Means for Guaging Minute displacements

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Fundamental phenomenon.—If we consider a flexible resilient blade (hereafter referred to as a “vibrator”) maintained in vibration by any suitable means, for example by an electromagnetic driving arrangement through which passes an alternating current (hereafter referred to as the “driving means”) and if we suppose that a surface on a solid body, perpendicular to the mean position of this vibrator, is caused to approach the said vibrator, it is known that, when the free end of the vibrator touches the face of the body the vibration is damped, and that, when the body is slightly withdrawn from the position it occupied when the vibration became damped, the vibration will resume its former undamped state.

Now, the present invention is concerned with a hitherto unknown physical phenomenon, recently discovered by myself, entirely different from the above, which takes place when a surface on a solid body, parallel to the mean position of a vibrator so proportioned and mounted that the frequency of one of its modes of natural or resonant vibration is near to (above or below) the (suitably chosen) frequency of the forces maintaining it in vibration, is caused to approach this vibrator: when the face of the body is so near the vibrator as to be touched by the said vibrator with a certain very small force of impact in its extreme excursion towards the said face (a position referred to as “vibratory contact”) instead of the vibration being damped, the vibrator breaks into a new, and particularly distinctive mode of intermittent contact with the face of the body, which new mode of vibration (hereafter referred to as the “vibratory contact”) is characterized, and distinguished from the damping referred to above, in that it is more vigorous than the normal steady mode of vibration impressed upon the vibrator by the driving means and is generally of greater amplitude, and in that, when the solid body is slightly withdrawn from the position it occupied when the initial impact occurred which caused this new, vigorous mode of vibration to set in, the vibrator does not return to its normal steady or controlled mode of vibration, but, on the contrary, the said vigorous mode of vibration persists until the said solid body is further withdrawn, when the normal steady mode of vibration sets in again.

General application.—I have found that this new, vigorous mode of vibration, which characterizes the occurrence of “vibratory contact” between the vibrator and the face of the solid body, sets in when the minimum distance between the two is of the order of one tenth millionth of an inch, that is to say, that “vibratory contact” indicates a proximity of the body and of the vibrator of this order of dimension, so that, by ascertaining the moment when the new vigorous mode of vibration sets in, the position of the solid body can be determined with that order of accuracy.

It will be appreciated therefore that this invention provides means for indicating in a simple, sensitive and accurate manner that a very slight force of contact has developed between two surfaces, e.g. gauging surfaces.

It has been found that the substitution of the distinctive mode of vigorous vibration of the vibrator for the steady or controlled state of vibration constitutes a far more precise indication of the close proximity of the vibrator and body than any method of mechanical or electrical contact hitherto provided can give, so that, by this method, displacements of the order of one ten millionth of an inch can be easily detected, observed, measured, indicated, recorded or made use of, as will be more fully shown hereafter.

According to my invention, I provide apparatus adapted to utilize the phenomenon described above for detecting, observing, indicating, measuring, recording or otherwise making use of minute displacements down to the order of dimension mentioned.

In order to carry out my invention, all such apparatus comprise as a fundamental element a linear distance gauge, consisting of a fixed supporting bed with a gauge carriage moveable with respect to the said supporting bed, and a contact indicating device, capable of fine adjustments, comprising a “feeder gauge surface” carried upon a vibrator mounted on a support fixed to the carriage, together with associated means for maintaining and controlling the vibration of the said vibrator, so that the latter is maintained in such a state of vibration as to become the seat of the new vigorous mode of vibration, when the “feeder gauge surface” comes into vibratory contact with a “contact gauge surface” carried by the body of which is to be detected, observed, indicated, measured, recorded or utilized.

Instead of one contact gauge surface on the
vibrator and on the body, there may be several surfaces in contact.

The contact gauge surface instead of being carried by the solid body the displacement of which is to be detected, observed, measured, indicated, recorded or utilized, may be on a separate member adapted to be displaced directly or indirectly, by the solid body. This member or system of members for carrying the feeler gauge surface may be interchanged, the resilient vibrating member carrying the feeler gauge surface being mounted on the solid body the displacement of which causes the phenomenon referred to and the contact gauge surface being carried by a suitable fixed member.

In the various cases referred to herein it will be assumed for the sake of illustration that the feeler gauge surface is carried by the flexible resilient member which is caused to vibrate, but it will be understood that the invention may also be applied in cases where the body under observation is vibrating and the feeler gauge surface, capable of fine adjustment, either is not vibrated, or is also caused to vibrate, the various surfaces being so defined and the driving frequencies being so chosen that the vigorous state of vibration is set up at the moment that vibratory contact is established between the two gauging surfaces. The position movement of the vibrator may also be kept constant, the contact gauge surface being then capable of fine adjustment, either together with the body, or with respect thereto.

The frequency at which the vibrator is driven must be near to and either above or below, but preferably above its fundamental frequency (or above its other modes) of vibration. For example the driving frequency may be below and near that of the higher modes, but above the fundamental mode of vibration. Only under exceptional circumstances does the driving frequency have to be very precisely chosen. For various subsidiary reasons, it should, however, be as constant as possible.

Typical form of apparatus.—The primary constitutive element in all the forms of apparatus, according to my invention, is therefore analogous to a linear distance gauge, one of the gauge surfaces of which is mounted on a vibrator, as has just been described, a gauging operation consisting in bringing one of the gauge surfaces corresponding, as a unit, with the usual “feeler” element of a distance gauge, in vibratory contact with the other gauge surface, by means of a combination of coarse and fine adjustments. Vibratory contact between the feeler gauge surface and the contact gauge surface on the body being gauged is indicated by the vigorous vibration described above.

