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Review of Remote Indicating Systems for Aircraft Instruments

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1. *Summary.* 1.1. *Object of the Review.*—As aircraft have increased in size it has become necessary to use remote indicating systems to transmit many readings to the pilot's or/and flight engineer's instrument panels. Such systems will be essential for future large civil and transport aircraft, and a number already exist operating on different principles and power supplies.

Many operate from a low voltage d.c. electric supply, but it seems certain that a higher voltage a.c. supply will be used in the type of aircraft under consideration.

A review was therefore required of all known and possible remote indicating systems, whether operated by a.c., d.c., or by any other source of power, in order to indicate how activities could be directed into the most promising channels, and to see if an ideal system for all remote indications is possible or known.

1.2. *Scope of the Review.*—Information about remote indicating systems already in use in aircraft has been collected from systems still being developed, from applications in other fields of engineering, and from published information concerning devices which might be applied to the problem of remote indication. Some original contributions are also included.

1.3. *Conclusions.*—The main conclusion arising from the review is that it is considered that electrically operated systems are more promising than any of the other systems, and that, apart from coping with the transmission of unrestricted rotation, much can be done in devising an ideal system for dealing with all other remote indications. The conclusions are detailed under a series of headings given below.

1.31. *For existing 12 and 24 volts d.c. supplies.*—(*a*) The Desynn type of system, and the repeater motor are the only devices capable of catering for the transmission of unrestricted rotation.

(*b*) The use of a repeater motor system is too complicated for most remote indications, and the use of impulse methods as shown in Figs. 23 and 24 cannot be recommended since they are not self-synchronizing.

(*c*) Systems of the Desynn or d.c. Selsyn type are the only ones suitable for universal application..

(*d*) Although the self-balancing system shown in Fig. 1 is attractive for all applications other than those involving unrestricted rotation, the moving-coil system is inferior in control torque to the Desynn system. With care a redesign of the latter system could be made to compete with the former in weight and compactness.

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(*e*) Bridge circuits as shown in Fig. 18 are attractive for the remote indication of temperature since they have no moving parts in the transmitter, but they cannot be recommended for universal use.

(*f*) Bridge circuits and those similar to Fig. 18 make exacting demands on the electric meter, which usually has to be a ratio-meter, and since scale lengths for ratio-meters never exceed, say, 120 deg., it is not considered that such systems can be recommended for universal transmission purposes.

(*g*) Since all systems operating on d.c. require a change in resistance at the transmitter, rubbing contacts are unavoidable, except for temperature measurements, and in spite of the very best of workmanship, they must be considered undesirable since they are potential sources of trouble.

1.32. *For a higher voltage a.c. supply.*—(*h*) For most purposes the value of the supply voltage is relatively unimportant in the design of electric meters and remote indicating motors, although some savings are obtained as the voltage is increased.

(*j*) There is a greater variety of remote indicating systems possible with a.c. than d.c., in spite of there being a wider range of d.c. measuring instruments available than for a.c.

(*k*) Rubbing contacts can be avoided with a.c. operated systems, and the use of inductive type transmitters permits of the use of small displacements without the need of gears or levers.

(*l*) It is considered that position repeating systems are more satisfactory than systems making use of electric meters, since they are only slightly affected by possible changes in the frequency and voltage of the electrical supply.

(*m*) It is considered that all types of self-synchronous electric motors are more suitable for large angular displacements than for small, and it is therefore suggested that they should be used exclusively for dealing with remote indication applications involving unrestricted angular rotation.

(*n*) It is considered that limited angle or limited linear displacement position repeating inductive devices should be used to form an ideal universal indicating system. Gearing or levers could be used in the transmitter to cope with large angular or linear displacements, whilst the receiver could be geared up to give the required cirscale movement of the pointer.

(*o*) It is considered that the position repeating circuit shown in Fig. 4 is worthy of investigation. Although resistive units are shown in the diagram, inductive devices could be used in their place.

(*p*) Although the suggestion has been made that it would be worth while to use a rotary converter to convert the a.c. into d.c., so that the Desynn type of remote indicator could be used, it is not considered that this is the most satisfactory solution of the problem.

(*q*) It is considered that the servo-motor and amplifier system shown in Fig. 17 is worthy of very serious consideration.

1.33. *For a stabilized electric supply.*—(*r*) It is considered that the question of stabilizing the voltage, and perhaps the frequency if the supply is a.c., is worthy of serious consideration in view of the possible simplification of remote indication systems for all applications other than those connected with unrestricted rotation.

(*s*) If the electric supply is stabilized, there is no need to use relatively complicated and insensitive ratio-meters, and a good case can be made for the use of simple sensitive meters of the cirscale type.

Note.—The layout of the report is such that it can read in as a brief or complete manner as desired. The summary consists of Sections 1 to 1.4. A more detailed review is obtained by reading the summary and the Sections labelled with whole numbers, *i.e.* 2, 3, 4, etc. A more complete review is obtained by reading all the sections labelled to the first decimal place, *i.e.* 6, 6.1, 7, 7.1, 7.2, etc., and finally, every Section of the review may be read.

2. *Reasons for the Review.*—As aircraft have increased in size, many of the pressure, temperature, displacement, etc., pick-up units are situated considerable distances from their respective indicators located on the pilot's or flight engineer's instrument panel. For many of the indications it is necessary to use a remote indicating, or data transmission system, consisting of a transmitter, a receiver, and the necessary connections, whilst in other cases there are functional reasons why some fluids under measurement should not be brought by pipes or tubing into the aircraft cockpit. For some time, sealed capillary systems have been used extensively, particularly in fighter aircraft, for transmitting pressure and temperature measurements, but these when used for large aircraft become unwieldy for storage, installation, and servicing purposes. It is apparent that an increasing demand is being made for data transmission purposes, and such systems will be essential for large civil aircraft of the future. An important feature of any proposed system for future use is that the connections between the transmitter and receiver should be easy to make and break.

A number of remote indicating systems have been developed and used in the U.S.A., in Germany and in this country. Such systems cover an extensive field, being mechanical, hydraulic, pneumatic, electrical, electronic, or combinations of them. Whilst some of the systems are fully developed, others are still in the development stages. Whilst some systems are almost universal in their application, others have only limited application. There are many servo-motor and remote indicating applications in fields other than that of aviation which could be examined with a view of their possible application to remote indicating problems peculiar to aircraft. Again, most of the existing electrical systems for aircraft have been designed to operate on either 12 or 24 volts direct current, but it seems certain that higher voltage alternating current will be used in large aircraft of the future. Advantages gained by the use of a.c. have been published elsewhere by Brice and Levoy[1] (1944).

The main purpose of this review is, therefore, to perform a critical and comprehensive survey of all known and possible remote indicating systems suitable for use in aircraft, whether operated by a.c., d.c., or by any other means such as hydraulic or pneumatic, etc. It was considered that the review was necessary to clarify the future of transmission systems, and it was hoped that it might indicate how activities on such systems could be directed into the most promising channels. A further reason for the review was to examine the possibility of an ideal system being found which would be suitable for all remote indications concerning aircraft instruments.

3. *Major Requirements for an Ideal Remote Indicating System.*—Many desirable features concerning transmitting type instruments are given below. In certain respects the requirements for a remote indicating system are not so exacting as those demanded in control and computing mechanisms. These latter devices usually require dead-beat follow-up systems capable of high-speed following, and it is desirable that the rotary inertias of both the transmitter and receiver should be kept to a minimum, whilst it is also desirable that their misalignment torque be kept to a maximum. Further, the receiver of such a system may have to perform a certain amount of work, and hence it appears inevitable that these systems should be bulky. In such devices it is usual to keep the transmitter and receiver to reasonable dimensions, but to arrange that the receiver operates in conjunction with a servo-motor or a thermionic amplifier, as described in articles by McNaney[2] (1944) and by Gille and Hutzler[22] (1944). Thus, although considerable research and development have gone into the design of control and computing mechanisms making use of remote indication, the devices are almost invariably too bulky and complicated for use with aircraft instruments. Further, these mechanisms do not make use of new fundamental ideas concerning remote indication ; they can be regarded as using a number of basic principles, modified and improved to give the required speed of response and accuracy desired. However, many of these systems have been examined to find out if any features made them particularly suitable for use with instrument remote indication.

The ideal remote indicating system, for the majority of aircraft instruments, does not require to be dead-beat, and it is not necessary for it to be capable of high-speed following. It should give a steady indication after a reasonably short interval, and in many cases it is even desirable that the response to rapid pulsations occurring at the transmitter end of the system should be poor. It is considered that the major requirements of an ideal system can be detailed as follows:—

(*a*) The system should be universal in its application.

(*b*) The complete installation comprising transmitter, receiver, connections, etc., should weigh as little as possible.

(*c*) Indications should be accurate and reliable.

(*d*) It should require little or no power supply for its operation. (A power supply, even if taken from an existing source represents a certain weight of prime-mover, and hence the importance of requirement (*d*) should be considered in conjunction with requirement (*a*).)

(*e*) The various components of the system should be easy to install and should require little or no maintenance.

(*f*) Connections between the transmitter and the receiver should be easy to make and break, should be certain in their action, and the system should be self-synchronous so that no resetting should be required.

3.1. *Other Requirements for an Ideal Remote Indicating System.*—These can be enumerated as follows :—

(*g*) A small number of types of transmitter should cater for all indications of pressure, temperature, linear and angular displacements, etc.

(*h*) Each transmitter should be capable of operating one or more receivers without affecting the accuracy of the indication.

(*j*) If possible rubbing contacts and parts liable to excessive wear should be avoided in the design of the transmitter.

(*k*) Transmitter units should be capable of satisfactory operation under severe conditions of vibration, preferably without recourse to special mountings.

(*l*) One type of receiver should be suitable for all remote indications.

(*m*) The receiver scale should be of the cirscale type extending over a range up to 270 or 360 degrees. (If the receiver and transmitter are capable of unrestricted rotation they could be used for remote compass indication, and for certain remote reading tachometers.)

(*n*) The receiver movement should be small and compact so that it could be fitted individually, in duplicate, in triplicate, or in quadruplicate in one case, in a variety of ways.

(*o*) If necessary, it should be possible to switch one receiver to operate in turn with a number of transmitters.

(*p*) It is a desirable feature that the components of the system should be such that they could be manufactured at a reasonable cost on mass-production lines.

(*q*) The components should be made of materials that would not deteriorate when stored for considerable periods under any and all climatical conditions. Deterioration includes fungoid growth.

