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An Automatic Self-Balancing Capsule Manometer

By

G. F. Midwood and R. W. Hayward

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ROYAL AIRCRAFT ESTABLISHMENT

An Automatic Self-Balancing Capsule Manometer

by

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SUMMARY

This note contains a brief description of an automatic self-balancing capsule manometer which has been developed primarily for the measurement of pressures encountered in the operation of supersonic wind tunnels.

A remote indicating system is employed which is suitable for use with digital recording and card punching apparatus.

The instrument has been designed to cover a range of 0-2 atmospheres absolute and has been adjusted and calibrated to give an accuracy of 0.01" Hg over the range 0.5" Hg to 60" Hg absolute.

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1 Introduction

Arising from the operation of supersonic wind tunnels, a demand has grown for the measurement of pressure differentials over much larger ranges than has been usual in the past. It has also been considered necessary that some form of recording shall be used in order to reduce the running time of the wind tunnel, and hence the operational costs, to a minimum.

Modern techniques rely on the simultaneous measurement of a large number of pressures, 100 is not unusual, and experience has shown that the conventional type of manometer using mercury in glass tubing is not entirely satisfactory for this purpose. The main troubles with this type of manometer are the difficulty of maintaining the mercury and the tubing in a clean condition and the sluggishness due to the large air volumes involved, since large bore tubing is essential for reliable results. In addition, liquid manometers of this kind cannot be adapted for automatic recording without considerable difficulty and complication.

In view of the above it was considered that a null-reading system using a capsule operated self-balancing weighbeam would be most likely to satisfy the requirements, the self-balancing arrangement ensuring minimum of error due to hysteresis effects in the capsules. The equipment would be very suitable for use with repeating and recording mechanisms.

This note describes such an instrument which, together with its associated equipment, has been in operation for some time and has proved reliable and accurate.

2 Description of Apparatus

2.1 General

The complete installation consists of the following:-

(a) Self-balancing capsule manometer, para. 2.2.

(b) Control unit, para. 2.3.

(c) Remote reading indicator, para. 2.4.

A block diagram of the arrangement is shown in Fig. 1.

2.2 Manometer

The manometer consists of a pair of opposed pressure sensitive capsule stacks connected to a weighbeam which is arranged to balance the moment applied by the pressure difference in the capsules by a travelling jockey weight.

This particular instrument was required to give measurements in terms of absolute pressure, consequently one of the capsule stacks was evacuated and sealed.

The arrangement is shown diagrammatically in Fig. 2 and a photograph of a capsule unit in Fig. 3.

The capsules are mounted horizontally with the outer ends firmly secured to a bracket which is bolted to the base of the instrument. The inner (free) ends of the capsules are connected together by a rigid bar which is coupled to the arm of the weighbeam by a pair of links in such a fashion as to ensure that the motion of the capsule bar will be horizontal.

In order to eliminate friction and backlash the attachments of the coupling links are of the flexural spring type. Photographs of the arrangement are shown in Figs. 4 and 5.

The weighbeam consists of a framework suspended from the capsule bracket by a set of crossed-spring flexural pivots. On the frame are mounted the jockey weight and its driving mechanism.

The travelling jockey weight is driven by a lead-screw which is turned by an electric motor (DR compass step-by-step repeater motor, Ref. No. 6A/1057) mounted on one of the end brackets of the beam. The lead-screw is supported in bearings provided in both end brackets and is coupled to the motor through spur reduction gearing. The gear ratio is such that a movement of two steps on the repeater motor causes a jockey weight shift which gives a change in moment corresponding to the prescribed limit of accuracy, in this case 0.01" Hg.

The above mentioned standard of accuracy demands that the precision of movement of the jockey weight shall be reliable to 0.001". Particular attention has, therefore, been paid to the elimination of friction and backlash. These two requirements conflict, but a satisfactory solution has been found in the particular method of supporting the jockey weight. This is shown in Fig. 6. A tripod arrangement of mounting is used, consisting of a pair of rollers located towards one end of the weight and a half-nut at the other end centrally disposed. The rollers bear upon the side rails of the beam, one roller being provided with flanges to give lateral location, whilst the half-nut engages with the threads of the lead-screw. In order to provide positive location of the jockey weight the threads of the lead-screw and half-nut are of truncated Whitworth form so as to ensure contact on the inclined faces and not on the tops of the threads. The lead-screw is spring loaded to prevent random axial displacement of the lead-screw and jockey weight assembly.

The load of the jockey weight is distributed between the side rails and the lead-screw in unequal proportion by the selected positions of the rollers and half-nut. These positions are so arranged relative to the centre of gravity of the weight that only sufficient load is carried by the half-nut to ensure positive engagement with the lead-screw; the remaining load is carried, via the rollers, on the side rails.

An iron armature is fixed to the end bracket of the beam remote from the lead-screw motor. This armature is positioned in the air-gap of the coils of an electro-magnetic pick-up unit which is mounted on the base and serves to generate the signal for the operation of the control unit, see para. 2.3.

At the same end of the beam are also mounted a simple type of oil dash-pot to damp the oscillations of the weighbeam and a pair of adjustable stops to limit the movement. To ensure the minimum of error due to hysteresis in the capsules, the stops are adjusted so that the maximum deflection of the capsule assembly does not exceed 0.002".

Electrical connections are made with a standard multi-pin plug and socket.

General views of the instrument are shown in the photographs Fig. 7 and 8.

2.3 Control Unit

The control unit (Fig 12) consists of a chassis on which are mounted the amplifier, motor-generator, (Ref. No. 5U/5009) transmitters, and power-pack. The transmitters are driven by the motor-generator through reduction gearing and are used to energise the step-by-step repeater motors which drive the weighbeam lead-screw and the remote reading indicator. Recording mechanism may also be driven by these transmitters, using parallel connections.

The transmitters used in the equipment described in this note were of the contactor type with eccentric roller drive, Ref. No. 6BB/893, shown in Fig. 16, but this type proved unreliable and has now been superseded by another of improved design (commutator transmitter type 1, Ref. No. 6BB/1093), in which commutation is derived from the action of rotating segmental slip-rings to which spring loaded brushes make electrical connection. To obtain reliable operation the brushes must be free in their holders and the brush pressure must not be less than 25 grammes, otherwise intermittent commutation may take place. Views of this transmitter are shown in Fig. 17.

The amplifier is simple in concept and has been designed to operate at a frequency of 50 c.p.s. so that it can be used directly from a standard A.C. mains supply.

The first valve is a double-triode, CV.181, used as a two-stage straight amplifier with a gain of about 500; this is followed by a phase discriminating rectifying bridge using a CV.181 with its anodes connected to 40 volt A.C. supplies in anti-phase. The output stage consists of two CV.510 pentodes, arranged in push-pull fashion, with the field windings of the motor-generator connected in the anode circuits. The output valves are biased to give a standing current of 25 mA each so that a maximum variation of 50 mA is obtainable in each field winding. A circuit diagram is shown in Fig. 9 and the operation is briefly described below.

The out-of-balance signal generated in the pick-up unit is amplified and passed to the two halves of the discriminating rectifier. (Fig. 10 shows details of the pick-up unit and Fig. 11 is a typical calibration). The rectifier is phase sensitive and controls the grids of the output valves so that the excitation of the field windings in the anode circuits varies in sympathy with the voltage and phase of the original out-of-balance signal and so causes the motor-generator to run in the appropriate direction to restore the equilibrium of the system. The armature is connected across a steady D.C. supply, and the output from the generator is connected across the cathodes of the discriminating valve to provide negative feed-back for stabilising purposes. The power-pack is of conventional design using a 5Z4 rectifying valve.

2.4 Remote Reading Indicator

The remote reading indicator (Figs. 13 and 14) is a mechanical device arranged to count the revolutions of the weighbeam lead-screw and to present the readings in terms of inches of mercury on a circular scale.

A repeater motor, mounted at the back of the instrument, drives a pointer through gearing so arranged that 200 steps on the repeater motor produce one revolution of the pointer. The scale on the circular dial is divided into 100 divisions, each division representing 0.01" Hg, hence one revolution of the pointer is equivalent to 1.0" Hg. Each revolution of the pointer is indicated on a set of number wheels visible through apertures in the dial, the particular arrangement allowing the instrument to indicate up to 99.99" Hg.

The instrument has many applications and can be used for the indication of force, temperature, position etc., in systems which employ this particular method of repeating.

It has certain advantages over the conventional wheel type counter; for instance, in the event of a fluctuating load, assessment of the reading is possible by observation of the limits of movement of the pointer, whereas with the wheel type counter assessment would be difficult owing to the loss of definition of the characters on the fast moving wheels.

A further advantage concerns the speed of operation. The conventional wheel type counter, using die-cast alloy gears is usually limited to a maximum speed of about 200 r.p.m; should higher speeds be demanded, more costly mechanisms using hardened and polished gears would be necessary.

The instrument described here dispenses with the first high speed count wheel and uses a pointer instead, it should thus be able to run at ten times the speed, but is in fact limited by the maximum permissible speed of the repeater motor which is in the region of 1000 r.p.m.

A conventional wheel type counter would probably be quite satisfactory given steady loading conditions and low operating speed.

Adjustments to the zero of the indicator are made by de-energising the motor and moving the pointer by means of the fingerknob at the back. This method, however, does not permit movements of less than six steps at a time (0.03" Hg), and a fine adjustment is now being fitted to all the indicators, which allows the pointer to be set to any position while the motor is energised.

