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[54] **SYSTEM FOR CONDUCTING HEAT FROM AN ELECTRODE ROTATING IN A VACUUM**

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[73] Assignee: **General Electric Company**

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[52] **U.S. Cl.** **313/60,** 313/11, 313/46, 313/330

[51] **Int. Cl.** **H01j 35/10**

[58] **Field of Search**.....................313/60, 330, 11, 46

[56] **References Cited**

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Assistant Examiner—Darwin R. Hostetter
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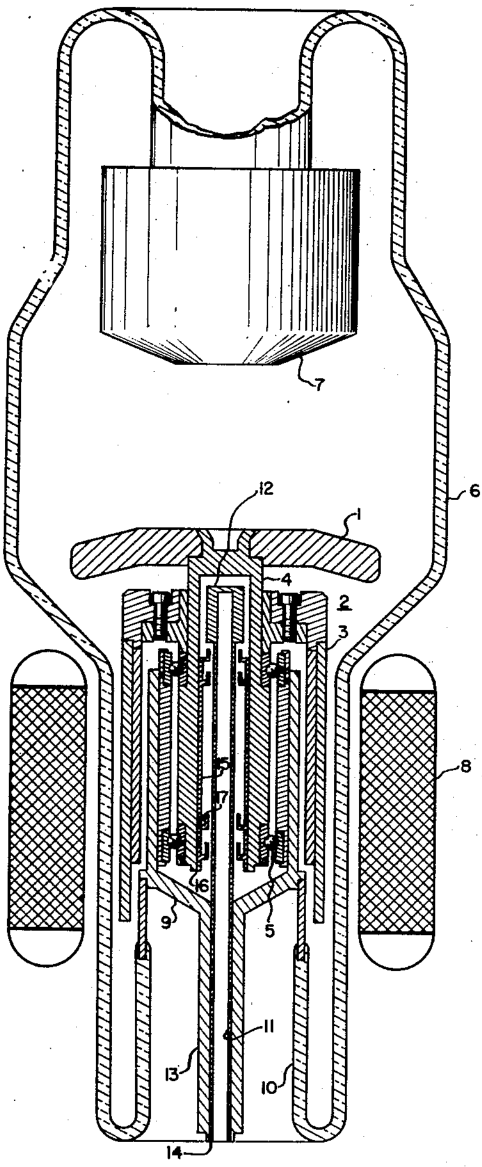
[57] **ABSTRACT**

Heat is conducted from an electrode moving in an evacuated enclosure and subject to heating by an electron beam by interposing a film of liquid metal between stationary and moving parts of the thermal path between the moving electrode and a stationary metal surface and cooling the stationary metal surface.

