PATENT SPECIFICATION

635,633

Date of filing Complete Specification: July 12, 1948

Application Date. June 13, 1947. No. 15580/47.

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PROVISIONAL SPECIFICATION

Improvements in Means for Measuring, Indicating, or Utilising Very Small Displacements

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SPECIFICATION No. 635,633

By a direction given under Section 17(1) of the Patents Act 1949 this application proceeded in the name of The Minister of Supply, of Adelphi, Strand, London, W.C.2.

THE PATENT OFFICE,
18th May, 1950

DS 37378/1(22)/3391 160 5/50 R

either by ... means at such a frequency and with such an amplitude and in such a mode that the amplitude and/or mode of oscillation is modified by the mechanical contact of the said rigid body with some part of the vibrating system or, alternatively, with subsidiary levers, plungers, triggers, etc., designed to cause motion of the said body to influence the amplitude or mode of oscillation.

In this specification the term "gauging device" is to be understood to include the mechanical vibratory system together with its associated driving or exciting means (referred to as the "motor"), and the term gauging element" is to be understood to refer to that part of the vibratory system which makes mechanical contact with the body under observation or alternatively with the subsidiary levers, etc., mentioned above.

As an illustration of the principle of this invention consider a simple telephone receiver. The receiver as a whole constitutes the gauging device and a small, hard piece of material fixed to and projecting from the centre of the diaphragm constitutes the gauging element. Most commercial telephone receivers exhibit a mechanical resonance near 1,000 c/s. If such a receiver is excited by alternating current of frequency rather lower than 1,000 c/s (say 700 or 800 c/s) the following phenomena will be observed. On approaching a rigid body towards the gauging element the electrical impedance of the receiver will pass through a series of stable values as the rigid body restricts more and more the amplitude of oscillation of the diaphragm, the impedance changing in a regular and steady manner as the oscillation is reduced to zero. In bringing the gauging ele-

connect... ceiver as one arm of an impedance bridge fed with (say) 800 c/s, and to adjust the other components of the bridge so that no voltage appears at the "detector" terminals of the bridge when the diaphragm is freely vibrating. It will then be found that, on bringing the rigid body into contact with the gauging element, the voltage at the "detector" terminals of the bridge rises from zero through a series of values approximately proportionate to the corresponding displacements of the rigid body.

The effects just described occur if the frequency of excitation is lower than the resonance frequency of the vibratory system. If, however, the frequency of excitation is slightly higher than the said resonance frequency the phenomena described in British Patent 443,485 make their appearance, and the general behaviour of the gauging device is thereby modified: special precautions, referred to below, must then be taken if it is desired to obtain approximately proportionality between the changes in the amplitude and/or mode of oscillation of the gauging element and the displacement of the observed body.

Th telephone receiver mentioned above serves to illustrate the general principles embodied in this invention, but other vibratory systems are preferably employed; again, a bridge network has been mentioned as a means of cancelling the voltage appearing at the "motor" terminals when the gauging element is freely vibrating, whereas alternative means may be equally or more effective.

The "motor" of a gauging device in accordance with this invention should have

[*Price 2/-*]

Price 25p

Price 4s 6d

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PROVISIONAL SPECIFICATION

Improvements in Means for Measuring, Indicating, or Utilising Very Small Displacements

I, EDMUND RAMSAY WIGAN, a British Subject, of the Ministry of Supply, London, do hereby declare the nature of this invention to be as follows:—

This specification discloses means for the conversion of small displacements of a relatively rigid body into corresponding, and, if desired, approximately proportionate, changes in the amplitude of oscillation of a mechanical system. The said mechanical system is maintained in a state of oscillation either by self-excitation, or by auxiliary means at such a frequency and with such an amplitude and in such a mode that the amplitude and/or mode of oscillation is modified by the mechanical contact of the said rigid body with some part of the vibrating system or, alternatively, with subsidiary levers, plungers, triggers, etc., designed to cause motion of the said body to influence the amplitude or mode of oscillation.

In this specification the term "gauging device" is to be understood to include the mechanical vibratory system together with its associated driving or exciting means (referred to as the "motor"), and the term gauging element" is to be understood to refer to that part of the vibratory system which makes mechanical contact with the body under observation or alternatively with the subsidiary levers, etc., mentioned above.