A modified indicator is shown in Figs. 18 and 19. The motor is mounted in a bearing on the back-plate of the instrument and can be rotated manually to give the precise setting required. Adjustment has been restricted to steps of 30 degrees, (equivalent to one step on the repeater motor) by a set of spring loaded catches which lock the motor in any of 12 equally spaced positions.

The electrical connections are made through slip-rings which allow unrestricted manipulation of the motor.

2.5 Wind Tunnel Installation

A battery of 50 manometers and associated equipment has been installed in a supersonic wind tunnel at N.A.E. and is in regular use on routine pressure plotting work.

The manometers cover a range of 0-70" Hg absolute and are mechanically identical with that which is described in this note.

The manometers, control units, and power packs are mounted in cabinets which are installed in a room remote from the observation room. Each cabinet houses 10 units and is provided with independent switching so that any or all of the cabinets can be put into operation as required.

A view of the installation is shown in Fig. 20.

The remote reading indicators are installed in the observation room adjacent to the control desk. The instruments are arranged in sets of 10 to suit the manometer installation and are mounted on hinged panels to facilitate setting prior to use.

The installation is shown on the left of Figure 21.

A tape indicator board is also installed in the observation room and is used to give a general display of the pressure plot; it is also useful in checking the operation of the equipment, as a faulty manometer or pressure pipe can easily be detected.

A view of the unit is shown on the right of Fig. 21.

3 Calibration

3.1 General

The manometer was calibrated against a precision mercury manometer, using a Kew type barometer as datum for absolute pressure. The readings were corrected to a standard temperature of 16.6°C.

A "Warming Up" period of about 30 minutes was required for the electronic apparatus to reach steady conditions, and this was allowed in all the tests.

A few preliminary tests were made to check the operation and after adjustments to the alignment of the capsules and the weight of the travelling jockey, the calibration shown in Fig. 15 was obtained. Results show that the instrument gave an accuracy of ±0.01" Hg over the entire range. This was repeated over a period of several days with only negligible variations and was considered satisfactory.

The response to changes in ambient pressure was checked by comparison with a Kew type barometer and found to be satisfactory. The changes in ambient pressure were due entirely to the variation in barometric pressure, as at that time equipment was not available for the direct control of ambient pressure.

Since the above tests were completed, however, a pressure chamber has been installed, and subsequent tests on similar instruments have shown that the changes in ambient pressure are followed faithfully and consistently.

3.2 Temperature Effects

Tests were made to check the effects due to variation of ambient temperature on zero readings and on the calibration.

The manometer was enclosed in a cubicle, the interior of which was heated electrically; it was also vented to ensure pressure equilisation with the room in which it was placed.

The interior temperature of the cubicle was controlled and varied over a range from room temperature, about 15°C, to 28°C. Up to the maximum temperature of 28°C negligible change in readings of ambient pressure was noted over several hours, the tests being repeated on different days. A check calibration was then made at the maximum temperature of 28°C and agreed fairly well with the original calibration made at a room temperature of 15°C. The results of this check are shown plotted in Fig. 15.

4 Further Developments

Further developments have resulted in the satisfactory operation of other instruments over a wide variation of ranges. The instruments were made to the same basic design as that which is described in this note, but were fitted with appropriate capsule assemblies and jockey-weights to suit the particular range for which the instruments were required.

One instrument was made to cover the range 0-15" H_2O pressure difference and was adjusted to give an accuracy of 0.01" H_2O over the entire range.

Another instrument was made to cover the range 0-4 atmospheres absolute. At first the results were not satisfactory, the calibration showing marked non-linear characteristics with errors of the order of 0.5%.

This surprisingly poor performance was unexpected, but was eventually traced to misbehaviour of the capsule assembly. Many tests and experiments were made to find the reason, but nothing definite emerged. The capsule assemblies were of the multi-diaphragm type soldered together to give stacks of the requisite dimension and it was presumed that internal stresses had been introduced during manufacture and became modified under certain conditions of loading.

These capsule assemblies were replaced by others consisting of standard hydraulically formed brass bellows. Satisfactory results were obtained with this arrangement, the calibration being linear, but with a mean slope of 1 in 2000, the deviation from the mean being of the order of 0.01" Hg. The slope could have been corrected by adjustment to the jockey-weight, but this was not done as the results were considered satisfactory for the purpose for which the manometer was required.

5 Conclusions

A self-balancing automatic manometer of the type described can be made and adjusted to give accurate readings over large ranges such as are encountered in the operation of supersonic wind tunnels.

The instrument described in this report was tested over the range 0.5" Hg to 60" Hg absolute and was found to give an accuracy of ±0.01" Hg throughout this range.

It is important that great care be taken of the following points:-

1 Assembly and alignment of the component parts to be made with great precision.

2 Spring centres and spring links must be initially flat and must remain so after asserbly.

3 The amplifier must be free from drift.

4 The manometer is sensitive to draughts and must be protected with a ventilated shield or cover.

5 A "warming-up" period of about 30 minutes is required before the instrument is ready for use.

Acknowledgements

Acknowledgements are due to K. V. Diprose for considerable help in the design of the electronic equipment and to E. C. Brown for help in connection with development and calibration.

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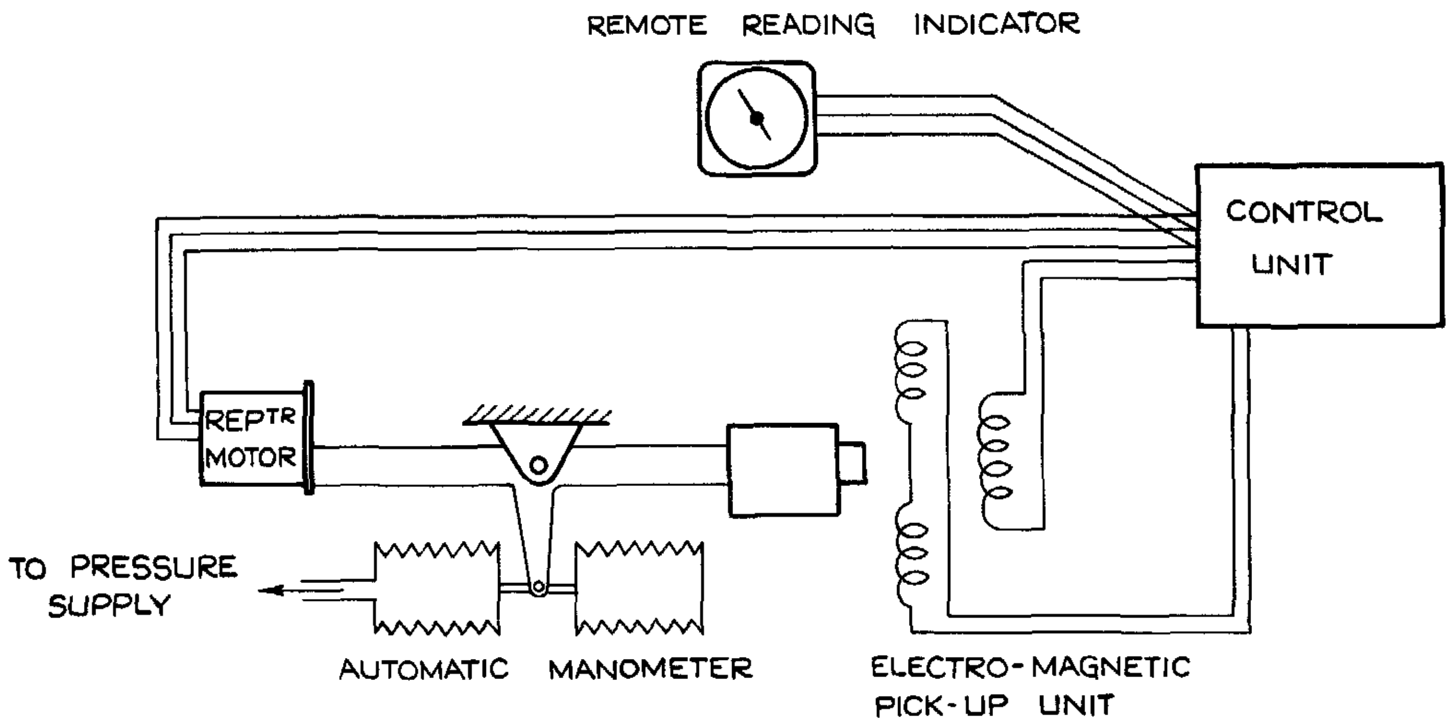


FIG. 1. BLOCK DIAGRAM. AUTOMATIC MANOMETER.

FIG. 1.

FIG. 2.