13 Claims, 5 Drawing Figures



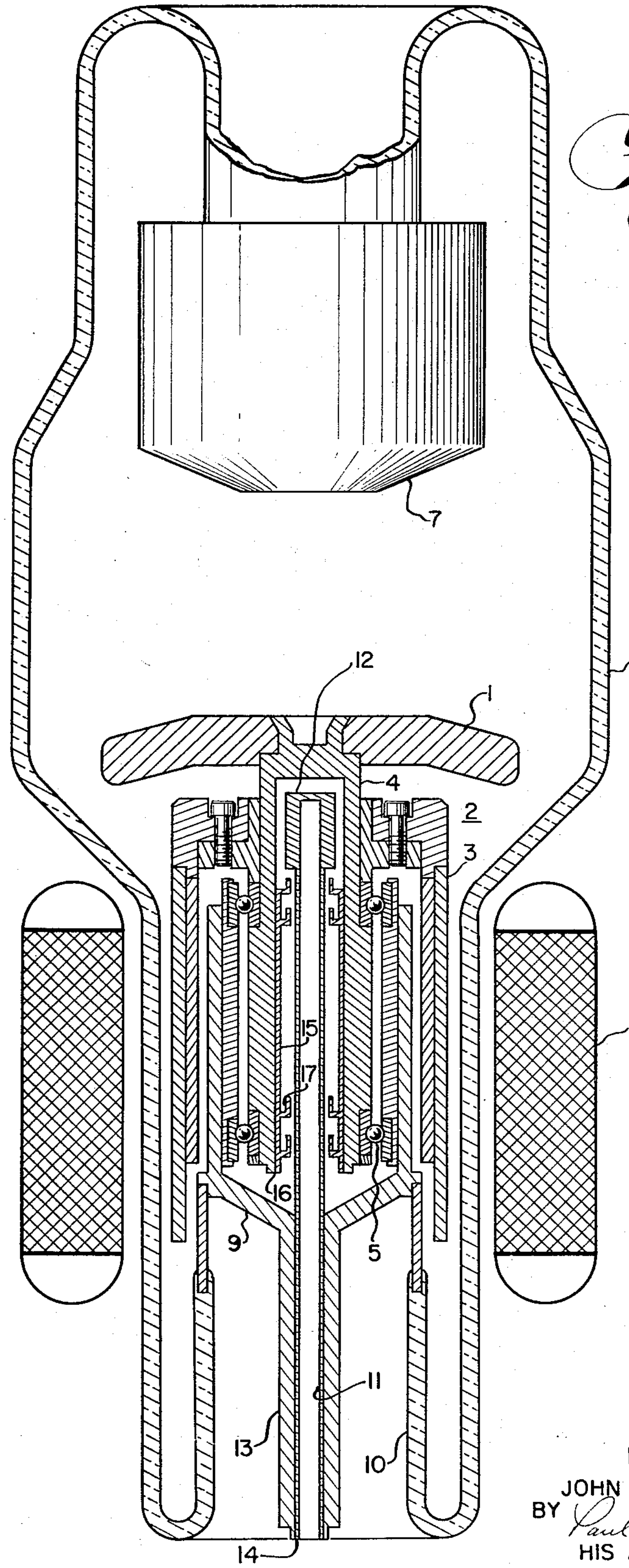


Fig. 1

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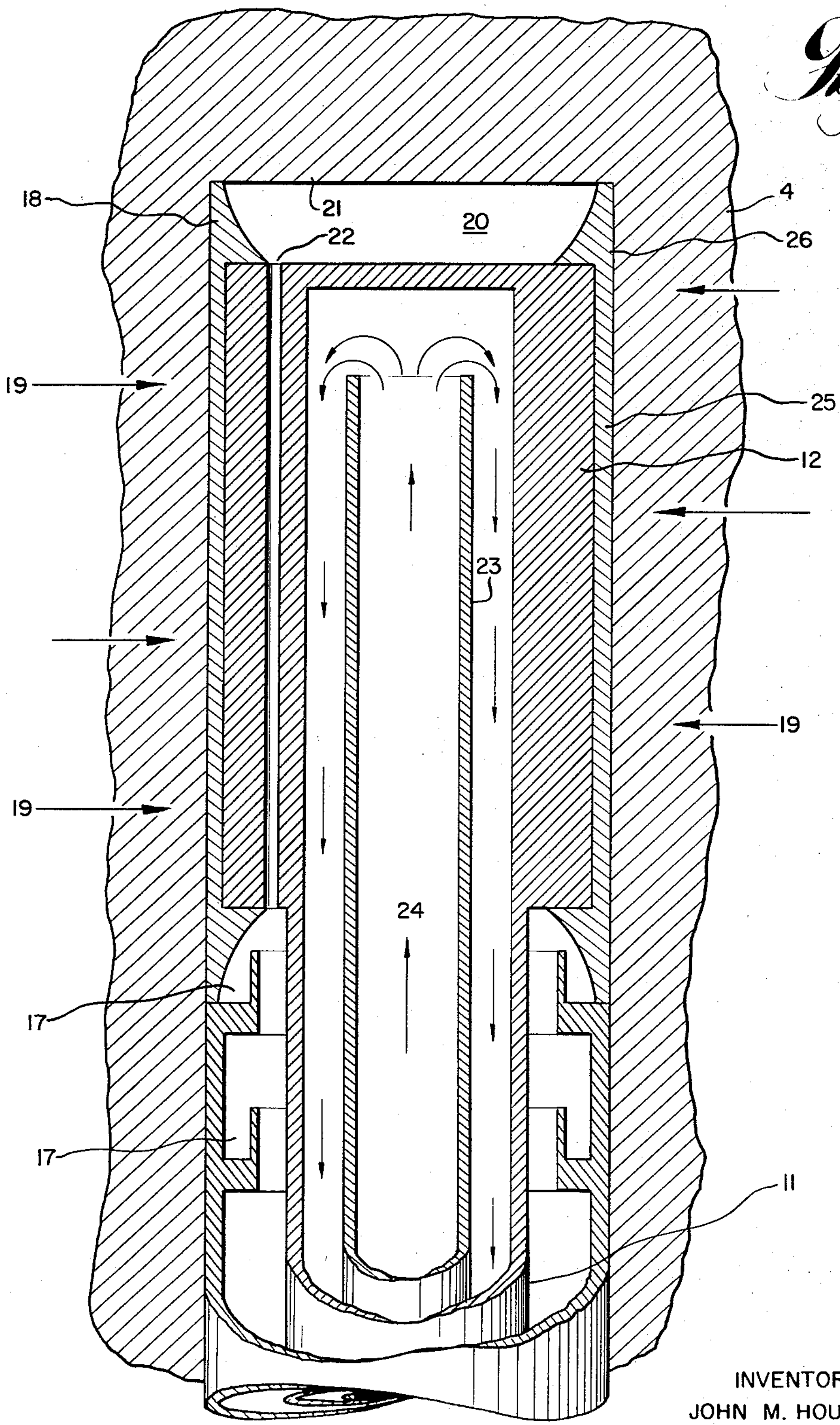
Fig. 2



