

May 18, 1965

P. J. GILINSON, JR

3,184,271

SUPPORTS FOR ROTATING OR OSCILLATING MEMBERS

Filed May 15, 1957

4 Sheets-Sheet 1

Fig. 1

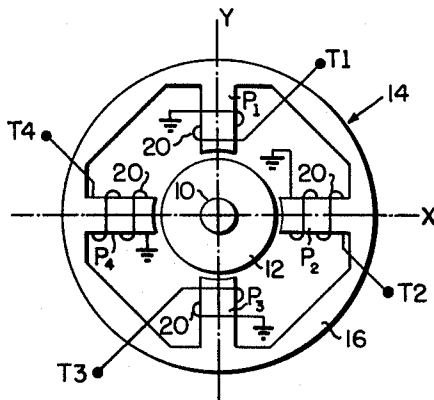


Fig. 2

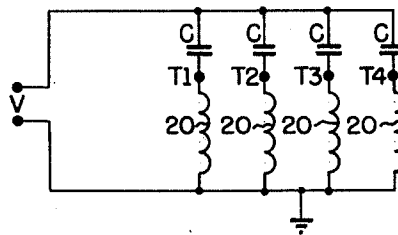
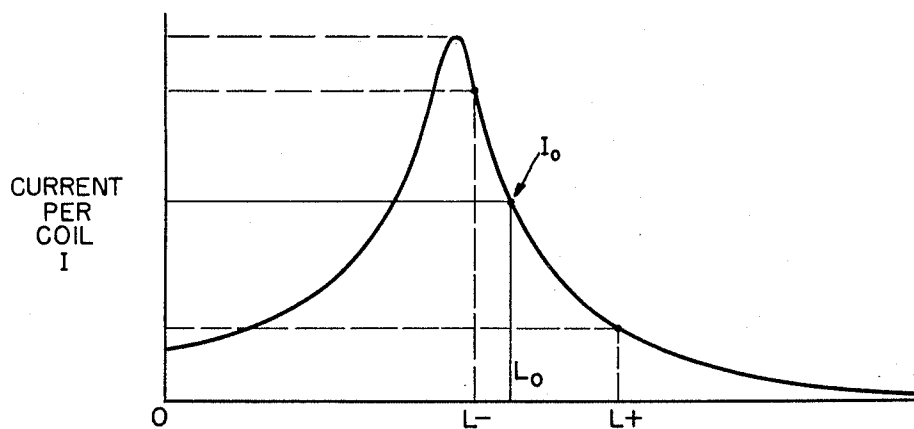


