219-121 CROSS REFERENCE SEARCH ROOI

Aug. 23, 1966 J. W. FLOWERS 3,268,758

HOLLOW GAS ARC DISCHARGE DEVICE UTILIZING AN OFF-CENTER CATHODE

Filed May 13, 1964 3 Sheets-Sheet 1

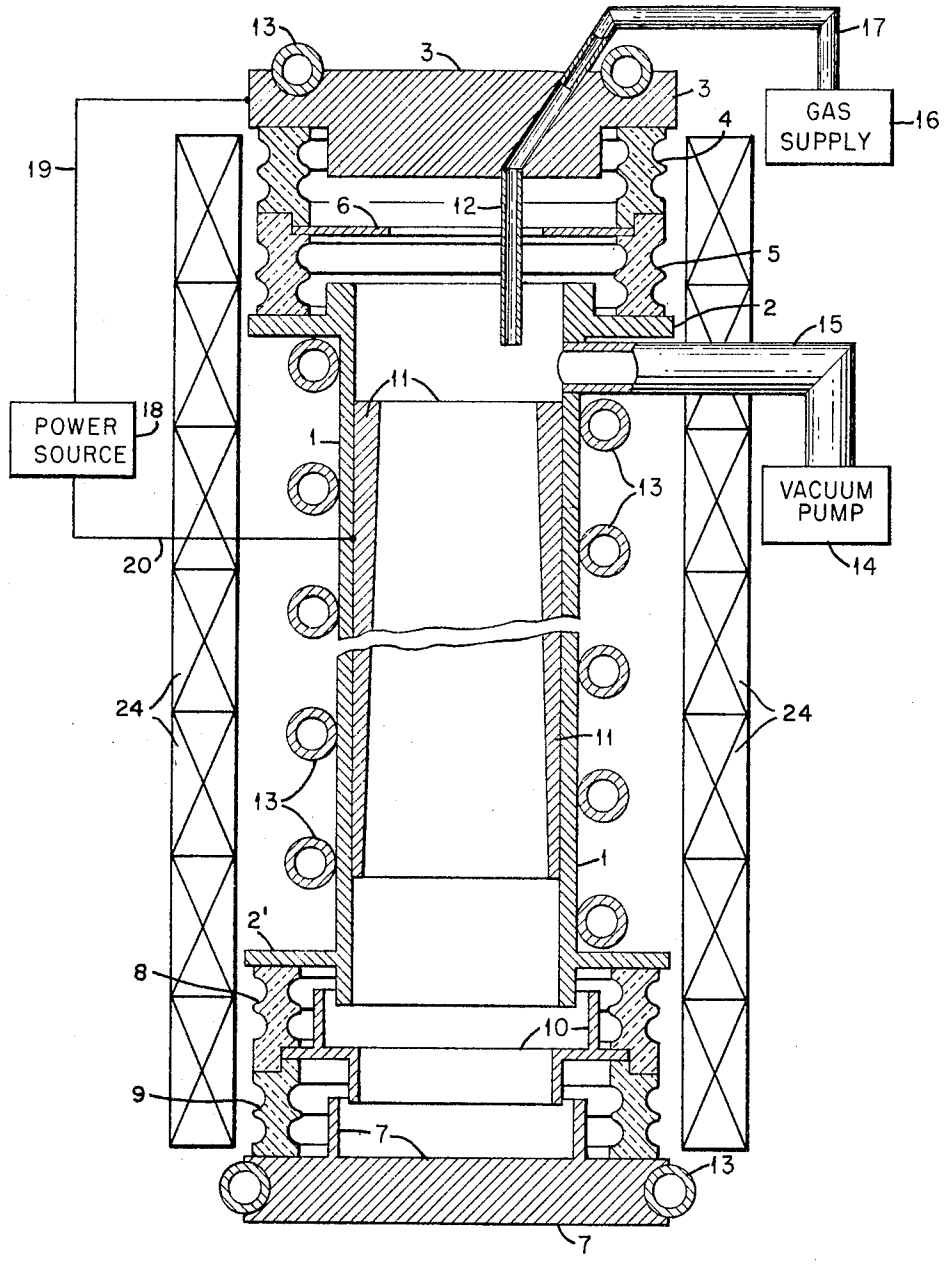

Fig. 1.