This fine adjustment comprises means for gradually causing one of the members of the gauge to approach the other, and for measuring the displacement so produced, so as to ascertain exactly the position of the other member of the gauge.

Methods of fine adjustment.—The fine adjustment of the “feeler gauge surface” of the linear gauge surface is preferably obtained by using a relatively stiff member or system of members for the vibrator and deflecting this by the application of forces, preferably derived from an electromagnetic arrangement. This may conveniently be obtained either by altering the amplitude of the vibration by varying the alternating current or by displacing the mean position of the vibrator by superposing an adjustable direct current on this alternating current. The apparatus can be calibrated so that either (or both) these currents, the magnitude of which can be read from a suitable indicator, becomes (or become) a measure of the linear distance through which the body under observation moves relative to the support thereof, that is, becomes (or become) a measure of the fine adjustment.

It is found that, by superposing in the same magnetic system the fluxes due to both the reflecting current (D.C.) and the main oscillatory driving current (A.C.) the flux due to the former current produces no serious hysteresis effects; moreover the deflection of the mean position of the vibrating feeler element becomes practically a linear function of the D.C. A current measuring instrument can therefore be arranged to indicate the deflection by indicating this current.

The rapid increase in the force of contact produced by the vigorous vibration serves to define the body’s position at the moment that contact is established between the two gauging surfaces. The position movement of the vibrator is set up near to the contact gauge surface is brought near to the contact gauge surface, or with respect thereto. The value of the current read on the current measuring instrument is a measure of the distance the feeler gauge surface has moved prior to contact. The reading can be checked by a violent rattling of the gauge device, indicates that “vibratory contact” has been established. The value of the current read on the current measuring instrument is a measure of the distance the feeler gauge surface has moved prior to contact. The reading can be checked by a violent rattling of the gauge device, indicates that “vibratory contact” has been established. The value of the current read on the current measuring instrument is a measure of the distance the feeler gauge surface has moved prior to contact. The reading can be checked by a violent rattling of the gauge device, indicates that “vibratory contact” has been established.
the return of the feeler gauge surface is made in such a way as to avoid abrupt movements as much as possible, for example, the current controlling the gauge movement is derived from a source network which only permits slow displacements of the mean position of the vibrator. In another arrangement the use of a relay is avoided by substituting for it a network containing a resistance combined with a condenser, the potential across which is the source of the controlling current and is directly controlled in magnitude by the amplitude of vibration of the vibrator.

Types of auto-control.—The amount of control exerted by the auto-controlling relay depends upon the function of the gauge device. If it is to keep a continuous record of a changing length the vigorous vibration is completely extinguished (as, for instance, by reducing the deflecting force to zero) immediately it is initiated.

If, however, the gauge is designed to give warning of very small changes in the length of, for example, a thermostat element, the vigorous vibration is not immediately extinguished when contact has been established, but, instead, it is brought to the point of incipient extinction by the withdrawal of the contact or feeler gauge surface through a small distance. With things adjusted in this manner, a very small further withdrawal of the gauge surface carried by the body under observation (i.e. as would be caused by a fall in temperature of a thermostat element) results in the complete extinction of the vigorous vibration, the re-opening of the relay, and the return of the gauge device to the position it occupied at the beginning of the cycle of events.

In this form the gauge device gives a warning (by the operation of the relay) directly the gauge surface carried by the gauged body reaches a certain point, namely, that at which vibratory contact is established, or goes beyond it. The warning is continued until this surface has been withdrawn sufficiently to extinguish the vigorous vibration. That is to say it is a maximum (or minimum) indicator without the addition of subsidiary control by a relay. Without this control, however, there is a large difference between the position (or length) of the gauge object at the moment the vigorous vibration is initiated by vibratory contact with the gauge contact surface, and the position (or length) to which it has to return before this vigorous vibration extinguishes itself.

This discrepancy between the lengths required to start and stop the vigorous vibration is a serious fault. The operation of the relay-controlled circuit is designed to reduce this discrepancy.

For example, in a gauge device which develops a considerable amplitude of vigorous vibration, the length-discrepancy referred to may be 50 to 100×10⁻⁶ ins. This can be reduced to about 1×10⁻⁵ ins. by an auto-control arrangement. The great value of this arrangement is that the gauge device can be designed to develop pronounced vigorous vibration (which is an advantage in operating relay controls) and still remain sensitive to very small reductions in the gauge distance.

Compensation for variation of supply voltage.—In all that has been said so far a tacit assumption has been made, namely, that the forces driving the vibrating member of the gauge device are either constant or variable, but that they are all known.

In many forms of the gauge device it is desirable to reduce to a minimum the influence of these forces upon the gauging operation and to produce all the required fine adjustment or "gauging" movements of the vibrator by means of a source of direct current. (The primary reason for this is that the discrepancy referred to above, due to the vigorous vibration, becomes greater as the alternating forces increase; for many purposes this increase appears to be unmanageable.) It will be appreciated that the distance between the feeler gauge surface and the contact gauge surface the displacement of which is being observed, is a function of the alternating driving forces as well as the unidirectional deflecting forces. As the value of the D. C. is the more readily controlled and indicated, it is the A. C. which is preferably kept constant while the D. C. measuring instrument is calibrated to read "distance".

When the apparatus is supplied from the public supply, a variation of at least ±5% is to be expected in alternating voltage. (Say 5×10⁻⁶ ins. uncertainty in the gauged length unless an A. C. meter is provided so that the driving current can be set to the proper value. This uncertainty is serious if ignored, and if provided for by separate control, the operation of the gauge ceases to be entirely automatic.

Two ways of avoiding this fault have been devised and will be now described.

