Nov. 28, 1967 R. D. MOORE, JR 3,354,644

LIQUID PROTECTION OF ELECTRODES

Filed June 8, 1965

FIG. 1.

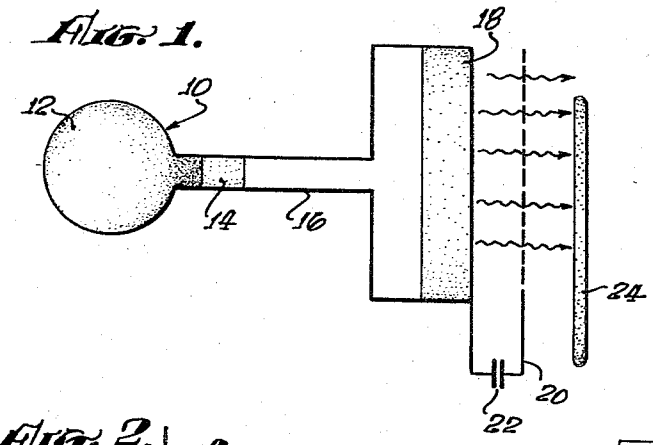


FIG. 2.

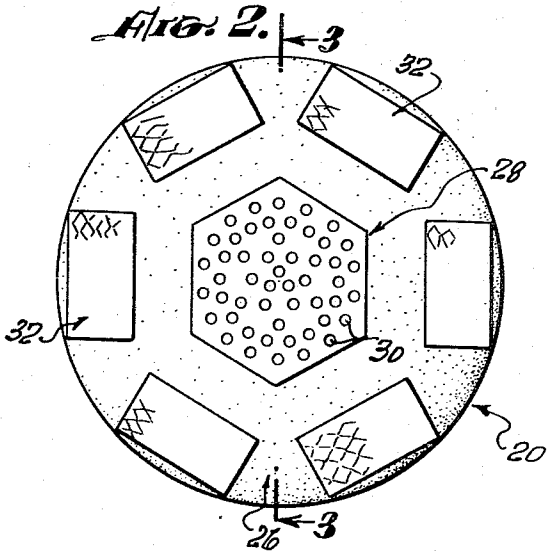


FIG. 3.

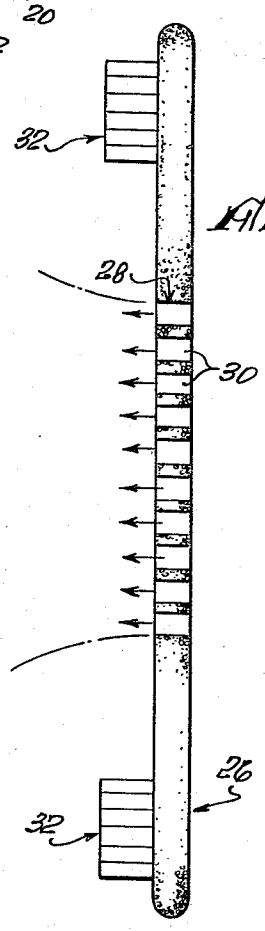
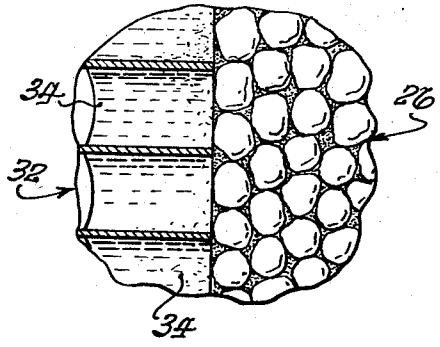


FIG. 4.



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LIQUID PROTECTION OF ELECTRODES

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This invention relates to a protective coating for a member subject to erosion by particle bombardment, vaporization, as well as other sources of erosion. In particular, this invention relates to electrodes, contacts and the like wherein a replenishable liquid is distributed over the surface of such members by surface tension forces and capillary action, whereby the surface of the member is protected.

It is well known in the electrical art that the erosion and deterioration of electrodes severely limits the life of such elements creating performance, maintenance and reliability problems along with increasing costs. To prevent this erosion, various prior art approaches have been taken, such as employing erosion resistant materials, minimizing the erosive forces and cooling the electrode by internal cooling arrangements. In some applications, these techniques have been proven helpful but in general it has meant only a slight lifetime increase. In many devices these techniques have not been applicable. These prior art techniques have had little success in the case of electronic device electrodes where the electrode controls the flow of electrons or ions. An ion engine and various electronic tubes are typical devices employing such electrodes. In these devices the electrodes are subject to ion and electron bombardment which tends to erode their surface decisively limiting their life and deteriorating their geometry. In such electrodes it is not possible to minimize the cause of erosion, as such is incident to normal operation of the devices. It is not practical to conventionally cool such electrodes, especially in the case of applications where weight and cost are an important factor. The application of improved materials can at best only slightly extend the life of such electrodes.

