

## Design and development of thermistor based gas flow measurement system for anaesthesia ventilator

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*Received 17 December 2007; revised 31 January 2008; accepted 04 February 2008*

This paper describes design and development of a gas flow measurement system, which is particularly helpful for airflow measurement in anaesthesia ventilator. The system measured accurately, required range (0-70 l/m), of airflow for anaesthesia ventilator. Main advantages of developed technique are simplicity of design, dynamic stability and fast response time. Thermistor based hardware design associated with graphical approach has been developed successfully and incorporated in indigenous prototype of anaesthesia ventilator.

**Keywords:** Airflow, Anaesthesia ventilator, Flowmeter, Gas flow rate, Mass flow controller, Thermistor

### Introduction

Anaesthesia ventilator<sup>1,2</sup> uses thermistor for measurement of instantaneous flow rate of respired gas. In application of thermistor for flow measurement, self heated region of V-I characteristic curve of thermistor has been used. An inexpensive flow measurement system based around thermistor is a module of indigenously developed anaesthesia ventilator. What has been envisaged here is to develop a flow measurement system using graphical approach<sup>3</sup>.

This study presents design and development of thermistor based system for airflow measurement in anaesthesia ventilator and results obtained are accurate (required range, 0-70 l/m).

### Materials and Methods

#### Instrument

Anaesthesia ventilator<sup>4</sup> developed is for use in anaesthesia to work under controlled mandatory ventilation (CMV) mode<sup>5,6</sup>. It is a pneumatically driven volume controlled time cycled ventilator, which controls various respiratory parameters (tidal volume, respiration rate, inspiration flow rate, I: E ratio). It consists of bellow

system, microcontroller based control system and a closed circuit rebreathing circle absorber type patient circuit. Breathing gas entry and exit to rubber bellow takes place through a single port where inspiratory flow of gas is in direction out of bellow. Expiratory flow of gas is directed towards bellow when expired gas is recycled through a soda lime purifier being put in a poly valve based circle absorber circuit (Fig. 1). Respiratory gas flow measures flow using flow sensor bead type thermistor YSI #421, which is placed in the path of medium, connected at patient airway and provides conduit for gas flow measurement (Fig. 2).

#### System Design

Thermistor, which is small in size and fast in response, on placing in breathing limb of patient circuit, measures airflow rate. There are three basic ways in which a thermistor can be used to give an output indicative of flow: 1) A simple potential divider circuit; 2) Wheatstone bridge, in which other arms are passive resistors; and 3) Wheatstone bridge incorporating a second thermistor in an adjacent arm, which results in the direction of increasing complexity.

In developed system, thermistor works as a separate arm of a wheatstone bridge. To self heat, thermistor is subjected to power levels that vary thermistor's body temperature above environmental surroundings. As

