

June 7, 1960

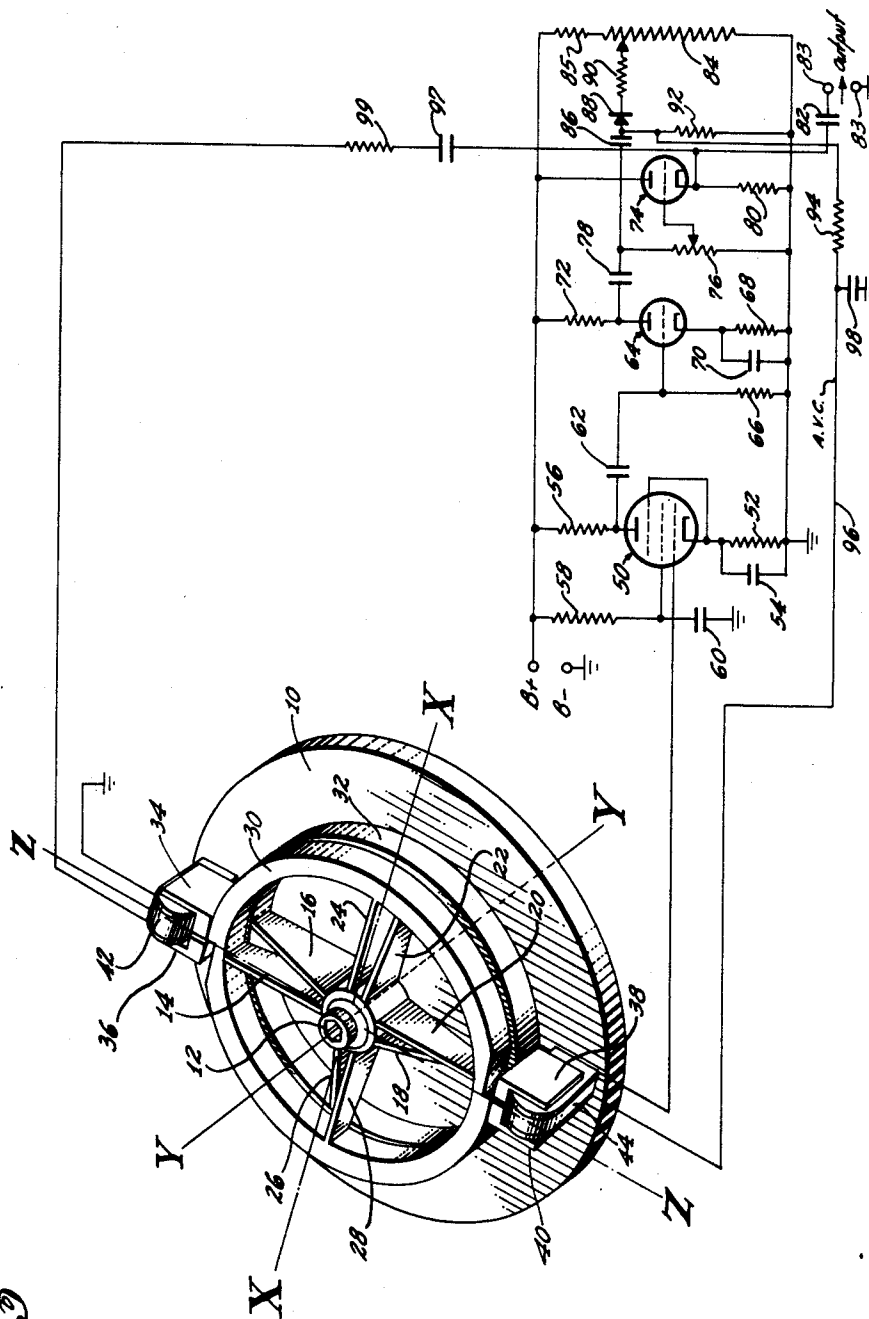
W. J. HOLT, JR

2,939,971

MECHANICAL VIBRATORY UNIT

Filed Oct. 22, 1956

3 Sheets-Sheet 1



INVENTOR:
William J. Holt, Jr.

By Smyth & Roston
Attorneys

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W. J. HOLT, JR

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Fig. 2

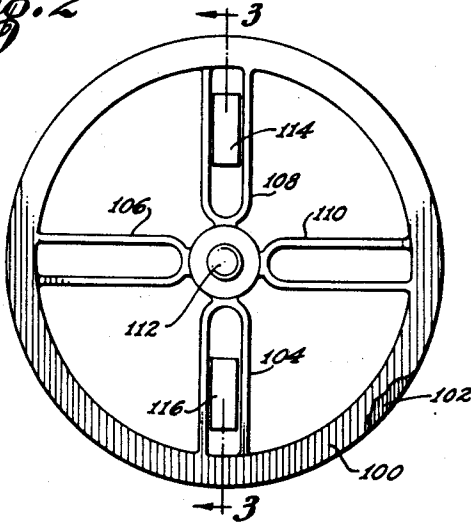


Fig. 3

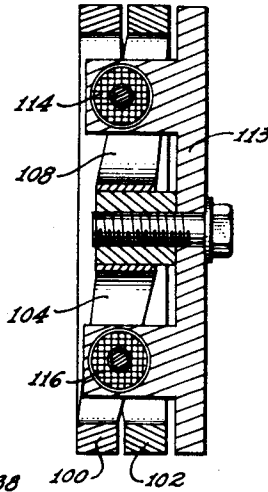
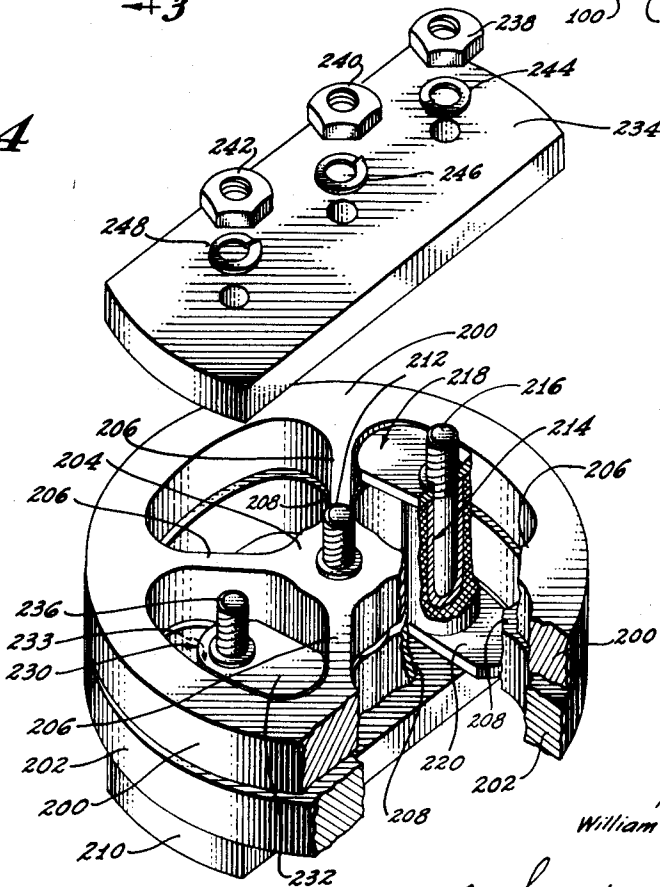


Fig. 4



INVENTOR:
William J. Holt, Jr.