4. *Existing and Future Electrical Systems for Large Aircraft.*—The major part of current electrical systems for aircraft operate on 12 or 24 volts. It is generally agreed, however, that particularly for large aircraft operating at high altitudes, there is a strong case for using a higher voltage a.c. system. A certain amount of aircraft equipment, mainly of U.S.A. origin, already operates on single-phase 400 cycles/sec. at 115 volts, but this supply is obtained by means of an inverter driven off the aircraft d.c. supply. One proposed U.S.A. system for future installations is a 400 cycles/sec. three-phase star system with the central point earthed to the airframe

is described in an article by Brice and Levoy[1] (1944). This supply system would have 120 volts between any phase and earth, and 208 volts across any two phases. A decision has now been made that this system, with certain modifications, will be used in this country on large aircraft of the future. The alternators will be engine driven, and thus the voltage and frequency of the supply will both vary with engine speed. It will be arranged that the voltage varies in a linear manner with the change in frequency, and also that the supply will be 400 cycles/sec. and 120 volts at the normal cruising speed.

It is proposed that a motor-alternator should be driven at constant speed with a Hayes type gear to supply 115 volts, three-phase, 400 cycles/sec. a.c. for operating the instruments and the aircraft lighting. Since aircraft lamps are only suitable for low-voltage operation, it would probably be necessary to transform the voltage down to make it suitable for the lighting. Many aircraft instruments, such as automatic pilots and bombsights, could operate direct from this instrument and lighting supply, but the exact details regarding the other aircraft instruments have yet to be fully explored. It is hoped that this review will be useful in these investigations.

It is considered that the speed of the alternator supplying a.c. to the instruments and lighting might be controlled to vary less than $\pm$ 1 per cent., but it is probable that actual tests of such a system will be necessary before the variation can be stated more exactly.

4.1. *Comparison of a.c. and d.c. Operation of Remote Indicating Systems.*—The main variables in d.c. systems are voltage and resistance, but with a.c. systems waveform, frequency, phase, inductance, and capacity are also important. With d.c. systems the transmitter is limited to resistive effects, and rubbing contacts are essential, but with a.c. systems the transmitter can operate on changes in resistance, capacity, and inductance or on impedance changes due to combinations of these properties. With inductive or capacitance types of transmitter, rubbing contacts, with their faults of wear and possible bad contact, are not required. Both inductive and resistive transmitters can provide sufficient current to operate a receiver directly, but the capacity type of transmitter, particularly for satisfactory operation at low frequencies of supply, requires an amplifier in order to operate a receiver. These points are discussed in published articles by Roberts[3] (1944–5) and by Godsye and Langer[4] (1944). The inductive transmitter is superior to the resistive type, since, as well as not requiring rubbing contacts, it can also give a bigger output for a smaller movement. Movements as small as one-millionth of an inch can be measured directly on a moving-coil meter without using an amplifier by means of the circuit[5] shown in Fig. 15. With such a system, however, which possesses both inductance and resistance, it is necessary to keep both the waveform and the frequency constant, otherwise errors of indication occur.

A good standard text book, such as that by Golding[6] (1944), shows that for use as a receiver, there is a wider choice available for d.c. than for a.c. instruments. Those most widely used in aircraft are either moving-iron, or permanent magnet moving-coil meters, and they are usually of the ratio type. The former are suitable for both a.c. and d.c. operation, irrespective of whether they are ordinary or ratio-meters, but the latter are only suitable for a.c. operation when specially designed as ratio-meters, and even then the correct phasing of the control and operating voltages or currents is of paramount importance. Dynamometer moving coil and induction instruments are widely used for a.c. measurements in fields other than aviation, and have good cirscales extending over 300 to 360 degrees. Unfortunately they cannot compete in weight, size, power consumption, and cost with the d.c. instruments, so that it is usually a better solution to fit metal oxide rectifiers to d.c. meters to cater for a.c. measurements. The induction meters suffer such serious frequency errors that they are really limited to switchboard purposes. Induction meters are in effect spring-restrained induction motors, and such devices can best be used in remote indicating systems in the capacity of self-synchronizing transmitter and receiver motors. These are described in Section 5.2 of this report. It would appear that a.c. operated remote indicating systems should preferably be of the position repeating type in which the transmitter and receiver have identical electrical characteristics.

Another effect requiring consideration is that the proposed a.c. system operates at a higher voltage than existing d.c. systems. Since, however, the sensitivity of most electrical measuring devices depends on the strength of a permanent or excited flux, and on the value of ampere-turns used in the coil system, and since the limiting factors are usually fixed by thermal considerations, it is considered that the value of operating voltage for aircraft instruments is not critical. It would be most economical to design instruments to operate on the voltage of the available supply. The use of a higher voltage would naturally demand more insulation than before, but the diameter of the wiring could be reduced, and a saving in the overall weight of the wiring always results from an increase in the supply voltage. The possible saving in the weight of the wiring for remote indicating installations would, however, be small, and a wire would probably be chosen that was sufficiently robust for handling purposes rather than being of a cross-section in keeping with the current it carries. Direct operation from the 120 volt a.c. supply would save the weight of a dynamotor, transformer, or rectifier system that would otherwise be necessary. The use of a higher voltage supply plays an important part in the possible stabilization of the electric supply to the instruments, and this point is discussed in the next section of this report.

4.2. *Voltage Stabilization of the Electric Supply.*—In existing d.c. systems the sole reason for the wide range of supply voltage is due to the generator supply voltage and the accumulator system discharge voltage. . For a nominal 24-volt system the former may be as high as 29 volts whilst the latter may be as low as 21·6 volts. If the supply voltage could be stabilized within close limits, the demands on the various instruments could be eased considerably, and the possibility would arise of using simple and efficient moving-iron or moving-coil meters instead of relatively inefficient and complex ratio-meters.

As an example of what can be accomplished, the special stabilized voltage d.c. systems used in the following aircraft can be quoted :—

Lincoln I, Halifax VI, Windsor, Tudor and others.

The supply voltage for these aircraft is 28·5 volts, and this does not vary more than $\pm$ 2 per cent. due to all causes. The particular method whereby this stabilization is obtained is outside the scope of this report, but it requires one extra regulator in addition to the regulators fitted to the engine-driven d.c. generators. The extra regulator is similar to those fitted to the generators, but it has a different shape of regulation curve. Thus the stabilization is obtained for no great increase in the weight and cost of the electrical system. Since, however, the instrument load represents only a very small proportion of the total electric load, it might be relatively easy to stabilize this supply separately from the others.

The supply voltage plays an important part in the problem of stabilization, since the use of electronic stabilizing devices is relatively difficult at voltages in the region of 12 or 24 volts, but becomes somewhat easier for moderate wattage supplies in the region of a 100 volts or more. Electronic devices are also being used in place of other methods to control the characteristics of the supply generator, particularly for a.c. operation, since their lack of inertia makes them eminently suitable for such control. It is more usual, however, to use electronic devices to obtain a stabilized supply from an existing supply, and one comparatively efficient method of obtaining a stabliized d.c. supply is shown in Fig. 22. The stabilizing element consists of a cold cathode gaseous glow tube, one type being the " Stabilivolt " ; such devices possess the characteristic of retaining almost constant voltage across them independent of the current which is passing. It is necessary to use a control resistance to accommodate the difference between the input and the stabilized voltage, and it is usual to arrange that the supply voltage is approximately 30 per cent. greater than the required value of stabilized voltage.

The most widely used devices for stabilizing a.c. potentials or currents are, constant-voltage transformers, regulating resistances, and regulating circuits using cold cathode gaseous glow tubes such as neon tubes or other gas discharge tubes. A brief review of such devices is contained in a published article by Roberts[3] (1944–5). Regulating bridge circuits making use of non-linear resistances are used to stabilize either a.c. or d.c. supplies. The non-linear resistance could be a tungsten filament lamp. Many of these circuits are inefficient, but owing to their simplicity they afford ready means of obtaining accurately regulated electrical supplies of the order of, say, 10 watts or more.

So far, apart from the special d.c. system already mentioned, the proposed scheme described in section 4, and the occasional stabilization of the electrical supply to radio apparatus, the subject of the stabilization of other of the electrical loads in aircraft is relatively unexplored, probably since many of them do not require a stabilized supply. It is considered that the provision of either a stabilized a.c. or d.c. supply to remote indicating systems for aircraft instruments would be advantageous, since it would permit of simple transmission systems such as the one shown in Fig. 20.

5. *Electrical Methods of Remote Indication.*—Electrical methods are used extensively in many fields of engineering. In most cases the system chosen depends on the function it has to perform, and the conditions under which it will operate. Much ingenuity has been expended in developing aircraft data transmission systems to make them operate accurately in spite of considerable fluctuations in the value of the supply voltage and temperature, and in the case of a.c. systems, also making them immune to changes in frequency and wave form. Electrical indicating systems, whether operated by a.c. or d.c., fall into two distinct classes, *i.e.* :—

(*a*) Those in which the transmitter and receiver are different in design ; the receiver usually being a meter or a ratio-meter.[7]

(*b*) Those in which the transmitter and receiver are substantially identical, as described in a text-book by Clark and Corbitt[8] (1942), and in a published article by Fink[20] (1944).

The first class comprises bridge circuits, potential and current measuring circuits, and some repeater motors. Typical examples are shown in Figs. 1, 2, 3, 4, 5, 7, 8, 9, 13, 14, 15, 18, 19, 20, 23 and 25.

The second class consists of linear and angular position repeating devices. Many of the latter are capable of unlimited rotation, and are based on the principle of the self-synchronizing electric motor. When two such motors, one the transmitter and the other the receiver, are interconnected and energized from an a.c. source, their rotors take up the same angular position relative to their stators. Thus, if the rotor of the transmitter motor is moved by an applied torque, the rotor of the receiver will follow up automatically until the two rotors are correctly aligned. The majority of class (*b*) systems possess mechanical reaction, and thus either motor can act in the capacity of transmitter or receiver. Because of reaction the resistance to movement of the receiver reacts back on to the transmitter, and hence the torque actuating the transmitter must be capable of overcoming the frictional torque of the two motors. Since frictional torque due to the bearings and the slip rings causes an angular misalignment between the two motors, a considerable amount of design and development has been expended on various types of motor to reduce friction and to obtain the highest possible value for the ratio of torque to rotor weight. Typical circuits of class (*b*) are shown in Figs. 6, 10, 11, 12, 16, 17 and 24. It is an inherent feature of this type or circuit that it is less affected by most changes than those of class (*a*).

A range of electrical methods of remote indication have been collected from many sources, and these together with a few original suggestions are illustrated in Figs. 1 to 25. Many of the circuits have been simplified so that they clearly indicate the fundamental principles, and it should be pointed out that all the potentiometers and coils shown in the diagrams could be wound on either linear or curved formers as required. Again, many of the magnetic circuits would be wasteful in current if constructed as shown diagrammatically, but much higher efficiencies would be obtained with the careful use of iron to concentrate the magnetic flux.

5.1. *Linear and Limited Angle. Transmitters.*—This classification covers a.c. and d.c. operated systems in which use is made of simple potentiometer and inductive types of transmitter suitable for limited linear and angular displacements. Such devices can, however, use gearing or arrangements to convert rotary into linear motion, or *vice versa,* in either the transmitter or the receiver. A number of circuits are shown in Figs. 1 to 8, and are described below.

