

Nov. 11, 1969

W. H. PERKINS ET AL
PIEZOELECTRIC BIMORPH DRIVEN TUNERS
FOR ELECTRON DISCHARGE DEVICES

3,478,246

Filed May 5, 1967

3 Sheets-Sheet 1

Fig. 1.

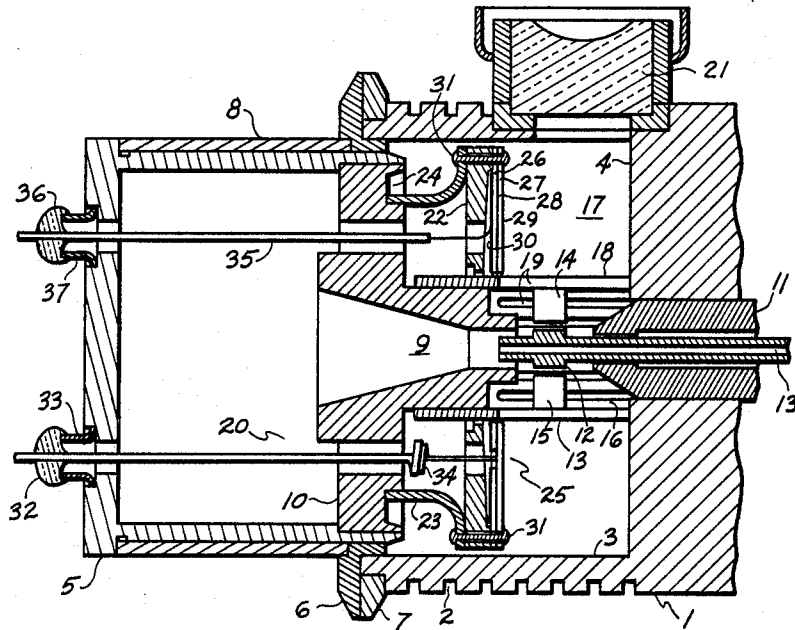
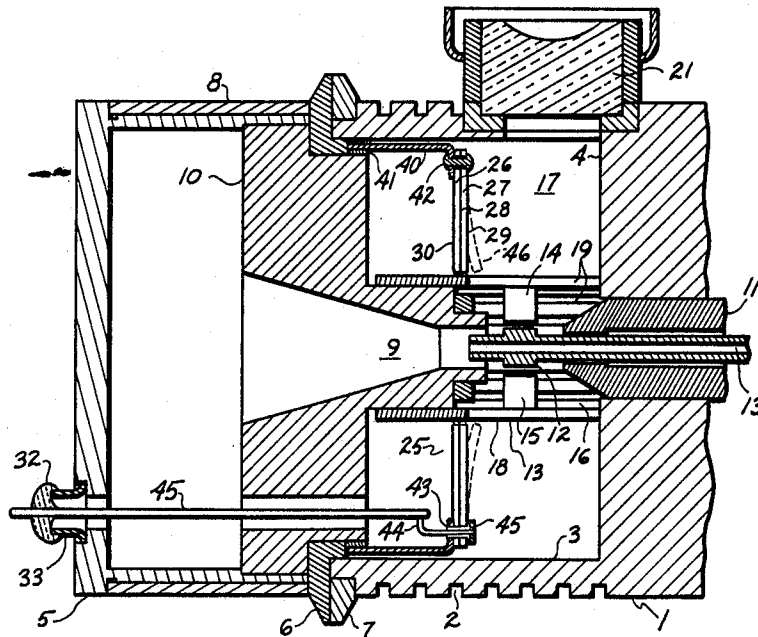


Fig. 2.



INVENTORS.
William H. Perkins
Robert E. Klotz

BY
Ronald M. Goldman
ATTORNEY

Nov. 11, 1969

W. H. PERKINS ET AL
PIEZOELECTRIC BIMORPH DRIVEN TUNERS
FOR ELECTRON DISCHARGE DEVICES

3,478,246

Filed May 5, 1967

3 Sheets-Sheet 2

Fig. 3.

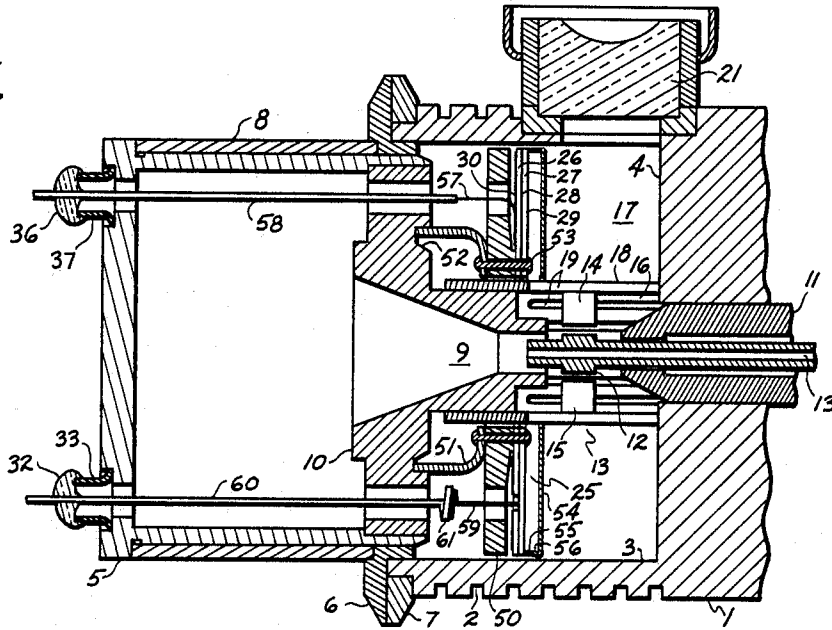
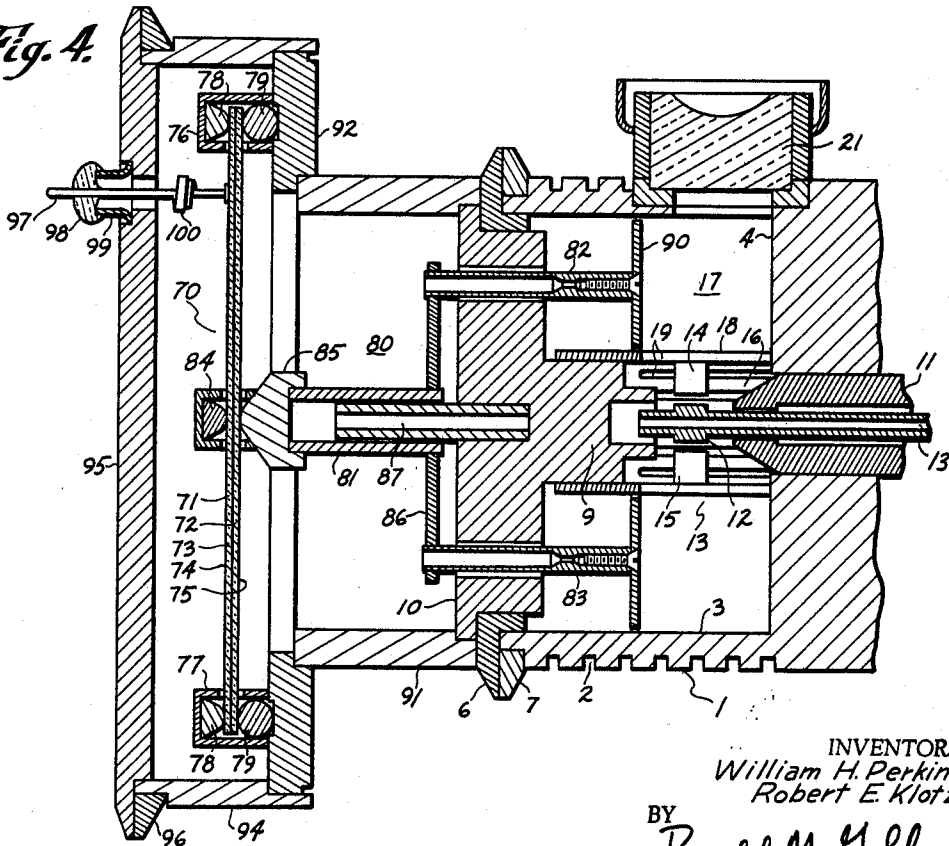


Fig. 4.



