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Baker, Jr.

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[45] ***Jan. 30, 1973**

[54] **RESONATOR HAVING COUNTER ROTATING RIGID PARTS**

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[*] Notice: The portion of the term of this patent subsequent to July 1, 1986, has been disclaimed.

[22] Filed: **Sept. 11, 1970**

[21] Appl. No.: **71,394**

Related U.S. Application Data

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[52] **U.S. Cl.** .....**310/8.2,** 84/409, 84/457, 331/116 M, 58/23 TF, 310/25, 333/72

[51] **Int. Cl.** **H01v 7/00**

[58] **Field of Search**.....333/71, 72; 310/8.2–8.5, 25, 36, 9.1, 9.6; 331/116, 116 M; 73/505; 58/23 TF; 84/409

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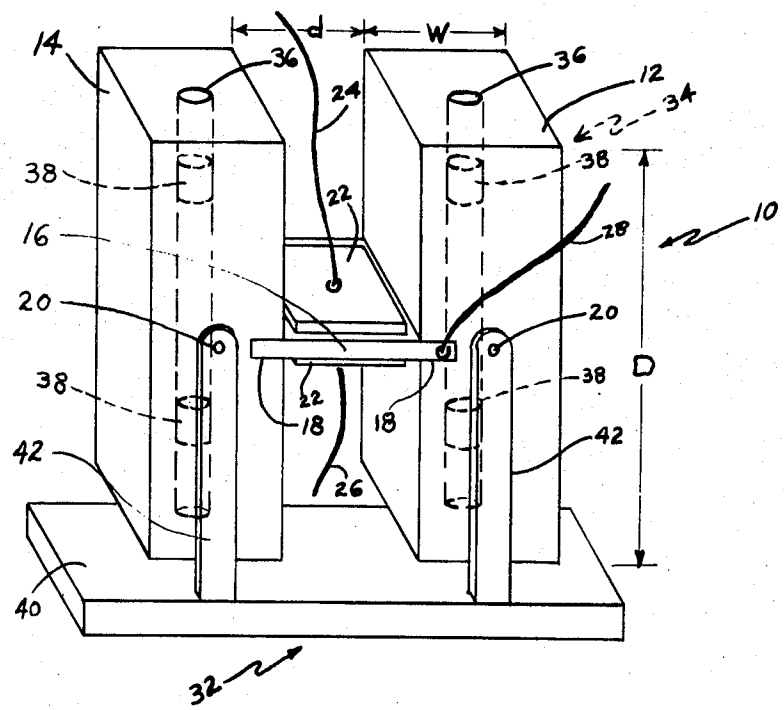
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[57] **ABSTRACT**

There is disclosed a resonator having rigid oscillating parts interconnected by a resilient web for inducing counterrotary movement of the rigid parts. The rigid parts are mounted to rotate about the nodal axis thereof. The nodal axis of each rigid part intersects the center of gravity of the part.

15 Claims, 8 Drawing Figures



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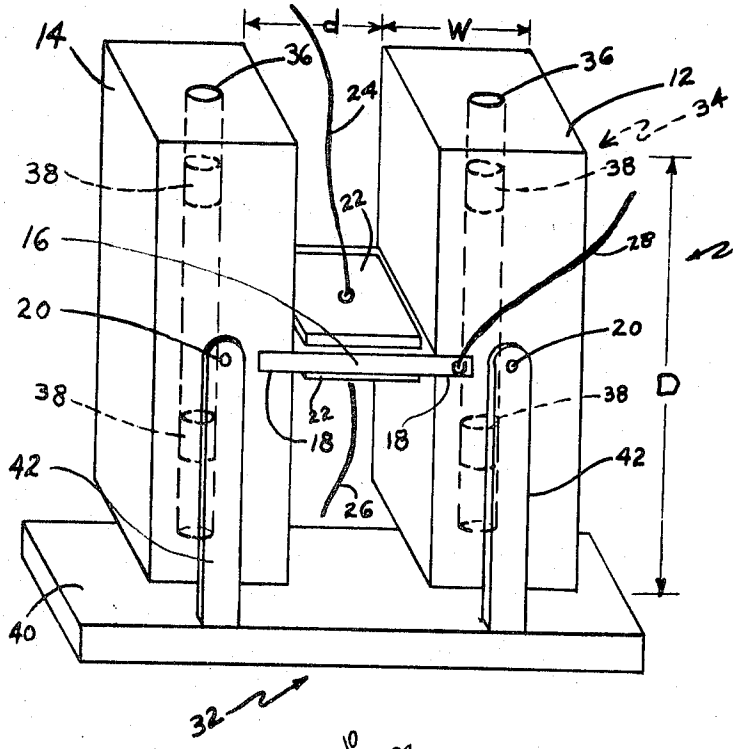


