Nov. 4, 1969 R. L. LAING 3,477,012

THERMIONIC CONVERTER

Filed Aug. 9, 1967 4 Sheets-Sheet 1

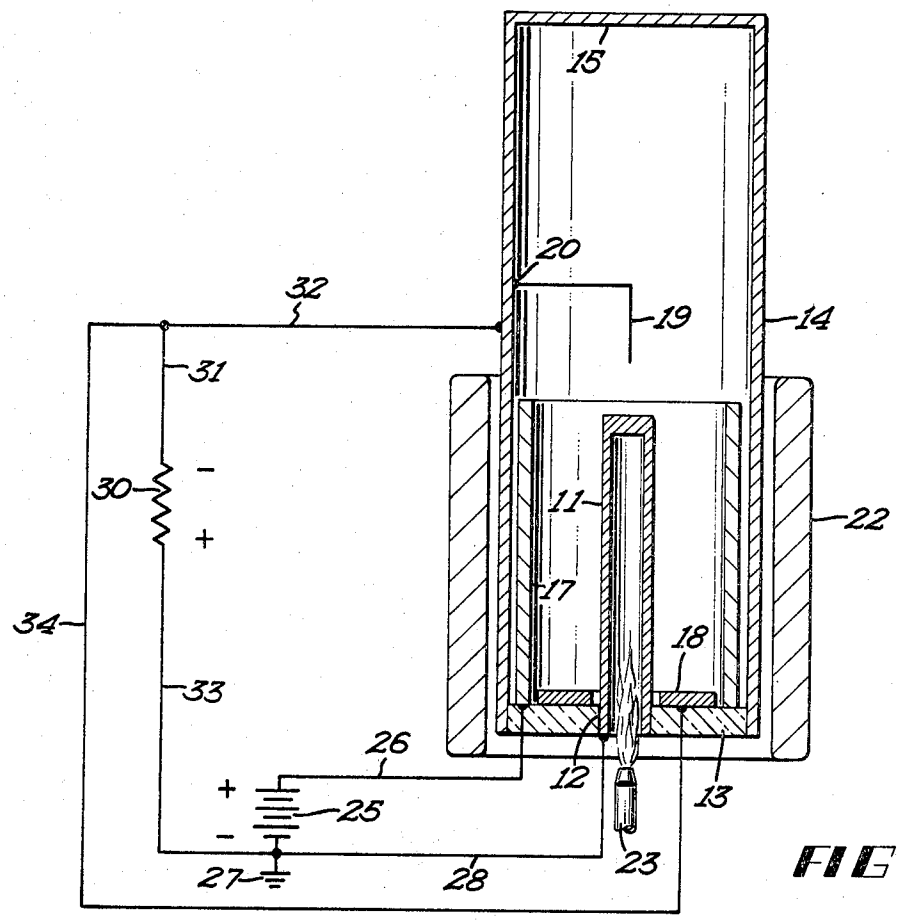

FIG 1

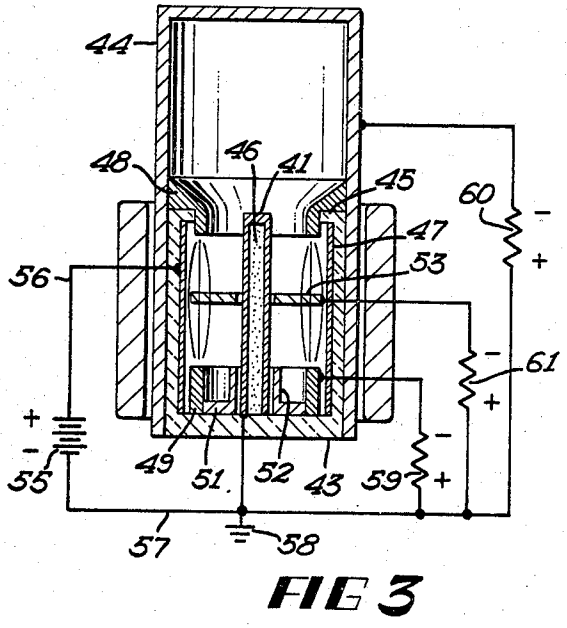

FIG 3

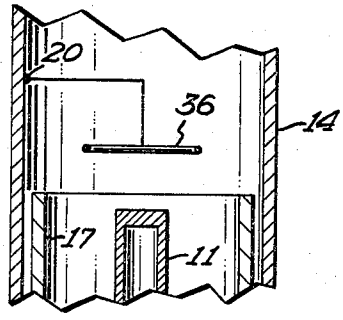

FIG 2

INVENTOR.
ROBERT L. LAING
BY Frederick E. Lange
ATTORNEY

Nov. 4, 1969 R. L. LAING 3,477,012

THERMIONIC CONVERTER

Filed Aug. 9, 1967 4 Sheets-Sheet 2

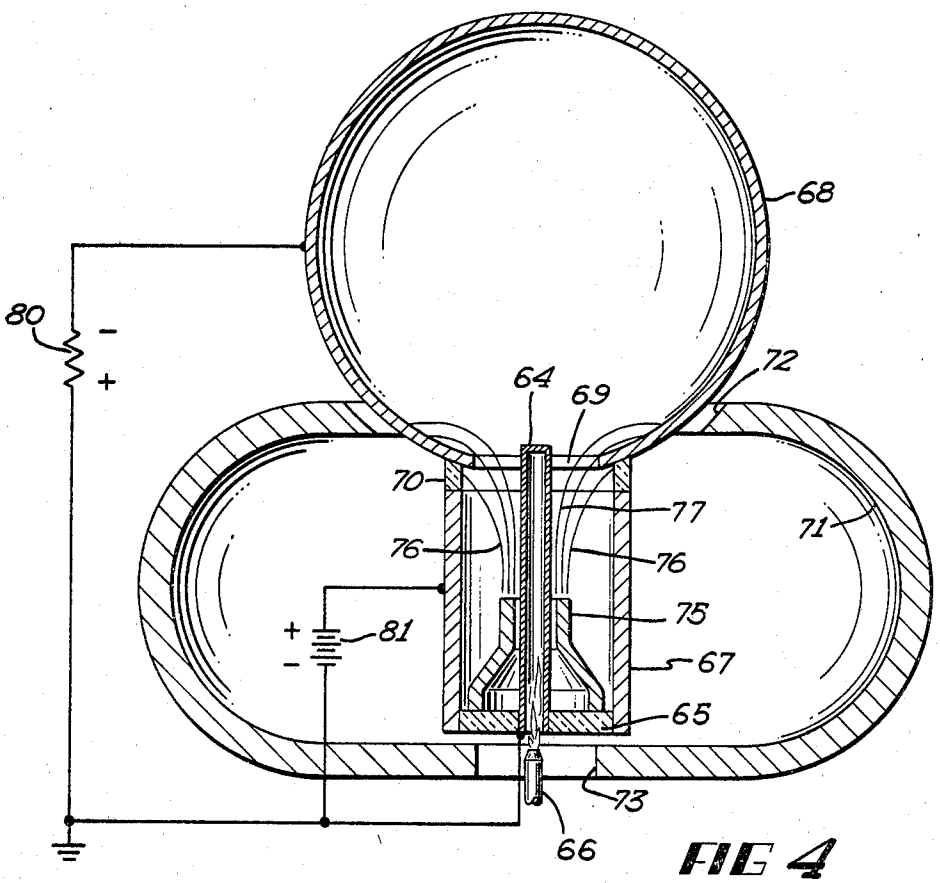

FIG 4

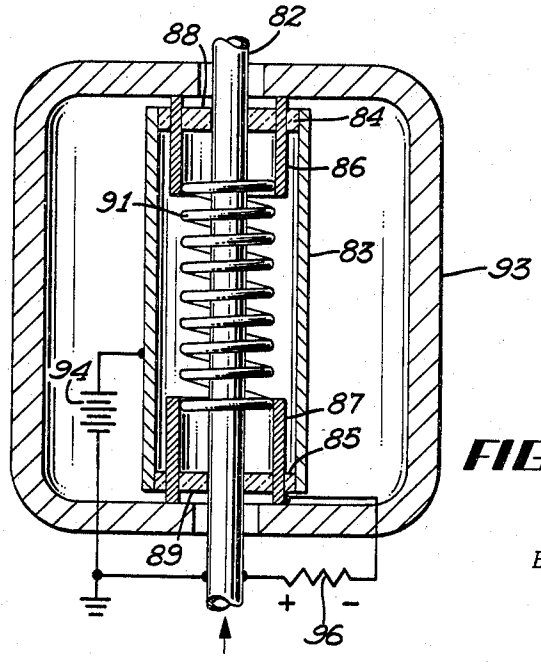

FIG 5

INVENTOR.
ROBERT L. LAING
BY Frederick E. Lange
ATTORNEY

Nov. 4, 1969 R. L. LAING 3,477,012

THERMIONIC CONVERTER

Filed Aug. 9, 1967 4 Sheets-Sheet 3

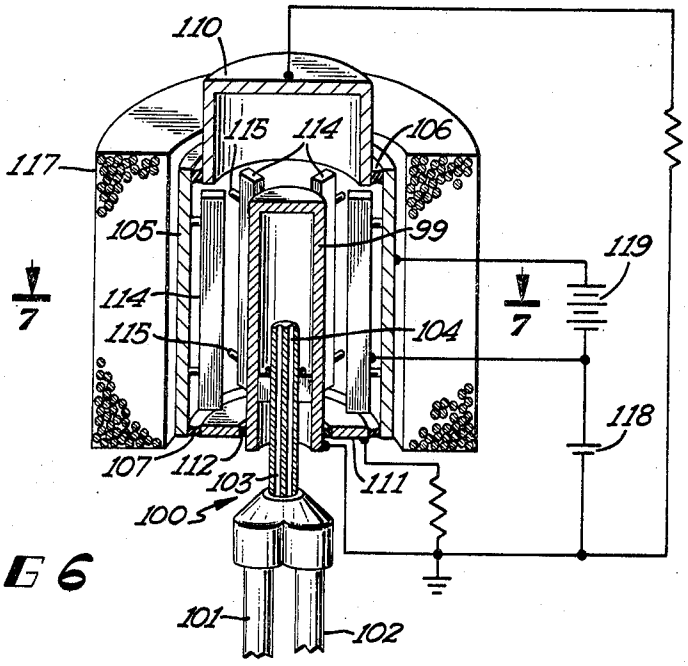

FIG 6

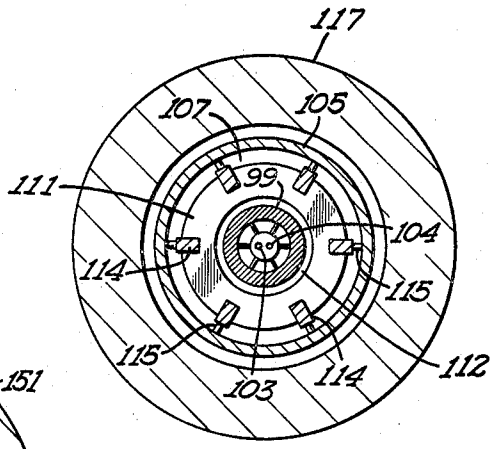

FIG 7

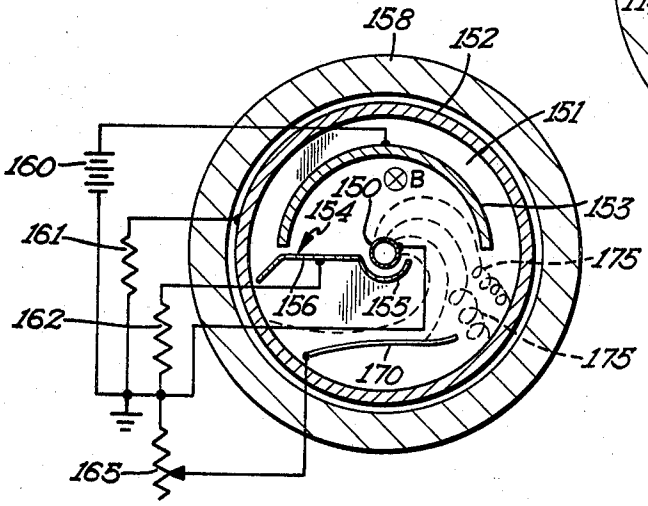

FIG 11

INVENTOR.
ROBERT L. LAING
BY
Frederick E. Lange
ATTORNEY

Nov. 4, 1969 R. L. LAING 3,477,012

THERMIONIC CONVERTER

Filed Aug. 9, 1967 4 Sheets-Sheet 4

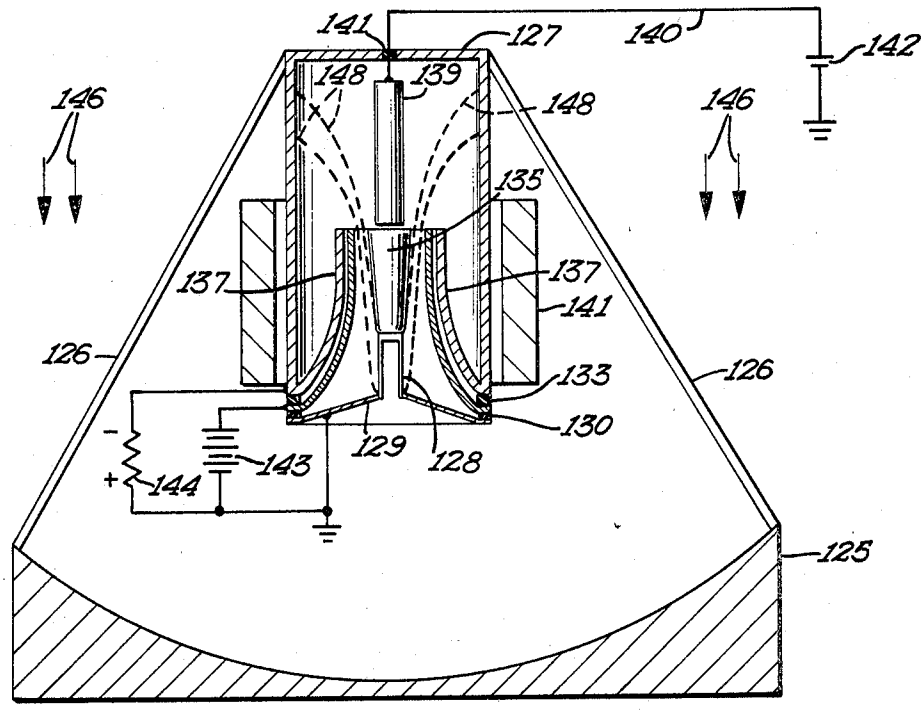

FIG 8

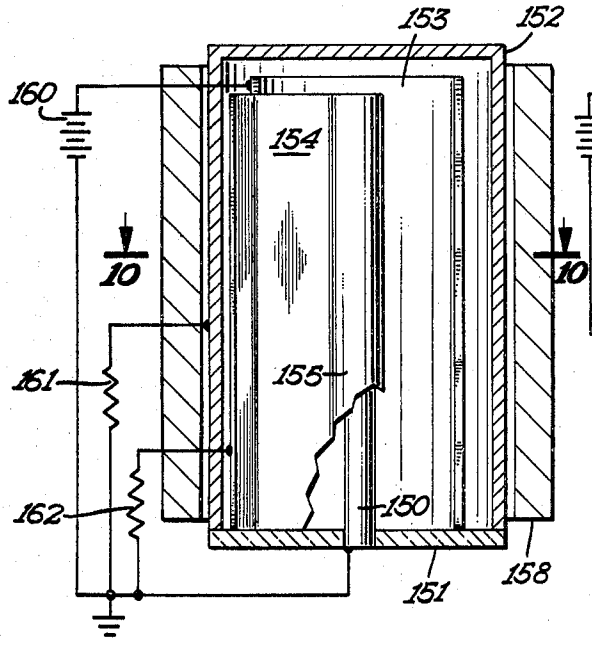

FIG 9

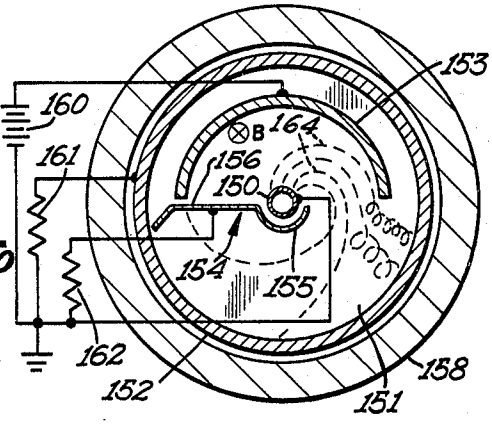

FIG 10

INVENTOR.
ROBERT L. LAING
BY Frederick E. Lange
ATTORNEY

United States Patent Office 3,477,012 Patented Nov. 4, 1969

3,477,012

THERMIONIC CONVERTER

Robert L. Laing, 3527 Aquila Ave. S., St. Louis Park, Minn. 55426

Filed Aug. 9, 1967, Ser. No. 659,484
Int. Cl. H02n 3/00, 7/00
U.S. Cl. 322—2 21 Claims

ABSTRACT OF THE DISCLOSURE

A thermionic converter in which a source of heat is used to apply heat to a cylindrical cathode which is surrounded by a cylindrical anode for accelerating the passage of the electrons from the cathode to at least one collector disposed adjacent an end of the anode and in which there is magnetic means surrounding the anode and producing a magnetic shield generally parallel to the axis of the anode for confining the electrons emitted by the cathode and minimizing the tendency of said electrons to engage said anode in passing from the cathode to the collector, there being a utilization circuit connected between the collector and the cathode to draw the energy from the collector, this utilization circuit being free of any external electrical source of power of the same order of magnitude of energy as that of the source of heat for heating the cathode.

BACKGROUND OF THE INVENTION

The present invention is concerned with a three-element type of thermionic converter in which there is a cathode for emitting electrons, an anode for accelerating the electrons, and a collector to which the electrons go after passing the anode. In such a device, there is a utilization circuit connected between the collector and the cathode and the load device is connected in this utilization circuit. The thermal energy to be converted into electrical energy is applied to the cathode to cause electrons to be emitted therefrom and the primary function of the source of power connected to the anode is to apply a potential such as to cause the electrons to be accelerated. Desirably, no appreciable current flow is in the anode circuit so that the source of power connected to the anode does not substantially contribute to the power input to the converter.

