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FREQUENCY CONTROL SYSTEM UTILIZING  
MAGNETOSTRICTIVE ELEMENTS

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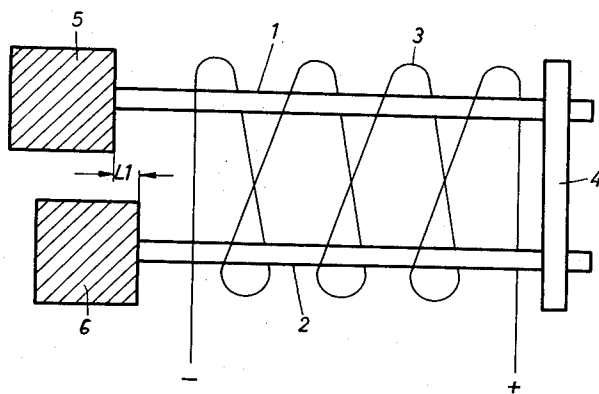


Fig. 1a

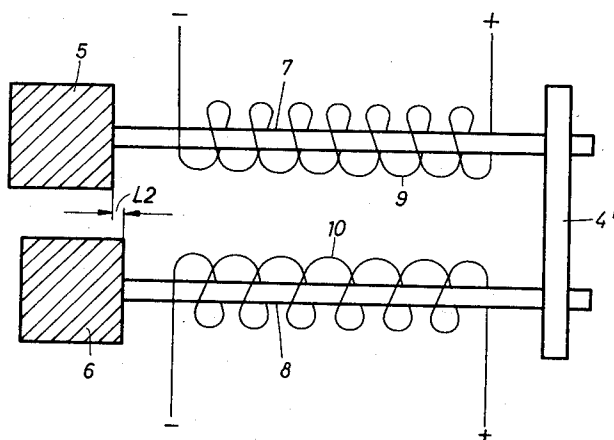


Fig. 1b

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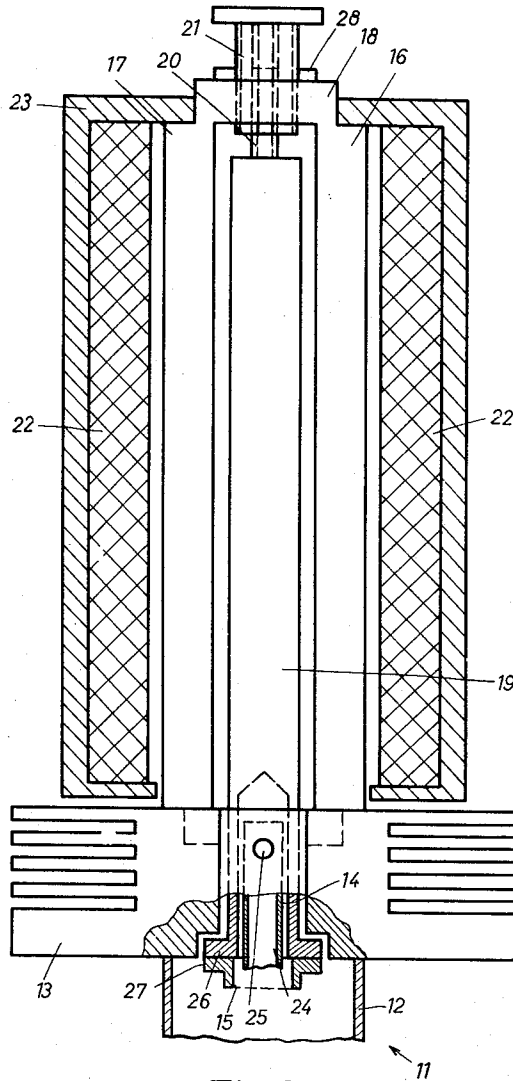