Fig 1

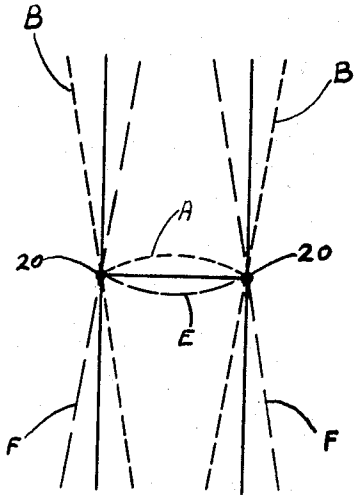


Fig 3

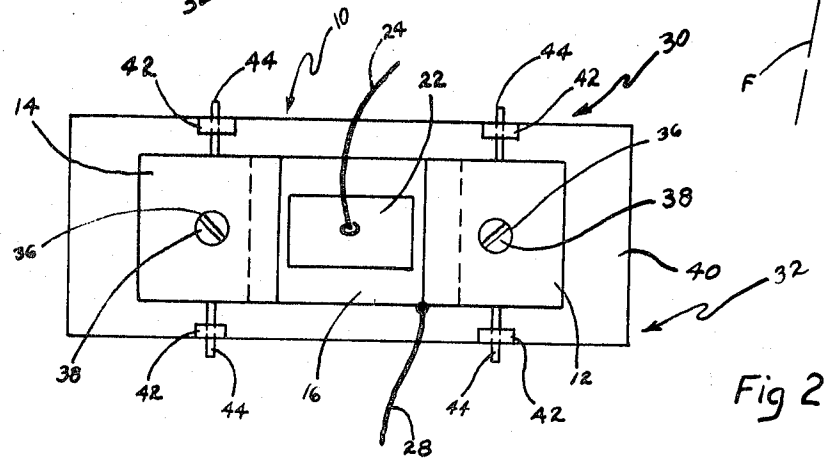


Fig 2

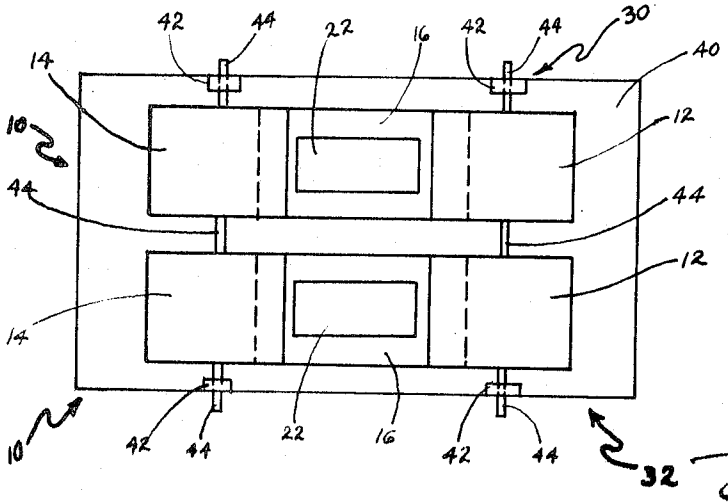


Fig 4

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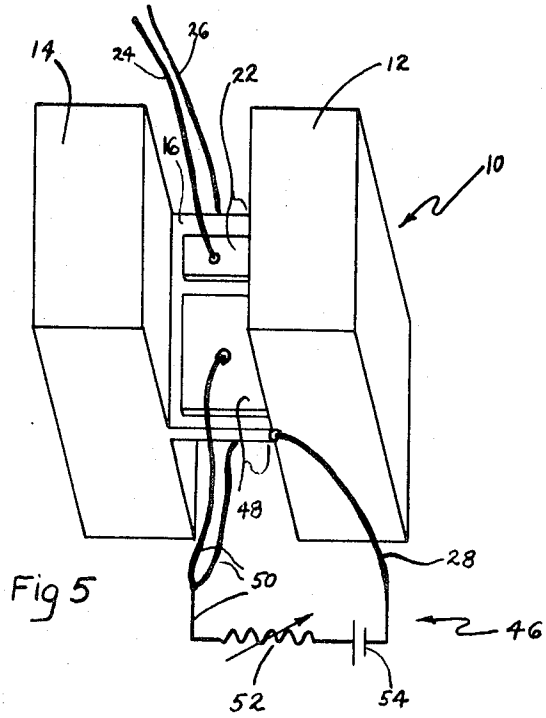
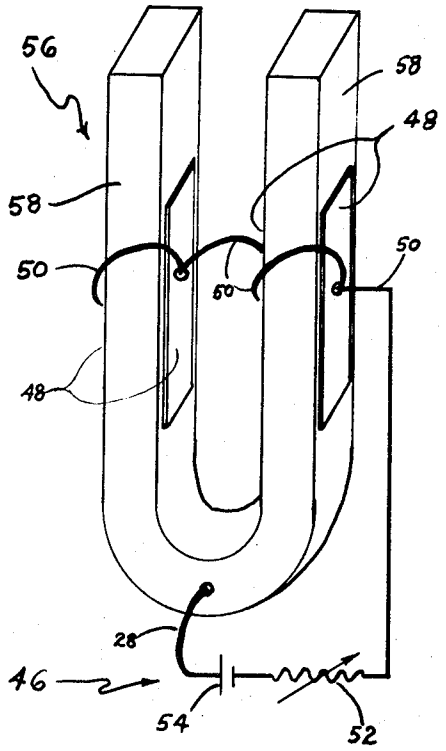