As an illustration of the principle of this invention consider a simple telephone receiver. The receiver as a whole constitutes the gauging device and a small, hard piece of material fixed to and projecting from the centre of the diaphragm constitutes the gauging element. Most commercial telephone receivers exhibit a mechanical resonance near 1,000 c/s. If such a receiver is excited by alternating current of frequency rather lower than 1,000 c/s (say 700 or 800 c/s) the following phenomena will be observed. On approaching a rigid body towards the gauging element the electrical impedance of the receiver will pass through a series of stable values as the rigid body restricts more and more the amplitude of oscillation of the diaphragm, the impedance changing in a regular and steady manner as the oscillation is reduced to zero. In bringing the gauging element to rest the body will have to move over a distance equal to approximately twice the amplitude of free oscillation of the said element.

This invention discloses means for utilising such a change of impedance to operate subsidiary indicating, recording or other apparatus in such a way as to obtain a measure of the displacement or position of the said rigid body relative to the gauging device.

A simple way of carrying this out is to connect the windings of the telephone receiver as one arm of an impedance bridge fed with (say) 800 c/s, and to adjust the other components of the bridge so that no voltage appears at the "detector" terminals of the bridge when the diaphragm is freely vibrating. It will then be found that, on bringing the rigid body into contact with the gauging element, the voltage at the "detector" terminals of the bridge rises from zero through a series of values approximately proportionate to the corresponding displacements of the rigid body.

The effects just described occur if the frequency of excitation is lower than the resonance frequency of the vibratory system. If, however, the frequency of excitation is slightly higher than the said resonance frequency the phenomena described in British Patent 443,485 make their appearance, and the general behaviour of the gauging device is thereby modified; special precautions, referred to below, must then be taken if it is desired to obtain approximately proportionality between the changes in the amplitude and/or mode of oscillation of the gauging element and the displacement of the observed body.

Th telephone receiver mentioned above serves to illustrate the general principles embodied in this invention, but other vibratory systems are preferably employed; again, a bridge network has been mentioned as a means of cancelling the voltage appearing at the "motor" terminals when the gauging element is freely vibrating, whereas alternative means may be equally or more effective.

The "motor" of a gauging device in accordance with this invention should have

[*Price* 2/-]

Price 25p

Price 4s 6d

a high motional impedance if the device is to have a high sensitivity a large number of well known methods of excitation are available, e.g. electromagnetic, electrostatic, piezoelectric and magnetostrictive each of which has its own field of usefulness. Any one of these may be employed to excite the vibratory element either directly or indirectly.

Means for cancelling the voltage at the motor terminals when the gauging element is freely vibrating may consist of any arrangement of circuit elements which has (a) the effect of feeding alternating power to the "motor" terminals, and (b), provision for the opposition of the said voltage. The provision under (b), above, may be made with the aid of an amplifier, if desired, and in this case may be chosen so that, the opposing voltage, instead of remaining constant, changes its magnitude and/or phase when the amplitude of vibration of the gauging element is restricted by contact with the body under observation; in this way the shape of the curve relating the net voltage (motor terminal p.d. less opposition p.d.), to the body displacement may be given any desired adjustment.

Again similar general arrangements may be made in cases in which the p.d. at the "motor" terminals is not used to indicate the state of motion of the vibratory element but in which the vibratory element excites the required p.d. in electromagnetic or electrostatic means adjacent to it.

For certain applications it may be desirable to cause the opposing p.d. to cancel the voltage induced by the vibrating element when the said element is brought to rest, or at some stage of restricted vibration.

With a view to improving the linearity of the calibration curve of a gauging device of this general type the vibratory element may be excited by two frequencies simultaneously, one preferably of larger amplitude and lower frequency than the other, filters being provided to remove from the output of the network currents of the lower frequency. One of these frequencies may be applied, not directly to the vibratory element, but to the framework of the gauging device, so as to cause the gauging element to execute in space a motion compounded of the two exciting frequencies.

To improve still further the linearity of calibration of the whole system electromagnetic or electrostatic "feed-back" may be used so that so fast as the observed body encroaches upon the field of vibration of the gauging element the whole body of the gauging device (or alternatively the gauging element alone), is drawn away from the observed body. If, for example, in the case of a bridge type network associated with an electromagnetic method of exciting the vibratory element, the voltage at the "detector" terminals of the bridge is amplified, rectified, smoothed and passed to an indicating current meter scaled to read the displacement of the body restricting the motion of the gauging element, all or some of the rectified current may be fed back into the bridge network so as to cause the gauging element to move away from the restricting object. If the "motor" is of the moving-iron type this procedure may induce spurious frequencies in the output voltage or modify the motor impedance; to avoid these effects the rectified current may be passed through an electromagnet disposed to deflect the whole gauging device away from the said object, for instance by bending a member upon which the gauging device is mounted.