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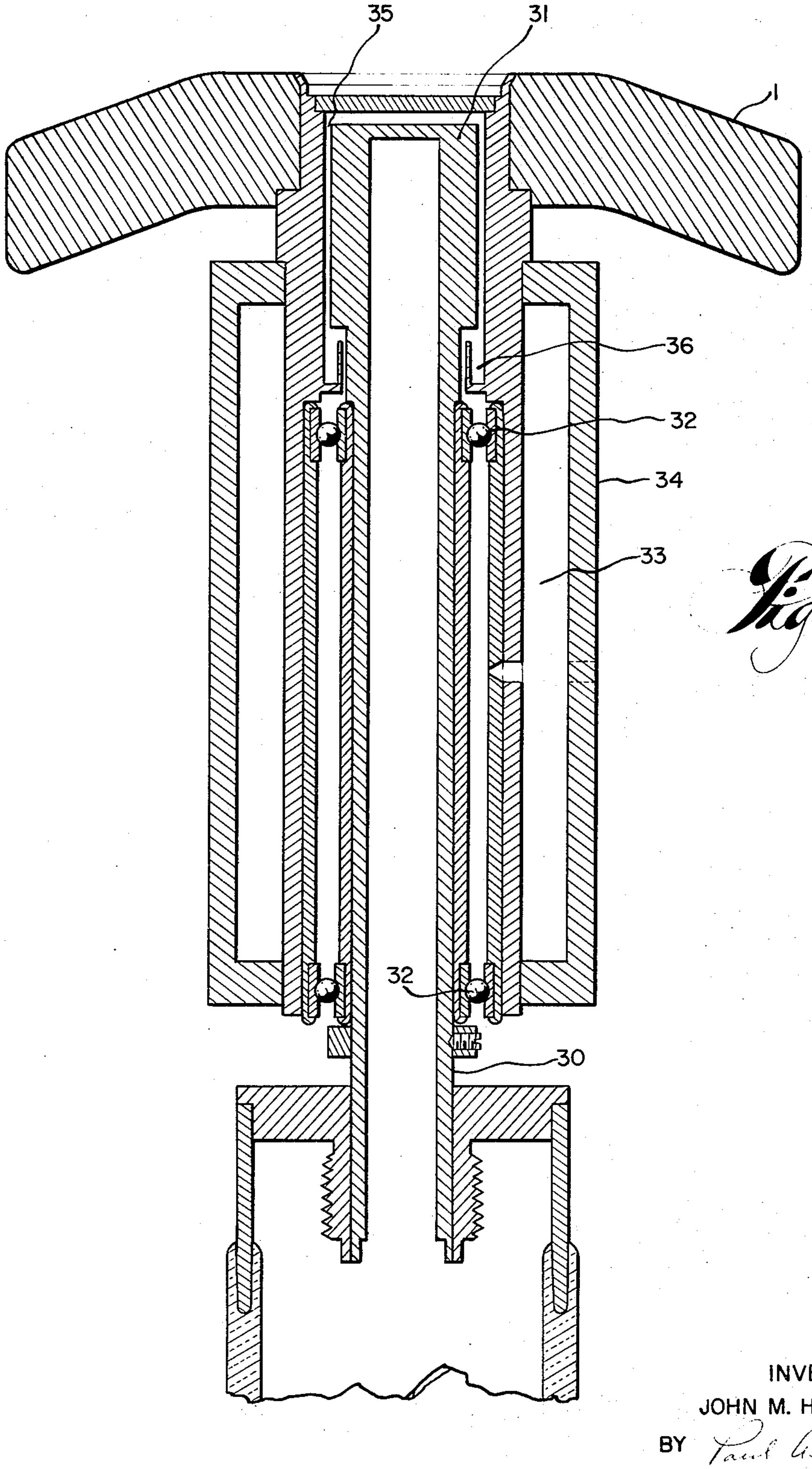

