United States Patent

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[54] **LIQUID METAL CATHODE WITH SINGLE CAPILLARY FLOW IMPEDANCE**
6 Claims, 2 Drawing Figs.

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[50] **Field of Search** 313/163, 173, 63, 231, 12, 29, 328; 60/202, 203

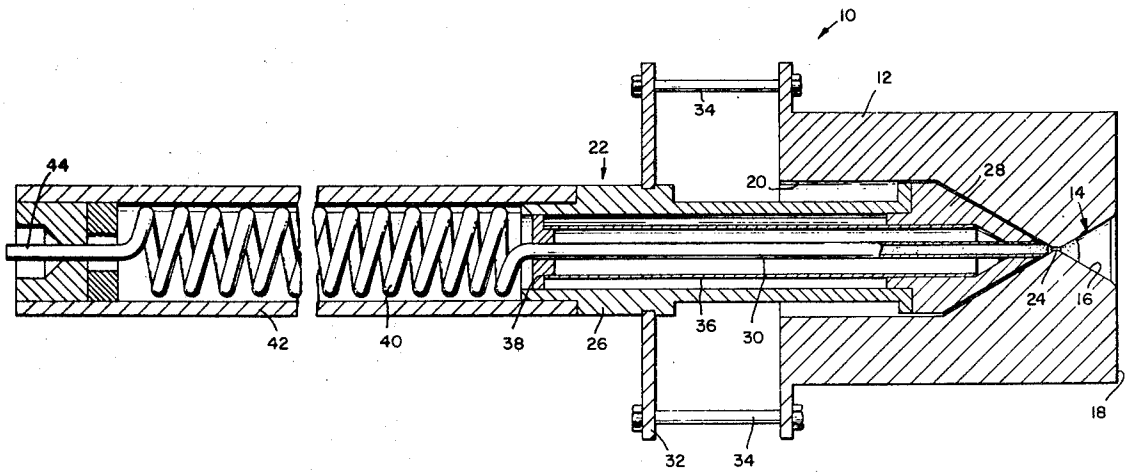
[56] **References Cited**

UNITED STATES PATENTS

1,828,645	10/1931	Cremer	313/328X
1,865,512	7/1932	Gaudenzi et al.	313/12X
3,163,799	12/1964	Buchman	(313/163UX)
3,475,636	10/1969	Eckhardt	313/231X

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ABSTRACT: The liquid metal cathode is employed as a cathodic electron source in arc discharges. A small liquid metal pool serves as the arcing material, and when it is kept small, improved electron-to-atom emission ratios are obtained, as well as gravity independence. However, when such a small pool is employed, feed to the pool must be free of feed rate perturbations. Otherwise, an instability in the level of the mercury in the pool results. The present invention obtains feed rate stability by providing a feed passage with a diameter which is everywhere larger than that of the feed channel which finally discharges to the pool. Feed flow impedance is provided by an elongated capillary feed channel.



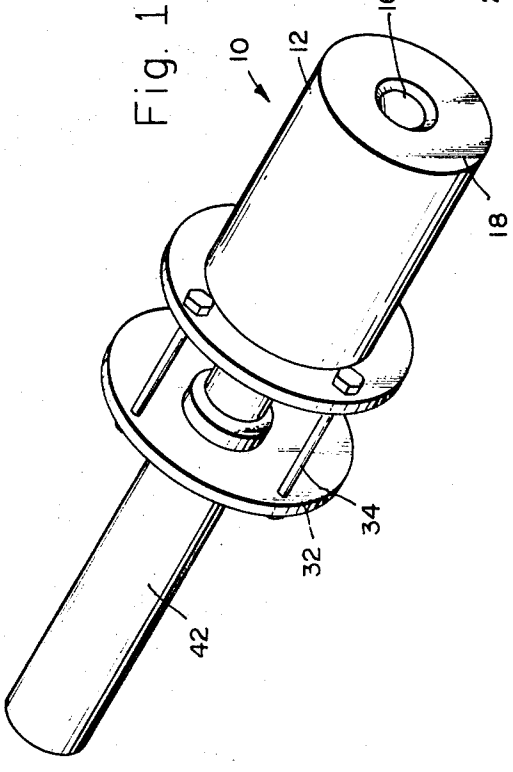


Fig. 1.