Fig 5

Fig 7



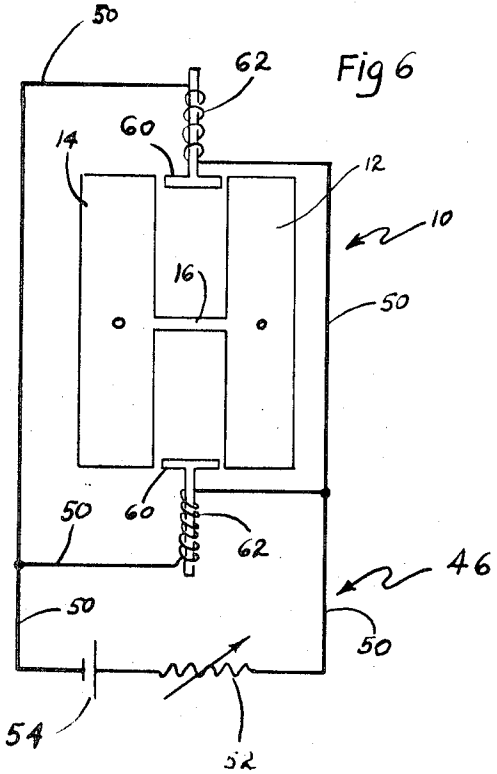


Fig 6

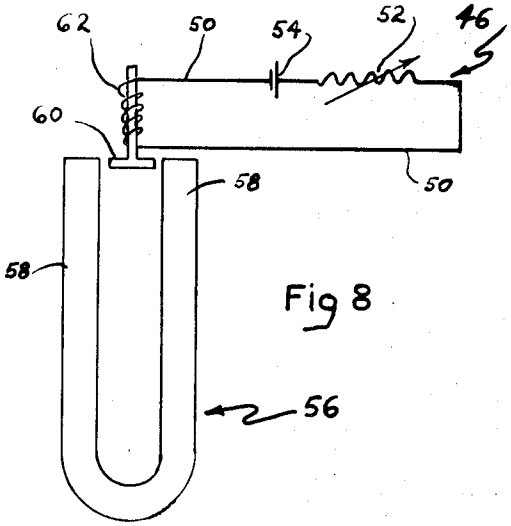


Fig 8

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RESONATOR HAVING COUNTER ROTATING RIGID PARTS

This application is a continuation of application Ser. No. 565,430, filed July 15, 1961.

This invention relates to resonators, filters, and more particularly to electromechanical type resonators and filters with piezoelectric, magnetostrictive and electromagnetic drive.

At frequencies below 20 KC, electromechanical filters and resonators are generally chosen over capacitance and resistance networks or capacitance and inductance networks since they offer the best temperature stability, frequency selectivity, small size and low cost combination.

While there are many forms of electromechanical resonators and filters, the ones most often selected for frequencies below 20 KC are tuning forks, some form of a simply supported loaded beam, and the cantilevered loaded beam.

Each of these devices has certain design, manufacturing or performance deficiencies. A common objectionable characteristic is reaction felt in the supporting members. Consequently, unless great care is taken to isolate one reasonating device from another, there will be objectionable interaction between them particularly when they are functioning as a frequency selective filter.

Another objectionable characteristic common to all of these devices, especially if they are loaded with high relative mass to obtain low frequency with high selectivity, is that they are affected by the attitude of their mounting or support because of gravitational effects. A tuning fork, for example, resonates at one frequency when mounted horizontally and another frequency when mounted vertically.

