

[54] **METHOD AND APPARATUS FOR DETERMINING WORK OF BREATHING**

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[58] Field of Search **128/2.08, 2.07, 2.05 F; 73/206**

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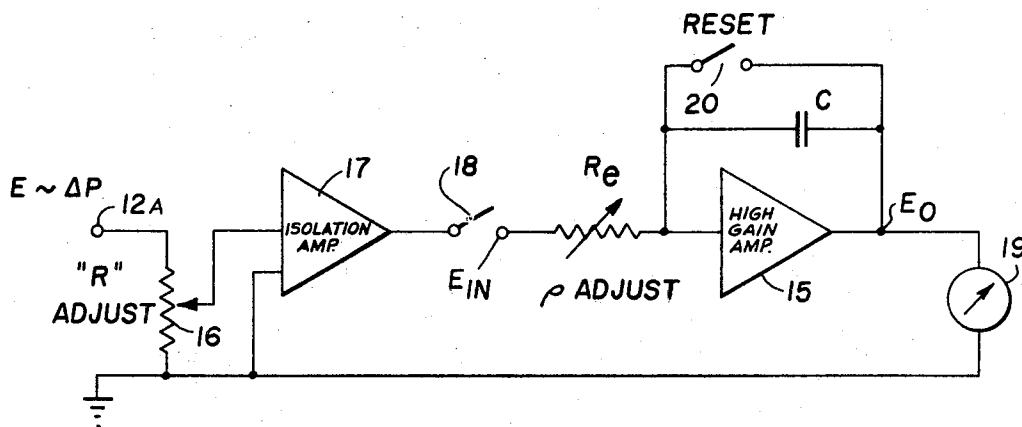
Primary Examiner—**Kyle L. Howell**

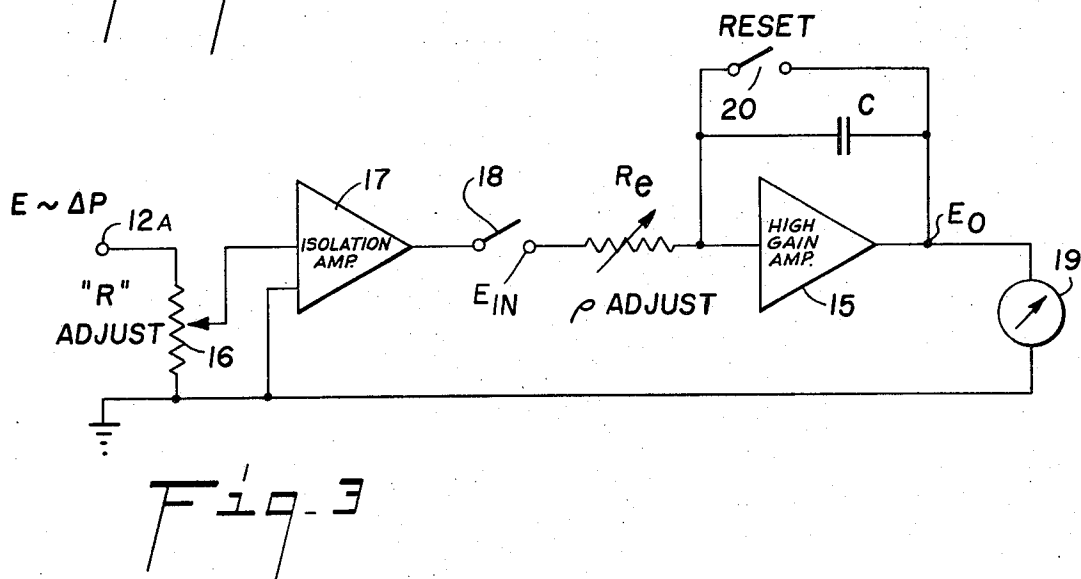
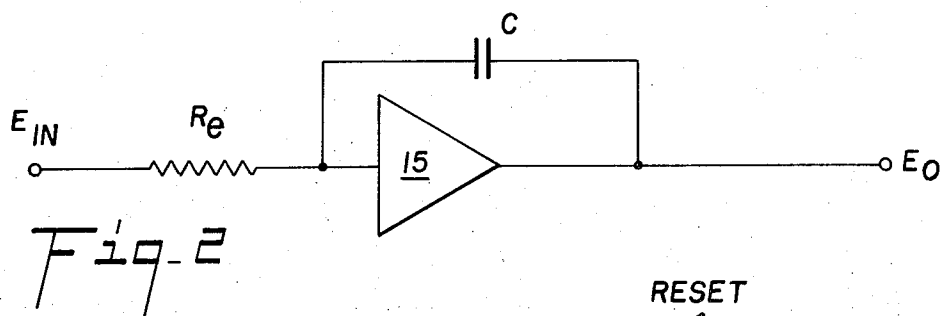
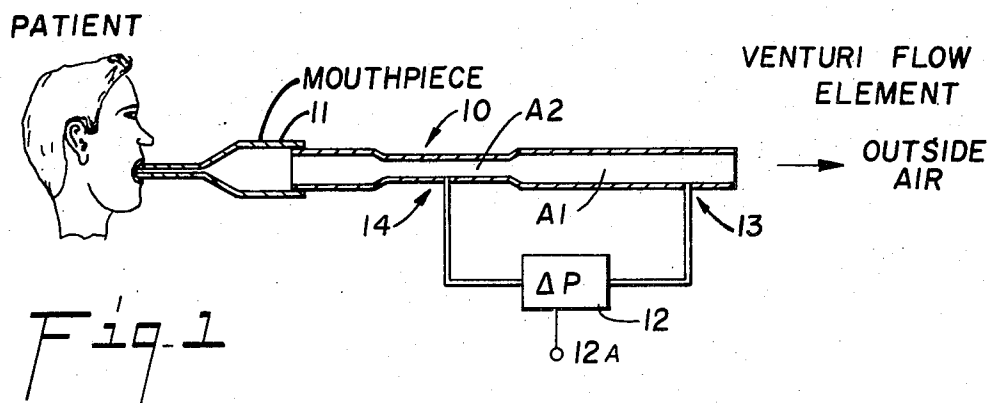
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[57] **ABSTRACT**