In the Laing and Feemster Patent 3,275,923, in which the present applicant is a co-inventor, use is made of a relatively fieldless hollow collector. As is pointed out in this patent, the hollow collector has the advantage that once the electrons leave the anode and enter the hollow collector, they are repelled away from each other to engage the walls of the collector. Thus, any tendency for a virtual cathode to be formed by reason of the space charge from slow-moving electrons in front of the collector surface is very substantially reduced or eliminated. In this prior patent, however, the electron beam is confined to a direct line extending from the cathode so that the cathode emission is reduced by the space charge depressed field of the beam.

In the Hatsopoulos Patent 2,915,652, there is disclosed a three-element thermionic converter in which a cross field is used to deflect the electrons leaving the cathode and to cause them to be directed towards a collector plate which is either flat or in some cases, convex. An arrangement of this type has the drawback that a virtual cathode is formed adjacent the collector surface by reason of the space charge from slow-moving electrons, as previously mentioned. This tends to retard the passage of electrons from the cathode to the collector.

SUMMARY OF THE INVENTION

The present invention is concerned with a thermionic converter having a portion similar to a magnetron injection gun for providing an electron stream. This means for providing an electron stream includes an accelerating means for accelerating the charged particles, which accelerating means has an elongated curved surface spaced from and at least partially surrounding a cylindrical surface for emitting charged particles, and a magnetic means surrounding the accelerating means and producing a magnetic field generally parallel to the longitudinal axis of the curved surface of the accelerating means for confining the charged particles emitted by the emitting surface and minimizing the tendency of the charged particles to engage the accelerating means. While I have shown a cathode as the means for emitting the charged particles, the charged particles being electrons in this case, and have shown the accelerating means as an anode having a positive voltage applied thereto, the invention contemplates the possibility of a similar arrangement using ions or other charged particles instead of electrons. Where the particles are charged positively, the polarities of the various voltages applied to the various electrodes will be opposite to those employed with electrons.

In one broad form of my invention, the anode is a cylindrical member completely surrounding the cathode and the collector is adjacent one end of the cathode. In fact, there may be a pair of collectors employed, one adjacent each end of the anode. In another broad form of my invention, the anode extends only partially around the cathode and the collector surrounds the cathode and anode so that the charged particles or electrons move past the anode and engage the surrounding cylindrical surface constituting the collector surface.

