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AN INSTRUMENT FOR DETERMINING LUNG AIR-WAY RESISTANCE

By

M. AINSWORTH AND J.W. EVELEIGH

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SUMMARY OF
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An instrument for determining lung air-way resistance

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The construction and operation of an instrument for determining lung air-way resistance is described. This is an improvement on the Kymograph - bellows - lever instrument used for the work described in P.T.P. 320 (Ainsworth and Eveleigh 1952) in being more robust and more rapid in use. The values obtained by the two methods correlate well.

(Sgd.) H. Cullumbine.,
Head, Physiology Section.

(Sgd.) E.A. Perren.,
Supt., Research Division.

MA/JWE/JW.

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AN INSTRUMENT FOR DETERMINING LUNG AIR-WAY RESISTANCE

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1. In a previous paper (1), a method of measuring changes in lung air-way resistance to flow was described. The alveolar pressure (P_2), measured as the equilibrium pressure at the mouth after interrupting the expiratory air-flow, was compared with that (P_1) across an external resistance. The lung resistance (R_L) was then calculated from the relation;

$$R_L = (m - 1) R_s$$

where R_s = external resistance coefficient, and m = ratio of P_2/P_1 at high rates of flow. Traces of the pressure changes at the mouth were made using a kymograph and a bellows - lever system.

An advantage of the method was that sufficient data, in the form of a recording, for a resistance estimation could be obtained in less than one minute. It was thus possible to carry out serial tests, but the use of a kymograph, involving the adjustment of levers and frequent changing of the recording paper, limited the rate of repetition of the test. Furthermore, a considerable time was occupied in measuring the traces and converting the measurements into pressure values.

It was considered that a substantial improvement in the technique would be effected if the recording and measurement of traces could be eliminated.

The instrument to be described is a simple electronic system operated by a push-button type of control and indicating the two required pressures directly on panel meters.

2. General description

The instrument consists of two units:

(a) An electro-mechanical unit containing the standard choke, the air-flow interrupter, and a pressure- voltage transducer.

(b) The electronic unit, the panel of which is shown in Fig 1., containing a relay system to control the sequence of events in time, and two capacitors with associated electrometers for storing and indicating the output from the pressure - voltage transducer.

Changes in pressure at the mouth deform the metal diaphragm of a small manometer and the axial movement is transmitted to the anode shaft of an R.C.A. 5734 transducer. The potential across a resistance in series with this valve is applied to a capacitor and is indicated as electrometer valve current on the P_1 meter (Fig. 1.).

When the subject is exhaling fairly steadily, as indicated by this meter, the key-switch is depressed. This operation causes the transducer output to be disconnected from the P_1 capacitor, the meter continuing to register the P_1 "pressure". At the same time, the relay system is actuated to transfer the transducer output to the P_2 capacitor, and the air-flow is interrupted. After some milliseconds, the transducer is disconnected from the P_2 capacitor, and its associated electrometer continues to indicate the equilibrium pressure as a deflection on the P_2 meter.

Release of the key-switch then re-establishes the air-flow. The time for which the key-switch is depressed does not influence the measurements, and usually a complete operation takes 0.5 second or so.

3. Details

Transducer and manometer

The diaphragm of the manometer used was stiffened with solder until the displacement of its centre was approximately 0.025 mm. for a pressure differential of 50 cm. H_2O; the displacement was then linear with applied pressure over this range.

The change in effective impedance of the RCA 5734 valve was not quite linear with deflection of the anode shaft over the full range (30 minutes of arc) and, to improve the linearity, the angular deflection was limited to 5 minutes.

This was achieved by extending the effective length of the shaft by soldering to it a very light brass tube (1.8 cm. long) turned to a sliding fit. The transducer was mounted in a brass block as shown in Fig. 2. This Figure also shows the mounting and the method of adjusting the position of the diaphragm with respect to the anode shaft of the transducer.