By *Smyth & Roston*
Attorneys

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Fig. 5

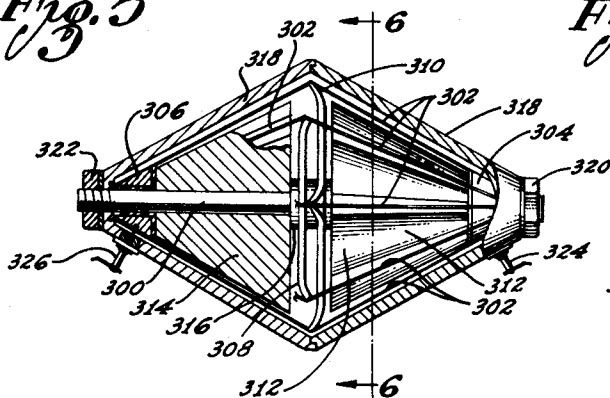


Fig. 6

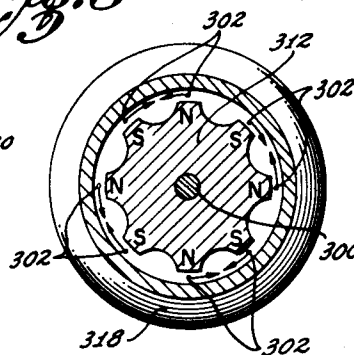


Fig. 7

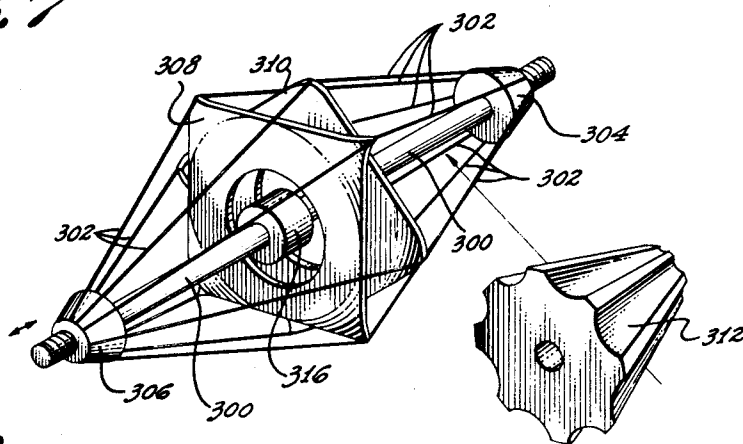
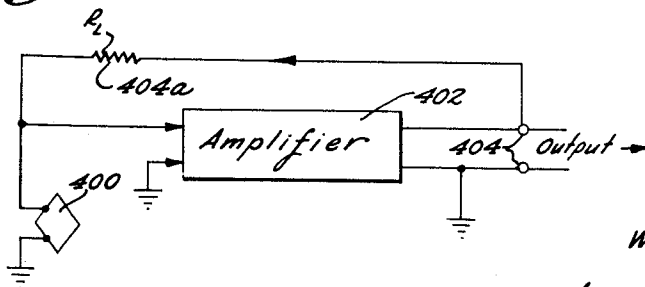


Fig. 8



INVENTOR:
William J. Holt, Jr.

By *Smyth & Roston*
Attorneys

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MECHANICAL VIBRATORY UNIT

William J. Holt, Jr., Pacific Palisades, Calif., assignor to
The Gyrex Corporation, Santa Monica, Calif., a corporation of California

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15 Claims. (Cl. 310—15)

The invention relates to mechanical vibratory units and assemblies, and more particularly to units of this type for use in low frequency oscillators, electro-mechanical filters, and the like.

There are innumerable applications, both commercial and military for precisely stabilized sources of low frequency electrical energy. Tuning forks have been used in the past as mechanical vibratory stabilizing elements for such sources. However, when the usual type of tuning fork is so used under conditions of high shock and vibration, there is a tendency for the source of energy to produce spurious output signals. This situation is particularly aggravated for vibration frequencies at or near the natural mechanical resonant frequency of the tuning fork used in the system.

In present day aircraft and missiles, vibration frequencies of the order of 50–2000 cycles are often encountered. These frequencies render a tuning fork having a typical resonant frequency of, for example, 400 cycles, most susceptible to spurious excitation. This spurious excitation of the tuning fork is found to occur even though it may be mounted on vibration isolators, shock absorbers, or the like. Therefore, the usual prior art mechanically stabilized low frequency sources of electrical energy are not usually suited for use in environments of shock and external vibrations.

In a mechanically stabilized low frequency source of energy such as described above, the mechanical vibratory element drives a transducer at the vibrating frequency of the element. The output signal from the transducer is then used to drive the vibratory element. The arrangement is such that the vibratory element is driven at its natural mechanical resonant frequency. The system develops a stabilized low frequency electrical signal whose frequency corresponds to the natural resonant frequency of the vibratory element.

Another application for mechanical vibratory elements of the general type with which the present invention is concerned is in an electro-mechanical filter. This type of filter is used, for example, in selective calling systems. In such systems, it is usual to provide a mechanical vibratory element in each of a plurality of receivers, with the element in each receiver being resonant at its own particular frequency and which is different from the others. A particular receiver is "called" by the use of a calling signal whose frequency matches the frequency of the vibratory element in the particular called receiver. This vibratory element responds to the calling signal, and its ensuing vibrations are used to activate a suitable local control or signaling system in the called receiver.

These mechanical vibratory elements and their associated components visually fall into two general types. A first type includes an input electromagnetic transducer for driving the vibratory element, and an output electromagnetic transducer for developing output signals in response to the vibration of the element. This first type develops a signal of maximum amplitude at the output

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transducer in response to the introduction to the input transducer of an input signal whose frequency corresponds to the natural resonant frequency of the vibratory element. This type of assembly is well suited for use in electro-mechanical filters, and in low frequency oscillators or energy sources, such as described above.

The second general type of assembly uses but a single electro-magnetic transducer. This transducer usually includes a winding wound around a core of magnetic material. The input impedance of the winding raises to a maximum at a frequency corresponding to the resonant frequency of the assembly. This second type of assembly is also well suited for use in stabilizing the frequency of low frequency oscillators, and for use in electro-mechanical filters.

In addition to the above described uses for stabilizing low frequency energy sources and in electro-mechanical filters, mechanical vibratory assemblies can themselves be used as transducers. This can be simply achieved by making the natural mechanical resonant frequency of the assembly responsive, for example, to pressure or temperature changes. Then, when the assembly is used in conjunction with an oscillator circuit, variations in temperature or pressure are reflected as variations in frequency of the output signal of the oscillator.