Fig. 3



INVENTOR.
PHILIP J. GILINSON, JR.
BY
KENWAY, JENNEY, WITTER & HILDRETH

ATTORNEYS

May 18, 1965

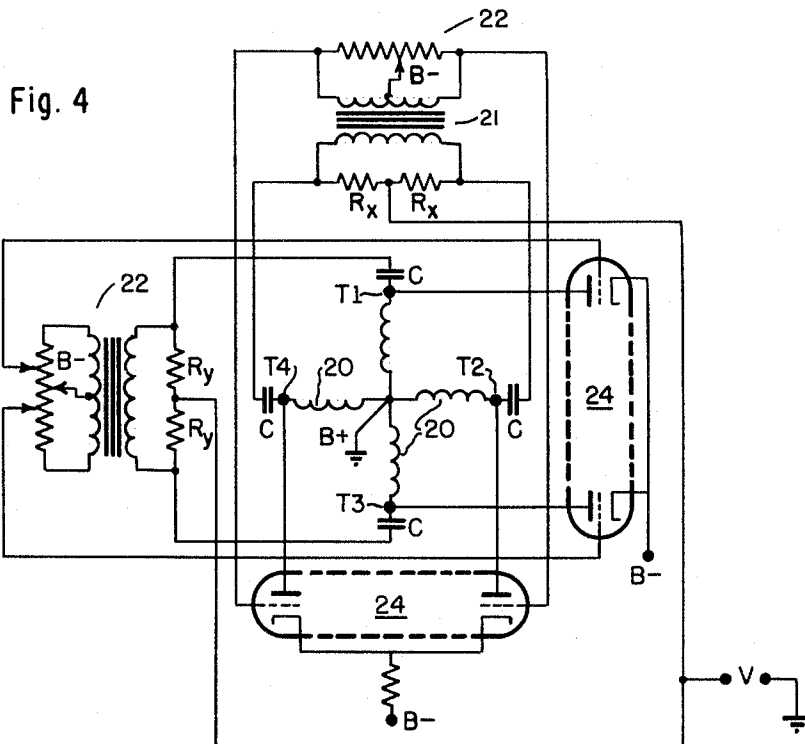
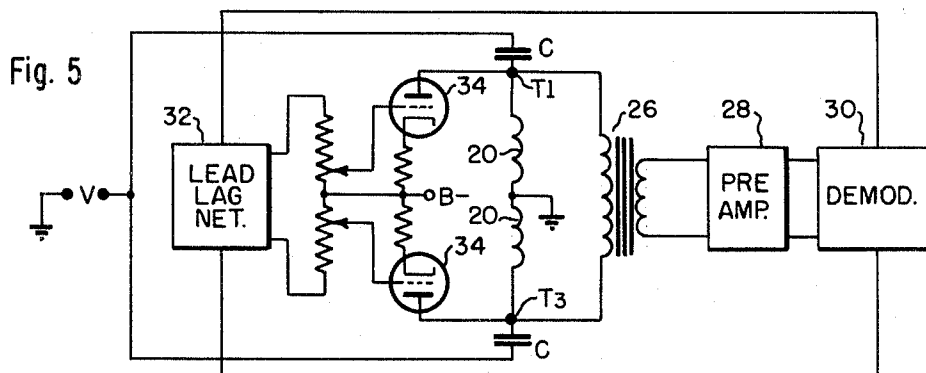
P. J. GILINSON, JR

3,184,271

SUPPORTS FOR ROTATING OR OSCILLATING MEMBERS

Filed May 15, 1957

4 Sheets-Sheet 2



INVENTOR.
 PHILIP J. GILINSON, JR.
 BY
 KENWAY, JENNEY, WITTER & HILDRETH

ATTORNEYS

May 18, 1965

P. J. GILINSON, JR

3,184,271

SUPPORTS FOR ROTATING OR OSCILLATING MEMBERS

Filed May 15, 1957

4 Sheets-Sheet 3

Fig. 6

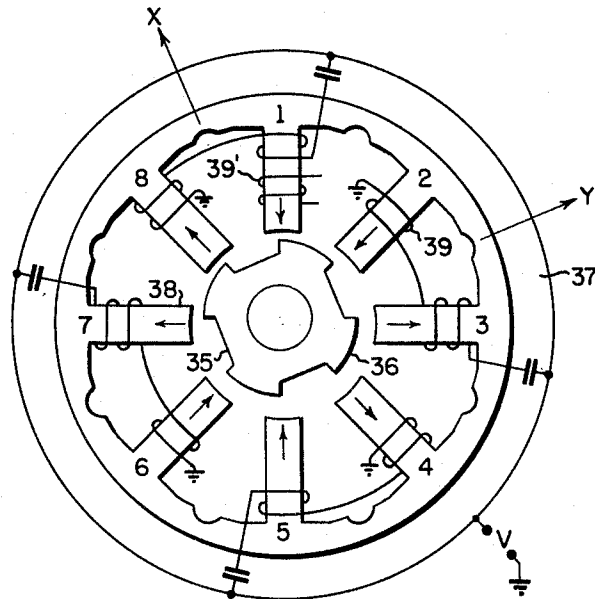
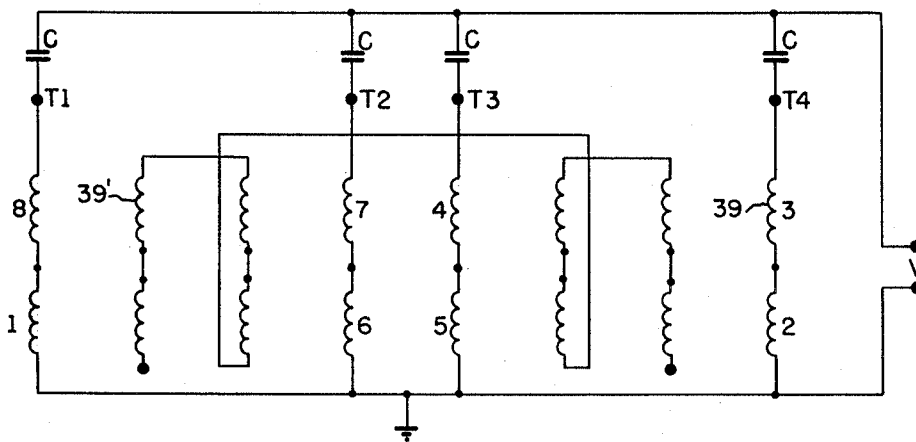