5.11. *Self-balancing resistance bridge* (Fig. 1).—This arrangement is of recent origin, and is used by the Germans to transmit indications of temperature, pressure, and displacement. The transmitter and indicating units are shown in detail in Figs. 32 to 35. A compact moving-coil meter is used for the joint purpose of providing angular movement to the indicating pointer and also acts as a motor to traverse the brush contact of the receiver potentiometer to a position identical with that of the transmitter. The system is extremely compact, and the indicating pointer is geared up to move over an arc of about 150 deg. Although this system satisfies many of the requirements of the ideal system, it is only possible to operate one receiver per transmitter, and it suffers from what must be considered a serious inherent fault, namely, the need for two rubbing contacts.

5.12. *Self-balancing resistance-magnetic circuit* (Fig. 2).—This is, perhaps,the simplest possible electric remote indicating circuit. It is preferably operated from d.c., although it will also function if supplied with a.c. If the transmitter contact is central, equal currents flow in each half of the receiver coils, and hence an equal length of iron core is pulled into each coil. If, however, the transmitter contact is not in the central position, unequal currents flow in the two receiver coils, and proportions of the iron core are pulled into the coils in proportion to the magnetic pull they exert. Thus for d.c. operation the system is reasonably immune to changes in supply voltage, and with care it should be possible to operate more than one receiver per transmitter.

For a.c. operation the iron core takes up a position such that the currents in the two paths are equal, but since the receiver possesses inductance as well as resistance, its response would be influenced by changes in frequency and waveform.

5.13. *Ohm-meter and ratio-meter circuits* (Fig. 3).—These circuits are in extensive use in aircraft, and the difference between the two types of circuit is due to the way the electrical supply is inserted. The accuracy of such systems and their immunity to changes in supply voltage and temperature depends almost entirely on the design of the meter used, which may be either of the moving-iron or the moving-coil type. Although it is usual to operate only one receiver from each transmitter, the use of more than one should present little difficulty.

Provided that the ratio-meter used is of a suitable type, these circuits can also be operated from a.c., but errors would arise due to changes in the frequency and waveform of the supply. Rectifiers could be inserted in each of the meter leads to enable a d.c. type ratio-meter to be used in conjunction with a.c. operation of the circuit.

5.14. *Self-balancing resistance bridge* (Fig. 4).—This is an original circuit based on that given in Fig. 1, but arranged to operate on an a.c. supply. Each transmitter and receiver requires only two connections, and since one side of the proposed future a.c. system will be earthed to the airframe, only one connecting wire will be required between a transmitter and its receiver. The second connection of the transmitter would be earthed, and the second connection of the receiver would be connected to one of the unearthed phase connections of the a.c. supply. By means of half-wave metal oxide rectifiers pulses of current are fed through the two paths in both the transmitter and receiver. If the two paths around the circuit are not equal in impedance, a certain amount of d.c. current will be flowing through the moving coil. The current will flow either up or down the coil, and its effect will be to move the potentiometer contact until it occupies a position identical with that of the transmitter. At this position the resistance of each path around the circuit is equal, and no d.c. current whatsoever flows through the moving coil. Thus, although this circuit is similar to that shown in Fig. 1, it operates on an entirely different principle.

This circuit has been constructed, and its performance reveals an important inherent feature. In operation, a.c. current is always flowing through the moving coil, but, owing to the low resonant frequency of the coil assembly, the receiver has poor response to the alternating current, and the needle oscillates through a relatively small arc about the steady reading of the meter.

It would be easy to arrange to bypass some of the a.c. ~~current~~ past the moving coil, and the ideal would be to let the moving coil accept just sufficient a.c. ~~current~~ to keep the pointer alive with a just discernible oscillation. This effect would overcome effects of static friction, and hence it would not be necessary to tap the instrument to obtain a true reading whether the instrument were on test or in operation. Although this system is promising as a universal one, it would only operate one receiver per transmitter, and if use were made of resistive potentiometers as shown in the diagram, it would suffer from the disadvantages of having two rubbing contacts. Since the transmitter and receiver are identical, the system is relatively immune to errors arising from changes in the supply voltage, frequency, waveform, temperature, etc. It is well known that metal oxide rectifiers possess many variable characteristics, but such changes can be made relatively unimportant by careful design of the circuit with which they operate. In the system shown in Fig. 4 it will be noted that each transmitter and receiver contains a pair of identical rectifiers, and it is a feature of the circuit that all rectifiers pass the same amount of current. Thus, the circuit is such that rectifier characteristics cancel out.

Although the circuit is drawn showing resistive potentiometers, it would function in a similar manner if used with inductive transmitters. Such a remote indicating system would be free from rubbing contacts, but would weigh more and would be slightly more bulky than one making use of resistive potentiometers. It is, however, a system worthy of attention.

5.15. *Potentiometer transmitter and ratio-meter* (Fig. 5).—This circuit is not original, but it does not appear to have been used for remote indicating systems for use in aircraft. It is similar in principle to those shown in Figs. 3 and 4, and again, although a potentiometer transmitter is shown, it could be replaced by an inductive transmitter, say, of the types shown in Figs. 14 or 15. Although the circuit is operated from an a.c. source, the ratio-meter operates on the flow of d.c. ~~current~~. The current through the ratio-meter is a combination of a.c. and d.c., but the a.c. does not cause a steady deflection, and if found objectionable it could easily be made to bypass the meter. As with most circuits making use of meters as receivers, it would be possible to arrange this circuit so that more than one receiver could be used with one transmitter.

As in the case of the circuit shown in Fig. 4, this circuit requires only one connecting wire between the transmitter and receiver, and with care in design the system should compare with it in its immunity to errors caused by variations in the supply characteristics, temperature, etc.

5.16. *Self-balancing inductance bridge* (Fig. 6).—This is, perhaps, the simplest possible position-repeating circuit for operation on an a.c. source. The transmitter and receiver are identical, and are mechanically reactive. If the soft-iron core of the transmitter is displaced from its central position, more current tends to flow along one path to the receiver than along the other. This causes the receiver core to move along the axis of the receiver coils until, when its position corresponds to that of the transmitter core, the impedance of each path is the same. It is necessary to cross the connections in the diagram, otherwise the cores would move in opposite directions similar to the pans of a pair of scales. The bridge is immune to almost all changes, but the simple inductive devices shown would require relatively heavy current for satisfactory operation. There is no reason why they should not be designed on more efficient lines, say, similar to the transmitter units shown in Figs. 14 and 15. As with most self-balancing bridge circuits only one receiver can be used with a transmitter.

5.17. *Inductor transmitter and a.c. ratio-meter* (Fig. 7).—This circuit is similar to that shown in Fig. 3, but it makes use of an inductive type transmitter, and operates off an a.c. supply. Care should have to be taken in the design of the transmitter and receiver to make the circuit reasonably immune to changes in frequency and waveform, since both the transmitter and receiver possess both inductance and resistance. In common with most circuits of class (*a*) the transmitter will operate more than one receiver.

5.18. *Inductor transmitter and d.c. ratio-meter* (Fig. 8).—This circuit is essentially the same as that shown in Fig. 7, but, since there is a wider available range of d.c. rather than a.c. operated ratio-meters, the former is shown making use of two full-wave metal oxide rectifying bridges. Half-wave rectifiers could also be used, but the circuit would be less efficient. With good design the circuit should be relatively immune to all variations of supply current and temperature.

5.2. *Rotary Motion Remote Transmission.*—Remote indicating systems capable of transmitting rotary motion are almost invariably of class (*b*) in type, and are usually self-synchronizing electric motors. Typical examples are shown in Figs. 9 to 12, and are described below.

5.21. *Desynn, d.c. Selsyn*[9], *etc.* (Fig. 9).—These devices are widely used in current aircraft, and are almost universal in their application, provided that the aircraft is fitted with a d.c. electric supply. In the U.S.A. the system is designated as a " d.c. Selsyn " whilst in this country the " Desynn ", system has been developed during the past few years. A small ring transmitter and a relatively large type of receiver also based on the same principle are used in the Siemans Patin remote compass system. Fundamentally all these systems are based on the circuit shown in Fig. 1, but it has been modified and improved to make it suitable for continuous rotation of both the transmitter and the receiver. Such alteration also means that five wires have to be led to the transmitter of which three interconnect with the receiver. The angular position of the input brushes distributes the current in the three receiver coils so that a resultant magnetic flux is produced diametrically across the receiver, which, apart from a small inherent error, has the same angular position as the brushes. Instead of a soft-iron rotor it is necessary to use a polarized permanent magnet rotor which aligns itself with this resultant flux and thus prevents the possible occurrence of an angular ambiguity of 180 deg. The Desynn transmitter is a potentiometer wound in the form of a circle as shown in the diagram, but a Micro-Desynn linear transmitter is also used for many applications, and this is illustrated in Fig. 21. The receiver is extremely compact, as can be seen from Fig. 44, and no difficulty is presented in fitting up to four movements in one standard instrument case. Although it is usual to operate only one receiver per transmitter it is possible to operate more than one.

The control characteristics of the receiver can be seen from the following comparison :—

Instrument	*Misalignment torque grm. cm./deg.*
Desynn receiver	0·05
Good quality moving-coil voltmeters and ammeters	0·005
Good quality moving-iron voltmeters and ammeters	0·002
Magnesyn receiver	0·0008

Owing to the large control torque of the Desynn receiver it could be fitted with ordinary bearings, *i.e.* a steel shaft running in brass bearings, but the other types of instrument listed require jewel bearings. Due to this high control torque, and since the torque to weight ratio is also high, errors due to friction should be small in the Desynn system ; particularly since jewel bearings are fitted to assure a long life.

In view of the simplicity of the system, its good control characteristics, its low weight, and its universal application, it has been suggested that there might still be a case for its use in aircraft having an a.c. supply, even although it would be necessary to use a rotary converter or a rectifying system to convert the a.c. to d.c.

5.22. *Magnesyn.* (Fig. 10).—This is a position-repeating motor system, but its theory is somewhat involved. It is described in a published article by Childs[10] (1944). It is based on the principle of producing harmonic voltages in a saturated reactor. Such a device is often used as a frequency doubler, and early forms operating in conjunction with the Earth's field were called " flux gates ". It was reasoned that, if with a flux gate a fundamental a.c. flux in combination with a uni-directional flux would produce an even harmonic a.c. flux, then the combination of a fundamental with an even harmonic a.c. flux would result in a uni-directional field. This is the basic principle of the Magnesyn remote indicating system.