A method and apparatus is disclosed for determining work of breathing by using a dynamic flow measuring means, such as venturi tube to obtain an electrical signal proportional to flow squared of air or other gas breathed. This signal is scaled in proportion to a previously obtained value of respiratory resistance and then integrated over one or more respiratory cycles to obtain a signal proportional to the work of breathing. The integrating means time constant is adjusted in accordance with the separately determined air or gas density.

6 Claims, 3 Drawing Figures





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METHOD AND APPARATUS FOR DETERMINING WORK OF BREATHING

This invention relates to physiological testing of the human respiratory system and in one of its aspects to a method and apparatus for determining work of breathing of such a respiratory system.

When a person has a severe lung disease life or death may depend on breathing efficiency, i.e., on whether or not the added consumption of oxygen necessary to effect a needed increase in ventilation may exceed the additional oxygen uptake resulting from the increased ventilation. The added consumption of oxygen is directly related to the total mechanical work of breathing done by all of the muscles involved in respiration. Therefore, quantitative determinations of the work of breathing under various conditions should prove to be extremely valuable to a physician making a diagnosis of the condition of the respiratory system.

In the past it has been considered impossible to measure the total work of breathing of a patient breathing spontaneously. It could be measured only by placing a patient who was no longer breathing spontaneously because of deep anesthesia, poliomyelitis or the injection of drugs which had caused a neuromuscular block, in a body respirator. It was then possible to measure the work done by the respirator which was considered to be the same work as would have been done by the muscles used in respiration to produce the same amount of ventilation.

No net work is done during a breathing cycle in overcoming the stiffness of the respiratory system because of volume changes, because the potential energy which is stored is later recovered. All net work done during a breathing cycle is done in overcoming total respiratory resistance to flow. It can be demonstrated mathematically that the work done during a breathing cycle is the total respiratory resistance of the respiratory system multiplied by the integral with respect to time of flow squared of the air or gas breathed during this breathing cycle. "Flow" is herein defined as volume velocity.

In my copending application titled "Method and Apparatus for Measuring Mechanical Properties of the Respiratory System," Ser. No. 83,421, filed Oct. 23, 1970, there are disclosed methods and apparatus for determining total respiratory resistance "R" using a forced volume oscillation. R is determined at the point of zero displacement and peak flow and includes the resistance of the airways, the tissue and the entire thoracic cage. An important feature of this invention is that once respiratory resistance R is determined by such a method, then work of breathing is determined by obtaining the integral of flow squared and combining it with this previously determined R. It is an object of this invention to provide a method and apparatus for measuring the total work of breathing expended by patients breathing spontaneously.

Another object is to provide simple and inexpensive apparatus for determining the integral of flow squared during one or more successive breathing cycles.

Another object of this invention is to provide apparatus for combining a previously obtained value of total respiratory resistance with the value of the integral of flow squared to provide a direct indication of the work of breathing.

