Inspiratory and expiratory flow rates determination using a single spirolog type flow sensor

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***Abstract*—The gas flow is the main parameter for pulmonary ventilation. Gas flow and flow direction control and monitoring are essential for inspiratory and expiratory tidal volume and the minute volume required values and determination, for determining the inhale-exhale patient system leakage and others.**

***Keywords*— flow rate sensor, flow direction sensor, flow rate.**

I. Introduction

Pulmonary ventilation is the process during which a gas mixture (air and oxygen) is introduced into the patient's lungs, using a machine called a ventilator, which delivers pressurized gas. The inspired gas mixture is delivered to the patient at certain flow rates and pressures.

Since the patient's life depends on the ventilator's proper functioning, it must operate at nominal parameters. Such equipment should be tested regularly. One of the most important parameters is the flow rate, both of gas delivered to the patient and the gas exhaled by the patient.

The main ventilation parameters, from the flow's point of view, are the following:

- inspiratory (VT_i) and expiratory $(VT_e \text{ or } VT)$ **Tidal Volume** – the inhaled or exhaled gas volume during normal breathing without applying a supplementary effort [1], [2].
- the **Minute Volume** – the inspired or expired gas amount in one minute [1], [2].

The ventilation test process includes also verifying if the checked equipment has the VT_i, VT_e, $\dot{V}_e$, $\dot{V}_i$, and MV parameters at nominal values. For this purpose flow rate sensors are used.

II. Using the Spirolog Type Flow Sensor

One of the most efficient flow sensors used in pulmonary ventilation is the spirolog sensor type. This type of sensor is manufactured by Envitec Honeywell. [3]

The spirolog sensor operates according to the principle of maintaining a constant temperature of the flow gauge heated wire. [4]

To use the spirolog sensor type an electronic device, shown schematically in Fig. 1, was designed and built.

The basic circuit diagram for the spirolog sensor is represented by a Wheastone bridge type voltage amplifier. A reference source is created using the TL 431 regulator, which provides the voltage controlled for a current source realized with the AO1 operational amplifier, LM324 type and a compound Darlington transistor, BD 237.

The current through the Wheastone bridge is adjusted with the Rvar adjustable resistor (10kΩ) and the current and flow sensor is brought to its highest sensitivity area. The Wheastone bridge imbalance generates an alternating current at its terminals, which is then picked by the differential amplifier, built with the AO2 operational amplifier. At the differential amplifier's exit terminals a voltage equal to the product between the gain and difference from the Wheastone bridge is generated.