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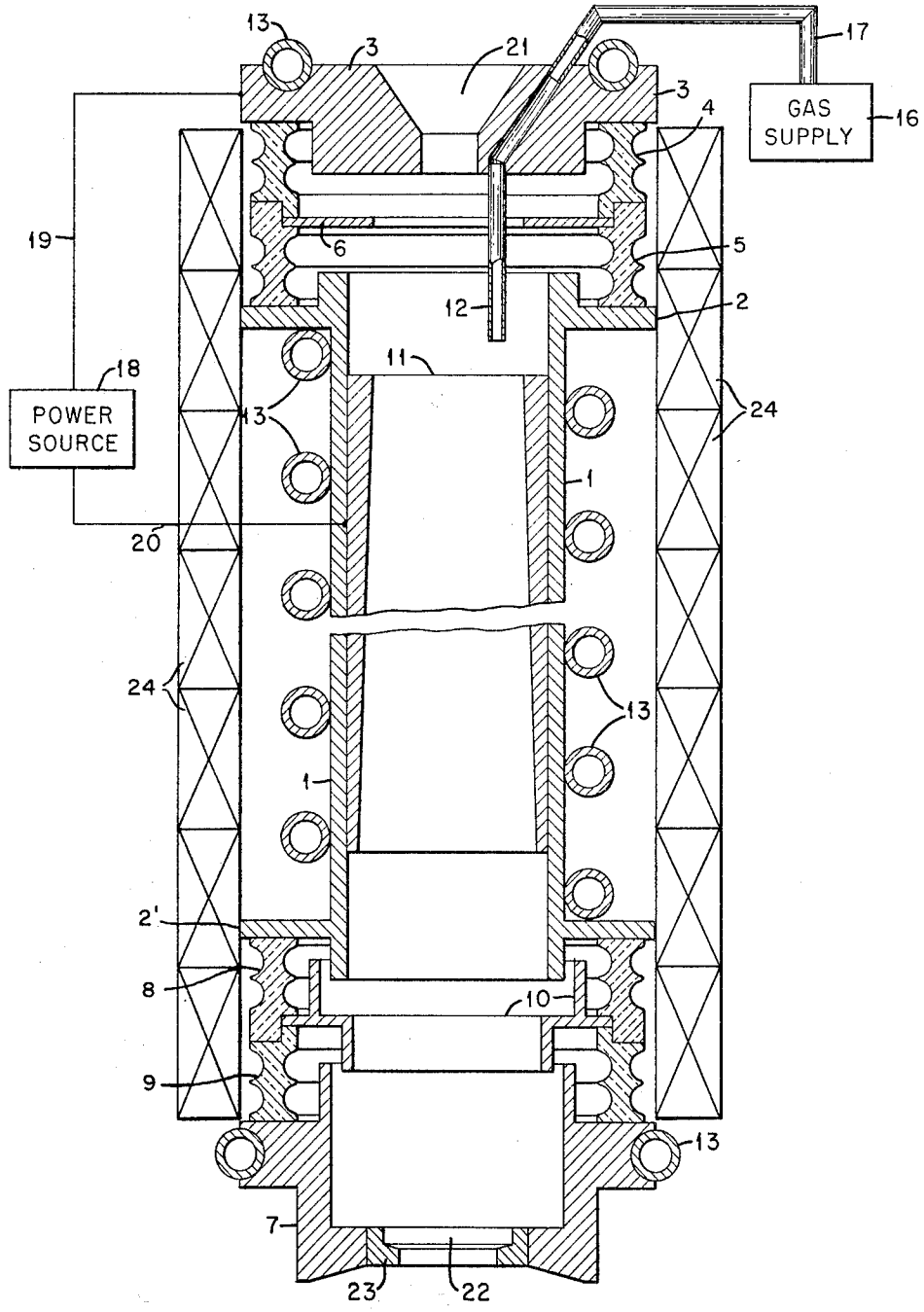

Fig. 2.