Such arrangements have the effect of correcting for non-linearity in the rectifier, the amplifier, and in the process of conversion of body displacement into voltage at the "detector" terminals of the bridge.

The systems of negative feed-back just described may be reversed so that positive feed-back is obtained. The device then becomes an extremely sensitive "trigger," the trigger being "pulled" by the encroachment of any object into the field of free vibration of the gauging element.

An external source of alternating energy has been assumed in all arrangements so far mentioned, but it may be dispensed with if the network containing the "motor" windings is so connected, via any necessary amplifier, that oscillations are self-induced.

Earlier reference has been made to British Patent 443,485. The vibrating systems described there are dynamicly unstable owing to their being excited at a frequency higher than their resonance frequency. This instability makes such systems extremely sensitive "triggers." By utilising the networks, described above, employing negative feed-back and a superposed large amplitude low-frequency excitation this sensitivity may be harnessed and the trigger effect brought under control. This is effected as follows: The higher frequency of excitation tends to make the vibratory element increase its amplitude of vibration if it touches a rigid body. The low-frequency excitation brings the element into contact with the body and thus induces this increase of high-frequency amplitude, but only for a part of the L.F. cycle. At first, as the body under observation approaches the gauging element, the instability lasts for a few cycles of the h.f. vibration only, then, as the body encroaches still further upon the field of l.f. vibration of the gauging element, it persists for longer periods. These bursts of h.f. vibration of course induce voltage at the "detector" terminals of the bridge and can be converted, as described above, into smoothed d.c. The d.c. represents the time-integral of the bursts of unstable vibration. The analogy with a super-regenerative radio receiver is obvious.

Although the greater part of the specification has particular reference to embodiments of the invention in the form of a linear displacement gauge or "fiducal indicator" (a most important field of application), it is to be clearly understood that devices of the type described may serve other purposes. For example the "body under observation" may be part of a barograph, thermostat, thermometer, etc., in fact any mechanism designed to convert variations of some physical quantity into linear displacement. For instance, the temperature-sensitive element of a thermostat may itself be the element which is caused to vibrate and whose amplitude is made a measure of the ambient temperature and is utilised to record or control the temperature.

Gauging devices in accordance with this invention can be made extremely sensitive; for example a 1 mA current meter of 1,000 ohms resistance may be calibrated to read 25 millionths of an inch at full scale, and readings will be stable to 2 or 3% of this value. When used at this high sensitivity it is desirable to have a simple way of approaching the gauging element towards the object gauged in steps of a few millioneths of an inch. For this purpose the magnitude of the before-mentioned large-amplitude l.f. excitation may be varied; alternatively a separate d.c. may be superposed upon the current producing negative or positive feed-back, and used to shift the gauging element to and from the object under observation.

Dated this 5th day of June, 1947.

E. RAMSAY WIGAN.

COMPLETE SPECIFICATION

Improvements in Means for Measuring, Indicating, or Utilising Very Small Displacements

I, EDMUND RAMSAY WIGAN, a British Subject, of the Ministry of Supply, London, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to means for measuring, indicating or utilising very small displacements of a relatively rigid body.

The present invention particularly relates to a device for measuring, indicating or utilising a small displacement of a relatively rigid body which includes the means of exciting a mechanical vibratory system into oscillation and controllably modifying the amplitude of the said oscillation by direct or indirect mechanical contact between the said body and the said system.

In Patent Specification No. 443,485 I described a method of detecting small displacement which comprises altering the mode of oscillation of a vibrating system by contact caused by a small displacement of a rigid body. This method utilised a "trigger" phenomenon since the mode of oscillation once initiated by the displacement builds up uncontrollably to an oscillation of much larger amplitude.

The present invention differs from my prior invention in that the change in amplitude of the oscillation of the vibratory system is controlled according to the present invention to produce a change in amplitude which depends upon, and is in fact very nearly proportional to, the small displacement. It will become apparent from the following description that the present invention requires radically different circuit arrangements. It will also be found that the present invention has the merit that the device is not sensitive to mechanical shock in the sense that the trigger mechanism described in my prior Specification No. 443,485 is sensitive. For instance a shock to the prior system leads to an uncontrollable burst of oscillation whereas in systems according to the present invention a shock will be recorded merely as a transient and when the shock is over the system returns to its previous state.