The diaphragm carries a knife-edge at its centre and this bears on the free end of the anode shaft. The valve block and manometer are rigidly attached to an open "loop" formed by the metal pieces shown (Fig. 2). This loop can be partially closed by the screw AS, thus allowing accurate adjustment of the knife-edge with respect to the shaft. The clearance between these when the screw AS is relaxed is arranged to be approximately 0.5 mm. and the loop can be deformed to close this gap, the system then possessing desirable rigidity. A metal block acts as a back - stop to prevent damage to the transducer due to excessive pressure in the manometer.

Air-flow interrupter (Fig. 3)

A sliding vane V is rotated through 30° of arc by the rotary solenoid* S and closes the air outlet O. The time to complete closure of this valve from applying 30 volts to the solenoid coil was found to be approximately 10 milliseconds. This time was reduced somewhat by applying a pulse from a 1000 microfarad capacitor charged to 60 volts.

Relay system

The sequence of events in time is of considerable importance. Disconnection of the transducer output from the P_1 capacitor must occur before the interruption of the air-flow, the interval being as short as possible.

* U.S.A. Type 75-1-PB1, rated at 28 volts.

Transference of the transducer output to the P_2 capacitor must be simultaneous with, or precede complete interruption of the flow. This condition is necessary because, after interrupting the flow, the equilibrium pressure at the mouth may rise and the recording time must therefore be as short as possible. The limit is set by the time - constant of the storage capacity and the impedance of the transducer. Finally, disconnection of the transducer output from the P_2 capacitor must precede re-establishment of the air-flow.

The correct sequence of events was achieved as follows, the description referring to Fig 4. Relays R1 and R2 are already ON and the contacts are set as shown in the diagram. The transducer output T is connected via R11 and R22 to the P_1 capacitor. When the key-switch is depressed to TRIGGER, S1 primes R23 to close the interrupter-solenoid circuit when R2 releases. S2 puts a large positive pulse on the grid of V12 and the "flip-flop" circuit operates, releasing R1. R11 then transfers the transducer output from the P_1 to the P_2 capacitor, R12 releasing R2, this release being made irreversible by R21. R23 closes the solenoid circuit and the air-flow is arrested; simultaneously R22 disconnects the P_1 capacitor from R11.

The "flip-flop" then resets after a time controlled by C1 and r7, leaving the P_1 and P_2 capacitors disconnected from the transducer output, R2 being OFF and the air-flow still arrested. The key-switch is then released and returns to the mid-position. This opens the circuit of the interrupter S and the air-flow is re-established; C2 is also recharged ready for a new operation of the flip-flop.

Before a second operation is carried out, the key-switch is put to RESET momentarily. S4 and S5 short the storage capacitors and the meter deflections return to zero; S3 puts a short on R21 and R2 is switched ON. On returning the key-switch to the mid-position, the transducer is re-connected to the P_1 capacitor by R22. The sequence of switching operations is shown diagramatically in Fig 5.

Transducer and electrometers

The structure of the RCA 5734 valve is such that it is most convenient to earth the anode, and in the present circuit (Fig 6) the transducer cathode is approximately 90 volts negative to earth for zero manometer pressure differential. The capacitor and electrometer potentials, therefore, are referred to a potential 150 volts above the -240 volt line, provided by a gas-filled stabilisor (V4). Accurate adjustment of the output of the transducer to this potential is effected by r1 and r4 which are taken to the panel; r4 serves as a coarse adjustment and is preset, and r1 is used as a "fine - balance" control.

The cathode resistor of the electrometer valve supplies negative feed-back and full-scale deflection of the 0 - 500 microammeter is obtained with approximately 5 volts on the grid, the effective gm being constant over this range. The cathode resistors are preset so that this gradient can be adjusted to be the same for both electrometer valves. The heaters of these valves are run at reduced temperature, being supplied at 4 volts. The standing current ($V_g = 0$) in each meter is backed-off by r6 (Fig 4) which is taken to the panel and used as an "adjust zero" control. The external valve screens are removed and the valves heated and coated with picien wax, this reducing surface leakage and excluding light.