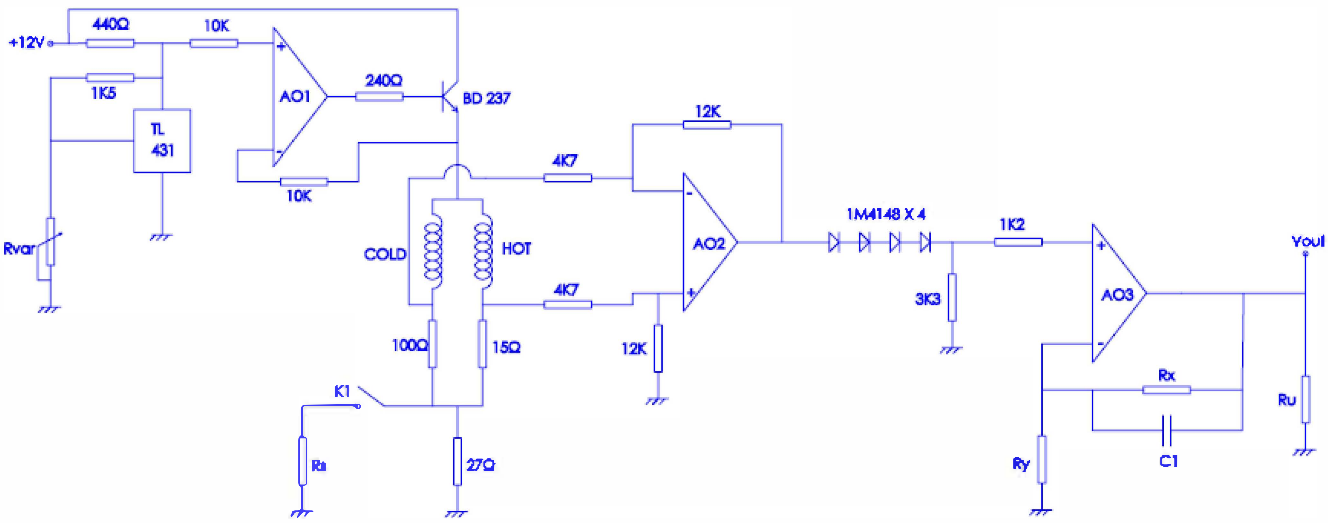

Fig. 1. The electronic diagram for the spirolog type flow sensor [5]

The diodes from the AO2 exit produce a voltage drop of about 2V, necessary to establish a reference from which the amplifier will work in a linear manner.

The AO3 is a simple DC amplifier with a gain value of A, the level's stability being given by the C1=47 nF capacitor.

At the AO3 output terminals there is a voltage variation between 10 and 0.19 V corresponding to the flow variations between 0 and 70 l/min.

For this work the spirolog sensor is connected to a computer, which is running the LabView software, through a data acquisition board USB 6009 [6] produced by National Instruments and the device shown schematically in Fig. 1.

III. Spirolog Type Flow Sensor Calibration

The sensor calibration means finding the equivalence between the voltage measured at the sensor's output and the gas flow that crosses it. To find this equivalence a device shown schematically in Fig. 2 was developed.

With a flow regulator 10, connected to a pressurized gas source 8, the gas with various flow values is directed towards the calibrated and metrological verified flow sensor 11 RAGL53, Rota Yokogawa type [7]). The gas goes from 11 into the sensor to be calibrated 13, the two sensors being connected in series. Sensor 13 is power from the constant voltage source 7 (12V) through the electronic system 5 (shown in Fig. 2) and the power cables 6 and 12. The voltage values resulting from 13 are read from the computer's display using the LabVIEW 8.5 software, the data acquisition board 3 and 5. The data acquisition board is connected to the computer 1 through the connecting cable 2 and to 5 through the connecting cable 4. The pneumatic connections are made using the hoses 9. The gas flows delivered by 10 are monitored directly by 11 and 13, or as an electrical value using 1 and 3 (this is the way Fig. 3 was obtained).

Because the voltage range 9.4 ÷ 9.59 V can be associated with two different flow values, the sensor will be used only for voltages below 9.4 V, that means for flow values over 0.4 l/min.

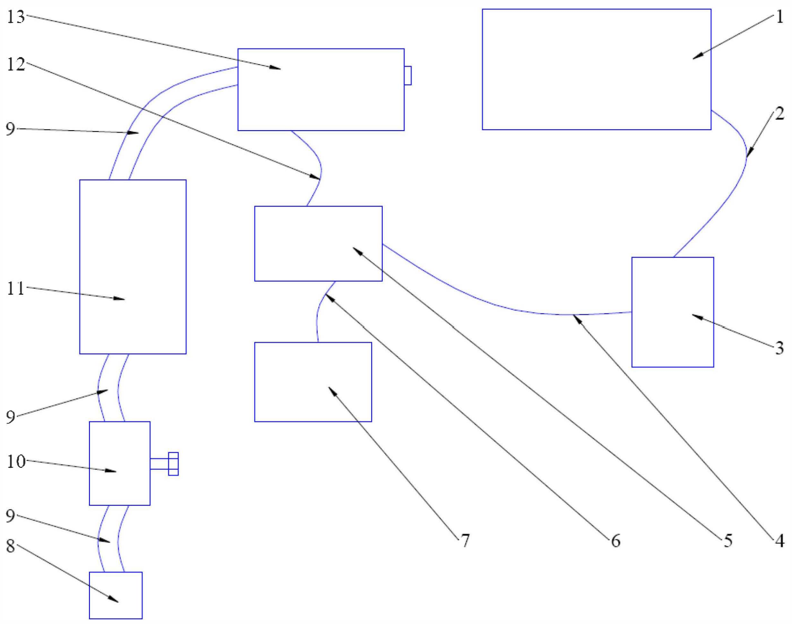

Fig. 2. The calibration device for spirolog type flow sensor scheme [3]