INVENTORS:
William H. Perkins
Robert E. Klotz
BY
Ronald M. Goldman
ATTORNEY

Nov. 11, 1969

W. H. PERKINS ET AL.
PIEZOELECTRIC BIMORPH DRIVEN TUNERS
FOR ELECTRON DISCHARGE DEVICES

3,478,246

Filed May 5, 1967

3 Sheets-Sheet 3

Fig. 5.

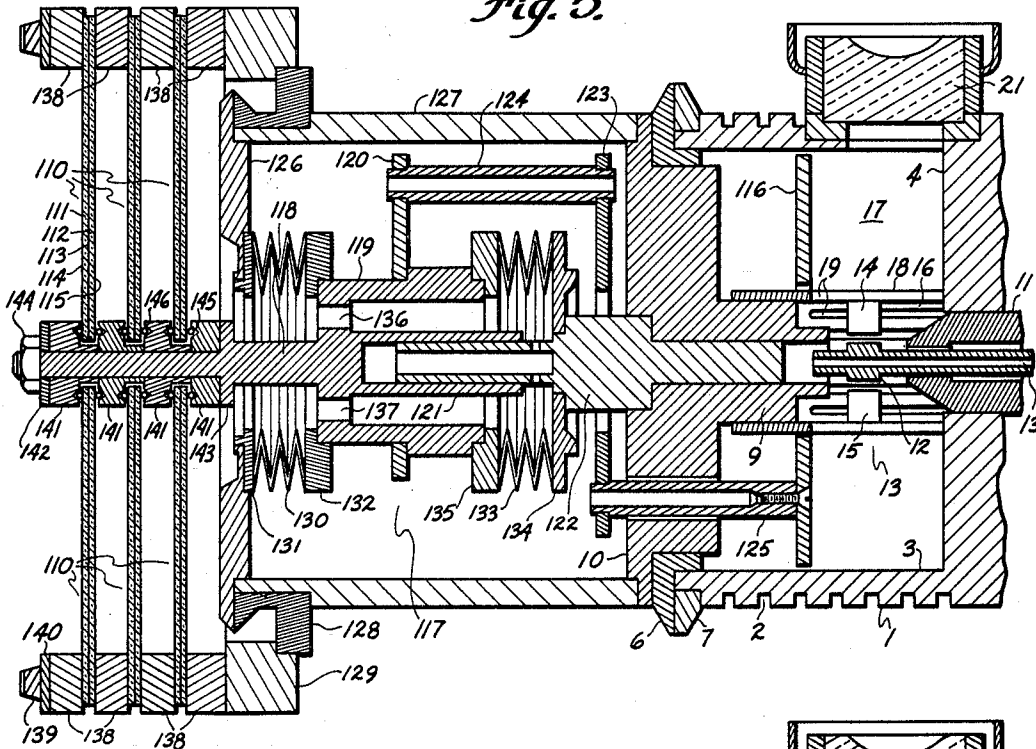
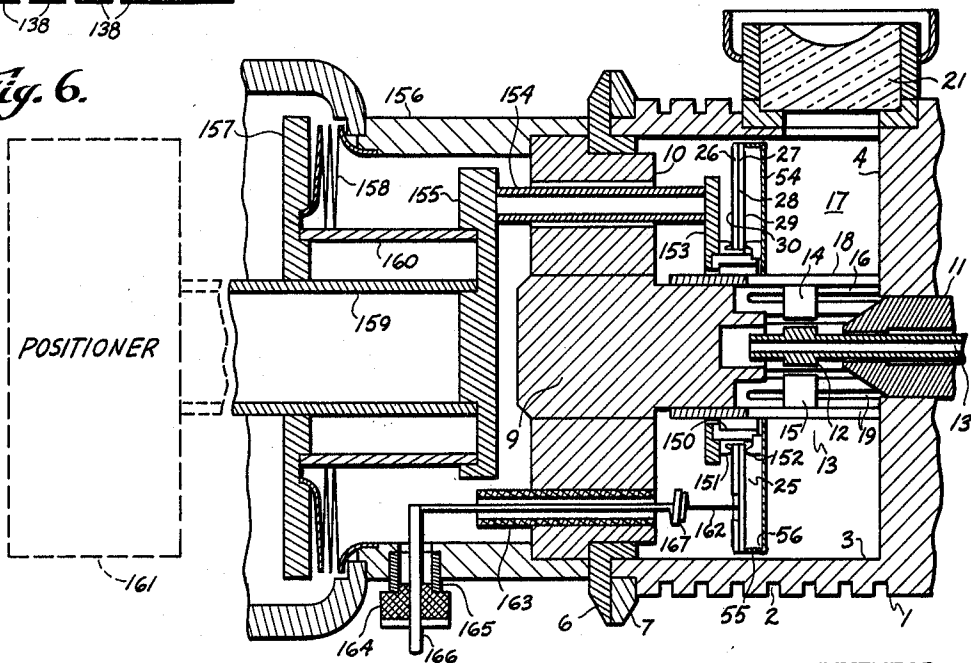


Fig. 6.



INVENTORS,
William H. Perkins
Robert E. Klotz
BY
Ronald M. Goldman
ATTORNEY

1

3,478,246

PIEZOELECTRIC BIMORPH DRIVEN TUNERS FOR ELECTRON DISCHARGE DEVICES

William H. Perkins, Montoursville, and Robert E. Klotz, South Williamsport, Pa., assignors to Litton Precision Products, Inc., San Carlos, Calif., a corporation of Delaware

Filed May 5, 1967, Ser. No. 636,540

Int. Cl. H01j 25/50

U.S. Cl. 315—39.55

14 Claims

ABSTRACT OF THE DISCLOSURE

A piezoelectric bimorph is utilized to position a movable cavity wall. The bimorph is capable of positioning the cavity wall as a function of the magnitude of a control voltage applied across the bimorph. In one example the microwave cavity is a resonant cavity found within an electron discharge device, and the cavity, including the positionable wall, forms the microwave tuner therefore for tuning the electron discharge device and especially for sweep tuning thereof. Further, the bimorph is capable of generating a position representative tracking voltage for representing the instantaneous frequency to which the microwave cavity is tuned.

This invention relates to microwave tuners, and more particularly, to a microwave tuner for a magnetron in which a movable wall is used to tune a microwave cavity to different resonant frequencies.

A microwave cavity; a cavity including conductive walls, possesses electrical properties similar to the conventional tuned circuit consisting of an inductance and a capacitance at low radio frequencies. At very high radio frequencies or microwave frequencies, a conductively walled enclosure or cavity possesses the familiar characteristics of resonance and impedance. With any given cavity, the frequency with which resonance occurs is primarily a function of cavity size or volume. Hence, as is known, a microwave tuner may be constructed with a cavity utilizing a movable wall therewith that is adjustably positionable relative to the other cavity walls so as to increase or decrease the effective size of the cavity, lowering or raising the frequency at which the cavity is in resonance.

Various types of mechanical devices are provided in the prior art for positioning the movable cavity wall, including rods, and screws, which may be driven by mechanical pneumatic or electromechanical arrangements.

Other devices are found in the prior art which adjust or change the effective resonance characteristics of a microwave cavity other than by the mechanical movement of one of the cavity walls. As an example, tuners are constructed utilizing conductive or dielectric rods or strips fixedly placed within the cavity or adjustably positioned within the cavity by a screw or slot and screw arrangement.

Additionally, ferroelectric devices are utilized as a tuner for a microwave cavity. In that instance, with a ferroelectric tuning device, the effective capacitance of the included ferroelectric; hence, the impedance of the microwave cavity, is adjustable with adjustment in the level of the voltage applied to the ferroelectric. In like manner, ferromagnetic or garnets are utilized as tuners for microwave cavities.

Electron discharge devices operable in the microwave frequency region, such as the klystron and magnetron, contain tunable cavities for adjusting the output frequency of the device. Such tunable cavities are used for setting the electron discharge device to the desired frequency and to modulate the frequency of the electron discharge device

2

for jamming radar stations, in addition to other more exotic applications of a modulated or swept signal.