A difficult problem has been encountered in the use of such mechanical vibratory assemblies. This problem is how to render the assemblies relatively insensitive to external shocks and vibrations. The prior art assemblies for the most part have been found to have a tendency to exhibit spurious responses to such extraneous vibrations, especially when the vibrations occur at or near the resonant frequency of the vibratory element. Extremely elaborate schemes have been devised in an attempt to overcome the adverse effects of external shocks and vibrations, especially in mobile equipment. It is important that vibrations experienced in the aircraft or other vehicle carrying the equipment do not cause spurious signals to be developed by the electromechanical filters, or cause erroneous variations to occur in frequency of the mechanically stabilized energy sources that might be included in apparatus carried by the vehicle.

The present invention provides a mechanical vibratory unit and assembly that is constructed in an improved and unique manner to be dynamically balanced in all planes. The assembly of the invention, for all practical purposes, is insensitive to external shocks and vibrations along or about any axis.

In one embodiment of the invention, a first mass and a second mass are rigidly held in axially spaced relation and coaxial about a central axis of rotation. These masses are adapted to be reciprocally rotated to a limited extent for angular vibration about the central axis. The masses are driven to vibrate angularly in out-of-phase relation about the central axis. The masses are held rigidly in all planes so that they are effectively unresponsive to external shocks and vibrations along any axis.

Other features and advantages of the present invention will be hereinafter apparent from the following description, particularly when taken in connection with the accompanying drawing, in which:

Figure 1 is a perspective view somewhat schematically showing the vibratory element of one embodiment of the invention and its associated transducer components, and this figure also illustrates an electric circuit control system for the assembly which intercouple the transducer components.

Figure 2 is a top plan view of a second embodiment of the invention in which a pair of axially spaced coaxial annular members are supported for annular vibration about a central hub by a plurality of U-shaped ribs

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of magnetic material, and in which the transducers are positioned between the ribs;

Figure 3 is a sectional view of the embodiment of Figure 2, substantially on the line 3—3;

Figure 4 is a perspective and exploded view of a third embodiment of the invention in which the vibratory masses and hub have an integral construction for manufacturing convenience;

Figure 5 is an elevational view, partly in section, of another embodiment of the invention in which the vibratory masses are supported by respective groups of electric wires, and in which the masses are caused to vibrate angularly about a central axis in out-of-phase relation in response to a current flow through the wires;

Figure 6 is a cross-sectional view of the embodiment of the invention shown in Figure 5 taken substantially along the line 6—6 of Figure 5;

Figure 7 is a perspective and exploded view of certain of the operating components of the embodiment of Figure 5; and

Figure 8 is a circuit diagram showing an electronic control system for the embodiment of the invention shown in Figures 5, 6 and 7.

The embodiment of the mechanical vibratory assembly shown in Figure 1 includes a base 10. This base may be any suitable supporting surface, or it may be secured to a suitable supporting bracket or frame. The base 10 has a hub 12 which extends perpendicularly outwardly from the plane of the base and which is rigidly affixed to the base by any appropriate means (not shown).

A first pair of spokes or ribs 14 and 16 extend radially outwardly from the hub 12 essentially parallel to the plane of the base 10. These ribs may have the form of flat, tapered, resilient, metallic members. The ribs are securely fastened to the hub 12 at their inner ends. A second pair of ribs 18 and 20 extend radially outwardly from the hub 12, and these ribs are diametrically opposed to the ribs 14 and 16. The inner ends of the ribs 18 and 20 are also securely fastened to the hub 12. A third pair of ribs 22 and 24, and a fourth pair of ribs 26 and 28, extend in diametrically opposed relation from the hub 12. The third and fourth pairs of ribs are angularly displaced by 90° from first two pairs.

The ribs of the last two pairs may, like the ribs of the first two pairs, have a flat tapered configuration. The wider dimension of each rib extends perpendicularly to the base 10. All the ribs may be formed of a resilient metal such as beryllium copper.

Two annular members 30 and 32 are supported by the ribs in coaxial relation with the hub 12, and these annular members are so supported in axially spaced relation to one another. The outer ends of the ribs 14, 20, 24 and 28 are affixed to the upper annular member 30, and the outer ends of the ribs 16, 18, 22 and 26 are secured to the lower annular member 32. The ribs 22, 24, 26 and 28 extend generally along an axis that shall be termed the "X" axis. The annular members 30 and 32 do not contact one another at any point, and these members are free to rotate to a limited extent about the axis of the hub 12 which is designated in Figure 1 as the "Y" axis. The annular members 30 and 32 may be composed of non-magnetic material having appreciable mass, such as brass.

A first pair of tabs 34 and 36 are affixed to respective ones of the annular members 30 and 32. These tabs are composed of magnetic material such as iron or steel. The tabs 34 and 36 are mounted on the annular members in mutually spaced and parallel relation, and they extend radially outward from the annular members in essential alignment with the ribs 14 and 16. A second pair of tabs 38 and 40 are affixed to respective ones of the annular members 32 and 30 diametrically opposite the tabs 34 and 36. The tabs 38 and 40 are also composed of magnetic material and are positioned in essential axial alignment with the ribs 18 and 20.

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The axis of the vibratory assembly along which the ribs 18, 20 and 14, 16 extend is designated the "Z" axis. The tabs 34, 36 and 38, 40 are placed as closely to the "Z" axis as possible so as to minimize their interference with the vibration of the annular members about the "Y" axis.

A first electro-magnetic transducer assembly 42 is mounted on the base 10, and this assembly is positioned between the magnetic tabs 34 and 36. The assembly includes a usual energizing winding wound around a core of soft iron or other suitable material. The cover extends into operative relationship with the tabs 34 and 36, and it forms respective air gaps with the tabs. When an electric current flows through the winding, the tabs 34 and 36 are drawn towards one another and move in the respective air gaps.

In accordance with one practice, the core of the transducer assembly 42 may be a permanent magnet. This provides that when an alternating current is passed through the winding of the assembly, only half cycles of the current of a particular polarity are effective to exert a magnetic force on the tabs 34 and 36. The effect of the other half cycles of the current is nullified by the permanent magnet core member. Therefore, an alternating signal current flowing through the winding of the electro-magnet 42 is capable of drawing the tabs 34 and 36 together and then releasing the tabs at a rate corresponding to the frequency of that signal. Such actuation of the tabs causes the members 30 and 32 to vibrate in opposite directions about the hub 12. The unit may be so driven at its natural mechanical resonant frequency by a signal whose frequency matches that resonant frequency.

A second electro-magnetic transducer assembly 44 is mounted on the base 10, and the latter assembly is positioned between the tabs 38 and 40. The transducer 44 assembly includes a usual energizing winding which is wound about a usual magnetic core. The core extends into operative relation with the tabs 38 and 40, and it defines respective air gaps with these tabs. The winding of this latter transducer assembly functions as a pickup coil, and an output signal voltage is developed across its terminals as the members 30 and 32 vibrate angularly about the "Y" axis in out-of-phase relation to cause the magnetic tabs 38 and 40 to move back and forth in the respective air gaps to change the flux linkage through the winding. The frequency of this output signal is determined by the angular vibrational frequency of the members 30 and 32 about the "Y" axis, and the amplitude of the signal depends upon the amplitude of such angular vibration. It is evident that an input signal whose frequency matches the resonant frequency of the vibratory assembly will produce optimum magnetic vibrational amplitude and at the resonant frequency.