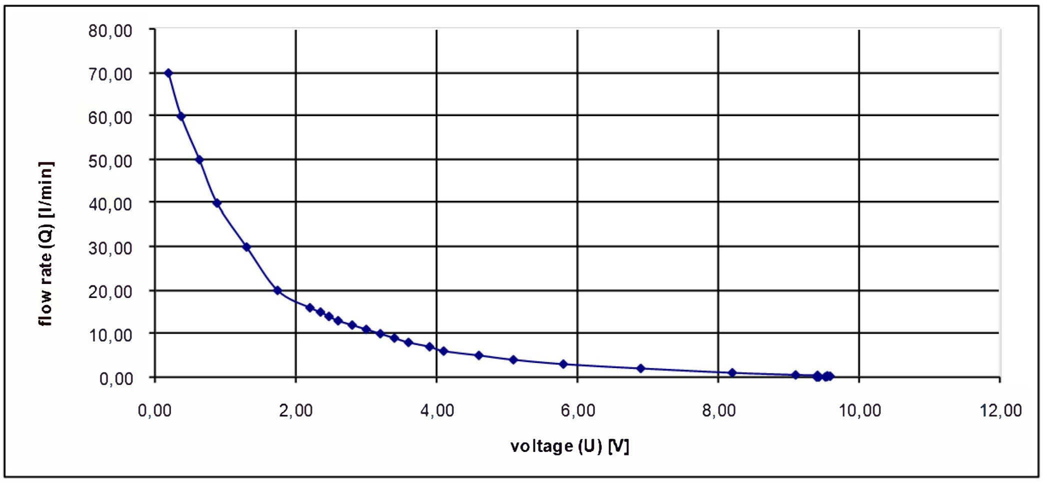

Fig. 3. The spirolog sensor's calibration curve [5]

For easier use the curve in Fig. 4 is approximated with a linear behavior on suitable electric power/flow intervals.

The calibration curve is given by the following equation:

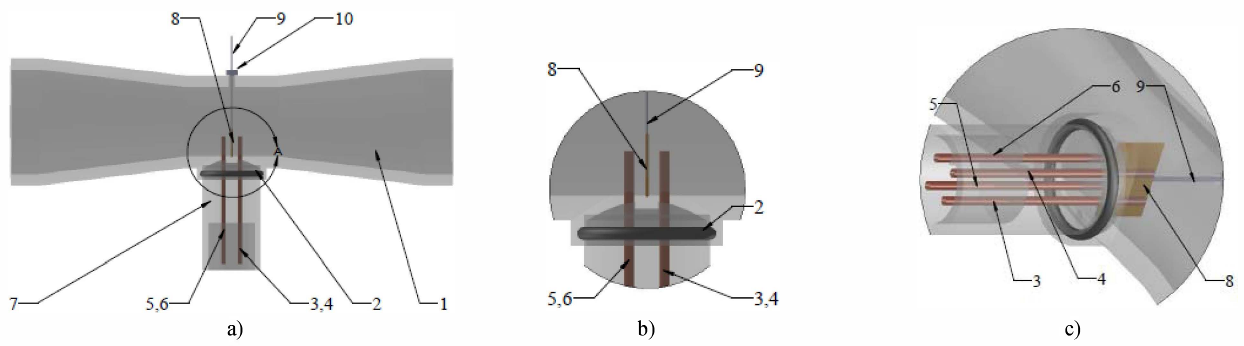

Fig. 4. Direction sensor: a) side view, b) detailed view, c) rotated detailed view [5]

$$\dot{V} = a \cdot U + b, \quad (1)$$

where: $\dot{V}$ - gas flow rate

U - electrical voltage

a and b - constants.

The constants a and b are determined for equation (1) with the data from Table 1 and the following values are obtained:

$a = -0.52$ and $b = 5.264$, for U>8.2 V,

$a = -0.833$ and $b = 7.831$, for 8.2 V ≥U>5.8 V,

$a = -1.765$ and $b = 13.236$, for 5.8 V ≥U>4.1 V,

$a = -5.32$ and $b = 27.12$, for 4.1 V ≥U>1.76 V,

$a = -36.036$ and $b = 76.84$, for 1,76 V ≥U.