According to one aspect of the present invention there is provided a device for measuring, indicating or utilising a small displacement of a relatively rigid body and comprising a mechanical vibratory system arranged to be driven at a frequency near to but below a free resonant frequency of the said system, means for causing the said small displacement to change the amplitude of oscillation of the said system by an amount depending on the magnitude of the said small displacement and means for measuring, indicating or utilising the change in amplitude so produced.

In a preferred embodiment the last said means comprises an electrical circuit associated with the said vibratory system, change in the electrical impedance of this circuit being used to indicate or utilise the said small displacement and to this end the said circuit may form an arm of a 4-terminal bridge-network.

According to a feature of the present invention there is provided means for displacing the said vibratory system relative to the said rigid body by an amount depending on the said small displacement to be measured and this displacement of the said system may be in such a direction as to increase the change of vibratory amplitude produced by the said small displacement but alternatively it may be in such a direction as to decrease the change of vibratory amplitude produced by the said small displacement. For convenience these two methods of relative displacement of the vibratory system will hereinafter be referred to as positive and negative feedback respectively.

When the negative feedback is used the oscillations of the vibratory system may be controllable even when the frequency of the drive applied to the said vibratory system is near to but higher than a free resonant frequency of the said system, although normally (as hereinafter explained) the use of a driving frequency just above a resonant frequency leads to uncontrollable change in the amplitude of oscillation of the said system.

According to another aspect of the present invention, therefore, there is provided a device for measuring, indicating or utilising a small displacement of a relatively rigid body and comprising a mechanical vibratory system arranged to be maintained in a state of oscillation, means for causing the said small displacement to change the amplitude of oscillation of said system by an amount depending on the magnitude of the said small displacement including means for applying negative feedback to the said system and means for measuring, indicating or utilising the change in amplitude of oscillation so produced.

The invention and some of its features have so far been described in general terms but other features and alternatives in the invention will become apparent from the following description of the invention made with reference to the accompanying diagrammatic drawings in which,

Fig. 1 illustrates an embodiment of the invention, and

Fig. 2 illustrates a modification of the embodiment illustrated in Fig. 1.

In Fig. 1 of the drawings there is shown a vibratory system 1 comprising a vibratory reed 2 indicated as flexibly mounted between the poles of a permanent magnet NS and excited by alternating current fed to the windings 3 which embrace the reed 2. The stiffness of the said flexible mounting and the mass of the reed 2 determine the resonant frequency of the reed. The system 1 is carried on the end of a flexible member 4 secured to a stiffer member 5 which is itself rigidly clamped at one end to a massive base-plate 5*a*. A probe 6 is held in a parallel motion assembly 7 consisting, for example, of two flexible discs secured to the probe at their centres and to the base-plate 5*a* at their circumferences.

The body 8 whose displacement is to be measured is brought into contact with the remote end 6*a* of the probe. The position of the end 6 of the probe is then registered by moving the assembly 1 towards the probe until the reed 2 touches it. This movement will be very small and is obtained by turning the dial 9 which pulls on the screw rod 9*a* and extends the spring 10 and thus applies a stress to the end of the blade 11. This stress bends the relatively rigid bar 5 about the point at which it is clamped to the base-plate 5*a*. Since the reed 2 lies on the line XX normal to 5 and passing through the said point of clamping, the reed 2 moves towards the probe 6 on a line normal to XX. Owing to the flexibility of the blade 11 and the rigidity of the bar 5, movements of the screw 9*a* of the order of thousandths of an inch thus result in movements of the assembly 1 of the order of millionths of an inch. This reduction factor is adjusted by sliding a clamp 11*a* along the blade 11. Calibration is done by substituting a micrometer for the body 8 and calibrating the reading of the scale 9 against known displacements.

The winding 3 forms one arm of a bridge 12 which is fed by an alternating current scource 13. A D.C. meter 14 fed from the amplifier and rectifier 15 with a current I, indicates the degree of unbalance of the bridge 12.

It will be found that when the frequency of the current from the source 13 is made just below a resonant frequency of the reed 2 and the probe 6 encroaches on the free vibration of the reed 2 the electrical impedance of the winding 3 will pass through a series of stable values as the probe 6 more and more restricts the amplitude of oscillation of the reed 2. The impedance will change in a regular and steady manner as the oscillation amplitude is reduced to zero. If, therefore, the bridge 12 is balanced when the reed 2 is just freely vibrating, it will then be found that, displacement of the body 8 bringing the probe 6 into contact with the reed 2, will cause the reading on the meter 14 to rise from zero through a series of values approximately proportional to the corresponding displacements of the rigid body 8.