Fig. 3

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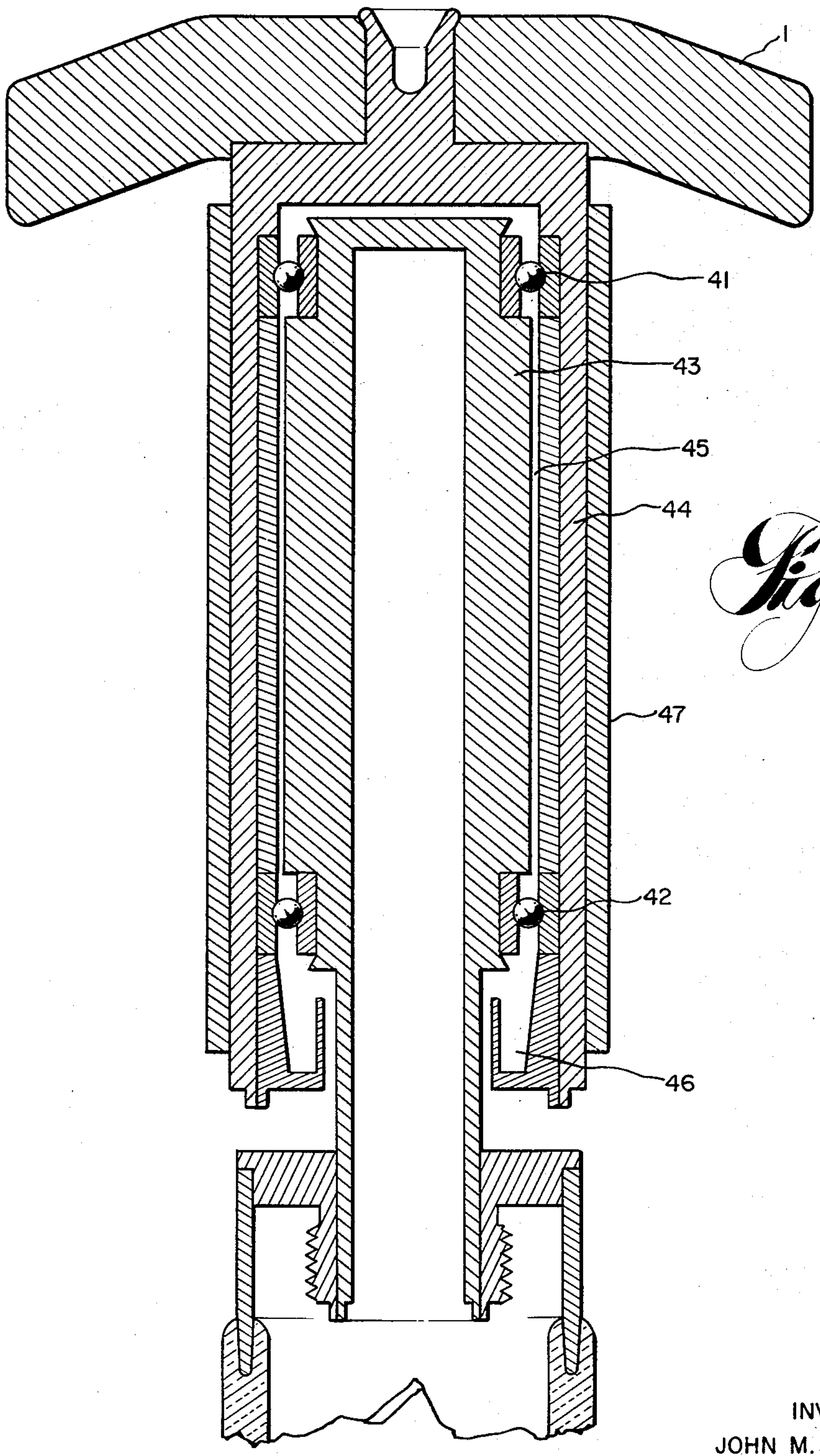