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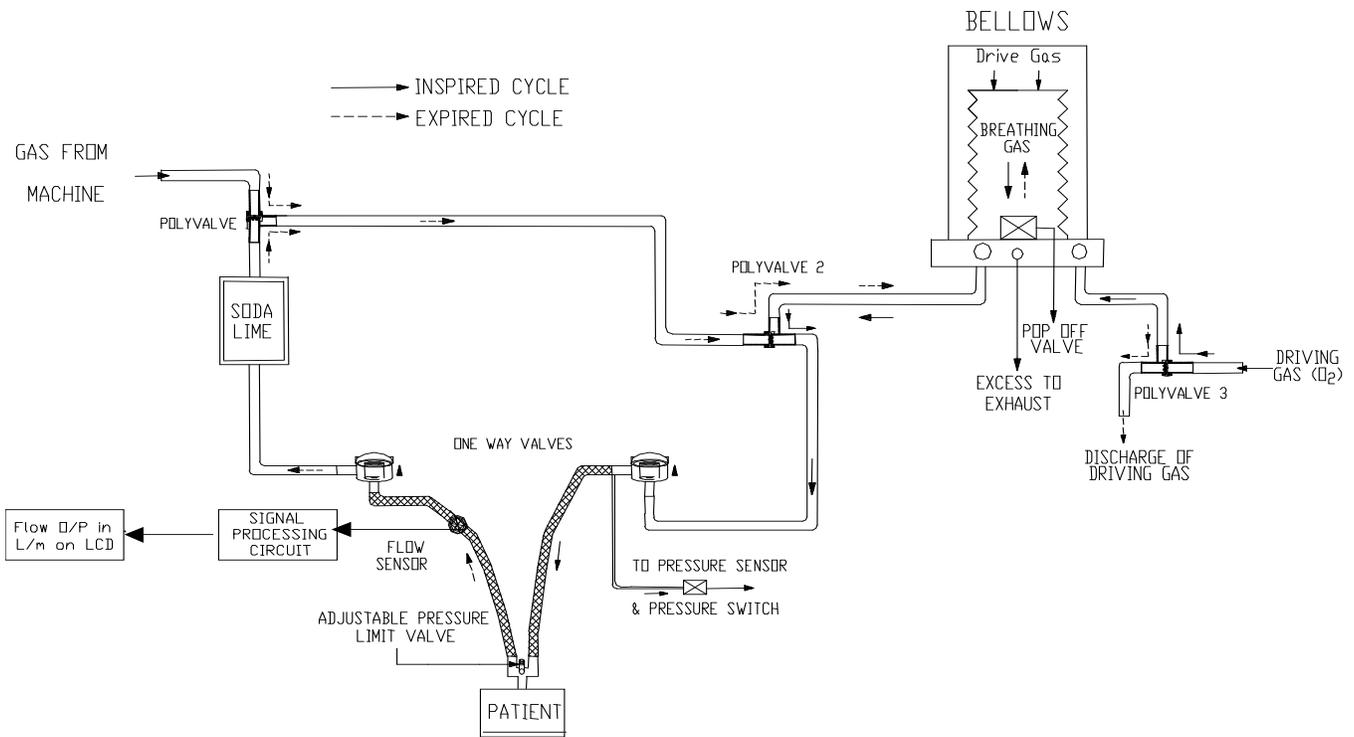


Fig. 1—Ventilator breathing circuit showing flow sensor

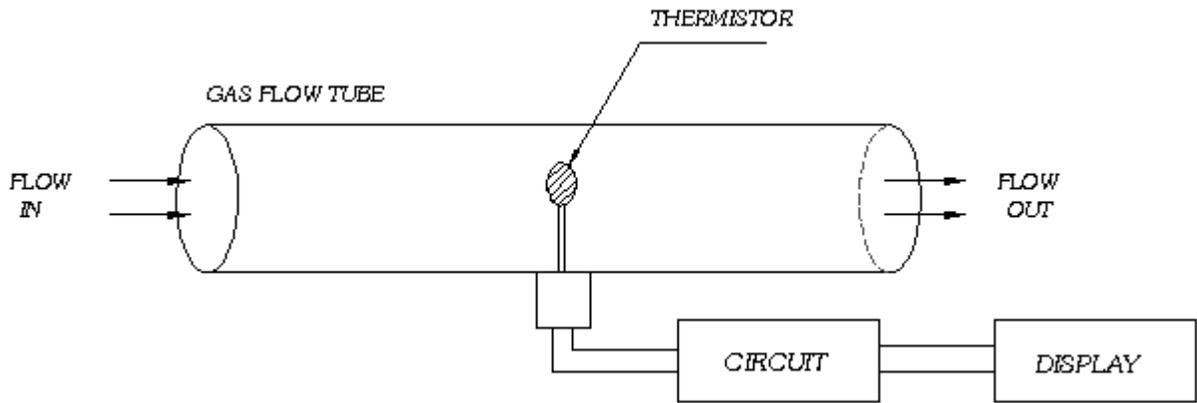


Fig. 2—Diagram showing flow sensor / thermistor assembly

environment changes, bridge becomes unbalanced, indicating change in flow, which is then calibrated. A self-heated thermistor in air is able to dissipate more power when transferred to an environment as compared to non-self heated region. This increase in power dissipation generates a sufficient change (increase) in resistance, which makes it possible to measure the flow.

