Design and development of microcontroller based human airway pressure measurement system with real time graphical display for anaesthesia ventilator

R N Sengupta, Jaspreet Kaur* and Jagdish Kumar
Central Scientific Instruments Organisation, Sector 30, Chandigarh 160 030

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A microcontroller based hardware design and system software associated with the graphical visualization of the airway pressure data acquisition system has been designed and developed, and successfully incorporated in indigenous prototype of anaesthesia ventilator. An inexpensive airway pressure monitoring system based around 80C31 microcontroller with RAM, EPROM, AD574 ADC, peripheral interface devices and graphical LCD etc., is a module of the indigenously developed instrument. What has been envisaged here is to get a real time pressure waveform on LCD. Air pressure changes over a respiratory cycle. This makes anaesthetist to have a feeling of how air pressure in the tract changes with time. An accurate and sensitive piezoresistive type of air pressure sensor has been used outside the mouth and inside the piping.

Keywords: Airway pressure, Anaesthesia ventilator, Microcontroller, Piezoresistive pressure, Sensor

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Introduction

Ventilators of different types in functional characteristics and construction have been used for anaesthesia and intensive care. The device used earlier in a ventilator has been a pressure pick up system from the patient’s mouth to the transducer and then to implement at suitable display device for it. A dial type pressure indicator with a pointer at the centre was being used for a long time and still in vogue as this has been a convenient and reliable method of air pressure measurement where the Pascal’s law of transmittance of air pressure is used. Measuring and displaying airway pressure (AP) waveform on front panel helps in monitoring functions such as disconnection in system, unrecognised leaks in the ventilator circuit. At the same time, a reduction in AP to the level of atmospheric pressure would indicate disconnection of device. By displaying real time airway graph, it is possible to realize the rise and fall of air pressure over a breathing cycle and their trends (Fig. 1).

This paper presents design and development of AP measurement system with real time graphical display for anaesthesia ventilator.

Materials and Methods

Instruments

Anaesthesia ventilator developed is an electropneumatic type of instrument, which controls tidal volume, respiration rate, inspiration flow rate, AP, I: E ratio etc. It has three basic subsystems: 1) Bellow system supported by pneumatic driving components; 2) Microcontroller based control system for ventilator parameter control, monitoring and alarms for safety; and 3) A closed circuit rebreathing circle absorber type patient circuit.

Ventilators provide the force that inflates lungs, and with controlled ventilation also determine respiratory time cycle. AP is monitored in new design through a LED bargraph display using piezoresistive

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*Author for correspondence
Tel: 0172-2657811, 2651831/Extn 467
E-mail: jaspreet_k123@rediffmail.com

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![Fig. 1—Schematic of the inspiratory and expiratory airway pressure versus time waveform](image-url)
miniaturized pressure sensor (Fig. 2). Also, as an additional facility, real time AP waveform is displayed on a separate LCD graphic display unit. By this, it is possible to realize the rise and fall of air pressure over a breathing cycle. Several audio and visual alarms have been added to AP measurement system so as to make the system safe and failure proof to the extent possible. Main alarm conditions are AP high and AP low.

System Design
Choice of transducer needs to be capable of measuring required pressure (0-1.71 psig or 0-120 cm of H$_2$O) and having response time of 10 milliseconds. Transducer has high accuracy, repeatability, long-term stability, high input impedance, linearity, negligible hysteresis, temperature compensation and small size. Further, for amplification of the output signal from transducer, precise low level, low time drift, accurate closed loop gain, high CMRR, high slew rate type amplifier system is designed and used.

The range of values of air pressure (0-120 cm H$_2$O) can be given either by a dial type pressure gauge of very large diameter or a water manometer with long heights. Both of these are very inconvenient as a part of a bigger system like a ventilator. Also, a low power consuming display device (graphics LCD module) with good contrast and backlight having full dot matrix graphics capability, is used to display graphics as well as characters.

Microcontroller based Hardware Design
Basic modules of the system contain a pressure sensor, instrumentation amplifier, low pass filter, buffer, bar graph driver, 10 segment LED bar graph, amplifier, 12-bit analog to digital converter and microcontroller based signal processing circuitry (Fig. 3). Block diagram can be subdivided in following major parts: i) Micro controller & memories; ii) Transducer based circuitry; iii) Peripherals and interfaces; and iv) Measurement and signal processing.

