Aug. 8, 1961 R. R. WARNECKE ET AL 2,995,675

TRAVELLING WAVE TUBE

Filed Dec. 23, 1958 4 Sheets-Sheet 1

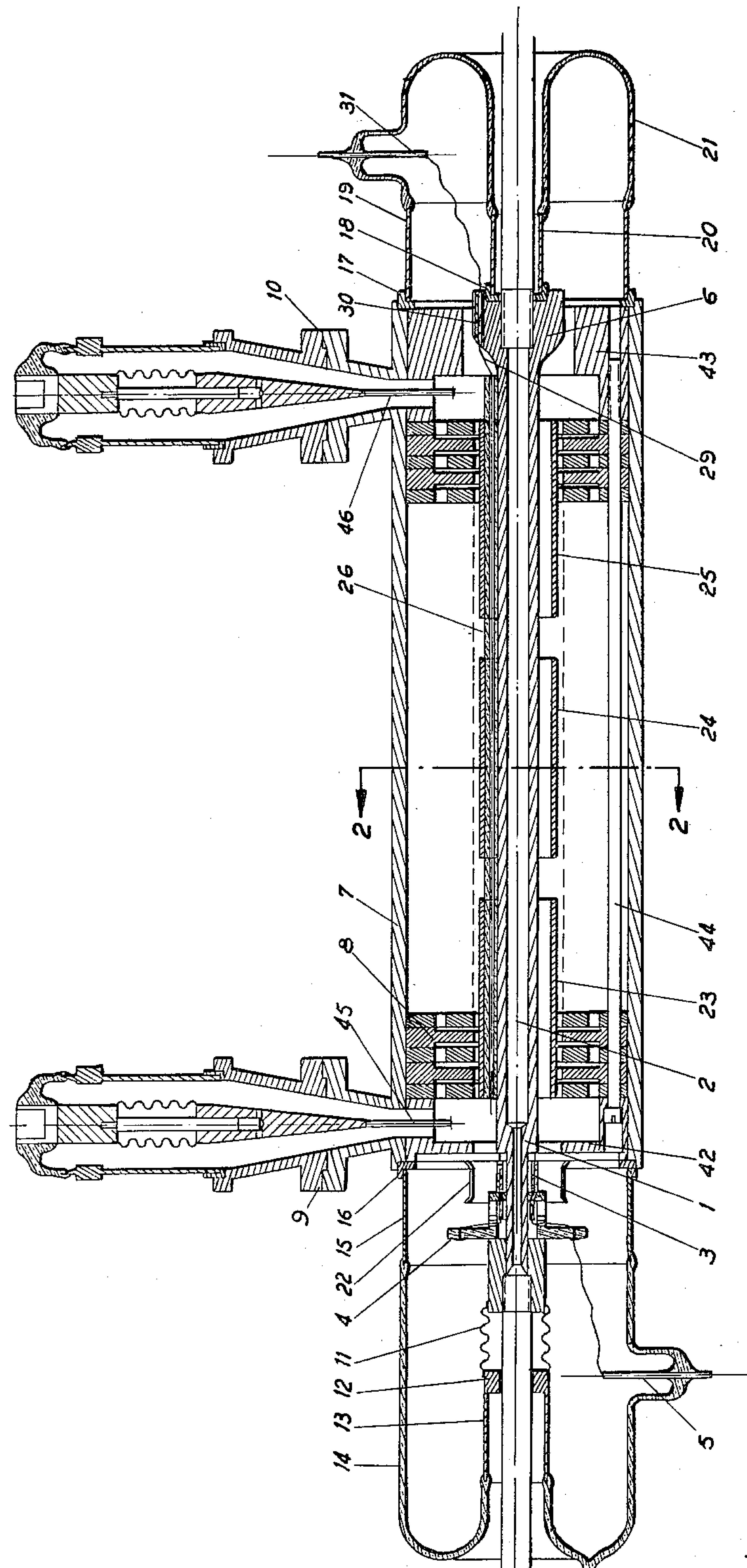

Fig. 1

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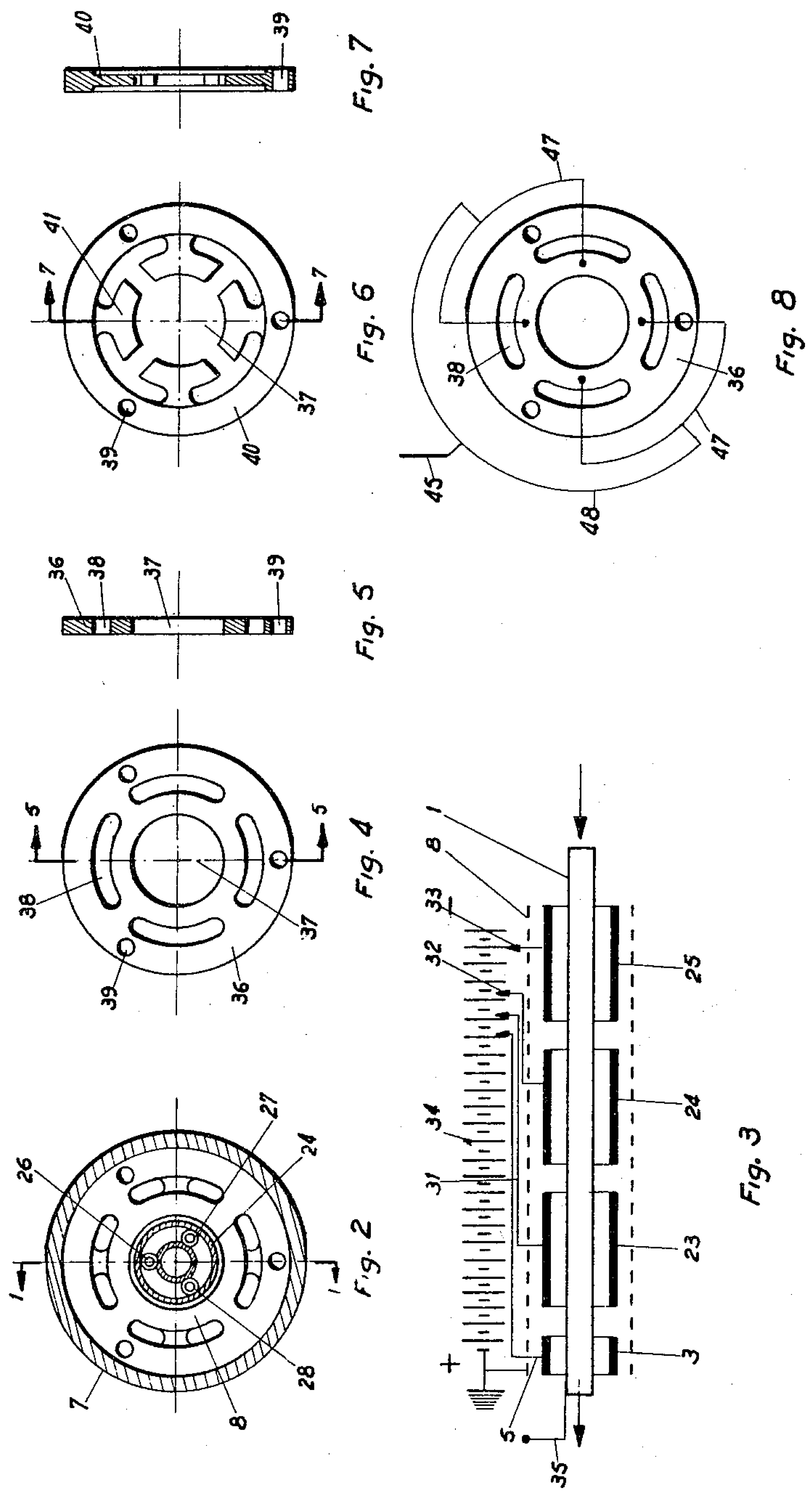