The readings on the meter 14 may be calibrated by holding the probe 6 fixed and displacing the system 1 by known amounts by means of the calibrated dial 9 (as hereinbefore explained) and noting the corresponding readings on the meter 14. Alternatively displacements may be measured by rotating the calibrated dial 9 so as to keep the meter reading at some fixed value as the probe 6 is moved by the body 8.

The effects just described occur if the frequency of the driving current from the source 13 is near to but lower than a resonance frequency of the vibratory system. If, however, the frequency of excitation is slightly higher than a resonance frequency of the reed 2 the amplitude of oscillation will change in an uncontrollable manner and the phenomena described in Specification No. 443,485 appear. This is due to the fact that, in this case, the transient vibration induced by contact between 2 and 6 is of such a phase at the next contact that the velocity of approach is increased and in a few cycles the vibrations of 2 build up to a very much larger amplitude. (It will be understood that although the probe 6 limits the movement of the reed 2 in one direction the reed is free to move, if so impulsed, to a greater extent in the other direction.)

When the excitation frequency is made slightly greater than a resonant frequency the system may still be made controllable by negative feedback. This may be effected in the embodiment illustrated by means of an electro-magnet 16 polarised by a permanent magnet 16*c* and fed with a direct current I derived by rectifying (after amplification) the "unbalance" current derived from the bridge 12 by the amplifying and rectifying device 15. The magnet is arranged to attract the arm 4 and so retract the system 1 away from the probe 6. The degree of negative feedback may be adjusted by the control resistance 17, and by the gain of the amplifier associated with element 15.

Negative feedback may also be used when the reed 2 is driven at a frequency slightly below a resonance frequency. In this case the negative feedback is not used to bring the amplitude change under control but to reduce the change in amplitude of 2 resulting from a given displacement of object 8 and so to extend the range of measurement of the device and to improve the proportionality between the readings of meter 14 and the linear displacement of object 8. Alternatively a positive feedback arrangement is obtained by reversing the connections 16*a* and 16*b* on the feedback magnet or by a reversing switch 18 so that the bar 4 and with it the system 1 is deflected towards the probe 6 as the rectified current I increases. By this means the sensitivity of the device may be increased. If too much positive feedback is used the whole device may become uncontrollable even when the excitation frequency is below a resonance frequency of the system 1, but this is easily avoided by adjustment of a control similar to 17.

The electro-magnetic system represented by elements 2 and 3 should have high ratio of motional impedance to clamped impedance if the device is to have a high sensitivity. A ratio greater than unity is readily obtainable without the need for minute air-gaps in the magnetic path. Instead of the electro-magnetic excitation means illustrated other means, e.g. electro-static, piezo-electric or magneto-strictive, may be used. The modifications to the construction shown to suit such means will be obvious to those skilled in the art.

The means used to cause the vibratory member to oscillate may be distinct from the means used to indicate changes in the amplitude of oscillation. A bridge-network such as 12 is not then required. Thus in the embodiment illustrated in Fig. 2 two coils A and B may be used, one directly supplied with current from the oscillator for driving the reed 2 and the other mounted adjacent to the reed 2. Vibrations of element 2 will generate a voltage in the second coil. A suitable fraction of the oscillator output may be arranged to cancel this voltage when the element 2 is freely vibrating. A difference voltage due to change of amplitude is applied to the input of 15. Again the means used to indicate the amplitude of the vibrating member is not limited to a coil, e.g. it may be a conductor mounted near the member and the amplitude may be indicated by the changes in the electric capacity between the conductor and the member.

The amplitude of vibration of the reed 2 will generally be very small, of the order of 100×10^{-6} inch. It is clear, therefore, that the range of linear measurement normally possible will be of the same order: if negative feedback is applied this range might be extended to about 300×10^{-6} inch. To increase this to several thousandths of an inch the following artifice may be employed:—A low frequency alternating current may be applied to the magnet system 16 through a separate circuit, suitable condensers and chokes being arranged to keep the current out of the loop containing the meter 14 and the rectifier 15. The amplitude of this current is adjusted so that the bar 4, and with it the assembly 1, oscillates with an amplitude of one or two thousandths of an inch. The reed 2 will then contact the probe 6 for no more than a small fraction of the low-frequency cycle if the probe 6 moves inwards a few millionths of an inch. Not until the probe 6 has been displaced several thousandths of an inch will the reed 2 be entirely prevented from oscillating and the meter 14 reach its maximum deflection.