IV. The Spirolog Sensor's Zero Calibration Before Each Use

Consider the flow sensor's calibration curve according to (5). At various moments, the curve given by (5) can be translated in the graph by a factor k.

$$k = U_{n0} - U_{i0} \quad (2)$$

where: U_{n0} - the calibration voltage for $\dot{V} = 0$ l/min, when doing the zero calibration, before each use,

U_{i0} - the initial voltage calibration for $\dot{V} = 0$ l/min (determined when the actual sensor calibration occurred, using the data acquisition board, upon which a and b were determined for equation (1), that is $U_{i0} = 9.4$ V).

The new flow curve is given by the equation:

$$\dot{V} = a \cdot (U_n - k) + b \quad (3)$$

where: a and b - the same as in (1),

U_n - the voltage determined by the data acquisition board for the $\dot{V}$ flow.

U_n is determined using the flow sensor. The U_n values are used in (3) to determine the gas flow values in the system. A no flow calibration digital flow meter is obtained.

V. The Direction Sensor

The spirolog type flow sensor determines the gas flow variation that crosses it, but not its direction. To use a single flow sensor, for inspiration and expiration, it is necessary to know the gas flow's direction. To determine the gas flow's direction a new, direction sensor, was designed and built. This sensor is shown in Fig. 4.

To build the direction sensor a plastic tube 1 from a faulty sensor, spirolog type, was used, through which the gas passes. The tube is drilled in the upper part of the tube in the middle. The hole diameter is φ=0.6 mm. A watch spring 9 (an elastic metal wire) is inserted through the orifice into the tube. A metal plate 8 was welded on 9. 9 is inserted into 1, leaving outside it the top part as an electrical terminal. 8 is positioned in the space originally occupied by the platinum wires (between terminals 3 and 4 and terminals 5 and 6). The part 2, in which 3, 4, 5 and 6 are connected, is rotated in a manner that places the terminals parallel with 8, two on each side. 3 and 4 are connected to a power supply of `+2.5 V and 5 and 6 are connected to a power supply of -2.5 V. 8 is moved in the gas that passes through 1 flow direction, making it an electric switch between terminals 5 and 6, terminals 3 and 4 and 9. At the upper end of 9 a cable is connected that links it to the data acquisition board. The gas passes through the sensor, 8 is moved in the flow's direction and makes an electrical contact between the data acquisition board and the + / - 2.5 V power supply, thus detecting the flow. To seal the sensor's hole of φ = 0.6 mm diameter, a layer of silicon 10 is deposited.

To determine the direction sensor's sensitivity the assembly shown in Fig. 5 was created. The direction sensor 13 is powered by a variable voltage source 3. A controlled gas flow is inserted into the sensor. The gas from the pressure source 4 runs through hose 5 into the flow regulator 6. It set certain gas flow values which get through the hose 7 into de flow meter 8 (RAGL53, Rota Yokogawa type [7]). After having the flow monitored, the gas reaches through the hose 9 the coupling 12 which is connected to 13. To change the gas flow's direction into 12 is moved from aperture A to aperture B or vice versa. 13 is connected to the power supply via cables 10 and 11. The connectors from aperture A are linked to the positive potential, +U, and the ones from aperture B to the negative potential, -U. The sensor's plate is connected through cable 14 to the meter 1. It is connected to the 3's null through cable 2. Testing is performed for various voltages U [V]. For each voltage the minimum gas flow at which the sensor worked properly was determined.

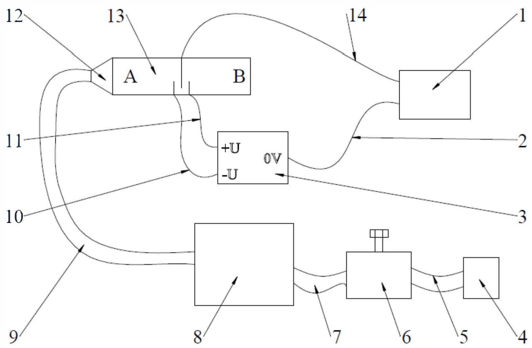

Fig. 5. The direction sensor testing assembly diagram [6]

The data obtained in this manner are presented in Table 1.

