# PATENT SPECIFICATION

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656,270

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PROVISIONAL SPECIFICATION

## Means for Indicating or Controlling Small Angles of Rotation of a Shaft

We, NATIONAL RESEARCH DEVELOPMENT CORPORATION, a British Corporation, of 1, Tilney Street, London, W.1, do hereby declare the nature of this invention to be as follows:—

Remote indication of the angle of twist of a shaft or of the torque responsible for such a twist are often required particularly in the telemetering of information, e.g. from rocket projectiles.

The invention aims to provide a device which will give such information directly in the form of a variable electrical frequency. If desired the output of the device may be used to control a corrective mechanism (e.g. in an auto-pilot) to maintain a shaft position or a torque at a prescribed position or value.

The invention involves the use of a "sine" spring such as is described in the provisional or complete specification of my application No. 32770/45, and according to it such a spring is mounted on two anchorages either or both of which are rotated by the torque under examination. As the torque increases in one sense the stiffness of the sine spring increases, and it decreases if the sense is reversed. The value of the stiffness is closely related to the angle of twist of the anchorage, or to the torque applied to the anchorage.

The stiffness variation is indicated by exciting the blade of the spring, e.g. by a trembler-bell system or an electromagnetic pick-up and amplifier. The frequency of oscillation will be directly related to the stiffness of the blade and therefore to the torque applied.

A signal may thus be transmitted directly from the maintaining circuits of the remote point, the frequency of which signal is a measure of the angle of twist of one or both anchorages and therefore of the applied torque.

Alternatively this frequency may be fed back to the mechanism responsible for the torque and, by means of a discriminator, or other frequency sensitive device, arranged to control the angle of twist so that it is between predetermined limits.

The system has the advantage, common to all systems which employ frequency as the indicating parameter, that the translating device between sender and remote receiver cannot distort the data fed to it; moreover, to a first order of approximation, the frequency of oscillation of the sine spring will be independent of the power supplied to the maintaining system.

Dated this 18th day of October, 1948.

S. W. SLAUGHTER,
Agent for the Applicants.

COMPLETE SPECIFICATION

## Means for Indicating or Controlling Small Angles of Rotation of a Shaft

We, NATIONAL RESEARCH DEVELOPMENT CORPORATION, a British Corporation, of 1, Tilney Street, London, W.1, 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 systems for the measurement, and control where desired, of angular displacement occurring between two relatively rotatable members,

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e.g. two axially arranged rotating shafts. It involves the use of springs of sinusoidal form (hereinafter referred to as sine springs) of the character described in British patent specification 617,076.

In telemetering, remote indication of the angular displacement between two relatively rotatable members is often required. It is an object of the present invention to provide a system whereby such indication may be presented in the form of a variable electrical frequency.

According to the invention a system for the measurement of angular displacement occurring between two relatively rotatable members comprises a sine spring interconnecting said members in such a way that its stiffness is caused to vary in accordance with the degree of relative rotation of said members, means for vibrating the spring and means for measuring the frequency of the vibration so induced.

It is shown in the above-mentioned patent specification that the stiffness of a spring mounted between two rotatable anchorages changes when one or both of the anchorages is rotated. The value of this stiffness is closely related to the angle of twist of the anchorage and the natural frequency of oscillation of a spring so mounted will be directly related to its stiffness. Thus the frequency of oscillation of the blade is related to the angle of twist of the anchorages or to the torque applied thereto, and so by maintaining the spring in a state of oscillation by a trembler bell or other means, and measuring the value of this frequency the angle twist or torque is derived.

A signal may thus be transmitted directly from the maintaining circuit, its frequency being a measure of angle of twist or torque. Alternatively the signal may be fed back into the mechanism responsible for the torque and, by means of a discriminator or other frequency sensitive device, arranged to control the angle of twist so that it is between predetermined limits.

The system has the advantage, common to all systems which employ frequency as the indicating parameter, that the translating device between sender and remote receiver cannot distort the data fed into it; moreover, to a first order of approximation, the frequency of oscillation of the sine spring will be independent of the power supplied to the maintaining system.

In order that the invention may be clearly understood, various embodiments in accordance with it will now be described in detail with reference to the accompanying drawings.

Figures 1, 2, 3 and 4 of these drawings are side elevations of a sine spring mounted between two anchorages capable of limited rotation.