Fig. 2

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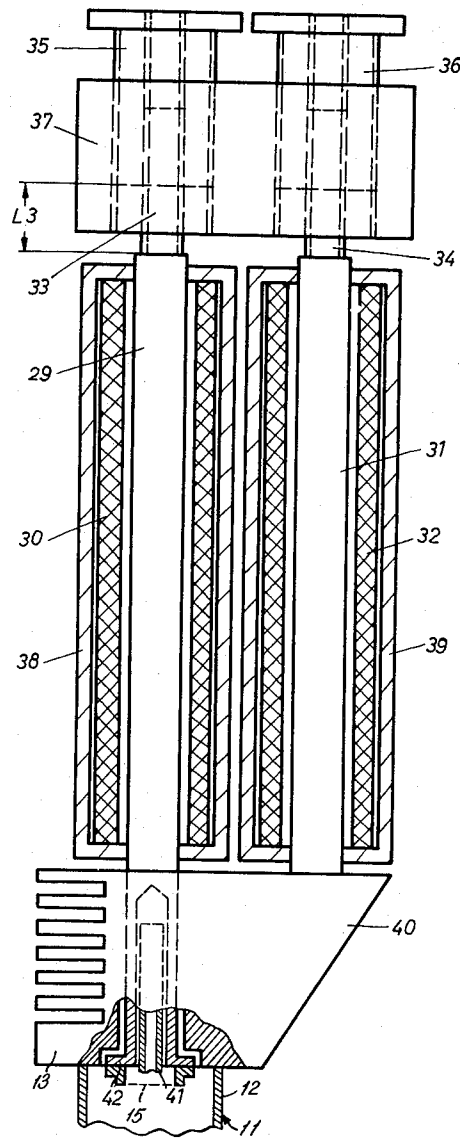


Fig. 3

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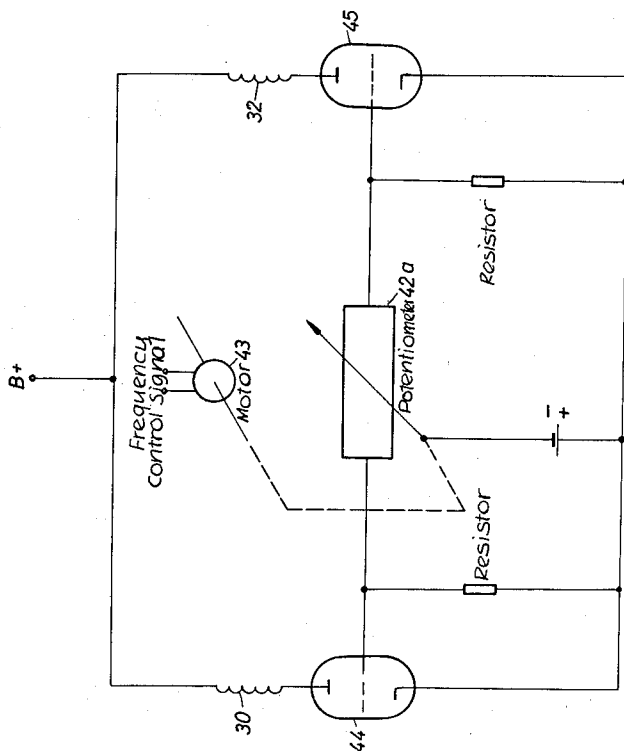


Fig. 4

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3,136,954

## FREQUENCY CONTROL SYSTEM UTILIZING MAGNETOSTRICTIVE ELEMENTS

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17 Claims. (Cl. 331-6)

This invention relates to frequency-control systems and more particularly to a mechanical-drive type of frequency-control system for an oscillator.

It is known that the resonant frequency of an oscillator may be adjusted by mechanical variation of the geometrical dimensions of a frequency-dependent element contained in the oscillator. It is also known that, within the frequency range of some gigacycles per second ( $10^9$  c.p.s.), frequency-dependent resistors respond very sensitively to any change in their geometrical dimensions to bring about frequency control. It is further known that, in the frequency range of 10 gigacycles per second, a variation of the distance or spacing of only a very minute amount, for instance 1 microinch, of the capacitive load of a cavity resonator or oscillator may cause the resonant frequency thereof to be changed in the order of a few megacycles. To realize these mechanical frequency-control systems, the driving mechanism to adjust the frequency-dependent element includes transmission gear trains. At the high frequencies with which these oscillators operate, there is considerable difficulty in the transmission gear train including gears and/or levers due to the bearing clearance and slackness or play. The bearing clearance and slackness can cause impairment of the mechanical adjustment of the frequency of an oscillator which cannot be removed even with a great investment in additional machining operations of highest precision. Thus, the mechanical gear-train type driving system for the frequency-control system of an oscillator operating at these high frequencies is unsuitable.