The respective air gaps between the tabs 34, 36 and the core of the transducer 42, and between the tabs 38, 40 and the core of the transducer 44, each have a sufficient length so as to allow the annular members 30 and 32 to vibrate about the "Y" axis freely at the maximum vibrational amplitudes required by the system.

The mechanical natural resonant frequency of the device is a function of the modulus of elasticity of the radial ribs 14, 16, 22, 24, 18, 20, 26 and 28; and of the moment of inertia of the annular members 30 and 32 about the axis "Y." Ideally, the annular members 30 and 32 should be thinner in their radial dimension than in their axial dimension so as to distribute as much weight as possible at the periphery of the rings.

It will be noted that the transducer 44 of the unit of Figure 1 develops an output signal only in response to the opposed angular vibration of the annular members 30 and 32 about the "Y" axis. The rings are rigidly held by the respective ribs so that any shocks or vibrations along, for example, the "X" axis which extends in the direction of the ribs 22, 24 and 26, 28; or along the

"Z" axis which extends in the direction of the ribs 14, 16 and 18, 20; have no appreciable effect on the positions of the annular members 30 and 32 with respect to one another. Also, any rotational shocks or vibrations about the "X" or "Z" axis will have no noticeable effect on the output signal because the shape of the ribs 14, 16, 18, 20, 22, 24, 26 and 28 inhibits any relative motion of the annular members 30, 32 in response to such rotational shocks. Moreover, any variations in the axial displacement of the annular members 30 and 32 due to such external shocks and vibrations have little or no effect on the output signal of the assembly. This is because relative axial movements of the annular members move the magnetic tabs 38 and 40 in a direction in which they do not affect the air gaps or change the flux linkage through the energizing winding of the transducer 44. Moreover, even angular shocks or vibrations about the "Y" axis will not materially effect the proper operation of the vibratory assembly, because the output signal depends upon movements of the tabs 38 and 40 in response to the opposed vibrational angular motion of the members 30 and 32 about the "Y" axis, rather than upon any in-phase rotational motion of these members about the "Y" axis as would be produced by such shocks.

The flat ribs 22, 24 and 26, 28 primary function is to act as stabilizers and they may be replaced, when so desired, by elongated round stabilizing rods. Such rods should be strong in tension so as to keep the annular members 30 and 32 precisely centered about the hub 12 in the presence of shocks along the "X" axis. The tabs 34, 36 and 38, 40 may be positioned inside the annular members 30, 32, and they may extend radially inwardly, for a more compact design.

The electronic control system of the vibratory unit of Figure 1 comprises an amplifier circuit connected between the pick-up transducer assembly 44 and the drive transducer assembly 42. The arrangement is such that the vibratory assembly is driven at its natural mechanical resonant frequency, and the system develops an output signal of the relatively low frequency corresponding to the mechanical resonant frequency of the vibratory assembly, and which output signal is precisely stabilized by the vibratory assembly, even in the presence of severe external vibrations and shocks extending through a wide frequency range.

One terminal of the winding associated with the pick-up transducer 44 is connected to the control grid of a vacuum tube 50. This tube may be of a usual pentode, such as the type presently designated as a 6BA6. The cathode of the tube 50 is connected to one terminal of a biasing resistor 52, and this resistor is shunted by a by-pass capacitor 54. A load resistor 56 connects the anode of the tube 50 to the positive terminal B+ of a source of uni-directional potential. The negative terminal of this source is connected to a common return path of reference or ground potential. A screen voltage-dropping resistor 58 is connected between the screen grid of the tube 50 and the positive terminal B+. The screen grid is established at ground potential for alternating currents by a by-passing capacitor 60 connected between it and ground.

A coupling capacitor 62 is coupled between the anode of the tube 50 and the control grid of a second tube 64. The second tube may be a triode such as a half-section of a double triode presently designated as a 12AT7. The control grid of the tube 64 is connected to ground through a grid leak resistor. A bias resistor 68 is connected between the cathode of the tube 64 and ground, and this resistor is shunted by a by-pass capacitor 70. The anode of the tube 64 is connected to the positive terminal B+ through a load resistor 72.

The other half of the double triode referred to above is designated as a vacuum tube 74 and this tube is connected as a cathode follower. The control grid of the tube 74 is connected to the movable arm of a potentiometer

76. One fixed contact of the potentiometer is connected to ground, and a coupling capacitor 78 is connected between the anode of the tube 64 and the other fixed contact of the potentiometer. A load resistor 80 is connected between the cathode of the tube 74 and ground, and the anode of this tube is directly connected to the positive terminal B+. The cathode of the tube 74 is connected through a coupling capacitor 82 to one of the output terminals 83 of the system. The other output terminal is connected to ground.

A second potentiometer 84 has one fixed contact connected through a resistor 85 to the positive terminal B+, and the other fixed contact of the potentiometer is grounded. The junction of the capacitor 78 and the potentiometer 76 is connected to a capacitor 86. This latter capacitor, in turn, is connected to the anode of a diode 88. A series resistor 90 connects the cathode of the diode 88 to the movable arm of the potentiometer 84.

The junction of the capacitor 86 and the diode 88 is connected to ground through a resistor 92, and this junction is also connected to one terminal of a resistor 94. The other terminal of the resistor 94 is connected by a lead 96 to the second terminal of the winding associated with the pick-up transducer assembly 44. The lead 96 is by-passed to ground for alternating currents by a capacitor 98. The cathode of the tube 74 is coupled through a capacitor 97 and a series resistor 99 to one terminal of the winding associated with the drive transducer 42. The other terminal of this winding is grounded.

In a constructed embodiment of the invention, the following constants were used in the control circuit of Figure 1. These constants are listed here merely by way of example, and this listing is not intended to limit the invention in any way.

Resistor 58	-----kilo-ohms---	47
Capacitor 60	-----microfarads---	.1
Resistor 56	-----kilo-ohms---	100
Resistor 52	-----ohms---	270
Capacitor 54	-----microfarads---	10
Capacitor 62	-----do---	.1
Resistor 66	-----kilo-ohms---	470
Resistor 72	-----do---	20
Resistor 68	-----ohms---	270
Capacitor 70	-----microfarads---	10
Capacitor 78	-----do---	.1
Potentiometer 76	-----kilo-ohms---	0-470
Resistor 80	-----do---	5
Capacitor 86	-----microfarads---	.1
Diode 88	-----IN 34	
Resistor 90	-----kilo-ohms---	47
Potentiometer 84	-----do---	0-100
Resistor 85	-----do---	470
Resistor 92	-----do---	470
Resistor 94	-----do---	470
Capacitor 98	-----microfarads---	.1
Capacitor 97	-----do---	.1
Resistor 99	-----kilo-ohms---	10

The tubes 50 and 64 function as a usual two-stage cascade amplifier and, as previously noted, the tube 74 is connected as a cathode follower to provide a suitable impedance match between the amplifier and the winding of the drive transducer 42. The potentiometer 76 provides a manual gain control for the system. The diode 88 develops a negative automatic volume control voltage across the resistor 92, and the amplitude of this A.V.C. voltage is manually controlled by the potentiometer 84.