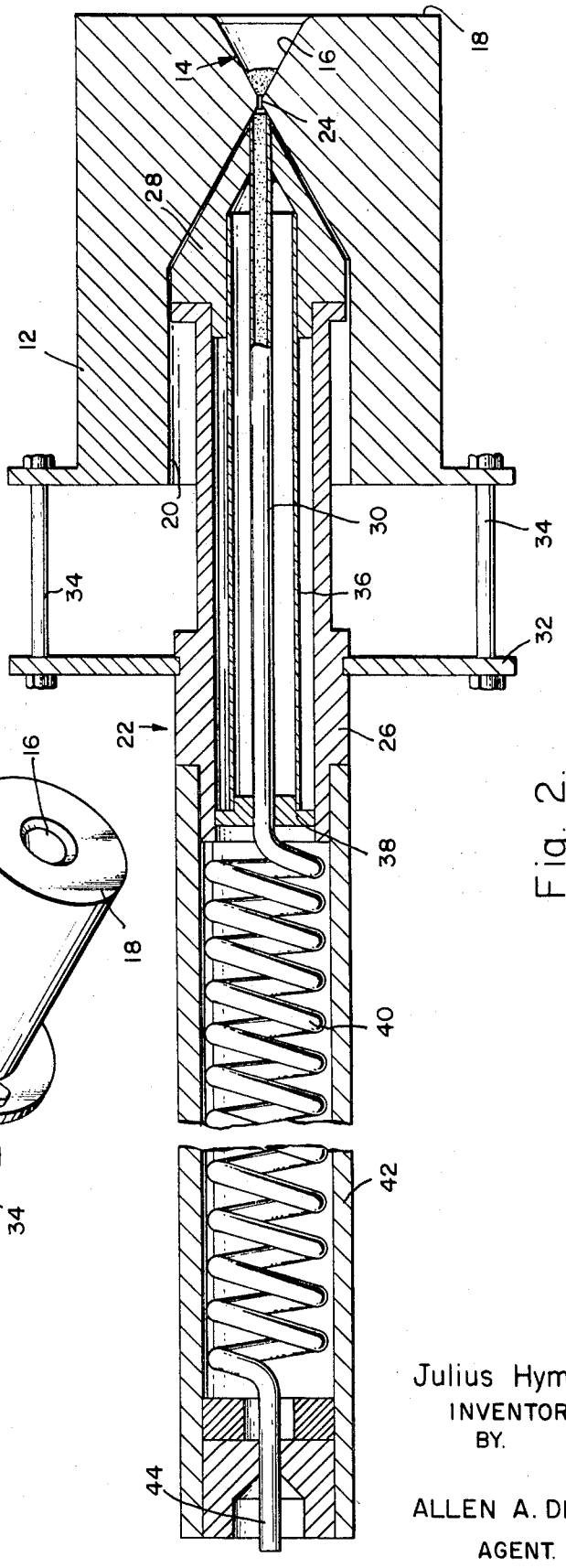


Fig. 2.

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LIQUID METAL CATHODE WITH SINGLE CAPILLARY FLOW IMPEDANCE

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85–568 (72 stat. 435; 42 U.S.C. 2457).

BACKGROUND

This invention is directed to a structure for feeding liquid-metal arcing material to a liquid-metal cathode which is employed in an electric arc structure.

The oldest and most widely used cathode device used to date is the thermionic cathode. This type of cathode is probably best known for its use as the electron emitter in electron vacuum tubes. However, it has now been incorporated as a source of electrons in electron bombardment ion sources for space propulsion devices. In this regard, reference may be made to an article entitled "An Ion Rocket with Electron Bombardment Ion Source" by H. R. Kaufman in NASA Technical Note D–585, Jan. 1960, and to H. R. Kaufman U.S. Pat. No. 3,156,090. Another application of this type of cathode is as a neutralizer for ion beams in space propulsion engines (thrustors).

Although they have been used extensively in recent years, cathodes of the type described in the above-referenced article have been found to have the disadvantage of experiencing deleterious effects from considerable ion bombardment. The result of this bombardment is that even the best thermionic emitters developed to date for thrustor applications, for example, have a useful life time which is shorter than desired for presently contemplated electric-propulsion missions. The problem arises from the difficulty in keeping the discharge voltage below the sputtering threshold of the materials used for the cathodes. Another disadvantage characteristic of many thermionic cathodes is that they are either destroyed or deactivated on being exposed to the normal atmosphere while in operation or even just after operation.