In order to overcome the shortcomings and disadvantages of prior art devices, a simple means for automatically and continually covering the surface of an electrode with a readily replenishable material has been invented. In particular, a liquid is distributed over the surface of the electrode by surface tension and capillary forces. These forces may be visualized as similar to the ones which occur when an ink blotter is touched to a wet wick. The blotter is immediately wet over a substantial area. In the invention a member containing a liquid and having relatively large pores is touched with a member having relatively small pores resulting in a wetting of the member having the relatively small pores. The liquid material and electrode material are such that the electrode is wetted or coated by the liquid. As the electrode is bombarded with particles, the liquid is eroded and the continual capillary and surface tension forces automatically replenish the liquid over the surface of the electrode.

By employing this invention, it has been found that indefinitely long lifetimes may be achieved. In early tests of the invention, lifetime improvement of fifteen to one (15:1) under the most severe conditions has been achieved. The integrity of the electrode geometry is maintained throughout such electrode life. This is especially important in devices where the electrode shape controls particle flow or movement or alternately controls the shape of the part being formed, such as in electric discharge machining and forming. In addition, the invented arrangement is relatively simple, lightweight, may increase reflection from the electrode to a radiating body where desired, enable operation under most severe conditions, reduce electron emission from the electrode, and impart other desirable properties to the electrode.

Briefly, the structure of the invention comprises: a porous electrode member for exerting an electric field, a reservoir means for supplying a liquid metal to said porous electrode member, and a liquid metal in said reservoir, whereby said electrode is covered with said liquid metal.

The above advantages and structural features will be readily understood by referring to the detail specification which follows along with the drawings wherein:

FIGURE 1 is a schematic drawing of an ion engine employing the invented electrode;

FIGURE 2 is a front view of an electrode embodying the invention;

FIGURE 3 is a sectional elevation view taken along the lines 3—3 of FIGURE 2; and,

FIGURE 4 is an enlarged view of a portion of FIGURE 3.

This invention will be explained in conjunction with an ion engine because it is in this application that the invention is exposed to severe operating conditions. It will be apparent from this particular use that the invented member may be readily employed in many less rigorous applications. Referring to FIGURE 1, an ion engine is shown comprising an ionizing material reservoir **10** which may contain an ionizing material **12**, such as cesium. The ionizing material is passed through a vaporizer **14** which is kept at the boiling point of the ionizing material which is usually stored in reservoir **10** in liquid form. Vaporized ionizing material is passed from vaporizer **14** via the feed line **16** to the back side of an ionizer **18**. The ionizing material then passes through the ionizer **18** which may be a porous tungsten ion emitter that is maintained at a temperature in the negihborhood of 1200° C. The ions emitted from ionizer **18** are accelerated by an accelerating electrode **20** which is connected to an energy source **22**. A thermionic neutralizer **24** is inserted in the path of the ions to prevent the ions from being attracted to the space vehicle after being ejected from the engine. It is the attraction and acceleration by the accelerating electrode **20** and the ejection of the ions from the engine that produces the desired engine thrust. This general description of an ion engine is only for purposes of placing the invented electrode in an environment which will clearly point out its significance and advantages. The advantages are present when the invention is employed in many different environments and this one should only be considered illustrative. The significance and advantages of the invention can be appreciated by considering FIGURES 2–4.

Referring to FIGURES 2–4, the electrode **20** comprises an electrode member **26** that is subject to erosion by bombardment with ions, by vaporization due to high temperatures or by other sources. In an ion engine, the primary source of erosion is ion bombardment. An ion engine is commonly operated at temperatures in the range of 800° to 900° C. and at pressures of less than 10^{-6} torrs. Under such operating conditions, it is preferred that the electrode be made from a sintered tungsten material having a maximum pore size of approximately 10 microns. Other materials such as iron and molybdenum may also be employed in an ion engine as electrodes. It should be understood that it is only necessary that the pore size be an appropriate size relative to the other elements of the electrode. The electrode material should be adapted to withstand the operating conditions of the electrode, should be compatible with the liquid employed in the electrode, and should have properties consistant with the function performed by an electrode.