Fig. 7



INVENTOR.
PHILIP J. GILINSON, JR.

BY
KENWAY, JENNEY, WITTER & HILDRETH

ATTORNEYS

May 18, 1965

P. J. GILINSON, JR

3,184,271

SUPPORTS FOR ROTATING OR OSCILLATING MEMBERS

Filed May 15, 1957

4 Sheets-Sheet 4

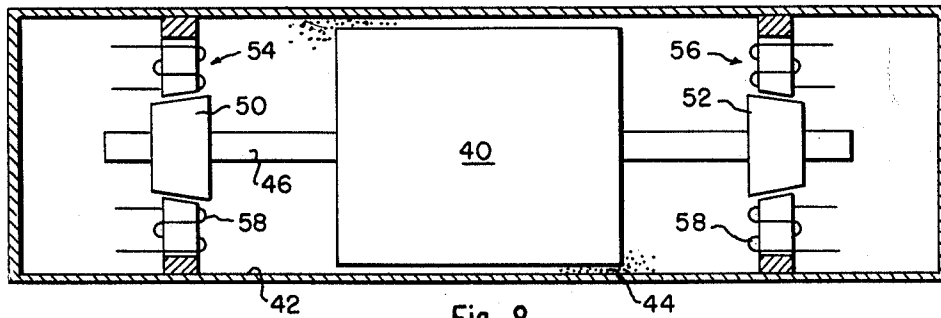


Fig. 8

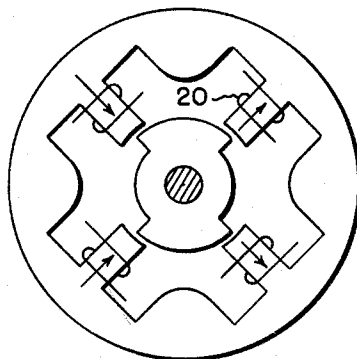


Fig. 9

INVENTOR.
PHILIP J. GILINSON, JR
BY
KENWAY, JENNEY, WITTER & HILDRETH
ATTORNEYS

1

2

3,184,271 SUPPORTS FOR ROTATING OR OSCILLATING MEMBERS

Philip J. Gilinson, Jr., Chelmsford, Mass., assignor, by mesne assignments, to Massachusetts Institute of Technology, a corporation of Massachusetts
Filed May 15, 1957, Ser. No. 659,395
7 Claims. (Cl. 308—10)

The present invention relates to supports for rotating or oscillating members and more particularly to magnetic "bearings" for supporting such members without the use of conventional bearings.

