

April 26, 1949.

S. F. VARIAN
CAVITY RESONATOR APPARATUS, INCLUDING
FREQUENCY CONTROL MEANS

2,468,145

Filed Nov. 25, 1943

2 Sheets-Sheet 1

FIG. 1.

FIG. 1A.

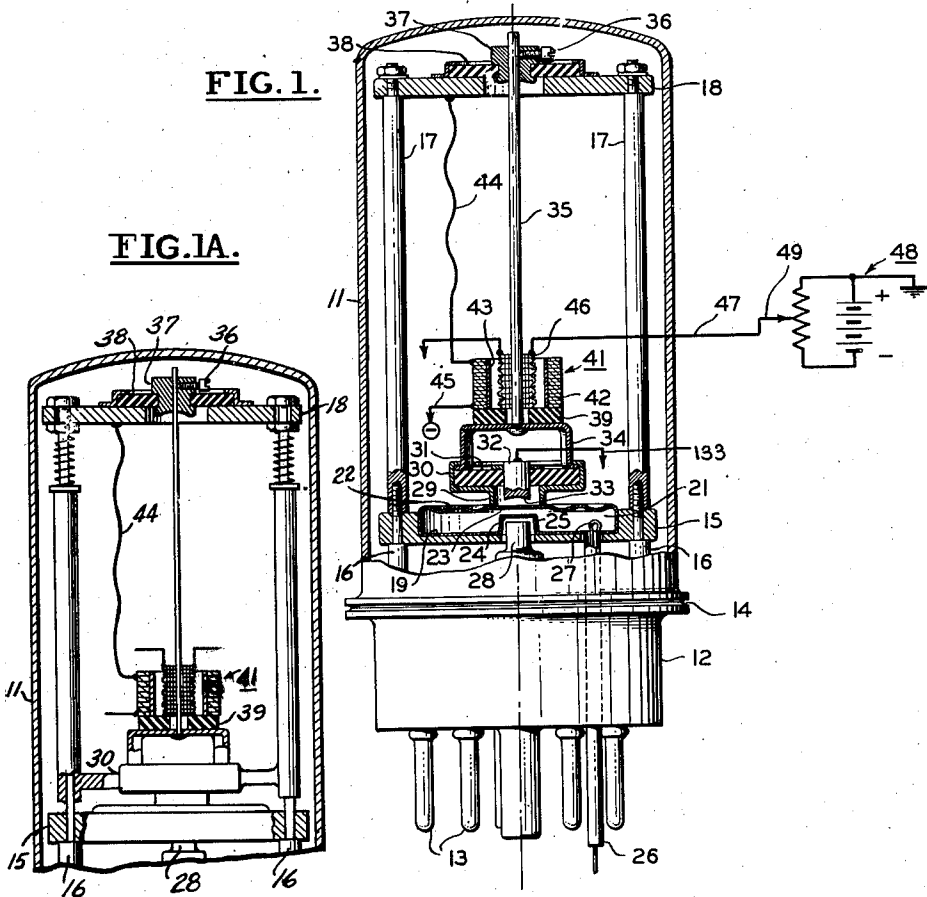
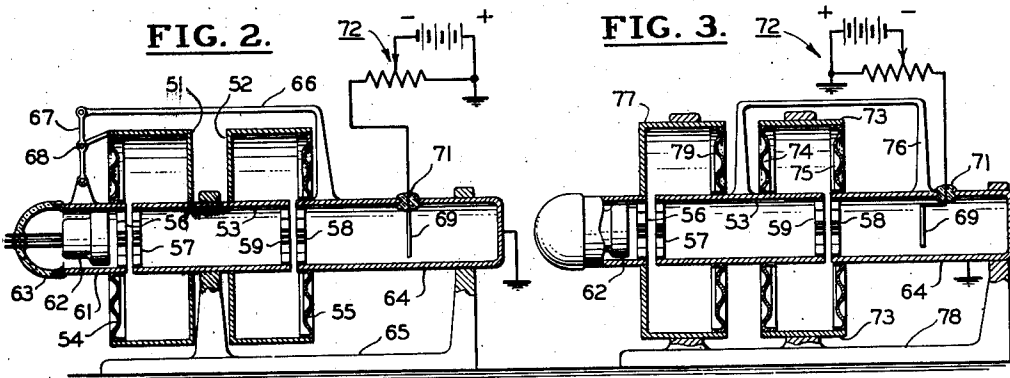


FIG. 2.