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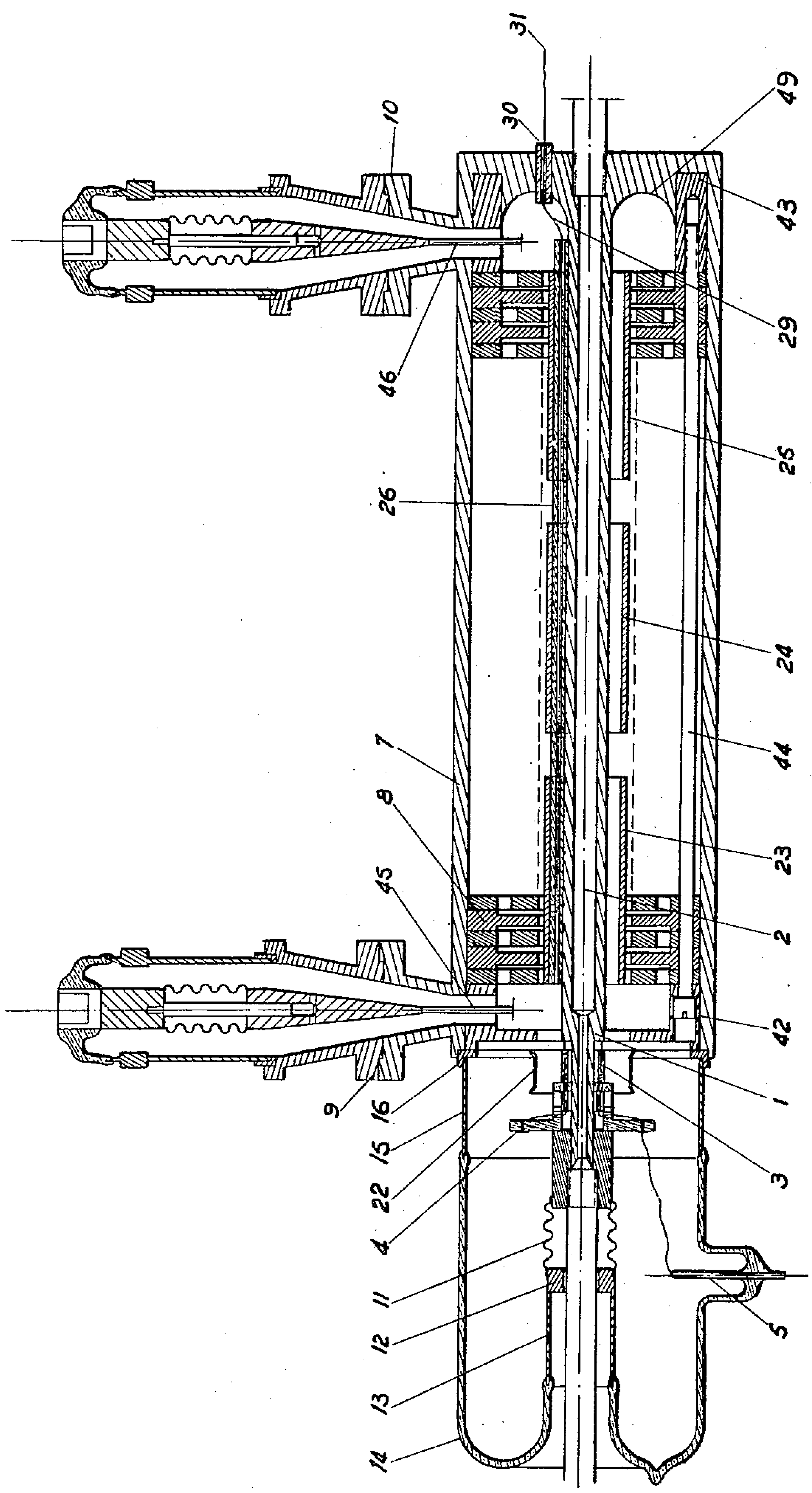

Fig. 9

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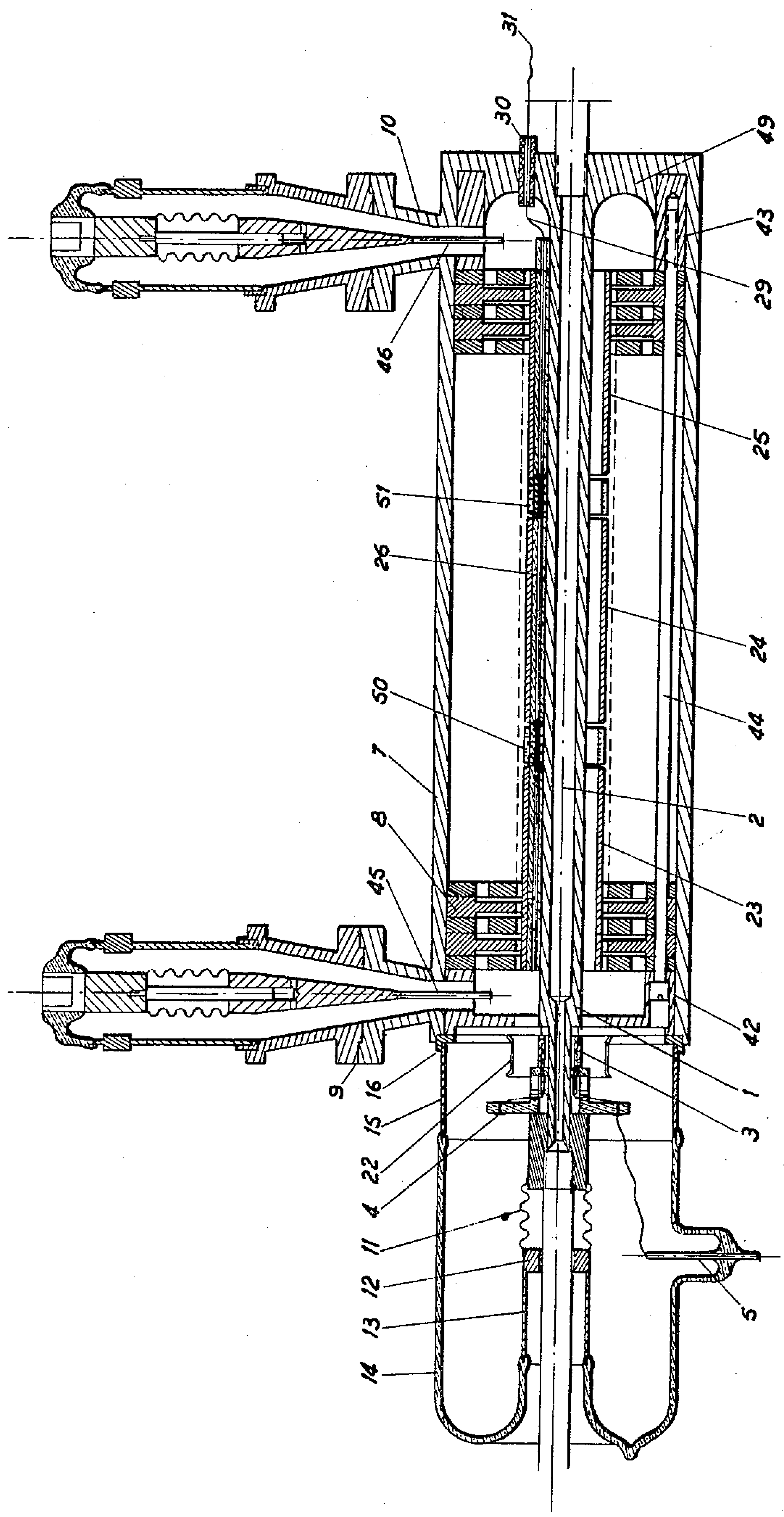