Another object of this invention is to provide such apparatus with means included to compensate for dif-

ferences of air density encountered at different altitudes.

These and other objects and advantages of this invention are accomplished according to the preferred embodiment of this invention by measuring air or gas flow at the mouth with a dynamic pressure flow measuring device which provides an electrical signal proportional to air flow squared at the mouth multiplied by the air density. This signal is then scaled or multiplied by a circuit parameter proportional to the previously referred to respiratory resistance to obtain a second signal which is, in turn, integrated over one or more breathing cycles. The time constant of the integrator is adjusted for air density. The integrator output signal is then scaled and read on a meter as work of breathing. The integration must be performed over at least one complete breathing cycle and preferably is performed over many such cycles for greatest accuracy.

In the drawings, wherein is illustrated a preferred embodiment of this invention and wherein like reference numerals are used throughout to designate like parts,

FIG. 1 is a sectional view through a venturi tube which is a preferred form of the dynamic pressure measuring means of this invention;

FIG. 2 is a schematic of an integrating circuit utilized by this invention; and

FIG. 3 is an over-all schematic of the electrical circuitry employed in the preferred embodiment of the invention.

Utilizing the relationship of work of the respiratory system to flow resistance, the following equation for work can be derived:

$$(1) \quad W = R X \int_{t_1}^{t_2} \dot{V}^2 dt$$

where R is respiratory resistance, $\dot{V}$ is the flow of the air gas breathed and t_1 and t_2 limits of integration

An important aspect of this invention is that flow squared $\dot{V}^2$ is obtained by use of a dynamic pressure flow element such as a bidirectional pivot tube, an orifice or, preferably, a venturi tube. A venturi tube is preferred because its low back pressure doesn't materially add to the work of breathing. As illustrated in FIG. 1 a venturi tube 10 is connected at one end to a mouthpiece 11 and is open at its other end to atmosphere. Mouthpiece 11 is adapted to be inserted into the mouth of a patient so that the patient breathes normally through tube 10. Tube 10 is preferably symmetrical and includes two adjacent areas A_1 and A_2 of different, symmetrical cross sections. A pressure difference in the air breathed is developed between areas A_1 and A_2 and this pressure difference proportional to the density and velocity squared is sensed by a pressure transducer 12 connected between point 13 in area A_1 of tube 10, and point 14 of area A_2 of tube 10. Pressure differential transducer 12 converts the pressure differential between points 13 and 14 to an electrical signal at an output terminal 12a. Alternately, the pressure transducer may be connected between any point in tube 10, preferably at point 14, and the atmosphere, if the end is suitably flared.

As previously noted, work is a function of the integral of air or gas flow due to breathing, squared. By using standard equations for flow, flow squared V^2 is defined by the following relationship:

$$V^2 = (K/\rho) \Delta p \quad (2)$$

K is a constant which is related to various dimensions of the dynamic pressure flow measuring means. ρ is the density of the air or other gas breathed and also constant during the breathing cycles examined and Δp is the pressure differential sensed by transducer 12.

Equations (1) and (2) may be combined to give:

$$(3) \quad W = K \frac{R}{\rho} \int_{t_1}^{t_2} \Delta p dt$$

The output electrical signal of transducer 12 at terminal 12a is proportional to Δp and, from equation (3) it is evident that it is also proportional to flow squared of the air breathed and to the air density. Even though at low flow rates this pressure differential is small, the fact that the flow rate is squared increases the accuracy. Also accuracy of the measurement of the pressure differential increases with increases in the rate of flow where, because of the greater contribution to work, greater accuracy is required than at the lower rates of flow.

In order to utilize the electrical signal obtained at terminal 12a to determine work, this signal must be integrated in accordance with Equation (3). FIG. 2 illustrates a very high gain amplifier 15 and accompanying circuitry which integrates an input E_{in} to obtain the value E_o according to the equation:

$$(4) \quad E_o = \frac{1}{R_o C} \int_{t_1}^{t_2} E_{in} dt$$

By comparison it can be seen that Equation (4) is analogous to Equation (3) for defining work with voltage analogous to pressure and with both density ρ and the time constant $R_o C$ in the denominators.