Fig. 4

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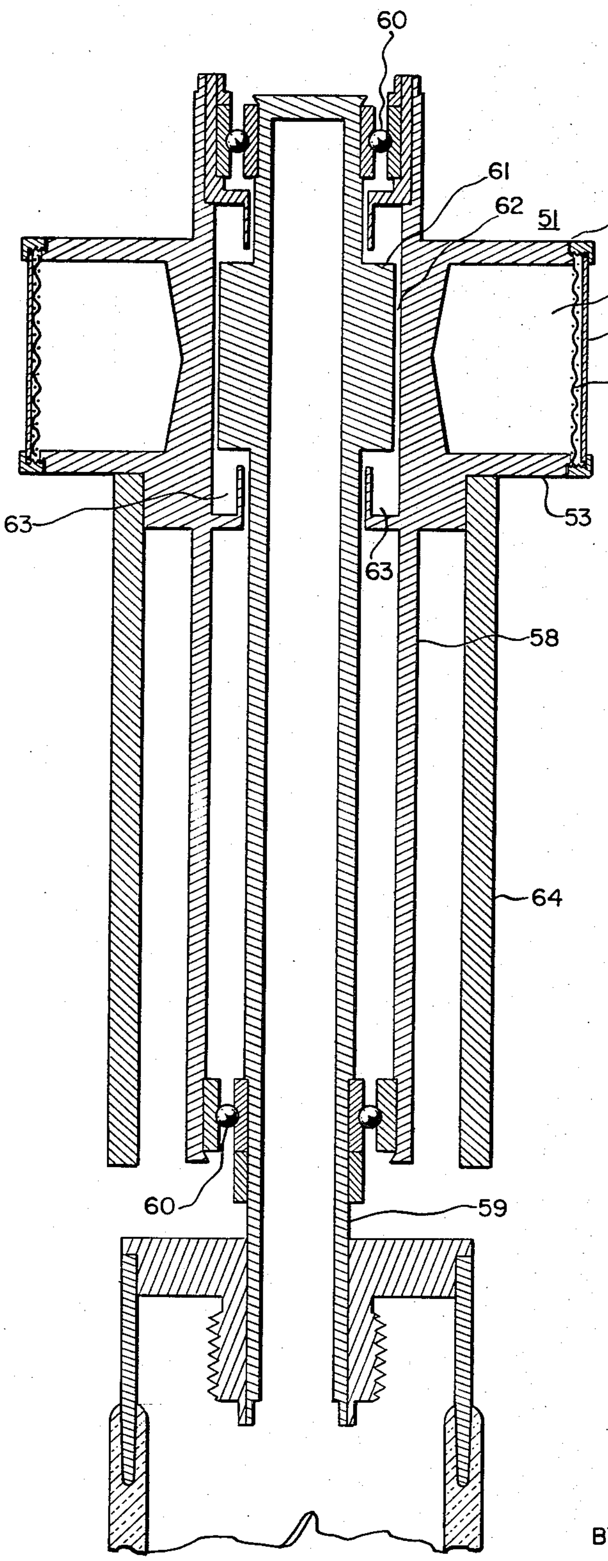

Fig. 5

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SYSTEM FOR CONDUCTING HEAT FROM AN ELECTRODE ROTATING IN A VACUUM

My invention relates to electron discharge devices, and in particular, to such devices which employ a rotating electrode which is subjected to a high intensity beam so that the electrode is heated to high temperatures.

Rapidly rotating electrodes are used in a variety of high vacuum devices, one principal user being the rotating anode X-ray tube which is the dominant device in current installations of medical X-ray equipment. Such rotating electrodes are subjected to high intensity electron beams which cause the electrode to heat rapidly. Conventionally, the rotating anodes are cooled by radiation, a process which can transfer only a small amount of heat unless the electrode is permitted to reach very high temperatures during its operation. Thus, in an X-ray tube the steady-state power dissipation through transfer of heat by radiation for a rotating anode is a mere 500 watts even when the anode is operating at bright red heat. In contrast, peak dissipation, or energy of the electron beam, is in excess of 100,000 watts. Even though the period of electron bombardment of the electrode for generation of X-rays is extremely short, the problem of overheating the anode limits the average permissible X-ray intensity. In addition to the fact that the anode is heated to excessive temperatures, the bearings in the structure supporting the anode are subjected to overheating because they are in the thermal path through which heat is conducted from the anode to the exterior of the tube.

The primary object of my invention is to provide new and improved apparatus and methods for cooling electrodes rotating in a vacuum.

Another object of my invention is to provide new and improved means for cooling rotating electrodes which permits increasing the average power output of the device employing such electrodes.

Still another object of my invention is to provide methods and apparatus for cooling the rotating anode of an X-ray tube which also reduces the vibrations of the anode.