When the desired resonant frequency is very low, the physical size of all three forms of resonators becomes a significant factor relative to the frequency selectivity. The flexing members, being very large, are dampened heavily by the surrounding medium such as air, atmosphere or the like. Thus, it is common practice to evacuate the surrounding medium from the container in which the structure is mounted in order to improve its frequency selectivity. The simply supported beam as well as cantilevered beam type of resonator have the further disadvantage of comparatively poor frequency selectivity in part due to damping introduced by a non-rigid base.

It is known by those versed in the art of electromechanical resonators that frequency selectivity is generally improved if the flexible portion of the resonator is made stiffer and a load is added to maintain a given frequency. In general, the frequency selectivity of the resonator is improved by a factor related to the square root of the product of the stiffness and the loading.

In the case of the simply supported beam and the cantilevered beam type of resonator, this is offset by a corresponding loss of frequency selectivity due to damping losses in the supporting base.

Because of their relatively complex shape, resonators in the form of tuning forks are more expensive to build and are difficult to design and produce with good temperature stability — although sufficient knowledge and experience have been gained to produce tuning forks with this quality. Often, several materials are laminated

to obtain a combination of thermo-elastic properties and compensating thermo-expansion properties.

Because of the physical form of a tuning fork type of resonator, great care must be taken to avoid disturbing the compensating effects of these two properties when bringing the tuning fork to the desired frequency once it is assembled.

In any form of mechanical resonator, the resonant frequency thereof can be adjusted only by changing the physical parameters of the structure of the resonator. Because such adjustments are generally awkward and time-consuming, they are permanent or semi-permanent in nature. There are many applications wherein it would be advantageous to produce a controlled temporary shift of the resonant frequency with ease and rapidity. It would be particularly advantageous if this shift could be accomplished by electrical means.

In order to overcome the disadvantages as stated above and to acquire the unforeseen, unobvious and desired results of the instant inventive concept as will be more fully described and disclosed hereinafter, it is an object of my invention to construct a mechanical resonator which may be piezoelectrically electromagnetically and magnetostrictively driven while not being affected by the position or mounting attitude thereof with the resonator having virtually no reaction impressed on the mounting base and therefore having minimal tendency for one resonator to adversely affect an adjacent resonator.

It is also of my invention to provide a mechanical resonator which is simple and inexpensive to design and construct with respect to frequency selectivity and thermal-frequency stability, and to achieve a high degree of frequency selectivity in a small size without need for evacuating the surrounding media from the container in which the resonator may be disposed.

Another object of this invention is to construct an electromechanical resonator which is substantially totally free of the effects of gravity and acceleration on the resonant frequency.

It is a further object of this invention to construct an electromechanical resonator assembly which may be semi-permanently adjusted over some range of resonant frequencies with ease and without cutting away or adding material to the loaded or flexing portions of the assembly.

It is a further object of this invention to provide an assembly by which the resonant frequency of any electromechanical resonator may be temporarily shifted a controlled amount with ease and rapidity via electrical means.

It is also a further object of this invention to provide an electromechanical resonator whose basic configuration is in the general form of the letter H.

Other objects and important features of the invention would be apparent from a study of the specification following taken with the drawing, which together show, illustrate, describe and disclose preferred embodiments or modifications of the invention and it is now considered to be the best mode of practicing the principles thereof. Still other embodiments or modifications may be suggested to those having the benefit of the teachings herein, and such other embodiments or modifications are intended to be reserved especially as they fall within the scope and spirit of the subjoined claims.

IN THE DRAWING

FIG. 1 shows a perspective view of one embodiment of a mechanical type resonator having the improvements of this invention incorporated therewith;

FIG. 2 is a plan view of the resonator as illustrated in FIG. 1;

FIG. 3 is a diagramatic illustration of the relative position of certain various parts of the resonator illustrated in FIG. 1 taken during a cycle of oscillation;

FIG. 4 is a plan view similar to FIG. 2 of the drawing but showing another embodiment thereof in which a plurality of resonators similar to those illustrated in FIGS. 1 and 2 may be cascaded to improve the frequency selectivity;

FIG. 5 is a perspective view of the resonator shown in FIG. 1 but illustrating a structural arrangement as well as a method of electrically tuning the resonator by employing a plurality of additional transducers;

FIG. 6 is a plan view of the resonator illustrated in FIG. 1 showing another embodiment of the structural arrangement and method of electrically tuning the resonator;

FIG. 7 shows a perspective view of a typical tuning fork illustrating the structural arrangement and the method for electrically tuning same which is similar to that as illustrated in FIG. 5, and

FIG. 8 is a plan view of the tuning fork shown in FIG. 7 but illustrating the embodiment of the structural arrangement and method for electrically tuning same as being similar to that as illustrated in FIG. 6.