As shown in FIGURE 2, the electrode is circular in shape and has a hexagonal portion **28** which includes a plurality of apertures **30** which facilitate the passage of the ions through the electrode. Situated adjacent each side of the hexagon **28** is a means for storing a liquid such as reservoir means **32**. The reservoir **32** is attached to the electrode member **26** and the electrode member **26** is operated at a temperature which maintains the material in reservoir **32** in its liquid state, thus additional heat sources are not required to maintain the liquid state. A cap (not shown) or other sealing means is placed over the reservoir to retain the liquid in reservoir **32**. While there are a plurality of reservoirs **32** shown, it should be understood that it is possible to employ fewer reservoirs. It is possible to distribute liquid over the surface of the electrode with one reservoir. The determination of the exact size, the number and the nature of the reservoirs will depend upon geometry, construction and the size of the electrode along with the period during which the reservoir **32** is not to be replenished and the importance of minimizing weight by not incorporating additional heating sources (that is, other than the electrode member **26**). It is, of course, within the scope of the invention to employ other types of reservoirs such as a separated tank with an independent heat source along with a wick connecting the independent tank and the electrode member **26** or reservoir **32**. Other reservoir and heating combinations may readily be devised for bringing a liquid in contact with the electrode **26**.

The reservoir **32** has pores that are relatively large in comparison with the pores of the electrode member **26**. In the specific embodiment described above, the pores of the reservoir **32** should be larger than 10 microns. These dimensions in general refer to the width or diameter of the pore. The term pore should not be taken as designating a particular configuration or shape. A pore may be any hollow or evacuated region or opening. Typically, the reservoir **32** may be made from a honeycomb or foil or a sponge structure of iron, aluminum, tungsten, molybdenum or other materials depending on the liquid used.

An important aspect of this invention is the liquid **34** that is employed in the reservoir **32** FIGURE 4. This is especially so in the case of an ion engine where the materials involved, ion bombardment and operating conditions (temperature, pressure, etc.) present difficult qualifications. The liquid **34** must first be capable of wetting the electrode surface. The liquid is said to wet a surface or solid when the contact angle between the liquid and the solid is less than 90° and preferably equal to 0°. This is necessary to allow surface tension and capillary action to combine to flow a liquid through the electrode and form a film over the electrode surface by merely bringing the fluid in reservoir **32** into contact with the smaller pores of the electrode. Stated simply, the smaller pores of electrode member **26** give rise to a greater surface area than the surface area of reservoir **32** resulting in the electrode member **26** exerting a greater surface tension force on liquid **34** than reservoir **32**. This differential of surface tension forces combines with capillary action to spread the fluid over the electrode surface by capillary action.

In addition to wetting, the electrode material must not melt or dissolve into liquid **34** to any appreciable extent and the vapor pressure of liquid **34** must be low enough at the electrode temperature that the mass loss of liquid **34** due to evaporation is a small fraction of the mass flow of ionizing material employed in the ion engine. In any case, the mass loss due to evaporation should be maintained at a relatively low figure in order to conserve liquid **34**. In the case of an ion engine operated in space or in regions approaching the environment of space, the vapor pressure of liquid **34** would have to be under approximately 10^{-5} torrs. Other requirements for liquid **34** are that it remain liquid at all electrode operating temperatures, that it not react with the ionized material, that it have high enough vapor pressure to evaporate from ionizer **18** faster than it is sputtered on to it and that it either not react with the ionizing material, or if reacting, form compounds which will liquify or evaporate at the electrode operating temperatures. This last requirement is necessary to prevent the electrode surface from becoming choked with ionizing material—liquid compounds which would interfere with the liquid flow or destroy the surface tension action. In an ion engine environment employing a sintered tungsten electrode and cesium ionizing material with the engine operating at temperatures in the range of 800° to 900° C. and pressures of less than 10^{-6} torrs, a liquid metal of tin and 2% iron by weight will operate satisfactorily.