C1 and C2 are good quality capacitors (7KV working) and all leads to these are well insulated, those passing through the chassis being led through blocks of Perspex. Insulation of the relays (type PO 3000) and the key-switch was found to be inadequate and was replaced with Perspex, all the connecting wires being air-insulated. With such precautions, the capacitor leakage, as indicated by the meter should not be more than 1.0 microamp. per minute (0.2% of full-scale). This is negligibly small, readings usually being taken within a matter of seconds from operating the intrument. The capacity of C2 is kept low (0.01 microfarad) to minimise the charging time-constant.

Power Supplies

The electrometer characteristics are not seriously affected by small changes in anode voltage, but the transducer circuit is not balanced and a stabilised supply is provided for this section of the unit. The supply is stabilised at - 240 volts using a cathode neon-stabilised pentode (V6) controlling a series valve (V8). V5 is employed to gain some sensitivity by allowing nearly all the line voltagr deviations to be impressed on the grid of V6, final adjustment of this grid potential being carried out with r5.

The rotary solenoid used for interrupting the air-flow requires a large initial current (2 amps.) which drops at the end of the motion to a holding current of 0.15 amp. A transformer and rectifier capable of supplying the holding current are used and a capacitor of 1000 microfarads provides the initial heavy current.

Setting up the instrument

The electrometers are first balanced by adjusting the preset bias resistors. The key-switch is depressed and returned to the mid-position to isolate the capacitors and electrometers from the transducer circuit. With the standing currents backed-out ("adjust zero" control) stepped voltages (0 - 5v) are applied to both grids and the i_a/V_g curves obtained; these should be rectilinear. Using V2 as a reference, and a grid potential giving a meter current of 400 - 500 microamps, the bias of V3 is adjusted until the meters read the same value. The grids are "grounded" by putting the key-switch to RESET and the current in the P2 meter is reduced to zero using the "adjust zero" control. The procedure is repeated until the meters read in parallel over the whole range.

When the electrometers are balanced, the key-switch is put to RESET and then returned to the mid-position. The transducer adjusting screw AS (Fig 2) is relaxed so that the knife-edge is not in contact with the transducer anode shaft. The balance controls, r1 and r4, are then adjusted until the P_1 meter reads zero. Screw AS is slowly rotated until contact of the knife-edge with the transducer shaft is indicated by a deflection on the meter (50 microamps. or so). The balance controls r4 and r1 are re-adjusted to reduce the deflection to zero, and the instrument is ready for operation.

Discussion

A certain amount of judgement must be exercised to depress the key-switch at the correct moment after the subject has commenced to exhale. As a general rule, the deflection on the P1 meter increases rapidly at first, but near the peak air-flow rate the deflection changes more slowly. This is the correct moment to operate the instrument. There is a delay of some milliseconds between registering the two pressures, and if, for example, the expiratory air-flow is rapidly increasing when the key-switch is depressed, the second pressure registered is too high. In addition, most subjects find a little difficulty at first in exhaling steadily for a second or so. Unreliable readings, therefore, do occur, and their occurrence is usually at the beginning of a series of operations. We have found it advisable to ignore the data from the first three or four operations of the instrument with a new subject; these operations serve as a practice run both for the subject and the observer. An estimate of the lung resistance is then based on ten or more pairs of P1 and P2 values, and we have adopted the procedure of first plotting these values. The points should lie closely about a straight line passing through 0,0, and values which are apparently unreliable plot aa points lying well removed from the line. In one series of estimates on ten subjects, the instrument was operated 600 times and the number of pairs of pressure values considered unreliable, from plots of the data, was 49. Of the latter, 28 occurred during the first four operations in each of 40 series of observations.