Attention is now directed to FIGS. 1 and 2 of the drawing wherein there is illustrated a novel resonator structure **10** which will be described and disclosed herein as being employed as a filter and in such capacity, the resonator **10** will possess certain highly desired, unobvious and unforeseen characteristics and will be explained in more detail hereinafter. It is to be expressly noted that the resonator **10** has a basic configuration which may be considered as being substantially in the form of an H with the resonator **10** being defined by an elongate first part **12** that is relatively bodily rigid having a longitudinal extent D and an elongate second part **14** which is also relatively bodily rigid and which is substantially coextensive with the first part **12** having similar longitudinal extent D.

The first **12** and the second **14** parts of the resonator structure **10** are disposed in parallel relationship relative to each other and are spaced apart a distance *d*.

The resonator structure **10** is further provided with an elongate third part which extends between and is connected to an intermediate portion **18** of each of the first **12** and the second **14** parts of the resonator structure **10**.

For the sake of illustration only, the first **12** and the second **14** parts of the resonator structure **10** have been shown as being of rectangular configuration in cross section with the third part **16** having a relatively large surface area. However, it to be understood that other shapes and configurations may be employed with regard to the first **12**, second **14**, and third **16** parts of the resonator structure **10** without departing from the spirit of the inventive concept which is being described and disclosed.

There are, however, certain physical characteristics of the parts **12**, **14** and **16** which are believed to be of importance, such as: the mass of each of the parts **12** and **14** should be substantially greater than the mass of the third part **16**, the longitudinal extent D of the parts **12** and **14** should be substantially greater than the distance d of the space therebetween, the material from which the first **12** and the second **14** parts are made should have a relatively low coefficient of expansion with the third part being formed of material having an isoelastic property, the intermediate portions **18** of the first **12** and second **14** parts as well as the third part **16** should be located in a plane that is common with the nodal axes **20** of the first **12** and the second **14** parts of the resonator structure **10** being defined respectively by the inner section of a longitudinal plane that is disposed along the one half the width W and a transverse plane which is disposed along the one half longitudinal extent D of the parts **12** and **14**.

The resonator structure **10** is further provided with transducers **22** which in the form as illustrated in FIG. 1 of the drawing is a piezoelectric material. However, other transducers may be employed in the form of electromagnetostrictive or electromagnetic without departing from the instant inventive concept.

The transducers **22** are secured to the third part **16** of the resonator structure **10**, in any suitable manner and as illustrated, the pair of transducers **22** is employed with one transducer **22** being disposed on each of the opposed surfaces of the third part **16** of the resonator structure **10**. Depending on the type of electrical circuitry to be employed, the number of transducers **22** may vary and the inventive concept as illustrated is an example of a three terminal type filter arrangement. If a two terminal type filter is to be employed, it is only necessary to have a single transducer **22** secured to the third part **16** of the resonator structure **10**.

In the three terminal circuitry as illustrated, electrical signals are applied to one of the transducers through a wire **24** and the signals generated on the other transducer **22** disposed on the opposed side of the bodily flexible third part **16** is taken off through another wire **26**. By reason of the fact that the flexible third part **16** is disposed between the transducers **22**, the flexible third part **16** in effect creates an electrical connection therebetween and the signals created therein are taken off through a wire **28** making the electrical network an effective three terminal device.

If the electrical signal is applied to the flexible third part **16** of the resonator structure **10** through the wire **24** and the transducers **22** associated therewith the flexible third part **16** will assume a position as illustrated in FIG. 3 by the reference character A during one half cycle and by reason of the connection of the third part **16** to each of the first **12** and second **14** parts of the resonator structure **10**, the relatively rigid nonflexing first **12** and second **14** parts will assume a position as illustrated by the reference character B. During the second one half cycle of the electrical signal, the flexible third part **16** will assume a position illustrated by the reference character E in FIG. 3 of the drawing which will position the nonflexing bodily rigid first **12** and second **14** parts of the resonator structure **10** in positions as illustrated by the reference character F. In FIG. 3 of the drawing the normal or relaxed positions of the first **12**, second **14** and third **16** parts of the resonator structure are illustrated in solid lines with the rela-

tive positions thereof during the one half cycle being shown by dotted lines and referred to with the third part **16** being illustrated by the reference character A and the first **12** and second **14** parts being illustrated by the reference character B with the relative positions thereof during the second half cycle of the electrical signal being shown with the third part **16** designated by the reference character E and the first **12** and second **14** parts illustrated by the reference character F. It will thus be apparent that the counterrotation between the parts **12**, **14** is substantially coextensive in time in the sense that the parts **12**, **14** begin rotation at substantially the same time and end at substantially the same time. Chronocoextensive is used to describe this relationship.