In some instances, I may employ a hollow collector having an opening facing the region between the cathode and anode. There may also be employed an additional collector in the form of a flat plate. In addition, the collector may be disposed intermediate the opposite ends of the anode, and may take the form of a helical coil. Instead of a flat plate, it is possible to employ two hollow collectors each having an opening facing the region between the cathode and anode. It is also possible to have the magnetic field diverge in the direction of the opening in the collector to facilitate entry of the electrons into the collector. The means for heating the cathode may take various forms. In some instances, this may take the form of a flame designed to heat the interior of the electron emissive surface. Or the cathode may enclose or be composed of radioactive material. In other instances, the cathode may be tubular and the source of heat may be a source of heated fluid which is circulated through the cylindrical cathode. It is also possible to employ a reflector adapted to be exposed to solar energy and in which the cathode is adjacent the focal point of the reflector.

The anode may take various forms. For example, it is possible to employ axial barlike electrodes which extend axially inside of the anode and are maintained at a different potential than the anode. It is also possible to employ an additional electrode disposed between the anode and collector and which is maintained at a potential such as to maximize the amount of energy withdrawn from the converter.

In the direct beam device of the Laing and Feemster Patent 3,275,923, the forces necessary to drive the electrons onto the negative collector are derived from the combination of mutual repulsion due to space charge in an essentially fieldless negative collector plus the velocity caused by cathode heat. In the Hatsopoulos Patent 2,915,652, the forces necessary to drive the electrons onto the flat or convex collector are derived primarily from the heat energy of electrons leaving the cathode. In the present invention, the forces that cause electrons to be driven onto the negative collector are derived not only from the mutual repulsion of space charge and a concave relatively

fieldless collector, plus the velocity imparted to the electrons due to cathode heat, but in addition to this, considerable extra velocity is imparted to the electrons towards the axial ends of the magnetron injection gun or compression chamber due to the magnetic fields which are established both in axially spinning electrons called Bohr magnetrons, and also in electrons spinning in a magnetron orbit. Additional forces are built up due to accumulation of space charge in the magnetron compression chamber, all of which enhances the velocity of the electrons towards the negative collector. These effects are further increased by the fact that the charged particles are forced out of the chamber at areas of irregularities or openings in either the electrostatic field or electromagnetic field, or a combination of both, due to the generation of space charge waves at such areas so that the charged particles leave the compression chamber with greater individual kinetic energy than the average kinetic energy of the charged particles within the compression chamber. Because of this additional energy, the charged particles can be collected on a highly charged collector electrode.