In other systems where the driving system and the elements to be driven are arranged to have the driven element pressed against the driving system by the action of a spring, the restoring force of the spring, because of temperature influence, does not guarantee a definite position of the driven element.

An object of the present invention is the provision of a frequency-control system of the mechanical-drive type which overcomes the abovementioned difficulties.

Another object of the present invention is to provide a frequency-control system of the mechanical-drive type to obtain extremely small mechanical variations of the frequency-dependent element by utilizing the well known magnetostriction phenomenon.

A feature of this invention is to provide a frequency-control system for an oscillator having a mechanically movable frequency-adjusting element and a magnetostriction arrangement having a portion thereof coupled to the frequency-adjusting element for mechanical movement thereof to control the operating frequency of the oscillator.

Another feature of the present invention is a magnetostriction arrangement to control the operating frequency of an oscillator, which compensates for temperature variation in the oscillator, enables a frequency modulation of the operating frequency of the oscillator, and provides a manual coarse adjustment for the operating frequency of the oscillator.

Still another feature of the present invention is the provision of a magnetostriction arrangement having a portion thereof coupled to an element of the frequency-control gap of a klystron-type oscillator to mechanically

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move this element to control the operating frequency of the klystron.

A further feature of the present invention is the provision of a magnetostriction arrangement employing a plurality of ferromagnetic bars. In one embodiment, the direction of magnetostriction of two bars is the same, and the direction of magnetostriction of a third bar is opposite to that of the two bars. These three bars are disposed in a common magnetic field to bring about the desired mechanical movement of the frequency-adjusting element. In another embodiment, two ferromagnetic bars have the magnetostriction effect in the same direction, with each of the bars being effected by its own magnetic-field-producing means to bring about the desired mechanical movement of the frequency-adjusting element.

The above-mentioned and other features and objects of this invention will become more apparent by reference to the following description taken in conjunction with the accompanying drawings, in which:

FIGS. 1a and 1b illustrate schematically two different magnetostriction arrangements which may be utilized in conjunction with an oscillator for mechanical tuning thereof;

FIG. 2 is an elevational view, partially in section, illustrating one embodiment of a frequency-control system following the principles of this invention for tuning a klystron oscillator;

FIG. 3 is an elevational view, partially in section, illustrating still another embodiment of a frequency-control system following the principles of this invention for tuning a klystron oscillator; and

FIG. 4 is a schematic diagram of one form of a control circuit operable with the magnetostriction arrangement of FIG. 3.

It is known that, when a ferromagnetic bar is placed in a magnetic field extending axially of the bar, the bar is subjected to a change in dimension due to the magnetostriction effect therein which is dependent upon the intensity of the magnetic field. By providing a fixed clamp or bridge to interconnect one end of two bars, it is possible to establish a completely rigid arrangement which does not include any gears or other such moving parts and enables the achievement of a defined change in dimension.

Referring to FIG. 1a, there is illustrated one possible arrangement for utilizing this magnetostriction phenomenon in a tuning or frequency-control arrangement. Two bars 1 and 2 of ferromagnetic material having opposite directions of magnetostriction are placed in parallel relation to one another and in a common magnetic field produced by coil 3. Bars 1 and 2 are rigidly connected to one another at one end by clamp 4. When the intensity of the magnetic field traversing the bars 1 and 2 in the axial direction is varied, one bar is reduced in length while the other bar is extended in length. At the free ends 5 and 6 of bars 1 and 2, there is available a useful stroke  $L_1$  equal to the sum of the changes in dimensions of both bars 1 and 2.

Referring to FIG. 1b, there is illustrated still another magnetostriction arrangement, which can be employed to provide a frequency-control system for oscillators. Bars 7 and 8, having the same direction of magnetostriction, are disposed parallel with respect to each other. Bar 7 has its own axial magnetic field produced by coil 9, and bar 8 has its own axial magnetic field produced by coil 10. Bars 7 and 8 are interconnected at one end thereof by means of clamp 4'. The two coils 9 and 10 are energized by a push-pull circuit so that at one instant of time only the dimension of one of the bars 7 and 8 is changed which contributes to the total useful stroke of plus or minus  $L_2$ . The advantage of this arrangement is that it requires no external control of its mean working point.