Figure 5 is a sectional elevation of an arrangement for obtaining the relative angular displacement of relatively rotatable members in the form of two rotating shafts.

Figure 6 is a sectional elevation of a form of torsion meter according to the invention and suitable for vertical shafts.

Figure 7 is a sectional elevation of another form of torsion meter according to the invention suitable for both horizontal and vertical shafts.

Figures 8 and 9 are a front elevation and a section on YY of Figure 8 respectively of an arrangement comprising a sine spring mounted between two rotatable anchorages and means for maintaining the spring in a state of oscillation.

Referring now to Figure 1, a blade member 4 is clamped between two anchorages 1 and 2 free to rotate about their axes on a base plate 3 so that the blade will take up the form shown in the figure. If the anchorage 2 is fixed to the base plate 3 by a screw 8, and the anchorage 1 is rotated anti-clockwise by an extension piece 5, the centre 6 of the blade will move towards the point 7 midway between the anchorages 1 and 2. It will be found that as the centre 6 of the blade approaches the point 7, the stiffness of the blade in a direction transverse to the line joining the centres of the two anchorages will become smaller, and if the adjustment is carried far enough the blade becomes unstable, tending to take up either of two possible extreme positions. In transit between these two extreme positions the stiffness of the blade becomes negative. To prevent it becoming negative the anchorage 2 is rotated slightly counter-clockwise. When this has been done it is possible to hold 6 over 7 by a correct setting of the arm 5.

If now another extension piece 9 (Figure 3) is secured to the anchorage 2, and the screw 8 loosened, the two arms will tend to spring apart, but if the ends of the two arms 5 and 9 are connected by a link 10, no movement will occur apart from that due to the play in the connecting pins. The anchorages 1 and 2, which are both now free to rotate will now turn together, i.e. if a force is applied along the link 10. The rotation of the anchorages 1 and 2 anti-clockwise by equal angles $\theta$ will raise the stiffness of the blade 4, but will leave its centre 6 at the point 7. Thus the stiffness of the blade 4 varies with linear motion of the link 10 or with rotation of the anchorages 1 and 2.

It is obvious that the arrangement will not allow more than a limited angular rotation of the two clamps. In general, if

$\theta_0$ is the angle of repose (Figure 1), the angle $\theta$ may be increased to about 2.5 $\theta_0$ without producing permanent set in the material of the blade, but this figure would be lower for a thickened blade.

In Figure 5 a frame 12 is secured to a shaft 11, and another shaft 2a passes through a clearance hole in this frame. An anchorage 1a is mounted in a bearing in the frame so that it is free to turn about its axis and a blade 4a is clamped at one end of a slot at the end of the shaft 2a, and in a slot in the clamp 1a at its other end. Two arms and a link arranged similarly to those shown in Figure 4 (not shown in Figure 5) are attached to the anchorage 1a and the shaft 2a to ensure that these latter members always turn together by equal angles. If the shaft 11 undergoes angular displacement relatively to the shaft 2a, relative motion of the frame 12 and the shaft 2a occurs, and thus a variation in the stiffness of the blade is effected.

Such an arrangement is suitable for the measurement of the relative angular position of two shafts whether they are static or in continuous motion. In the latter case the frame 12 is duplicated as shown at 13, and a counterweight 14 fitted to complete the balance of the arrangement.

In Figure 6 the same general construction as in Figure 5 is followed but there is only one shaft, and the angular displacement measured is that due to the torque transmitted by the shaft. An extended frame 17 is clamped at one end to the shaft by a screw 18 and carries a flange 15 at its other end. To this flange is attached an anchorage 1b, balanced by a counterweight 14a. A blade 4b is clamped between the anchorage 1b and a collar 19 rigidly fixed to the shaft 2b, and a pair of arms (not shown) couple the collar 19 and anchorage 1b as before.

In Figures 8 and 9 one of the many methods of maintaining the blade 4c in a state of oscillation is indicated. An armature 22 is of cylindrical form and is clamped to the centre of the blade 4c between two solenoids 20 and 21. In the central position of the blade 4c, the axis of the armature 22 is offset from the axis of the solenoids 20 and 21 and the magnetic circuit (not shown) is thus open. If therefore the system is provided with a D.C. supply via a make and break contact in series with the solenoids, which is operated by the motion of the blade 4c, the system will oscillate at a frequency largely determined by the stiffness of the blade 4c, and therefore determined by the angle of rotation of the anchorages 1 and 2 relative to their mounting plate 3.