Methods of compensation.—In the first method of compensation, the vibrator is driven by an unpolarised magnet system. This has the effect of:

(1) Causing the vibrator to vibrate with a frequency which is twice that of the driving forces;

(2) Shifting the mean position of the vibrator towards the magnet system.

As the amplitude of (1) is of the same order as the value of (2), the net effect is that changes in the driving current have little or no effect upon the position in space of the extreme point reached by the gauge surface carried by the vibrator when the latter is receding from the driving magnet. Other advantages of an unpolarized winding are simplicity and the removal of one source of possible error, namely, the ageing of the magnet causing a diminution of the total flux.

In the second method of compensation the driving magnetic circuit is polarized by a magnet and is supplied with both alternating and direct current, both derived from the same source, the latter by rectification. The direction of the D. C. is arranged so as to shift the mean position of the vibrator away from the surface gaused, as the alternating voltage rises. Owing to the non-linear characteristic of the rectifier this arrangement is not perfect but can be adjusted to reduce very considerably the influence of variations of the mains voltage upon the true reading of the gauge device. The advantage of this arrangement is that the driving system may be modified on whichever side of the vibrator is most convenient mechanically. Moreover, owing to the permanent magnet, this scheme permits further control of the vibrator by superposition of a second, controlled, and indicated, direct current which can be used...
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cipal ways of operating the relay:

1. By a circuit completed through the feeler and the contact gauge surfaces;

2. By the vigorous vibration causing a sub-
ploy-sary jar-sensitive or "chatter" contact to break circuit.

Circuits controlling the relay.—It has now been shown that the gauge device can be made insensitive to supply variations, and that it can be arranged to be auto-recording, or auto-con-
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(8) Any pointer instruments, whether electrical or not, can be provided by its means with maximum or minimum deflection indicators; (9) Particularly designed electrical pointer instruments can be developed which avoid the complication of pivots and coiled springs and have the desirable feature that the deflections are, however, magnified and if necessary recorded on the lines of (7) and (8) above.

10. The setting-in of the particularly distinctive mode of vigorous vibration may be observed either by ear, directly or by means of a microphone, or by eye, for example by the flicker of the pointer of a current meter, as already mentioned or by the change of the shape of the oscillation envelope, as viewed by means of an oscilloscope, a method which will be described hereafter.

It will be understood that I do not claim as my invention the numerous manners of observing the setting-in of the instability phenomenon. These methods of observations are well known and belong to usual laboratory technique.

**Examples of apparatus.—** A few apparatus, showing among the most important of the applications of which the invention is capable, will be now described as examples which are by no means limitative in any respect.

Referring to the drawings left herewith, which illustrate, for the sake of illustration only, apparatus embodying the present invention:—

Fig. 1 represents diagrammatically a vibrator for a simple form of gauge suitable for an apparatus according to the invention;

Figs. 2, 3a, 3b, 4a, 4b, 4c, 4d, 5 and 6, are diagrams of electric circuits used in connection with the gauge shown in Fig. 1;

Figs. 7, 8a, and 8b represent diagrammatically constructional parts of apparatus embodying the invention;

Fig. 9 is a diagram of an electric circuit illustrating an application of the invention for ascertaining with extreme accuracy the position of a pointer on a scale.

Fig. 10 represents diagrammatically a pointer instrument.

In the form of vibrator shown in Fig. 1, the vibrator element 4 is mounted on a support 5 and a base 1, and is maintained in oscillation by an alternating current in the winding g of an electromagnetic system 3; it carries the feeler gauge member 1, and also a mass 2 adjustable in magnitude, near to the fundamental frequency of the forces developed on the vibrator 4 by the system 3, or to one of the overtones of this frequency. When so adjusted, as it has been explained above, the vibration of the vibrator element becomes unstable and changes its mode of vibration as soon as the gauge surface on the member 1 touches with a certain minimum force a gauge surface 1' on a solid body, for example on the body the displacement of which is to be detected, observed, indicated, measured, recorded or utilized. (This minimum force becomes smaller as the frequency of vibration of the vibrator increases. These defl)
When the circuit is closed at contacts 1 and 1', the degree of discharge depends upon the duration of the contact and the resistance of the discharge circuit. It is found that, with condensers of 2000 micro-farads charged to 4-6 volts, a safety resistance of 50 ohms or more can be inserted in the circuit without seriously interfering with the operation of the circuit. Such a resistance reduces the risk of the contacts at 1 and 1' becoming welded together. By suitably selecting the value of the resistance $R$, the relay $B$ can be made to remain with its contacts "open" for a considerable period of time, say 1 second, if in this interval of time no new closing of the circuit has occurred at 1-1'. In this way, an intermittent contact at 1-1' results in the continued partial de-energization of the relay $B$ and, consequently, in the contacts of this relay being maintained in the same position. The cessation of the contacts at 1-1' results, after a delay, in the contacts of the relay moving back into their alternative position.

This delay is a disadvantage in certain cases, and it may be avoided by using a circuit which combines the arrangements of the circuit shown in Fig. 2 and of another circuit, as shown in Fig. 3b, in which the pair of contacts 1-1' make intermittent contact when the circuit is completed through the feeler gauge surface of the member 1 of Fig. 1 and the contact gauge surface 1' of the body under observation. These contacts 1 and 1' may be used as shown in Fig. 3b to operate a quick acting relay 10 by means of a battery circuit 11; this relay has contacts 18 which take the place of the jar-sensitive or "chatter" contact 8' of Fig. 2.

Fig. 4a shows the simplest method of controlling the movement of the vibrator of a gauge of the type shown in Fig. 1. In this figure, the winding $g$ is the winding of the electromagnetic driving system 3 of Fig. 1.