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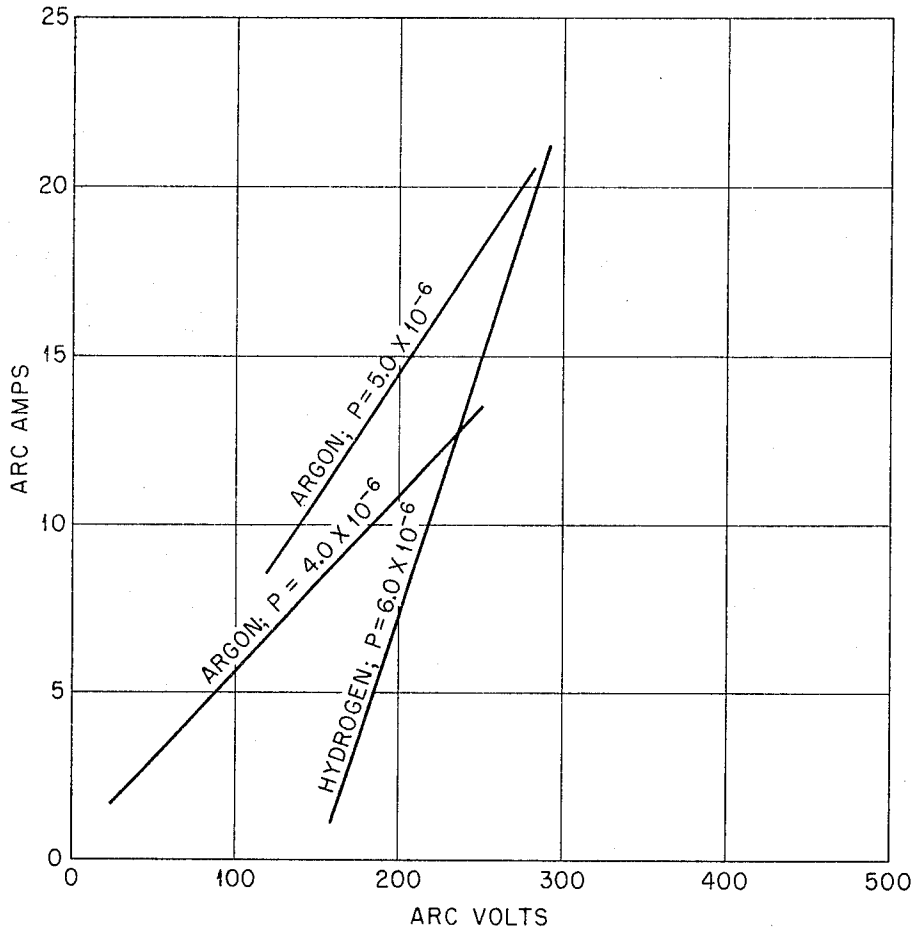

Fig. 3.

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3,268,758

HOLLOW GAS ARC DISCHARGE DEVICE UTILIZING AN OFF-CENTER CATHODE

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5 Claims. (Cl. 313—231)

This invention relates to an improved means for operating a hollow gas arc discharge at lower power requirements and with higher gas utilization than was heretofore possible.

A method of forming, and a use for, hollow gas arcs is described in U.S. Patent No. 2,927,232, issued March 1, 1960. In that patent an arc discharge was run by two methods. One type was run between a hollow cathode and a hollow anode which were aligned in a magnetic field. Gas was fed into the central portion of the cathode, and the cathode was heated by bombardment of the ions striking the same. By proper adjustment, low flow, of the gas feed, the arc operated from the inside of the cathode. At higher pressures it ran from the end of the cathode. Currents of the order of 100 amperes were obtained at a voltage of about 400 volts in a vaccum of 3×10^{-5} Torr and a magnetic flux density of the order of 6000 gauss.

The second method of operation in the above patent utilized a PIG-type discharge. In this latter method a pair of hollow cathodes were aligned along the magnetic field with an aligned coaxial hollow anode interspersed therebetween and gas was fed to both cathodes. Arcs of this type have been run at about 100 amperes and a voltage of about 1000 volts with other parameters being about the same as those for the arc discharge in the first method described above.

Both of the above methods of operation result in the production of a relatively small hollow arc discharge that may be utilized for many applications. Typical uses are: breakup centers for an injected molecular ion beam to effect magnetic trapping of a plasma; an ionized shield to prevent the influx of neutrals into a plasma; and the formation of space-charge neutralized ion beams for propulsion, high energy injection, etc. One major problem existed, however: the power input must be high to maintain stability of the arc discharge. Also, the gas utilization was poor in the above described discharges.

With a knowledge of the limitations of the above described arc discharges, it is a primary object of the present invention to provide a device in which relatively large diameter hollow arc discharges may be produced with lower power requirements for stability and with significantly improved gas utilization.

It is another object of this invention to provide a device for producing a hollow arc discharge whose diameter may be varied depending upon the position of the cathode thereof.

These and other objects and advantages of the present invention will become more apparent upon a consideration of the following detailed description and the accompanying drawings, wherein:

FIG. 1 is a cross-sectional view of one embodiment of the present invention for producing a hollow arc discharge;

FIG. 2 is a cross-sectional view of a second embodiment for producing a hollow discharge; and

FIG. 3 is a graph showing the measured relationship between arc voltage and current for various operating conditions for the device of FIG. 1 or FIG. 2.