The total incidence of unreliable values was therefore 8.2%. Amongst the group comprising the first four operations in each sereis the incidence was 17.5%, and in the rest 4.8%. Results obtained using thisinstrument were compared with those obtained previously using a bellows-lever system and a kymograph (1). The same standard choke and external resistance were used, estimates being made of the lung" resistance with and without the external resistance. The results are summarised below in Table 1.

TABLE I

Measurements of an artefact increase in lung air-way resistance

Subject	Estimated resistance coefficient (cm. H_2O / (litres/sec.)$^{1.6}$)		
	A Lung	B With external resistance	(B - A) External resistance
Ga	4.21	10.95	6.74
Le	3.34	9.25	5.91
Ma	3.20	9.52	6.32
Sm	3.34	10.60	7.26
Ev	4.35	11.00	6.65
Va	4.28	10.10	5.82
Ha	3.61	11.05	7.44
As	2.80	8.80	6.00
Mean	3.64 ± 0.54		6.52 ± 0.56
The corresponding values obtained previously (1) were:-			
	3.72 ± 0.36		6.39 ± 0.52

This comparison indicates that the same degree of precision is obtainable with either the kymograph - bellows - lever system, or with the instrument described. The latter is more robust and considerably more convenient in use, especially when many estimations are involved.

(Sgd.) H. Cullumbine,
Head, Physiology Section.

(Sgd) E.A. Perren,
Supt., Research Division.

MA/JWE/JW

<u>Reference</u>

(1) Ainsworth M. and Eveleigh J.W. P.T.P. 320 1952.