In this arrangement, a resistance $a$, and a current-measuring instrument $m_a$ are connected in series with the winding $g$. The former is preferably invariable in order that the behaviour of the gauge may remain uniform when the vigorous vibration has set in; the adjustment of the alternating current is made by means of the potentiometer resistance $b$. The current-measuring instrument $m_a$ should be quick acting, for example, of the rectifier-fed type. The resistance $b$ is adjusted by hand until the amplitude of vibration of the gauge is sufficient to cause contact between the feeler gauge surface of the member 1 (Fig. 1) and the contact gauge surface of the object gauged. The sudden appearance of the vigorous vibration indicates that the vibratory contact has been established. The reading of the current-measuring instrument $m_a$ corresponding to the appearance of the vigorous vibration is noted. Any relative displacement between the feeler gauge surface and the contact gauge surface on the gauge object can then be measured by repeating this process and noting the new reading of the current-measuring instrument $m_a$. The difference in the readings is a measure of the displacement.

The three main drawbacks of this arrangement are:

1. The changes in current must be made very gently so that the vibrator is not noticeably jarred; otherwise the accuracy of measurement varies from point to point on the scale of measurement, for when the current is large the gauge is most sensitive and reciprocally.

2. As the accuracy attainable is not much better than 1%, (owing to (1), above) the smallest distance measurable is comparable with the amplitude of vibration (which may be $600 \times 10^{-4}$ ins.).

Practically all these deficiencies can be made good by using the circuit shown in Fig. 4b. It will be noted that, in this circuit, the winding of the electromagnetic driving system now carries direct as well as alternating current, the intensity of the latter being constant while measurement is in progress. A "blocking" condenser $C$ prevents leakage of D.C. through the alternating current-measuring instrument $m_a$. The D.C. is used to make the measuring operation by shifting the mean position of the vibrator towards the contact gauge surface of the body under observation. This D.C. is read on the current-measuring instrument $m_a$. In practice if this current-measuring instrument $m_a$ has a uniform scale and the gauge windings are polarized, its readings are very closely proportional to the displacement of the mean position of the vibrator of a gauge, and can be made to have a very large time-constant the movement of the needle of the current-measuring instrument $m_a$ being slow and its position can be judged very closely by eye when the vigorous mode of vibration makes its appearance. Since the amplitude of vibration is practically unaltered by the superposition of the D.C. on the A.C., the precision of operation of the gauge is practically independent of the reading of the current-measuring instrument $m_a$. Again, very small displacements can be measured with this arrangement (e.g. a displacement of $10^{-4}$ ins. can be measured with an accuracy of about 5 to 10% when the amplitude of vibration of the feeler gauge surface is from 000 to 300 $\times 10^{-4}$ ins.). By using a vibrator element of greater stiffness, measurements of still smaller displacements can be made.

It is found that the presence of the alternating flux due to the A.C. reduces the hysteresis effects naturally associated with the unidirectional, but non-linear,特性 of the D.C. during the gauging operation. The maximum value assumed by the D.C. may equal the maximum value of the A.C. without the hysteresis becoming sufficiently large to affect the calibration of the gauge. A choke coil $\phi'$ may be inserted in the D.C. circuit to reduce the intensity of the A.C. passing through the current-measuring instrument $m_a$.

Owing to the extreme slowness with which the D.C. can be altered this arrangement can be made to give very high accuracy. In order to obtain results more quickly, but with slightly less accuracy, the arrangement of Fig. 4c can be used. In this the gauging operation is entirely automatic and cyclic.

A suitable amplitude of vibration is obtained by setting the A.C. at a fixed value. The gauging operation is carried out by D.C. on the same principles as with the arrangement of this patent shown in Fig. 4b. The D.C. is controlled by the operation of a relay such as $R$ in Figs. 2 or 3a, which is itself under the control of the gauge contacts. Thus the relay may be connected so...
that the contact 16 of this relay 8 is opened at the moment vigorous vibration sets in.

If, now the connections are such that the current from the battery 11 causes the contact and feeler gauge surfaces to approach each other, the opening of the contact 16 results in the condenser 19 slowly discharging and in the contact and feeler gauge surfaces separating. The separation will continue so long as the vigorous vibration persists, but, as soon as the withdrawal is sufficient, the vigorous vibration vanishes, the relay contact closes again and the gauge surfaces again approach each other. Thus a cyclic operation is carried out; the maximum indication of the current-measuring instrument \( m_4 \) is a measure of the distance through which the feeler gauge surface has been displaced by the D. C. An alternative circuit is possible in which the relay 8 short-circuits the condenser 19 at the moment that vigorous vibration is initiated. This restores the current-measuring instrument and the vibrator to their undeflected positions and the cycle of operations proceeds as above. Here also a choking coil 9 may be inserted in the D. C. circuit.

In Fig. 4d, instead of operating a relay, the jar-spring 20 is arranged so that the large condenser 19 to charge up as soon as the contact 6" begins to chatter. In the figure, the source of potential difference by which the condenser 19 is charged is shown as a single wave rectifier 13. The appearance of a potential difference at the terminals of the condenser 19 causes a unidirectional current to flow through the D. C. measuring instrument \( m_4 \) and the driving winding \( g \) of the gauge, and this causes the arrangement to function in a manner similar to that of the circuit shown in Fig. 4c. The object of this modified arrangement is to obtain a quicker response of the controlling current to the chattering of the contact 6".

Fig. 5 represents a circuit which is adapted to be inserted between the driving winding \( g \) of the gauge and the source of A. C. in order to make the condenser 22 charge or discharge with a proportion on the reading of the D. C. measuring instruments of Figs. 4b, 4c, and 4d, independent of small chance variations in the alternating current supplying the driving system of the vibrator.