The type of apparatus to which the present invention is especially suited is the gyroscopic apparatus described in the Jarosh, Haskell & Dunnell Patent No. 2,752,791, dated July 3, 1956, although it may also be used for other rotating or oscillating members, particularly where precision of operation and freedom from frictional effects are required. In the Jarosh et al. patent which will serve as an example for applicability of the present invention, there is a gyroscopic unit which is mounted within a cylindrical case, which in turn is floated within an outer casing. The density of the float liquid is such as to buoy the inner case as freely as possible, and the clearance space between the outer casing and the inner case is preferably very small, of the order of a few thousandths of an inch. The buoying liquid then acts as a damping medium to damp motions between the inner case and the outer casing. This provides what is termed the integrating gyro. In the form of apparatus shown in the patent the axis of the inner casing is fixed by conventional bearings, and it is one object of the buoying medium to reduce the load on the bearings as much as possible. In some applications of the gyroscopes where high precision is required, the friction due to the bearings may still be too high, not withstanding the buoyancy of the liquid.

It is the object of the present invention to provide a magnetic suspension by which rotating or oscillating member may be magnetically supported in a precise position without the necessity for use of conventional bearings.

With this object in view the present invention comprises units of the general type described in the Mueller Patent 2,488,734 (known as microsyns), together with external circuit connections arranged to provide centralizing forces to support the rotating or oscillating member. In the several forms of the present invention stator units of the type shown in the Mueller patent are used, and in some forms of the invention the rotor is of circular cylindrical form. This construction allows the supported member to be either oscillated or rotated.

Another feature of the invention contemplates the use of microsyn devises which are not only capable of performing their signal or torque generating functions, but also serve as rotor supports. As described in the Mueller patent, the rotor and windings of the microsyn may be arranged to form either a signal generator or a torque generator, in the latter case, the generated torque may either be uniform or may vary with angular displacement. The above Jarosh et al. patent describes the use of a torque generator at one end of the shaft and a signal generator at the other end of the shaft. According to the present invention the microsyn units are arranged to perform their normal functions and still provide for the magnetic support of the inner casing.

A further feature of the invention consists of an arrangement for centering the unit axially.

A further feature of the invention consists of external circuits of simple form to provide the necessary electrical currents to the microsyn units for effecting proper support of the supported member. In one form of the invention a simple resonant circuit is used and in another form of

the invention feedback circuits are used to give greater stiffness to the support assembly.

Further features of the invention consist of certain novel features of construction and combinations and arrangements of parts hereinafter described and particularly defined in the claims.

In the accompanying drawings, FIG. 1 is an end view of a magnetic bearing according to the present invention;

FIG. 2 is a diagram of connections;

FIG. 3 is a graph illustrating the operation of the apparatus;

FIGS. 4 and 5 are diagrams of feedback circuits;

FIG. 6 is an end view of a modified form of the invention;

FIG. 7 is a diagram of the connections for the apparatus of FIG. 6;

FIG. 8 is a side view of an axial restraint device, and

FIG. 9 is an end view of another modified form of the invention.

In FIG. 1, I show an end view of a magnetic support or bearing device at one end of a shaft which is indicated at 10. Any suitable member which is not shown may be mounted on the shaft. The magnetic support for the shaft comprises a "rotor" 12 which is here shown as being cylindrical in form, the rotor being mounted within a microsyn stator 14 of the general type described in the above-mentioned Mueller patent. The stator 14 comprises a ring 16 of magnetic material with four salient poles designated P_1 to P_4 . Each pole has a coil 20. In the simple connections shown in FIGS. 1 and 2 one end of each of the four coils is grounded and the other is brought out to a suitable terminal. The four terminals are designated at T_1 to T_4 . As shown in FIG. 2 each of the coils is externally connected in series with a condenser C, and the four condenser-coil combinations are connected in parallel to a suitable source of alternating current indicated at V.

The coils are preferably energized to produce alternately inward and outward instantaneous fluxes in consecutive poles.