Therefore, while a converter of the type shown in the Hatsopoulos patent is able to produce output voltages of less than minus one volt, the present invention enables voltages of −200 volts at the maximum output efficiency, and open circuit voltages up to −900 volts, in actual experiments.

In addition to the possible modifications of my invention described above, various other modifications and various other objects of the invention will be apparent from the accompanying specification and drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIGURE 1 is a vertical sectional view of one form of my thermionic converter with a flame being shown as the means for heating the electron emissive surface;

FIGURE 2 is a fragmentary view showing a modification;

FIGURE 3 is a vertical sectional view of a further form of my invention employing a magnetic member adjacent the collector aperture and showing radioactive material as the source of heat, and also showing an additional collector in the form of a disc disposed intermediate the opposite ends of the anode;

FIGURE 4 is a vertical sectional view of a further form of my invention employing a substantially spherical collector at one end of the anode and showing a permanent magnet for producing a magnetic field which diverges outwardly adjacent the opening to this collector;

FIGURE 5 is a vertical sectional view of a still further form of my invention in which the cathode is in the form of a tube through which hot fluid is circulated and in which there is an intermediate helically wound coil concentric with the cathode and anode and disposed between the two;

FIGURE 6 is a vertical sectional view of a further species of my invention in which the anode is provided with axial bars which are electrically insulated from the anode and which are maintained at a lower potential than the anode proper;

FIGURE 7 is a cross-sectional view of the thermionic converter of FIGURE 6, the section being taken along a plane defined by the line 7—7 of FIGURE 6;

FIGURE 8 shows a species in which certain of the electrodes are contoured to maximize the collection of electrons on the collector surface. In addition, in FIGURE 8, I have shown a parabolic reflector designed to reflect the solar energy into the interior of the electron emitting cathode;

FIGURE 9 is a further form in which the anode is only partially cylindrical and in which the electrons are deflected past the anode onto the interior of a cylindrical collector;

FIGURE 10 is a cross-sectional view taken along the line 10—10 of FIGURE 9; and

FIGURE 11 shows a modification of the species of FIGURES 9 and 10 in which an additional electrode has been inserted, which electrode is curved to conform with a potential plane existing within the collector and which is maintained at an intermediate potential such as to maximize the passage of electrons to the collector surface.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGURE 1, my thermionic converter is shown as comprising a cylindrical hollow cathode **11** which is closed at its upper end and is open at its lower end. The cathode may either be formed of an electron emissive material, such as thoriated tungsten, or may be coated on its exterior surface with a suitable electron emissive material. The lower end of the cathode is hermetically sealed at **12** to a circular base member **13** of heat resistant insulating material, such as ceramic. A cylindrical collector **14** has a closed upper end **15** and a lower open end which closely fits over the base member **13** and is suitably hermetically sealed thereto. The collector **14** may either be of highly conductive material or may be formed of less conductive material with an interior conductive coating.

Also secured to the base member **13** in any suitable manner is a cylindrical anode member **17** which is mounted within the assembly with the axis thereof parallel to the axis of the cathode **11** and the collector **14**. An auxiliary collector **18** in the form of an apertured disc surrounds the cathode **11** and is secured to the upper surface of the insulating base member **13** coaxially of cathode **11**.

In some instances, it is desirable to employ a probe **19** which is shown as being electrically connected at **20** to the collector **15**. As will be explained in more detail, the probe **19** acts as the pickup probe to aid in the collection of the electrons by the collector **14** or acts as to shift the electric field lines in such a way as to maximize the collection of electrons by the collector.

The entire equipment described so far is hermetically sealed together and evacuated. The techniques of such evacuation and sealing are well known and are not described in detail herein.

Surrounding the unit adjacent the anode **17** is a cylindrical permanent magnet **22** which cylindrical magnet is coaxial with the anode **17** and produces a magnetic field generally parallel to the surface of the anode **17**.

Various means may be employed for heating the cathode **11**. Since the device is intended to function as a thermionic converter, the source of heat may be any suitable source of heat which it is desired to convert into electricity. In the particular embodiment in FIGURE 1, I have shown a conventional burner **23** in which the flame therefrom extends into the interior of the cathode **11**.

The anode **17** is maintained at a positive potential with respect to cathode **11** by any suitable source of voltage shown for illustrative purposes as a battery **25**, the positive terminal of which is connected by conductor **26** to the anode **17** and the lower terminal of which is connected to ground at **27**, this ground connection **27** being connected to the cathode **11** through conductor **28**.

In the operation of my device, as will be presently described, the heat to be converted to electricity is used to heat the cathode and the electrons emitted therefrom are caused to move to the interior surface of the collector **14** and onto the auxiliary collector **18**. Because of the electrons being negative, the collectors **14** and **18** become highly negative.

A suitable load device **30** has one terminal thereof connected by conductors **31** and **32** to the collector **14** and has the opposite terminal thereof connected to ground by conductor **33**. The load **30** is thus connected between the collector **14** and ground so that the electrons accumulating on collector **14** can flow through the load device **30**

back to the cathode **11**. The load device **30** is similarly connected through conductors **28**, **33**, **31**, and **34** between the cathode and the auxiliary collector **18** so that the electrons accumulating on auxiliary collector **18** can flow through conductors **34** and **31**, the load device **30** and conductors **33** and **28** back to the cathode **11**. In some cases, it may be desirable to employ a separate load device between the auxiliary collector **18** and the cathode since the negative potential which the auxiliary collector **18** assumes may be different than that assumed by the collector **14**.

Referring to the operation of FIGURE 1, the electrons emitted from the cylindrical surface **11** are attracted to the annular anode **17**. They are prevented, however, from actually engaging the anode **17**, to any appreciable extent, by the magnetic field produced by magnet **22**, the lines of force of which run parallel to the anode **17** between the anode **17** and cathode **11**. The beam of electrons is thus deflected and tends to travel in the space between the cathode **11** and anode **17**. The effect of the magnetic field tends to cause the electrons to rotate so that they tend to travel in a helical path between the cathode **11** and the anode **17**. As the electrons spin in magnetron orbits in the chamber between the anode **17** and the cathode **11**, they are repelled out of that region by their own mutual repulsion, and also are magnetically attracted to the poles of the magnet, which are adjacent to the collector, due to both electron axial and magnetron spin velocities. As they approach the upper end of anode **17**, they are also repelled by the lower electrons into the hollow space formed by collector **14**. Once they enter this hollow collector, they are in a relatively field-free region and are repelled by each other to engage the interior wall of the collector much as electrons go to the outside of a hollow Van de Graaff generator collector. The electrons which pass downwardly engage the auxiliary collector **18**. Both the electrons engaging the wall of the hollow collector **14** and those engaging the flat auxiliary collector **18** flow through the load **30** back to the cathode.

The pickup probe **19**, where used, tends to aid the electrons in passing to the wall of the hollow collector since this probe is located centrally of the hollow collector and is engaged by those electrons furthest from the wall of the collector. Furthermore, as pointed out above, the probe acts to shift the electric field lines to maximize the collection of electrons by the collector. The latter effect can be obtained even if the probe is insulated from the collector and the potential thereof adjusted for maximum collection.

With the arrangement just described, it is possible to obtain very high voltages as compared with a conventional thermionic converter. As pointed out above, instead of a voltage output of less than a volt, I have obtained voltages of approximately 200 volts between the collector and the cathode while drawing maximum power through the load. By employing the magnetic field **22** to prevent the electrons engaging the anode **17** and by giving the electrons a spiraling effect, it is possible for a much larger proportion of the electrons leaving the cathode **11** to be forced onto the collector surface with only a relatively small portion of the electrons engaging the anode surface. As has been pointed out, the ideal situation is to have the anode **17** act merely as a means for attracting the electrons without any of the electrons ever touching the anode. Under ideal conditions, the current flowing in the anode circuit should be substantially negligible.