In the following discussion with reference to FIGS. 2

and 3, there are disclosed two embodiments relating to a mechanical frequency-control system for a directly modulated reflex klystron. It is to be remembered, however, that the description of FIGS. 2 and 3 is not meant to limit the scope of this invention but rather is employed as an example of the application of the magnetostriction principle to the mechanical frequency control of an oscillator.

As is well known, there is no possibility of effecting an electronic frequency control in a directly modulated klystron because the reflector electrode utilized for this purpose is already occupied by the modulating voltage. If a direct-current frequency-control signal were superimposed on the modulating voltage for frequency control, there would result an undesirable varying or deterioration of the linearity of the converter characteristics of the klystron. With respect to this type of oscillator, it is, therefore, most appropriate to influence the operating frequency by varying the distance between the electrodes forming the so-called control gap. It has been observed that a change of distance between these control electrodes of only 10 microinches in the gigacycle-per-second frequency range causes a frequency variation of 50 megacycles per second. Thus, a frequency-control system utilizing the magnetostriction phenomenon for the mechanical positioning of the frequency-adjusting element is particularly suitable to obtain frequency control for this type of klystron with a frequency stability of plus or minus 500 cycles per second.

Referring to FIG. 2 and FIG. 3, there is illustrated therein a portion of the klystron 11 to be mechanically tuned. Klystron 11 includes a member 12, which could be the envelope thereof, secured to the cooling assembly 13, a housing 14 for the repeller or anode electrode and electrode 15 forming one element of the control gap whose physical displacement relative to the other element of the control gap fixed in its physical location will bring about the desired frequency control. The mechanical drive arrangement for the frequency-adjusting element, electrode 15, includes ferromagnetic bars 16 and 17 each of which has negative magnetostriction and, hence, is reduced in length when placed in a magnetic field extending in its axial direction. Bars 16 and 17 are rigidly connected to cooling assembly 13 at their lower ends, while their upper ends are connected to one another by means of bridge 18. Within this forklike structure there is disposed ferromagnetic bar 19 having a positive magnetostriction. At the upper end of bar 19 is mounted a threaded bolt 20, which engages the internal threads of bushing 21 composed of a non-magnetic material. The external threads of bushing 21 engage threads of the threaded bore disposed in bridge 18. The magnetic field which is necessary for magnetostriction in bars 16, 17, and 19 is produced by a common field coil 22 enclosing bars 16, 17, and 19. To complete the magnetic flux path on the outside of the coils, without any substantial loss of magnetic energy, and to provide a magnetic shield therefor, there is provided an enclosing structure 23 of ferromagnetic material. Bar 19 is provided with a bore 24 into which the housing 14 of klystron 11 projects. In order to feed the operating voltage to the electrode contained in housing 14, there is provided a bore 25 at right angles to bore 24. Bar 19 also includes a terminating ring 26 which is rigidly connected to member 27, carrying electrode 15. Member 27 and, hence, electrode 15 are capable of movement with respect to a fixed portion of the magnetostriction arrangement, such as cooling assembly 13, and also the other element of the control gap whose position is fixed. With this arrangement, the useful stroke for electrode 15 relative to assembly 13 is the sum of the magnetostriction deformation of bar 19 and bars 17 and 16 substantially as described with respect to FIG. 1a, and will thereby provide the desired frequency control of the operating frequency of klystron 11.

It is of importance to the operation of the frequency-

control system disclosed in FIG. 2 that the material for bars 16, 17, and 19 be so chosen that the changes in dimension of bars 16 and 17 on one hand and bar 19 on the other hand, resulting from temperature variations, annul each other, while the changes in dimensions due to magnetostriction add to one another upon variation of the common magnetic field. A manual coarse adjustment of the operating frequency of klystron 11 can be obtained by manually turning bushing 21. According to one method of accomplishing this manual coarse adjustment, the external threads of bushing 21 are provided with a different pitch than the internal threads thereof so that one rotation of bushing 21 will cause bar 19 to move axially by an amount corresponding to the difference of the pitches of the internal and external threads. The thusly obtained coarse frequency adjustment can then be fixed by means of locknut 28.