If the receiver rotor is not correctly aligned with that of the transmitter, harmonic current will flow between the transmitter and the receiver and tend to bring the two rotors into correct alignment. When this takes place the same even harmonic voltages will be induced in the transmitter and receiver stator coils, and flow of harmonic current ceases. The transmitter and receiver are identical, and a round disc magnet weighing less than one gram is used as the rotor. The stator is laminated and consists of a number of identical annular ring punchings from sheets of mu-metal, and is wound toroidally with tappings brought out at points spaced 120 deg. apart. If necessary, the stator, leads, etc., can be moulded concentrically on the transmitter shaft, thus forming a waterprooof, dirtproof, and oilproof device capable of withstanding temperatures from −100 deg. to +200 deg. C., and sustained vibration in any direction of 100*g* intensity. The stator coils are normally excited at 400 cycles/sec., and no connections whatsoever are required for either the transmitter or the receiver rotors.

Owing to the small value of the misalignment torque it is necessary to use jewelled pivots for satisfactory operation. The system is reactive, but owing to its small reaction torque it can be used in conjunction with air-speed, rate of climb, compass, and altitude instruments ; devices too weak to operate some of the other remote indicating systems. Although the motors bear a striking resemblance to the Desynn receiver, they do not possess the good control torque of that system.

5.23. *Selsyn, Autosyn, etc.* (Fig. 11).—These systems are natural developments of the self-balancing inductance bridge shown in Fig. 6, but they are arranged to have complete freedom in rotation. They are of the self-synchronous motor type, and, since they are actually motors constructed on precision lines, they have a high control torque. Articles dealing with their operation have been published by Fink[20] (1944), and by Savage [21] (1944). Their most extensive use is with control and computing devices where they are required to be dead-beat and precise in their possible high-speed operation. Although they have been used to give remote indications of aircraft instruments, they are usually too bulky and expensive for this purpose. One of the smallest designs of this type of motor is the German one shown in Fig. 43, but if activity were directed to manufacturing a special small motor for exclusive use with remote indicating aircraft instruments, there is no reason why it could not be made as small or smaller than the Desynn motor shown in Fig. 44, or the even smaller d.c. Selsyn unit. An exceedingly small disc type of motor, used in conjunction with a thermionic amplifier, is made by the Pioneer Instrument Division of Bendix Corporation, U.S.A. A further flat type of motor, contained in a volume about 2·3 inches diameter by 0·75 inches deep, is under construction for the Instrument Division, Royal Aircraft Establishment. Although the flat type of motor is relatively wasteful in copper, and has a ratio of control torque to weight of rotor inferior to that for the conventional type of Selsyn motor, the shape fits in well with certain apparatus, and the relatively large diameter of rotor tends to reduce the angle of misalignment between the transmitter and receiver motors. The construction of existing motors calls for no special comment, and there is no difficulty in designing motors to operate from almost any frequency and voltage of the a.c. supply. Synchronous motors of this type are relatively immune to errors arising from variations in the electric supply, temperature, etc.

5.24. *Telegon, Admiralty Magslip, etc.* (Fig. 12).—These operate on the same fundamental principle, and since there are no small lightweight Magslip units the description is confined to the Kollsman " Telegon " motor. Kollsman " Circutrol " units are self-synchronizing motors, but are designed to operate entirely by induction. There are no brushes, rubbing contacts or windings on the rotor, and the field and rotor coils are stationary. Although the field windings can be polyphase, two windings mutually at right angles are sufficient for remote indication of aircraft instruments. The rotor and field coils are all mutually at right angles to each other, but only the former is energized, and it surrounds the iron armature. Salient poles at each end of the armature direct the magnetic flux to a soft cylindrical outer shell, hence the two field coils are inductively coupled to the rotor coil, and the voltage across each phase varies with the angular position of the pole pieces.

Special miniature units called " Telegon " motors have been developed for remote indication purposes. The transmitter and receiver motors are identical, and a complete unit is compact as can be seen in Fig. 45, and weighs only 5 oz. The control torque is, however, small, and it is necessary to use jewel bearings. The complete armature weighs only 0·06 oz. (1·7 grams). Telegon units have been used extensively in U.S.A. aircraft, and they satisfy many of the requirements of the ideal universal remote indicating system. A number of receivers can be used with one transmitter.

5.3. *Miscellaneous Transmission Systems.*—A selection of miscellaneous remote indicating systems is shown in Figs. 13 to 20. They illustrate the wide variety possible with electrically operated systems, and the examples described below have been chosen to illustrate certain salient features.

5.31. *Remote position transmitter* (Fig. 13).—Although this device does not appear to have been used in aircraft, it is widely used in other fields for the remote indication of the angular position of a lever.[11] The transmitter consists of two inductive units each possessing a winding on a set of laminations. The two units are coupled inductively by coils situated at the ends of a lever, and are so arranged that, as one coil moves off a limb of one unit, the other moves further on a limb of the second unit. The coils form a closed circuit and provide the only coupling between the two units. With this form of transmitter the ratio of the input and output voltages or currents gives the indication of the position of the lever. If a similar device is used as the receiver, the circuit automatically becomes a position repeater.

5.32. *Inductance bridge transmitter* (Fig. 14).—This device is included to illustrate another form of inductive transmitter. If the two primary windings are wound so that their two fluxes unite in the central limb, and the secondaries are wound so that their currents oppose each other, then the magnitude and direction of the output current are a measure of the angular displacement of the lever.

5.33. *Balanced magnetic reluctance bridge* (Fig. 15).—This circuit[5] shows a further type of inductive transmitter, and illustrates the inherent sensitivity of inductive devices, provided that they are designed with efficient magnetic circuits. With no thermionic amplifier whatsoever, the arrangement shown provides a simple and rugged apparatus capable of measuring displacements as small as one-millionth of an inch.

If the transmitters shown in Figs. 13, 14 and 15 were to be used in conjunction with electric meters as the receivers, errors would result from any changes in the frequency and waveform of the supply. A simple filter circuit arranged to bypass harmonics in the supply is shown in Fig. 15.

5.34. *Sine-cosine potentiometer transmission system* (Fig. 16).—This system is based on features incorporated in the G.3 fluxgate compass developed in the R.A.E. Although it is considered too complicated for use as a universal remote indication system, it is included in this review for completeness. Its main features are that the system possesses complete freedom in rotation, that the potentiometer plates occupy little depth behind the panel indicator, and that a relatively cheap motor can be used to rotate the receiver potentiometer contacts. Misalignment between the transmitter and the receiver feeds a signal into the amplifier which varies as the angle of misalignment, and the motor is caused to rotate until correct alignment is reached.

There are many similar amplified control systems in operation in which a motor moves a sliding contact along or around a potentiometer until a bridge circuit is balanced, as described in articles published by Fraser[12] (1945), and by Gille and Hutzler[22] (1944), but most of these are too complicated for the purpose contemplated in this review.

5.35. *Inductive follow-up system* (Fig. 17).—This is an original circuit making use of a thermionic amplifier and an electric servo-motor. The essential part of the transmission system consists of the simplest inductance bridge possible, similar to that shown in Fig. 6, but not self-balancing, and the transmitters and receivers would be miniature coils with simple moving-iron cores.

The bridge would not possess sufficient energy to be self-balancing since its sole function would be to provide a signal capable of being amplified and fed to the electric servo-motor. When the transmitter and receiver cores occupy identical positions, the bridge is balanced and the input voltage to the amplifier is nil. The transmitters and receivers of this system would have no rubbing contacts, and since they are inductance units even small devices would deliver an appreciable signal to the amplifier. For simplicity and reduction in weight the amplifier could be a single stage operated from an a.c. source. The motor could be simple and small of a watt or so in rating, since its only functions would be to move the small iron core of the receiver and to turn the pointer of the indicator. With careful design and universal application it is considered that this system could compete successfully in weight against some of the self-synchronous motor systems.

These systems, as described by McNaney[2] (1944), and by Fink[20] (1944), require two motors, whilst the suggested system requires only one motor of a much simpler type, plus a valve and a few radio type components, and it could operate with extremely light connecting wires. Although the weight and bulk of the transmitter could be ignored, the bulk of a single stage amplifier would be added at the receiver. Rather than fit an amplifier inside each receiver case it would be preferable to embody all the amplifiers in one case which could be located in the most convenient place. The advantages of such a system would be considerable, the transmitter would be simple, small, free from wear, and would be uninfluenced by vibration or friction. Further, the force or torque necessary to operate the transmitter would be negligible, and the resistance of the receiver system would not react back on the transmitter. Although the system is not capable of unlimited rotation, the one amplifier could drive a number of motors, and it would not be necessary to fit inductance units to more than one motor, since the angular position of the rotors would be determined by the phase of the amplifier output.

There are a number of amplifier servo systems already in use capable of continuous rotation. One such system is based on the circuit shown in Fig. 11, but only the transmitter rotor is energized, and the receiver rotor coil is used as a pick-up system. The signal is fed to an amplifier whose output causes an electric motor to rotate the receiver rotor until it is correctly aligned with the transmitter rotor. Although the suggested system is very similar to such existing schemes, it is, however, a very much simpler version, and it would be constructed on miniature lines since it would not be required to perform work other than turning a pointer and moving a small iron core.

5.36. *Resistance bridge and moving magnet ratio-meter* (Fig. 18).—This circuit has been included to illustrate the resistance bridge circuit used with temperature sensitive resistance bulbs and the latest forms of moving magnet ratio-meter, as described by the R.A.E.[13] (1944), and by Sims and Fisk[14] (1944) in a published article. The permanent magnet rotor is usually a sintered oxide chosen for its high coercive force and its low density. Such meters have control characteristics that compare favourably with the best moving-coil meters, are simpler to make, and can be constructed so that the pointer moves almost linearly over a scale length of 120 deg. or more. This circuit is also used with a potentiometer type transmitter to indicate position or fuel contents, and is reasonably immune to changes in temperature and supply voltage.

5.37. *Phase transmitter and phase meter* (Fig. 19).—Position repeating self-synchronous motors are in effect phase operated devices. There are many phase sensitive circuits that could be used for remote indication purposes, and it is a feature of such circuits that they are uninfluenced by reasonable changes in supply voltage. Simple potentiometers can be used as phase transmitters, and one such transmitter is shown in the diagram. This device will operate over a phase change of about 120 deg. by sliding the potentiometer contacts from one end to the other. It should be noted, however, that the Micro Desynn transmitter shown in Fig. 21 also makes use of two potentiometers and obtains a phase change of 360 deg. It is not considered that phase sensitive circuits of the type shown in Fig. 19 have much promise as remote indicating systems.

5.38. *Voltage transmission circuit using stabilised d.c.* (Fig. 20).—Considerable time and ingenuity has been spent on developing special devices to nullify the effects of temperature and changes in the supply voltage of remote indicating systems. As already explained in Section 4.2 it is now possible to stabilize the supply voltage. If such stabilization is used it becomes possible to use extremely simple transmission systems, such as the one shown in the diagram. Since the impedance of the leads would be small in comparison with that of the transmitter and the voltmeter resistances, their lengths would be relatively unimportant. Instead of fairly complicated and insensitive ratio-meters being necessary, it would be possible to use straightforward sensitive meters, preferably of the cirscale type. The use of two or more receivers would present no difficulty, and, provided that the system were used universally, it is doubtful if such a stabilized system would add much weight to the aircraft, if compared with the total weight of other unstabilized systems. Although the system is shown for use with stabilized d.c., it could equally well be used with a stabilized a.c. supply, if the meter were altered accordingly, possibly by the addition of metal oxide rectifiers.