The arrangement of FIGURE 1 in which the flat collector **18** is directly connected by conductors **34** and **32** to the hollow collector **14** tends to create an oscillatory condition due to transient effects causing imaging currents at collectors **14** and **18**, which are fed from each collector back to the other. In one particular instance, a frequency component of 50 mHz. was found to exist. This further aids in the collection of the electrons.

In FIGURE 2, I have shown a modified form of pickup probe. In this case, the probe instead of being in the form of a longitudinal wire-like electrode, as in FIGURE 1, is in the form of a circular ring **36** which is connected at **20** to the collector **14**. This ring has the advantage of having a somewhat extended surface which is engaged by more of the electrons entering the collector chamber.

FIGURE 3 shows a further modification of my invention. In this case, the hollow collector **44** is of substantially the same configuration as collector **14** of the species of FIGURE 1. Instead, however, of employing a flat insulating disc, I employ a cup-shaped insulator member **43** which is provided at its upper end with an inturned flange **45**. The cathode **41**, as with cathode **11**, is hollow and has an open lower end. Since I have shown radioactive material **46** as the source of heat in this modification, I have shown the lower end of the cathode as being closed by the insulating member **43** so that the interior of the cathode is sealed from the atmosphere. It is to be understood that even though the cathode **41** is entirely within the enclosure formed by insulating member **43** and collector **44**, it is desirable to have the lower end of the cathode **41** sealed to the upper surface of insulating member **43** to prevent the escape of radioactive material into the area surrounding the cathode. The anode **47** in this modification is in the form of an annular sleeve which engages the interior of the upstanding cylindrical wall of the cup-shaped insulating member **43**, this cylindrical wall serving to electrically insulate the anode **47** from the collector **44**.

In the modification of FIGURE 3, there is a cylindrical magnetic pole piece **48** which is secured on top of the flange **45** of the insulating member **43** and which is formed of magnetic material. This magnetic member tends to aid the entry of the electrons into the hollow collector **14** in several ways. In the first place, the line of force of the magnetic field do not extend beyond the magnetic member **48** because of the fact that this magnetic member forms an easier means of passage of the magnetic lines of force into the area between the anode and cathode. Furthermore, the magnetic field extends more closely adjacent to the anode by reason of being directed by the downwardly turned flange of magnetic member **48**. The magnetic field thus has less effect on the emission from the cathode. To aid this effect, I also provide a lower magnetic cylindrical sleeve **49** which is of the same diameter as the downwardly turned flange of magnetic member **48**. This tends to shorten the air gap in the magnetic field causing it to pass more closely adjacent to the interior of the anode **49**. Located adjacent to the cylindrical magnetic sleeve **49** is an auxiliary collector **51** which has an upturned cylindrical portion **52**. This auxiliary collector member **51**, like collector member **44**, is of conductive material. A further advantage of the magnetic members **48** and **49** is that these tend to attract the electrons to the collector since each electron tends to act like a tiny magnet due to both axial spin and magnetron orbital spin. Thus, the magnetic members **48** and **49** not only serve to limit the extent of the magnetic field and decrease its tendency to enter the hollow collector **44** but they also serve to confine the magnetic lines of force more closely to an area adjacent to the anode **47** and further to aid the electrons in being magnetically attracted into the collector areas.

A further feature of the modification of FIGURE 3 is that I provide an auxiliary intermediate collector **53**. This auxiliary collector **53** is in the form of a flat annular disc having a central aperture therethrough, the disc being suitably mounted by a suitable means, not shown, concentrically with the cathode **31** with the cathode extending through and spaced from the walls of the apertured disc in the collector **53**.

As with the species of FIGURE 1, a positive voltage is maintained between the anode **47** and the cathode **41** by a suitable source of voltage such as battery **55**, the positive terminal of which is connected by conductor **56**

to the anode 47 and the negative terminal of which is connected by conductor 57 to ground connection 58 to which the cathode is connected. In the present embodiment, I employ three loads 59, 60 and 61. The load 60 corresponds to load 30 of FIGURE 1, being connected between the main collector 44 and the cathode. The load 59 is connected between the magnetic member 49 associated with collector 51, and the cathode. The load 61 is connected between the intermediate collector 53 and the cathode. By using three separate loads, it is possible for each of the collectors to be maintained at a different potential and to obtain the maximum efficiency in collection of the electrons on the respective collector surfaces.

The intermediate collector 53 has the advantage that there is some tendency for a portion of the electrons to be attracted to the center of the magnetic compression chamber and by placing the collector 53 in an intermediate portion of this chamber, such electrons are collected by collector 53 and caused to flow through load 61.

The modification of FIGURE 4, like the modification previously described, employs a hollow cylindrical cathode 64 which extends through an aperture in an insulating disc 65 which may be of ceramic material. The cathode 64 is hermetically sealed to the disc 65 and the interior of the cathode is heated by a suitable source of heat such as a burner 66, the flame of which extends into the interior of cathode 64. A cylindrical anode 67 is sealed at its lower end to the insulating disc 65, this anode being mounted concentrically with respect to the cathode 64. Secured to the upper end of the anode 67 is a spherical conductive collector member 68 which has an opening 69 therein adjacent the interior of the anode member 67. A ceramic spacer sleeve 70 is interposed between the collector 68 and the upper end of the anode member 67, being hermetically sealed to both the anode and the collector.

In the modification of FIGURE 4, I have provided for a divergent magnetic field. To accomplish this, I provide an annular magnetic member 71 shown as a permanent magnet. This magnetic member is provided with upper and lower annular openings 72 and 73 to provide opposite pole portions. The lower magnetic opening 73 is disposed adjacent the lower end of anode member 67 and the upper opening 72 surrounds the lower portion of the spherical collector 68. It will be noted that the upper opening 72 is substantially larger than the lower opening 73. In order to guide the magnetic lines of force, I have provided a cylindrical magnetic member 75 which converges upwardly and which is of substantially the same diameter as the opening 73 at the lower end of the magnet. The upper portion of magnetic member 75 converges so that the interior of the upper end of this member more closely approaches the exterior of the cathode member 64. It will be readily apparent from the lines of force indicated by reference numerals 76 and 77 that the magnetic field is initially confined by the magnetic member 75 to a point closely adjacent to the cathode 64. As it passes upwardly to the upper portiton of magnet 71, it diverges. The effect of this is to permit the electrons to diverge as they pass upwardly. By confining the electrons at the lower end of the chamber and permitting them to diverge as they pass upwardly, the tendency for the electrons to engage the anode 67 is minimized and the tendency of the electrons to enter the interior of the hollow chamber 68 is increased. Once they enter the hollow collector chamber 68, they are in a relatively field-free region and the mutual repulsion of the electrons causes them to spread out and engage the interior of the collector.

As with the other modifications, a load device 80 is connected between the collector 68 and the cathode 64 through connections which are readily apparent from the drawing. Similarly, as with the other modifications, the anode 67 is maintained at a suitable positive potential with respect to the cathode by a suitable source of potential, such as battery 81.

In the species of FIGURE 5, the cathode 82 is in the form of a cylindrical tube through which hot fluid is circulated. The hot fluid is the source of heat energy which is to be converted into electrical energy. It is to be understood that the portion of the tube 82 extending through the converter is coated with a suitable electron emissive material. The anode 83 is in the form of a cylindrical sleeve which is sealed at its end to annular insulating members 84 and 85 of heat resistant insulating material, such as ceramic. Sealed to the interior of these annular insulating members 84 and 85, respectively, are cylindrical members 86 and 87 which are formed of magnetic material and constitute part of the collector structure. Further annular insulating members 88 and 89 are sealed to the collector members 86 and 87 and to the cathode tube 82. Extending between the two magnetic collector members 86 and 87 and electrically connected thereto is a helically wound wire 91 of electrically conductive material. The helical turns of the coil 91 are preferably wound in the same direction as the direction of rotation of the magnetic beam, this direction of rotation being determined by the polarity of the magnetic field. Where the coil is wound in the same direction as the direction of magnetic field, the current flowing through the coil between the two magnetic collector members 86 and 87 tends to attract the moving electrons just as two wires conducting current in the same direction are attracted to one another. For relatively small currents, it may be desirable to have the helical coil 91 wound in the opposite direction to the direction of rotation of the magnetic field so that there is more tendency for the electrons to engage the turns of the wire 91. Or the helical wire 91 may be wound in opposite directions in each axial direction beginning at the center of the coil.