Fig. 10

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TRAVELLING WAVE TUBE

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16 Claims. (Cl. 315—3.5)

The present invention relates to travelling-wave type electronic discharge devices, and more particularly to electron tubes having crossed magnetic and electric fields, commonly known as M-type tubes, especially to the tubes of coaxial structure of which the principle of operation has been already described more fully in the United States Patent No. 2,761,088 to Robert R. Warnecke et al., entitled "Travelling-Wave Amplifying Tube," filed February 16, 1950, and issued August 28, 1956, and assigned to the assignee of the present application.

It will be remembered that in this type of tube the magnetic field is produced by the circulation of a current in a central conductor disposed in the axis of the coaxial structure, this central, coaxial conductor being surrounded by a cylindrical delay network and an electric radial field being established between this delay network and the coaxial conductor while cathode means are provided to propagate a tubular beam of electrons between this delay network and this coaxial conductor whereby the electrons in the beam propagate, as is well known, perpendicularly to the lines of force of the radial electric field as well as to the lines of force of the magnetic field circular about the axis of the tube.

The known tubes of the prior art constructed in accordance with this principle are characterized by a relatively modest gain.

The present invention consists in improvements in connection with such types of tubes having as purpose a considerable increase in the gain thereof.

Consequently, it is a primary object of the present invention to provide a tube of this type which has a significantly improved gain.

The tube in accordance with the present invention utilizes, between the delay network and the axial conductor, at least one auxiliary electrode, a so-called "sole" insulated from the coaxial conductor and maintained at a negative potential with respect to the cathode.

In case several soles are used that are spaced along the axial conductor, these soles are preferably energized by an increasingly negative potential in a direction away from the cathode, as described, for example, in the United States Patent No. 2,695,929 to D. Reverdin, entitled "Travelling Wave Tube Having Transverse Magnetic and Electrostatic Fields," filed March 22, 1952, and issued November 30, 1954, and also assigned to the assignee of the present application in which a somewhat similar arrangement has been described in connection with a tube having a transverse magnetic field and including one or a plurality of cathodic plate members that are energized in such a way that the negative voltage increases in a direction away from the cathode thereof.

The increase in gain makes it possible, with a tube in accordance with the present invention, to realize and obtain relatively large and significant output powers. Consequently, the tube in accordance with the present invention has to be provided with a type of delay line capable to dissipate the losses that occur with such considerable power ratings, and in particular requires a massive cylindrical monoblock delay line, preferably constructed by the so-called "lamination" process.

By reason of the considerable dimensions of such a

delay line, it has to be preferably geometrically periodical not only in the axial direction, as is conventional, but also in the peripheral direction thereof in order to suppress the tendency to propagate undesirable modes of operation including those that might produce undesired oscillations since the large or considerable dimensions of this line normally favor the appearance of these parasitic modes of operation.

Accordingly, it is an object of the present invention to provide an electron discharge tube of the travelling wave type having a coaxial structure which is characterized by a significantly increased gain.

It is another object of the present invention to provide an electron discharge tube of the coaxial travelling wave type which is capable of handling very significant power outputs.

Still another object of the present invention is the provision of a particular delay line structure for use in a high-power coaxial travelling wave type tube which is capable of dissipating the losses caused by the relatively high power handled by the tube while at the same time suppressing or minimizing undesired modes of operation of the tube.

Still another object of the present invention is the provision of a delay line structure for use with a coaxial high-power travelling wave tube in which the delay line has a geometric periodicity in two planes thereof.