FIG. 3.



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2 Sheets-Sheet 2

FIG. 4.

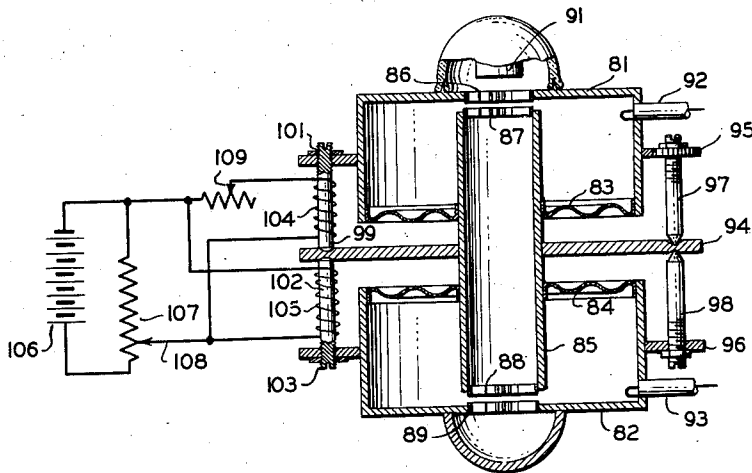
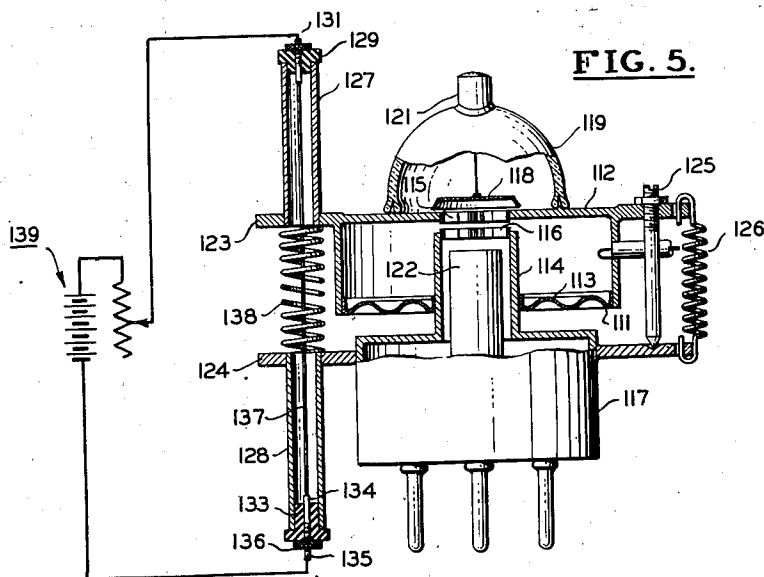


FIG. 5.



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UNITED STATES PATENT OFFICE

2,468,145

CAVITY RESONATOR APPARATUS, INCLUDING FREQUENCY CONTROL MEANS

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5 Claims. (Cl. 315—6)

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This invention relates to frequency control of hollow resonator devices and is more particularly concerned with electrothermal arrangements and methods for controlling frequency in such devices.

Application Serial No. 580,526, filed March 2, 1945, is a division of the present application covering the disclosure of Figs. 4 and 5.