System design is based around 80C31 microcontroller connected through address bus, data bus and control bus to the 64Kbytes of EPROM 27C512 for monitor and control program, 8Kbytes of RAM and peripheral I/O device 8255 for interfacing, 12-bit
A/D converter, 30 characters × 8 lines alphanumeric / graphic LCD display. AP is seen in the form of bar graph and as well as on LCD screen in graphical form.

Transducer based Circuitry
Transducer-based system consists of pressure sensor, instrumentation amplifier, low pass filter, buffer, bargraph driver and 10 segment LED bargraph (Fig. 4). Sensor consists of a sensing element (0.254 cm$^2$ silicon chip) with internal sensing diaphragm and 4 piezoresistors. Sensing resistors are connected as 4 active elements constituting a bridge. LM 3914 bargraph display driver is a monolithic IC that senses the analog voltage levels and drives 10 LEDs. Each successive LED of bargraph will glow for every 125 mV increase in input voltage. Data and control pins of the module are controlled through software to bring out display of values and real time bargraph display of AP.

Signal Processing
In AP display system of anaesthesia ventilator, the sensor selected has a pressure range of 0-5 psig. Pressure applied to the diaphragm to flex causes change in the resistance of the resistors. As AP changes, it is sensed by transducer, thus an amount of voltage proportional to AP is obtained. Output signal obtained from transducer is of very low magnitude (0-17 mV). Thus there is a need for some amplification where low noise, low thermal and noise.
Fig. 5—Flow diagram for system software
drifts, high input impedance and accurate closed loop gain are required.

Output of filter is amplified and then passed to a buffer known as voltage follower (Table 1). Use of unity gain buffer amplifier reduces loading effect in measurement system. After calculating analog value of AP, it is converted in digital form by using 12-bit A/D converter. Microcontroller processes digital data and displays on LCD in graphical form. Measurement and design requirements are as follows: pressure range, 0-120 cm of H₂O; response time of sensor, 10 millisec; resolution, 7 cm of H₂O; time period (X-axis), 1-15 sec; maximum frequency of signal, 1 Hz; output signal of pressure transducer, 0-17 mV; output signal from instrumentation amplifier, 0-1.25 V; and gain required in instrumentation amplifier, 73.

**System Software**

On the basis of flow diagram (Fig. 5), system software has been developed using ‘C’ cross compiler for Intel 8031 micro controller in modular form. System software is very much in optimised form and also maintains integrity of real time data and provides a very efficient way to represent in graphical form and also provides FREEZE button to store the graph for quick analysis of real time data, which is very useful for an anaesthetic analyst. The main program calls the sub functions and executes them accordingly. System software is stored in the system EPROM.

**Results and Discussion**

The system, fabricated and thoroughly tested for AP, has been found working satisfactorily giving accurate results. Its noise immunity has been observed to be excellent as it works in harsh environments. LCD module helps to monitor AP both alphanumeric as well as graphics without going through complex sequential operations, thus making the system ideal for ventilators. Total system is operated by air pressure and calibration is done by using Fluke Pressure Meter. For calibration of AP measurement system of anaesthesia ventilator, air is supplied with Fluke Pressure pump and this pressure goes simultaneously to the input to pressure sensor and to standard Fluke pressure calibrator. Output of AP measurement system is then calibrated with pressure calibrator. Graph between AP measurement system output and the pressure calibrator output is a straight line and thus shows satisfactory results (Fig. 6). It is observed that variation in the voltage required to glow an LED is less than 5% of the true value, which is quite acceptable. The resolution of bar graph LED is 7 cm of H₂O.

**Conclusions**

AP measurement is useful for anaesthetist to manually control AP to reach maximum level. In the present work, provision is made to display only air pressure but display capacity can be increased up to 8 ventilator parameters by altering software a little and incorporating a small additional hardware.

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**Table 1**—Instrumentation amplifier input and buffer amplifier output

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<th>S No.</th>
<th>Instrumentation amplifier input (mV)</th>
<th>Buffer amplifier output (V)</th>
<th>S No.</th>
<th>Instrumentation amplifier input (mV)</th>
<th>Buffer amplifier output (V)</th>
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**Fig. 6**—Graph between airway pressure measurement system output and pressure calibrator output reading
Acknowledgements
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References