Other modifications will now be obvious to those skilled in the art.

There are many practical applications of the invention. For example, it may be used as a gauging device for accurate comparison of standard length gauges and will give results comparable with those obtained by optical interference methods which are much more difficult to perform. In other applications the rigid body under observation may be part of a barograph, thermostat, thermometer, etc., in fact any mechanism designed to convert variations of some physical quantity into small displacements.

For instance, the temperature-sensitive element of a thermostat may itself be the vibrating member, the amplitude of oscillation being a measure of ambient temperature and used to record or control the temperature, for example through an electrical relay operated by the "unbalance" current I from a bridge such as 12 in the drawing.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

1. A device for measuring, indicating or utilising a small displacement of a relatively rigid body and comprising a mechanical vibratory system arranged to be driven at a frequency near to but below a free resonant frequency of the said system, means for causing the said small displacement to change the amplitude of oscillation of the said system by an amount depending on the magnitude of the said small displacement and means for measuring, indicating, or utilising the change in amplitude of the said vibratory system so produced.

2. A device for measuring, indicating or utilising a small displacement of a relatively rigid body and comprising a mechanical vibratory system arranged to be maintained in a state of oscillation, means for causing the said small displacement to change the amplitude of oscillation of the said system by an amount depending on the magnitude of the said small displacement including means for applying negative feedback to the said system and means for measuring, indicating or utilising the change in amplitude of oscillation so produced.

3. A device according to Claim 1 or 2 in which the last said means includes an electrical circuit associated with the said system arranged so that its electrical impedance depends on the amplitude of oscillation of the said system.

4. A device according to Claim 1 and comprising means for applying positive or negative feedback to the said system.

5. A device according to Claim 3 in which the said circuit is also adapted to carry current to excite said system into a state of oscillation.

6. A device according to any of the preceding claims and comprising means for producing small displacements of the said system relative to the relatively rigid body displacements of which are to be measured, indicated or utilised

7. A device for measuring, indicating or utilising small displacements of a relatively rigid body substantially as hereinbefore described with reference to the accompanying drawings.

8. A device for measuring, indicating or utilising small displacements of a relatively rigid body substantially as hereinbefore described.

Dated this 12th day of July, 1948.

H. W. GRACE,
Agent for Applicant.

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Published at The Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies, price 2s. 0d. each (inland) 2s. 1d. (abroad) may be obtained