The result of passing the electrical signal to the bodily flexible third part **16** of the resonator structure **10** is that a counter rotational oscillation is created in the first **12** and second **14** parts of the resonator structure **10** occurs about the respective nodal axes **20** and by reason of a rotational or pivotal connection **30**, to be described in more detail hereinafter that is provided between the resonator structure **10** and a support structure **32** there is no reaction to the rocking oscillatory motion of the bodily rigid non-flexing first **12** and second **14** parts since the parts **12** and **14** are, in effect, counterbalancing each other about the pivotal connections **30** along the nodal axes **20**.

Having thus balanced all of the various parts or portions of the resonator structure **10** about the rotational or pivotal connections **30** which are common with the respective nodal axes **20** there is no effective gravitational forces or influences operating on the resonator structure **10** against the resonant frequency which may be created thereby. In other words, in dealing with the low frequencies with which we are currently interested, and with the relative properties and characteristics being in existence that relate to the first **12**, second **14** and third **16** parts, such as the relative masses etc., and by reason of the non-flexing relatively bodily rigid first **12** and second **14** parts being counterbalanced about the rotational or pivotal connections, there is virtually no effect created by any gravitational forces or influences on the resonant frequency of the resonator structure **10** and further, the characteristics and relative relationship of the parts as disclosed and described creates a condition in which acceleration also has virtually no effect on the resonant frequency of the resonator structure **10**.

In the resonator structure **10**, as herein described and disclosed, the resultant resonant frequency is determined by the relative stiffness of the bodily flexible third part **16** and the mass as well as the moment of inertia about the pivotal connections **30** of the bodily rigid non-flexing first **12** and second **14** parts and in the preferred embodiment or modification of the resonator structure **10** the bodily flexible third part **16** is preferably formed of a material which has the property of isoelasticity, that is, a material whose elastic properties are least affected by temperature changes such as a material which may be a homogenus steel alloy of 30 percent nickel and 10 percent chromium as described and disclosed in U.S. Pat. No. 1,763,853 with the bodily rigid first **12** and second **14** parts being of a material having a low coefficient of expansion such as Invar or certain glass compounds.

None of the moving parts of the resonator structure **10** are comparatively large for a given resonant frequency and further because the total of distance of travel of any moving part of the resonant structure **10** is similar, the damping effects of the surrounding atmosphere are minimal. If it is desirable to recuce the damping effects of the surrounding atmosphere even further the non-flexing bodily rigid first **12** and second **14** parts may be made of circular cross section wherein the modal axes **20** would extend through the longitudinal center lines thereof at a location which is halfway of the longitudinal extent with the nodal axes being normal to the longitudinal axes thereof.

By reason of the description and disclosure made herein, it is believed obvious on passing the electrical signal through the resonator structure **10** that a resultant resonant frequency will be created and it is under certain conditions highly desirable to be able to vary the resultant resonant frequency and in order to so vary the resultant frequency there is provided structure **34** which will effectively semi-permanently efficiently and readily enable the resonant frequency of the resonator structure **10** to be varied.

As illustrated in FIG. **1** of the drawing, the structure **34** comprises a generally longitudinally extending bore **36** that passes along the longitudinal axis of each of the first **12** and second **14** parts in which there is longitudinally spaced a plurality of plug-like members **38** with the plug-like members **38** being retained within the respective bore **36** by suitable securements such as a press or friction set as well as screw threads or the like. The relative position of each of the plug-like members **38** from the respective nodal axes **20** will, in effect, vary the resonant frequency of the resonator structure **10** and by reason of the mass of the plug-like members **38** the moment of inertia of the first **12** and second **14** parts may be varied by reason of the disposition of the plug-like members **38** relative to the respective nodal axes **20**. It is to be understood that the plug-like members **38** should be of the same mass and position the same distance from the respective nodal axes **20** in order to maintain the balance of the resonator structure **10**.

It is to be understood that an arrangement similar to the plug-like members **38** and the bore **36** may be conveniently employed on resonators such as tuning forks, cantilevered beams, some forms of simple supported beams and other similar mechanical resonators to effectively vary the resonant frequency thereof by varying the moment of inertia in a manner similar to that as described and disclosed herein with regard to the first **12** and second **14** parts of the resonator structure **10**.