The coaxial magnetron is one type of electron discharge device in which a resonant cavity of simple geometry having a movable wall is adjusted in size to change the frequency at which the device oscillates. In a coaxial magnetron, the outer surface of the anode is surrounded by a single resonant cavity, which might be considered donut shaped, which is designed to support the existence of the TE_{011} circular electrical mode of oscillation in a manner adequately described in any standard text on microwave tubes. After oscillation commences, the existence of the TE_{011} mode provides a magnetic field at all points about the outer surfaces of the anode within the resonant cavity which is in the same electrical time phase. This in-phase magnetic field is admitted into alternate anode resonators, resonators commonly formed of slots or vanes, through coupling slots through the anode between alternate anode resonators and the outer cavity resonator. The anode resonators not coupled to the resonant cavity have voltages induced therein by the magnetic field introduced within the coupled anode resonators. These induced voltages are 180° out of phase with the voltages in the coupled anode resonators, and thus adjacent anode resonators alternate in electrical phase by 180° , a condition necessary to ensure the generation of the well known π mode of oscillation and the resulting frequency thereof. In conventional magnetrons, this fixing of the π mode may be accomplished by a special anode, such as the rising sun anode, or with conventional anode strapping. Of practical advantage, the coaxial magnetron possesses greater mode stability and a lesser probability of starting oscillation in a mode other than the π mode.

Because the coaxial magnetron possesses a single resonant output cavity of a large size relative to the size of the anode resonators, the resonant output cavity stores a large amount of microwave energy relative to the smaller anode resonators. Therefore, the cavity resonator is advantageously utilized for frequency control or tuning of the coaxial magnetron. As is evident from the simple construction of a conductively walled cavity of a coaxial magnetron, relatively simple types of devices, such as a movable washer shaped wall, can be utilized to tune this type of magnetron than the more complicated tuners used with the ordinary magnetron.

Other microwave tubes, such as the klystron, contain resonant cavity structures of relatively simple geometry and also use the aforesaid relatively uncomplicated means of tuning to advantage.

However, the use of a movable wall to vary the frequency of resonance of a microwave cavity within a microwave tube, such as the coaxial magnetron, possesses some practical disadvantage. Since a plunger or rod must be connected to the movable wall within the coaxial magnetron to position the wall, some provisions must be made to allow a movable member to be extended between the vacuum or evacuated region of the coaxial magnetron where the movable wall is located and the exterior of the magnetron housing. Obvious mechanical complexities are thus encountered.

As is apparent, these mechanical provisions required for positioning a part separated from the actuating device by a chamber "enclosing" a vacuum increase the size of the entire magnetron unit and complicate its manufacture. For instance, U.S. Patent No. 3,032,680 to H. M. Olson reveals the large number of ancillary mechanical parts utilized and located within the evacuated space of the magnetron in order to provide the simple movement of the cavity wall.

In addition to the foregoing disadvantages, a mechanically actuated movement for moving a cavity wall

is relatively slow. Tuning at relatively rapid rates, of above 500 or 3,000 cycles, such as is useful with frequency modulation or sweeping of a magnetron through a band of frequencies, is not practically possible. As is apparent, the more rapidly a change in tuning can be effected, the more versatile is the microwave tuner and the electron discharge device within which it is embodied.

To obtain rapidly tunable tuner suitable for electron discharge device, various schemes are utilized. This rapid sweeping is commonly termed "dithering." Means to effect dithering include a rapid periodical change in the magnetron anode voltages within the limits for which oscillation exists, a magnetically operated plunger which is moved back and forth within the evacuated space of the magnetron by a changing magnetic field coupled from the outside into the magnetron and rapid periodical change in the size of cavities. These methods are, however, effective over a small bandwidth of frequencies. Although some of these schemes permit some fast sweep rates in tuning, they do not provide the large bandwidths desirable.

A proposal for a purely electronic tuner theoretically capable of fast sweep rates with no movable parts is advanced by M. G. Kroger in U.S. Patent No. 2,752,495.

A ferroelectric device is placed within at least one of the anode resonators of a magnetron and exposed directly to the microwave field. In accordance with the teachings of that proposal, the ferroelectric device changes its dielectric constant, and hence, its effective capacitance as a function of the voltage applied thereacross.

Problems presented by the use of a relatively lossy ceramic, such as the ferroelectric material therein utilized, render this alternative impractical in a high powered magnetron. Such problems have neither been presented nor disclosed in the U.S. Patent No. 2,752,495. For example, at any significant power the microwaves appearing within a microwave cavity heat a relatively lossy ceramic, such as the ferroelectric material exposed to the fields within the cavity, causing it to decompose and contaminate the vacuum within the magnetron. Moreover, in some manufacturing procedures, a magnetron is subjected to very high temperatures and this presents the same aforementioned problems.

In addition to tuners, a further consideration of importance with tunable microwave cavities, and hence, to tunable magnetrons in many applications in the utilization of some means to obtain a signal representative of the frequency at which the magnetron is operating; because a magnetron, in many instances, operates at frequencies in excess of 10,000 mHz. Various means to directly measure or indicate the frequency at which the magnetron is operating are relatively expensive, and as a practical matter, unavailable.

With some of the tuners of the prior art, for example, those utilizing a movable wall driven by a plunger or rod, complicated servo mechanisms are included which directly monitor the position of the plunger. Such devices are complex, expensive, and bulky. A simpler means of obtaining a signal representative of the movement of the cavity wall is obviously desirable.

Therefore it is an object of the invention to provide a rapid tuner which tunes a microwave cavity to different frequencies of resonance.

It is another object of the invention to provide an electrically operated microwave tuner for a magnetron, which mechanically moves a cavity wall and which does not require movable members extending between the exterior of the magnetron and the evacuated portions of the magnetron.

It is another object of the invention to provide a tuner within a coaxial magnetron having a mechanically movable wall that provides a high sweep rate of more than 50 Hz. and possible up to 1 mHz., by purely electrical actuation.

It is another object of the invention to provide a

rapid tuner for a magnetron which is protected against the heated effect of direct radiation with microwave energy found within the magnetron.

It is still another object of the invention to provide a coaxial magnetron rapidly tunable over a relatively large bandwidth without extending any movable parts between the inside evacuated portion of the tube and the exterior.

It is an additional object of the invention to provide a voltage signal representative of the frequency to which the microwave tuner is tuned.

It is a further object of the invention to provide a means for monitoring the position and shape of a movable tuner wall within a microwave cavity that is neither bulky in size or complex in its construction.

In accordance with the invention, a microwave cavity includes a movable wall. A piezoelectric bimorph device located outside the formed microwave cavity has one portion fixed to a support outside the microwave cavity and another portion connected with the movable cavity wall for creating mechanical movement of the wall in response to the application of voltage to the piezoelectric bimorph device. The piezoelectric bimorph device comprises at least a first and a second layer of piezoelectric material separated by a layer of conductive material, and conductive layers on the outer sides of the piezoelectric layers affixed together to form a thin integral sandwich. Each conductive layer is adapted for connection to a source of voltage. Preferably the two piezoelectric layers are oppositely electrically poled.

Further in accordance with an additional feature of the invention, electrical leads connected across the second piezoelectric layer are utilized to convey voltages representative to the mechanical movement of the piezoelectric bimorph device which are generated by the second piezoelectric layer in response to mechanical stress created by the first piezoelectric layer.

The invention may be further characterized in that the cavity wall is of a low mass, such as a conductive coating placed or deposited upon one of the layers of the piezoelectric bimorph device or a thin layer attached thereto. Additionally, in accordance with the invention, a novel tunable coaxial magnetron structure embodies the foregoing tuner to provide rapid tuning or sweep rate.

The foregoing and other objects and advantages of the present invention become apparent from a reading of the specification in view of the drawings, in which:

FIGURE 1 is a partial view in section of a tunable coaxial magnetron embodying a piezoelectric bimorph actuator and tuner in which the movable cavity wall is deposited upon a piezoelectric layer;

FIGURE 2 is a partial view in section of another tunable coaxial magnetron embodying a piezoelectric bimorph actuator and tuner in which the movable cavity wall is deposited upon a piezoelectric layer, and the actuator and tuner are mounted along the outer edge to a tubular support;

FIGURE 3 is a partial view in section of a third form of tunable coaxial magnetron embodying a piezoelectric bimorph actuator and tuner in which the movable cavity wall is spaced from the actuator and mechanically coupled thereto along its outer periphery;

FIGURE 4 is a partial view in section of another tunable coaxial magnetron embodying a piezoelectric bimorph actuator and tuner in which the movable wall is coupled to the actuator by rods and linkages;

FIGURE 5 is a partial view in section of another coaxial magnetron embodying a piezoelectric bimorph actuator and tuner in which the actuator is mounted externally of the evacuated regions of the magnetron, and the movable wall is connected to the actuator by a bellows and rod arrangement; and,

FIGURE 6 is a partial view in section of a tunable coaxial magnetron embodying a piezoelectric bimorph ac-

5

6

tuator that is in turn adjustably positionable and carried by a prior art positioner, and in which the movable wall is positioned by both the positioner and the actuator.