TABLE I. Minimum Flow Rate for the Direction Sensor

U [V]	$\dot{V}$ *(Q) [l/min]*
5	3.12
4	2.7
3.5	1.1
3	0.19
2.5	0.19
2	0.18

The 2.5 V voltage is chosen as power supply value for the direction sensor because it is easily obtained from 5 V and the minimum sensor operating flow value at this voltage is acceptable for the intended purpose (in ventilation, for an adult patients, flow rates grater then 1 l/min are used, compared to the minimum operating value of 0.19 l/min).

VI. FLOW DIRECTION THROUGH THE SPIROLOG SENSOR DETERMINATION

To determine the flow direction into the spirolog sensor type the direction sensor is used connected in series with the flow one. The direction sensor is powered by a power supply voltage of +2.5 V and -2.5 V. Depending on the gas flow's direction the switch closes the +2.5 V or the -2.5 V contacts. For the +2.5 V voltage the flow is considered positive (towards the patient), and for the -2.5 V voltage the flow is considered negative (from the patient). $\dot{V}_i$ represents the flow's value that comes out of the direction sensor.

$$\dot{V}_i = \dot{V} \text{ for } U_{\text{direction sensor}} > 0 \text{ V} \tag{4}$$

$$\dot{V}_i = -\dot{V} \text{ for } U_{\text{direction sensor}} < 0 \text{ V} \tag{5}$$

For reading and processing data from the spirolog and from the direction sensors a program is done in LabView.

VII. INSPIRATORY AND EXPIRATORY FLOWS DETERMINATION

To determine the inspiratory and the expiratory flows, in artificial ventilation, the flow and direction sensors are connected into the breathing circuit connection between the Y-piece and the patient.

The system consisting of the flow rate and the direction sensors, the flow rate device, the data acquisition board and the computer that runs the software presented above determine the inspiratory and the expiratory gas flows for a ventilation equipment running in VC-CMV mode (Volume Control – Continuous Mandatory Ventilation), as shown in Fig. 6.

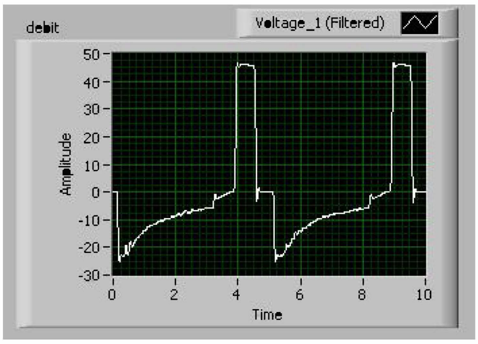

Fig. 6. Inspiratory and expiratory flows view [9]

The similarity between the experimentally determined and the theoretical curves shows the inspiratory and expiratory flows determination system proper functioning.

VIII. CONCLUSION

This paper presents a zero calibration and direction determination digital flow meter for flow rates between 0.4 and 70 l/min design and building.

For this purpose have been designed and built:

- an electronic device for a spirolog flow sensor type,
- a sensor for determining the gas flow's direction,
- a flow sensor calibration assembly,
- a direction sensor testing assembly,
- a dedicated software in LabView.

REFERENCES

[1] R. Rathjen, Basisseminar, version 1.00, ENGLGRU.DOC, Dräger, Lubeck, Germany,1995

[2] R. L. Chatburn, Fundamentals of Mechanical Ventilation, Manu Press Ltd., Ohaio, S.U.A., 2003

[3] http://www.envitec.com/uploads/products/00000_0253_2011_04_13_030832.pdf

[4] *** Technical documentation, Evita XL, Drager Medical, revision 59.0, Lübeck, Germany , 2005

[5] B. M. Ciurea, "Contributions to the improvement and evaluation of pulmonary ventilation equipment", PhD thesis, University "Politehnica" of Bucharest, 2012

[6] http://www.ni.com/pdf/manuals/371303l.pdf

[7] http://aspzone.us.yokogawa.com/downloads/MI/General%20Specificati ons/General%20Specification/GS1R1B8-E-H(E3).pdf