Electron discharge apparatus of the type wherein a beam of electrons is passed in energy exchanging relation with the electromagnetic field of a hollow resonator device are widely used, especially in ultra high frequency systems. In most of such systems, careful and reliable frequency control over the resonator circuit is important. It is known that the effective capacity and inductance of the circuit of a hollow resonator device depends mainly on the shape and/or volume of the resonator, and various mechanical and electrical arrangements and mechanisms have been heretofore suggested for variably controlling the circuit characteristics and frequency of the resonator by altering the resonator shape and/or volume.

The present invention contemplates improvements in such electrical and electromechanical frequency control of hollow resonator devices.

The major object of the invention is to provide novel electrically energized, extremely sensitive, thermally responsive apparatus and methods of frequency control for hollow resonator devices.

A further object of the invention is to provide novel frequency control arrangements for a hollow resonator device wherein a thermally responsive frequency control member such as an expandable and contractible strut or wire operatively connected to said device is heated by electron bombardment.

Further objects of the invention will presently appear as the description proceeds in connection with the appended claims and the annexed drawings wherein:

Figure 1 is an elevation, partly in section, illustrating details of a preferred thermal tuning mechanism according to the invention;

Figure 1—A is a fragmentary elevation view illustrating a modification of Figure 1;

Figure 2 is an elevation, partly in section, of a further embodiment of the invention wherein normally wasted electron energy is utilized for frequency control;

Figure 3 is an elevation, partly in section, of a still further embodiment of the phase of the invention illustrated in Figure 2;

Figure 4 is an elevation, partly in section, illustrating a further embodiment of the invention

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including simultaneous and individual thermally actuated frequency control in a multiple hollow resonator device; and

Figure 5 is an elevation, partly in section, illustrating a further embodiment of the invention wherein a flexible non-rigid frequency control member is operatively connected to a hollow resonator device.

Referring now to Figure 1, an electron discharge device is contained within a cylindrical metal envelope 11 mounted on a conventional type vacuum tube base 12 having prongs 13 for insertion in a supporting socket. Base 12 and envelope 11 are formed with mated lips which are welded or similarly joined as at 14 to complete a vacuum tight closure within the envelope.

A platform 15 within the envelope is supported by posts 16 arising from base 12, and similar support posts 17 extend upwardly from platform 15 for rigidly mounting a bridge plate 18 generally parallel to platform 15. Posts 17, platform 15, posts 17 and plate 18 provide a strong rigid frame solid with base 12 for mounting the various elements of the device within envelope 11.

Platform 15 is formed with a surface recess 19 in which is seated a cylindrical hollow resonator 21 having relatively rigid side and bottom walls soldered or similarly conductively fastened to platform 15. Resonator 21 has a flexible upper wall or diaphragm 22 in which an apertured grid structure 23 is centrally mounted. An adjacent associated parallel grid structure 24 is mounted on the end of a pole 25 formed by a reentrant integral portion of the resonator bottom wall. Grids 23 and 24, which are thus flexibly interconnected, may be of any suitable form, such as wire mesh or the grids disclosed in United States Letters Patent No. 2,261,154.

Resonator 21 is preferably made of copper, with flexible wall 22 comprising an annularly crimped area which has sufficient resiliency to tend to return to its illustrated position where the general plane of wall 22 is normal to the resonator axis.

The bottom resonator wall and platform 15 are apertured for rigidly mounting the inner end of a coaxial conductor transmission line 26 having a conductive loop 27 suitably disposed within the resonator chamber. Line 26 extends in vacuum tight relation through base 12 so as to be accessible for energy extraction. Any desired number of such lines may be provided.

Platform 15 is centrally apertured so that a suitable cathode 28 upstanding from base 12 may be located as close as possible to entrance grid

24 of the resonator. Cathode 28 is suitably energized by connection to selected prongs 13.