In Figure 7 an arrangement is shown embodying the oscillating arrangement shown in Figures 8 and 9. In this case, the stiffness of the blade 4d is controlled by the rotation of the anchorages 1c and 2c carrying pinions 30 and 31 which are mounted so as to be free to rotate in a flange 26 rigidly secured to a shaft 23. The pinions 30 and 31 engage teeth on an extended frame 28 concentric with the shaft 23 and clamped rigidly to it by the collar 27. A shaft 24, forming in effect a continuation of the shaft 23 has a frame 25 rigidly attached to it at its end, forming a housing for the blade 4d, the frame 25 being secured to the flange 26 by studs and nuts 34. Slip rings 32 and brushes 33 are provided to carry the current to two solenoids 20a and 21a arranged on each side of an armature 22a. The magnetic circuit in this case may be completed by the flange 26 and housing frame 25. If the length of shaft 23 between the collar 27 and the flange 26 be twisted by the transmission of power from the shaft 23 to the shaft 24, the pinions 30 and 31 will be rotated and a change in the stiffness of the blade 4d will occur resulting in a change in its frequency of oscillation. The mass of the armature 22a lies at the centre of rotation of the system and rotation of the shafts 23 and 24 therefore has negligible influence upon the oscillation of the blade whether the shafts be vertical or horizontal.

Many devices are known which allow the resonant frequency of a mechanical system to be registered electrically or which set such a system into self oscillation. They will not be detailed here, it being understood that they have obvious application in the present invention.

Again, it will be obvious to those skilled in the art, that the difference in the frequency of oscillation of the blade 4a, Fig. 5, from some predetermined frequency could form the error signal for a positional zero system whereby the shaft 11 would be caused to " follow up " the shaft 2a. In this way a small torque applied to the shaft 2a would position the shaft 11 against a considerable opposing torque.

It may be shown that when the angle $\theta$ of both the clamps exceeds the angle of the anchorage for zero stiffness $\theta_0$ by a very small amount, the rate of change of frequency is very much greater than the rate of change of $\theta$. Thus where high sensitivity is a requirement, e.g. as in the torsion meter applications of the present invention, it is preferable that setting of the anchorages for no angular displacement of the mechanism is such that the ratio $\theta/\theta_0$ should only slightly exceed unity. The degree of sensitivity obtainable by this means, however, is limited (if it is desired to measure a displacement on each side of the initial position of $\theta$) by the fact that $\theta$ obviously must not fall below $\theta_0$ into the region of unstable negative stiffness of the blade.

Again, when small changes in $\theta$ have to be measured it is clearly desirable to make $\theta_0$ small also, i.e. to make the amplitude of the spring small. This cannot be carried too far, however, because when the deflection becomes large compared with the distance apart of the supports the instantaneous stiffness grows approximately in proportion to the square of the instantaneous deflection. Where, therefore, the greatest sensitivity is required, the blade is maintained in oscillation by electromagnetic means associated with an amplifier the gain of which is arranged to fall rapidly when the amplitude becomes excessive. This enables very small values of $\theta$ and $\theta_0$ to be used.

In general, to allow for flexing, the blade of the spring should be as thin as possible consistant with strength required for stability. The width of the blade can be increased to any desired extent to increase rigidity.

It can be shown that when $\theta/\theta_0=2.666$, the frequency of oscillation is proportional to the angle $\theta$ for small changes of $\theta$. This ratio may be achieved by using very thin blades and may be advantageous for certain purposes.

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

1. A system for the measurement or control of small angular displacement occurring between two relatively rotatable members comprising a sine spring interconnecting said members in such a way that its stiffness is caused to vary in accordance with the degree of relative rotation of the said members, means for vibrating the spring and electric means responsive to the frequency of the vibration so induced for measuring or controlling the said angular displacement.

2. A system according to Claim 1 wherein the sine spring is mounted between two anchorages each associated with one of the relatively rotatable members, the two said anchorages being rotatable and connected together so as to execute like angular displacement.

3. A system according to Claim 2 wherein the two rotatable anchorages are each provided with an extension rod, the two rods being connected at their extremities by a link.

4. A system according to Claims 1, 2 or 3 for the measurement of the relative angular displacement between two axially aligned shafts wherein the spring lies transversely to the axes of said shafts and interconnects the first of the two shafts and an anchorage located in a frame member rigidly connected to the second shaft.