5.4. *Impulse and Repeater Motor Remote Indicators.*—A number of such systems are in general use, for such devices as remote clock mechanisms which repeat the time given by a master clock, and the dialling system of the automatic telephone. Such systems operate from a series of electrical impulses, and are thus relatively immune to such factors as changes in the supply voltage, variation of operating temperature, etc. The transmitters and receivers can be polarized or arranged to function in either direction, and can be either self-synchronous or non-synchronous. Three different systems suitable for the remote indication of aircraft instruments are described below.

5.41. *Self-generating impulse method* (Fig. 23).—An attempt has been made in the diagram to illustrate the principle of operation of this method, but it should be understood that this illustration is only diagrammatic. The information regarding the system is meagre. It is an impulse-type oil pressure gauge and the transmission system is that used in telephones. It consists of a coil of wire being deflected in a magnetic field by a ratchet device and returned rapidly by means of a retaining spring. This operates a phase-sensitive ratchet device within the repeater. No external current is required and the generated current flows only when any transmitted movement occurs. The system does not indicate any failure of the transmitter, indicator, or connecting wires. Manufacture of the repeater requires watchmaking accuracy.

One proposed use for the system is that of throttle operation as positive positions are given with no backlash and there is no trouble from structure flexing. The units can be of reasonable size.

A system such as this might be suitable for a universal remote indicating system, but more information is required regarding the details of the system before its merits or demerits can be assessed. It might be that the freedom from an external source of electricity is obtained at the expense of delicate construction. It would appear that the system is not self-aligning.

5.42. *Remote clock mechanism* (Fig. 24).—Clock mechanisms of this type are usually arranged to rotate only in one direction, but the diagram is drawn for a system arranged to rotate in either direction, and the transmitter is a modified receiver. If the contact bridge of the transmitter is moved up or down, impulses will pass in series through one transmitter and one receiver solenoid coil, and the two toothed discs will be ratcheted through a number of angular displacements. Eventually the contact on the transmitter disc moves away from the contact on the bridge piece. If it touches the opposing contact on the bridge, the discs will be oscillated backwards and forwards about the correct angular position, but, if the gap between the bridge contacts is sufficient, the disc contact will float midway, and the pointer on the receiver disc will be steady for a given displacement of the transmitter. The system would suffer from a differential error, but this could be arranged to be negligible. It is not considered that the small impulsive movements of the receiver are objectionable. As drawn, the transmitter would only operate over a limited angle, but it could easily be arranged to operate over an unlimited angle. The mechanism would contain a number of moving and wearing parts, and the system suffers from the drawback that it is not self-aligning. It is possible, however, by means of suitable gearing to transmit from a small displacement and to produce a large displacement of the receiver.

5.43. *Repeater motor circuit* (Fig. 25).—The circuit shows a three-coil stator system as used for the M-type repeater motor. The transmitter consists of three cams attached to a shaft, and each cam operates a switching system as shown in the diagram. Thus, as the transmitter shaft rotates, the stator coils are connected in such a sequence that the receiver rotor follows it with angular steps of 30 deg. It is necessary to fit trains of gears to both the transmitter and receiver shafts so that the incremental steps of the receiver pointer are reasonably small, and hence the system demands a considerable effort to operate the transmitter.

The use of gearing is undesirable since, except for a limited misalignment angle between the motors, it makes the system non-synchronous, and alignment errors equal to a number of turns of a motor in either direction can be caused by an imperfect switch contact, or by disconnecting the leads, and then after an interval, reconnecting them. It is therefore considered that this possible fault renders the repeater motor system unsuitable for use as an ideal remote indicator. The dimensions of the M-type repeater can be seen from Fig. 42. Most repeater motors are designed for control and computing arrangements.

6. *Hydraulic Methods of Remote Indication.*—Although hydraulic methods are used extensively for remote control, they have few applications to remote indicating systems for use in aircraft. One simple system is the " Exactor " control, which has no pump, and only one pipe line. It is claimed that a single lever will remotely operate another lever with an accuracy of alignment of a fraction of a degree over a connecting pipe 150 feet long. For remote instrumentation, however, the use of hydraulics is mainly confined to the remote indication of pressure, although it has been tried out for use with fuel contents gauges and flap indicators.

6.1. *Capillary Systems.*—The capillary systems mentioned in Section 2 are used for the remote indication of pressure and temperature and are manufactured by many firms in the country. Instruments for both measurements make use of small bore tubing to connect the transmitting and receiving units. The tubing cannot be disconnected from either unit since sealed systems are required. Hence it is not convenient to use such systems for large aircraft since they are difficult to install, maintain, or store.

For some temperature measurements a mercury in steel system is used. This consists of a steel bulb, a length of steel capillary, and a bourbon pressure gauge, all carefully filled with mercury.

For pressure measurements the primary fluid under measurement is fed to a compartment in a banjo fitting where it acts on a flexible capsule. The capsule, a length of small-bore tubing, and a bourdon pressure gauge are filled with a selected fluid, which is therefore at the same pressure as the fluid under measurement. The fluid is chosen to have a low viscosity at low operating temperatures, and a feature of the design is that failure of the gauge or line does not allow the primary fluid to escape. Should such a failure occur the capsule collapses.

6.2. *Minneapolis-Honeywell Pressure Transmitting System* (Fig. 26).—The Minneapolis-Honeywell system is essentially an open system and hence is free from all errors due to temperature. The transmitter is divided into two compartments by a flexible diaphragm made of neoprene, and hence the pressure of the fluid under measurement is transmitted to a second fluid on the pressure-gauge side of the diaphragm. The transmitting fluid is chosen to be suitable for operation over a wide range of temperature, and thus oil pressure variations at low temperatures of the gauge line is quickly indicated with little time lag. It is of course necessary to prime the gauge line when the system is first installed or after an overhaul, and care must be taken always to make sure that leaks are prevented. In operation the diaphragm must displace sufficient fluid to operate the pressure gauge indicator, but its zero pressure position will depend on the volume of fluid displaced or taken up by thermal expansions or contractions of the system. It is claimed that the standard transmitter will function for gauge lines up to 70 feet in length. If more than one receiver is used, a shorter total length of gauge line must be used.

Although the system is simple, light, and reliable, it does not lend itself to the use of one pressure gauge and a switching system, so that a number of transmitters can be indicated one after the other. For the measurement of low pressures, the difference of ambient pressure at the transmitter and receiver, and the installation head due to differences in level of the transmitter and receiver, are important. The Minneapolis-Honeywell system is essentially one for remotely measuring fluid pressure, and due to its principle of operation it could not easily be adapted to make other measurements, such as temperature or displacement. It is thus unsuitable for the purpose of a universal remote indicating system.

7. *Pneumatic Methods of Remote Indication.*—Pneumatic remote indicating systems are used in many fields of engineering, but so far, apart from an occasional use, such as its remote indication with the Askania distant-reading compass, such methods have not been widely used in aircraft. One of the main attractions of using air as the operating fluid is the fact that it can readily be discharged into the atmosphere, and hence there is no need to use a return pipe. A disadvantage of pneumatic methods is that clean and dry air is usually required ; whereas air taken direct from the atmosphere is usually contaminated with dust and moisture. Although the amount of air required to operate most pneumatic systems is small, the apparatus required to dry and clean the air would occupy considerable space, and there has therefore been some reluctance in the fitting of pneumatic remote indicating systems in aircraft. Should a suitable air supply be available in aircraft, the possible use of such systems would become more attractive. Five different methods of remote indication by pneumatic means are described below.

7.1. *K.D.G. Pneumatic Pressure Transmission System*[15] (Fig. 27).—In certain respects this system has some features in common with the Minneapolis-Honeywell system. Both systems make use of a flexible diaphragm to separate the fluid under measurement from the pressure transmitting fluid, and in both cases the diaphragm must be capable of withstanding the full fluid pressure, should the gauge line fail. The K.D.G. system requires two valves and actuating gear, which must be regarded as potential sources of trouble, whereas the Minneapolis-Honeywell system has none. Again, the former uses an external power supply in the form of clean and dry compressed air in excess of the pressure being measured, whilst the latter requires no external power supply. The K.D.G. system is superior to the Minneapolis-Honeywell system in one feature, namely that the one receiver may be used for a number of transmitters by means of a selector valve. It is claimed by the makers of the K.D.G. system that small leaks in any of the pipe lines will not affect the reading, but small leaks are more likely to develop in the K.D.G. system than in the Minneapolis-Honeywell system. A number of tests carried out on the test bed, in the laboratory, and in the air have been satisfactory. In common with the Minneapolis-Honeywell system, the K.D.G. system has been developed for the measurement of pressure, and could not easily be modified to measure temperature and displacement.

*7.2. *Negretti and Zambra Air Transmission System*[16] (Fig. 28).—In this system, remote indications of pressure, temperature, displacement, etc., are obtained by means of a special design of transmitter unit. One design arranged to measure fluid pressure is shown in the diagram. The double diaphragm unit is arranged to be unaffected by vibration, and the outlet valve is arranged to close against the jet of air leaving the capacity underneath the lower diaphragm. Fundamentally, although the system is extremely simple, it is of the servo-operated follow-up type. The air operated diaphragm is arranged to follow-up the fluid operated diaphragm, and as coincidence is approached the air throttling outlet valve attains an equilibrium position. For this position the value of the air pressure below the diaphragm depends on the deflection

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* *See* Editorial Note on page 21.

of the diaphragm, and is thus a measure of the fluid pressure, but does not necessarily have the same value. Such a system is extremely sensitive to small movements of the outlet valve, and, if the valve movement is small in comparison with the deflection of the diaphragm, the reading is almost unaffected by the pressure of the air supply. It is necessary, however, for the quantity of the escaping air to be small so that the kinetic effects of the air flow are negligible, so that it can be assumed that the static pressure attained under the air diaphragm is constant at all points connected with that space. This flow restriction limits the maximum pressure of the air in the remote indicating connection. The makers suggest a supply pressure about 15 lbs./sq. in., and also suggest a pressure gauge having a range of say 1 to 6 lbs./sq. in. for the receiver. Owing to the low pressure operating the receiver it is necessary to enclose the transmitter and receiver units in containers connected by a comparatively large-bore pipe line to ensure that the static pressure is constant throughout the system. This large bore is an undesirable feature of the system. It is apparent that suitable transmitter units could be arranged to operate for most remote indication applications.