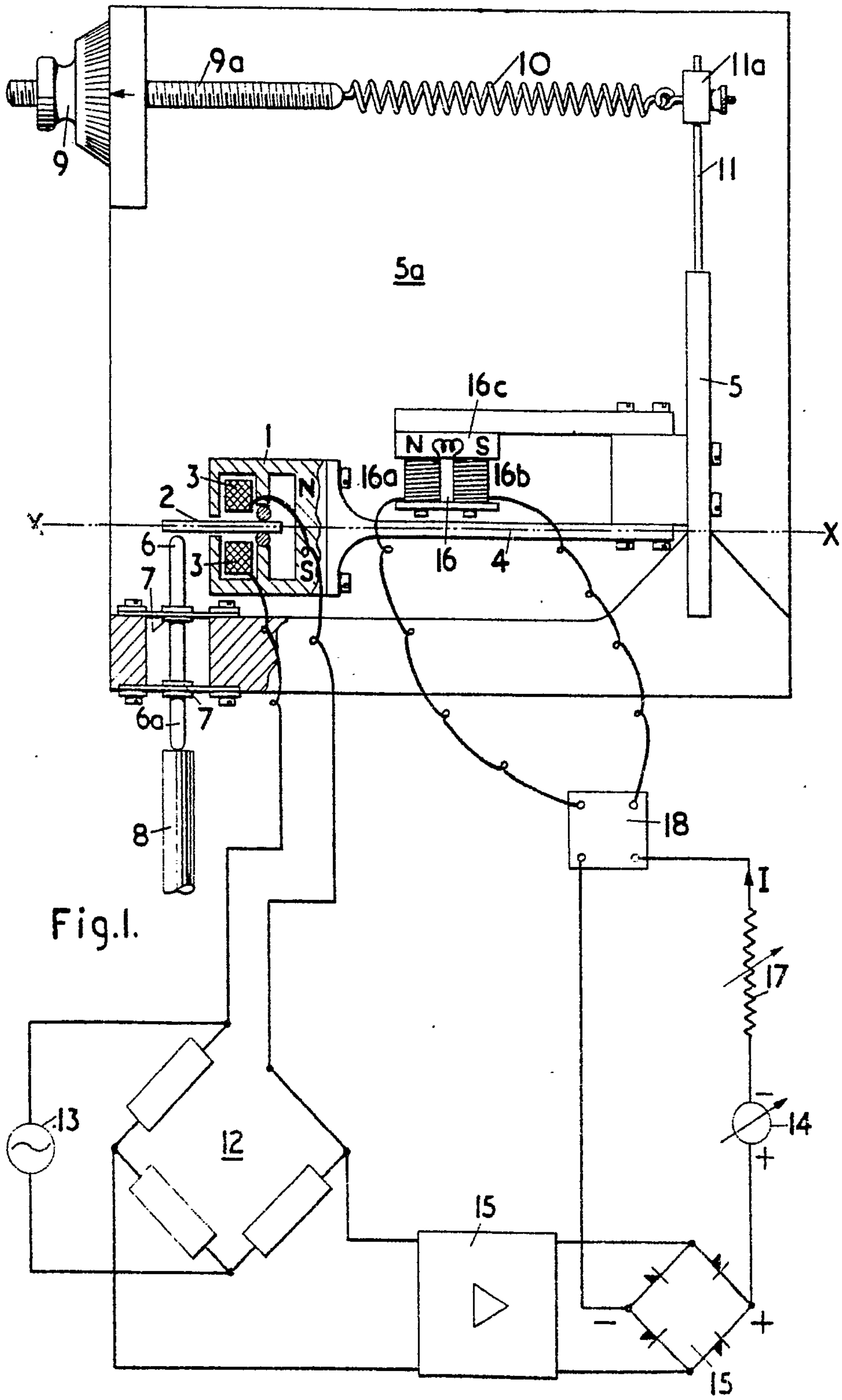
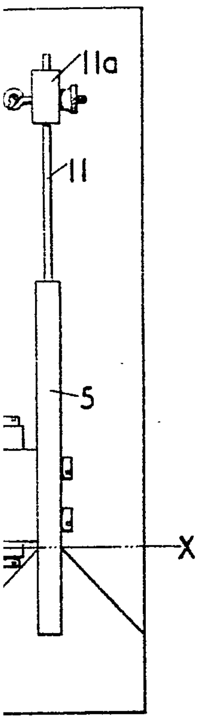
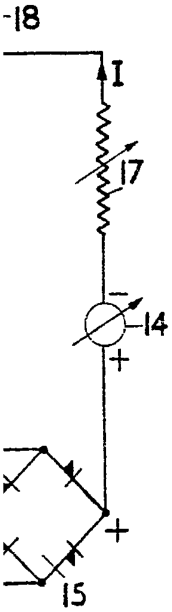


Fig.1.

[This Drawing is a reproduction of the Original on a reduced scale.]