FIGURE 1 shows, in cross section, a partial view of a coaxial magnetron embodying one form of the invention. This includes an evacuated housing which includes a first cylindrical cup-like housing or body portion 1, containing grooves 2 for the installation of conventional cooling fins, not illustrated, a cylindrical wall portion having an inner cylindrical surface or wall 3; a top washer shaped inner surface or wall 4; and a second smaller cup-like body 5 attached along the cup rim to the first cup-like body 1, by annular seals 6 and 7. A cylindrical jacket 8 is also sealed to the side of the second cup-like body 5 to provide a more rigid structure. A pole piece 9 is seated within the top of the second cup-like body 5 by a flange portion 10 of the hole piece and partitions the two body portions of the magnetron housing. Pole piece 9 projects above its flange portion 10 into first cup-like housing portion 1 and projects beyond wall 4.

Pole pieces 9 and 11 are conventionally constructed of ferromagnetic material and have their ends or tips facing each other across a gap to provide a path for magnetic flux between the pole pieces across the interaction region of the magnetron. Magnetic flux is coupled to the pole pieces from a source such as the conventional permanent magnet or electromagnet, not illustrated, which is mounted to the body of the magnetron in the usual manner. Extending through a passage through pole piece 11 is a cylindrical cathode 12 of emissive material. A heater or filament winding, not illustrated, for heating the cathode surfaces to enhance electron emission is conventionally included within the hollow passage 13 through cathode 12. However, if desired, the cathode may consist of heater or filament windings coated with an electron emitting material.

Concentrically surrounding and spaced from the cylindrical cathode is a cylindrical anode 13 supported upon pole piece 9 which contains a plurality of anode resonators surrounding cathode 12 in the customary manner. In the magnetron of this figure, each of the plurality of anode resonators is formed in the small space, not illustrated, between each of a plurality of spaced conductive vanes, such as vanes 14 and 15 which are attached to the inner wall 16 of anode 13. These vanes are spaced symmetrically about the inner wall 16 of anode 13 and project out from inner anode wall 16 to within a predetermined distance of cathode 12 leaving a gap therebetween. The gap between the projecting tips or ends of the vanes and the cathode is termed in the art as the "interaction region." In the illustrated section of FIGURE 1 only two nonadjacent ones of these vanes 14 and 15 are visible.

An outer resonant output or microwave cavity 17 surrounds the outer wall 18 of anode 13. This cavity 17 is effectively formed between the top washer shaped inner wall 4 of housing portion 1; the surrounding inner side wall 3 of housing portion 1; the outer wall 18 of cylindrical anode 13; and a washer shaped conductive wall 29, which in this embodiment additionally functions as an electrode of a washer shaped piezoelectric bimorph sandwich to form a donut-like shaped cavity. A plurality of microwave energy passages or slots 19 extend through cylindrical anode 13 to couple microwave energy between alternate ones of the anode resonators and resonant output cavity 17.

A conventional microwave window 21, illustrated in part, is mounted in a housing wall to couple microwave energy generated by the magnetron and appearing in the resonant output cavity 17 to external loads. The window 21 may be constructed of material that passes microwave energy but which is impervious to air, such as alumina.

A washer shaped or annular plate 22 surrounds an end of pole piece 9 and is fixedly mounted to the flange portion 10 of pole piece 9 by a flared cylindrical support member 23, which contains a flat rim portion that is

seated within a groove 24 of flange portion 10 to position plate 22 within the chamber formed between the first cup like body portion 1 and pole piece 9 within the magnetron housing. Plate 22 is a nonconductive lossy ceramic to suppress undesired modes of microwave energy incident thereon. In accordance with the present invention, there is mounted to plate 22 a piezoelectric bimorph sandwich 25, previously referred to, which in order to conform to the shape of the space between cylindrical inner wall 3 and cylindrical pole piece 9 is also washer-like in shape. In the embodiment shown, the washer shaped piezoelectric bimorph sandwich 25 comprises two thin layers of piezoelectric material 26 and 27, a thin layer of conductive material 28 which separates layers 26 and 27 and which forms the center electrode, and two thin layers of conductive material 29 and 30 which form, respectively, the first and second outer electrodes. These elements are sandwiched together in a thin integral assembly. One piezoelectric layer is electrically poled in one direction from the middle electrode and the other layer is oppositely poled. Alternatively both layers of piezoelectric material may be electrically poled in the same direction.

Plate 22, tubular support 23, and the piezoelectric bimorph sandwich 25 are fastened together with rivets or bolts 31 that extend through the aforesaid washer shaped elements about their outer peripheries. The bolts are insulated from electrodes 28 and 30 of the bimorph by non-conductive washers which may be of alumina or by removing a surrounding portion of an electrode of the piezoelectric bimorph 25. As is necessary, insulating sleeves may extend through these holes. Rivets 31 contact the outer electrode 29. Plate 22 has its surface facing bimorph 25 recessed or slightly concave toward the center so as to leave sufficient clearance in which the bimorph sandwich 25 may be flexed.

Although the bimorph sandwich is illustrated as being supported along the outer rim, it is apparent that it may be fastened in place along the inner rim. In the latter instance, the plate 22 possesses a convex shaped outer surface to provide clearance in which to allow the free end of the piezoelectric sandwich to flex. The conductive movable wall 29 of the formed resonant output cavity 17 in FIGURE 1, in addition, functions as one of the electrodes of the piezoelectric bimorph sandwich 25.

An electrical lead 20 is soldered to electrode 28 and extends through an opening in layer 26 of the piezoelectric bimorph sandwich 25, plate 22, flange 10, and second cup portion 5 of the housing. The lead 20 is supported by a glass bead 32 that insulated lead 20 from the housing and glass bead 32 is in turn supported by a flared tube 33 sealed to housing portion 5. Glass bead 32, in addition, prevents leakage of air into the evacuated portions of the magnetron housing. Inserted in series with lead 20 is a flexible helical conductive spring 34 which allows lead 20 to move with movement of the bimorph 25 while imposing little restraint thereon.

A second electrical lead 35 is connected to electrode 30 and extends through an opening in plate 22, flange 10, a glass bead 36 which in turn is supported by the flared tube 37. A third lead substantially identical with lead 20 may be soldered to the outer conductive electrode 29; however, because of the symmetry of the illustration, such lead would be located behind lead 20 and would be entirely visible and, hence, is not illustrated. Structure substantially identical to that provided for lead 20 would be provided to connect such lead through to the exterior of the housing. Since one of the electrodes, such as electrode 30, is normally of ground polarity, in lieu of the aforementioned electrical lead to connect such electrode to ground potential, a satisfactory ground connection is obtained by using the magnetron housing which is normally electrically grounded. Such an electrical path exists between electrode 29, rivets 31, support 23, and pole piece flange 10 to the metallic housing walls. Circuit

connections for ground polarity are then made to the housing or to conductive supports carrying the housing.

Electrical connections from a source of high voltage are made to the cathode 12 and from a source of filament voltage to the filament winding, not illustrated, are made through an electrical socket assembly mounted to the rear of the first body portion 1 of the magnetron. Such socket and assembly are conventional; for example, as disclosed in U.S. Patent 3,032,680, and is not herein illustrated. The anode 13 is both physically and electrically connected to portions of the magnetron housing and is electrically grounded through the housing in the conventional manner to create an electric field between the anode and cathode. The magnetron is evacuated and otherwise assembled in any conventional manner and the conventional magnets are mounted to the housing in the conventional manner to create a magnetic field between the pole pieces.

The theory of operation of a coaxial magnetron is conventional and is described in the literature. In essence, under the interaction of the crossed electric and magnetic fields, e.g., the electric field extending between the cathode 12 and the surrounding anode 13 across the interaction region, and the magnetic field extending axially between the ends of pole pieces 9 and 11 within this same interaction region, potential energy from the electrons emitted from the cathode is transferred to an electromagnetic wave apparently traveling around the anode at a predetermined phase velocity. Oscillation builds up in the interaction area generating R.F. fields in the anode vanes, then across the slots which induce R.F. fields in the outer cavity. Microwave energy in the form of a TE_{011} circular electric mode of oscillation is sustained within the output cavity 17. This TE_{011} mode has a magnetic field H of fixed phase extending around the outer wall 18 of anode 13. The coupling slots 19 couple this H-field from resonant output cavity 17 to alternate anode resonators which thus placed in the same phase. Each of the other anode resonators, not so coupled to the output cavity, has voltages induced from the electromagnetic waves within the coupled anode resonators and are 180° out of phase with those fields in the cavity coupled resonators.