Thermionic, as well as various other types of cathodes, in conjunction with anodes and gas feed systems, are also used in plasma arc devices serving as high intensity light and heat sources. As one example of this application, reference may be made to U.S. Pat. No. 3,136,915 for a High Energy Plasma Source, to W. Jaatinen, et al. The devices described utilize solid cathodes and have the disadvantage of very limited life of the cathode or associated anode or both, depending on the particular configuration.

Liquid-metal arc cathodes have also been either used or proposed for applications in the foregoing described devices and other applications such as in rectifiers and switches. In the use of this type cathode in very-high-voltage high-power-level rectifier and switching devices, the fact that the amounts of metal evaporated from the cathode is not controllable is a distinct disadvantage because it may lead to an excessively high mercury vapor pressure which can result in frequent high-voltage breakdown. For a more complete description of liquid-metal arc cathodes reference may be made to an article entitled "Kraftuebertragung hochgespannten hockgespannten Gleichstrom," in De Ingenieur 67/2 nr. 44 dd. (Apr. 11, 1955) by Erich Uhlmann, and to a book entitled "The Arc Discharge" by H. de B. Knight, published by Chapman and Hall Ltd., London, 1960.

Another disadvantage that may be present in the use of conventional liquid-metal arc cathodes is that they are gravity dependent for their operation in order to keep the liquid metal in a confined cathode area. Furthermore, these devices are not self-protecting in their operation and in the event of a high current surge from a short circuit, for example, these devices may be permanently damaged.

These problems are solved by the use of a small pool cathode. However, as pool size decreases, the amount of liquid metal in the pool becomes more important. If the pool is exhausted of liquid metal, the arc is starved. If the pool is too large, the electron-to-atom emission ratio goes down. Therefore, the amount of liquid metal delivered to the pool by the liquid-metal feed structure must remain proportional to the amount of metal lost from the pool due to arc current and evaporation. Perturbations in feed become objectionable and result in unsteady arc conditions.

SUMMARY

In order to aid in the understanding of this invention, it can be stated in essentially summary form that it is directed to a liquid-metal arc cathode with a single capillary flow impedance. The cathode includes a pool-keeping structure, for retaining a liquid-metal pool and employs a single channel flow impedance passage which has a diameter which is sufficiently large that at any point, the pressure due to surface tension at that point is less than the hydraulic pressure at that point due to the sum of the pressure caused by surface tension at the downstream end of the tube and the pressure drop due to flow between that point and the downstream end of the tube. This prevents separation of the liquid metal in the feed channel, to prevent nonuniformity of liquid-metal feed due to liquid-metal separation in the channel.

Accordingly, it is an object of this invention to provide an impedance to control the flow of liquid metal to a liquid-metal cathode. It is a further object to provide such an impedance which is especially arranged for uniformity of liquid-metal flow to the liquid-metal cathode. It is another object to provide a liquid-metal feed passage which delivers liquid metal to a feed channel which immediately discharges to the liquid-metal pool, wherein the passage is larger than the feed channel. It is still another object to provide a feed passage which does not increase in diameter from the source to the delivery feed channel. It is a further object to provide a feed passage from a source to a liquid-metal pool, which passage has a diameter which is everywhere sufficiently large that at any point the pressure due to surface tension is less than the hydraulic pressure at that point due to the sum of the pressure caused by surface tension at the downstream end of the tube and the pressure drop due to flow between that point and the downstream end of the passageway in order to minimize flow fluctuations. Other objects and advantages of this invention will become apparent from a study of the following portion of the specification, the claims and the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of the liquid-metal cathode with a single capillary flow impedance in accordance with this invention.

FIG. 2 is a longitudinal section therethrough.

DESCRIPTION

Referring to the drawings, the cathode with a single capillary flow impedance is generally indicated therein at 10. Cathode 10 comprises cathode body 12 which has a pool-keeping structure 14 therein. In the present embodiment, pool-keeping structure 14 is comprised of conical walls 16 which define the lateral bounds of the liquid-metal pool therein. The walls 16 are open to face 18 which is directed toward the anode which is associated with cathode 10. The liquid metal within the pool-keeping structure is the material which is active with respect to the arc to supply electrons thereto. The size of the pool in pool-keeping structure 14 is minimized in order to maximize the electron-to-atom emission ratio of the liquid metal into the arc chamber, by reducing evaporation, and to permit the cathode to be gravity independent. Cathode body 12 is preferably made of a high arc voltage material, such as molybdenum, and it is suitably treated so that walls 16 are wet by the liquid metal. In the present description, mercury is the preferred liquid metal.