In its broadest aspect, my invention consists in conducting heat from a moving electrode in an evacuated enclosure, which electrode is subjected to heating by an electron beam, by interposing a film of liquid metal between stationary and moving parts of a thermal path between the moving electrode and a stationary metal surface which can be cooled by conventional cooling means external to the device employing the moving electrode. An annular gap in the supporting structure is filled with a low vapor pressure liquid metal which conducts heat from the moving electrode to a hollow stationary metal cylinder, the stationary cylinder being cooled by conventional means such as a circulating fluid. In addition to conducting heat from the electrode, the liquid metal also damps vibrations normally present in rotating anode X-ray tubes.

These and other important objects and advantages of the invention will become apparent as the invention is understood from the following description which, taken in connection with the accompanying drawings, discloses preferred embodiments of the invention. In the drawings,

FIG. 1 is a vertical view, partly in section, of a rotating anode type of X-ray tube embodying the invention;

FIG. 2 is an enlarged view of a portion of the rotating anode of FIG. 1 which illustrates details of the cooling system for rotating electrodes;

FIG. 3 illustrates another form of a rotating anode for an X-ray tube embodying my invention;

FIG. 4 illustrates another bearing structure for a rotating anode for an X-ray tube embodying my invention; and

FIG. 5 illustrates still another form of a rotating anode for and X-ray tube embodying my invention.

The rotating electrode structure shown in FIGS. 1 and 2 comprises an anode 1 mounted at one end of armature 2 comprising an outer electrical rotor portion 3 and a hollow central shaft 4 supported by bearings 5. The electrode structure is contained within an evacuated region formed by a glass envelope 6. Also contained within envelope 6 is a cathode 7. A field coil 8 surrounds the portion of envelope 6 which contains rotor 3 and supplies the electrical field for rotating the armature structure. A hollow metal cylinder 9 is positioned between rotor 3 and cylinder 4 and provides a stationary support for bearings 5. The lower portion of cylinder 9 is sealed to a reentrant portion 10 of the glass envelope. Along the axis of concentric members 3, 4 and 9, there is located a fixed, hollow metal cylinder 11 having an enlarged portion 12 at its upper end. Cylinder 11 is supported by cylinder 9, having its lower end sealed to a depending portion 13 of cylinder 9 by a weld 14. A metal sleeve 15 is slipped within the central bore of shaft 4 and has its bottom end welded to cylinder 4 at point 16. Sleeve 15 carries a plurality of traps 17 on its inner surface.

In accordance with my invention, the annular gap between the enlarged portion 12 of cylinder 11 and the inner surface of hollow shaft 4 is filled with a low vapor pressure liquid metal 18 illustrated in FIG. 2. This liquid metal is initially placed in either uppermost trap 17 or the region 20 between the upper end of portion 12 and a transverse portion 21 of shaft 4. A duct 22 in enlarged portion 12 facilitates evacuation of region 20 during initial processing of the X-ray tube. Fixed metal cylinder 11 and enlarged upper portion 12 which are rigidly attached to the bearing structure of the tube are cooled from sources external to the X-ray tube. As shown in FIG. 2, one such method of cooling tube 11 comprises a conduit 23 centrally located within cylinder 11 and through which a cooling fluid 24, such as oil or water, is circulated. The outer surface of enlarged portion 12 and the inner surface of the upper end of shaft 4 are closely spaced so that the annular gap 25 between these surfaces has a width of a few thousandths of an inch, i.e., in the range of 0.0005 to 0.030 inch.

The liquid metal 18 contained within gap 25 may be any suitable alloy of low vapor pressure metals and preferably is liquid at the ambient temperature of the apparatus. One suitable metal possessing a low vapor pressure and which is liquid at room temperature comprises an alloy of gallium, indium and tin. While a metal having a melting point somewhat above room temperature could be used, preheating of the anode and the coolant to above the melting point of the liquid metal would be required before the device may be used. Hence, it is desirable that the metal be liquid at room temperature. Additionally, the coolant metal employed should have a low vapor pressure at the temperature at which the X-ray tube is baked-out during its evacuation to prevent distilling of the metal around the inside of the X-ray tube. During such evacuation, the tube is typically heated to a temperature of the order of 450° C. Consequently, it is desirable that the metal employed have a low vapor pressure at this temperature. Additionally, the metal employed should have a low viscosity so that the viscous drag on the rotating electrode does not cause an appreciable increase in the power required to produce rotation.