A metal collar 29, rigid with exit grid 23 and the adjacent portion of flexible wall 22, is formed with an enlarged flange 30 in which is seated a disc 31 of insulating material centrally supporting a metal block 32. Block 32 has its lower face formed as an arcuate reflector 33 in alignment with grids 23 and 24 and cathode 28. Reflector 33 is thus mounted at a fixed distance from exit grid 23. A lead 133 (not fully shown) for applying a desired electrical potential to reflector 33 is connected between a prong 13 and block 32.

A generally U-shaped rigid bracket 34 has its opposite legs secured to flange 30 and also holds disc 31 in its seat.

An elongated relatively rigid strut or rod 35 has its lower end tightly secured to bracket 34, and its upper end fastened as by screw 36 to a metal block 37 seated on a disc 38 of insulating material fixedly mounted on plate 18 which is suitably apertured for free passage of the strut. Strut 35 is preferably made of stainless steel or some material having a large coefficient of thermal expansion, and is preferably axial with the resonator. Strut 35 is thereby anchored and fixedly secured at opposite ends to grids 23 and 24, so as to determine their spacing.

A collar 39 of insulating material is suitably fastened upon the top of bracket 34 for supporting a cylindrical electron emission electrode structure 41 symmetrically disposed about strut 35. Emission electrode 41 comprises a heater coil 42 and an internal oxide coated electron emission surface 43. Coil 42 has one end electrically connected to the normally grounded frame, as by wire 44, and its other end connected by wire 45 to a suitable prong 13. For clarity of disclosure, all of wire 45 is not shown.

Collar 39 also supports a cylindrical wire mesh grid electrode 46 symmetrical with and between surface 43 and strut 35. A suitable potential is applied to grid 46 as by a lead 47 connected to an adjustable power source 48. Preferably grid 46 is maintained positive with respect to surface 43 as indicated, and adjustment of tap 49 changes the potential on grid 46. Lead 47 and power source 48 have been illustrated diagrammatically in Figure 1 for clarity of disclosure. It will be understood, however, that in practice lead 47 will extend to a prong 13, which will make contact through a suitable socket with source 48.

Electrode 46 need not be a grid but may be any electron control electrode of suitable structure. For some purposes, grid 46 may be omitted and the supply of electrons impacting strut 35 controlled simply by varying the power supply to coil 42.

Where an indirectly heated emitter such as 41 is employed about strut 35, there may be an appreciable time lag in heating and cooling thereof. This time lag may be considerably reduced by using a simple filamentary emitter such as a directly heated tungsten wire coil filament arranged about strut 35, in place of emitter 41. Another short time lag arrangement embodies a nickel wire spiral coil filament emitter arranged about strut 35 and coated directly with emission material.

In operation, an electron stream from cathode 28 is projected through grids 24, 23 and is returned into the resonator through exit grid 23 by reflector 33. According to accepted theories of operation of such devices, the electron stream excites and maintains an oscillatory electromagnetic field

within resonator 21. For detailed discussion of such theory of operation based on velocity modulation of the electrons in the stream, reference is made to United States Letters Patent No. 2,250,511, as such details of operation do not comprise part of the present invention. It is important to the invention only to understand that resonator 21 contains an electromagnetic field or circuit regardless of how the latter is produced.

Closely spaced grids 23 and 24 bound field regions of maximum intensity. Hence, control over the grid spacing will afford optimum control over the frequency of the energy which may be extracted on line 26.

In this phase of the invention the grid spacing, and consequently the shape and volume of resonator 21, is controllably varied by controllably varying the length of strut 35. Upon energization of electrode 41, electrons emitted from surface 43 bombard strut 35, thereby heating strut 35 substantially in proportion to the power input to electrode 41. When heated, strut 35 expands in length as power is expended in heating it and, since its upper end is anchored on the frame, its downwardly displaced lower end acts through bracket 34 and collar 39 to displace grid 23 toward grid 24 as permitted by the flexibility of wall 22. While electrode 41 is shown as coextensive with only a portion of strut 35, it may be made coextensive with any length of strut 35 according to the heating effect desired.