The function of this circuit is to provide a biasing unidirectional current which is proportional to the alternating current which passes through the circuit. For many purposes the circuit of Fig. 5 does this with sufficient accuracy, but, when greater accuracy is essential more complex circuits can be easily devised on the same principles. It will be seen that the rectifier 24 with resistance 21 and condenser 20 are connected in parallel with the source of A. C. The potential difference across the rectifier 24 will therefore vary in conformity with any change in the potential difference supplying the driving winding \( g \) of the gauge. The rectified current produced by 24 passes to the winding \( g \) through a choke coil 26. The A. C. measuring instrument \( m_4 \) is isolated from the D. C. circuit by the condenser 22. Adjusting resistances 21, 23 and 27 make it possible to adjust the relative proportions of A. C. and D. C. supplied to \( g \). The direction of the D. C. is arranged so that it withdraws the mean position of the vibrator away from the contact gauge surface on the body under observation. In a gauge employing this circuit it was found that \( \pm 25\% \) variation in the value of the alternating potential at the terminals of the apparatus resulted in an error of \( 5 \times 10^{-7} \) ins. in the measurement scale. The amplitude of vibration of the feeler gauge surface was 200 to 300 \( \times 10^{-8} \) ins.

As mentioned earlier the same effect can be obtained by employing a non-polarized winding at \( g \), without the biasing circuit. Then if the gauge has the form shown in Fig. 1, the position in space of the upper edge of the envelope of the vibration of the contact gauge surface of the member 1 can be made practically independent of the value of the A. C. flowing in the windings 3. If there is a slight fall of the envelope edge when the A. C. is increased, the mass 2 (Fig. 1) is readjusted to bring the vibrator more closely into resonance with the driving current, and reciprocally.

When the gauge is employed for other than pure distance-measurement various subsidiary circuits are useful. For example, if the circuit of Fig. 4c is modified by the omission of the resistance \( r \) and of the contact 17 it may be used to convert the gauge into a device which gives an indication or sets in action subsidiary apparatus (by the operation of a relay, for example), when the body gauge reaches a certain position relatively to the gauge itself, that is, to convert the gauge into a maximum or minimum indicator or controller, the current from the source 18 of D. C. being adjusted so that the closure of the contact 16 does not completely extinguish the vigorous vibration, the extinction being completed by the withdrawal of the contact gauge surface of the body gauge.

If it is found desirable to control the circuit of Fig. 4c by automatic means, it becomes necessary to alter the alternating current in a gradual manner. This can be done by the artifice illustrated in Fig. 6. A "bridge" rectifier is inserted in one of the A. C. leads, having a large condenser 30, shunted by a resistance 29 in series with a contact 28 which, for example, may be one of the contacts controlled by the relay 8. This contact is normally closed so that the condenser 30 charges up slowly and opposes the A. C. If the contact 28 is opened, however, (as a result, for instance of the setting-in of the vigorous vibration and the operation of a relay) the condenser 30 charges up slowly and opposes the A. C. This has the effect of retarding the A. C. facing the vibrator and therefore causes the extinction of the vigorous vibration.

On the closing of the contact 28 the condenser discharges slowly through the resistance 29 and the cycle repeats itself. A condenser of 2000-4000 microfarads is suitable with a bridge having an effective resistance of about 1000 ohms.

The two methods of extinguishing the vigorous vibration, namely, the shifting of the main position of the vibrator by a D. C. and the reduction of the amplitude of vibration by the method just described may be combined with advantage in those cases in which the amplitude of the vigorous vibration is excessive.

In some cases it is not convenient to suppress the vigorous vibration by a movement of the mean position of the vibrator or by the method referred to above. Fig. 7 illustrates a method of reducing the amplitude of vibration and extinguishing the vigorous vibration by induced eddy currents. A suitable shaped electromagnet 31 is arranged to produce eddies in a conducting metal strip 32.
passing between its poles. The current energizing the magnet may be auto- or hand-controlled.

Fig. 8a represents an arrangement by means of which a gauge may be built which can be used to measure with accuracy distances which are greater than the amplitude of vibration of the vibrator. The feeler gauge surface (for example) is mounted on a frame which can be deflected (preferably so that the gauge surface is moved in its plane of vibration), for example, by a mass 33 sliding on a bar 34. The deflections of the feeler gauge surface due to a given displacement of the mass 33 can be measured by the gauge shown at 4, 5, which operates in any one of the manners described above. In the figure the mounting of the gauge bracket ensures that it bends about the point 0, vertically below the gauge surface 1.

Fig. 8b represents another arrangement by means of which a gauge system 4—5—6—7—35 may be used to measure the distance between two surfaces. The gauge carries a double-faced gauge piece 35. This can be brought near to the surface of either of the test surfaces 37 by a device similar to that shown in Fig. 8a. It is clear that, knowing the length of the gauge piece 35 and the calibration of the gauge the distance between the pieces 37 can be found and changes in the length of the object 36 can be measured.