In operating the X-ray tube of FIGS. **1** and **2**, when anode **1** begins to rotate, centrifugal force causes the liquid metal **18** contained in trap **17** to migrate rapidly into gap **25**. Since the outer surface, rather than the inner surface, is the rotating surface, centrifugal forces on the liquid metal tend to drive the liquid metal from trap **17** into annular gap **25**. During rotation the surface of the liquid metal assumes a shape similar to that shown in region **20** of FIG. **2**. When rotation of the anode ceases, while capillary attraction will tend to maintain the liquid metal in annular gap **25**, any of the metal which does not remain within the gap is caught by one of the traps **17**.

During operation of the X-ray tube when anode **1** is heated to a high temperature, a thermally-conductive path for cooling the anode is provided by the short thermal path from anode **1** to the upper portion of hollow cylinder or shaft **4** which supports the anode and through the layer of liquid metal in annular gap **25** to enlarged portion **12** of central cylinder **11**. Heat transferred from the anode through this short, direct, thermal conductive path is carried away by circulating fluid **24**. The film of liquid metal in gap **25** is thus a direct thermally-conductive path between rotating shaft **4** and stationary cylinder **11**. The presence of this direct thermal conductive path in proximity to the heated anode causes rapid transfer of heat from the anode to the external cooling means and prevents or largely reduces transfer of heat to the rotor **3** and bearings **5**. The arrows **19** indicate the direction of the heat flow from shaft **4** through the liquid metal in gap **25** to enlarged portion **12**.

When gallium is one constituent of the liquid metal used for cooling the rotating electrode, certain care should be observed in choosing metals in contact with the liquid metal because gallium tends to alloy readily with many other metals. The metals rhenium, tungsten, molybdenum, tantalum, niobium, zirconium, and stainless steel, however, are among those which do not alloy readily with gallium up to temperatures of the order of 400° C.

In the embodiment of my invention shown in FIG. **3**, central shaft member **30** with its enlarged upper portion **31**, in addition to functioning to conduct heat from anode **1**, also supports two bearings **32**, which in turn support hollow shaft **33**, anode **1** and rotor **34** being mounted on shaft **33**. In this structure, a film of liquid metal is maintained in an annular gap **35** between member **31** and the inner surface of the upper portion of hollow shaft **33**. Trap **36** is located on the inner surface of shaft **33** and positioned below gap **35**.

In the modification of my invention shown in FIG. **4**, ball bearings **41**, **42** positioned between a stationary central cylinder **43** and a rotating cylinder **44**, upon which is mounted rotor member **47**, are exposed to the liquid metal film which fills an annular gap **45** between cylinders **43**, **44**. In such a structure, ball bearings **41**, **42** may be formed of any hard bearing material which does not react with the liquid metal. Where that liquid metal comprises an alloy of gallium, indium, and tin, the ball bearings may be formed of either steel or aluminum oxide. In this construction, trap **46** located below gap **45** may initially be filled with the liquid metal which, upon operation of the tube, rises into gap **45**. While most of the liquid metal will remain in the annular space **45** during inoperative periods of the apparatus, trap **46** receives any which drops out of this gap so that it may be returned upon subsequent operation of the tube.

The structures of FIGS. **3** and **4** may be cooled by circulation of a cooling liquid, as is shown in FIG. **2**, or alternatively may be cooled by a conventional low temperature heat pipe in which hollow cylinders **30** and **43** are filled with a fluid, such as water, mercury, cesium, or rubidium which conducts heat to the exterior surroundings. The use of a heat pipe in this respect is advantageous in that it avoids requirements of pumps and ancillary equipment for circulating fluids. Additionally, the conduct of heat from the anode **1** is temperature-dependent. Thus, for example, if a cesium or rubidium heat pipe is employed, the heat pipe conducts heat strongly only at a temperature above about 350° C. By conducting heat strongly only at temperatures above this point, the tungsten anode **1** tends to remain at a temperature above 350° C and thus avoids passing through its ductile, brittle temperature during periods of intermittent use. Such use of a heat pipe, therefore, helps to prevent local thermal stressing and cracking of the tungsten surface of the anode.