Referring to FIG. 3, there is illustrated another embodiment of the magnetostriction arrangement of this invention described in connection with the frequency control of a klystron oscillator. Bar 29 of ferromagnetic material is placed in the magnetic field produced by coil 30, and bar 31 of ferromagnetic material is placed in the magnetic field produced by coil 32. Both of these ferromagnetic bars are of the same material and, thus, have the same magnetostriction direction, that is, they either both expand (lengthen) under the influence of the magnetic field extending in their axial direction, or they both are contracted (shortened). Bar 29 has fastened to one end thereof threaded bolt 33, and bar 31 has fastened to one end thereof bolt 34. Bolts 33 and 34 are screwed into their associated threaded bushings 35 and 36. Threaded bushings 35 and 36 are in turn screwed into the specially provided threaded bores in bridge 37 composed of a non-magnetic material. With this structural arrangement, a rigid connection is established between bars 29 and 31, which transfers any axial displacement of one bar to the other bar. To complete the magnetic flux path and to shield the magnetic fields, coils 30 and 32 are surrounded by their associated ferromagnetic shields 38 and 39 respectively. The bar 31 is rigidly connected to the cooling assembly 40, which in turn is coupled to a fixed portion of the klystron being frequency controlled substantially as illustrated and described with respect to FIG. 2. Bar 29 includes a bore 41 which receives a portion of the klystron being frequency controlled and includes a flanged portion 42 coupled to the grid-retaining member, which is movable with respect to the fixed member, assembly 40, substantially as illustrated in FIG. 2. Movement of the grid-retaining member provides the desired change in position of the movable electrode of the control gap with respect to the fixed electrode thereof.

The operation of the arrangement of FIG. 3, which in principle corresponds to that shown and described in connection with FIG. 1b, will now be explained with reference to the control arrangement for the two field coils 30 and 32 illustrated in FIG. 4.

Referring to FIG. 4, a potentiometer 42a is driven by means of motor 43, which responds to a frequency-control signal whose magnitude and polarity are related to the magnitude and direction of the frequency drift of the klystron with respect to the desired operating frequency. By means of potentiometer 42a, the grids of the two push-pull connected tubes 44 and 45 are biased more or less negatively. The operating condition of both tubes is chosen so that, when potentiometer 42a is positioned at its midpoint, the tubes draw almost no current or at least only small equal amounts of residual currents whose magnetostrictive effects upon bars 29 and 31 annul each other. If potentiometer 42a, due to a frequency drift of the operating frequency of the klystron, is shifted to the left, then tube 44 is rendered nonconductive, and tube 45 is rendered conductive. Accordingly, only the field coil 32 will produce a magnetic field which will cause bar 31 to change in dimension (length) and consequently through

bridge 37 will cause the grid holder of the klystron to be displaced in a direction counteracting the frequency drift. Thus, a difference in position of the free end of bar 29 with respect to the cooling assembly 40 will appear as soon as a current flows through one of the two field coils. The advantage of this arrangement over the arrangement illustrated in FIG. 2 resides in the fact that the two field coils at the median working point of the frequency-control system, corresponding to the desired or assigned operating frequency of the klystron, are practically deenergized (currentless), and thus, do not contribute towards a variation of the length (change in dimension) of the bars by way of heating due to current flowing in the field coils which would be difficult to counteract.

Instead of employing potentiometer 42a, it would also be possible to feed an alternating-current voltage via a transformer provided with a center tap to the tubes 44 and 45. With this arrangement, there would then be provided a wobulator having a relatively large modulating frequency swing, in the order of approximately 100 megacycles per second.

The magnetostriction arrangement described in connection with FIG. 3 can enable a compensation of the variation in the operating condition of the klystron due to temperature and also provide a manual coarse adjustment for the operating frequency of the klystron.