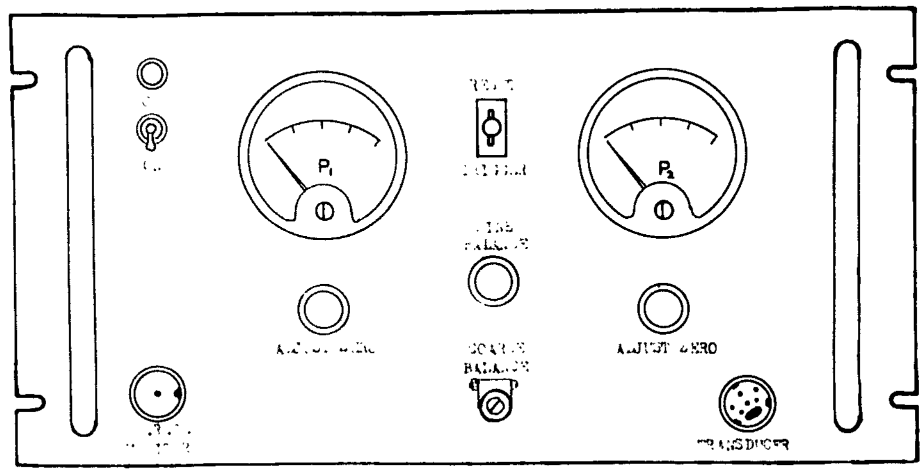

Fig. 1 ELECTRONIC UNIT

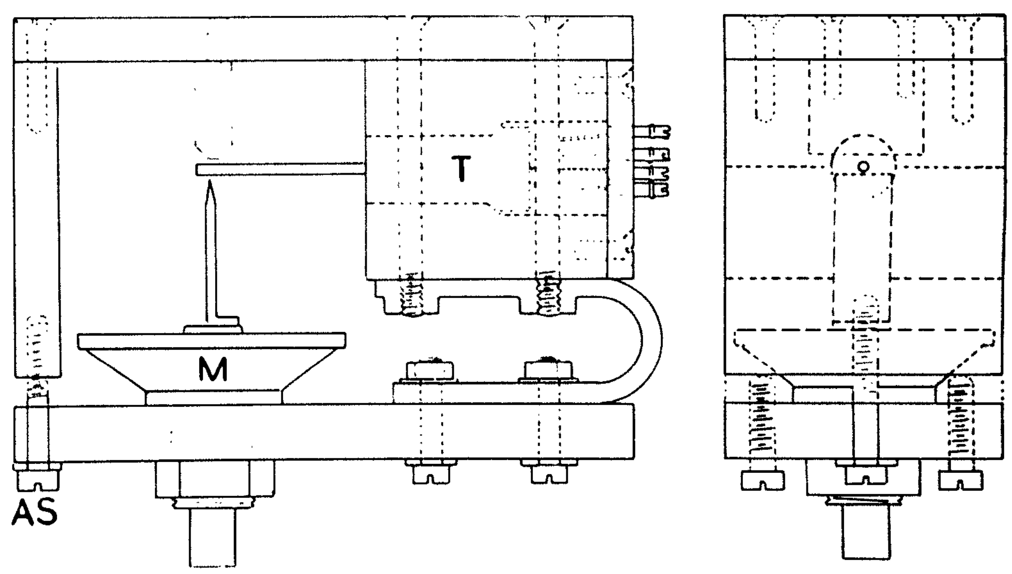

Fig. 2 TRANSDUCER-MANOMETER MOUNTING