In operation, liquid metal **34** is placed in the reservoir **32** by suitable means and the ion engine electrode member **26** is brought up to operating temperatures in the range of 800° to 900° C. whereupon the material in reservoir **32** retains or assumes a liquid state. With the metal **34** in its liquid state, the differential in pore size between electrode member **26** and reservoir **32** results in the electrode member **26** soaking up a given amount of liquid metal **34** and automatically distributing this metal over its surface by capillary and surface tension action. The liquid metal **34** forms a film over the surface of the electrode member **26**. As the ions are accelerated from ionizer **18** through electrode member **26**, a number of them collide with electrode member **26** and act as an erosive force. The liquid film acts as a protecting surface and though it may be momentarily broken by the ion bombardment, the reservoir **32** and the capillary and surface tension action function to soon thereafter replenish the eroded material. This eroding and replenishing action serves to greatly extend the lift of the electrode and to preserve its geometry. In the case of an ion engine as well as other electronic devices, the coating of the electrode with a liquid metal may, with proper choice of liquid, reduce the electron emission of the electrode. In the case of an ion engine, the emission of electrons results in a power loss. The reduction of this electron emission may increase the efficiency of an ion engine by as much as 2%. In addition, in an ion engine the coating of the electrode surface adjacent ionizer **18** with a fluid such as tin results in this surface of the electrode reflecting a substantial portion of the radiant energy transmitted by ionizer **18**. This both adds to the efficiency of the engine and helps in reducing electrode temperature. The invented arrangement is lightweight, simple and relatively low in cost. These features broaden its scope of application.

It should readily be apparent from the above description pertaining primarily to an ion engine that the invented arrangement employing a reservoir, an electrode having different pore sizes and a liquid metal distributed from the reservoir to the electrode by capillary and/or surface tension action have application in many other fields. For example, the invented arrangement could be employed to protect electrodes in other electronic devices such as microwave amplification tubes employing plasmas or to protect the contacts in circuit breakers, vibrators and other electrical devices or to protect the electrodes in spark discharge machines as well as a host of other applications. Therefore, various embodiments of the present invention in addition to what has been described in detail may be employed without departing from the scope of the invention which is defined in the claims which follow.

What is claimed is:

1. An electrical member having a potential applied thereto comprising:

a porous member subject to erosion, said porous member having pores of a first given volume that extend at least over a part of the surface of said member;

a means for supplying a liquid to said pores of said porous member;

said means having pores of a volume greater than the pores of said porous member to attract the liquid from said means to said member by surface forces and to distribute the liquid over said surface; and,

a liquid in said means that is adapted to flow from said means to said porous member and be distributed through said pores, whereby said porous member is covered with said liquid and the erosive forces which said porous member is exposed to are substantially absorbed by said liquid.

2. The structure recited in claim 1 wherein said porous member is an electrode, said means is a metal sponge, and said liquid is a liquid metal maintained in a liquid state by the temperature of said electrode.

3. The structure recited in claim 2 wherein said electrode includes tungsten and said liquid metal includes tin and iron.

4. In an ion engine having a reservoir of ionizing material, a vaporizer for vaporizing said ionizing material and an ionizer for ionizing said vaporized material, the combination comprising:

an electrode in the path of said ionizing material for accelerating said ionized material;

a liquid coating the surface of said electrode; and,

means for maintaining a substantial portion of a surface of the electrode coated with said liquid metal, whereby erosion of the electrode is prevented.

5. In an ion engine having a reservoir of ionizing material, a vaporizer for vaporizing said ionizing material and an ionizer for ionizing the vaporized material, the combination comprising:

an electrode of porous material having pores of a first given size;

said electrode in the path of said ionizing material for accelerating said ionized material;

a liquid for coating at least a part of the surface of said electrode; and,

means having pores larger than the pores of said electrode for maintaining a substantial portion of a surface of the electrode coated with said liquid, said

liquid flow from said means to said electrode resulting from differential surface tension forces and the capillary action of said electrode and said means, whereby erosion of the electrode is prevented.

6. The structure recited in claim 5 wherein said liquid is a tin-iron alloy.

7. An electrode comprising:

a porous electrode member for exerting an electric field;

a porous reservoir means for supplying a liquid metal to said porous electrode member, said means having pores larger than said electrode member; and,

a liquid in said reservoir means, whereby said electrode is covered with said liquid.

8. The structure recited in claim 7, wherein said liquid is an alloy including iron and tin.

9. An electrical member having a potential applied thereto comprising a member subject to erosion and normally operated at temperatures in excess of 700° C., and a means for supplying a liquid over the surface of said member, said liquid having a vapor pressure at temperatures in excess of 700° C. that maintains the mass loss attributable to evaporation as a negligible amount.

10. The structure recited in claim 9, wherein said liquid is a metal and said member is a metal.

11. A method for preventing erosion of an electrical member comprising operating such member at an excess of 700° C.; and covering at least a part of said member with a liquid which has a vapor pressure that maintains evaporation mass loss at a negligible quantity at temperatures in excess of 700° C.

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