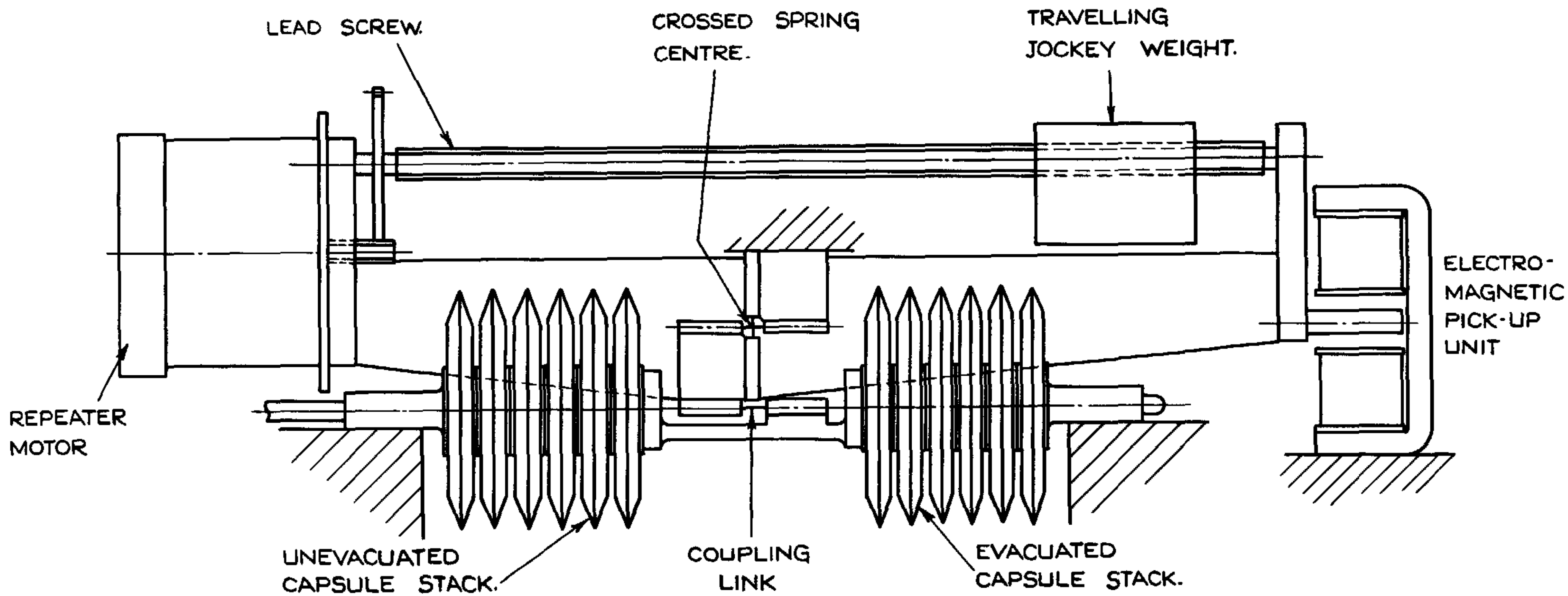


FIG. 2. DIAGRAMMATIC ARRANGEMENT. AUTOMATIC MANOMETER.

