow was measured by direct water collection method and the corresponding transducer output and hardware circuit output were measured by a 3½ digit digital voltmeter as well as the indicated reading in LabVIEW based virtual indicator was noted.

The experimental data for transducer output are shown in Table 7.1, those for hardware circuit output are shown in Table 7.2 and those for PC based flow indicator are shown in Table 7.3. In direct water collection method water was collected for a particular length of time and its volume was measured by a measuring cylinder and actual flow rate was determined by dividing the collected volume with the collection time. This was repeated 5 times for each reading of rotameter and average of those readings was taken as the actual flow rate. The same experiment was repeated by decreasing the flow rate of water in steps. The procedure was repeated for other two sets of increasing and decreasing flow rates and the average value of transducer output was calculated for each step. All the corresponding data are shown in the said tables.
Now the static characteristic graph of the transducer was drawn by plotting transducer output against flow rate for each set of data given in table 7.1 and is as shown in Fig. 7.7. The percentage deviation curve from linearity of the average data given in Table 7.1 is shown in Fig. 7.8. The corresponding standard deviation curve for six sets of readings given in table 7.1 is shown in Fig. 7.9. The static characteristic curves for the hardware
circuit output for six sets of data given in Table 7.2 are shown in Fig.7.10. The corresponding percentage deviation from linearity and the standard deviation curves from the readings given in Table 7.2 are shown in Fig.7.11 and Fig.7.12 respectively. The static characteristic graphs of the PC based flow indicator drawn from six sets of data given in Table 7.3 are shown in Fig.7.13. The percentage error characteristics of the flow indicator and the standard deviation curve obtained from the readings given in Table 7.3 are shown in Fig.7.14 and Fig.7.15.

![Flow transducer characteristics](image1)

**Fig.7.7:** Static characteristics of flow transducer

![Percentage deviation from linearity](image2)

**Fig.7.8:** Percentage deviation from linearity of the average value of flow transducer output

![Standard deviation curve](image3)

**Fig.7.9:** Standard deviation curve of the average value of flow transducer output

![Static characteristic curve (hardware)](image4)

**Fig.7.10:** Static characteristic of hardware circuit
Study of a modified anemometer type flow meter

![Percentage deviation curve](image)

**Fig. 7.11:** Percentage deviation from linearity of the average value of hardware circuit output

![Standard deviation curve](image)

**Fig. 7.12:** Standard deviation curve of the average value of hardware circuit output

![Flow indicator characteristics](image)

**Fig. 7.13:** Flow indicator characteristics

![Percentage error curve](image)

**Fig. 7.14:** Percentage error characteristics of PC based flow indicator

![Standard deviation curve](image)

**Fig. 7.15:** Standard deviation curve of PC based flow indicator
7.5 DISCUSSIONS

The design of the transducer is very simple and requires little technical expertise. The static characteristic of the transducer output is found to be linear in both increasing and decreasing modes as shown in Fig.7.7. The percentage deviation from linearity of the average value of flow transducer output in three increasing and three decreasing modes is found to be within +/- 0.2% of full scale reading as shown in Fig.7.8. The repeatability of the transducer is also found to be quite satisfactory as shown in the standard deviation curve in Fig.7.9.

The static characteristic of hardware circuit output is also found to be linear in both increasing and decreasing modes as shown in Fig.7.10. The percentage deviation from linearity and the standard deviation are also found to be within tolerable limit as shown in Fig.7.11 and Fig.7.12 respectively.

The PC based flow indicator is also found to be linear with very low percentage deviation from linearity and good repeatability as shown in Fig.7.13, Fig.7.14 and Fig.7.15 respectively.

The flow head in the present work is fabricated from PVC pipe. It may also be designed with the metallic pipe by using suitable insulation for the transistors. In the experiment the rotameter has been used only to change the flow rate in regular steps by observing the reading of the rotameter. But the actual flow rate was measured by direct water collection method.
### 7.6 EXPERIMENTAL DATA TABLE

Table 7.1 Experimental data table for flow transducer output characteristics

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Actual Flow rate (LPM)</th>
<th>Flow transducer output (mV)</th>
<th>Standard deviation</th>
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Table 7.2 Experimental data for hardware circuit output (final output of opto-isolator) with flow rate

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<th>Sl No.</th>
<th>Actual Flow rate (LPM)</th>
<th>Output of signal conditioner (V)</th>
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Table 7.3 Experimental data for LabVIEW based virtual flow indicator

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