The forces acting to support the rotor 12 can best be explained by considering the two opposed poles P_2 and P_4 lying along the axis X and the two opposed poles P_1 and P_3 lying along the axis Y. If the rotor is exactly centered, there is no net magnetic force tending to move the rotor in any direction. The circuit parameters are such that any slight displacement of the rotor away from its center position results in a net magnetic force which restores it to its center position.

Considering first the two poles lying along the X-axis, let it be assumed that the rotor is displaced a small distance x toward the right-hand pole face, thus diminishing the right-hand air gap and increasing the left-hand air gap. The inductance of the right-hand coil is increased and that of the left-hand coil is reduced. The series condenser C is of such magnitude that the operating point of each RLC circuit of FIG. 2 is on the down slope of the resonance curve, so that an increase of inductance of any coil results in a decrease of current in that coil. A plot of current against inductance is given in FIG. 3. When the rotor is centered the inductance of any coil has the value L_0 . The quiescent current is I_0 . Upon a displacement to the right the inductance of the coil on P_2 increases to L_+ and hence the current is reduced, while the inductance of the coil on P_4 decreases to L_- and the current in the coil increases.

The magnetic energy in the air gap due to any coil is $\frac{1}{2} LI^2$ and the magnetic force acting on the rotor due to that coil is the derivative of energy with respect to displacement. The changes in the inductances of the two coils upon the occurrence of a small displacement, x , may be calculated from the changes in reluctances of the air

3

gaps, and the changes in currents in the coils may be calculated from the changes in the inductances, so that an analytic determination of the resultant force may be obtained. It may be stated in general that the components of force due to inductance changes alone are non-centralizing (i.e., a slight motion away from center would result in continued motion until the rotor contacted one of the pole pieces), but the components of force due to changes of current are centralizing, and they overbalance the non-centralizing components. Stated in another way, the center position is a position of minimum energy, and the axis is centralized by virtue of the tendency of the system to assume the minimum-energy condition.

The same considerations apply to the poles P_1 and P_3 on the Y-axis. Hence they apply to any components of displacement along the X- and Y-axes and therefore to a displacement in any direction; in other words, any slight displacement from the symmetrical center position results in a force which restores the rotor to center. Hence the magnetic suspension acts as a bearing to fix the shaft, without, however, introducing any friction of the type encountered in conventional metal-to-metal bearings.

The magnitude of the centralizing force depends on the size of the microsyn, the magnitude of the quiescent current, the circuit parameters and also upon the frequency.

The suspension may be stiffened by the use of a feedback circuit. Two types of feedback circuits are shown in FIGS. 4 and 5. In FIG. 4 there is what is termed an alternating current feedback circuit. The X-axis coils 20 are connected in series with the condensers C to input resistors R_x , to the junction of which is connected the source V. A transformer 21 has its primary connected across the resistors, and its secondary connected through a divider network 22 to the grids of a dual tube 24, the plates of which are connected to the terminals T_2 and T_4 of the coils. A substantially identical circuit is provided for the Y-axis coils. An increase in the magnitude of the current in one coil is accompanied by a decrease in the magnitude of the current in the other coil. The signals from 22 as impressed on the tube 24 are used to feed power to the coils 20 in such directions as to cause centralization of the rotor. Some centralizing effect is obtained from the resonance condition existing as shown in FIG. 3 and the centralizing force due to this condition is enhanced by the amplified power fed back to the coils. As heretofore noted, the centralizing forces are those due to the changes of current, whereby the decentralizing forces due to inductance changes are overbalanced; the feedback circuits amplify the current changes and hence increase the centralizing forces.

The purpose of the divider networks is to permit the initial setting to be made for precise centralization without unbalance torques.