FIG. **5** illustrates an X-ray tube anode employing my invention in which the anode structure is of the type disclosed in U.S. Pat. application Ser. No. 602,999 — Harold F. Webster, filed Aug. 3, 1970 and assigned to the assignee of this invention. In this structure, the anode **51** comprises a hollow metal member comprising spaced walls **52**, **53** and a connecting peripheral target wall **54**. Walls **52**, **53** are formed of a refractory metal such as tantalum or niobium, while target wall **54** is formed of a good X-ray target material such as tantalum, tungsten, rhenium, or alloys of these metals. Included within the hollow region defined by walls **52**, **53**, **54** is a liquid metal **55** which may consist of sodium, lithium, cesium, or potassium which is in contact with wall **54**. This liquid metal evaporates to provide rapid cooling of the anode and after condensing is returned to the hot-spots of the anode by centrifugal force. A metal mesh **56** is attached to the inner surface of the hollow member to retain the liquid metal adjacent the target surface while the tube is cooling below the melting point of the liquid metal. Anode **51** is mounted on hollow cylinder **59** which surrounds shaft **58**, ball bearings **60** being provided for rotation of shaft **58** about cylinder **59**. Enlarged portion **61** on hollow cylinder **59** is closely spaced with respect to the inner surface of shaft **58** adjacent anode **51** to provide an annular gap **62** which is filled with a low vapor pressure liquid metal. Trap **63** functions to receive any liquid metal which escapes from the annular gap and return it to that gap upon rotation of the anode. Shaft **52** also supports rotor **64** which operates external field coils (not shown).

In the initial operation of my invention in the various embodiments illustrated, after a short period of rotation of the shaft bearing the rotating electrode the liquid metal rises into the gap between the electrode supporting shaft and a stationary part of the structure. Thereafter, except for extremely long periods of non-use, a film of liquid metal usually remains in that gap. During operation of the device, as the rotating anode heats, heat is transferred through the short conductive path from the electrode through the liquid metal in the annular gap between that shaft and a stationary member. As pointed out previously, preferably a low pressure liquid metal is employed so that the electrode may be portion of a device operating in a high vacuum. The heat transferred or conducted through the thin layer of liquid metal to the non-rotating portion of the device can then be transferred to the exterior of the device either by convection currents, a heat pipe, or forced cooling means. When my invention is embodied in an X-ray tube employing a rotating anode, for example, the rotating anode may be operated at average power levels of the order of several times greater than those currently employed without overheating the anode surface.

While I have shown and described several embodiments of my invention, it will be apparent to those skilled in the art that many changes and modifications may be made without departing from my invention in its broader aspects and I, therefore, intend the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. The combination in an evacuated electric discharge device comprising a rotatable electrode structure subject to heating, a supporting structure for said electrode structure, means for cooling said supporting structure, and means for conducting heat from said electrode structure to said supporting structure comprising a film of liquid metal interposed between said electrode structure and said supporting structure.

2. The combination of claim **1** in which the liquid metal is an alloy having a low vapor pressure at the normal operating temperature of the device.

3. The combination of claim **2** in which the liquid metal is an alloy which is liquid at ambient temperature.

4. The combination of claim **2** in which the liquid metal has a low viscosity.

5. The combination of claim **2** in which said liquid metal is an alloy of gallium, indium and tin.

6. The combination of claim **2** in which said device is an X-ray tube, said electrode structure comprises an anode and a supporting shaft, and said supporting structure contains a passageway for receiving a cooling fluid from a source external to said device.

7. The combination of claim **6** in which a bearing is interposed between said rotating electrode structure and said supporting structure and said liquid metal comprises a material which does not alloy readily with the materials of said bearing and said rotating structure.

8. The combination of claim **7** in which the liquid metal comprises an alloy of gallium, indium and tin, said bearings are ball bearings and are formed of material from the group consisting of steel and aluminum oxide.

9. The combination of claim **6** in which said supporting structure includes a centrally positioned hollow cylinder and means for providing a cooling fluid to the interior of said cylinder.

10. The combination of claim **6** in which said supporting structure includes a centrally positioned hollow cylinder and heat pipe means are included in said hollow cylinder.

11. The combination of claim **6** in which said supporting structure has a closed end which is opposed to said anode to form a region therebetween for receiving liquid metal, said supporting shaft has a liquid metal trap on the inner surface thereof spaced from said supporting structure and said supporting structure includes a passageway for returning liquid metal from said closed region to said trap.

12. The method of conducting heat from a moving electrode subject to heating by an electron beam in an evacuated enclosure which comprises interposing a film of liquid metal between stationary and moving parts of a thermal path between the moving electrode and a stationary metal surface and cooling the stationary metal surface.

13. The method of claim **12** in which the moving electrode is the anode of an X-ray tube, the moving part is a shaft supporting the anode, the stationary part is a bearing structure for the shaft, and which includes the steps of interposing a film of liquid metal between the shaft and the bearing structure, trapping any liquid which escapes from the region between the shaft and bearing structure during non-use periods of the tube and returning it to the region during periods of use.

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