As previously noted, the opposed angular vibration of the annular members 30 and 32 produces an output signal voltage across the winding associated with the pick-up transducer assembly 44. This output signal is amplified by the amplifier of the tubes 50 and 64, and it is impressed across the energizing winding of the drive transducer 42. The resulting current flow through the winding of the transducer 42 produces mutually opposite

angular vibration of the members 30 and 32 about the "Y" axis in the manner described.

The tendency for such opposed angular vibration of the members 30 and 32 about the "Y" axis is damped by the physical properties of the vibratory unit at all frequencies except at the natural resonant frequency of the vibratory assembly. Therefore, only at that frequency does the transducer 44 tend to develop an output signal. Therefore, the amplifier amplifies the output signal having a frequency corresponding to the natural resonant frequency of the assembly, and the assembly is driven by the drive transducer 42 at this frequency. Therefore, oscillation is built up in the vibratory unit at its natural resonant frequency. Also, the amplifier develops a stabilized output signal across the output terminals 83. The frequency of this signal is precisely held at the resonant frequency of the vibratory assembly because of the inability of the vibratory assembly to depart from that frequency. Also, and for the described reasons, external shocks and vibrations along or about any axis have no appreciable effect on the frequency of this relatively low frequency stabilized output signal.

A portion of the signal appearing at the anode of the tube 64 is rectified by diode 88. This diode, as previously pointed out develops a negative A.V.C. voltage across the resistor 92. This voltage by the elements 94, 98 to produce a negative unidirectional automatic volume control voltage on the lead 96. This A.V.C. voltage is used to provide maximum gain in the amplifier when the system is first turned on. This enables the assembly to reach its stabilized resonant frequency in an extremely short time, for example, in less than one second.

It is noted that the system and assembly of Figure 1 constitutes a mechanically stabilized source of low frequency oscillatory energy. For the reasons described, the vibratory assembly is insensitive to shocks or vibrations in any plane, so that the system can be used in an environment of such shocks and vibrations without affecting the frequency of its output signal to any material extent.

The input terminals of the control circuit of Figure 1 instead of being connected to the pick-up transducer 44, may when so desired be connected to an external source of low frequency energy. The system will then function as an electro-mechanical filter, and an output signal of appreciable amplitude will appear across the output terminals 84, only when the frequency of the input signal has a predetermined value corresponding to the natural mechanical resonant frequency of the vibratory unit.

The embodiment of the invention shown in Figures 2 and 3 is similar in most respects to that of Figure 1, and this latter embodiment also serves to illustrate the principles of the invention. The embodiment of Figures 2 and 3 includes a pair of annular members 100 and 102 which constitute the vibrating masses. The annular members are supported one above the other by a series of U-shaped ribs 104, 106, 108 and 110. The ribs extend in a radial direction from a central hub 112. The hub 112 is fastened to an appropriate base 113. The ribs are composed of a suitable magnetic material such as iron or steel.

The U-shaped ribs are angularly displaced from one another by, for example, 90 degrees and these ribs are preferably composed of magnetic material. In each instance, the apex of the U-shaped rib is secured to the central hub 112 as by welding or brazing, and the two legs of the member are fastened to the top and bottom annular members 100 and 102 respectively. The latter embodiment includes an electro-magnetic transducer drive assembly 114 which is positioned between the legs of the U-shaped member 108. In like manner, an electro-magnetic pick-up transducer unit 116 is mounted on the base member 113 and is positioned between the legs of the U-shaped member 104. These transducers may

be similar in their construction to the transducers 42 and 44 of Figure 1.

The electro-magnetic transducer 114 represents but one instrumentality for driving the unit, and other known transducers may be used. As before, when the transducer 114 is energized by an electric current, the legs of the U-shaped member 108 are drawn together since they are composed of magnetic material. This imparts relative angular vibrational movements to the annular members 100 and 102 in the opposite directions about the hub 112. Therefore, an angular vibration about the hub is established by means of a suitable drive current in the winding of this transducer. As in the previous embodiment the core of this transducer may include a permanent magnet for biasing purposes. This enables an alternating current to be used in the winding. Such angular vibration of the annular members causes the legs of the U-shaped member 104 to move toward and away from the pick-up transducer assembly 116. This motion of the legs induces an output signal in the winding of this transducer in the same manner as in the previous embodiment. The pick-up transducer 116 need not be electro-magnetic, as other types of transducers, such as optical or capacitive types, can be used.

The embodiment of Figures 2 and 3, like the embodiment of Figure 1 and for the same reasons, is relatively insensitive to shocks and vibrations along or about any axis.

The embodiment of the invention shown in Figure 4 has a desirable feature in that it lends itself to convenient mass production. In this latter embodiment, the vibrating masses are constituted by a pair of annular members 200 and 202. These annular members are formed integral with a hub 204; and they are connected with the hub by means of a series of mutually-perpendicular integral radial ribs 206 connected to the top annular member 200, and by a corresponding series of mutually-perpendicular integral annular ribs 208 connected to the bottom annular member 202. The top group of ribs 206 in this embodiment is positioned directly above respective ones of the bottom group 208. The annular members and the integral ribs may conveniently be composed of a magnetic material, such as iron or steel.

The integral assembly described in the preceding paragraph is mounted on a supporting base 210 by means, for example, of a stud 212 extending upwardly from the base and perpendicular to the plane of the base. This stud serves to support the central hub 204 rigidly on the base, with the annular members 200 and 202 being rigidly supported by the hub and integral ribs in an axial sense, but being resiliently supported by the hub and ribs in a rotational sense about the axis of the hub.

The drive assembly comprises an electro-magnetic transducer 214 which is rigidly mounted on the base 210 as by a stud 216. The electro-magnetic drive assembly has a top pole-piece 218 which is held in place by the stud 216. The pole-piece extends into operative relation with one of the integral ribs 206 associated with the top annular member 200 and defines an air gap with that particular rib. This relation between the pole piece and rib is such that when the winding of the transducer 214 is energized, the member 200 is caused to rotate in a clockwise direction about the hub 204 and by a small amount.

The transducer 214 also has a bottom pole-piece 220 which extends into operative relation with one of the lower integral ribs 208 associated with the lower annular member 202, and which is at right angles to the upper rib 206 engaged by the top pole-piece 218. The lower pole-piece defines an air gap with that lower rib. The relation between the pole-piece 220 and its associated lower rib is such that, when the winding of the transducer 214 is energized, its lower pole piece 220 imparts a counterclockwise rotational movement to the lower annular member 202 about the axis of the hub 204. Therefore, when the drive transducer 214 is energized by a pulsating current, angular

vibrational movement in opposite directions about the hub 204 is imparted at the frequency of that current to the annular members 200 and 202. As in the previous embodiment, such vibrational movement of the annular members at frequencies other than the natural mechanical resonant frequency of the vibratory unit is inhibited.

The unit also includes a pick-up transducer assembly 230, which may be of the electro-magnetic type. This latter transducer may be similar in its construction to the drive transducer assembly 214 and is supported on the base 210 by a stud 236.

The transducer 230 has a top pole-piece 232 which extends into operative relationship with the one of the top integral ribs 206 diametrically opposite the rib engaged by the pole-piece 218 of the transducer 214. The pole-piece defines an air gap with this particular top rib.