It is, of course, to be understood, as with the other species, that the interior of the chamber enclosed by anode 83 is highly evacuated in a manner commonly employed in electronic discharge devices.

Surrounding the sealed unit enclosed by the anode 83 is a cylindrical permanent magnet 93 having inturned opposite ends which are apertured to provide opposite poles. The cathode 82 extends through the apertures in the magnet 93. The magnet 93 produces a magnetic field which extends generally to the anode 83 within the same.

Still referring to the species of FIGURE 5, a suitable source of potential such as the battery 94 is connected between the anode 83 and the cathode 82 so as to apply a positive potential to the anode 83. A suitable load device 96 is connected between the magnetic collector member 87 and the cathode 82 so as to be connected between the collector assembly and the cathode.

In the arrangement of FIGURE 5, the electrons leaving the cathode are attracted to the anode 83 but are prevented from engaging the anode 83 to any substantial extent by the magnetic field created by magnet 93. The electrons are thus forced to travel spirally in opposite directions. Some of these electrons are collected by the helical wire 91 and some enter the magnetic collectors 86 and 87, being attracted thereto by the magnetic action between the collector members and the spinning electrons. The electrons flow through the load device 96 back to the cathode.

Referring to the species of FIGURE 6, the cathode is indicated by the reference numeral 99. This cathode is either formed of electron emissive material or coated with an electron emissive coating. The cathode takes the form of an inverted hollow tube as in the other species. Extending into this tube is a burner 100 which is of a type which burns a mixture of gas and air or oxygen and acetylene, etc. A gas supply line 101 supplies gas to the burner and an air supply line 102 supplies air thereto. The gas and air are passed through passages 103 and 104, respectively,

and pass out through the burner **100** where they are mixed and burned. As with some of the other modifications, the anode **105** takes the form of a cylindrical sleeve of conductive material. This sleeve is secured at its opposite ends to annular members **106** and **107** of suitable heat resistant insulating material, being hermetically sealed thereto. Hermetically sealed to the inner wall of the annular insulating disc **106** is a cup-shaped collector member **110**, likewise formed of conductive material. Secured to the interior surface of the annular insulating member **107** is a flat collector plate **111** of conductive material. This flat collector plate, along with the rest of the assemblage, is supported from the cathode **99** by an interposed annular insulating member **112** which is hermetically sealed to the collector plate **111** and to the cathode **99**.

In this modification, I provide a plurality of auxiliary anodes **114** in the form of longitudinal bars or "cogs" of conductive material. As best shown in FIGURE 7, which is a cross-sectional view taken along the line **7—7** of FIGURE 6, these bars **114** are uniformly spaced about the periphery of the cathode **99** being suitably spaced therefrom. Each of the bars **114** is insulated from the main anode **105** by a series of insulating posts **115**.

The entire assemblage including the collector members and the anode member with the enclosed cathode and auxiliary anode members **114** is hermetically sealed and evacuated. Surrounding this evacuated structure is an electromagnetic winding **117** which produces a magnetic field similar to that of the other species, this magnetic field passing between the anode and cathode and generally parallel thereto. Any suitable energizing means, not shown, is employed for energizing the winding **117**.

In this species, as shown, I maintain the main anode **105** at a higher potential than the auxiliary bar electrodes **114**. A first source of power, such as a battery **118** is connected between the cathode and the auxiliary anodes **114**. While I have shown the connection to only one of these anodes, it is to be understood that a similar electrical connection is made between battery **118** and the other auxiliary anodes. A second source of power such as a battery **119** is interposed between the auxiliary anodes and the main anode **105** so that the main anode **105** is maintained at a higher potential than the auxiliary anodes. While I have shown the auxiliary anodes as being maintained at a lower potential than the main anode **105**, in some instances, it may be desirable to have the auxiliary anodes at the higher potential, relying upon the spacing between the auxiliary anodes to prevent the electrons from engaging the auxiliary anode. The effect of the auxiliary anodes connected as shown in the drawing, however, is to minimize any tendency of the electrons to pass to the high potential anode **105**. This, of course, is aided by the effect of the electromagnetic field.

While I have shown longitudinally extending bars **114** as constituting the auxiliary anode, it is to be understood that these auxiliary anodes or anode may take any other form. For example, it is possible to employ, instead of bars, a coiled wire such as wire **91** of FIGURE 5. In such a case, the coiled wire, instead of acting as auxiliary collector as in FIGURE 5, would act as an auxiliary anode, being maintained at a different potential than the main anode.

It is also possible to have the longitudinally extending bars connected to the opposite collector members and act as part of the collector structure, instead of being connected to a source of voltage to act as auxiliary anodes. These bars in such an arrangement would function in a manner similar to the coiled wire **91** of FIGURE 5. In such a case, the bars may be concave to increase the collecting effect.

It is also possible for the bars **114** or a coiled wire such as wire **91** to be connected to a variable negative source of voltage to function as a grid. In such a case, this auxiliary electrode or electrodes would be insulated from the anode and collector as is the case with the bars **114**.

In the modification of FIGURE 8, I have shown an arrangement in which solar energy is employed to heat the cathode. Furthermore, I have shown an arrangement in which certain of the electrodes are curved to more effectively direct the electrons onto the collector surface. Referring specifically to FIGURE 8, the thermal converter is supported from a parabolic mirror **125** by a plurality of struts **126** which engage an inverted cup-shaped collector **127** of suitable conductive material. The cathode **128** is cylindrical and hollow with the hollow portion facing downwardly, as in other modifications. Secured to the cathode **128** is a conical flange **129** of conductive material which is hermetically sealed at its outer upper edge to an annular ring **130** of suitable heat resistant insulating material such as a ceramic. The anode **131** is basically cylindrical but curves inwardly so that its diameter at its upper end is substantially less than its diameter at its lower end. This lower outer edge of the anode **131** is hermetically sealed to the insulating member **130** and to a second similar annular insulating member **133** which, in turn, is hermetically sealed to the lower end of the collector **127**. Thus, the cathode, the anode and the collector are held together to form a hermetically sealed enclosure which is suitably evacuated.

The cathode **128**, in this embodiment, is provided with an elongated inverted conical electrode **135** which electrode is of conductive material and functions as a focusing electrode. Because the electrode is connected to the cathode, it is at the same ground potential as the cathode. In this embodiment, I have also shown a curved shield **137** which is either integral with or conductively secured to the lower end of the collector **127** and extends upwardly and inwardly from this lower end. The general curvature of this shield corresponds approximately to the curvature of the anode **131**. The shield **137** functions as a Faraday shield to tend to reduce the effect of the electrons to go to the anode **131**.

To further aid the direction of the electrons, I provide a beam controlling "sole" **139**. A conductor **140** connected thereto through an insulator **141** located in the upper wall of collector **127** extends to a suitable source of positive voltage such as a battery **142**. The battery **142** tends to maintain the sole at a slightly positive potential with respect to the cathode, this positive potential being relatively small, however, as compared with the voltage applied to the anode **131**.

Permanent magnet **141** extends around the outside of the collector **127** and serves to provide an axial field which passes between the anode **131** and the cathode **128** including the focusing electrode **135**.

As with the other forms of the invention, the anode **131** is maintained at a positive potential with respect to the cathode **128** by a suitable source of power such as a battery **143**. Similarly, a suitable load **144** is connected between the collector **127** and the cathode **128** so that the electrons reaching the collector flow through this load resistor back to the cathode.