FIG. 3 illustrates electrical circuitry for providing from this electrical analogy a readout of respiratory work. An input signal E proportional to Δp at terminal 12a is conducted to a potentiometer 16. The ratio of output to input signal across potentiometer 16 is scaled to correspond to the value of respiratory resistance R previously obtained such as by the apparatus and method in my copending application previously referred to, and the resulting electrical signal at the wiper arm of potentiometer 16 is then amplified through an isolation amplifier 17. The output of amplifier 17 is connected through a start-stop switch 18 to the input of the integrating circuit which includes resistor R_e , capacitor C , and high gain amplifier 15. Switch 18 determines the time of integration over a selected number of breathing cycles and the closing of switch 18 represents time t_1 in Equations (1), (3) and (4), and the opening of switch 18 represents time t_2 in these equations. A change in $R_e C$, the integrator time constant, is equivalent to a change in density ρ . Resistor R_e is preferably variable and it can be set to a value which corresponds to the density component ρ

which is one of the constants in Equation (3). Thus, the integrated output voltage E_o of amplifier 15 will be proportional to work and is read on a meter 19 connected to the output of amplifier 15 and scaled to read work directly. After the reading is taken from meter 19 for work expended during breathing between the times t_1 to t_2 then a switch 20, which is connected across integrating capacitor C can be closed to reset the integrating circuit to permit separate determination of work during different succeeding breathing cycles. For greatest accuracy, t_1 and t_2 should occur at the same portion of the breathing cycle, for example, at the end of expiration, regardless of how many cycles are indicated.

Thus, by the circuit of FIG. 3, the previously obtained value of respiratory resistance R is effectively combined with the integral of flow squared during selected breathing cycles to obtain the value of the work expended during these breathing cycles.

It is evident that although density correction by adjustment of the time constant or the resistance R_e is most convenient because the relationship is analogous and proportional, a scaling correction for density could be performed by gain changing means anywhere between pressure transducer 12 and meter 19. If a linear potentiometer is used, the density setting scale will be non-linear because of the reciprocal relationship in Equation (3). Also, density compensation and scaling for respiratory resistance could be made by correcting the value of the integral of flow squared obtained from the apparatus used.

From the foregoing it will be seen that this invention is one well adapted to attain all of the ends and objects hereinabove set forth, together with other advantages which are obvious and which are inherent to the apparatus and methods disclosed.

It will be understood that certain features and sub-combinations are of utility and may be employed without reference to other features and sub-combinations. This is contemplated by and is within the scope of the claims.

As many possible embodiments may be made of the invention without departing from the scope thereof, it is to be understood that all matter herein set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

The invention having been described, what is claimed is:

1. Apparatus for use in determining the total work of breathing of the human respiratory system, comprising, in combination: Dynamic pressure flow measuring means providing for conduction of gas in and out of such a respiratory system during at least one complete breathing cycle and responding to the pressure of said gas to provide an electrical output signal proportional to flow squared of said gas; adjustable means connected to the output of said dynamic pressure flow measuring means for simulating the total respiratory resistance of said respiratory system to provide a second electrical signal which is a function of said electrical output signal and said total respiratory resistance, integrating means for integrating said second electrical signal with respect to time to provide an electrical value proportional to work of breathing during at least one complete breathing cycle and means for indicating the work of breathing.

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2. The apparatus of claim 1 wherein said dynamic flow measuring means includes a flow element through which said air is conducted, and a pressure differential transducer connected with said flow element, said pressure transducer providing said electrical output signal proportional to said flow squared.

3. The apparatus of claim 1 wherein said integrating means includes means for scaling the time constant of integration in proportion to the density of the gas breathed.

4. The apparatus of claim 1 further including means for starting and stopping said integration to provide said integration over at least one complete breathing cycle.

5. A method of determining the work of breathing of the human respiratory system comprising the steps of: determining the value of flow squared during spontaneous breathing by conducting the gas breathed through a dynamic pressure flow measuring element and sensing the pressure drop across said element to obtain an electrical signal proportional to flow squared; modifying said electrical output signal to simulate the effect of total respiratory resistance on the work of breathing, and utilizing integrating means to integrate said modified electrical output signal over one or more

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breathing cycles to obtain work of breathing.

6. The method of claim 5 wherein said modifying step includes the step of setting a resistance scaling means to scale for predetermined respiratory resistance of said respiratory system; and further including the step of setting a density scaling means to scale for the density of the gas; and wherein said step of determining the value of flow squared includes the steps of conducting gas during one or more breathing cycles through a relatively low resistance dynamic pressure flow element and thereby creating a pressure differential proportional to flow squared and air density, utilizing a pressure transducer to measure said pressure differential and obtain a first electrical signal proportional to gas density and gas flow squared, scaling said signal by utilizing said respiratory resistance and density scaling means to obtain a second electrical signal proportional to respiratory resistance and flow squared; and wherein said integrating step includes the step of integrating said second signal over one or more breathing cycles to obtain a third signal proportional to the work of breathing expended during said one or more breathing cycles.

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