The pick-up transducer assembly 230 also has a lower pole-piece 233 which co-operates with one of the bottom ribs 208 diametrically opposite the rib engaged by the pole-piece 220. Therefore, in a manner similar to that described, the opposed vibrational motion of the annular members 200 and 202 produced by the drive transducer assembly 214 produces a voltage across the winding associated with the pick-up transducer assembly 230.

The unit is conveniently held in assembled condition on the base 210 by a top supporting bracket 234 composed of suitable non-magnetic material. The bracket 234 has three aligned apertures which receive the studs 212, 216 and 236 respectively. A corresponding series of nuts 238, 240 and 242 are adapted to threadably engage the studs 212, 216 and 236 on the opposite side of the bracket 234. The nuts also have respective lock washers 244, 246 and 248 interposed between them and the bracket 234.

For production purposes, the unit of Figure 4 may be conveniently machined, the unit being composed (as mentioned above) of magnetic material such as iron or steel which exhibits the desired resilient characteristics. It might be pointed out that the magnetic circuit for the transducer drive assembly 214 is completed through its top pole-piece 218 and through the associated rib 206, the hub 204, the rib 208 associated with the lower pole-piece 220, and through the lower pole-piece 220. A similar magnetic circuit may be traced for the pick-up transducer assembly 230.

The unit of Figure 4 may also be conveniently formed by a series of laminates, with these laminates being soldered or brazed to one another. Alternately, the laminates may be riveted together or fastened by any other suitable means.

The use of laminates permits the units to be constructed by a simple stamping operation. It also permits different materials to be used in the construction of the unit for temperature compensation. That is, each laminate for any particular unit may alternate from one material to another to produce an overall temperature co-efficient that is essentially zero. With such a construction, temperature changes will not affect the natural mechanical resonant frequency of the vibratory unit to any extent. It might also be pointed out that all the laminates may be brazed simultaneously in accordance with the known production techniques and by placing the assembled unit in a brazing furnace.

In the embodiment of Figures 5, 6 and 7 the angularly vibrating masses are supported by tightly stretched wires. A central rod 300 supports the structure, and a plurality of wires 302 are fastened to a pair of electrically conductive hubs 304 and 306 which are mounted on the opposite ends of the rod 300 and which are insulated from the rod.

The vibrating masses may take the form of a pair of rectangular plates 308 and 310 each having a central aperture. A first group of, for example, four of the wires 302 are fastened to respective ones of the corners of the plates 308 in a manner more clearly shown in Figure 7; and a second group of, for example, four of the wires 302

are respectively fastened to the corners of the second plate 310.

The aperture plates are supported by the wires in co-axial relation with the rod 300 and axially spaced from one another. Each of the plates is free to rotate to a limited extent about the rod 300 and against the biasing action of the wires 302. The conductive hubs 304 and 306 are insulated from the rod 300 as noted above, and all the wires 302 are connected in parallel by the hubs. Two salient pole permanent magnet structures 312 and 314 of the illustrated frusto-conical configuration are supported on the central rod 300 on opposite sides of the plates 308 and 310. A cylindrical spacer member 316 is positioned on the rod 300 between the permanent magnets 312 and 314, this spacer member being positioned within the apertures in the vibrating plates 308 and 310.

The salient pole magnets 312, 314 have a generally frusto-conical configuration as stated above, with rib-like pole portions extending longitudinally at spaced angular distances from base to apex along the surface of each such magnet. These rib-like portions exhibit in alternation north and south poles, as shown in Figure 6. As best shown in Figure 5, each of the wires 302 extends along a corresponding one of the rib-like pole portions of the permanent magnets 312 and 314.

The structure may be housed in a suitable double two-piece conical shaped housing 318. This housing may be composed, for example, of steel or other magnetic substance to constitute a return path for the magnetic flux from the conical magnets 312 and 314.

The unit may be held in assembled condition by means of a pair of nuts 320 and 322 which are threaded respectively on the opposite ends of the rod 300. These nuts hold the housing sections together, and they also hold the hubs 304 and 306 firmly against the magnets 314 and 312 which, in turn, are securely held against the spacer 316.

As previously stated, the hubs 304 and 306 connect the various wires 302 in parallel, and the hubs are insulated from the remaining portions of the vibratory unit. A first electric terminal 324 is connected to the hub 304 for connection to one end of the parallel connected wires 302. A second electric terminal 326 is connected to the hub 306 for connection with the other end of the parallel connected wires 302.

As shown, for example, in Figure 6, when an electric current is passed through the wires 302 as by introducing an electric signal across the terminals 324 and 326, the resulting magnetic fields around the wires react with the magnetic flux between the respective rib-like poles of the magnets 314, 312 and the housing 318 so that the group of wires supporting the plate 310 (which, for example, are associated with north poles) shift in one direction and the group of wires supporting the plate 308 (which, for example, are associated with south poles) shift in the opposite direction. Therefore, and as in the previous embodiments, the signal introduced to the unit causes the two masses 308, 310 to rotate in opposite directions. A pulsating current through the wires 302 will set up angular vibrations in the opposite directions for the masses 308 and 310 about a central axis.

At rest, the electrical impedance exhibited by the wires 302 between the terminals 324 and 326 is relatively low. However, when the frequency of the introduced signal approaches the natural mechanical resonant frequency of the unit, a back electromotive force is generated in the wires and the impedance between the terminals rises sharply.

One typical system for utilizing the vibratory unit of Figures 5, 6 and 7 is shown in Figure 8. In the latter figure, the vibratory unit (which is indicated as 400) is placed across the input terminals of an amplifier represented by the block 402. The output terminals of the amplifier are connected to the output terminals 404 of

the system, one of which is shown as being connected to ground. The ungrounded output terminal of the amplifier is connected through a resistor 404a to one of the terminals of the vibratory unit 400.

Feed-back for the amplifier is provided by the connection through the resistor 404a, and this feed-back is insufficient to sustain oscillation in the amplifier at any frequency except at the natural resonant frequency of the vibratory unit 400. This is because the unit exhibits a low impedance which essentially short circuits the input of the amplifier at all frequencies except at its resonant frequency. However, at the resonant frequency of the vibratory unit, it exhibits a relatively high impedance across its terminals, and a feed-back signal is established across these terminals of sufficient amplitude and of proper phase to sustain oscillation in the amplifier.

Therefore, an output signal is developed across the output terminals 404 of the amplifier whose frequency is precisely stabilized to the natural resonant frequency of the unit 400. It is preferable to provide an automatic volume control for the amplifier 402, so that high gain is available when the system is initially energized to enable the system rapidly to reach its oscillatory state at the resonant frequency of the unit 400.

It is evident that the unit of Figures 5, 6 and 7 is, like the previous embodiments, relatively insensitive to external vibrations and shocks. That is, the characteristic impedance developed between the terminals 324 and 326 is dependent upon the relative rotational vibration of the masses 308 and 310 about the axis of the rod 300, and this impedance is independent of other vibrational movements of these masses.