7.3. *Cambridge Pneumatic Transmission System*[17] (Fig. 29).—This remote indicating system operates on the same fundamental principle as the Negretti and Zambra system, and differs only in the method of construction. In both systems the fluid pressure causes a displacement, and a pneumatic system is arranged to follow-up this displacement. Negretti and Zambra make use of diaphragms, whilst the Cambridge design uses two concentric bourdon tubes. So far no design has been suggested making use of bellows or sylphon units, but these could be used just as readily as any other form of pressure responsive unit. In the Cambridge system the fluid is admitted to the inner tube, and air is fed through a restriction to the outer tube. Thus, if fluid pressure opens out the inner tube, the air leak from the end of the outer tube is sealed until a pressure has been built up in it sufficient to open out the tube and to lift the valve from its seat. Equilibrium conditions are quickly attained, and then the air pressure in the outer bourdon tube gives a measure of the fluid pressure in the inner tube. The makers suggest an air supply pressure of about 25 lbs./sq. in. So far this system has only been used for the measurement of temperature by means of the pressure of a sealed system, but any comments made regarding the Negretti and Zambra system apply with equal force to the Cambridge system.

7.4. " *Barnes* " *Type Air Valve* (Fig. 30).—Although this device is usually used for testing such instruments as air-speed indicators or is incorporated in a force magnifying system, it could be used for the purpose of remote indication. In Sections 7.2 and 7.3 the measurement to be transmitted is first converted into a displacement, but if a Barnes type valve were used it would be necessary to convert the measurements into forces. This would present little difficulty since a spring provides a ready means of converting a displacement into a force.

The principle of operation of the valve is as follows. Air is supplied to a cavity through a restriction, and hence the pressure of the air in the cavity rises until the force exerted by the air on the underside of the sharp edged valve just equals the force holding it on its seat, and further supply of air lifts the valve and escapes. The pressure of the air in the cavity is then a measure of the force acting on the valve. Although a system based on this principle might be somewhat simpler in construction than either the Negretti and Zambra or Cambridge systems, it suffers from the same disadvantages, namely, the need for clean and dry air, and the low working pressure of the system compared with that of the surrounding atmosphere.

7.5. *Balanced Diaphragm Devices* (Fig. 31).—Such devices operate on the same fundamental principle as that described in Section 7.4, but a flexible diaphragm is used in place of the sharp rimmed valve, and the design shown balances a large force by means of a comparatively low air pressure. It is claimed that torque-meters making use of a balanced diaphragm, in which the force applied to the diaphragm is automatically balanced by air pressure, and whose value is indicated at a remote position, have been used with success for many years. One design is shown in Fig. 31, and it is claimed that one of the features of the system is the remarkably small movement of the diaphragm required to balance the system. Air pressures up to 25 lbs./sq. in. have been used. The main advantage of such devices is that large forces can be automatically balanced by the use of compressed air. Although such devices have only occasionally been used for remote indication, it would be possible to modify them and make them function for most of the remote indications required in an aircraft. Clean and dry air would be advantageous even with this scheme.

8. *Comments on Various Features of the Systems Described.*—Before a comparison can be made of the various systems described in the previous sections of this review, it is considered desirable that some comments should be made regarding some of the features of the systems.

8.1. *Design of Meter Magnets and Cirscale Movements.*—During the past few years new magnetic materials such as Comal, sintered oxide, copper-nickel-cobalt alloys, and the various types of Alnico have made their appearance. Although these materials have much improved qualities over those previously used, there appears to be no reason to assume that such improvement is nearing its end. The recently developed Alnico V actually produces approximately twice the external energy per unit volume of Alnico II. These new materials have affected the design of instrument magnets to a considerable extent, and hence extremely compact electrical meters can now be constructed. Fig. 36 shows a compact design of moving-coil meter permanent magnet developed by General Electric Co. (U.S.A.) about 1941, and Fig. 37 shows a construction used in recent examples of moving-coil meters used in German aircraft. In both designs a soft-iron cylindrical shield performs the dual function of acting as a shield and a return path for the magnetic flux. The scale length of both designs is limited to about 90 deg., and recourse to gearing is necessary to obtain a cirscale indication. Fig. 38 shows for comparison the most recent form of one piece Comal magnet, but again the scale length is limited to about 90 deg.

Fig. 39 shows a Meylan type magnet which permits of a scale length of about 180 deg., but such a design is comparatively inefficient, and only one side of the moving coil operates in the air-gap. A more compact magnet design, which allows of a scale length of almost 270 deg., is the Siemens instrument shown in Fig. 40, but again this only uses one side of the moving coil. In spite of this the meter requires only 2 ma. for full scale deflection. The meter is used in recent types of German aircraft. The conventional method of obtaining a cirscale movement of about 270 deg. is shown in Fig. 41 which illustrates the Record type magnet system. This meter uses two sides of the moving coil, as with the Weston type of meter, but the design shown, which is taken from a current movement, is bulky and not self-screening.

8.2. *Comparison of Ordinary and Ratio-meters.*—It would appear that it is an inherent property of ratio-meters that they sacrifice some of the good features of ordinary non-ratio meters in order to possess the ratio characteristic. Usually they are less accurate, more complex in construction, and require considerably more current to operate than the simple straightforward meter. It is extremely difficult to design a reasonably efficient, and not too complex ratio-meter, having a long cirscale indication. As far as is known it would appear that no really satisfactory aircraft instrument of the cirscale type has so far been constructed, and the maximum length of scale for either a moving-iron, moving-magnet, or moving coil ratio-meter is in the region of 120 deg. Recourse to gearing is necessary to extend the instrument scale, such as is used with the Simmonds Pacitor fuel contents gauge. Although this geared ratio-meter appears to be functioning satisfactorily, it cannot yet be stated that ratio-meters are suitable for use with step-up gearing.

When voltage stabilisation of the power supply to aircraft instruments is considered, a double-fold gain is obtained by using ordinary meters in place of ratio-meters. The first gain is in using a simpler and more accurate standard meter, and the second is that since such meters require much less current for their operation, the total load requiring stabilisation is thereby reduced.

Since it is considered that it will always be possible to make the conventional meter more compact than ratio-meters, no difficulty is presented in fitting up to four of them in one instrument case as shown in Fig. 33. The straightforward meter is also somewhat easier to use if more than one meter is required to operate from one transmitter.

8.3. *Characteristics of Metal Oxide Rectifiers.*—Metal oxide rectifiers are used in some of the remote indicating systems described in this review. Such rectifiers, whether they are of the copper-oxide type described in an article published by Smith[18] (1944) or of the selenium type, they must be used with extreme care. Their current voltage curve approximates to a square law, and their characteristics vary with tempereature. The resistance in both the high and low conducting directions varies considerably with the applied potential. It is therefore necessary to use a high resistance in series with the rectifier to minimise its changes in resistance, or to arrange the circuit so that the variable characteristics of the rectifiers are comparatively unimportant.

A good feature of the rectifier is that it is extremely robust and not liable to errors caused by severe vibration.

8.4. *Application of Electronics to the Problem.*—When sufficient power is available to operate the conventional electro-magnetic instruments and motor devices, there is no particular advantage in substituting electronic apparatus in their place, but there are many cases wherein electronic methods offer new and far reaching opportunities. There is no doubt that wartime conditions has accelerated the use of electronic devices, as can be seen from articles by Middel[19] (1944), and by Gille and Hutzler[22] (1944), and have done much to break down the prejudice against their use. In this review, the use of electronics has been confined to applications wherein immediate benefits would result without too drastic an alteration to current instrument practices. It has been accepted that the ideal remote indication to aim for is that given by a pointer type instrument operating over a long cirscale, and possible uses of cathode ray oscillographs and other electronic tubes for presentation of the remote indications are therefore not included in the review.

8.5. *Power Requirements for Remote Indication.*—Many of the electrical remote indicating systems, as for example, the Telegon, d.c. Selsyn, German self-balancing bridge and moving magnet temperature indicators, ratio-meter circuits, etc., require a power supply of the order of two watts.

Although the air consumption of most pneumatically operated systems is small, it would probably take more than two watts to supply sufficient clean and dry air to operate the Negretti and Zambra scheme, and a much higher wattage to operate the Cambridge system. If clean and dry air is obtained, as suggested by Negretti and Zambra by first cooling high-pressure air, then filtering it to clean it, and finally reducing its pressure to a suitable value, then the equivalent wattage required would far exceed that required to operate electrical systems.

The fact is stressed that the Minneapolis-Honeywell pressure transmitting system requires no external power supply, but owing to the small electrical demand of most remote indicating systems, this feature actually becomes relatively unimportant. Thus the importance of whether or not an external power supply is required, depends more on the possible simplification of the system than anything else.

9. *Comparison of the Various Systems.*—(*a*) The first point that arises from the review is the major part played by electrically operated systems. As well as permitting of a greater variety in types of system, the electrical methods can claim many important features over the other systems.

(*b*) Comparatively simple and readily made connections are possible between the transmitter and the receiver for electrically operated systems, and they lend themselves to simple switching arrangements. Satisfactory connections for hydraulic and pneumatic methods cannot be made with the same ease, and multi-point connections for them are almost unknown. Even although most pneumatic systems can tolerate a few leaks, these would greatly affect the total air consumption, and the testing of the connections after installation or overhaul would entail some difficulty. In almost all respects, it is considered that electricity is a more satisfactory fluid to use then either air or a liquid.

(*c*) In the interests of standardization, the remote indicating system or systems should operate from a power supply already required for other purposes. Even the use of a unique method, such as the Minneapolis-Honeywell pressure transmission system, which is only suitable for one type of remote indication, and which is quite different in principle to those used for most of the other remote indications, can only be justified if its advantages far outweigh its disadvantages. If it is taken that the other systems operate, say, from the electric supply, then the disadvantages are that a special technique must be learnt to install and service the one special system, and that a special fluid is required for it.

(*d*) Although pneumatic systems require a special supply of air, this could easily be supplied from a special small self-contained installation. Such a requirement, however, could only be justified if pneumatic systems possessed outstanding advantages over other systems, and could be used for all remote indications. However, it is not considered that this is the case, and so far no pneumatic method has been suggested capable of dealing with the remote indication of unrestricted rotary motion.

(*e*) It has been suggested that pneumatic systems might have considerable use for the instrumentation of power plants. This suggestion is based on a comparison of the pneumatic and the Desynn systems, and stresses some points in favour of the former system. It is considered, however, that the comparison deals with the performance of two competitive designs rather than with the underlying fundamental principles of the two systems.

(*f*) Electrical methods, whether operated by a.c. or d.c., do cater for every type of remote indication, but since the remote indicating compass is probably the only instrument which requires the transmission of unrestricted rotary motion, it is not considered essential that a universal system need cater for this application. It is, however, considered important that it should operate from the same power source as the universal system.

(*g*) The resistive type of transmitter is perhaps the simplest that can be devised, and occupies the minimum of space. Such transmitters, whether slab or toroidally wound are used extensively in German transmitting systems, and these are usually made on exceedingly small lines. The workmanship of these components is superlative, and compared with these transmitters Allied designs are bulky and heavy in conception.

(*h*) Resistive transmitters cater for large angular and comparatively large linear movements, but cannot be used direct for small displacements.