The manual coarse frequency adjustment is provided by cooperation of threaded bolt 34 and bushing 36 substantially as described with respect to threaded bolt 20 and bushing 21 in FIG. 2. The temperature compensation is provided by having bridge 37 and threaded bolt 33 made of materials having a different temperature coefficient and positioning the bottom of bushing 35 on bolt 33 a distance L3 from the top of bar 29. The proper selection of the material for bolt 33 and bridge 37 to provide the desired difference in temperature coefficient, and proper positioning of bushing 35 on bolt 33, will have the effect of a difference in length appearing between bars 29 and 31, with the amount of this difference being selected to counteract operating variations of the klystron due to temperature variations. The polarity of this control quantity is decided merely by the fact of which one of the two materials has the smaller or greater temperature coefficient, and the intensity of this control quantity is determined by the position of bushing 35 in bridge 37. To achieve this temperature compensation, it is preferred that the internal and external threads of bushing 35 have the same pitch. In a successful reduction to practice of the temperature-compensation arrangement, the bridge 37 and bolt 34 were made of brass, and the bolt 33 was made of invar steel.

While I have described hereinabove embodiments of the frequency-control system of this invention in connection with klystron oscillators, it is possible to employ the principles of this invention in conjunction with an oscillator including a mechanically variable capacitor wherein one plate of the capacitor is fixed in position and the other plate of the capacitor is movable with respect to the fixed plate. Thus, by employing the principles of the magnetostriction arrangements described herein, it would be possible to adjust the frequency of the oscillator circuit, dependent upon the magnitude of the magnetic field, by shifting the movable plate of the capacitor in accordance with the magnetostriction deformation in the ferromagnetic bar connected thereto.

While I have described the principles of my invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of my invention as set forth in the objects thereof and in the accompanying claims.

I claim:

1. A frequency-control system for an oscillator comprising a frequency-adjusting element mechanically movable with respect to a fixed member, and a magnetostriction arrangement having one portion thereof coupled to

said fixed member and another portion thereof coupled to said frequency-adjusting element for mechanical movement thereof relative to said fixed member to control the operating frequency of said oscillator, said magnetostriction arrangement including first and second ferromagnetic bars disposed in a parallel relation, each having one end coupled to said fixed member, a third ferromagnetic bar disposed in parallel relation to said first and second bars and having one end coupled to said frequency-adjusting element, said first and second bars having a direction of magnetostriction opposite to the direction of magnetostriction of said third bar, means to produce a magnetic field axially of and in common to each of said bars, and means rigidly interconnecting the other end of each of said bars, to impart to said frequency-adjusting element a movement equal to the magnetostriction deformation of said first and second bars plus the magnetostriction deformation of said third bar.

2. A frequency-control system for an oscillator comprising a frequency-adjusting element mechanically movable with respect to a fixed member, and a magnetostriction arrangement having one portion thereof coupled to said fixed member and another portion thereof coupled to said frequency-adjusting element for mechanical movement thereof relative to said fixed member to control the operating frequency of said oscillator, said magnetostriction arrangement including a first ferromagnetic bar having one end thereof coupled to said fixed member, first means to produce a magnetic field axially of said first bar, a second ferromagnetic bar having one end thereof coupled to said frequency-adjusting element, second means to produce a magnetic field axially of said second bar, said first and second bars being disposed parallel to each other and having the same direction of magnetostriction, means rigidly interconnecting the other end of each of said bar, and means controlling said first and second field-producing means to selectively produce magnetostriction in one of said first and second bars to impart to said frequency-adjusting element a movement equal to the magnetostriction deformation of the selected one of said first and second bars.

3. A frequency-control system for an oscillator, said oscillator having a pair of elements which cooperate to form a frequency-determining gap, a first one of said elements being movable with respect to a second one of said elements, said system including a plurality of ferromagnetic bodies, said ferromagnetic bodies being coupled together, a first one of said ferromagnetic bodies being coupled to said first one of said elements, a second one of said ferromagnetic bodies being coupled to said second one of said elements, and magnetic-field-producing means disposed relative to said ferromagnetic bodies to produce magnetostriction therein and to control the spacing of said first one of said elements with respect to said second one of said elements.

4. A system according to claim 1, wherein said interconnecting means includes a manual coarse frequency adjustment arrangement coupled to said third bar.