The vibratory unit of Figures 5, 6 and 7 can also be used as a pressure or temperature transducer merely by making one or both of the hubs movable in response to pressure or temperature changes. That is, the hub 306, for example, may be spring biased with respect to the magnet 314 by a suitable spring (not shown). This hub may be coupled to a pressure responsive element so that changes in pressure cause it to move back and forth on the rod 300 and change the tension of the wires 302. This, of course, changes the resonant frequency of the unit so that the frequency of the output of the system of Figure 7 could be made dependent upon such pressure changes. Likewise, the hub 306 could be coupled to a temperature sensitive element so that the output signal from the system of Figure 7 would have a frequency indicative of temperature.

The vibratory units of the invention, when so desired, can be made relatively independent of temperature changes by the use of materials having different coefficients of expansion. The predominant factor causing a frequency drift in the resonant frequency of the units for temperature changes is the coefficient of expansion of their various components. A bi-metal construction may be utilized for the components of the units, using, for example, carbon steel having a negative coefficient of expansion in conjunction with a nickel-steel alloy having a positive coefficient of expansion. This provides a composite structure having essentially zero coefficient of expansion, and whose natural resonant frequency is essentially independent of temperature changes.

The embodiment of Figure 4 particularly lends itself to this bi-metal construction when that embodiment is of a laminated configuration. Then, and as previously pointed out, alternate laminations of the unit can be composed of different metals so that the overall structure has an essentially zero coefficient of expansion. In the embodiments of Figures 1 and 2, the radial ribs can be made of composite longitudinal strips of different metals so that they effectively do not change their lengths as the temperature varies.

The invention provides, therefore, an improved mechanical vibratory unit and assembly that is independent of all external shocks and vibrations for all practical

purposes. The unit is well suited for use in precisely stabilized sources of low frequency electrical energy and in electro-mechanical filters exhibiting extremely high quality factors. In the manner described, the various embodiments of the invention may be readily adaptable to function as temperature or pressure transducers. Also, by the use of suitable bi-metal construction, the resonant frequency of the units can be made to be substantially independent of temperature changes.

My description in specific detail of the selected embodiments of the invention will suggest various changes, substitutions and other departures from my disclosure within the spirit and scope of the appended claims.

I claim:

1. A dynamically balanced mechanical vibratory assembly including a base, a hub rigidly supported on the base, a first pair of resilient members extending radially from said hub, a second pair of resilient members extending radially from said hub in substantially diametrically opposed relation to said first pair of members, a first annular member secured to a first resilient member of each of said pairs and supported thereby coaxially with said hub for angular vibratory motion about said hub, a second annular member secured to a second resilient member of each of said pairs and supported thereby coaxially with said hub and axially spaced from said first annular member for angular vibratory motion about said hub, and driving means for imparting oppositely-phased angular vibratory motion about said hub to said first and second annular members.

2. The mechanical vibratory assembly defined in claim 1 in which said driving means comprises: an electro-magnetic unit.

3. A dynamically balanced mechanical vibratory assembly including, a base member, a hub rigidly mounted on said base and extending outwardly therefrom, a first pair of radial ribs extending outwardly from said hub in diametrically opposed relation, a second pair of radial ribs extending outwardly from said hub adjacent respective ones of said first pair, a first annular member secured to said first pair of ribs and supported thereby for angular vibrational motion about said hub, a second annular member secured to said second pair of ribs and supported thereby in axially spaced relation with said first annular member for angular vibrational motion about said hub, at least one of said ribs of each of said pairs having a flat configuration and positioned with the flat surface perpendicular to the planes of the annular members to prevent angular vibration of the angular members about other axes diametrically opposed stabilizing means extending from said hub to respective ones of said annular members substantially at right angles to said pairs of ribs, and driving means for imparting oppositely-phased angular vibratory motion to said first and second annular members about said hub.

4. The assembly defined in claim 3 in which at least one of said ribs secured to said first annular member and at least one of the ribs secured to the second annular member is composed of magnetic material, and in which said driving means comprises an electro-magnetic unit interposed between such ribs.

5. The assembly defined in claim 3 in which both said pairs of ribs are composed of magnetic material, in which said driving means comprises an electromagnetic unit interposed between one of said ribs secured to said first annular member and one of said ribs secured to the second annular member, and which includes an electro-magnetic pick-up means interposed between the other of said ribs secured to the first annular member and the other of said ribs secured to the second annular member.

6. A dynamically balanced mechanical vibratory assembly including, a base member, a hub rigidly mounted on said base and extending outwardly therefrom, a first resilient support means in the form of a first pair of flat radial ribs extending outwardly from said hub in dia-

metrically opposed relation, a second resilient support means in the form of a second pair of flat radial ribs extending outwardly from said hub adjacent respective ones of said first pair, a first oscillatory inertial mass annular member having a configuration to define an area in a first particular plane secured to said first pair of ribs in a position surrounding said hub and with the longitudinal axis of the hub extending perpendicular to said first particular plane and supported thereby for angular vibrational motion about the longitudinal axis of said hub and said first resilient support means rigidly supporting said first annular member against oscillatory motion about any other axis, a second oscillatory inertial mass annular member having a configuration to define an area in a second particular plane secured to said second pair of ribs and supported thereby in a position surrounding said hub with the longitudinal axis of the hub extending perpendicular to said second particular plane and in axially spaced relation with said first annular member with said second particular plane disposed in spaced parallel relationship with the first particular plane for angular vibrational motion about said hub and said second resilient support means rigidly supporting said second annular member against oscillatory motion about any other axis, said ribs being positioned with their flat surfaces extending perpendicularly to the planes of said annular members to prevent angular vibration of said annular members about any other axis diametrically opposed stabilizing means extending from said hub to respective ones of said annular members at substantially right angles to said pairs of ribs, a first tab of magnetic material secured to said first annular member in substantial axial alignment with one of said first pair of ribs, a second tab of magnetic material secured to said second annular member in substantial axial alignment with the one of said second pair of ribs adjacent said one of said first pair, said first and second tabs being spaced and essentially parallel to one another, and electro-magnetic driving means mounted on said base and positioned between said first and second tabs.

7. A dynamically balanced mechanical vibratory assembly including, a base member, a hub rigidly mounted on said base and extending outwardly therefrom, a first resilient support means in the form of a first group of four flat radial ribs formed integral with said hub and extending outwardly therefrom at right angles to one another, a second resilient support means in the form of a second group of four flat radial ribs formed integral with said hub and extending outwardly therefrom at right angles to one another and directly over respective ones of the ribs of said first pair, a first oscillatory inertial mass annular member having a configuration to define an area in a first particular plane integral with said ribs of said first group in a position surrounding said hub and with the longitudinal axis of the hub extending perpendicular to said first particular plane and supported thereby for angular vibrational motion about the longitudinal axis of said hub and said first resilient support means rigidly supporting said first annular member against oscillatory motion about any other axis, and a second oscillatory inertial mass annular member having a configuration to define an area in a second particular plane integral with said ribs of said second group and supported thereby in a position surrounding said hub with the longitudinal axis of the hub extending perpendicular to said second particular plane and in axially spaced relation with said first annular member with said second particular plane disposed in spaced parallel relationship with the first particular plane for angular vibrational motion about said hub and said second resilient support means rigidly supporting said second annular member against oscillatory motion about any other axis, said hubs being positioned with their flat surfaces extending perpendicular to the planes of the annular members to prevent angular vibration of said angular members about any other axis.