**Thermistor based Circuitry**

Using different flow rates (0-70 l/m), V-I characteristics of thermistor YSI # 421<sup>7</sup> are drawn (Fig.

3). Basic circuit for single thermistor wheatstone bridge (Fig. 4a) optimizes output response to change dissipation constant for thermistor YSI #421. Bridge circuit is converted to an equivalent Thevenin circuit. This has been done in two stages. In first stage (Fig. 4b), delta-star transformation has been used on  $R_1$ ,  $R_2$  and  $R_L$  and this leads directly to the equivalent circuit (Fig. 4c), where  $E_{th}$  and  $R_{th}$  are effective source emf and load resistance calculated as

$$R_s' = R_s + (R_1 \cdot R_2) / (R_1 + R_2 + R_L) \quad \dots(1)$$

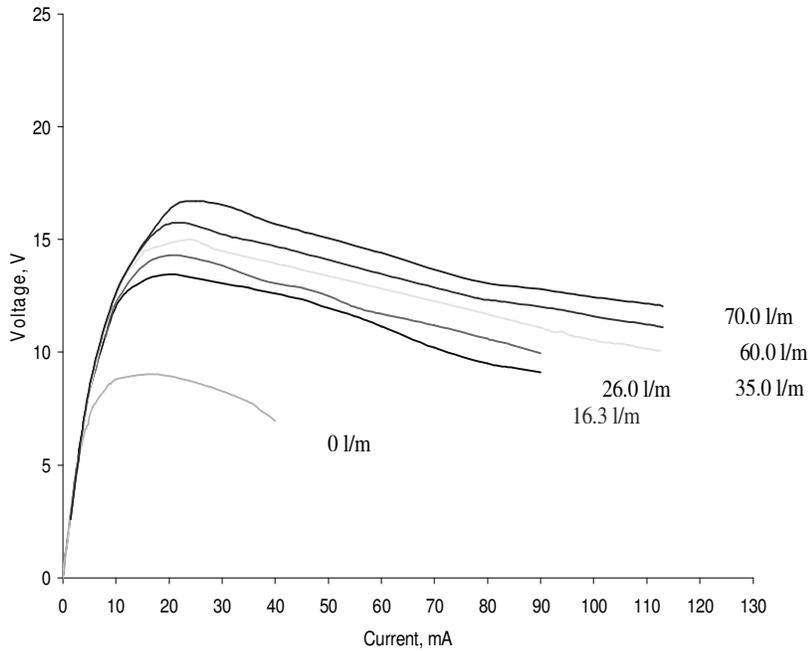


Fig. 3—V-I characteristics of thermistor at different values of flow

Fig. 4—Wheatstone bridge using thermistor (a) basic circuit (b) transformed circuit (c) reduced circuit

$$R_4 = (R_1 \cdot R_L) / (R_1 + R_2 + R_L) \quad \dots(2)$$

$$R_5 = (R_2 \cdot R_L) / (R_1 + R_2 + R_L) \quad \dots(3)$$

$$R_{th} = R_4 + [R_s' (R_3 + R_5)] / [(R_s' + R_3 + R_5)] \quad \dots(4)$$

$$E_{th} = (R_3 + R_5) E / (R_s' + R_3 + R_5) \quad \dots(5)$$

$R_1, R_2, R_3$  and  $R_s$  values are determined from Eqs (1)-(5) and thermistor based circuitry is designed based around these resistances.