Thus, between any two adjacent anode resonators there exists a forced 180° shift in electrical phase. This is the mode of oscillation commonly denoted as the π mode since a magnetron is capable of operating in many different modes, it is necessary to select and attempt to maintain operation in only a single mode; desirably the π mode. The resonant output cavity 17 through the alternate anode resonator coupling tends to lock the magnetron in the π mode.

The microwave energy generated by the magnetron is transmitted from the resonant output cavity 17 through the microwave window 21 to an electrical load or other microwave equipment. Because the resonant output cavity is so much larger than any of the individual anode resonators, it stores a larger proportion of microwave energy and therefore, has a much larger frequency determining effect on the magnetron. The frequency of oscillation of the coaxial magnetron is thus determined primarily by the size of the resonant output cavity; hence, the resonant output cavity is effectively tuned by adjusting the position of movable wall 29.

A known effect exhibited by piezoelectric material is the expansion or contraction of the material that occurs with increases or decreases of voltage applied across the material relative to the polarity exhibited by the material. Utilizing this movement to move a microwave cavity wall provides some degree of tuning. However, with a pure piezoelectric material, the movement caused by the application of voltages is very small. The bimorph or piezoelectric sandwich type of piezoelectric device multiplies the effects produced with a homogeneous piezoelectric mass.

Piezoelectric bimorphs are commercially available ele-

ments which are formed with two thin layers of barium titanate piezoelectric material. A thin brass shim serves as the middle conductor sandwiched between the two layers. The outer surfaces of the thin layers are coated or fired-on silver which serves as the two outer conductors. Electrical leads are pressed against each of the conductive surfaces. The piezoelectric layers are given an electrical polarity by applying a high D.C. voltage at elevated temperatures for several minutes across each layer. To oppositely pole the piezoelectric layers, polarizing the voltage is applied across each in an opposite direction.

Thereafter when voltages are applied across each layer of such a sandwich in such polarity so as to cause one layer to expand and the other to contract, the sandwich bends or warps proportionally to the magnitude of the applied voltage in the same manner as a bi-metallic thermostat or switch material bends or warps proportionally with temperatures. In the alternative, a voltage or source of sweep voltage may be applied across the electrodes of only one of the piezoelectric layers, which effects a lesser amount of bending. However, the stress produced by the bending or flexure of that one layer causes the second piezoelectric layer to also bend and generate a voltage across its electrodes proportionally in magnitude to the amount of such bending or flexure.

While the commercial construction of the piezoelectric bimorph is acceptable for use in evacuated microwave cavities or in microwave tubes which are evacuated solely with a vacuum pump with the tube constructions of FIGURE 1 and the other figures, other constructions of the piezoelectric means are desirable if the manufacturing process used requires heating the tubes to high temperatures during the vacuum pumping process.

It has been found advantageous to make the bimorph of the following construction: A laminate is formed on each side of the two layers of piezoelectric material which includes a first thin layer, perhaps 500°A. of chromium oxide; a second thin layer of about the same thickness of chrome; a third layer of perhaps .1 to .2 mill thickness of copper; and a fourth layer of .1 to .2 mill of gold. A thin sheet or layer of molybdenum, which has thermal expansion characteristics substantially similar to the barium titanate piezoelectric material is placed between the two piezoelectric layers. The piezoelectric layers and molybdenum sheet are then pressed together in a sandwich and exposed to a high temperature causing diffusion of the gold resulting in an integral sandwich construction. These materials have low vapor pressures and do not boil off during the heating process encountered in the aforementioned tube assembly procedure. The outer gold layers form a portion of the outer conductors and the molybdenum forms the middle electrode of the piezoelectric bimorph sandwich.

The movable wall 29 is thus moved or positioned by the bending flexing of the piezoelectric bimorph 25, integrally formed therewith in the embodiment of FIGURE 1, which bends or flexes as a function of the voltage applied to the bimorph electrodes. Voltages from an alternating voltage source may be applied to the electrodes to cause the washer shaped bimorph to flex back and forth, to increase or decrease the effective size of surrounding resonant output cavity 17. Since the frequencies at which the magnetron oscillates are normally very high, the small movement of wall 29 is sufficient to vary significantly the size of the cavity relative to the wavelength of those microwave frequencies.

Alternatively, a source of sweep voltage may be applied between only the middle conductive layer or electrode 28 and one of the outer conductive layers, such as electrode 29. This voltage causes the bimorph sandwich to flex back and forth to a lesser degree than is obtained with the previous application of voltage to the outer electrodes to move the movable wall 29, and hence, vary the size of and frequency of resonance of the micro-

wave cavity. The second piezoelectric layer responds to the bending or flexing caused by the first piezoelectric layer by generating a voltage which appears across the middle electrode 28 and the other one of the outer electrodes 30, proportional in magnitude to the amount of bending or flexing. Therefore, this generated voltage is indicative of the frequency to which the microwave cavity or resonant output cavity 17 is tuned, and is, in essence, a tracking voltage. Moreover stresses created in the piezoelectric caused by vibration or shock also induce a transducer output voltage proportional thereto. This, therefore provides a most accurate tracking signal. Connection of these electrodes to suitable equipment responsive to tracking voltages may then be made.

FIGURE 2 shows many of the details of the magnetron construction utilized in FIGURE 1, and such details are similarly labeled. In this embodiment, the washer shaped piezoelectric bimorph tuner 25, including a first piezoelectric layer and a second piezoelectric layer 26 and 27 sandwiched together with three conductive electrodes or layers 28, 29, and 30, is disposed within an annular chamber within the first cup-like body portion 1 bordering the resonant output cavity 17 in the space between cylindrical anode 13 and cylindrical wall 3. The outer conductive layer 29 in addition to its functions as an electrode of bimorph 25 forms the movable wall of the annular resonant output cavity 17.

A tubular support member 40 contains a bent over lip portion. This tubular support member is sealed to a rim 41 surrounding the pole piece flange 10, and is frictionally seated and brazed in place. A plurality of holes through the outer rim of bimorph 25 and the lip portion of support 40 contain bolts 42 that extend through some of these holes and fasten the bimorph to the tubular member 40. Other holes through bimorph 25 and support 40 are provided for connection of electrical leads to the electrodes of the bimorph. An insulator sleeve 43 is shown extending through such a hole and a smaller diameter conductive lead 44 extends therethrough. Lead 44 is soldered to a coupling member 45 to make conductive contact with the movable wall or outer conductive layer 29 of the bimorph 25. A like electrical lead is connected with the inner or middle conductive layer 28 of the bimorph, but is not visible in the sectional view shown. Electrical lead 44 is connected to a larger diameter electrical lead 45. Lead 45 extends to the magnetron exterior through a glass bead 32 supported in an opening in the magnetron housing by a support member 33. Glass bead 32 both electrically insulates the electrical lead from the housing walls and provides a seal to prevent loss of the vacuum within the magnetron.

A third electrical connection is made to electrode 30 through the magnetron housing which is always connected to an electrical ground. Such connection extends from electrode 30, tubular support member 40 which abuts against the electrode, rim 41, and flange 10 to the magnetron housing walls.

The washer shaped bimorph 25 in this figure is fixed in position along its outer rim and, therefore, in response to the application of sweep voltages across the electrodes is free to flex along the inner rim to shorten or lengthen the size of resonant output cavity 17. One such position of flexure is illustrated in FIGURE 2 by dotted outline 46.

FIGURE 3 shows an embodiment of the invention in which the piezoelectric bimorph actuator 25 is coupled to a physically separate movable wall to form the tuner. The discussion of conventional elements of the coaxial magnetron discussed with respect to FIGURE 1 is not repeated and reference is made to that description.