Another form of network is shown in FIG. 5 in which direct current power is fed to the coils. This is shown for the Y-coils only, and a similar network will be duplicated for the X-coils. The coils 20 are excited from alternating current through the condensers C as in FIG. 1. Across both coils in series is the primary of a signal transformer 26, the secondary of which feeds into a pre-amplifier 28 and a demodulator 30. Any shift of the rotor will result in such changes of impedance in the series circuit of the two coils as to cause a change of voltage across the coils. Hence the output of the demodulator 30 comprises a fluctuating direct current the magnitude of which is dependent on the displacement of the rotor from its symmetrical center position. The output of the demodulator is fed into a lead-lag network 32 and hence to the grids of tubes 34, the outputs of which are applied to the coils 20. This gives a stiff suspension by which the centralizing force due to the resonant condition is materially enhanced. The lead-lag

4

network may be of a type familiar in the servo art. In general, a lead network is a high-pass filter while a lag network (or integrating circuit) is a low-pass filter. The lead-lag network 32 therefore emphasizes the high and low frequencies. The high frequencies improve the stability of the system and increase the centralizing forces, while the integration due to passage of low frequencies tends to eliminate long-term errors.

In any of the systems thus far described there will be some tendency toward radial oscillation. The rotor and shaft will tend to oscillate at a frequency determined by the mass of the suspended elements and the stiffness due to the magnetic centralizing forces. It is desirable that the radial motions be damped. Therefore the invention is particularly useful in connection with floated damped instruments of the type described in the abovementioned Jarosh et al. patent since the damping fluid itself will serve to damp any radial oscillations.

The apparatus shown in FIG. 1 may be used either for an oscillating shaft or a rotary unit. Since the rotor 12 is cylindrical it may be used with a continuously rotating shaft.

The preferred forms of the present invention reside in the use of microsyn units which are constructed to perform their regular functions and also to serve as a magnetic bearing or suspension. From the Mueller patent above-mentioned it will be clear that the microsyn unit as used for uniform-torque or signal generation requires a minimum of four poles in order to maintain total fluxes constant upon rotation of the rotor. According to the present invention a minimum of eight poles is required in order to maintain total fluxes due to the rotation of the rotor constant. The preferred form of microsyn is shown in FIG. 6. The rotor 35 has four protruding pole faces 36. The stator 37 is provided with eight reentrant poles 38 which are numbered from 1 to 8 in the drawing. Each pole face 36 of the rotor spans the distance between centers of adjacent stator poles. In FIG. 6 the primary windings 39 are fully shown on the poles. Each pole has a secondary winding 39', shown on one of the poles only. The windings are so arranged that with the rotor in its normal zero position, the instantaneous fluxes are in one direction in poles 1, 2, 5 and 6 and in the opposite direction in poles 3, 4, 7 and 8. They are shown as ingoing fluxes in poles 1, 2, 5 and 6 and outgoing fluxes in the other poles. (The showing of the windings themselves in FIG. 6 is conventional, and no effort is made to indicate winding directions or numbers of turns; the primary windings are arranged to produce the relative flux directions indicated by the arrows, and the secondary windings are connected for either torque or signal generation in accordance with the teachings of the Mueller patent.)

A schematic view of connections is given in FIG. 7. The primary windings are numbered 1 to 8, and each secondary winding 39' is adjacent to its corresponding primary winding. The primary windings are connected in series pairs with the terminals T_1 to T_4 as in FIG. 2, and each pair is connected in series with a condenser C. The four coil-condenser series circuits are connected in parallel with each other and to a voltage source V.

The secondary windings are all shown as connected in series.

It is necessary to consider both rotational and radial displacements of the rotor.

First, with respect to rotation, it will be observed that if the rotor turns, say, through a slight angle in a clockwise direction the reluctances of the air gaps 1 and 5 will increase while the reluctances of air gaps 4 and 8 will decrease, so that the total inflowing flux will remain constant. The outflowing fluxes in poles 3, 4, 7 and 8 will also remain constant. Thus the conditions for uniform total flux in the torque generator or signal generator shown in FIGS. 2, 3 and 5 of the above-mentioned Mueller patent are satisfied, the only difference being that

5

each of the four poles of the Mueller patent may be considered to be divided into two poles. The secondary may be energized from its terminal to generate a torque, or an output signal may be taken from the secondary.