In order to maintain the size of the liquid-metal pool in pool-keeping structure 14, additional liquid metal must be fed to the pool as the pool is consumed by arc activity and evaporation.

Cathode body **12** has bore **20** therein into which is inserted capillary structure **22**. Bore **20** has a conical bottom which communicates with the pool-keeping structure **14** through feed channel **24**. Capillary structure **22** comprises capillary body **26** which carries capillary nose **28** thereon. Capillary nose **28** is conical in shape to fit into the conical bottom of bore **20**. Capillary nose **28** has an opening in the front thereof through which capillary tube **30** extends. Capillary tube **30** is secured with respect to nose **28** by any suitable means, such as electron-beam welding, and extends slightly beyond the nose.

The end of capillary tube **30**, beyond nose **28**, is formed as a truncated cone so that the capillary tube directly engages with the conical walls of the bottom of bore **20** to seal with respect thereto. The arrangement is such that the truncated nose of capillary tube **30** engages in the conical bottom of bore **20** without any increase in diameter, but instead the diameter of the flow channel from the interior diameter of capillary tube **30** continuously decreases from the diameter of the capillary tube to the diameter of feed channel **24** by means of the conical bottom of hole **20**. The end of capillary tube **30** is held in sealing relationship to the bottom of bore **20** by means of clamp ring **32** and clamp bolts **34**.

The downstream end of the capillary feed tube **30** is shielded from contact with the capillary structure **22** by means of a guide tube **36** which extends from nose **28** to spacer washer **38**. Avoidance of such contact prevents transmission of heat from the cathode body **12** through the capillary structure **22** to the capillary tube **30**. Such heat transmission would effect the flow characteristics of the capillary tube. Heat transmission to the bulk of the capillary **40** is diminished by utilization of thin wall construction in the fabrication of the downstream end of the capillary structure **22**.

The upstream end of capillary tube **30** is conveniently coiled, as at **40** to provide the proper capillary length within a reasonable space. The coil **40** is protected by tube **42** which forms part of capillary structure **22**. The inlet end **44** of capillary tube **40** is arranged to be connected to a source of liquid metal under pressure from any conventional source by any conventional means. A gravity head of liquid metal can be connected to inlet end **44** by a tube fitting, or the like.

In the embodiment illustrated, feed channel **24** has a diameter of 0.0015 inch and is 0.005 inch long. When capillary tube **30** has an interior bore of 0.005 inch and is in the order of 34 feet long, the cathode structure of this invention is capable of providing liquid mercury to the pool-keeping surface from a mercury supply in the order of 15 p.s.i. differential pressure from the inlet end **44** to the arc chamber to provide sufficient liquid mercury to supply an arc of from 5 to 30 amperes. Any other arc current can similarly be accommodated by adjusting the drive pressure with this configuration. Arc currents of very different magnitude may better be accommodated by capillaries of different size.

The capillary tube **30** is normally made of material which is not wet by mercury, and the molybdenum of cathode body **12** is not wet by mercury, unless it is specially treated. Thus, the entire interior of the feed passage, including the capillary passage in the feed channel is unwet by the mercury being fed. On the other hand, walls **16** are wettable by the mercury. This presents a feed fluctuation problem. During mercury feed there is a continuous pressure drop along the length of the feed passage, from the supply pressure to the opening of feed channel **24** into the pool-holding structure. Assuming that there is a steady-state mercury flow at the entrance to feed channel **24** from the capillary tube, the mercury passes through the feed channel into the pool-keeping structure.

The liquid in the pool-keeping structure is at a very low pressure which is determined by surface tension forces, by the momentum change imparted by surface evaporation of mercury atoms and by arc pressure (the pressure in the arc chamber is taken to be zero). Since the pressure exerted by the surface tension is inversely proportional to the radius of curvature of the liquid surface, the magnitude of the pressure due to the surface tension rises to a maximum value within the feed channel where the radius of curvature is at a minimum. In the upstream direction the pressure due to surface tension in the feed channel **24** is balanced by the driving pressure of the flow system.