The parabolic mirror **125** is designed so that the rays of sun indicated by the reference numerals **146** are reflected into the interior of cathode **128**. It other words, the cathode **128** is located at the focal point of the parabolic mirror **125**. Because of this arrangement, the cathode **128** can be intensely heated by the solar energy directed onto the reflecting surface of mirror **125**. It is to be understood, of course, that the arrangement involving the parabolic mirror **125** may be used with other forms of the invention and that as far as the modification of FIGURE 8 is concerned, other forms of heating the cathode may be employed.

Referring generally to the operation of the thermionic converter of FIGURE 8, electrons leaving the surface of cathode **128** are directed as indicated by dotted lines **148** upwardly between the anode **131** and the focusing elec-

trode **135**. They are prevented from engaging the anode **131** by the combined effects of the electromagnetic field and the Faraday shield **137**. After passing upwardly beyond the end of the anode **131**, they are immediately repelled from each other so as to engage the interior wall of the collector **127**. This action is aided by the beam directing sole which exerts an attractive force upon the electrodes to further accelerate the same. At the same time, because of its relatively low positive potential and because of the fact that the electrons by the time they reach the region of the sole have obtained sufficient velocity in paths away from the sole, relatively few of the electrons engage the sole, substantially all of them passing beyond the sole and engaging the interior walls of the collector from whence they are drawn away through the load **144**. With this type of arrangement, in which the various beam guiding surfaces are curved, the electrons are very effectively directed towards the interior collector surface with relatively little loss to the anode or other auxiliary electrodes.

The arrangement of FIGURES 9 and 10 operates in a somewhat different manner in that the electrons instead of passing out beyond the end of the cathode are directed outwardly from the cathode in a curved path to engage a collector surface which is generally coextensive longitudinally with the cathode. In this modification, as will be presently explained, the anode does not encircle the cathode but merely extends part way around it permitting the electrons to pass beyond the edge of the anode and engage the collector.

Referring specifically to the structure shown in FIGURES 9 and 10, the cathode is indicated by the reference numeral **150**. This cathode, like that of the other modifications is preferably of tubular form having the lower end thereof open. This lower end extends through and is sealed to a ceramic base plate **151**. A suitable means, not shown, may be employed for introducing heat into the interior of the cathode **150** to cause the same to emit electrons. Also secured to the insulating base plate **151** is an inverted cup-shaped collector **152**, the lower open end of which is hermetically sealed to the insulating base plate **151**. The enclosure formed by the collector **152** and the base plate **151** is evacuated as in the other species. Also secured to the base plate is an anode member **151** which, unlike the other species, is only semi-cylindrical, as best shown in FIGURE 10. A sole electrode **154** is also secured to the insulating base plate **151**. This sole, as shown in FIGURE 9, is of substantially the same vertical extent as the anode **153** and the cathode **150**. As best shown in FIGURE 10, the sole **154** has a curved portion **155** which is curved so as to be concentric with the cathode **150**, the radius of curvature being somewhat larger than that of cathode **150** so as to be spaced therefrom. The intermediate portion of the sole **154** is in the form of a flat plate **156**. The outer portion of the sole is bent at an angle to portion **156** and closely approaches but is spaced from the collector **152**. The collector is surrounded by a permanent magnet **158** having a magnetic field parallel to the cathode **150**.

The anode **153**, as in the other species, is maintained at a relatively high positive potential with respect to the cathode by a suitable source of potential such as a battery **160**. A load device **161** is connected between the collector **152** and ground and hence between the collector and the cathode. Another load device **162** is connected between the sole **154** and the cathode.

In operation, the electrons leaving the cathode **150** tend to approach the anode **153** being attracted thereby. The magnetic field, however, produced by the magnet **158** is effective as indicated by the dotted lines **164** to deflect the electrons away from the anode **153** causing them to pass outwardly from beyond the right-hand edge of the anode **153** to engage the inner surface of collector **152**. Due to the rotative effect of the magnetic field and the slowing down of the electrons as they approach the negative and an acceleration of the electrons as they move back towards the accelerating anode, the electrons will follow a trochoidal path as indicated by the dotted lines. The electrons so engaging the collector cause the collector to assume a relatively high negative voltage and these electrons are conducted through the load **161** back to the cathode. Any electrons which continue to curve around in a clockwise direction, if they travel far enough, due to the mutual repulsion between the electrons, will engage the sole **154**. These electrons will be picked up by the sole and will travel back through load resistor **162** to the cathode. The sole **154**, by reason of the stray electrons engaging the same, tends to assume a somewhat negative voltage, the magnitude of which is determined by the magnitude of load resistor **162**. The sole **154**, being maintained at this negative voltage, prevents any electrons from returning to the cathode **150**. It also protects against any electrons continuing to move in a clockwise direction until they engage the positively charged anode **153**. The electrons traveling in this clockwise direction are thus either forced onto the sole **154** or onto the collector **152**. In either case, the energy resulting from the movement of these electrons is utilized in either of the loads **161** or **162**.

The arrangements of FIGURES 9 and 10, by reason of the concave collector **152**, the provision of the sole and the general organization of the unit, result in relatively high output voltages as compared with conventional crossed-field thermionic converters. I have obtained in one embodiment, a voltage output of −100 volts, such voltage being very much higher than those obtained with conventional thermionic converters. As with my other embodiments, the magnetic field acts to compress the space charge causing it to assume the nature of a compression chamber and due, in part to areas of irregularities or openings in either the electrostatic field or electromagnetic field or a combination of both, the charges leaving the compression chamber have much greater individual kinetic energy than the average kinetic energy of the charges within the compression chamber. Because of this additional energy, the electrons can be collecteo on the highly charged collector electrode **152**.

While I have shown the base member **151** as being of insulating material, it is also possible for this to be of conductive material and either integral with or electrically connected to the collector member **152**. In such a case, it is, of course, to be understood that the cathode **150**, the anode **153** and the sole **154** will be suitably insulated from this lower member. The advantage of picking the lower member of conductive material is that any electrons which spiral out above or below the anode **153** will engage a conductive surface of the collector and will increase the current flowing through the load **161**.

The species of FIGURE 11 shows an additional feature shown in connection with a thermionic converter of the type shown in FIGURES 9 and 10 but which can be employed with the other species. In order to enable a ready comparison of FIGURES 9 and 10 with FIGURE 11, the same reference characters have been used in connection with FIGURES 9 and 10, as far as identical elements are concerned. Thus, there is a cathode **150**, semi-cylindrical anode **153**, a cylindrical collector **152** and a sole electrode **154**. In addition to the elements included in the species of FIGURES 9 and 10, I have a further electrode **170** which is curved to conform to an equi-potential surface within the chamber formed by collector **152**. This further curved electrode **170** will be of substantially the same height as the anode **153** and is connected through an adjustable load **165** to the cathode **150**. Because the auxiliary electrode **170** lies in the path of electrons, it will tend to assume a negative charge by reason of the electrons engaging this element. By adjusting the load **165**, the amount of this negative voltage can be adjusted. It is preferable to adjust the negative voltage so that the voltage is slightly less negative than would otherwise exist along the equi-potential surface

existing at the location of this electrode **170**. It has been found in actual experiments that by doing so, the electrons tend to travel deeper into the collector region and then to be deflected through the area between the right-hand end of the electrode and the right-hand end of anode **153**, as shown by the dotted lines **175**. As with the arrangement of FIGURES 9 and 10, the electrons tend to follow a trochoidal path. It has been found in actual experiments that the efficiency of the unit is greatly increased when such an additional electrode is employed.

While I have shown the additional electrode **170** in connection with a thermionic converter of the type shown in FIGURES 9 and 10, it is to be understood that a similar type of electrode could be employed in connection with the other species. In each case, the contour of the additional electrode would be selected to conform with an equi-potential surface existing at the area in which it is located.