(*j*) Owing to the limited use of a.c. in aircraft the inductive type of transmitting circuit is relatively undeveloped, apart from the self-synchronizing electric motor. Although in many cases the inductive device will be larger than the resistive unit, it will deal with all types of displacement, and can be made suitable for dealing with very small linear or angular movements. Apart from those units catering for unrestricted rotary motion, no rubbing contacts whatsoever are required for the inductive transmitter.

(*k*) Although it is considered that inductance type position repeating systems will have considerable use in the future, the possible use of repeater motors will be restricted, owing to the difficulty of always supplying the required number of turns at the transmitter shaft from the indication being transmitted.

(*l*) It is considered that position repeating circuits operated from an a.c. source could be developed to form an ideal remote indicating system suitable for universal use. The self-synchronous electric motor could be confined for use where it is necessary to transmit rotary motion ; but limited angle or limited displacement self-synchronous inductance units, perhaps with the use of an amplifier, could cater for all other indications.

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15	K. D. G. Inst., Ltd.	Pneumatic Transmission Oil Gauge. Firm's Note dated March, 1943.
*16	Negretti and Zambra, Ltd.	Scheme of Air Transmission for Distant Reading Aircraft Instruments. Firm's Report No. 3224.
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19	H. D. Middel	Electronics in Instrumentation. *G.E. Review*, November, 1944, Vol. 17, No. 11, p. 9.
20	L. R. Fink	Position Control. *G.E. Review*, December, 1944, Vol. 47, No. 12, p. 40.
21	C. F. Savage	Influence of Electricity on Aircraft Instrumentation. *Electrical Engineering*, November, 1944, p. 802.
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**Editorial Note, March, 1947.*

Messrs. Negretti and Zambra, Ltd. point out that, in their report No. 3224, an attached diagrammatic description of the lay-out of their air transmission system applied to aircraft has apparently given the impression that the "static pressure equalising tube" is required to be of much larger bore than is in fact necessary.

Actually, they estimate that, for an installation of, say, 10 instruments with the transmitters 50 ft. from the indicators, a pipe of about 0·20-in. bore only would be adequate.

An alternative method, which in some cases might be advantageous, is to make the indicating instruments differential pressure gauges, with two lines of tubing between each indicator and its transmitter, both being of small bore.

Note.—Potentiometers can be wound on linear or curved formers.

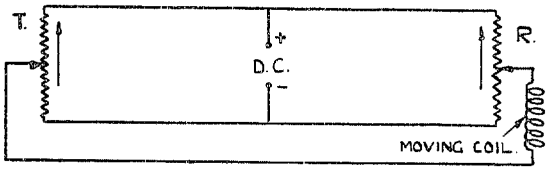


FIG. 1. Self-balancing Resistance Bridge.

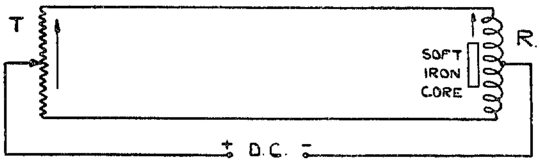


FIG. 2. Self-balancing Resistance—Magnetic Circuit.

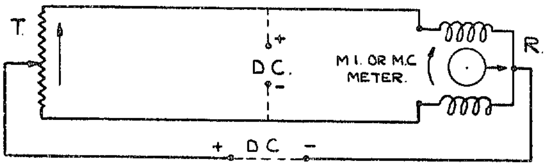


FIG. 3. Ohm-meter and Ratio-meter Circuits.

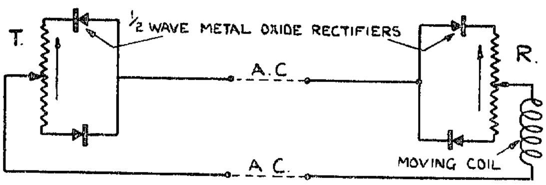


FIG. 4. Self-balancing Resistance Bridge.

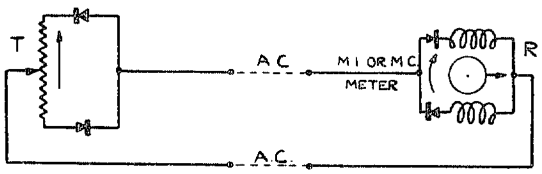


FIG. 5. Potentiometer Transmitter and Ratio-meter.

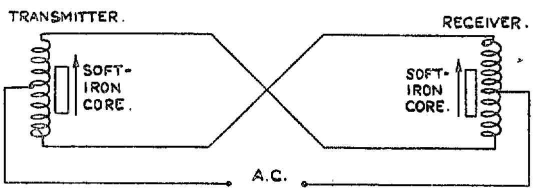


FIG. 6. Self-balancing Inductance Bridge.

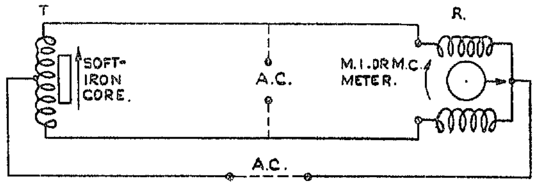


FIG. 7. Inductor Transmitter and A.C. Ratio-meter.

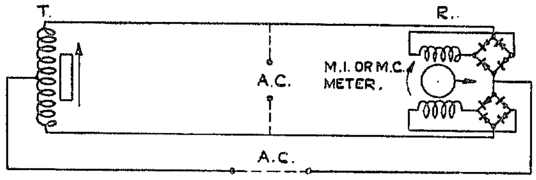


FIG. 8. Inductor Transmitter and D.C. Ratio-meter.

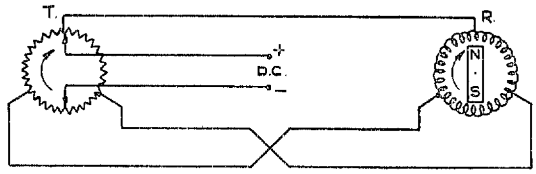


FIG. 9. Desynn, D.C.-Selsyn, etc.

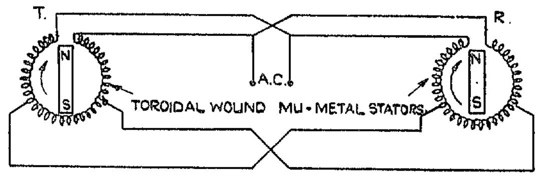


FIG. 10. Magnesyn.

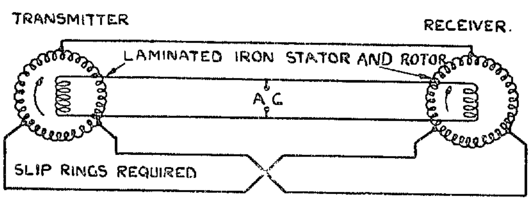


FIG. 11. Selsyn, Autosyn, etc.

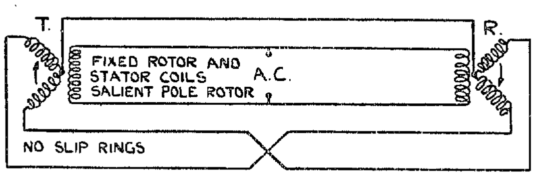


FIG. 12. Telegon.

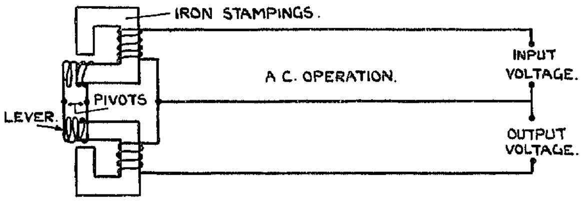


FIG. 13. Remote Position Transmitter.

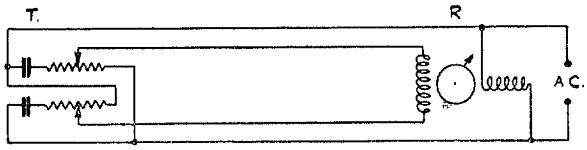


FIG. 19. Phase Transmitter and Phase Meter.

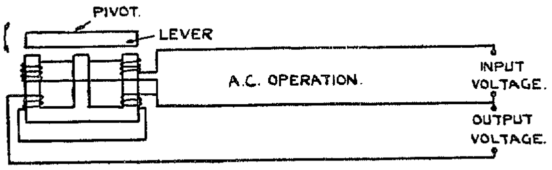


FIG. 14. Inductance Bridge Transmitter.

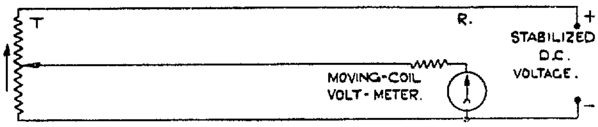


FIG. 20. Voltage Transmission Circuit Using Stabilised D.C.

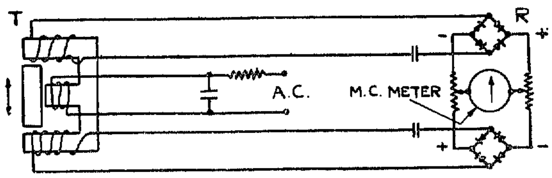


FIG. 15. Balanced Magnetic Reluctance Bridge.

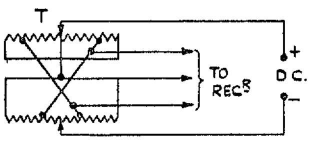


FIG. 21. Micro Desynn Transmitter.

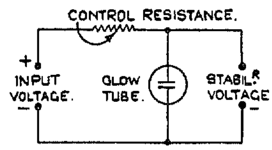


FIG. 22. D.C. Voltage Stabiliser.

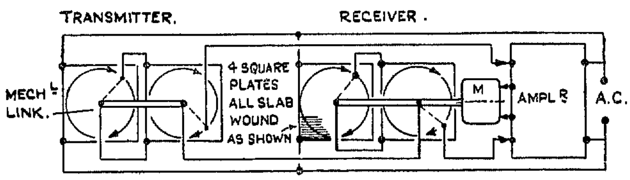


FIG. 16. Sine-Cosine Potentiometer Transmission System.

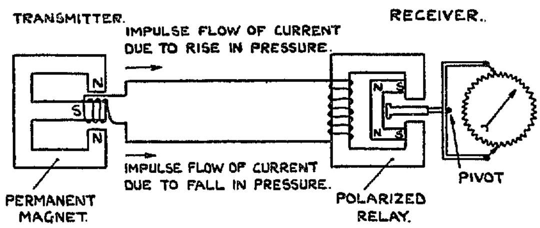


FIG. 23. Self-Generating Impulse Method of Pressure Indication Transmission.

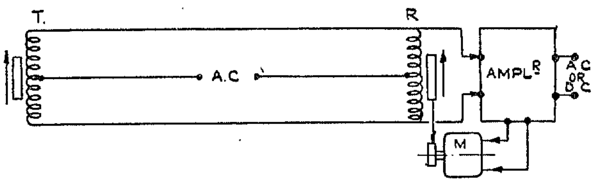


FIG. 17. Inductive Follow-up System.