The support structure **32** may comprise as illustrated a base portion **40** from which there projects a plurality of bracket-like members **42** with the bracket like-members **42** being disposed in pairs, one pair being adjacent the first **12** and another pair adjacent the second **14** parts of the resonator structure **10** with the first **12** and second **14** parts thereof being intermediate the respective pair of the bracket-like members **42**.

A suitable pivotal pin type connection **44** extends between the associated pair of bracket-like members **42** and passes through the respective nodal axes **20** and the associated first **12** and second **14** parts of the resonator structure **10** and the pivotal pin type connectors **44** divide the rotational or pivotal connection **30**

for supporting the resonator structure **10** with the first **12** and the second **14** parts thereof being in the counterbalanced condition.

Attention is now directed to FIG. **4** of the drawing wherein there is illustrated another embodiment or modification of the inventive concept wherein it is desired to obtain a better selection of resonant frequency and in this embodiment or modification there is provided a plurality of resonator structures **10** which are disposed in cascaded relationship relative to each other.

It is to be noted that the pivotal pin type connectors **44** are common to the adjacent resonator structures **10** and thus enable the motion of one of the resonator structures **10** to be coupled to the next adjacent resonator structure **10**. It is to be understood that the disposition of a plurality of resonator structures **10** in cascading relationship relative to each other should not be limited to two and by extending or increasing the number of resonator structures **10** which may be employed there occurs a corresponding improvement in the resonant frequency selectivity. Further, the resonator structures **10** which may be disposed in the cascaded relationship as illustrated may be electrically coupled with no mechanical coupling, electrically and mechanically coupled or mechanically coupled in order to obtain a specific frequency selectivity characteristic.

Attention is now directed to FIGS. **5** through **8** of the drawing wherein there is illustrated and shown certain embodiments and modifications of an apparatus and method for changing or varying the existing resonant frequency of a resonator and as illustrated in FIG. **5** of the drawing, the resonator **10** is illustrated and like characters of reference are relied upon for the purpose of identification which should correspond to the character references as shown in FIGS. **1** and **2**.

The resonator structure **10**, as previously described and disclosed, is driven through the external circuit which is connected by the wire **24** that is attached to the one transducer **22** which is illustrated as a piezoelectric wafer with the resonator structure **10** thus effectively having a resultant resonant frequency which, for reasons previously stated, may be desirable to vary or change.

Apparatus **46** is provided for varying or changing the resultant resonant frequency of the resonator structure **10** and the apparatus **46** comprises at least one and preferably a pair of additional transducers **48** which, as illustrated, are in the form of piezoelectric wafers with the additional transducers **48** being secured to bodily flexible third part **16** of the resonator structure **10** and suitable wiring **50** is provided to create a circuit that comprises a potentiometer **52** that is in series with a battery or source of electrical energy **54** so that a DC voltage which may be varied is applied to the additional transducers **48**.

As illustrated in FIG. **7**, a similar apparatus **46** is employed to a conventional type of tuning fork **56** having a plurality of tines **58** to which there is secured the additional transducers **48** which are provided with wiring **50** that creates a circuit that includes the potentiometer **52** and the source of electrical energy **54**, all in a manner similar to the circuitry of FIG. **5**.

Since in any mechanical resonating device there is a relationship between the resultant resonant frequency and the stiffness of the flexible portion of the resonant structure the resultant resonant frequency may be shifted, changed, varied or altered by the relative stiffness of the flexible member or members as the case may be. In the resonant structure **10** and **56**, as illustrated in FIGS. **5** and **7** of the drawing, the additional transducers **48** employed in the apparatus **46** form part of the respective bodily flexible portions or members, that is the third part **16** and the tines **58** and contribute to shifting, changing varying or altering the relative stiffness thereof. As the voltage of the circuitry of the apparatus **46** which is supplied from the source of electrical energy **54** through the potentiometer **52** and the wiring **50** is applied across the additional transducers **48**, the additional transducers **48** will stretch or contract according to the polarity and magnitude of the applied voltage as varied by the potentiometer **52**.

By attaching or securing the additional transducers **48** to the bodily flexible portions or members **16** and **58** of the resonator structures **10** or **46**, as the case may be, so that the additional transducers **48** are disposed on opposite surfaces of the associated bodily flexible part or member the additional transducers **48** will tend to stretch or contract, in the same direction in response to a given applied voltage and accordingly, increase or decrease, as the case may be the relative stiffness of the part **16** or member **58** in response to the variance of the voltage from the source of electrical energy **54** as opposite polarities thereof is applied.