Application to pointer instruments.—Any of the previous arrangements of the gauge may be adapted, if desired, to the measurement of the displacement of pointers of pointer-instruments. In this way the arrival of the pointer at any chosen point of the scale, the current-measuring instrument 35 at the zero position of the pointer, is in vibratory contact with a feeler gauge surface 1. The pointer of the current-measuring instrument 35 is deflected by the value of which is required, and is also deflected, but in the opposite direction by a very small fraction of an opposing current read on another current-measuring instrument 36, whose current is derived from a large condenser 38 charged by a battery 11. When these two currents, passing in opposite directions through the current-measuring instrument 35 are exactly equal, the current-measuring instrument 35 indicates zero, the pointer reaches the position in which the vibratory contact becomes operative, and this may be caused to make a relay 6 to function. This relay opens the contact at f (or closes a contact at h) and so causes the current in the current-measuring instrument 36 to fall (or become nil) thus removing the pointer of the current-measuring instrument 36 away from the gauge and so initiating the cycle of operations. The maximum deflection of the current-measuring instrument 36 is a measure of the current deflecting the current-measuring instrument 35 and the indication of the instrument 36 is a measure, on a large scale, of the small current flowing through the instrument 35. If, in such an arrangement, the vibrator is so placed that vibratory contact occurs between the pointer of the instrument 35 and the feeler gauge surface, then when the current through 35 has a certain value, a movement of the pointer of the instrument 35 then serves to indicate the moment at which the vigorous vibration sets in, and its deflection from zero becomes a measure of the excess of the current in 35 over the certain value chosen. Alternatively the condenser may be charged or discharged directly by way of the gauging surface carried by the pointer of the current-measuring instrument 35.

By this means one micro ampere at 35 can be made to appear as a deflection of one millimpercept at 36.

It is preferable that the current-measuring instruments 35 and 36 should have a similar response to transient forces. Alternatively if 36 is the more swiftly acting instrument it may be made sluggish by connecting condensers in parallel or other known means.

The fact that the pointer of the current-measuring instrument 35 is not required to deflect more than a small fraction of an inch (or a fraction of a degree) permits the use of pointers without pivots and without coiled springs, for example, of pointers the stem of which is flexible and rigidly fixed at one end, the other end being deflected by a force which is a known function of the quantity to be measured. This would simplify the construction of such instruments to a degree hitherto impossible. Such an instrument is illustrated diagrammatically in Fig. 10.

The above devices provide methods and apparatus for micro-measurements hitherto unequalled for their accuracy and simplicity of technique. It will be understood that variations in details may be made to the apparatus described and to the electric circuits required for their operation, as well as applications of the methods and apparatus herein described to purposes not referred to, without departing from the spirit of the invention, as set forth in the statements of claims.

In Fig. 10, 46 is a resilient member constituting the pointer of a measuring instrument adapted for the measurement of any quantity whatever the magnitude of which is capable of being indicated by the position of a pointer on a graduated scale. In the instrument shown diagrammatically in the figure, there is no scale and the flexible resilient member is clamped to the fixed frame of the instrument at 41, and it is acted upon by a force F, which bears a definite relationship to the quantity to be measured, so that the magnitude of the quantity to be measured can be derived easily and accurately from the magnitude of the force F, this latter magnitude being ascertained by the deflection or bending of the member 46 from the position it occupies when the force F= zero. 42 is a contact gauge surface on the said member 46, and 4 is a vibrator, with a feeler gauge surface 1 and driving means 6.

The most minute deflection of the member 46 is measured by means of the feeler gauge member 4 in combination with any suitable arrangement among those described above and shown diagrammatically in the drawings.

When describing the application of the vibrator to pointer instruments, it has been shown (paragraph 8) that any pointer instrument can be provided by its means with maximum or minimum sensitivity which may be constant or variable and it is always possible to adjust the instrument so that any desired deflection of the member can be caused to correspond to the condition of the current-measuring instrument 35.
minimum deflection indicators. In this particular case, this is carried out by setting the vibrator 4 away from the position occupied by 42 when the force F is zero; the same arrangement then serves to give an indication of the moment at which the force F reaches any desired relatively large (maximum) value, and to measure, if necessary, the excess of the force over this value.

As a particular example in the case of a microbarometer, the member 40 may be of the nature of a Bourdon gauge element.

The operation of any apparatus provided with a means for maintaining the vibration of the vibrator, comprising a compensating arrangement for shifting the mean position of the vibrator away from the contact gauge surface on the object being gauged when the alternating driving forces increase, so that the position in space of the feeler gauge surface at its extreme excursion towards the contact gauge surface is independent of small changes in the alternating driving current, and in which the means for ascertaining substantially the instant when the vigorous vibration sets in comprise an instrument for performing at that instant, a subsidiary operation.

A contact indicating device for a linear dimension gauge as claimed in claim 1, in which the vibration of the vibrator is maintained by an electromagnetic drive, comprising a compensating arrangement for shifting the mean position of the vibrator away from the contact gauge surface on the object being gauged when the alternating driving forces increase, so that the position in space of the feeler gauge surface at its extreme excursion towards the contact gauge surface is independent of small changes in the alternating driving current, the means for ascertaining substantially the instant when the vigorous vibration sets in comprising an instrument for performing at that instant, a subsidiary operation.

A contact indicating device for a linear dimension gauge as claimed in claim 1, in which the vibration of the vibrator is maintained by an electromagnetic drive, comprising a compensating arrangement for shifting the mean position of the vibrator away from the contact gauge surface on the object being gauged when the alternating driving forces increase, so that the position in space of the feeler gauge surface at its extreme excursion towards the contact gauge surface is independent of small changes in the alternating driving current, the means for ascertaining substantially the instant when the vigorous vibration sets in comprising an instrument for performing at that instant, a subsidiary operation.

A contact indicating device for a linear dimension gauge as claimed in claim 1, in which the vibration of the vibrator is maintained by an electromagnetic drive, comprising a compensating arrangement for shifting the mean position of the vibrator away from the contact gauge surface on the object being gauged when the alternating driving forces increase, so that the position in space of the feeler gauge surface at its extreme excursion towards the contact gauge surface is independent of small changes in the alternating driving current, the means for ascertaining substantially the instant when the vigorous vibration sets in comprising an instrument for performing at that instant, a subsidiary operation.
ject carrying the contact gauge surface, in combination with a pointer instrument the pointer of which carries the contact gauge surface and the position of which can be very accurately as-
said by the setting in of the vigorous vibra-
tion.