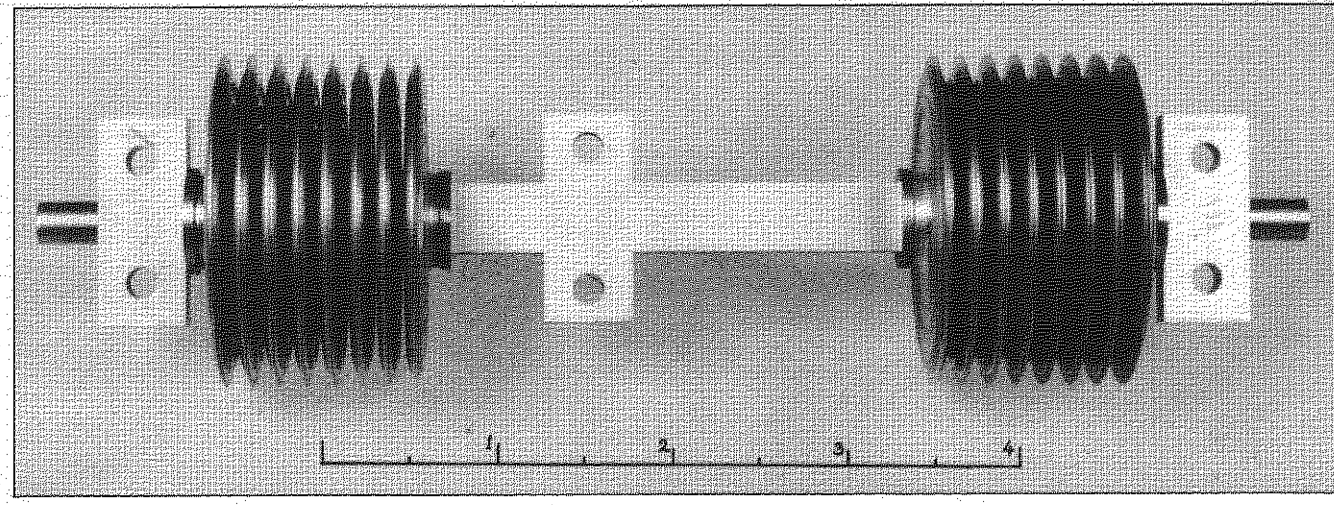


FIG.3. CAPSULE UNIT

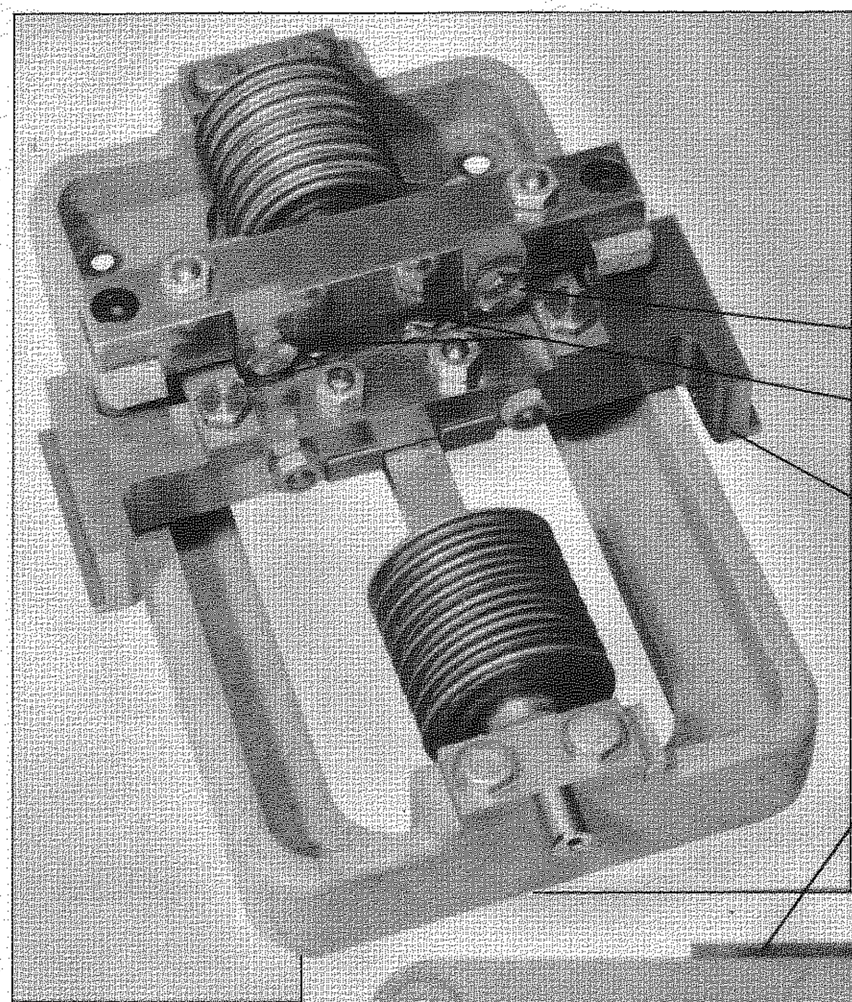


FIG.4.
CAPSULE ASSEMBLY,
TOP VIEW

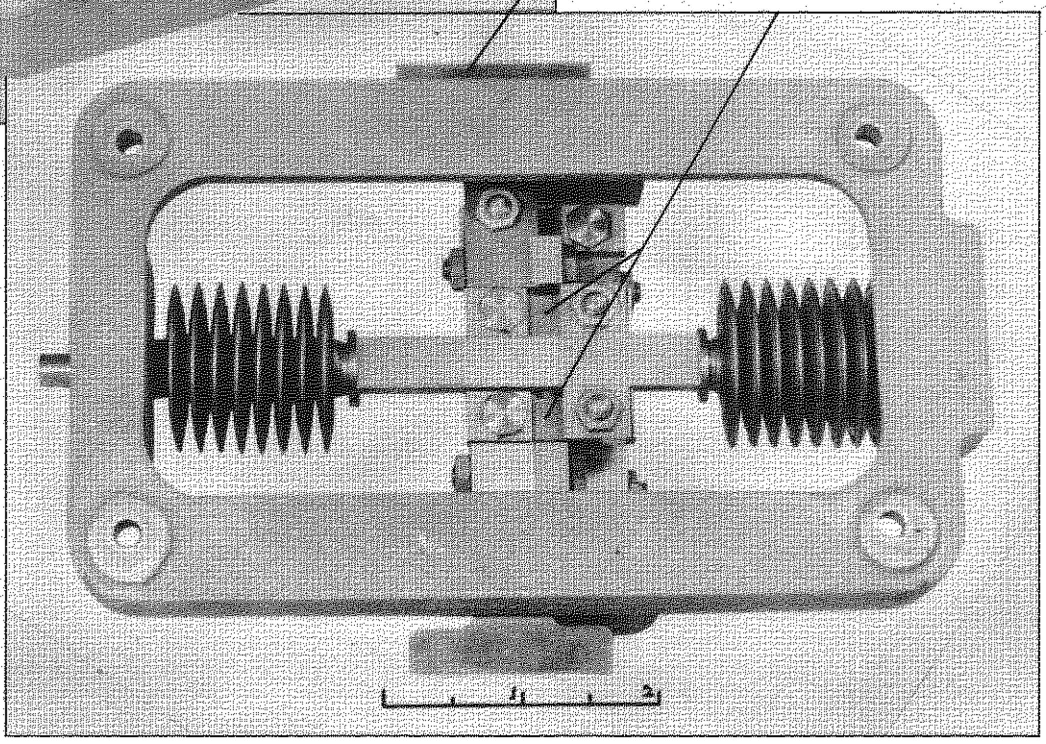


FIG.5. CAPSULE ASSEMBLY, UNDERNEATH VIEW

FIG.3,4 & 5. AUTOMATIC MANOMETER

FIG.6,7 & 8

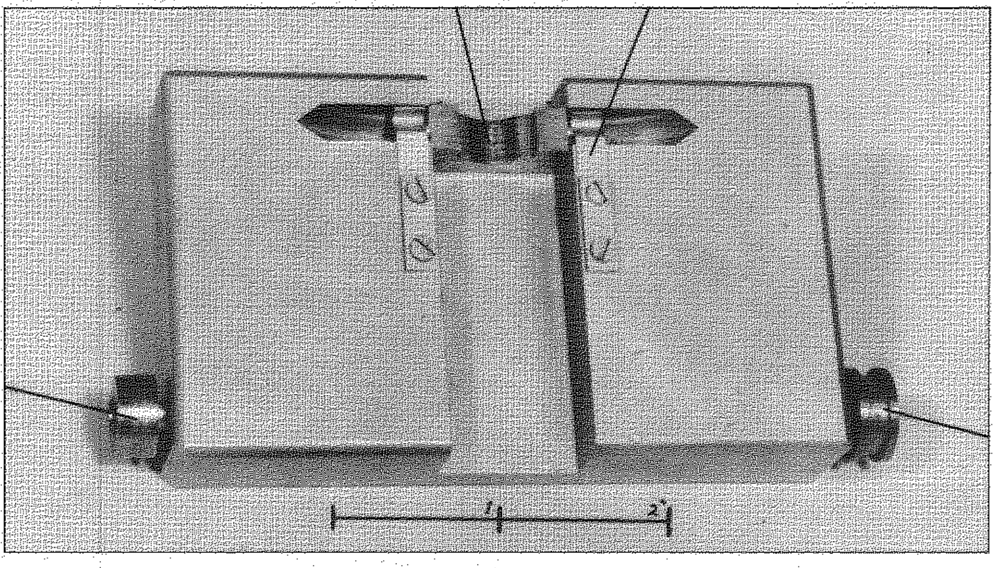


FIG.6. UNDERNEATH VIEW OF JOCKEY WEIGHT

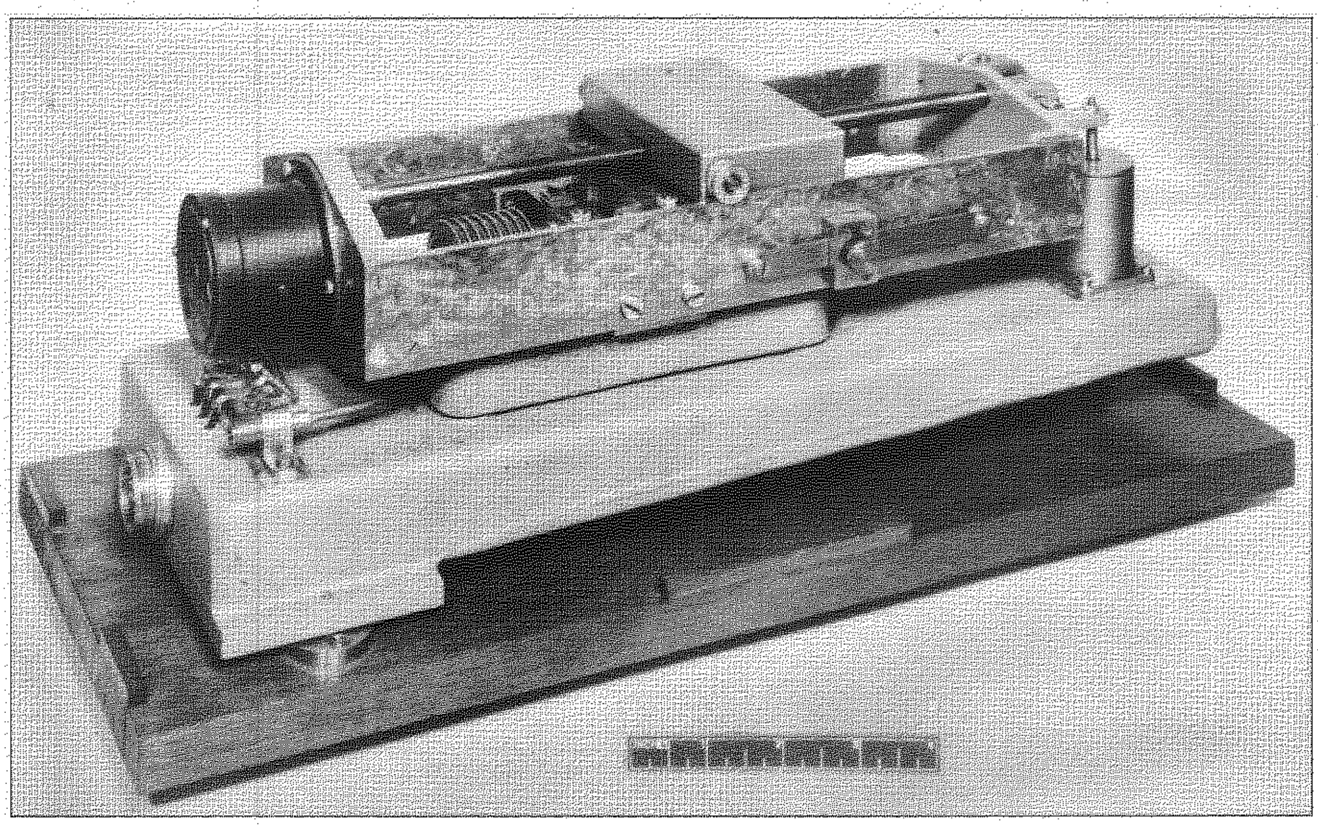


FIG.7. GENERAL VIEW

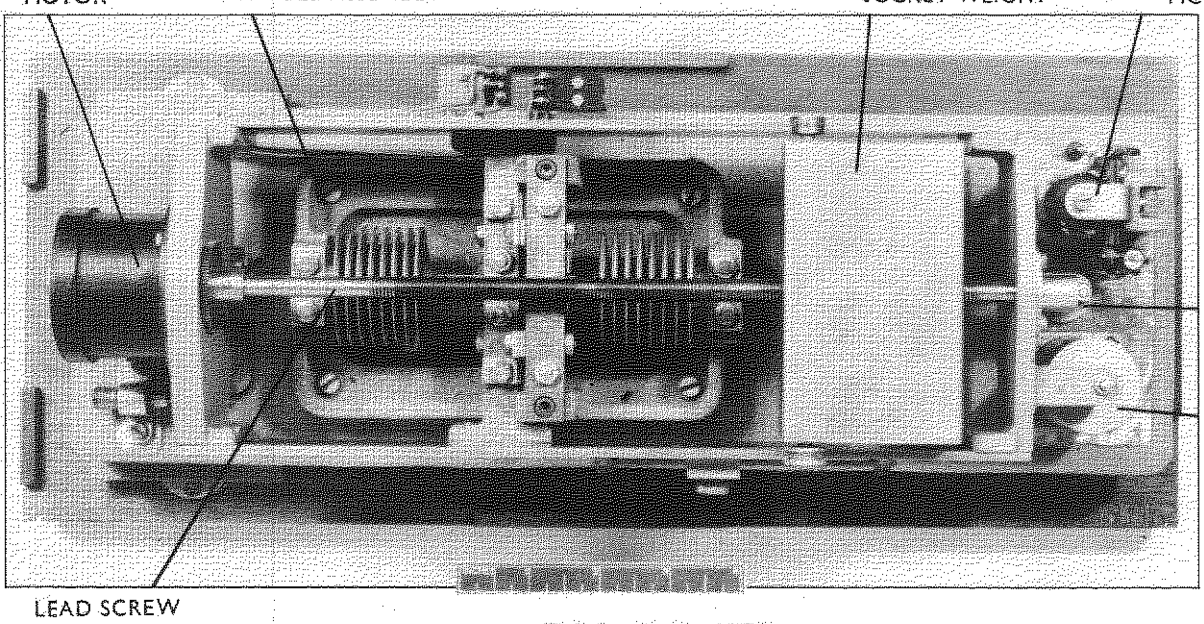


FIG.8. PLAN VIEW

FIG.6,7 & 8. AUTOMATIC MANOMETER

FIG. 9.