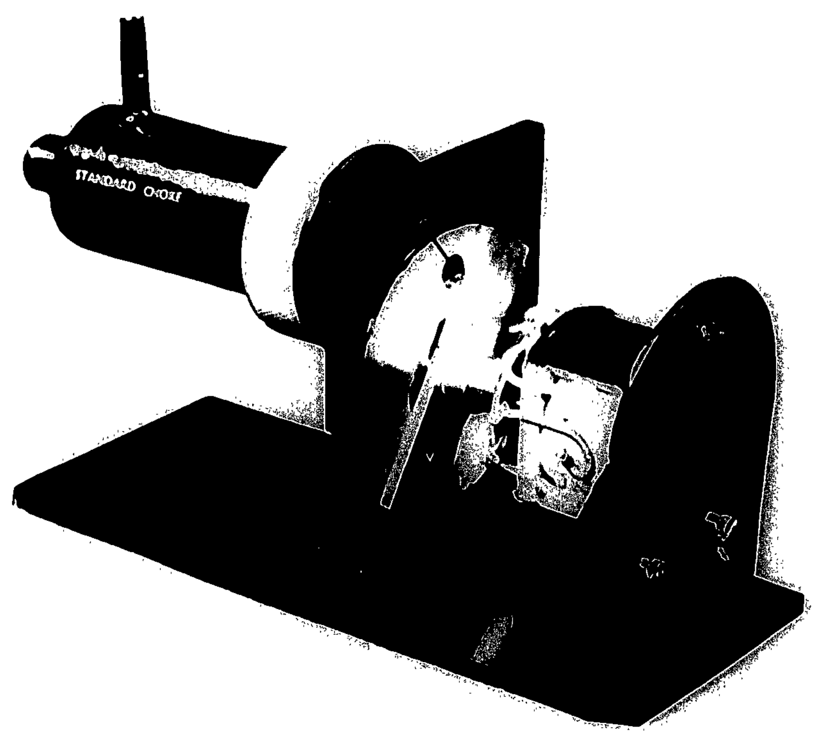

Fig.3 AIR-FLOW INTERRUPTER

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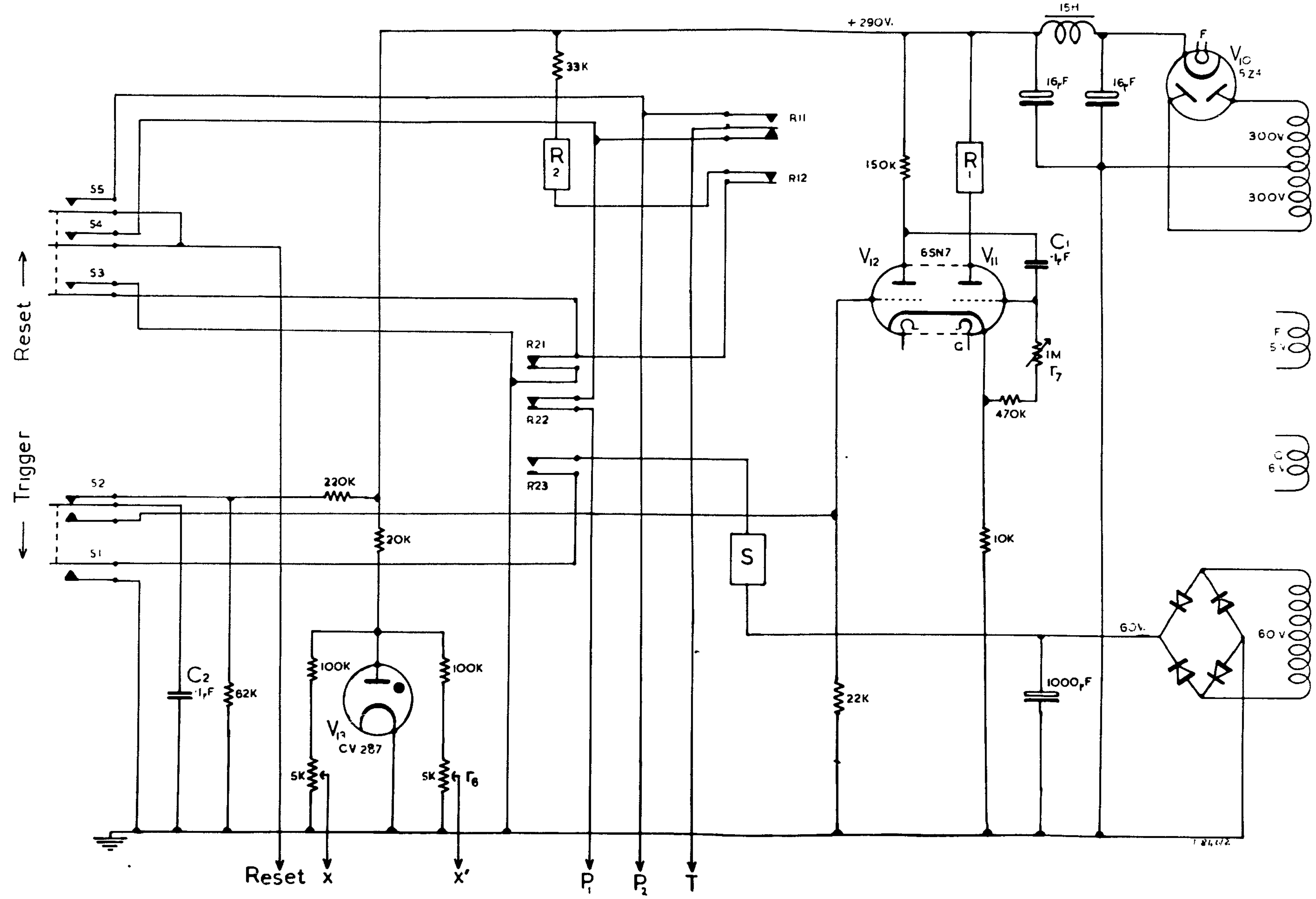