8. The assembly defined in claim 7 and which includes, an electro-magnetic driving means mounted on said base and positioned between adjacent ones of said ribs of said first and second groups, said electro-magnetic driving means having a first pole-piece extending into operative relation with one of said ribs of said first group, and said electro-magnetic driving means having a second pole-piece extending into operative relation with one of said ribs of said second group disposed at right angles to said one of said ribs of said first group.

9. A dynamically balanced mechanical vibratory assembly including, a central supporting rod, a first resilient support means in the form of a first group of electrically conductive wires extending from one end of said rod to the other, a first oscillatory inertial mass apertured member having a configuration to define an area in a first particular plane positioned coaxial with said rod in a position surrounding said rod and with the longitudinal axis of the rod extending perpendicular to said first particular plane and supported for angular vibrational motion about the longitudinal axis of said rod by said first resilient means and said first resilient support means rigidly supporting said first annular member against oscillatory motion about any other axis, a second resilient support means in the form of a second group of electrically conductive wires extending from one end of said rod to the other and respectively interposed with the wires of said first group, and a second oscillatory inertial mass apertured member having a configuration to define an area in a second particular plane positioned coaxial with said rod in a position surrounding said rod with the longitudinal axis of the rod extending perpendicular to said second particular plane and in axially spaced relation with said first member with said second particular plane disposed in spaced parallel relationship with the first particular plane and supported for angular vibrational motion about said rod by said second resilient means and said second resilient support means rigidly supporting said second annular member against oscillatory motion about any other axis.

10. A dynamically balanced mechanical vibratory assembly including, a supporting rod, a cylindrical spacer member centrally positioned on said rod, a pair of frusto-conical salient-pole permanent magnets positioned on said rod on the opposite sides of said spacer, a pair of hub members positioned at the respective ends of said rod, a first resilient support means in the form of a first group of electrically conductive wires extending from one of said hubs to the other, a first oscillatory inertial mass apertured member having a configuration to define an area in a first particular plane positioned coaxial with said rod in a position surrounding said rod and with the longitudinal axis of the rod extending perpendicular to said first particular plane surrounding said spacer and supported for angular vibrational motion about said rod by said first resilient means and said first resilient support means rigidly supporting said first annular member against oscillatory motion about any other axis, a second resilient support means in the form of a second group of electrically conductive wires extending from one of said hubs to the other and respectively interposed with the wires of said first group, a second oscillatory inertial mass apertured member having a configuration to define an area in a second particular plane positioned coaxial with said rod in a position surrounding said rod with the longitudinal axis of the rod extending perpendicular to said second particular plane and surrounding said spacer axially spaced from said first member with said second particular plane disposed in spaced parallel relationship with the first particular plane and supported for angular vibrational motion about said rod by said second resilient means and said second resilient support means rigidly supporting said second annular member against oscillatory motion about any other axis, the wires of said first group extending along magnetic poles of said

pair of magnets of a first polarity, and the wires of said second group extending along magnetic poles of said pair of magnets of a second polarity, and a housing of magnetic material surrounding said wires and magnets and providing a return path for the poles of said pair of magnets.

11. A dynamically balanced mechanical vibratory assembly including, a rigid hub, a first plurality of elongated members extending radially outwardly from said hub, a second plurality of elongated members extending radially outwardly from said hub, a first annular mass member secured to the members of the first plurality and resiliently supported thereby for angular vibratory motion about said hub and rigidly supported thereby against vibratory motion about any other axis, a second annular mass member secured to the members of the second plurality and resiliently supported thereby for angular vibratory motion about said hub but rigidly supported thereby against vibratory motion about any other axis, and driving means for imparting oppositely phased angular vibratory motion about said hub to said first and second annular mass members.

12. A dynamically balanced mechanical vibratory assembly including, a base member, a hub rigidly mounted on said base and extending outwardly therefrom, a first group of four flat radial ribs secured to said hub and extending outwardly therefrom at right angles to one another, a second group of four flat radial ribs secured to said hub and extending outwardly therefrom at right angles to one another and adjacent respective ones of the ribs of the first pair, a first annular mass member secured to said ribs of said first group and supported thereby for angular vibratory motion about said hub, and a second annular mass member secured to said ribs of said second group and supported thereby in axially spaced relation with said first annular mass member for angular vibratory motion about said hub, said ribs being positioned on said hub with their flat surfaces extending perpendicularly to the planes of said annular members to prevent angular vibratory motion of said annular members about any other axis.

13. The assembly defined in claim 22 and which includes, an electro-magnetic driving means mounted on said bases and positioned between selected ones of said ribs of said first and second groups, said electro-magnetic driving means having a first pole-piece extending into operative relation with one of said ribs of said first group, and said electro-magnetic driving means having a second pole-piece extending into operative relation with one of said ribs of said second group.

14. A dynamically balanced mechanical oscillatory assembly including a first oscillatory inertial mass member having a configuration to define an area in a first particular plane, first supporting means for said first inertial mass member for resiliently supporting said first inertial mass member for angular oscillatory motion of the first inertial mass member in the first particular plane about a central axis extending through the first inertial

mass member perpendicularly to the first particular plane and for rigidly supporting said first inertial mass member against oscillatory motion thereof about any other axis, a second oscillatory inertial mass member having a configuration to define an area in a second particular plane, second supporting means for resiliently supporting said second inertial mass member in position such that said second particular plane is spaced from and parallel to the first particular plane and such that said central axis further extends through the second inertial mass, said second supporting means resiliently supporting said second inertial mass for angular oscillatory motion of said second inertial mass in said second particular plane about said central axis and said second supporting means rigidly supporting said second inertial mass member against oscillatory motion about any other axis, and means for imparting oppositely-phased angular oscillatory motion about said central axis to said first and second oscillatory inertial mass members.

15. A dynamically balanced mechanical vibratory assembly including: rigid hub means, first resilient support means extending from said hub means, second resilient support means extending from said hub means, a first oscillatory inertial mass member having a configuration to define an area in a first particular plane secured to said first resilient support means in a position surrounding said hub means and with the longitudinal axis of said hub means extending perpendicularly to said first particular plane, said first resilient support means resiliently supporting said first inertial mass member for angular oscillatory motion about the longitudinal axis of said hub means and said first resilient support means rigidly supporting said first inertial mass against oscillatory motion about any other axis, a second oscillatory inertial mass member having a configuration to define an area in a second particular plane secured to said second resilient support means in a position surrounding said hub means with the longitudinal axis of said hub means extending perpendicularly to said second particular plane and with said second particular plane disposed in spaced and parallel relationship with the first particular plane, said second resilient support means resiliently supporting said second inertial mass for angular oscillatory motion about the longitudinal axis of the hub means and said second resilient support means rigidly supporting said second inertial mass against oscillatory motion about any other axis, and driving means for imparting oppositely-phased angular vibratory motion to said first and second oscillatory inertial mass members about the longitudinal axis of said hub means.

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