5. A system according to Claims 1, 2 or 3 for the measurement of the angular displacement of a length of shaft due to the transmission of power thereby wherein the spring lies transversely to the axis of the shaft and interconnects one part of the said shaft and one end of an extended frame member which is concentric with said shaft and rigidly clamped thereto at its other end.

6. A system according to Claims 1, 2 or 3 for the measurement of the angular displacement of a length of shaft due to the transmission of power thereby comprising a sine spring arranged transversely to the axis of the shaft and interconnecting two rotatable anchorages wihch are on a diameter of and equi-distant from the centre of a flange member rigidly connected to one end of the shaft, each of the two said rotatable anchorages being provided with a pinion meshing with a peripheral rack at one end of an extended frame member which is concentric with said shaft and rigidly clamped thereto at its other end.

7. A system according to any of the preceding claims wherein the means for vibrating the spring take the form of a trembler bell mechanism, the said spring forming the armature and contact carrying member.

8. A system according to any of Claims 1 to 7 wherein electrical means associated with an amplifier are provided for vibrating the spring.

9. A system according to Claim 8 wherein the gain of said amplifier is arranged to fall rapidly when the amplitude of vibration of the spring becomes excessive.

10. A control system according to Claims 1, 2 or 3 wherein the frequency responsive means cause one of two relatively rotatable shafts to follow the angular motion of the other.

11. A system as claimed in Claim 1 arranged for operation substantially as hereinafter described with reference to the several examples as shown in Figures 1 to 9 of the accompanying drawings.

Dated this 18th day of October, 1949.
S. W. SLAUGHTER,
Agent for Applicants.

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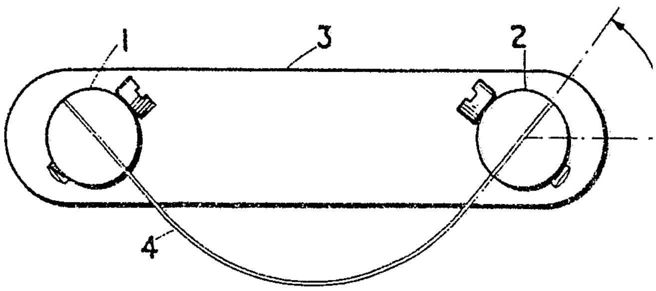