Electron bombardment of strut 35 from surface 43 is accurately and sensitively controlled by varying the potential of grid 46 by adjustment of tap 49. As grid 46 is made more positive, more electrons are drawn from surface 43 and permitted to impact strut 35, to thereby increase the temperature and elongation of strut 35. As grid 46 is made less positive, fewer electrons from surface 43 are permitted to impact strut 35, thereby decreasing the temperature and length of strut 35.

Operation of the above-described arrangement for controlling the temperature of strut 35 may be compared to operation of the conventional three element vacuum tube, with strut 35 and electrode 41 corresponding to the usual anode and cathode, respectively, and grid 46 functioning as the usual control grid. The top of bracket 34 is designed to serve as a shield for preventing stray electromagnetic fields from the strut heating unit from affecting the operation of resonator 21.

Thus, as strut 35 is elongated by an increase in temperature, grids 23 and 24 approach each other and the resonant frequency of resonator 21 is decreased. As strut 35 is shortened by any decrease in temperature, grids 23 and 24 are separated and the resonant frequency of resonator 21 is increased. The space charge control afforded by grid 46 gives instantaneous and reliable control over the heating power for strut 35. This manner of frequency control is especially useful for automatic frequency regulation systems where instantaneously responsive control action is important.

While, in Figure 1, I have illustrated the expansible and contractible frequency control member as a rigid strut which effects positive frequency control motion in opposite directions, it will be apparent that this phase of the invention is also applicable to devices wherein strut 35 is replaced by an expansible and contractible non-rigid member such as a tungsten wire connected

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between block 37 and bracket 34 and biased by a suitable spring tending to keep the wire taut as shown in Fig. 1A.

Figures 2 and 3 illustrate further similar embodiments of the invention wherein the electron stream, after interaction with a hollow resonator device, is employed to actuate frequency control in the device.

Referring to Figure 2, spaced hollow cylindrical resonators 51 and 52 having adjacent walls rigid with a drift tube 53 are provided with flexible opposite end walls 54 and 55. Grids 56 and 57 are provided in wall 54 and the adjacent end of tube 53, and grids 58 and 59 are provided in wall 55 and the adjacent end of tube 53.

A collar 61, rigid with grid 56, supports a suitable cathode 62. The end of collar 61 is vacuum sealed by a glass or like cap 63 through which extend leads for energizing the cathode.

At the other end of the device, an elongated hollow strut or tube 64 of stainless steel or like high coefficient of thermal expansion material is rigid with exit grid 58 and has its outer end anchored in a suitable base or support 65. The whole hollow resonator device is further mounted on base 65 by rigid attachment to drift tube 53 as illustrated.

Tube 64 has securely fastened thereto a radially and longitudinally extending bar 66 pivotally connected to one end of a lever 67 which has its other end pivoted on collar 61. Intermediate its ends, lever 67 is fulcrumed upon a pivot point 68 rigid with drift tube 53 as illustrated.

A suitable electrode 69 which enters tube 64 through an aperture sealed by glass bead 71 is energized from a suitable adjustable unidirectional power supply indicated at 72. Electrode 69 is maintained negative as will appear.

In operation, electrons in the electron stream from cathode 62 are velocity modulated by passage through resonator 51, become velocity grouped during passage along tube 53, and give up energy to resonator 52 before passing through exit grid 58. Operation of such a device as an amplifier or oscillator is explained in detail in United States Letters Patent No. 2,242,275.

The electron stream emerging from exit 58 represents considerable energy which is usually wasted by dissipation in cooled collector electrodes. In the present invention, negatively biased electrodes 69 repels, deflects and otherwise disperses the electrons in the emergent stream so that many of the electrons impact tube 64. Tube 64 is thus heated by electron bombardment, and the degree of such heating can be sensitively controlled by making electrode 69 more or less negative to control the electron dispersion.