FIGURE 3 shows the washer shaped piezoelectric bimorph actuator 25. This consists of a first and second piezoelectric layer 26 and 27 of piezoelectric material such as barium titanate, a middle conductive layer or electrode 28, and two outer conductive layers or electrodes 29

and 30 forming an integral flexible thin sandwich. The dimensions of the sandwich, as is apparent, are exaggerated for purposes of illustration. This piezoelectric actuator is disposed within the chamber formed between the pole piece flange 10 and the walls of the first cup-like housing portion 1 of the magnetron.

The movable wall 54 of cavity 17 consists of a thin metallic member of washer shape spaced from the body of the bimorph 25 and supported thereby by an annular lip portion 55 which borders the space between movable wall 54 and the bimorph 25. This lip portion 55 is constructed from a bent over portion physically integral with movable wall 54. A minute groove 56 extends around the bend or juncture of this lip portion with the movable wall in order to reduce restraint to flexure of the bimorph 25.

In FIGURE 3 a fixed washer shaped support plate 50 is mounted to the flange portion 10 of pole piece 9 by tubular support member 51 mounted in a circular groove 52 in flange portion 10. Tubular support member 51 is connected to the inner rim of support plate 50 by a plurality of spaced bolts 53. The washer shaped piezoelectric bimorph actuator 25 is mounted along its inner periphery to support plate 50 by, for instance, the same bolts 53 that mount plate 50 to the tubular support 51. The bolts 53 are suitably insulated from the electrodes 28, 29, and 30 of the bimorph actuator 25 as discussed with respect to FIGURE 1. Plate 50 in this figure is convexly recessed to allow some clearance between the outer peripheral portions of the piezoelectric bimorph 25 and plate 50 for permitting the flexure of the piezoelectric bimorph.

An electrical lead 57 is soldered to electrode 30. Lead 57 is connected to a larger electrical lead 58 that extends through a passage in pole piece flange 10 and through a passage in a wall of the second cup-like housing portion 5 to the exterior of the housing. Lead 58 is supported in the housing wall by a glass bead 36 which insulates lead 58 while preventing air from entering the evacuated magnetron housing. Glass bead 36 is supported by a flared tube 37, sealed to the housing wall.

A second electrical lead 59 is soldered to the middle electrode 28 of the piezoelectric bimorph actuator 25. A portion of piezoelectric layer 26 and outer electrode 30 is cut away in order to allow lead 59 to have convenient access to the middle electrode 28. In turn, electrical lead 59 is connected to a larger diameter electrical lead 60 in series with a helical conductive spring 61. Helical spring 61 completes an electrical connection to the bimorph electrode without posing a substantial mechanical restraint to the flexing or bending of the bimorph. The electrical lead 60 extends through a passage in the pole piece flange portion 10 and through a passage in a wall of the second cup-like housing portion 5. A glass bead 32 insulates the electrical lead 60 from the housing and maintains the vacuum within the magnetron housing. Glass bead 32 is supported by tubular support 33 which is sealed to the housing wall.

A third electrical lead, having structure substantially identical with that of electrical leads 59 and 60 is hidden behind the leads 59 and 60 in the sectional view shown. That lead, not illustrated, provides an electrical connection from the housing exterior to electrode 29 of the piezoelectric bimorph actuator 25.

In this embodiment, since the piezoelectric bimorph actuator 25 is free to flex at the outer edges, the largest possible amount of movement is provided. This movement is coupled mechanically to the movable wall 54 by lip portion 55 which causes the entire wall 54 to be moved as a unit for the largest possible distance. The manner and the theory of operation is the same as that discussed with respect to the embodiment of FIGURE 1.

FIGURE 4 shows an embodiment which has a rectangular shaped piezoelectric bimorph linked or coupled at its middle with a movable wall 90 of the resonant output cavity of a coaxial magnetron. The conventional magnetron elements similar to those utilized in the foregoing

figures and having the same function are identically labeled and the discussion is not repeated.

The relatively large rectangular piezoelectric sandwich or actuator 70 includes first and second thin layers of piezoelectric material 71 and 72, a middle conductive layer or electrode 73 and two outer conductive layers or electrodes 74 and 75. The foregoing layers are affixed together to form a physically integral thin flexible element. As is apparent, the dimensions of this element are exaggerated for purposes of illustration. The relatively large rectangular shaped piezoelectric bimorph actuator 70 is mounted by two spaced bearing members 76 and 77 located at the respective ends of the elongated rectangular bimorph. Each bearing includes supports 78 and 79 which restrain horizontal movement of the ends of the piezoelectric bimorph actuator, but which allows limited vertical or reciprocating movement of the ends of bimorph caused by flexure of the bimorph at its center.

A coupling or linking means 80 connects any movement at the center of bimorph actuator 70 to the movable wall 90 of resonant output cavity 17. This coupling member 80 includes a plurality of rods 81, 82, and 83. The first rod 81 is connected between the center of bimorph by clamplike bearings 84 and 85, to a linking members 86. Rod 81 is hollow, and a guide member 87, mounted in the pole piece 9 supports and guides the movement of rod 81. The other rods 82 and 83 extend through openings in flange portion 10 and are coupled to linking member 86 and to the movable cavity wall 90.

A tubular cylindrical wall 91 is connected to seal ring 6 and pole piece flange 10. Connected to this wall is a washer shaped wall 92 joined to wall 91 along its inner rim. Bearing members 76 and 77 which support bimorph 70 are supported upon wall 92. A cuplike body portion has a cylindrical side wall 94 attached to the outer perimeter of wall 92 and a circular disk shaped wall 95 joined to wall 94 with a seal ring 96 to close the housing.

An electrical lead 97 is soldered to the outer electrode 74 of piezoelectric bimorph actuator 70 and extends from the interior to the exterior of the housing through a passage in wall 95. Supporting lead 97 is a glass bead 98, which is itself supported by a flared tube 99 connected to the disk shaped wall 95. An electrically conductive helical spring 100 is interposed between portions of electrical lead 97 to allow the lead to follow the movements of the bimorph, while providing minimal restraint. A like electrical lead is soldered to the middle electrode 73 piezoelectric bimorph actuator 70, located immediately behind the lead 97 and is not visible in this cross-section. Access of this electrical lead is provided by cutting a passage through electrode 74 and the piezoelectric layer 71. The bearings 78, preferred to previously, are constructed of insulator material, and the second bearings 79 are constructed of conductive material. Thus, a third electrical connection is made between the electrode 75 of bimorph 70 to wall 92 of the magnetron housing in lieu of another electrical lead.

Since the two ends of the bimorph actuator are restrained, the bimorph actuator warps or flexes at its center upon application of a sweep voltage to the leads. This motion of bimorph actuator 70 is transmitted to rod 81. From rod 81, this motion is transmitted through the linking member 86 to rods 82 and 83; hence, to movable wall 90. As the position of movable wall 90 is varied, the frequency of resonance of the resonant output cavity 17 is accordingly changed.

FIGURE 5 shows an embodiment of the invention in which the motion a plurality of mechanically coupled bimorphs 110 is transmitted to a movable wall 116 of resonant output cavity 17 through a mechanical coupling or linkage assembly which extends from the exterior of the evacuated interior. The construction of this embodiment allows the bimorphs to be placed outside the evacuated regions of the magnetron where they are more easily accessible to adjust or substitution. The conventional

magnetron elements are labeled identically to the corresponding elements in the foregoing figures. Insofar as they are already discussed in the foregoing description, the description of these elements is not repeated.

Each of the rectangular shaped piezoelectric bimorph actuators 110 includes a first and second thin layer 111 and 112 of piezoelectric material such as barium titanate a middle conductive layer or electrode 113 and two other conductive layers or electrodes 114 and 115. The foregoing layers are affixed together to form a physical integral thin flexible element. As is apparent, the dimensions of this element are exaggerated for purposes of illustration.

The mechanical linkage assembly 117 coupling the bimorph assembly to the movable wall includes a first rod 118 which extends from the exterior to the interior of the magnetron housing. An enlarged cuplike end portion 119 of this rod is surrounded by and connected with a second linkage 120. A hollow stem extension portion 121 protrudes from within the cuplike portion 119. A guide member 122, mounted to pole piece 9, extends within the hollowed stem portion of stem extension 121 to provide a guide and support for the linkage assembly 117. A second linkage 123 is coupled to the first linkage 120 by one or more rods 124. Linkage 123 in turn is coupled to the washer shaped movable wall 116 with one or more rods 125 extending through openings in the pole piece flange 10. Rod 125 supports the movable washer shaped wall 116 of resonant output cavity 17 for reciprocating movement.