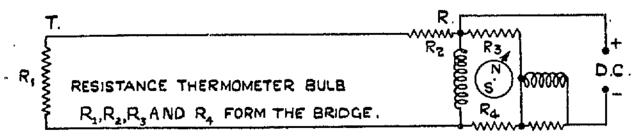


FIG. 18. Resistance Bridge and Moving Magnet Ratio-meter.

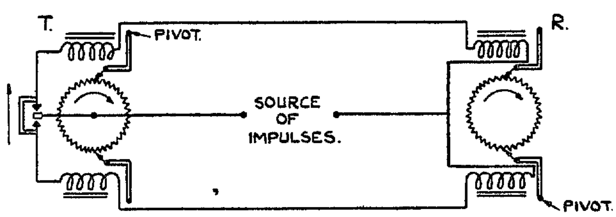
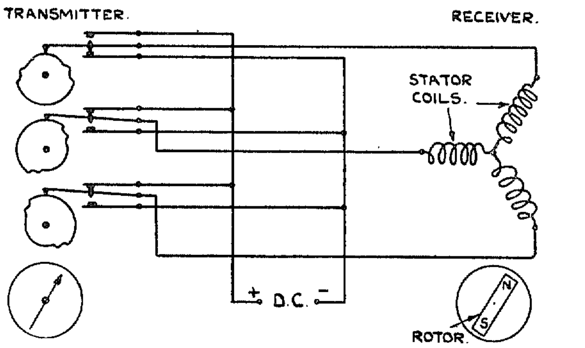


FIG. 24. Remote Clock Mechanism Arranged for Clockwise or Anti-clockwise Rotation.



Note. The three cams are fitted to one transmitter shaft.

FIG. 25. Repeater Motor Circuit.

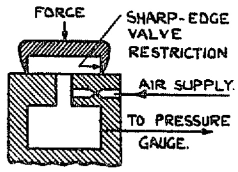


FIG. 30. "Barnes" Air Valve.

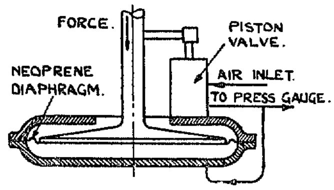


FIG. 31. Balanced Diaphragm.

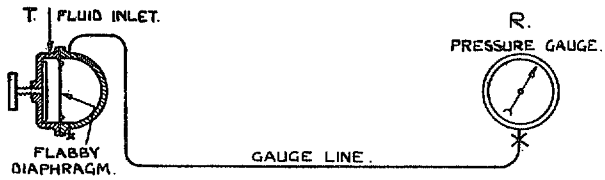


FIG. 26. Minneapolis-Honeywell Pressure Transmission System.

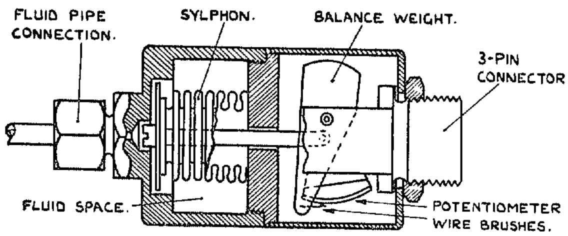


FIG. 32. German Fluid Pressure Transmitter Unit. (Scale : Half size.)

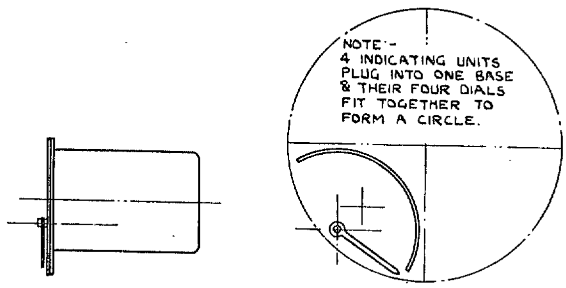


FIG. 33. Pressure Indicating Unit. (Scale : Half size.)

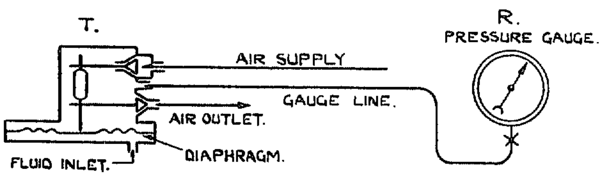


FIG. 27. K.D.G. Pneumatic Pressure Transmission System.

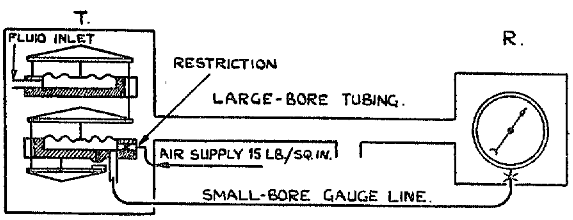


FIG. 28. Negretti and Zambra Air Transmission System.

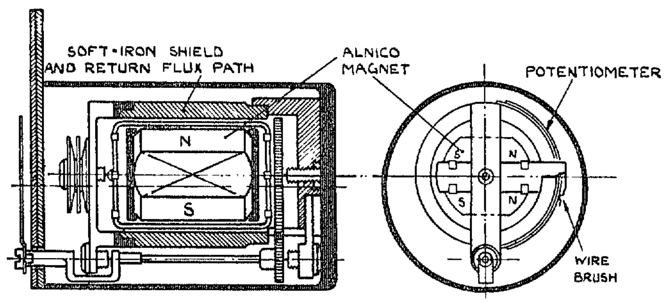


FIG. 34. Indicating Unit. (Scale : Full size.)

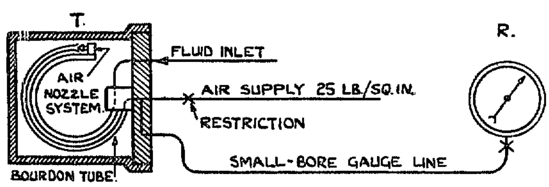


FIG. 29. Cambridge Pneumatic Transmission System.

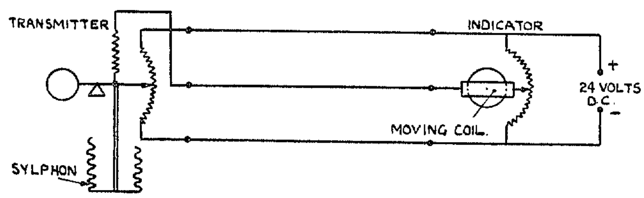


FIG. 35. German Self-balancing Bridge.

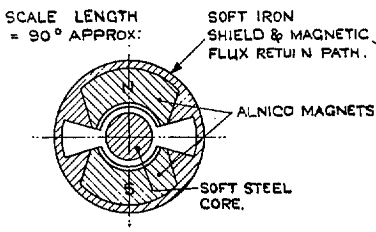


FIG. 36. General Electric Co. (U.S.A.) Meter Type D.P. 9. (Not to scale.)

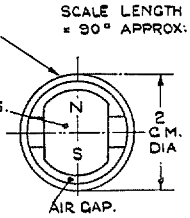


FIG. 37. A.E.G.–D.V.L. Meter.

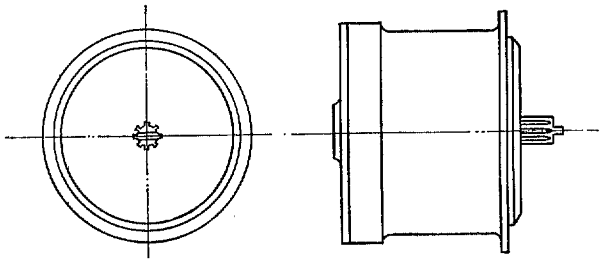


FIG. 42. Type M Repeater Motor. (Scale : Half size.)

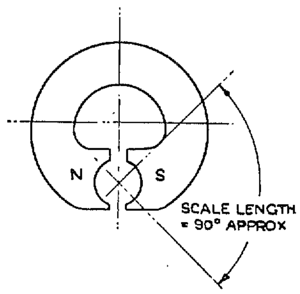


FIG. 38. General Electric Co. (U.S.A.) Comal Magnet (Scale : Half size.)

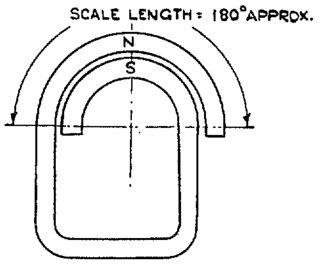
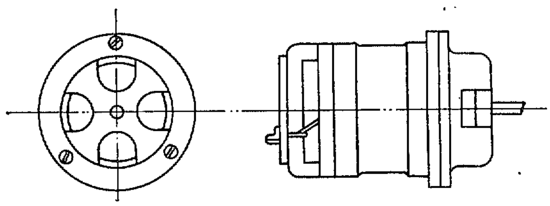


FIG. 39. Meylan Type Magnet. (Not to scale.)



Rotor diameter = 15 mm.

FIG. 43. German Autosyn Type Motor. (Scale : Half size.)

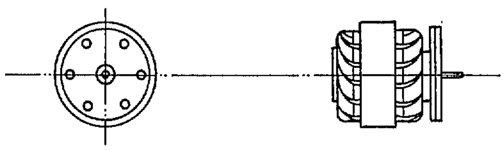


FIG. 44. Desynn Receiver. (Scale : Half size.)

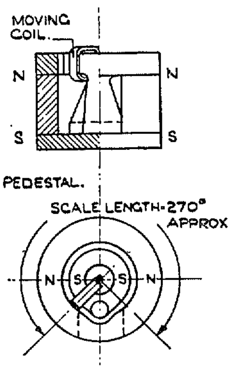


FIG. 40. Siemens Meter.

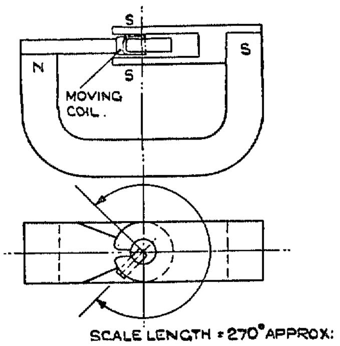


FIG. 41. Record Meter.

Arrangement of Magnetic Circuits for Moving-coil Cirscale Meters.

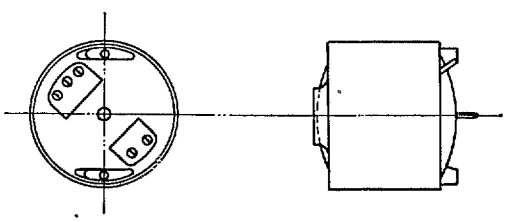


FIG. 45. Telegon Motor. (Scale : Half size.)

(79308) Wt. 10/7116 1/48 Hw. G.377/1