Tube 64 elongates when its temperature is raised. Since the outer end of tube 64 is anchored with respect to grid 59, elongation of tube 64 causes grid 58 to become displaced toward grid 59 as permitted by flexible wall 55, to thereby decrease the frequency of resonator 52. Equivalent motion of grid 56 toward grid 57 to proportionately decrease the frequency of resonator 51 is obtained through the motion transmitting mechanism consisting of bar 66 and lever 67.

Thus by controlling the power supplied to electrode 69, I may sensitively effect coordinated frequency control of gang tuning of both resonators 51 and 52.

Electrons which pass electrode 69 bombard the outer end of tube 64 thereby heating that end. This heat is, however, effectively dissipated due to the large surface for radiation at the tube end,

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and due to conduction by the supporting base, and does not appreciably interfere with the above described frequency control.

In the embodiments of the invention of Figures 1 and 2, I effect accurate and reliable frequency control with the expenditure of very little power. In Figure 1, the power required to energize emitter 41 is low, and the power required for control grid 46 is almost negligible. In Figure 2, the power required to actuate control electrode 69 is only of about the same magnitude as required for grid 46.

Since the movements necessary for frequency control are small, the inherent resilience of flexible wall 54, which is the same as wall 22, renders it unnecessary to employ lost motion linkage and keeps the mechanism tight under all operating conditions. Figure 3, however, illustrates a device of the type of Figure 2 where pivotal motion transmitting links are eliminated.

Resonator 52 is replaced by a resonator 73 having two flexible end walls 74 and 75 secured respectively to drift tube 53 and exit grid 58. Bar 66 and lever 67 are replaced by a rigid bar 76 having its opposite ends secured to drift tube 53 and substantially the medial portion of tube 64. Resonator 51 is replaced by a resonator 77 which together with resonator 73 is rigidly mounted on base 78 and has a flexible wall 79 connected to drift tube 53.

At its outer end, tube 64 is anchored to base 78, and bar 76 is secured to tube 64 about halfway between that fixed end and grid 58. This arrangement insures equal and corresponding displacement of each pair of grids when tube 64 changes in length. For example, when tube 64 increases its length upon being heated, grid 58 moves a predetermined distance toward grid 59 and displacement of bar 76 causes longitudinal shift of tube 53 and both grids 57 and 59 about one-half that distance. Thus, the distance between each pair of grids 56, 57 and 58, 59 is decreased by one-half the total displacement of grid 58. The reverse operation is accomplished when tube 64 contracts.

The invention as applied to Figures 2 and 3 is equally applicable to amplifiers and oscillators where the two resonator chambers are usually of equal size, and to devices such as frequency multipliers including unequally sized resonators. In the latter case, the dimensions of lever 67 (Figure 2) and the point of attachment of bar 76 to tube 64 (Figure 3) may be selected to secure the required proportionate tuning displacement.

While I have shown control electrode 69 as within strut 64 in the path of the electron beam, it is within the scope of the invention to employ for the same purpose any electron beam deflecting electrode or member such, for example, as a suitably polarized magnet laterally outside tube 64.

Figure 4 illustrates a two hollow resonator device having individual thermally responsive frequency control members arranged for gang or differential tuning.

Two hollow cylindrical resonators 81 and 82 are connected by adjacent flexible walls 83 and 84, similar to wall 22, to a drift passage tube 85. Electron permeable grid pairs 86, 87 and 88, 89 are provided on opposite ends of tube 85 and the adjacent resonator walls. A suitable cathode 91 is mounted in alignment with the grids, and the usual concentric line terminals are provided at 92 and 93.

A heavy radial flange 94, rigid with drift tube

85, is disposed equally intermediate similar parallel flanges 95 and 96 rigid with grids 86 and 89 respectively. A plurality of circumferentially spaced adjustable screw assemblies such as indicated 97 and 98 are provided between the associated flanges as illustrated. Usually screw assemblies 97 and 98 are so adjusted as to produce some flexure of walls 83 and 84 so as to select a predetermined grid spacing and keep the parts tight.