The result of employing the apparatus **46** as a method for altering, shifting, varying or changing the resultant resonant frequency of a resonator structure is that the resultant resonant frequency may be altered, shifted, varied to correspond to the magnitude or polarity of the voltage which may be applied from the source of electrical energy **54** which passes through the additional transducers **48**.

While the apparatus **46** has been illustrated in FIGS. **5** and **7** of the drawing as having a component part thereof piezoelectric wafers which define the transducers **48**, it may be desired that the additional transducers **48** take the form of an electromagnet **60** which, as illustrated in FIGS. **6** and **8** of the drawing may be employed with the apparatus **46** to alter, vary, change, shift or modify the resultant resonant frequency of resonator structures **10** and tuning forks **56**.

As illustrated in FIG. **6** of the drawing, the electromagnet **60** is disposed between the first **12** and the second **14** bodily rigid part of the resonator structure **10** with the electromagnetic field thereof being controlled by a coil **62** which is connected through the wiring **50** to a source of electrical energy **54** and a potentiometer **52**.

As current from the source electrical energy **54** is increased by the potentiometer **52** to the coil **62**, such an increase in the current will thus increase the influence of the magnetic field which will in turn bring a strain or bias to the end portions of the first **12** and the second **14** parts of the resonator structure **10** and such strain or bias will influence and thus vary, change, modify and effectively control the relatively flexibility of the third part **16** and thus alter the stiffness thereof. Accordingly, the resultant resonant frequency of the

resonator structure **10** may be altered, influenced, varied and changed in accordance with the current flow to the electromagnetic **60**.

Similarly and as illustrated in FIG. **8** of the drawing, the electromagnetic **60** may be placed between the tine members **58** of a resonator structure which may be in the form of a tuning fork **56** and as the current flow to the coil **62** of the apparatus **46** will influence the flexibility of the tine members **58** and thus vary, change, modify and control the resultant resonant frequency thereof.

The variation of the electromagnetic field of the apparatus **46** as illustrated in FIG. **8** through varying the current from the source of electrical energy **54** by the potentiometer **52** is reflected as a change in the stress on the tine members **58** which thus changes the relative stiffness thereof and as the stiffness is altered, there is a corresponding change in the resonant frequency of the tuning fork **56**. While the invention has been shown, illustrated, described and disclosed in terms of certain embodiment or modifications which it has assumed in practice, the scope of the invention should not be deemed to be limited by the precise embodiment or modification has herein shown, illustrated, described or disclosed and such other embodiments or modifications intended to be reserved especially as they fall within the scope of the claims here appended.

I claim:

1. A resonator comprising

first and second parts rigid at a resonant frequency of the resonator;

means supporting the first part to enable the same to rotate about the nodal axis thereof, means supporting the second part to enable the same to rotate about the nodal axis thereof, the nodal axes substantially intersecting the centers of gravity of the respective first and second parts;

means for providing a resilient connection between the first and second parts for inducing counter rotary movement of the first and second parts upon a movement of one of the parts, the resilient means comprising a third part connected to the first and second parts and flexible at a resonant frequency of the resonator; and

means for moving at least one of the parts.

2. The resonator of claim **1** wherein the nodal axes define a plane.

3. The resonator of claim **2** wherein the first and second parts are substantially parallel.

4. The resonator of claim **1** wherein the third part is independent of the supporting means.

5. The resonator of claim **1** wherein the resilient means comprises means for transmitting rotary movement of the first part into counterrotary movement of the second part.

6. The resonator of claim **1** wherein the resilient means comprises means for transmitting rotary movement of the first part into substantially simultaneous counter rotation of the second part.

7. The resonator of claim **1** wherein the moving means comprises an electromechanical transducer disposed on the third part.

8. The resonator of claim **1** wherein the third part comprises a planer section and the moving means comprises an electromechanical transducer on surfaces of the planar section which are in opposed relation to each other.

9. The resonator as set forth in claim **1** wherein the first and second parts are formed of material having a relatively low coefficient of expansion, and the third part is formed of material having isoelastic properties.

10. The resonator as set forth in claim **1** wherein the mass of the first and second parts are each substantially greater than the mass of the third part.

11. The resonator as set forth in claim **1** wherein the length of the first and second parts are each substantially greater than the space therebetween.

12. The resonator as set forth in claim **1** wherein the mass moment of inertia of the first part is substantially equal to the mass moment of inertia of the second part.

13. The resonator of claim **12** wherein the connection between the third part and each of the first and second parts produces equal moments on the first and second parts upon rotation thereof.

14. The resonator of claim **1** wherein the nodal axes are spaced apart.

15. The resonator of claim **1** further comprising means for adjusting the resonant frequency of the resonator including means for changing the relative stiffness of the third part.

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