In order to examine the conditions existing upon a radial displacement let it be assumed that the rotor is displaced from its center position slightly along the X-axis which is here shown as lying symmetrically between the centers of poles 1 and 8. The air gaps at 1 and 8 will then decrease and the gaps at poles 4 and 5 will increase. Each such pair of primary coils is connected in series with a condenser C as shown in FIG. 7. By proper choice of the size of the condenser so that operation occurs on the down slope of the resonance curve, the currents in the coils on 4 and 5 can be made to increase and those in the coils on 1 and 8 to decrease in a manner to provide a centralizing force along the X-axis in exactly the same manner as in FIG. 1. Likewise, any motion in a radial direction along the Y-axis will produce a centralizing force.

From the description thus far given it will be seen that the actions of the microsyn of FIG. 6 in respect to rotation and radial displacement are completely independent and uncoupled. In other words, a rotational movement of the rotor generates either a torque or signal in exactly the same manner as described in the Mueller patent, while a radial motion produces a centralizing restoring force to maintain the shaft in the proper position. Hence the microsyn serves as both a torque or signal generator and a centralizing device.

When greater radial stiffness is desired, the feedback circuit of either FIG. 4 or FIG. 5 may be used. It is only necessary to connect the terminals T_1 to T_4 to the correspondingly designated terminals of FIG. 4 or 5. The feedback circuits operate in the same manner as previously described to provide large centralizing forces against radial displacements, while leaving the microsyn free to respond in its usual manner to rotational displacements.

In the use of gyroscopic instruments of the type shown in the Jarosh et al. patent, a torque generator is frequently used at one end of the shaft and a signal generator at the other end. According to the present invention, the torque and signal generators may be arranged to serve as magnetic bearings to support the inner casing. They may also be used to provide axial restraint, so that conventional thrust bearings may be dispensed with.

FIG. 8 shows the means of providing axial restraint. A floated instrument 40 may be the inner case of the gyroscopic instrument of the Jarosh et al. patent. The floated instrument is contained within a casing 42, there being a slight clearance space between the parts 40 and 42 which is filled with a viscous floating and damping liquid 44 as described in the Jarosh et al. patent. At each end of the shaft 46 is a microsyn rotor, the two rotors being indicated at 50 and 52, each rotor being centered within a stator indicated diagrammatically at 54 and 56. The rotors may be circular in end view, as in FIG. 1, or may be provided with poles, depending on whether rotational sensitivity is desired. As shown in FIG. 8 the pole faces of the rotors 50 and 52 of the stators 54 and 56 are tapered in opposite directions. Each stator pole is provided with a suitable winding or windings, indicated at 58. The several windings may be connected into any one of the external circuits shown in FIGS. 2, 3, 4 and 7. The conditions that provide radial centralization also provide axial restraint since if there is any tendency for the unit to move to the right or left, the air gap in one of the units will increase and that in the other will decrease, thus bringing about a change of currents to restore the proper axial position.

As heretofore noted, it is desirable in operation of this system that radial damping be applied in order to minimize oscillatory effects. This is provided by the gyroscopic member itself as described in the Jarosh et al.

6

patent. Such damping also damps any axial movements in FIG. 8.

The forms of microsyns heretofore described are signal generators or uniform-torque generators, comprising some of the types described in the Mueller patent. Also described in the Mueller patent is an elastic restraint generator, which is a generator capable of generating a torque that increases with angular displacement from a neutral position. This gives the effect of a torsional spring. In this case a secondary winding is not necessary and it is only required that each primary winding be connected in series with the condenser, the several coil-condenser circuits being connected in parallel. The coils are connected so that inflowing and outflowing fluxes alternate. In such a system the total inflowing or outflowing flux is not a constant independent of rotor angular displacement, but actually varies as the rotor is displaced. Hence, for a magnetic suspension involving an elastic restraint generator it is only necessary that four poles be used as shown in FIG. 9, although any multiple of four poles may also be used. The windings are connected to give the instantaneous flux pattern shown in FIG. 9, which is the same as in FIG. 3 of the Mueller patent. This is to be distinguished from the signal generator or torque generator in which some multiple of four poles, not less than eight, is required.