One pair of the screw assemblies is thermally responsive and controllably energized as illustrated at the left of Figure 4. A strut 99 of stainless steel, aluminum, duralumin or the like is held between flange 94 and a short screw 101 threaded in flange 95. Similarly an aluminum or like strut 102 is held between flange 94 and a short screw 103 threaded in flange 96. Heater coils 104 and 105 of resistance wire are electrically insulatingly mounted about rods 99 and 102 respectively.

A battery 106 has a resistor 107 in parallel therewith and both heater coils 104, 105 are connected across the resistor so that adjustment of tap 108 similarly varies the power delivered to each coil. The lead to coil 104 also passes through an adjustable resistor 109 by which the relative power delivered to coils 104 and 105 may be varied for trimming or differentially tuning the resonators.

Usually three 120° spaced tuning control assemblies are employed, two aligned screw assemblies 97, 98 and one aligned strut arrangement 104, 105. The small frequency control movements involved render any departures from parallelism of the grids due to such movement immaterial. If desired moreover, all three strut assemblies may be made identical with that at 104, 105 and all connected to battery 106 and resistor 107 in the same manner. This will give accurate and exactly parallel relative displacement of the grids.

In operation, preliminary and rough frequency control adjustments are made with screw assemblies 97, 98 and screws 101 and 103. Expansion and contraction of rods 99 and 102 by controlled energization of coils 104, 105 result in corresponding displacements of grid pairs 86, 87 and 88, 89. If the inherent resiliency of walls 83 and 84 is not sufficient to keep the parts tight, tension springs (not shown) may be provided between the flanges. Simultaneous and similar frequency control of each resonator 81 and 82 can thus be obtained by adjustment of tap 108. This is electrical gang tuning. The frequency of resonator 81 may be independently varied by adjustment of resistor 109. This is a trimming adjustment to compensate for physical and/or electrical inequalities between the resonators.

I have found that, using struts 99, 102 of aluminum, an elongation of about 0.008 inch for a 300° C. rise in strut temperature. The amount of movement is ample for the usual required tuning range. If desired, struts 99 and 102 may be hollow with heater coils 104, 105 inside.

This gang tuning arrangement may be also accomplished by passing heating current directly through struts 99 and 102, the latter being suitably insulated and rigidly connected to flanges 94, 95 and 96.

In Figure 5, a hollow resonator 111 has a rigid end wall 112 and a flexible end wall 113 centrally supporting a hollow post 114 which extends into the resonator to terminate adjacent wall 112. Suitable electron permeable grid structures 115 and 116 are provided in wall 112 and the inner end of post 114. The outer end of post 114 is se-

cured to a conventional pronged vacuum tube base 117. On the other side of resonator 111, a shallow cup-shaped metal reflector 118 is suitably mounted within a glass or like sealing cap 119. Reflector 118 is electrically connected to an external terminal 121 by which a suitable potential may be applied to the reflector. A cathode 122 extends within the post 114 in alignment with the grids and reflector.

Radial flanges 123 and 124 are provided rigid with grids 115 and 116 respectively. A plurality of circumferentially spaced adjustable length screw assemblies 125 (only one shown), each biased by associated tension springs 126, are provided between flanges 123 and 124, for manual frequency control adjustments.

Flanges 123 and 124 are formed with aligned apertures in which hollow tubes 127 and 128 of Invar or some metal or alloy having a very low coefficient of thermal expansion are fixed and extend in opposite directions. The end of tube 127 is closed by a plug 129 of insulating material in which is securely imbedded a conductive rod 131, and the threaded outer end of rod 131 carries a reinforcing nut 132.