8. A contact indicating device for a linear di-
men son gauge as claimed in claim 1, in which the vibration of the vibrator is maintained by
an electromagnetic drive, comprising a com-
pen sing arrangement for shifting the mean po-

tion of the vibrator away from the contact
gauge surface on the object being gauged when the alternating driving forces increase, so that
the position in space of the feeler gauge surface
at its extreme excursion towards the contact
gauge surface is independent of small changes in the alternating driving current, the means for
ascertaining substantially the instant when the
vigorous vibration sets in comprising an instru-
ment for performing a subsidiary operation, said subsidiary operation consisting in moving the
contact open to the fixed frame of the instru-
ment and carries at its free end the contact
gauge surface, the position of the free end of
which position can be very accurately asces-
tained by the setting in of the vigorous vibra-
tion.

9. A contact indicating device for a linear di-
men son gauge as claimed in claim 1, character-
ized by electromagnetic means for maintaining
the vibration of the vibrator, one bridge compris-
ing diagonals, a compensating arrangement for shifting the mean po-

tion of the vibrator away from the contact
gauge surface on the object being gauged when the alternating driving forces increase, so that
the position in space of the feeler gauge sur-
face at its extreme excursion towards the con-
tact gauge surface is independent of small changes in the alternating driving current, and in which the means for ascertaining substan-
tially the instant when the vigorous vibration sets
in is a compensating arrangement for performing a sub-


10. A contact indicating device for a linear di-
men son gauge as claimed in claim 1, character-
ized by an electromagnetic drive for mainte-
ning the vibration of the vibrator, comprising a
compensating arrangement for shifting the mean position of the vibrator away from the contact
gauge surface on the object being gauged when the alternating driving forces increase, so that
the position in space of the feeler gauge surface
at its extreme excursion towards the contact
gauge surface is independent of small changes in the alternating driving current, in which the
means for ascertaining substantially the instant when the vigorous vibration sets in, comprise an
instrument for performing a subsidiary opera-
tion, said subsidiary operation consisting in alter-
ing the amplitude of vibration of the vibrator, and means for indicat-
ing the said change of amplitude.

11. A contact indicating device for a linear di-
men son gauge as claimed in claim 1, character-
ized by an electromagnetic drive for maintain-
ing the vibration of the vibrator, comprising a
compensating arrangement for shifting the mean position of the vibrator away from the contact
gauge surface on the object being gauged when the alternating driving forces increase, so that
the position in space of the feeler gauge surface
at its extreme excursion towards the contact
gauge surface is independent of small changes in the alternating driving current, in which the
means for ascertaining substantially the instant when the vigorous vibration sets in, comprise an
instrument for performing a subsidiary opera-
tion, said subsidiary operation consisting in alter-
ing the amplitude of vibration of the vibrator, and means for indicating the said change of am-
plitude, the circuit comprising a source of alternat-
ing current in the electric circuit of the said
drive, a "bridge" rectifier assembly connected with one of its diagonals in series with the said
source, a relay, a resistance in series with one of
the pairs of contacts of the said relay, and a
large electric condenser connected in the other
the said condenser, so that when the contacts open owing to the relay being energized by the setting-in of the vigorous vibration, the condenser charges up slowly and reduces the alternating current supplied to the gauge winding, the said condenser discharging slowly when the contacts close, the whole arrangement being in combination with a pointer instrument the pointer of which carries the contact gauge surface and the position of which can be very accurately ascertained by the setting-in of the vigorous vibration.

15. A contact indicating device for a linear dimension gauge as claimed in claim 1, characterized by electromagnetic driving means for maintaining the vibration of the vibrator, said means comprising a compensating arrangement for shifting the mean position of the vibrator away from the contact gauge surface on the object being gauged when the alternating driving forces increase, so that the position of the vibrating forces in the alternating driving current, and a source of alternating current, a rectifier in the alternating current circuit feeding the said driving current to the said driving system, in such a direction as to shift the mean position of the vibrator away from the contact gauge surface when the alternating driving current increases, the means for ascertaining substantially the instant when the vigorous vibration sets in comprising an instrument for performing a subsidiary operation, said subsidiary operation consisting in altering the amplitude of vibration of the vibrator and means for indicating the resultant change in amplitude of vibration, the circuit comprising a source of alternating current in the electric circuit of the said drive, a "bridge" rectifier assembly connected with one of its diagonals in series with the said source, a relay, a resistance in series with one of the pairs of contacts of the said relay, and a large electric condenser connected in the other diagonal of the bridge, said resistance and relay contacts in series being connected as a shunt to the terminals of the said condenser, so that when the contacts open owing to the relay being energized by the setting-in of the vigorous vibration, the condenser charges up slowly and reduces the alternating current supplied to the gauge winding, the said condenser discharging slowly when the contacts close, the whole arrangement being in combination with a pointer instrument the pointer of which is a flexible resilient member clamped at one end to the fixed frame of the instrument and carries at the free end the contact gauge surface, the position of the free end of the pointer can be very accurately ascertained by the setting-in of the vigorous vibration.

14. A contact indicating device for a linear dimension gauge as claimed in claim 1, characterized by electromagnetic means for maintaining the vibration of the vibrator, comprising a compensating arrangement for shifting the mean position of the vibrator away from the contact gauge surface on the object being gauged when the alternating driving forces increase, so that the position of the vibrating forces in the alternating driving current, and in which the mean position of the vibrator relatively to its support and means for indicating the said additional displacement of the mean position of the vibrator.