It is also to be understood that in connection with any of the embodiments of my invention that a suitable grid can be employed between the cathode and the anode to vary the emission from the cathode and hence to vary the output current.

While I have referred in numerous cases to electrodes being cylindrical in the specification and claims, it is to be understood that the term cylinder is to be construed in its broad geometric sense as the surface formed by any line being continuously moved parallel to a fixed line. In other words, the term cylindrical as used in the specification and claims is not intended to be limited to a right circular cylinder.

CONCLUSION

It will be seen that I have provided a thermionic converter in which a magnetic field is employed to hold the electrons under compression until they are forced out of the compression chamber at areas of irregularities or openings in the electrostatic or electromagnetic field. At such irregularities, space charge waves are generated and the charged particles leave the compression chamber with greater individual kinetic energy than the average kinetic energy of the charges within the compression chamber. Because of this additional energy, the charged particles can be collected on a highly charged collector electrode with great efficiency. The magnetic fields generated by the rotating electrons are an additional aid in generating velocity towards the collectors. Since the energy exchanges between the heat input, the charged particles in the cross-field space, and the collector are extremely complex, no effort has been made to explain these exchanges, except to point out the various actions known or suspected to occur. For purposes of brevity, it should be sufficient to note that the combination of a cathode to which heat is added, with a magnetron-like compression chamber, and a concave or hollow collector enables an output voltage much higher than the one or two-volt limits of conventional thermionic converters. By reason of the employment of a concave collector surface, the presence of a virtual cathode in front of the collector surface is materially reduced. It will also be seen that my arrangement is broad enough to contemplate either forcing the electrons or other charged particles out of the end of the chamber into or onto collectors disposed at the ends thereof or to cause the charged particles to pass out sidewise beyond the anode to engage an adjacent concave collector surface.

While I have shown a number of embodiments of my invention, it is to be understood that this is for purposes of illustration only and that the scope of the invention is to be limited solely by the appended claims.

I claim as my invention:

1. A thermionic converter for converting heat energy to electrical energy comprising:

an enclosure including

a cylindrical thermionic electron emissive cathode designed to emit electrons from the exterior cylindrical surface thereof when said cathode is heated,

means for accelerating said electrons comprising an anode having an elongated curved surface spaced from and at least partially surrounding said cathode, and

a collector having a concave conductive surface within said enclosure and disposed so that said conductive surface extends beyond one extremity of said anode so as to be in the path of electrons emitted by said cathode and moving past said curved surface of said anode,

a source of heat for applying heat to said cathode, said source of heat being of a magnitude such that it constitutes the primary source of external energy applied to said converter,

means for applying a positive voltage between said anode and cathode to accelerate the passage of electrons from said cathode to said collector,

magnetic means surrounding said anode and producing a magnetic field generally parallel to the longitudinal axis of the curved surface of said anode for confining the electrons emitted by said cathode and minimizing the tendency of said electrons to enage said anode,

and means operative to withdraw the electrical energy from said converter resulting from the heat applied to said cathode,

said means including a utilization circuit connected between said collector and said cathode to withdraw the energy from said collector due to the electrons engaging the conductive surface thereof, said utilization circuit being free of any external electrical source of power of the same order of magnitude of energy as that of said source of heat.

2. The converter of claim **1** in which the anode is a cylindrical member completely surrounding said cathode and in which the collector is adjacent one end of said anode.

3. The converter of claim **1** in which the anode extends only partially around the cathode and in which the collector surrounds the cathode over a sector through which the anode does not extend.

4. The converter of claim **2** in which the collector is hollow and has an opening facing the region between said cathode and anode.

5. The converter of claim **2** in which the magnetic field diverges in the direction of the collector.

6. The converter of claim **2** in which there is an additional collector disposed intermediate the opposite ends of said anode.

7. The converter of claim **6** in which the additional collector is in the form of a helically wound coil.

8. The converter of claim **6** in which the additional collector is in the form of a flat plate.

9. The converter of claim **2** in which the collector consists of two portions each disposed adjacent an opposite end of said anode.

10. The converter of claim **9** in which the two portions of said collector are each hollow and each has an opening facing the region between said cathode and anode.

11. The converter of claim **1** in which the cathode is tubular and in which the source of heat is a source of heated fluid which is circulated through said cylindrical cathode.

12. The converter of claim **1** in which the cathode includes radioactive material which constitutes the source of heat.

13. The converter of claim **1** in which the collector is of magnetic material.

14. The converter of claim **1** in which the collector is hollow and one or more pick-up probes or field forming electrodes are placed within, or form the end of the collector.

15. The converter of claim 1 in which the source of heat is a reflector adapted to be exposed to solar energy and in which the cathode is adjacent to the focal point of the reflector.

16. The converter of claim 1 in which axial barlike electrodes extend axially inside of said anode and are maintained at a different potential than said anode.

17. The converter of claim 1 in which there is an additional electrode disposed beyond one extremity of the anode and which is maintained at a potential such as to maximize the amount of energy withdrawn from said converter.

18. The converter of claim 1 in which there is a coupling between electrodes of the converter to cause oscillations which aid electron flow to the collector.

19. The converter of claim 1 in which there is a grid for controlling electron flow from the cathode.

20. A thermionic converter for converting heat energy to electrical energy comprising:

an enclosure including

a cylindrical thermionic electron emissive cathode designed to emit electrons from the exterior cylindrical surface thereof when said cathode is heated,

means for accelerating said electrons comprising an anode having an elongated curved surface spaced from and at least partially surrounding said cathode, and

a collector having a conductive surface within said enclosure and extending across the corresponding axial ends of said cathode and said accelerating means so that said conductive surface lies across the path of electrons emitted by said cathode and moving past the end of said curved surface of said anode,

a source of heat for applying heat to said cathode, said source of heat being of a magnitude such that it constitutes the primary source of external energy applied to said converter,

means for applying a positive voltage between said anode and cathode to accelerate the passage of electrons from said cathode to said collector,

magnetic means surrounding said anode and producing a magnetic field generally parallel to the longitudinal axis of the curved surface of said anode for confining the electrons emitted by said cathode and minimizing the tendency of said electrons to engage said anode,

and means operative to withdraw the electrical energy from said converter resulting from the heat applied to said cathode,

said means including a utilization circuit connected between said collector and said cathode to withdraw the energy from said collector due to the electrons engaging the conductive surface thereof, said utilization circuit being free of any external electrical source of power of the same order of magnitude of energy as that of said source of heat.

21. A thermionic converter for converting heat energy to electrical energy comprising:

an enclosure including

a cylindrical source of charged particles designed to cause charged particles to move from the exterior cylindrical surface thereof when said electrode is heated,

means for accelerating said charged particles comprising a second cylindrical electrode surrounding said first named electrode, and

a collector having a conductive surface within said enclosure and extending adjacent one end of said second electrode,

a source of heat for introducing heat within the interior of said first named hollow electrode, said source of heat being of a magnitude such that it constitutes the primary source of external energy applied to said converter,

means for applying a voltage between said second electrode and said first named electrode to accelerate the passage of charged particles from said first named electrode to said collector,

magnetic means surrounding said second electrode and producing a magnetic field generally parallel to the axis of said second electrode for confining the charged particles moving from said first electrode and minimizing the tendency of said charged particles to engage said second named electrode,

and means operative to withdraw the electrical energy from said converter resulting from the heat applied to said cathode,

said means including a utilization circuit connected between said collector and said first named electrode to withdraw the energy from said collector due to the charged particles engaging the conductive surface thereof, said utilization circuit being free of any external electrical source of power of the same order of magnitude of energy as that of said source of heat.

References Cited

UNITED STATES PATENTS

3,267,307	8/1966	Fox	310—4
3,275,923	9/1966	Laing et al.	322—2

ORIS L. RADER, Primary Examiner

H. HUBERFELD, Assistant Examiner

U.S. Cl. X.R.

310—4