The outer end of tube 128 is closed by a suitable insulating plug 133 which is centrally apertured to slidably receive a short conductive rod 134 having a threaded outer end 135 for mounting a knurled nut 136. A non-rigid expansible and contractible conductor 137, preferably a thin flexible tungsten strip or wire, is secured at opposite ends to rods 131 and 134. Conductor 137 may be set at predetermined tension by adjustment of nut 136. A wire is preferable because it heats up and loses heat rapidly whereby lending itself to automatic tuning, and a tungsten wire is preferable because of its exceptional strength and toughness even at high heat. Any metal or alloy having a slow uniform expansion and contraction in response to heating by electrical current passing therethrough may be employed for wire 137. A suitable compression spring 138 is arranged between flanges 123 and 124 and surrounding conductor 137.

In operation, relative separation of grids 115 and 116, and hence frequency control of resonator 111 may be effected by controllably energizing conductor 137 from an adjustable power source 139. As conductor 137 is increasingly heated, it expands in length, and spring 138 is permitted to increase the spacing between grids 115, 116 to thereby increase the resonator frequency. When conductor 137 cools it contracts to produce the reverse frequency control. Springs 126 are not sufficiently strong to interfere with the above operation.

Besides permitting the use of a long wire 137 for obtaining appreciable tuning motion, tubes 127 and 128 provide protective draft shields for wire 137.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. High frequency apparatus comprising a cavity resonator having a pair of aligned relatively movable electron-permeable wall portions, a rigid tuning strut coupled between said wall portions and adapted upon expansion or contrac-

tion to alter the spacing of said wall portions and thereby to tune said resonator, said strut extending along the direction of alignment of said wall portions, a source of electrons adjacent to said strut and adapted to project electrons thereat to heat and alter the length of said strut, and a control electrode between said source and said strut for controlling the magnitude of the heating electron current from said source to said strut.

2. High frequency apparatus comprising a cavity resonator having a pair of relatively movable electron-permeable wall portions, a cathode on one side of said resonator, a reflector electrode on the other side of said resonator, a rigid tuning strut coupled between said wall portions and extending generally in alignment with said cathode, wall portions and reflector electrode and adapted upon expansion or contraction to alter the spacing of said wall portions and thereby to tune said resonator, a source of electrons adjacent to said strut and adapted to project electrons thereat to heat and alter the length of said strut, and a control electrode between said source and said strut for controlling the magnitude of the heating electron current from said source to said strut.

3. High frequency apparatus comprising a vacuum envelope, a cavity resonator within said envelope and having a pair of relatively movable electron-permeable electrodes, means in said envelope for projecting a stream of electrons through said electrodes to be velocity modulated by the field therebetween, means in said envelope for reflecting said electrons and reprojecting them through said electrodes to give up energy to said field, a rigid elongated thermally expansible tuning strut in said envelope rigidly connected at each end to a respective one of said electrodes, said strut extending along the direction of said electron stream path, a cylindrical control grid surrounding said strut, and a cylindrical cathode surrounding said control grid, whereby said strut may be controllably heated by electrons from said cathode under the control of said control grid to adjust the spacing of said electrodes and thereby tune said resonator.

4. High frequency apparatus comprising a vacuum envelope, a cavity resonator within said

envelope and having a pair of relatively movable electron-permeable electrodes, means in said envelope for projecting a stream of electrons through said electrodes, a rigid elongated thermally expansible tuning strut in said envelope rigidly connected at each end to a respective one of said electrodes, said strut extending substantially parallel to the direction of said electron stream path, a control grid surrounding said strut, and a cathode surrounding said control grid, whereby said strut may be controllably heated by electrons from said cathode under the control of said control grid to adjust the spacing of said electrodes and thereby tune said resonator.

5. High frequency apparatus comprising a cavity resonator having a pair of relatively movable electron-permeable electrodes, means in said apparatus for projecting a stream of electrons through said electrodes, a thermally expansible tuning member rigidly connected at each end to a respective one of said electrodes, said member extending substantially parallel to the direction of said electron stream path, a control grid adjacent said member, and a cathode aligned with said control grid and said member whereby said member may be controllably heated by electrons from said cathode under the control of said control grid to adjust the spacing of said electrodes and thereby tune said resonator.

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