The windings of FIG. 9 are preferably externally connected in exactly the same fashion as in FIG. 1 whereby rotational, radial (and axial) centralization may be attained.

Having thus described my invention, I claim:

1. Microsyn apparatus comprising a stator having a multiple of four pairs of poles, a rotor having circular arcs equal in number to the pairs of poles, each arc spanning adjacent poles, primary coils on the poles arranged to direct fluxes inward and outward in the poles of each pair, a plurality of condensers to form with the primary coils a number of resonant circuits, means for energizing said circuits so that the rate of change of current in any coil with respect to the inductance of the coil is negative, whereby radial centralizing forces on the rotor are generated upon any departure of the rotor from a centralized position, and secondary coils on the poles to carry microsyn currents related to the angular position of the rotor.

2. Microsyn apparatus comprising a stator having a multiple of four pairs of poles, the poles of each pair being adjacent, a rotor having circular arcs equal in number to the pairs of poles, said arcs spanning poles of adjacent pairs, primary coils on the poles, the coils of each pair being connected to direct fluxes alternately inward and outward in the coils of each pair and to direct fluxes in the same direction in adjacent poles of adjacent pairs, a condenser connected with each pair of primary coils to form a resonant circuit, means for energizing each resonant circuit at such a frequency that the rate of change of current in any coil with respect to the inductance of the coil is negative, whereby radial centralizing forces on the rotor are generated upon any departure of the rotor from a centralized position, and secondary coils on the poles to carry microsyn currents related to the angular position of the rotor.

3. Apparatus according to claim 2 having means to measure differences in voltages across opposed pairs of coils and amplifier means to vary the currents in the coils to increase the radial centralizing forces on the rotor.

4. A gyroscopic unit comprising an outer casing, an inner casing having a shaft, a buoying liquid within the outer casing to float the inner casing, and two microsyn devices as claimed in claim 2, each having a rotor on the shaft, the liquid acting to damp both rotational and radial motions of the inner casing.

5. An elastic restraint generator comprising a stator having four salient poles, a rotor having two circular arcs spanning adjacent poles, coils on the poles to direct fluxes alternately outwardly and inwardly, a condenser in series

7

with each winding to form a resonant circuit, and means for energizing the resonant circuits such that the rate of change of current with respect to inductance is negative, whereby radial centralizing forces on the rotor are generated upon any departure of the rotor from a centralized position and whereby, upon angular displacement from a neutral position, a torque increasing with said displacement is generated.

6. A magnetic bearing comprising a stator having a number of salient poles, a rotor of magnetic material, a coil wound on each pole, a condenser in series with each coil and forming a resonant circuit, means for energizing the resonant circuits so that the inductive reactance of each coil is slightly greater than the capacitive reactance of its associated condenser, whereby each resonant circuit is energized at a steep portion of the resonance curve wherein the rate of change of current with respect to inductance is negative, to provide radial centralizing forces on the rotor, means to measure voltages across the coils, and amplifier

8

means for varying the currents in the coils to increase the radial centralizing forces on the rotor.

7. Apparatus according to claim 6 in which the coils are connected in pairs according to coordinates, measuring means for comparing the voltages across the coils of the separate coordinates, and amplifier means for varying the currents in the coils in a direction to increase the centralizing forces on the rotor.

References Cited by the Examiner

UNITED STATES PATENTS

1,589,039	6/26	Anschutz-Kaempfi	308—10
2,377,175	5/45	Peer	308—10
2,602,660	7/52	Shannon	308—10
2,733,857	2/56	Beams	308—10
2,809,526	10/57	Lundberg	308—10

MILTON O. HIRSHFIELD, *Primary Examiner*.
ORIS L. RADER, NORMAN H. EVANS, *Examiners*.