These and other objects, features and advantages of the present invention will become more obvious from the following description when taken in connection with the accompanying drawing which shows, for purposes of illustration only, several embodiments in accordance with the present invention and wherein:

FIGURE 1 is a longitudinal axial cross-sectional view, taken along line **1—1** of FIGURE 2, of a first embodiment of an electron discharge tube in accordance with the present invention;

FIGURE 2 is a transverse cross-sectional view of the tube illustrated in FIGURE 1, taken along line **2—2** of FIGURE 1;

FIGURE 3 is a schematic diagram indicating the relative supply voltages applied to the principal electrodes of a tube in accordance with the present invention;

FIGURE 4 is an end view of one type of washer used in connection with the stacked delay line in accordance with the present invention;

FIGURE 5 is a cross-sectional view through the washer of FIGURE 4 taken along line **5—5** thereof;

FIGURE 6 is a cross-sectional view of a modified embodiment of the other type of washer used in connection with the stacked delay line in accordance with the present invention which is used alternately with the type of washer of FIGURE 4 in the actual construction of the delay line;

FIGURE 7 is a cross sectional view of the washer of FIGURE 6 taken along line **7—7** of FIGURE 6;

FIGURE 8 is a schematic diagram of the high-frequency coupling used between either end, such as the input or output end of the delay line and the high-frequency input or output of the tube;

FIGURE 9 is a longitudinal axial cross-sectional view of a second embodiment of an electron discharge tube in accordance with the present invention; and

FIGURE 10 is a longitudinal, axial, cross-sectional view through a third embodiment of an electron discharge tube in accordance with the present invention.

Referring now to the drawing, wherein like reference numerals are used to designate like parts in the various views thereof, and more particularly to FIGURES 1 and 2 thereof, the tube illustrated therein includes in the axis thereof a sleeve or tubular member **1** which is intended to be traversed by a current generating the magnetic field of the tube. A channel **2** is provided in sleeve **1** for the circulation therethrough of a cooling liquid. An electron-emissive cylindrical cathode 3 is disposed over the sleeve 1, which cathode 3 is insulated from the sleeve 1 by means of any suitable spacer members. The feed conductors for the cathode 3 and for the filament heating the cathode 3 extend toward the left, as viewed in FIGURE 1, onto the insulating disk 4 from where suitable output conductors such as output conductor 5 provide the connections with the external power supply. The sleeve 1 is provided with an enlarged portion 6 at the end thereof opposite to the cathode end 3, i.e., at the right end as viewed in FIGURE 1.

A second part of the tube is formed by the vacuum-tight cylindrical envelope or casing 7 to which is secured a delay line 8 coaxially surrounding the sleeve 1. The envelope 7 supports therein coaxial high-frequency input and output devices 9 and 10 which may be constructed as will be described more fully hereinafter by reference to FIGURE 8. At the left end of the envelope 7, the sleeve 1 and the envelope 7 are connected with each other in such a manner as to form a vacuum-tight enclosure of such construction as assures a certain yieldingness in order to permit an expansion, by the intermediary of a bellows 11 made of tombac, by a ring 12 adapted to slide over the sleeve 1, by a Kovar member 13, by a glass seal 14, by a second Kovar member 15 and by a steel ring 16. At the right end of the envelope 7, as viewed in FIGURE 1, the corresponding vacuum-tight enclosure is completed by two steel rings 17 and 18, by two Kovar members 19 and 20, and by a glass seal 21.

An electron-optical anode 22 in the form of a coaxial cylinder is placed within the tube so as to face the cathode 3.

According to the present invention, intermediate the delay line 8 and the sleeve 1 is arranged a certain number of soles, that is, electrodes insulated from the sleeve or tubular member 1 and carried at successively increasing negative potentials with respect to the cathode 3 in a direction away therefrom. As an example, three soles 23, 24 and 25 have been illustrated in FIGURE 1 of the drawing, which soles are in the form of cylinders placed over, for instance, three tubular, longitudinal insulating members 26, 27 and 28 forming appropriate spacers. The sole 23 is fed by the connection 29 traversing an aperture in the wall of the tubular member 26, thereupon extending along the same, traversing the enlarged portion 6 of the sleeve 1 through an insulated passage 30, and leaving through an output 31 across the glass seal 21. The soles 24 and 25 are fed with respective voltages in a similar manner by means of corresponding connections passing, respectively, along the interior of the other tubular members 27 and 28 and leaving by analogous outputs 32 and 33 as indicated schematically in FIGURE 3.

FIGURE 3 represents a schematic diagram showing the connections of the voltage or power supply with the principal electrodes of the tube which are designated therein by the same reference numerals as in FIGURES 1 and 2. The high voltage source 34 has the positive pole thereof connected to ground and to the delay line 8. The outputs 5, 31, 32 and 33 of the cathode 3 and of the three soles 23, 24 and 25, respectively, are connected with taps of the power supply 34 providing an increasingly more negative voltage in the direction away from the cathode 3. The sleeve 1 is provided with a connection for applying thereto a potential of which the end thereof has been left free to indicate the different possibilities insofar as the numerical value of this potential is concerned. For example, the sleeve 1 may be connected to the potential of the cathode 3. However, the sleeve 1 may also be connected, as will be seen hereinafter in connection with the embodiments of FIGURES 9 and 10, to the potential of the delay line 8.