Fig. 1

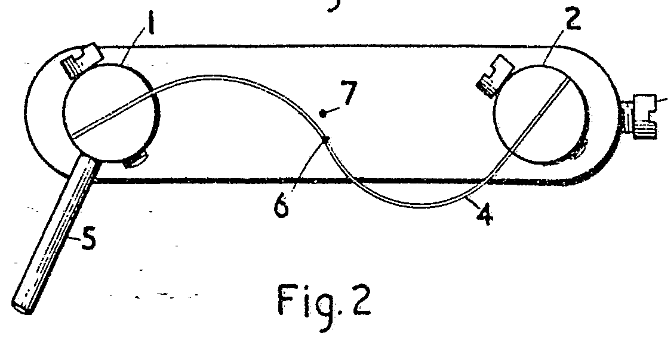



Fig. 2

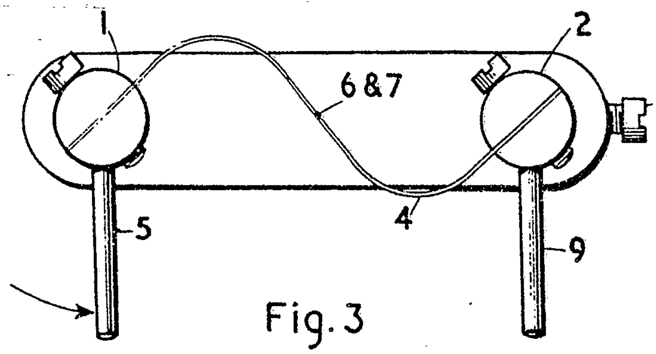



Fig. 3

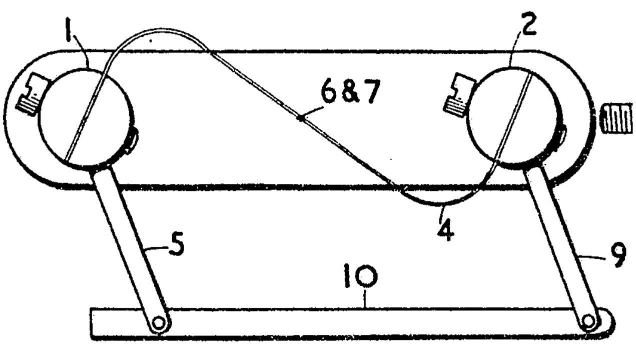
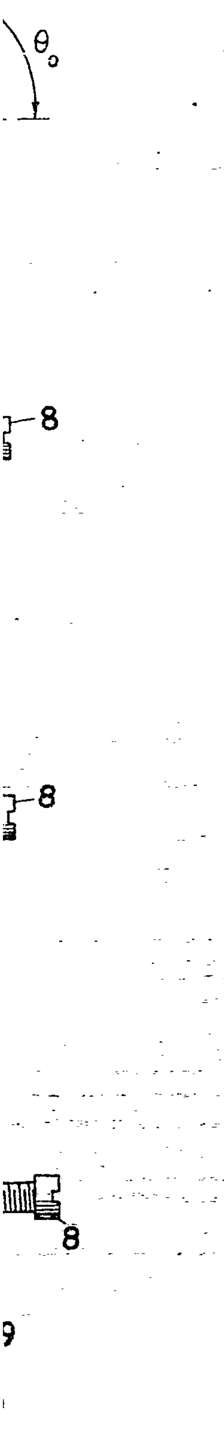