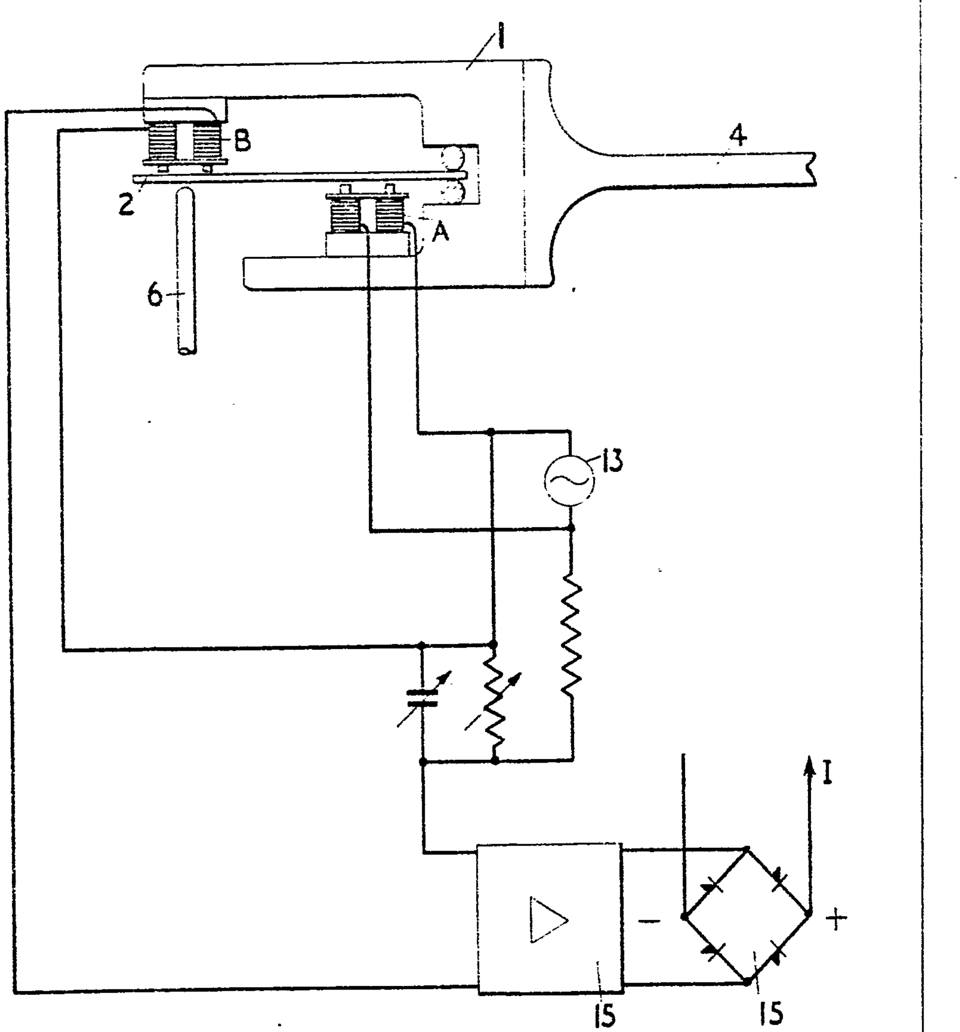


Fig. 2.

SHEET 1

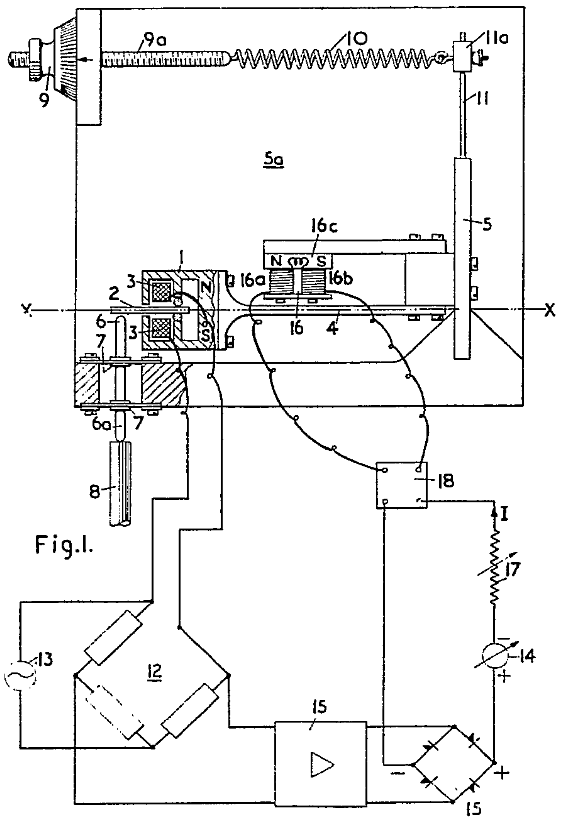


Fig.1.

SHEET 2

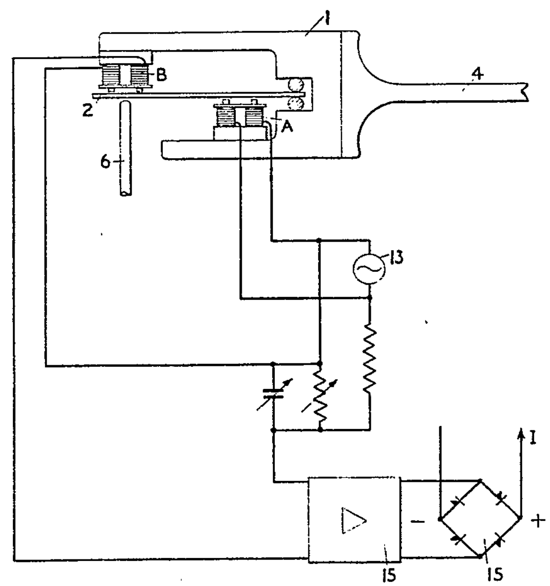


Fig. 2.

[This Drawing is a reproduction of the Original on a reduced scale.]

H.M.S.O. Ty P.