The ends or extremities of the sleeve 1 are connected to terminals of a generator which supplies current through this sleeve 1. This current may be of direct current type having a direction indicated by the arrow, or, particularly if the tube operates in a pulsed manner, the generator supplying a current to the sleeve 1 may be an alternating current generator of which the direction coincides with the arrow indicated in the drawing during the fractions of the period in which the beam of the tube is unblocked by the pulses. As is well known in the art, this current creates a magnetic field having a circular symmetry about the axis, which is necessary for proper operation of the tube.

The delay line 8 has to be a massive line, adapted or matched to the power ratings occurring in this tube having an improved gain. In view of the difficulties of technological realization in connection with such a delay line when cut out or machined from a single block, the delay line 8 in accordance with the present invention is preferably made by the so-called "lamination" process which will be described more fully hereinafter by reference to FIGURES 4 through 7.

The delay line 8 in accordance with the present invention is composed by stacking together alternately washers of which the shapes and constructions are shown, for example, in FIGURES 4 and 5, on the one hand, and in FIGURES 6 and 7, on the other. The washer 36 of FIGURES 4 and 5 is a disk provided with a central aperture or hole 37 coaxially surrounded by four elongated apertures or openings 38 which impart to the delay line a geometirical periodicity in the peripheral direction. The bores or holes 39 serve for purposes of assembly of the delay line 8. The washer 40 according to FIGURES 6 and 7 resembles a stator iron of an electric machine having four poles 41, suitably cut out or stamped out in such a manner that the superposition of the two types of washers 36 and 40 produces in end view an arrangement of which the outlines are visible in FIGURE 2. The holes 39 of the washers 40 are intended to be aligned with those carrying the same reference numerals in washers 36.

For purposes of manufacture of such a delay line 8, the washers 36 and 40 are alternately stacked, one upon the other, and the assembled line is then tightened at the ends thereof through the terminal members 42 and 43 (FIGURE 1) by means of bolts 44 (FIGURE 1) passing through the holes 39. The bolt members 44 are preferably of a material having a coefficient of expansion which is less than that of the washers 36 and 40 so that the tightening is increased when the assembly is heated for purposes of the brazing operation. After brazing, the assembly forms a monoblock delay line, which is both sturdy and rigid and which presents not only the usual geometric periodicity in the axial direction, clearly visible in FIGURE 1, but also a geometric periodicity in the peripheral direction thereof, as also clearly visible from FIGURE 2. The delay line 8 thus assembled is introduced into the cylinder 7 forming a casing therefor prior to the emplacement of the sleeve 1 and prior to the closure of the tube by the glass seals 14 and 21 and is brazed onto the interior surface of the cylinder 7 thereby forming a monoblock or unitary assembly with the envelope 7.

In order to connect the ends of the delay line 8 to the interior conductors 45 and 46 of the coaxial input and output couplings 9 and 10, a coupling arrangement schematically illustrated in FIGURE 8 is used for the input side thereof, it being understood that the output coupling is analogous thereto. In order to provide an inphase output connection with the delay line 8, four points on the first washer 36 are selected in the center of the metallic bands formed between the apertures 38 and the central aperture 37, and two of each of these four points are connected with one another by means of loops 47. Additionally, the center points of these loops 47 are interconnected by a loop 48 and finally the sleeve 45 is operatively connected with the loop 48 at the center point thereof.

The embodiment according to FIGURE 9, in which the same reference numerals have been used as in FIGURE 1, differs from the latter only by reason of the fact that the sleeve **1** is carried at the same potential as the envelope **7**, and that, consequently, these two elements of the tube may be combined into a single structural part. The seal **21** with the intermediary members **17, 18, 19, 20** therefore becomes unnecessary and is eliminated, and instead the element **43** now takes the shape of a simple hollow cylinder which is placed into a circular recess provided at the bottom of the closed tube which constitutes the envelope **7**. The metallic surface of this bottom **49** forms the electron collector electrode. The output **31** leaves directly to the outside of the tube across a passage **30** which is made to be vacuum-tight in any suitable manner.

The tube of FIGURE 10, constructed, for example, like that of FIGURE 9, nevertheless differs from that of FIGURE 9, as well as that of FIGURE 1, by the presence of auxiliary cathodes **50** and **51** intended to function, respectively, in the systems including the soles **24** and **25**, whereas the original cathode **3** functions with the sole **23**. The three spaced electrodes thereby produce effectively an electron beam in which the electron density is replenished as the beam travels toward the collector by cathodes **50** and **51**, respectively, so as to offset the losses in the electron beam due to stray electrons collected by the other electrodes of the system. Otherwise, the tube of FIGURE 10 does not differ from that of FIGURE 9 and the same reference numerals have been used therein as in FIGURE 9.