Fig. 4





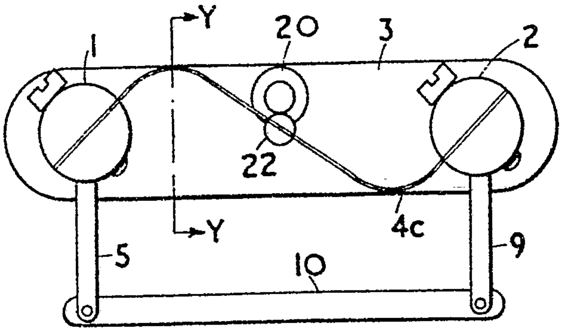




Fig. 8

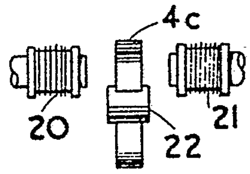



Fig. 9

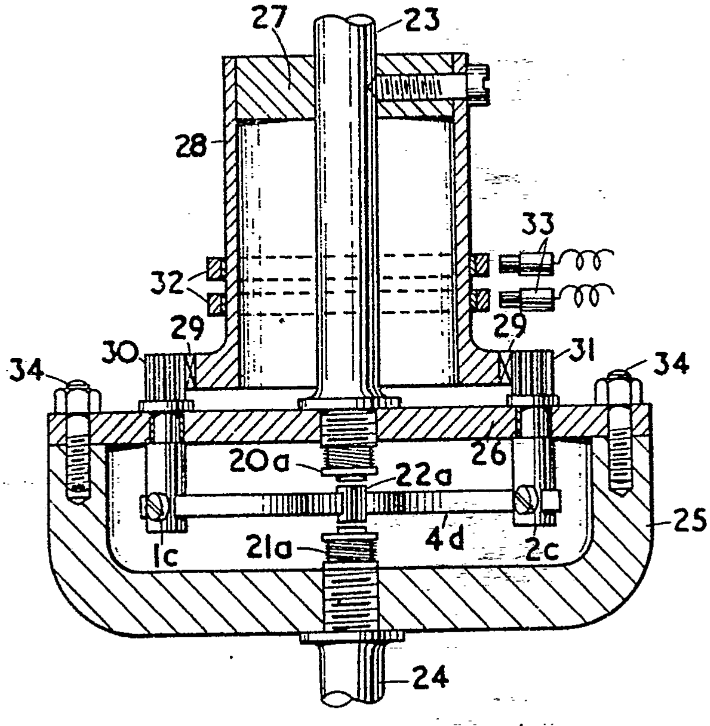



Fig. 7

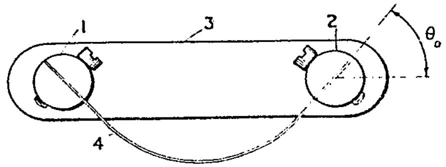



Fig. 1

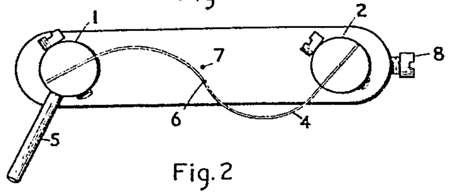



Fig. 2

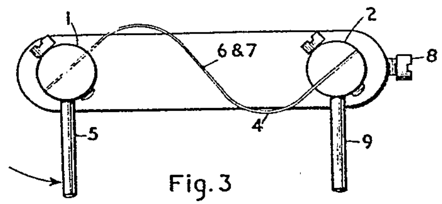



Fig. 3

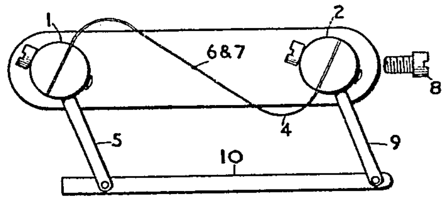



Fig. 4

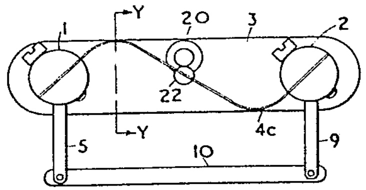



Fig. 8

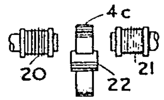



Fig. 9

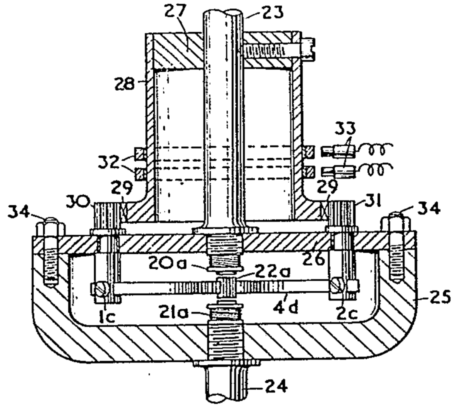



Fig. 7

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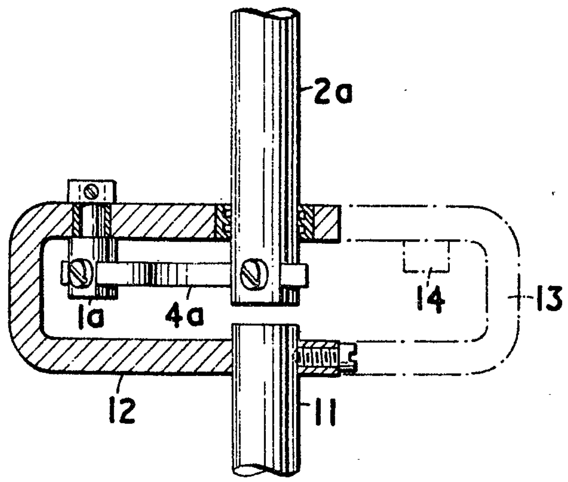


FIG. 5

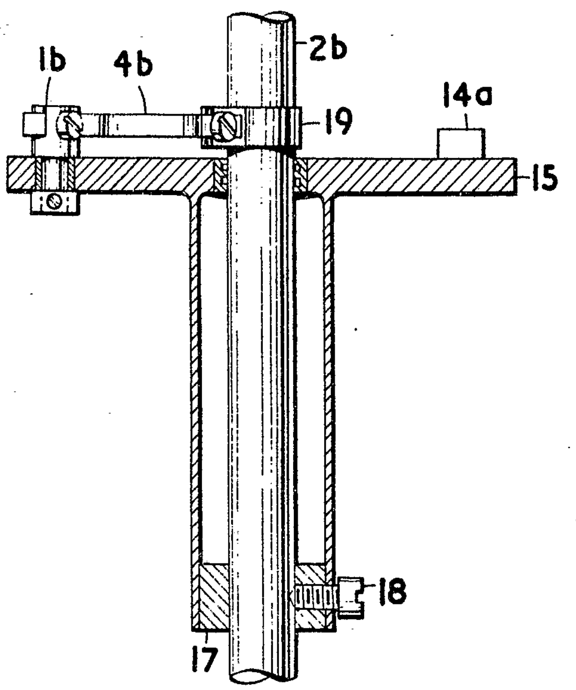


FIG. 6