In the downstream direction, however, the pressure due to surface tension may not be balanced and thus the downstream segment of the minimum diameter mercury column is unstable. It tends to be expelled into the pool-keeping structure. Such expulsion leaves a void, and no further mercury flow enters the pool-keeping structure until the void is filled by flow from the source. When it is again filled, the system is again unstable and the mercury contained in the feed channel may again be expelled into the pool-keeping structure.

It should be noted that the point of separation of the column of mercury cannot be further upstream from the pool-keeping structure than the upstream terminus of the minimum diameter feed channel **24**. Thus, the magnitude of the flow of fluctuations is limited to the volume of the minimum diameter feed channel. The effect of these flow fluctuations is made to be practically negligible by the very small volume of the feed channel, as is illustrated by the exemplary dimensions given above, as compared to the volume of the mercury contained in the pool-keeping structure, when the mercury in the pool-keeping structure is of the desired value.

Thus, it can be generalized for viscous flow that the fluctuation amplitude due to surface tension can be reduced to a minimum value, which is imposed by the feed channel itself, by feeding the mercury to the cathode through a passage which has a diameter which is sufficiently large such that at any point the pressure due to surface tension is less than the sum of the pressure due to surface tension in the minimum diameter feed channel plus the pressure drop due to flow between that point and the minimum diameter feed channel at the downstream end of the feed passage. By keeping the feed channel volume as small as possible, the fluctuations are minimal.

Another desirable end which minimizes the fluctuation into the liquid-metal pool is accomplished by this construction. Where a plenum chamber filled with mercury exists between the flow impedance and the feed channel to the liquid-metal pool, the mercury in the plenum has a volume which fluctuates with changes in temperature in the plenum. Thus, increases in cathode temperature cause expansion of the mercury in the plenum to expel a portion of the mercury into the liquid-metal pool. This undesirable effect is eliminated in the present construction by eliminating any plenum chamber. Thus, in no location downstream from inlet end **44** is the feed passage diameter larger than that of capillary tube **30**. Accordingly, there is no plenum chamber in the present construction.

This invention having been described in its preferred embodiment, it is clear that it is susceptible to numerous modifications and embodiments within the ability of those skilled in the art and without the exercise of the inventive faculty. Accordingly, the scope of this invention is defined by the scope of the following claims.

I claim:

1. Feed means for a liquid-metal arc cathode, said cathode comprising:

a cathode body, walls in said cathode body defining a pool-keeping structure, said feed means comprising:

a feed channel in said cathode body, said feed channel being open on one end to said pool-keeping structure to feed liquid metal to said pool-keeping structure;

a tube connected to said feed channel, said tube having its interior opening in communication with said feed channel so that liquid metal passing through said tube passes through said feed channel to said pool-keeping structure, said feed channel having a small cross-sectional area as compared to the cross-sectional area of the opening in said feed tube;

said feed tube and said feed channel, together with the connecting means therebetween, forming a feed passage, the maximum cross-sectional area of said feed passage being in said feed tube;

said feed channel having a short length as compared to said feed tube, said feed tube being mounted in a mounting structure, a nose on said mounting structure, said feed tube extending beyond said nose, an opening in said cathode body, said feed channel opening into said opening in said cathode body, said nose of said feed structure extending into said opening so that said feed tube seals in said opening with respect to said feed channel.

2. The feed means of claim 1 wherein said nose of said feed structure is held spaced from said cathode body by said feed tube.

3. The feed means of claim 1 wherein clamp means is interengaged between said mounting structure and said cathode body to retain said nose in said opening in said cathode body to retain said feed tube in sealing relationship with respect to said feed channel.

4. The feed means of claim 3 wherein said feed tube is an elongated tube and the major portion of said feed tube is positioned outside of said cathode body to protect said feed tube from heat of said cathode body.

5. The feed means of claim 4 wherein a housing tube encloses the major portion of said feed tube outside of said cathode body, said housing tube having a wall of sufficient thinness to protect the portion of said feed tube exterior of said cathode body from cathode heat.

6. The feed means of claim 5 wherein a heat shield tube is positioned around said feed tube, interiorly of said housing tube to further protect said feed tube from cathode heat.