Operation

The operation as high-power amplifiers of the tubes which have been described hereinabove has been fully explained in theory in the aforementioned United States Patent No. 2,761,088 so that there is no need to repeat this explanation again. It is believed sufficient to indicate that in FIGURE 1 the electrons emitted by the cathode **3** are concentrated into a tubular beam under the action of the magnetic field produced by the circulation of the current through sleeve **1** and under the action of the electron optical anode **22**. The tubular electron beam thus focused passes through the space formed between the delay line **8** and the soles **23, 24** and **25**, that is, through the interaction space, and finally passes into the space between the enlarged portion **6** and the member **43** to be collected on the internal surface of this member **43** which constitutes the collector.

In the embodiments of FIGURES 9 and 10, the electrons of the electron beam are captured or collected by the internal surfaces **49**. Furthermore, in the embodiment of FIGURE 10, the beam produced by the cathode **3** is reinforced along the course of the trajectory thereof by analogous beams provided by cathodes **50** and **51**. Consequently, the tube behaves in fact as three tubes in cascade of which the gain and power are further increased.

As indicated hereinabove, the important effect obtained by the arrangement of the soles consists in the improvement of the gain. This effect has been experimentally noted and has permitted applicant to realize tubes of the type in question which have clearly improved performance characteristics. Among these performance characteristics also figures the relatively important, high output power of the tube which has necessitated the use of a massive delay line, of which the delay line **8** in accordance with the present invention constitutes a particularly favorable example. This line is conveniently manufactured and assembled by the so-called "lamination" process. If this same line had been constructed as plain disks, i.e., as a line having a geometric periodicity in only one direction, it would have presented, as also proved and demonstrated experimentally, a tendency to cause propagation of undesirable modes. This tendency has been suppressed by imparting to the line a two-dimensional periodical structure, that is, by making the delay line periodic not only in the axial direction, as is usual, but also in the peripheral direction thereof.

However, it is understood that the present invention is not limited to the use of the delay line described and illustrated herein, but is susceptible of many modifications within the scope of a person skilled in the art without departing from the spirit of the present invention.

The advantage resulting from putting or placing the axial sleeve at the same potential as the delay line and the envelope of the tube which are connected to ground, according to the embodiments of FIGURES 9 and 10, resides in the ease and facility of the realization of the voltage supply for the sleeve with a current producing the magnetic field by means of a source which does not require any insulation with respect to the high voltages used, for example, by a homopolar machine.

It should also be noted that there is no danger that eddy currents circulate in the soles, for with the magnetic field being of circular symmetry, these currents have a tendency to circulate perpendicularly to these lines of force, that is, along the generatrices of the cylinders constituting the soles, which are open circuits in the direction of these generatrices.

While we have shown and described several embodiments in accordance with the present invention, it is understood that the same is not limited thereto but is susceptible of many changes and modifications within the spirit and scope of the present invention, and we, therefore, do not wish to be limited to the particular embodiments, described herein only for purposes of illustration, but intend to cover all such modifications and changes as are encompassed by the scope of the appended claims.

We claim:

1. A travelling wave electron discharge tube of the coaxial type, comprising within an evacuated envelope, an axial conductor, means for feeding to said conductor a current for producing a magnetic field having circular lines of force around said conductor, a delay line in the form of a massive structure having a first geometrical periodicity in the direction of said conductor and a second geometrical periodicity in the direction of said magnetic lines of force, at least one sole electrode disposed between said axial conductor and said delay line and electrically insulated from said axial conductor, means for applying a voltage between said delay line and said sole electrode with the positive pole connected to said delay line and negative pole connected to said sole electrode, thereby producing a radial electric field perpendicular to said magnetic lines of force, and means comprising an electron source for injecting into the interaction space between said delay line and said sole electrode an electron beam substantially perpendicular to both said electric and magnetic crossed fields.

2. A tube as claimed in claim 1, wherein said axial conductor is electrically connected to said electron source.

3. A tube as claimed in claim 1, wherein said axial conductor is electrically connected to said delay line.

4. A tube as claimed in claim 3, wherein said delay line is secured to the interior surface of said envelope, and wherein said envelope is a cylinder forming an integral body with said axial conductor.

5. A tube as claimed in claim 1, whereby said delay line is composed of two sets of alternately interleaved metal washers, said washers being brazed together.

6. A tube as claimed in claim 5, wherein the washers of the first set have a form similar to the pole faces of the stator of an electric machine, and wherein the washers of the second set have a series of elongated apertures extending along a predetermined circumference.

7. A high-power travelling wave tube of the coaxial type, comprising axial conductor means, means for supplying to said axial conductor means a current to thereby

produce a magnetic field having circular lines of force about said conductor means, delay line means with means imparting thereto a bidimensional geometric periodicity, sole electrode means disposed between said axial conductor means and said delay line means and electrically insulated from said axial conductor means, means for producing a radial electric field between said delay line means and said sole electrode means, and cathode means for injecting into the space between said delay line means and said sole means an electron beam propagating in a direction essentially perpendicular to said electric and magnetic fields.