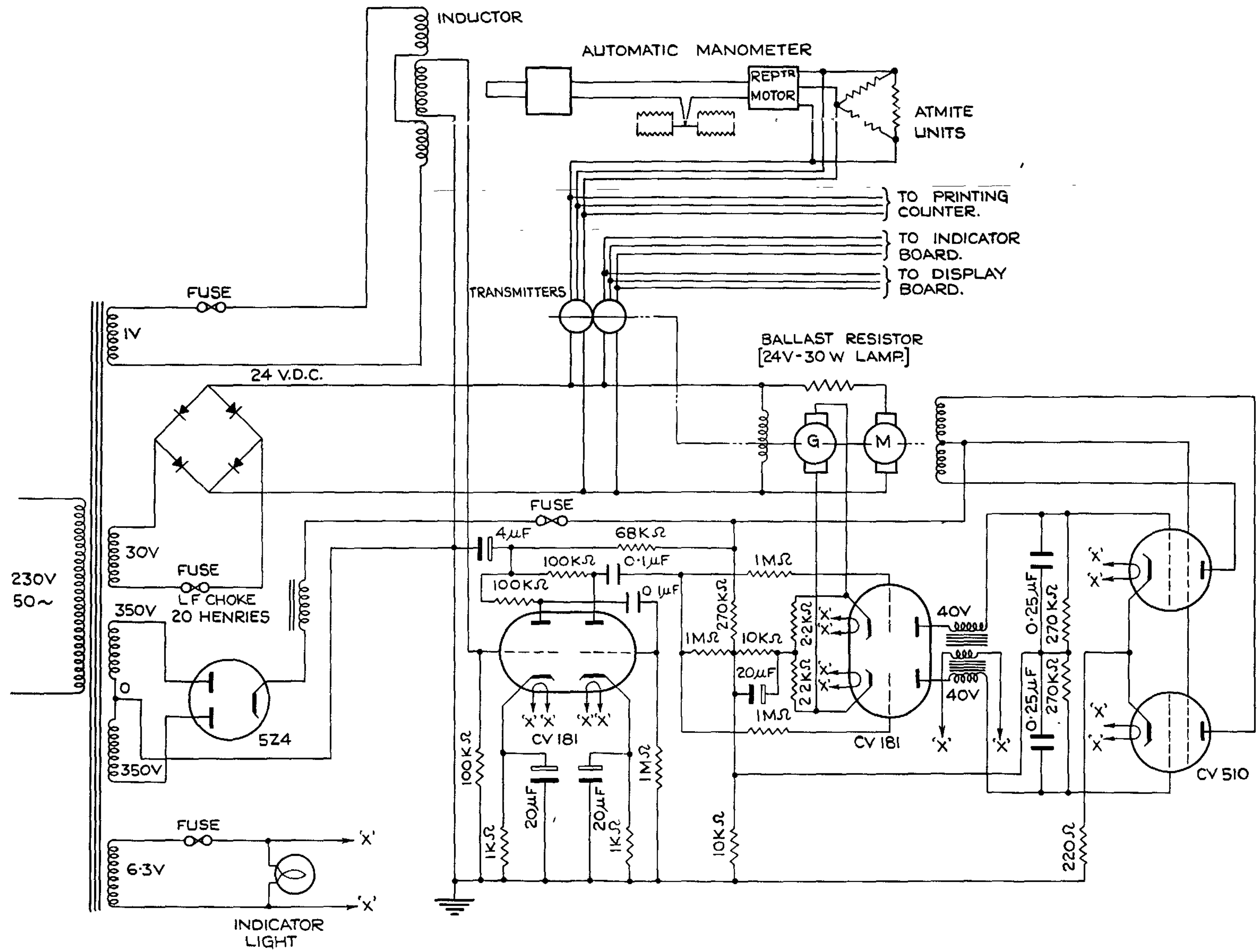


FIG. 9. CIRCUIT DIAGRAM.
AUTOMATIC MANOMETER.

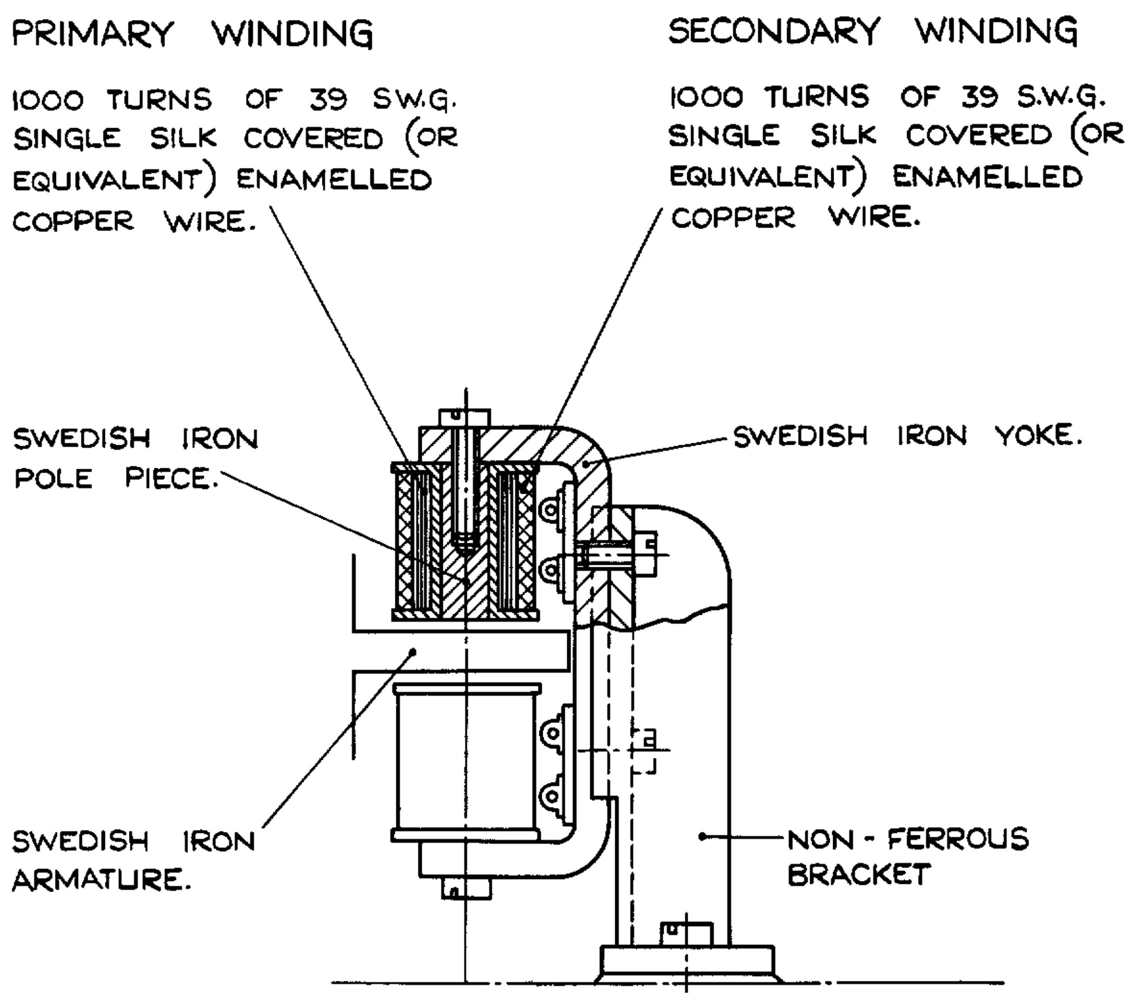


FIG. 10. ELECTRO - MAGNETIC PICK-UP UNIT.
AUTOMATIC MANOMETER.

FIG. 11.

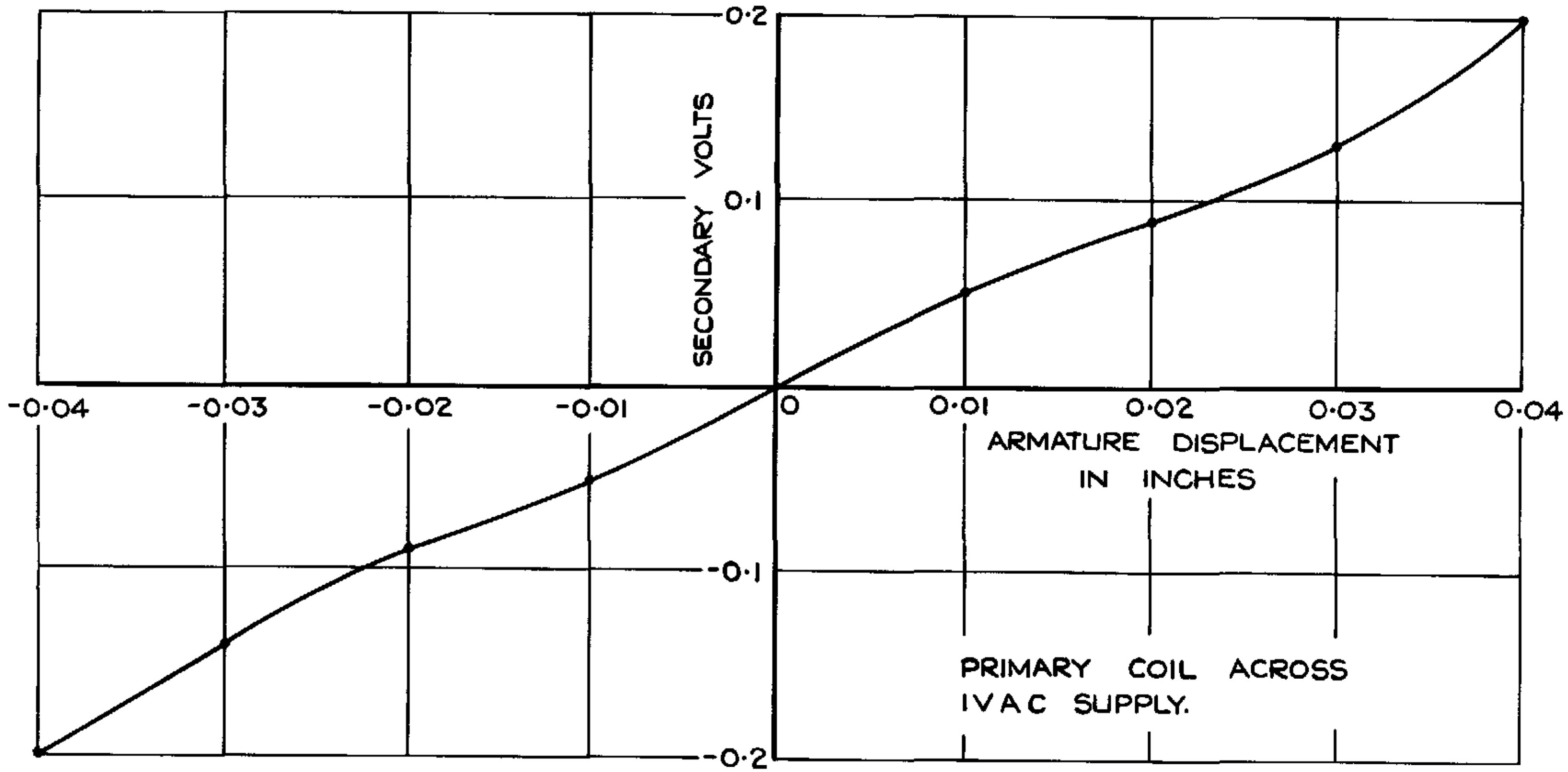


FIG. 11. CALIBRATION OF ELECTRO-MAGNETIC PICK-UP UNIT.
AUTOMATIC MANOMETER.