The housing includes a washer shaped disk wall 126 sealed at its outer rim to a cylindrical wall 127 by a combined support and seal ring 128. Rod 118 extends from the housing exterior through the center opening of washer shaped wall 126 into the inner portion of the housing surrounded by wall 127. A support ring 129 is connected to seal ring 128 for supporting the plurality of rectangular shaped piezoelectric bimorphs 110.

A first bellows 130 is connected at one end to a washer shaped flange 131 itself connected to disk wall 126 surrounding the opening therethrough and through which rod 118 projects into the formed chamber. The other end of bellows 130 is connected to a washer shaped flange 132 attached to and surrounding the cuplike portion 119 of rod 118. This bellows is constructed of thin metal which is impervious to air. A second bellows 133 is sealed at one end to a washer shaped flange 134 that is connected and sealed along its inner rim to a portion of guide member 122. The other end of bellows 133 is sealed to another flange 135 that is in turn sealed around the cuplike end portion 119 of rod 118 to enclose the stem portion 121 of rod 118 within the bellows. These bellows are vacuum tight but because of the accordion-like action, they allow motion from rod 118 to be transmitted from the exterior to the interior of the evacuated magnetron housing. As opposed to the use of a single bellows, the use of two bellows and openings 136 and 137 in the cuplike member 119 permits equalization of air pressure on either side of the cuplike member. This permits the rod 118 to reciprocate more linearly in either direction than otherwise.

The exemplary construction of this embodiment shows six rectangular shaped piezoelectric bimorph actuators 110 mechanically clamped and spaced between insulating spacers 138 at one end in two stacks of three bimorphs. A bolt 139 and washer 140 serves to clamp the outer end of each stack to the rim 129. The inner ends of the bimorphs are clamped and spaced between insulating spacers 141 attached to the rod 118. Insulating spacers 141 are clamped between two spaced rim portions, 142 and 143 of rod 118. A bolt 144 secures the clamping action. Bearing members 145 are contained in grooves 146 formed in each of the insulating spacers 141 to allow some movement of clamped bimorph actuator. In addition, the bearings are of a conductive metal

which thus contacts each of the outer electrodes 114 and 115 of the bimorph actuators. Electrical leads, not illustrated, are attached to these bearings for connection to a source of sweep voltage.

The center electrode 111 of each bimorph actuator extends beyond the insulators 138 to permit attachment of an electrical lead also connected to the sweep voltage source. The application of a sweep voltage to those leads causes the flexure of the bimorphs at their free ends, in this illustration the ends connected to the movable rod 118. This creates a force sufficient to depress rod 118. The movement of rod 118 is accordingly transmitted to the movable wall 116 by rod 125, link 123, rod 124, link 120, cup portion 119, and the rod 118, while the bellows 130 and 133 move with rod 118 in accordionlike fashion. Any change in position of the movable cavity wall 116 causes a change in the frequency of resonance of the resonant output cavity 17.

FIGURE 6 shows the tunable magnetron structure incorporating another embodiment of the present invention. Insofar as the elements are similar to the structure of FIGURE 3, they are identically labeled, and since previously described in detail, reference is made to that previous description. The construction of washer shaped piezoelectric bimorph actuator 25 utilized to position a washer shaped movable wall 54 closing the resonant output cavity 17 and forming a tuner therewith is identical to that used in FIGURE 3. Therefore reference is made to that description.

The piezoelectric bimorph actuator is mounted along an inner rim to a movable sleeve-like member 150 by two clamping members 151 and 152 fastened to sleeve-like member 150 while the outer rim of the piezoelectric bimorph is free to flex. Movable sleeve-like member 150 is connected to a linkage 153, which in turn is connected to a rod 154 that extends through an opening in the flange portion 10 of pole piece 9. Rod 154 is connected to another link 155. A cylindrical wall 156 is sealed to pole piece flange 10 and seal ring 6 to form a chamber. A disk shaped end wall 157 is fastened to the cylindrical wall 156 by a thin metal bellows 158 and at the other end to a groove in cylindrical wall 156. This permits end wall 157 to move relative to cylindrical wall 156. A piston or rod 159 is connected to link 155 fitting within a circular groove on link 155. A cylindrical hollow rod 160 is connected between the disk wall 157 and link 155, fitting within a circular groove therein. Piston 159 extends through disk wall 157 for connection with any of the heretofore known mechanical or electromechanical tuner actuator mechanisms or plunger positioner, as variously termed, symbolically shown by the rectangle 161 located outside the magnetron housing. The bellows 158 permits the coupling of a driving movement from positioner 161 and rod 159 to the link and rod elements located within the evacuated interior of the magnetron by expansion and contraction in accordionlike fashion with the movement of rod 159.

External control or sweep voltages are applied to the electrodes of the bimorph 25 over electrical leads extending from within the magnetron housing to the exterior. An electrical lead 162 is soldered to middle conductor 38 of the piezoelectric bimorph actuator 25. This lead extends through an insulator 163 within an opening through flange portion 10 to the lower portion of magnetron housing. An insulator 164 is supported within an opening that extends through the cylindrical side wall 156 by a tubular support 165. An electrical lead 166 of larger diameter than lead 162 extends through insulator 164 from the exterior to the interior of the housing and is connected with lead 162. A helical conductive spring 167 is connected in series with lead 162 to allow the lead to yield with the motion of the tuner which prevents the electrical lead from imposing any substantial restraint upon the movements of the piezoelectric bimorph 25. A second electrical lead, not visible in the sectional view of FIG-

URE 6, is similarly coupled to the outer conductive layer or electrode 30 of the piezoelectric bimorph actuator 25, extending through the magnetron housing in the same manner as electrical leads 162 and 166. That second electrical lead is located immediately behind the illustrated electrical leads and has similar accompanying structure, but is not visible in the section of the magnetron illustrated in FIGURE 5. The third conductive layer or electrode 29 of the bimorph tuner is electrically grounded to the conductive magnetron housing by the conductive clamp ring 152, support 150, the conductive linkage 153, through rod 154, linkage 155, rod 160, wall 157, bellows 158 to the conductive wall 156 of the magnetron housing. This forms a third conductive path, used in lieu of a third electrical lead.

The external positioning or tuning mechanism 161 is used for setting the initial position of movable cavity wall 54; and hence, the initial frequency of resonance of resonant output cavity 17. The piezoelectric bimorph actuator 25 coupled to movable wall 54 provides additional movement of the movable wall as desired to change the frequency of resonance of cavity 17. Moreover, the actuator 25 can provide a periodic sweep movement of wall 54 at a very fast speed to rapidly tune or sweep the cavity 17 through a bandwidth of frequencies about the initial frequency. Alternatively, the external positioning or tuning mechanism 161 reciprocates rod 159 to provide a periodic sweep movement of cavity wall 54 to tune the resonant output cavity 17 over a predetermined wide bandwidth of frequencies at sweep rates low relative to the sweep rates provided by the piezoelectric bimorph actuator 25 while the bimorph actuator simultaneously reciprocates the cavity wall at a faster sweep rate over a smaller bandwidth. Thus, a very fast sweep rate of tuning or either over a small bandwidth of frequencies is superimposed upon a lower sweep rate of tuning over a larger bandwidth of frequencies. It is apparent that while the tunable magnetron embodied in FIGURE 6 incorporates the piezoelectric tuner construction used in FIGURE 3, other forms thereof such as that illustrated in FIGURES 1 and 2 may be likewise modified to be carried upon the sleeve 150.

Moreover, it is apparent that the details of any conventional external plunger positioning member or tuner may be utilized to carry the piezoelectric actuator 25 and movable wall 54 forming the tuner, and that the invention embodied in this figure is not limited to the constructional details found therein.

Each of the foregoing embodiments of the invention contain many conventional elements and utilizes conventional mechanical assembly techniques known to those of ordinary skill in the art. Insofar as these techniques are not necessary to the understanding of the improvements disclosed in this application, they are not discussed. As is apparent, the tunable magnetrons disclosed in this application are in the complete construction mounted within a permanent magnet, and contain a socket assembly mounted to the housing for making electrical connection with the power supplies necessary to provide the magnetron anode, cathode, and filament with operating voltages. This is conventional in the prior art and is not illustrated. Likewise, for providing operation of the piezoelectric tuner, a conventional source of sweep voltage is connected between the appropriate electrical leads previously described. Moreover, in the event that a layer of the piezoelectric material is utilized to generate a tracking voltage representative of the frequency to which the tuner is in resonance, a suitable indicator such as one oscilloscope or a control circuit is provided in the customary manner.