**Hardware Design and Signal Processing**

Hardware is designed for measuring gas flow in a gas delivery system for anaesthesia ventilator. The module is adapted to be connected to a source of gas. The module also includes a fixed volume pipe in

connection with gas source. Mass flow controller can be used to control gas flow within the chamber. Hardware design comprises in combination, a thermistor based circuitry, signal-processing circuit containing buffers and difference amplifier, analog to digital converter, microcontroller 89C51 and an alphanumeric LCD for flow display (Fig. 5).

Signal processing circuit consists of a wheatstone bridge, one arm of which is thermistor and other arms are resistances. Bead of thermistor is placed in air medium, whose flow is to be measured. Output of thermistor-based circuit is a voltage, which varies directly with gas flow passed through the tube. Bridge output is fed to buffers, then applied to inputs of a difference amplifier that gives analog voltage output. This output signal is converted into digital value by a 12-bit analog to digital converter. Microcontroller<sup>8</sup>

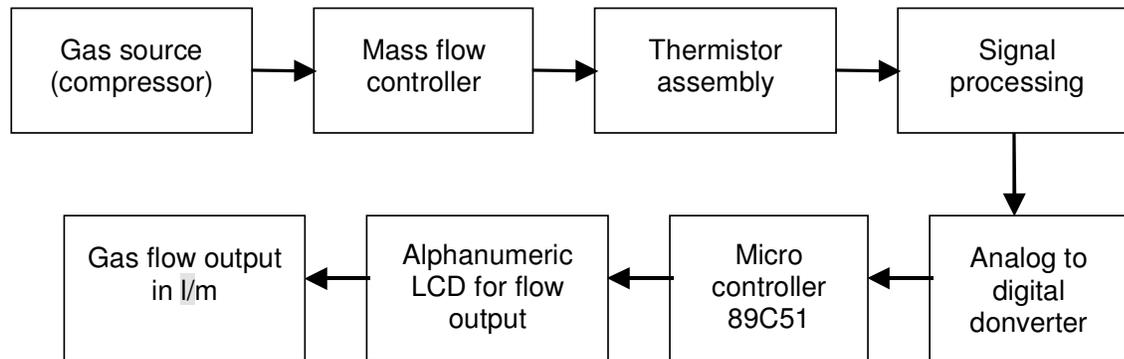


Fig. 5—Block diagram of hardware based circuitry

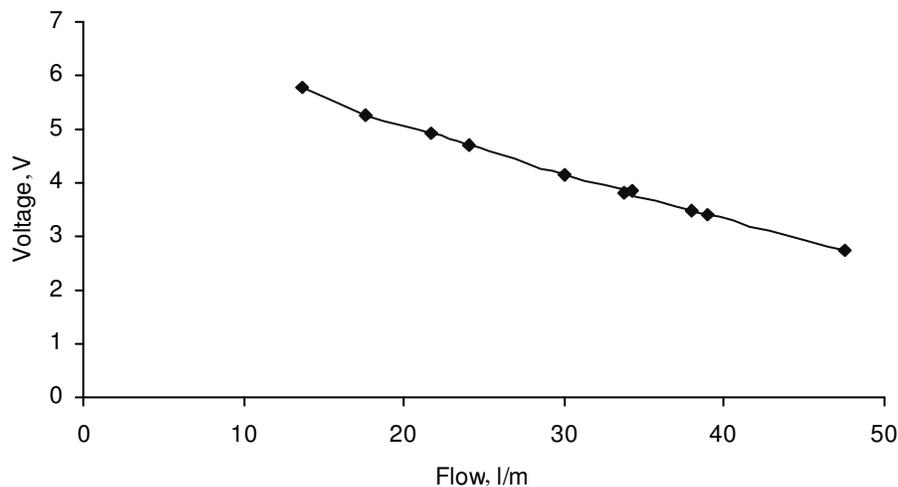


Fig. 6—Flow vs output voltage

performs calculations on these digital values and results are displayed on LCD.

### Results and Discussion

Flow sensor is incorporated in the system and test data is recorded to get flow vs voltage output (Fig. 6). In developed system, linearization has been performed in digital domain using a look up table in microcontroller-based system.