5. A system according to claim 1, wherein said means to produce a magnetic field includes an arrangement to modulate the operating frequency of said oscillator.

6. A system according to claim 1, wherein said first and second bars are composed of a first type of ferromagnetic material and said third bar is composed of a second type of ferromagnetic material to annul dimension changes of said bars due to temperature variations.

7. A system according to claim 2, wherein said interconnecting means includes a manual coarse frequency adjustment arrangement coupled to one of said bars.

8. A system according to claim 2, wherein one portion of said interconnecting means is composed of a first material having a first temperature coefficient and another portion of said interconnecting means cooperating with said one portion is composed of a second material having a temperature coefficient different than said first tempera-

ture coefficient to effect compensation for variations in said oscillator due to temperature variations.

9. A system according to claim 2, wherein said first and second producing means are coupled to a circuit arrangement to modulate the operating frequency of said oscillator.

10. A system according to claim 2, wherein said first and second field producing means each include a coil disposed coaxially about the associated one of said bars and a push-pull circuit arrangement coupled to said coils to provide substantially no current through said coils at the operating frequency of said oscillator.

11. A frequency-control system for a klystron comprising a movable member coupled to one electrode of the control gap of said klystron to adjust the operating frequency thereof, a cooling assembly for said klystron, first and second ferromagnetic bars disposed in a parallel relation each having one end coupled to said assembly, a third ferromagnetic bar disposed in parallel relation to said first and second bars having one end coupled to said movable member, said first and second bars having a direction of magnetostriction opposite to the direction of magnetostriction of said third bar, means to produce a magnetic field axially of and common to each of said bars, and a bridge member rigidly interconnecting the other end of each of said bars to impart to said movable member a movement equal to the magnetostriction deformation of said first and second bars plus the magnetostriction deformation of said third bar to control the operating frequency of said klystron.

12. A system according to claim 11, wherein said interconnecting means includes a manual coarse frequency adjustment arrangement including a threaded bore in said interconnecting means, a bushing having external threads engaging the threads of said bore and internal threads, a threaded bolt connected to said third bar screwed into the internal threads of said bushing, the internal and the external threads of said bushing having a different pitch, and means coupled to said bushing to manually position said third bar with respect to said fixed member by a distance equal to the difference in pitch between the internal and the external threads of said bushing.

13. A system according to claim 11, wherein said means to produce a magnetic field includes an arrangement to vary the intensity of the magnetic field in accordance with a modulating frequency to modulate the operating frequency of said klystron.

14. A frequency-control system for a klystron comprising a movable member coupled to one electrode of the electrodes forming the control gap of said klystron, a cooling assembly coupled to said klystron, a first ferro-

magnetic bar having one end thereof coupled to said cooling assembly, first means to produce a magnetic field axially of said first bar, a second ferromagnetic bar having one end thereof coupled to said movable member, second means to produce a magnetic field axially of said second bar, said first and second bars being disposed parallel to one another and having the same direction of magnetostriction, a bridge member interconnecting the other end of each of said bars, and means controlling said first and second producing means to selectively produce magnetostriction in one of said first and second bars to impart to said movable member a movement equal to the magnetostriction deformation of the selected one of said first and second bars to control the operating frequency of said klystron.

15. A system according to claim 14, wherein said interconnecting means includes first and second threaded borings therein, two bushings each having internal and external threads, the external threads of each of said bushings being adapted to be received by the threads of an associated one of said borings, two threaded bolts each connected to one of said bars to be received by internal threads of an associated one of said bushings, and means to manually adjust the longitudinal position of one of said bushings to displace one of said bars with respect to said fixed member to provide a coarse adjustment for the operating frequency of said klystron.

16. A system according to claim 15, wherein the other of said bushings and said interconnecting means are composed of materials having different temperature coefficients, and means to position the other bushings within its associated one of said borings to adjust the axial position of its associated bar to effect a compensation for operating variations of said klystron due to temperature variations.

17. A system according to claim 14, wherein said first and second means to produce includes a circuit arrangement responsive to an error signal proportional to the frequency drift of the operating frequency of said oscillator to produce a current having a magnitude and polarity determined by said error signal in one of said means to produce to return the frequency of said klystron to the desired operating frequency.

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