In each of the foregoing embodiments, it is apparent that the invention affords the piezoelectric elements substantial protection from exposure to the microwave energy appearing in the resonant cavity, which can cause heating. In each of the foregoing embodiments, the piezoelectric layers are isolated from the microwave field by the con-

ductive wall forming the movable boundary of the cavity which reflects microwave energy incident thereupon. This protection is equally afforded in the embodiment where the movable wall is connected to all points of the adjoining piezoelectric layer, and is, in fact, the electrode deposited upon the piezoelectric layer which performs the additional function of acting as a cavity wall. Although there is some clearance between the walls of the magnetron and the movable wall in order to allow the back and forth movement of the piezoelectric bimorph, this clearance is relatively small as compared to the wavelength of the dominant mode present in the microwave cavity, and therefore, acts as a very large impedance to prevent access of microwave energy to the piezoelectric bimorph elements of the tuner located in the rear portion of the formed chamber. Thus, as compared to other types of tuners composed of relatively lossy ceramic materials, such as the ferroelectric type, which are directly exposed to high power microwave fields, a substantial advantage accrues. Because the piezoelectric elements are effectively isolated from microwave fields, the lossy material is not heated nor are the brazing alloys holding the bimorph together heated which encourages the emission of vapors that might either eventually spoil the vacuum or otherwise change the operating characteristics of the magnetron.

As is apparent, a microwave cavity incorporating the invention may be adapted to and be used with various types of microwave frequency devices such as electron discharge devices. As is known, many electron discharge devices are utilized as oscillators. However, the type of oscillatory circuits used depends upon the construction or type of electron discharge device or microwave tube considered. Insofar as some type of microwave cavity is utilized as the tuning mechanism for the tubes, the microwave tuner of the present invention is of utility. Conventional magnetrons, which utilize a plurality of tightly coupled anode resonators, open on three sides, are also tunable by the simultaneous positioning of a wall at each of the anode resonators to one of the resonator openings. In such instance, the utility of the instant invention is readily apparent. Moreover, in each of the foregoing embodiments, the piezoelectric bimorph tuner is of a two piezoelectric layer sandwich construction. While this is preferable, it is apparent that the invention can include a piezoelectric tuner having more than two piezoelectric layers.

Of course it is to be understood that this invention is not restricted to the particular details as described above, as many equivalents will suggest themselves to those skilled in the art. The foregoing embodiments, it is understood, are presented solely for purposes of illustration and are not intended to limit the invention as defined by the breadth and scope of the appended claims.

What is claimed is:

1. In a coaxial magnetron tunable at high rates which includes in a housing, a cathode, an anode surrounding said cathode, said anode including an outer wall and a plurality of anode resonators supported adjacent to and spaced about said cathode; a resonant output cavity surrounding said anode, said cavity defined by the space between conductive walls which includes the outer wall of said anode, and a movable conductive wall, said movable conductive wall being movably mounted for changing the size of said resonant output cavity; said outer wall of said anode including a plurality of slots therethrough, a respective one of said slots connecting said resonant output cavity with a corresponding alternate one of said anode resonators; and means for creating crossed electric and magnetic fields between said anode and said cathode, the improvement comprising: piezoelectric bimorph means located outside said output cavity and being connected by a first connecting means to said movable conductive wall for changing the position of said movable wall as a function of the magnitude of an applied control voltage and for generating a position representative voltage as a func-

tion of the position of said movable wall, and electrical circuit means connected to said piezoelectric bimorph means adapted to convey control voltages to said piezoelectric bimorph means from a source of control voltage and adapted to convey a position representative voltage generated by said piezoelectric bimorph means to a monitoring or control means.

2. The invention as defined in claim 1 wherein said anode includes a cylindrical inner wall, a plurality of vanes symmetrically connected at one end to and spaced about said inner wall extending radially inward from said cylindrical inner wall within a predetermined distance of said cathode, wherein each one of said plurality of anode resonators comprises the space between adjacent vanes; and wherein said resonant output cavity includes an outer cylindrical housing wall; and wherein said movable conductive wall is annular shaped to conform to the space between said outer anode wall and said outer housing wall.

3. The invention as defined in claim 2 wherein said piezoelectric bimorph means is annular shaped.

4. The invention as defined in claim 3 further comprising: support means within said housing connected to said piezoelectric bimorph and to said housing for fixing the position of a portion of said piezoelectric bimorph while allowing the other portions thereof freedom to flex.

5. The invention as defined in claim 4 wherein said first connecting means comprises a metallurgical bond between said movable wall and said piezoelectric bimorph means whereby the movable wall is integral with said piezoelectric bimorph means.

6. The invention as defined in claim 4 wherein said first connecting means connecting said piezoelectric bimorph means to said movable wall comprises a thin annular strip.

7. The invention as defined in claim 6 wherein said thin annular strip further comprises a bent over lip portion integral with said movable wall, and a groove at the juncture of the lip portion and said movable wall.

8. The invention as defined in claim 2 wherein said first connecting means connecting said piezoelectric bimorph means to said movable wall comprises a mechanical rod coupling means.

9. The invention as defined in claim 8 wherein said mechanical coupling means further comprises a first rod, a movable plate, and a plurality of second rods; and wherein said second rods are connected between said movable wall and said plate at spaced locations; and said first rod is connected between said piezoelectric bimorph means and said plate.

10. The invention as defined in claim 9, wherein said mechanical coupling means connected between said piezoelectric bimorph means and said movable wall further comprises, a movable rod means extending through an opening in said housing, and a bellows surrounding a portion of said rod means and connected at one end to the housing surrounding the opening and at another end to a portion of said rod means to seal said opening.

11. The invention as defined in claim 10 further comprising a second bellows means surrounding a second portion of said rod means at one end and to a second location on said housing at another end.

12. In a tunable electron discharge device tunable at a very high rate which includes a microwave cavity having a plurality of conductive walls including a movable conductive wall located within an evacuated portion of a discharge device housing; positioning and tracking means connected to said movable wall for positioning said movable wall; said positioning and tracking means comprising: piezoelectric bimorph means including in a thin flexible physically integral sandwich; a first layer of piezoelectric material; a second layer of piezoelectric material; a middle layer of conductive material separating said first and second piezoelectric layer; a first outer layer of conductive material on the outside of said first layer of piezoelectric material; and, a second outer layer of conductive material on the outside of said second layer of

piezoelectric material; first electrical circuit means being adapted for connection to an external control signal source and connected between said middle and first outer layer of conductive material for applying a control signal from an external control signal source across said first piezoelectric layer to position said movable wall, and second electrical circuit means being adapted for connection to a tracking device and connected between said middle and second outer layer of conductive material for conveying a position representative signal generated by said second piezoelectric layer.

13. The invention as defined in claim 4 wherein said support means is movably mounted, and further comprising, external positioning means connected to said support means for moving said support means, whereby the movable wall is moved at a first rate by said external positioning means and at a dither second rate higher than said first rate by said piezoelectric bimorph means.

14. In a coaxial magnetron having an annular output cavity resonator bounded on one side by a movable metallic wall, a piezoelectric bimorph means attached to said movable wall responsive to applied control voltages for varying the position of said movable wall to change the resonant frequency of said cavity and for generating a voltage as a function of the position of said movable wall; first electric circuit means connected to said piezoelectric

bimorph means for receiving applied control voltages from a source and conveying said control voltages to said piezoelectric bimorph means and second electric circuit means connected to said piezoelectric bimorph means for conveying a position representative voltage generated by said piezoelectric bimorph means to an external monitoring or control means.

References Cited

UNITED STATES PATENTS

2,463,472	3/1949	Bach	331—155	X
2,752,495	6/1956	Kroger	315—39.55	X
3,034,014	5/1962	Drexler	315—39.77	
3,048,797	8/1962	Linder	332—5	X
3,087,124	4/1963	McLeod	315—39.61	X
3,317,785	5/1967	Truax	315—39.77	
3,333,148	7/1967	Buck	315—39.77	
3,334,267	8/1967	Plumridge	315—39.55	

HERMAN KARL SAALBACH, Primary Examiner
S. CHATMON, Jr., Assistant Examiner

U.S. Cl. X.R.

310—8; 315—39.61, 39.77; 331—90, 155