15. A contact indicating device for a linear dimension gauge as claimed in claim 1, characterized by electromagnetic driving means for maintaining the vibration of the vibrator, said means comprising a compensating arrangement for shifting the mean position of the vibrator away from the contact gauge surface on the object being gauged when the alternating driving forces increase, so that the position of the vibrating forces in the alternating driving current, and a source of alternating current, a rectifier in the alternating current circuit feeding the said driving current to the said driving system, in such a direction as to shift the mean position of the vibrator away from the contact gauge surface when the alternating driving current increases, the means for ascertaining substantially the instant when the vigorous vibration sets in comprising an instrument for performing a subsidiary operation, said subsidiary operation consisting in altering the amplitude of vibration of the vibrator and means for indicating the resultant change in amplitude of vibration, the circuit comprising a source of alternating current in the electric circuit of the said drive, a "bridge" rectifier assembly connected with one of its diagonals in series with the said source, a relay, a resistance in series with one of the pairs of contacts of the said relay, and a large electric condenser connected in the other diagonal of the bridge, said resistance and relay contacts in series being connected as a shunt to the terminals of the said condenser, so that when the contacts open owing to the relay being energized by the setting-in of the vigorous vibration, the condenser charges up slowly and reduces the alternating current supplied to the gauge winding, the said condenser discharging slowly when the contacts close, the whole arrangement being in combination with a pointer instrument the pointer of which is a flexible resilient member clamped at one end to the fixed frame of the instrument and carries at the free end the contact gauge surface, the position of the free end of the pointer can be very accurately ascertained by the setting-in of the vigorous vibration.

16. A contact indicating device for a linear dimension gauge as claimed in claim 1, characterized by electromagnetic driving means for maintaining the vibration of the vibrator, said means comprising a compensating arrangement for shifting the mean position of the vibrator away from the contact gauge surface on the object being gauged when the alternating driving forces increase, so that the position of the vibrating forces in the alternating driving current, and a source of alternating current, a rectifier in the alternating current circuit feeding the said driving current to the said driving system, in such a direction as to shift the mean position of the vibrator away from the contact gauge surface when the alternating driving current increases, the means for ascertaining substantially the instant when the vigorous vibration sets in comprising an instrument for performing a subsidiary operation, said subsidiary operation consisting in altering the amplitude of vibration of the vibrator and means for indicating the resultant change in amplitude of vibration, the circuit comprising a source of alternating current in the electric circuit of the said drive, a "bridge" rectifier assembly connected with one of its diagonals in series with the said source, a relay, a resistance in series with one of the pairs of contacts of the said relay, and a large electric condenser connected in the other diagonal of the bridge, said resistance and relay contacts in series being connected as a shunt to the terminals of the said condenser, so that when the contacts open owing to the relay being energized by the setting-in of the vigorous vibration, the condenser charges up slowly and reduces the alternating current supplied to the gauge winding, the said condenser discharging slowly when the contacts close, the whole arrangement being in combination with a pointer instrument the pointer of which is a flexible resilient member clamped at one end to the fixed frame of the instrument and carries at the free end the contact gauge surface, the position of the free end of the pointer can be very accurately ascertained by the setting-in of the vigorous vibration.
crease, so that the position in space of the feeler gauge surface is independent of small changes in the alternating driving current, and a source of alternating current, a polarized driving system, a rectifier in the alternating current circuit feeding the said driving system so connected as to provide a rectified biasing current substantially proportional to the driving current and means for also feeding the rectified current from the said rectifier into the said driving system, in such a direction as to shift the mean position of the vibrator away from the contact gauge surface when the alternating driving current increases, the means for ascertaining substantially the instant when the vigorous vibration sets in comprising an instrument for performing a subsidiary operation, said subsidiary operation including the production of a unidirectional force (besides that due to the compensating arrangement) resulting in an additional displacement of the mean position of the vibrator relatively to its support and means for indicating the said additional displacement of the mean position of the vibrator, the subsidiary apparatus controlling the mean position of the vibrator being itself controlled by a relay brought into operation by the setting-in of the vigorous vibration, the whole arrangement being in combination with a pointer instrument the pointer of which can be very accurately ascertained by the setting-in of the vigorous vibration.

19. A contact indicating device for a linear dimension gauge as claimed in claim 1, characterized by electromagnetic driving means for maintaining the vibration of the vibrator, said means comprising a compensating arrangement for shifting the mean position of the vibrator away from the contact gauge surface on the object being gauged when the alternating driving forces increase, so that the position in space of the feeler gauge surface is independent of small changes in the alternating driving current, and a source of alternating current, a polarized driving system, a rectifier in the alternating current circuit feeding the said driving system so connected as to provide a rectified biasing current substantially proportional to the driving current and means for also feeding the rectified current from the said rectifier into the said driving system, in such a direction as to shift the mean position of the vibrator away from the contact gauge surface when the alternating driving current increases, the means for ascertaining substantially the instant when the vigorous vibration sets in comprising an instrument for performing a subsidiary operation, said subsidiary operation including the production of a unidirectional force (besides that due to the compensating arrangement) resulting in an additional displacement of the mean position of the vibrator relatively to its support and means for indicating the said additional displacement of the mean position of the vibrator, the subsidiary apparatus controlling the mean position of the vibrator being itself controlled by a relay brought into operation by the setting-in of the vigorous vibration, the whole arrangement being in combination with a pointer instrument the pointer of which is a flexible resilient member clamped at one end to the fixed frame of the instrument and carrying at its free end the contact gauge surface, the position of the free end of which pointer can be very accurately ascertained by the setting-in of the vigorous vibration.

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