### Calibration

For calibration of flow measurement system of anesthesia ventilator, air, is supplied to a flow controller

through Whispair air compressor and this flow goes to input of flow sensor assembly and Aalborg mass flow controller, which gives output of flow digitally on its LCD in l/m. Output of flow measurement system is thus calibrated with Aalborg mass flow controller digital output.

### Accuracy and Repeatability

Accuracy of developed flow measurement system is  $\pm 1\%$  of full scale. Graph (Fig. 7) between developed flow measurement system output on LCD and mass flow controller output shows satisfactory result. Repeatability of system is  $\pm 0.5\%$  of full scale.

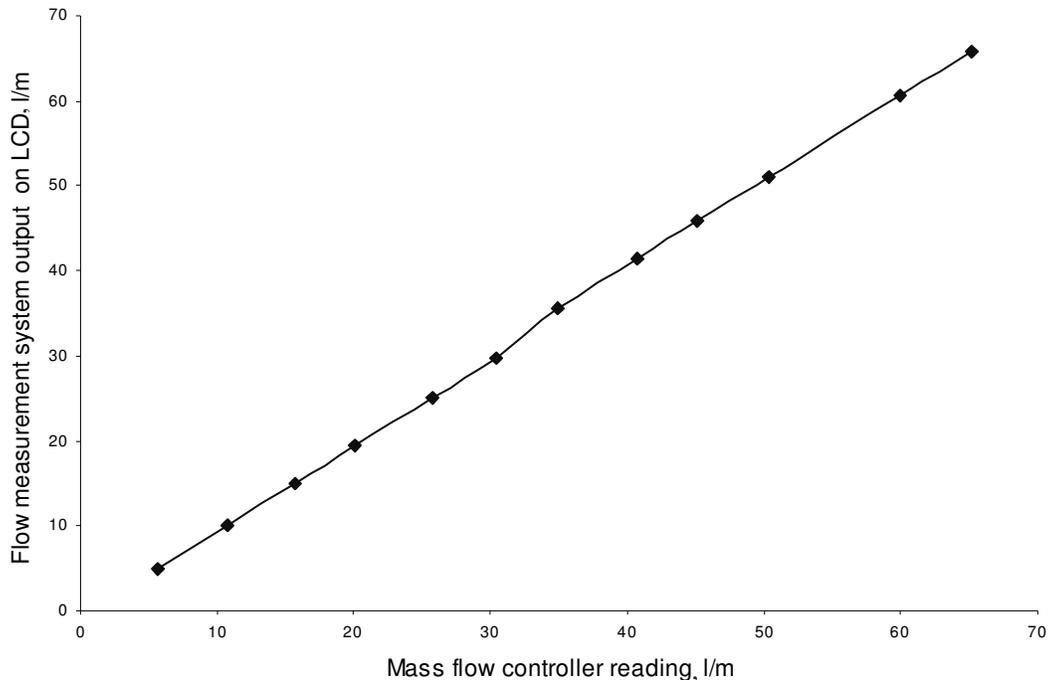


Fig. 7—Graph between flow measurement system output and mass flow controller output reading

#### Resolution

Developed system using thermistor allows flow rate measurement with a resolution of 0.1 l/m. It is a compact design with small size thermistor and fast response time. Design is accurate and reproducible. Components used are easily available and have low cost.

#### Conclusions

A flow measurement technique, which used a single thermistor operating in the self-heated region, has been described. It allows flow rate measurements with a high degree of accuracy. Single thermistor is highly preferred due to increasing stability. It is connected in series with resistance and forms a bridge circuit, which is supplied with a source voltage and obtained output voltage is proportional to flow. High performance realized by this technique makes it attractive for airflow measurement in anaesthesia ventilator.

#### Acknowledgements

This work is partly sponsored by DST, New Delhi. Authors thank Director, CSIO and late Shri R N

Sengupta, Scientist, CSIO for their kind help, guidance and constant encouragement.

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