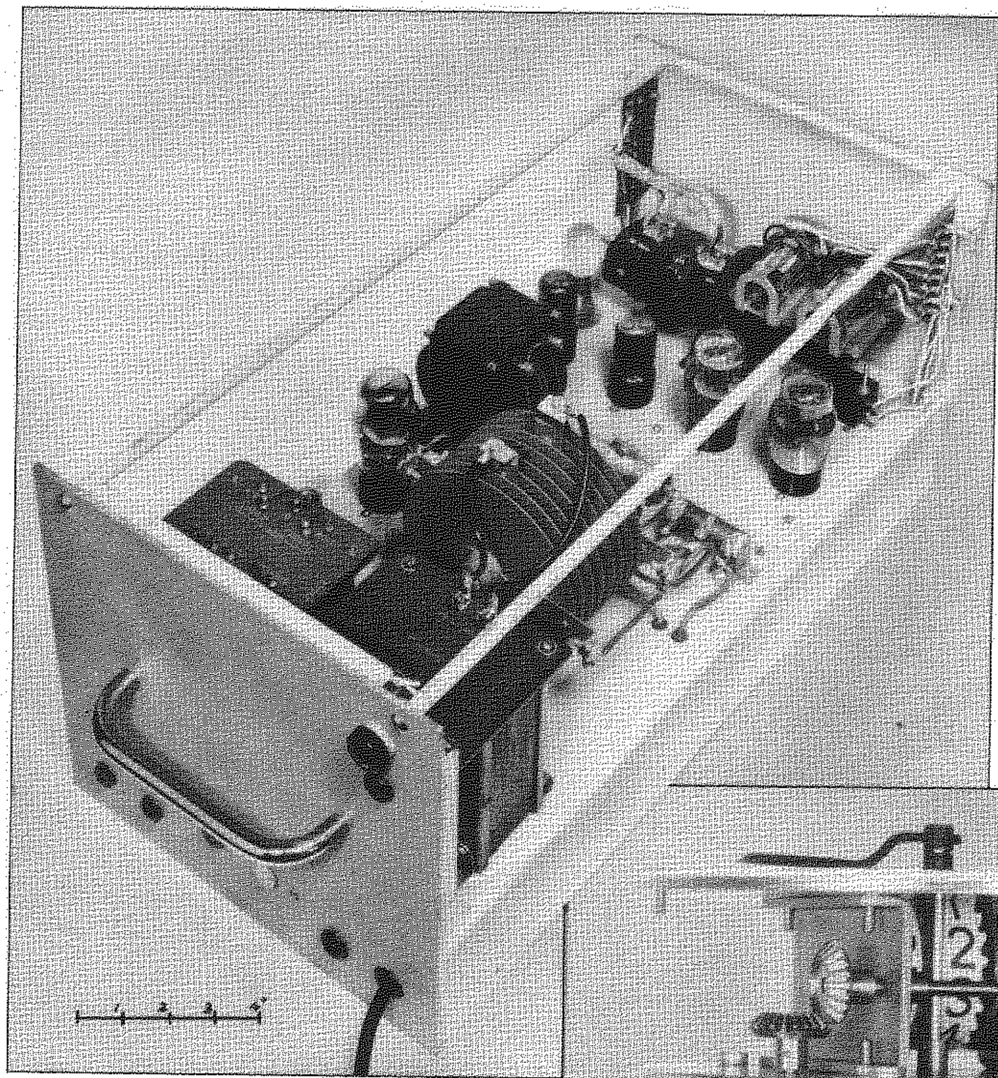


FIG.12. CONTROL UNIT

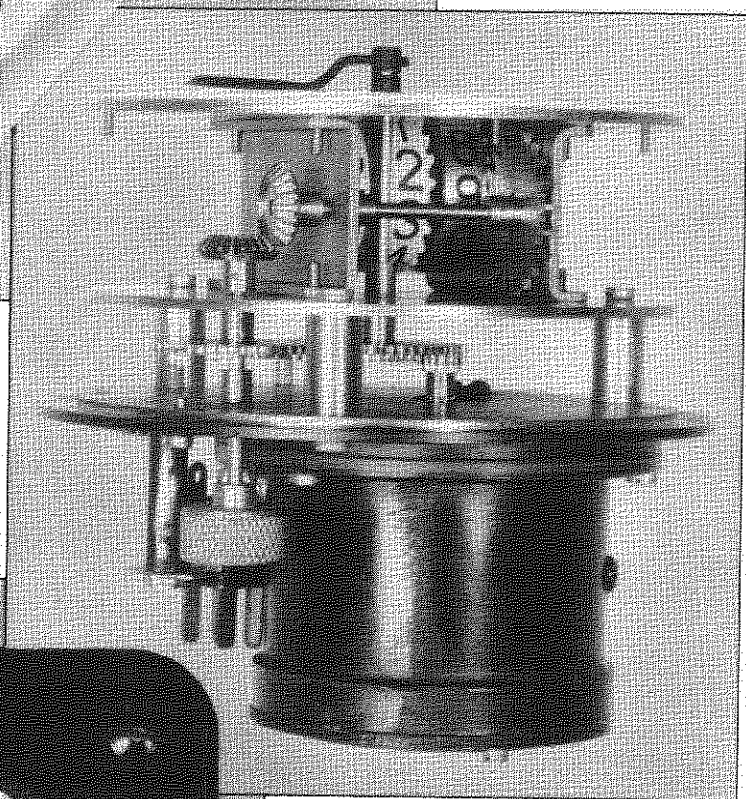


FIG.13.
GENERAL VIEW OF REMOTE
READING INDICATOR

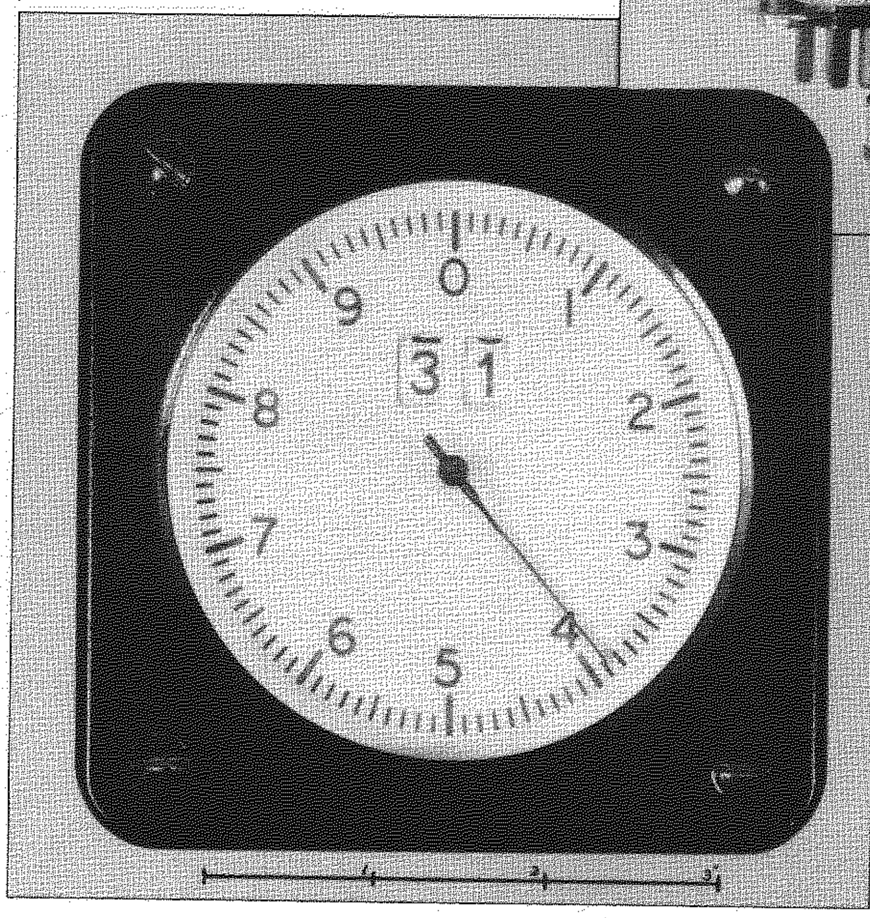


FIG.14. FRONT VIEW OF REMOTE READING INDICATOR

FIG. 12, 13 & 14.
AUTOMATIC MANOMETER

FIG. 15.