Fig. 4 RELAY SYSTEM

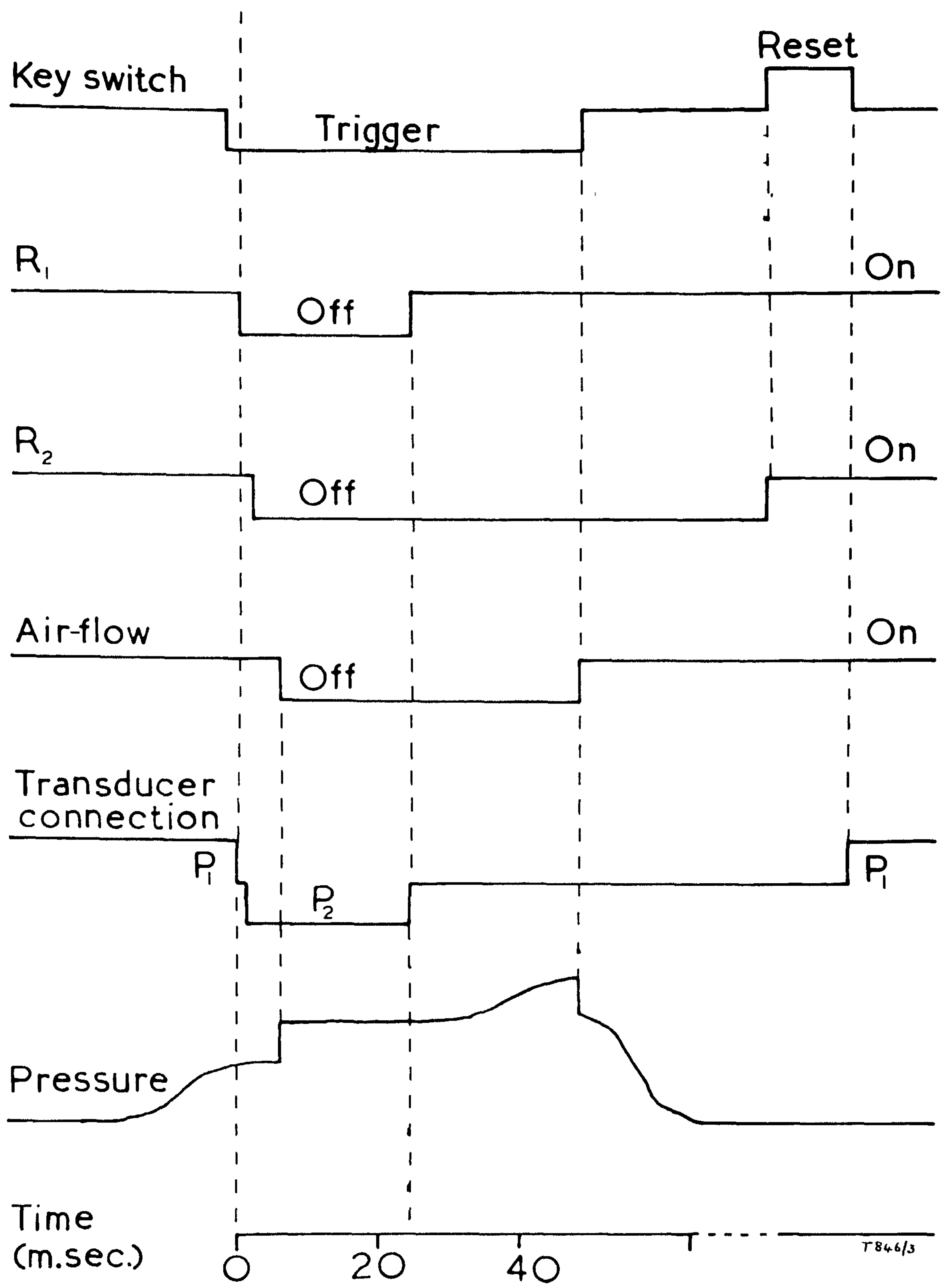

Fig. 5 Switching sequence

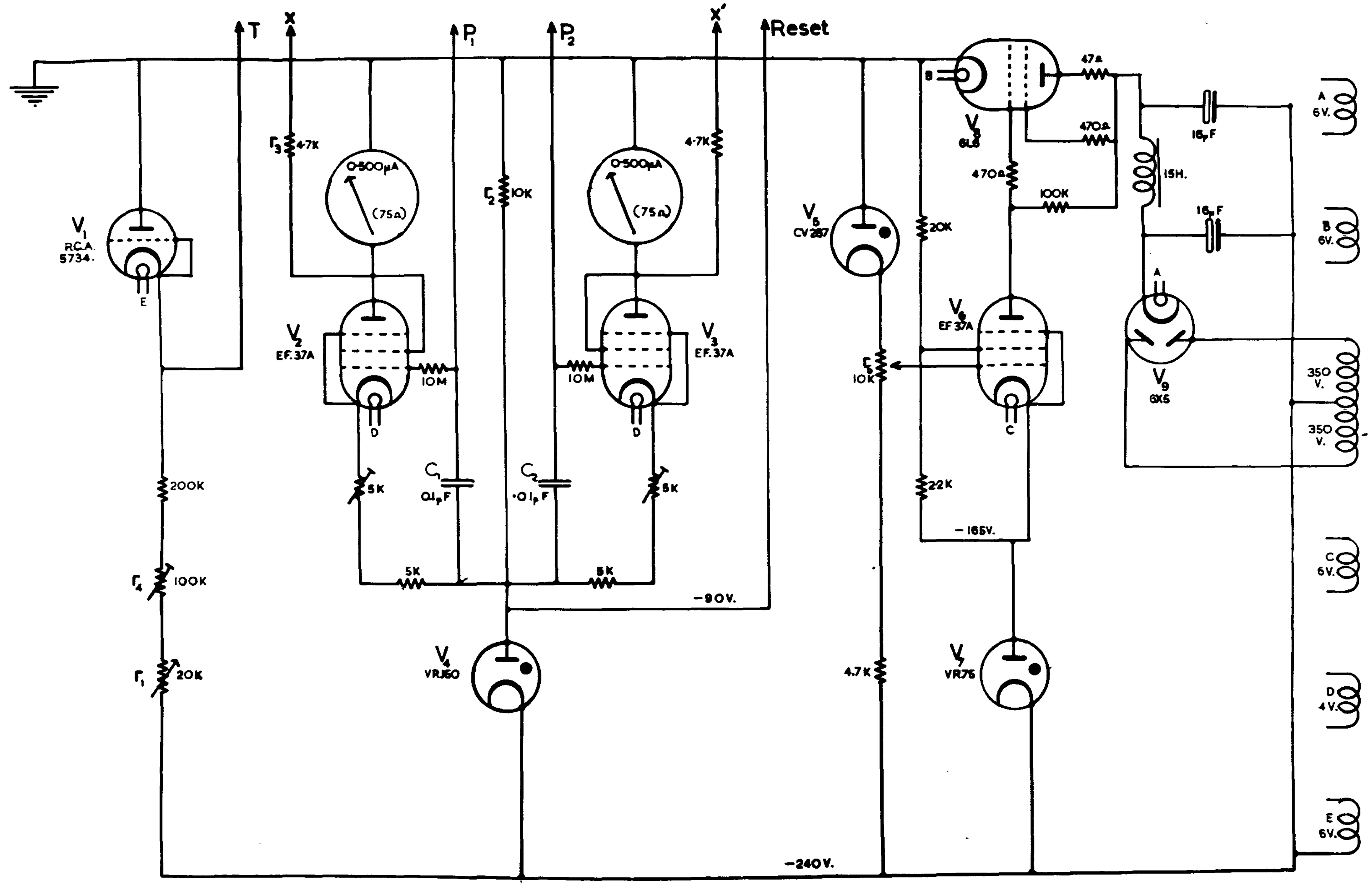

Fig. 6 TRANSDUCER AND ELECTROMETERS

P.T.P. 331

CIRCULATION
INTERNAL

P.D.S.R.(D)
D.C.D.R.D.
C.S.,C.D.E.E.(28)
D.D.R. Branches (2)
S., C.D.R.E. (2)
D.P.B.R.
R.D.Arm.2.
T.P.A.3/T.I.B. (2)
S.A.C.(15) for Biology
Committee, C.D.A.B.
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Advisory Board (12)
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C.D.A.B. (6)

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British Joint Services Mission

D.C. Evans, Esq., (12)

War Office

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U.S.A.

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