8. A high-power travelling wave tube of the coaxial type according to claim 7, wherein said delay line means is effectively a unitary assembly.

9. A high-power travelling wave tube of the coaxial type, according to claim 7, wherein said delay line means is composed of a plurality of washers stacked together, and the stack of said washers effectively providing a geometric periodicity in said two directions constituting the bi-dimensional periodicity thereof.

10. A high-power travelling wave tube of the coaxial type, according to claim 7, wherein said delay line means is composed of alternate washers belonging to two types of washers, said washer assembly effectively providing a periodicity in the axial direction and a periodicity in the circumferential direction thereof.

11. A travelling wave amplifier tube comprising an elongated conductor, a number of cylindrical sole electrodes spaced apart and aligned around said conductor, a cylindrical delay line surrounding said sole electrodes and having geometrical periodicity both along and around said conductor, said sole electrodes and delay line defining therebetween an electron and wave interaction space, means for producing in said conductor a current to set up thereabout magnetic lines of force, means for bringing said sole electrodes to negative potentials relative to said delay line to produce between said sole electrodes and said delay line electrostatic lines of force perpendicular to said magnetic lines of force, an electron gun at one end of said conductor for injecting into said interaction space an annular electron beam propagating toward the other end of said conductor, input means connected to said delay line at the end thereof adjacent said gun for feeding to said delay line ultra-high frequency waves in energy transfer relationship with said electron beam, and output means connected to the other end of said delay line for picking up amplified ultra-high frequency energy.

12. A high-power travelling wave tube of the coaxial type, comprising coaxial conductor means, means for supplying to said axial conductor a current to thereby produce a magnetic field having circular lines of force about said conductor means, delay line means disposed about said conductor means, electrode means disposed between said axial conductor means and said delay line means and defining with said delay line means an interaction space, said electrode means being spaced from and effectively insulated electrically from said axial conductor means, means for producing an electric field between said delay line means and said sole electrode means, means including cathode means for injecting an electron beam into said interaction space, and energy transfer means operatively connected with said delay line means to enable energy transfer with said delay line means.

13. A travelling wave electron discharge tube of the coaxial type, comprising within an evacuated envelope an axial conductor, means for feeding to said conductor a current for producing a magnetic field having circular lines of force around said conductor, a delay line in the form of a massive structure having a first geometrical periodicity in the direction of said conductor and a second geometrical periodicity in the direction of said magnetic lines of force, a plurality of sole electrodes separated therebetween and disposed between said axial conductor and said delay line, means for applying to said sole electrodes negative potentials with respect to said delay line thereby producing radial electric fields essentially perpendicular to said magnetic lines of force, means comprising an electron source for injecting into the interaction space between said delay line and said sole electrodes an electron beam substantially perpendicular to both said electric and magnetic crossed fields, and means for biassing said soles successively more and more negatively in the direction of said beam.

14. A high power travelling wave tube of the coaxial type, comprising axial conductor means, means for supplying to said axial conductor means a current to thereby produce a magnetic field having circular lines of force about said conductor means, delay line means with means imparting thereto a bidimensional geometric periodicity, sole electrode means disposed between said axial conductor means and said delay line means, means for applying to said sole electrode means a negative voltage with respect to said delay line means thereby producing a radial electric field, and cathode means for injecting into the space between said delay line means and said sole means an electron beam propagating in a direction essentially perpendicular to said electric and magnetic fields, said voltage being increasingly more negative in a direction away from said cathode means.

15. A travelling wave amplifier tube comprising an elongated conductor, a number of cylindrical sole electrodes spaced apart and aligned around said conductor, a delay line surrounding said sole electrodes and defining therewith an electron and wave interaction space, means for producing in said conductor a current to set up thereabout magnetic lines of force, means for bringing said sole electrodes to negative potentials relative to said delay line to produce between said sole electrodes and said delay line electrosatic lines of force perpendicular to said magnetic lines of force, an electron gun at one end of said conductor for injecting into said interaction space an annular electron beam, input means connected to said delay line at one end thereof for feeding to said delay line ultra-high frequency waves in energy transfer relationship with said electron beam, and output means connected to the other end of said delay line for picking up amplified ultra-high frequency energy.

16. A travelling wave tube comprising an elongated conductor, a number of cylindrical sole electrodes spaced apart and sligned around said conductor, a delay line surrounding said sole electrodes and defining therewith an electron and wave interaction space, means for producing in said conductor a current to set up thereabout magnetic lines of force, means for bringing said sole electrodes to negative potentials relative to said delay line to produce between said sole electrodes and said delay line electrostatic lines of force perpendicular to said magnetic lines of force, and an electron gun at one end of said conductor for injecting into said interaction space an annular electron beam in energy transfer relationship with an ultra-high frequency wave propagating along said delay line.

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