FIG. 15. CALIBRATION.
AUTOMATIC MANOMETER.

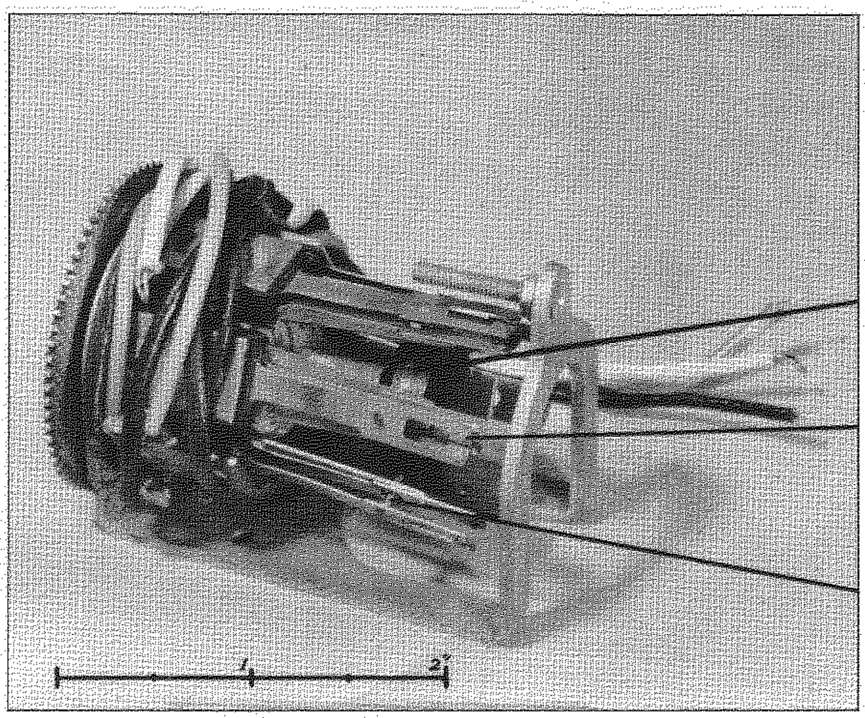


FIG. 16. TRANSMITTER ASSEMBLY

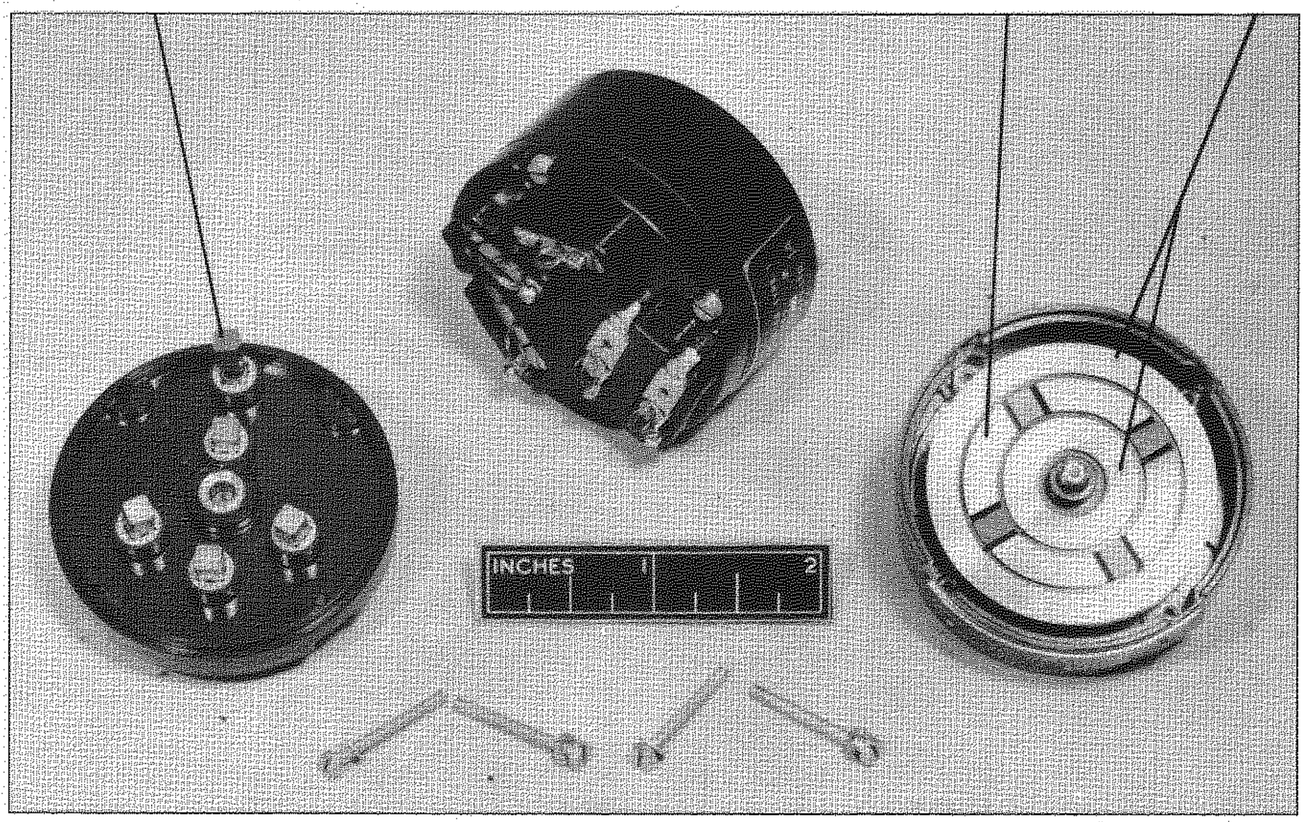


FIG. 17. COMMUTATOR TRANSMITTER

FIG. 16 & 17. AUTOMATIC MANOMETER

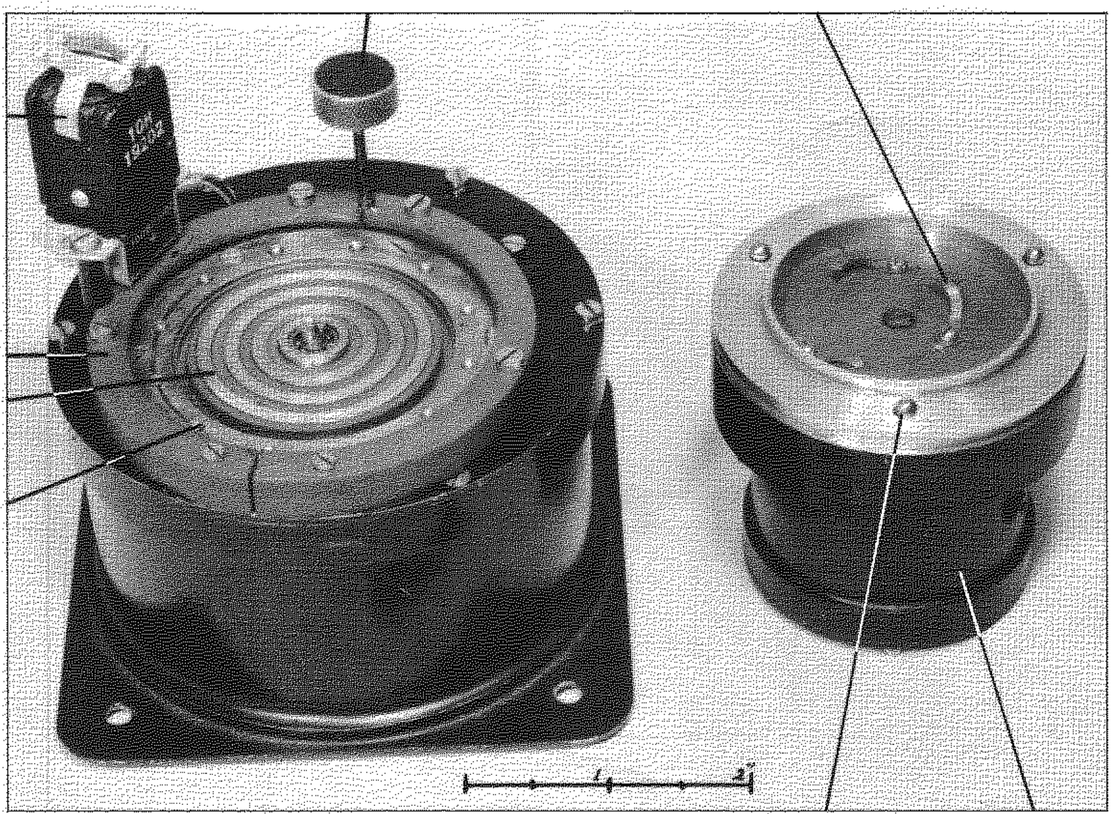


FIG. 18. REMOTE READING INDICATOR WITH FINE ADJUSTMENT MECHANISM

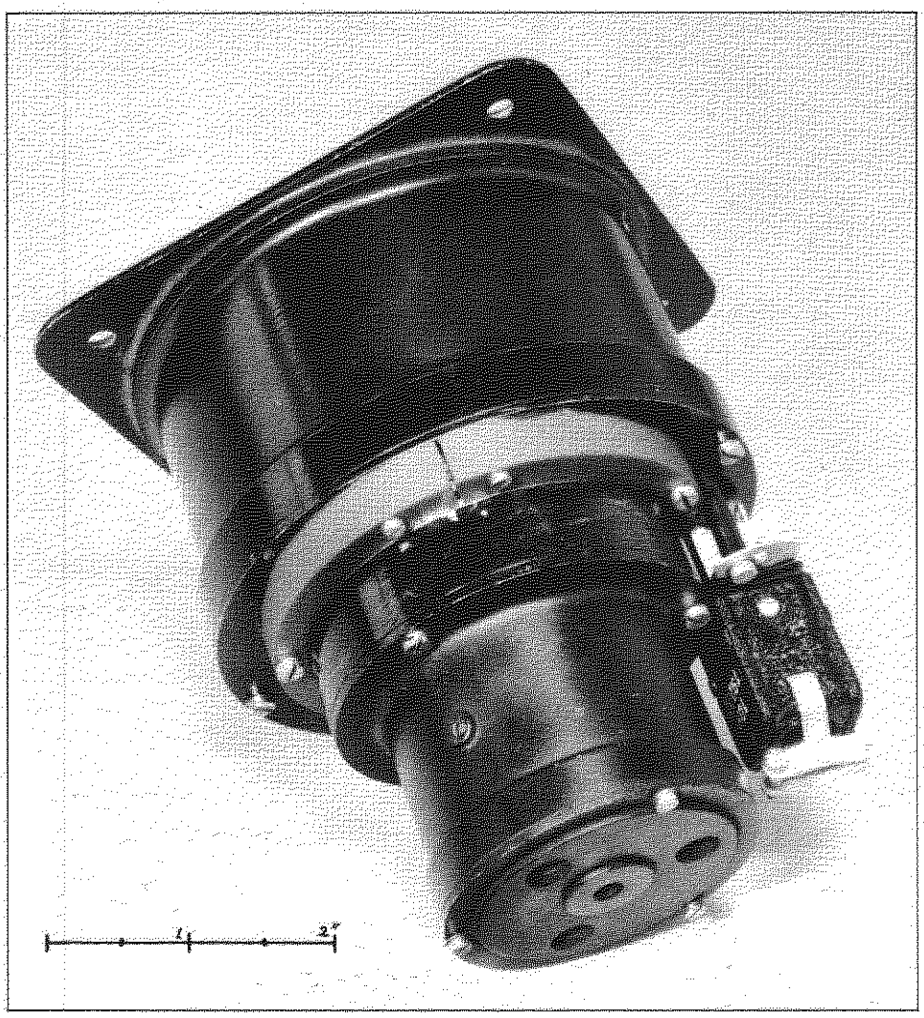
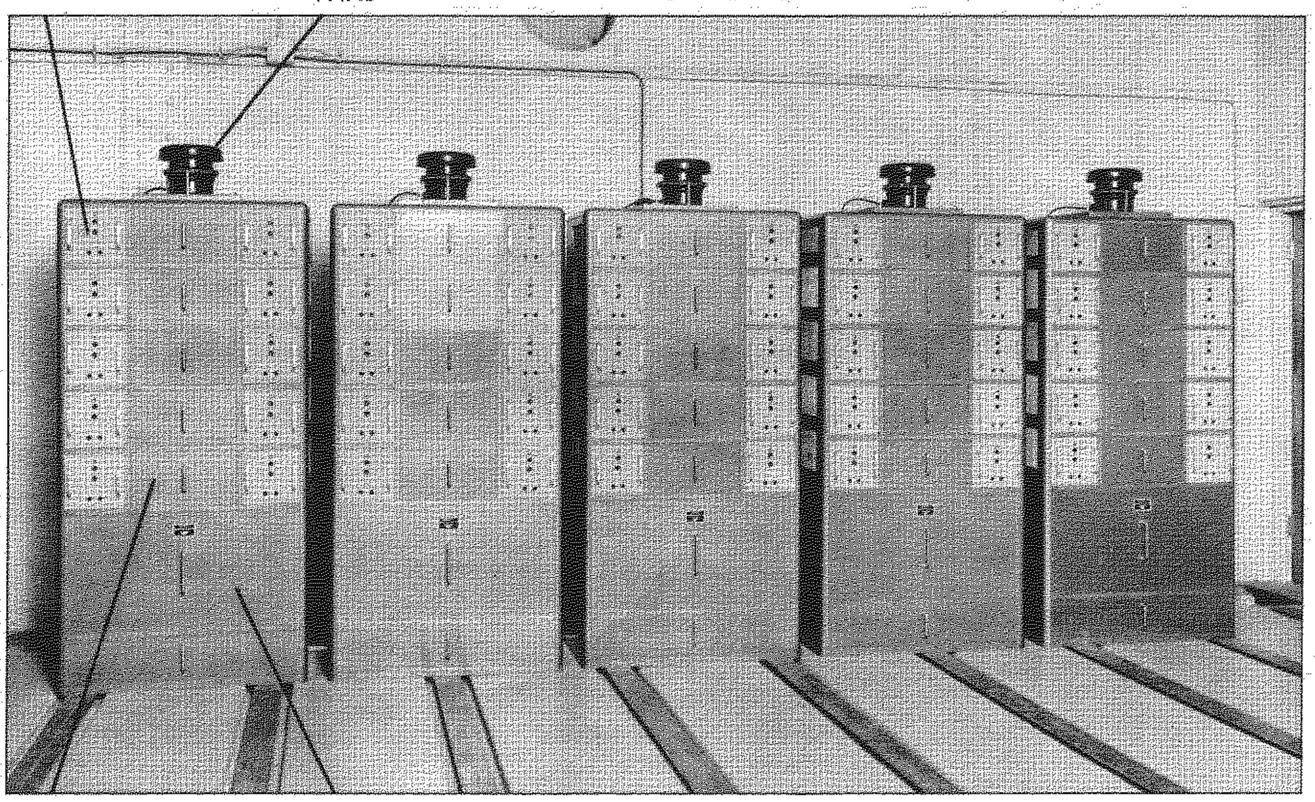


FIG. 19. REMOTE READING INDICATOR WITH
FINE ADJUSTMENT MECHANISM

FIG. 18 & 19 AUTOMATIC MANOMETER

CONTROL UNITS

VENTILATING FANS



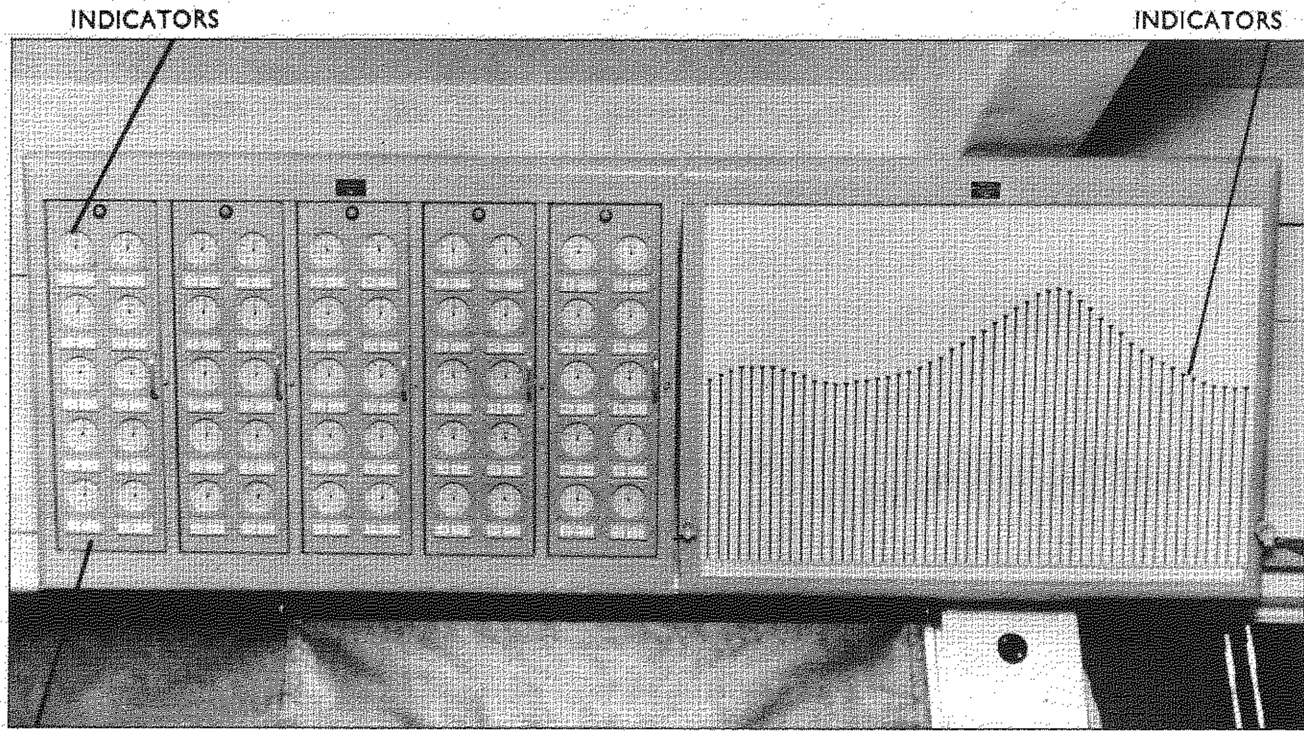
AUTOMATIC MANOMETERS

POWER PACK

FIG.20. INSTALLATION OF FIFTY MANOMETERS IN TUNNEL ROOM

REMOTE READING INDICATORS

TAPE INDICATORS



HINGED PANELS

FIG.21. REMOTE READING INDICATOR AND TAPE INDICATOR BOARDS

FIG.20 & 21 AUTOMATIC MANOMETERS

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