The above objects have been accomplished in the present invention by providing a self-heated cathode or

cathodes disposed and mounted off-center of the axis of the discharge chamber and of an axial magnetic field. A refluxing-type discharge is established with this cathode or cathodes, and a surrounding cylindrical anode provides a sufficiently large radial component of electric field so that there is a large rotational drift of the discharge to produce a hollow discharge symmetrical about the axis of the anode. The size of the hollow discharge thus produced is determined by the distance that the cathode is mounted from the axis of the anode.

In FIG. 1 of the drawings, a cylindrical vacuum chamber **1** is provided with externally projecting end flanges **2**, **2'**. One end of chamber **1** is closed with a cathode mounting block **3** which, in turn, is separated from flange **2** with a pair of hollow cylindrical insulators **4**, **5**. Interposed between these insulators is an annular radial disc-shaped shield **6**. The structure of the anticathode or reflector end of the chamber **1** is similar, with the reflector being a block **7** spaced from flange **2'** by two insulators **8**, **9**. A second radial shield **10** is held between the insulators **8**, **9**. Within the chamber **1** is mounted an annular anode **11** spaced about equally between flanges **2**, **2'**. At least one small hollow cathode **12** is mounted perpendicular to the cathode mounting block **3** so that the axis thereof is parallel to, but not on, the axis of the chamber **1**. The position of the cathode is at a smaller radius in the chamber **1** than is the inner surface of the anode **11** or the inner diameters of the shields **6**, **10**. It should be understood that the dimensions of the radius of the inner surface of the anode **11** and the inner diameters of the shields **6**, **10** as shown in FIG. 1 are by way of example only. These dimensions may be made larger than those shown in FIG. 1, if desired, and the cathode **12** can thus be placed at a larger radius to thereby increase the diameter of the hollow discharge to be provided by this device.

The cathode mounting block **3**, reflector block **7**, and the chamber **1** are provided with cooling means such as tubing **13** through which water or other coolant is caused to flow. The chamber **1** is evacuated by means of a vacuum pump **14** which is in communication with the chamber by means of a conduit **15**, and annular magnetic field coils **24** are provided to produce an axial magnetic field within the chamber **1** in a conventional manner.

A gas supply **16** is provided to supply feed gas such as argon or hydrogen, for example, to the cathode **12** through a feed tube **17**. A source of electrical power **18** is provided to impress, through leads **19**, **20**, the proper voltage to the anode **11** and cathode **12**. The reflector **7** is normally permitted to electrically "float." Although not shown, the chamber **1** may be provided with a port through which ions, neutrals, etc., may be injected for reaction with the hollow discharge.

In FIG. 2 it should be noted that this embodiment only differs slightly from that of FIG. 1. Specifically, the cathode mounting block **3** is provided with an aperture **21** for injecting ions, electrons, etc., axially into the hollow discharge. In addition, an aperture **22** is provided in the reflector block **7** to permit axial withdrawal of ions, etc., from the hollow discharge. The aperture **22** may be lined with an insert **23** to withstand the heat generated by the passage therethrough of the ions, etc. Because of the manner of operation of this embodiment, it would be operated within a separate vacuum chamber; therefore, no means for producing a vacuum are shown.

The operation of either FIG. 1 or FIG. 2 of the present invention is essentially the same. The chamber **1** is evacuated to a pressure of about 5×10^{-6} Torr, and the magnetic field adjusted to be of the order of

6000 gauss at the cathode **12**. A D.C. potential of about 300 volts is applied between the cathode **12** and anode **11**, and as gas is admitted through the cathode, an arc discharge is struck using, for example, a short burst of RF signal superimposed upon the D.C. voltage. Although the arc discharge is initiated from the off-axis cathode, the radial component of electric field introduced by the annular anode causes a rotational drift in the discharge so as to create a hollow discharge symmetrical about the axis of the chamber **1** having a radius equal to the distance the cathode is spaced from the axis. This radius of the hollow arc discharge may be adjusted, if desired, and this could be accomplished by providing means, not shown, for adjusting the radial position of the cathode **12** with respect to the axis of the chamber **1**.

In a typical operation of an arc discharge in accordance with the above description, one cathode about ⅛ inch in diameter and located about 5/16 inch off the axis of the chamber produced a discharge about ¾ inch in diameter. The intensity of the discharge was then controllable by regulating the gas feed to the cathode and/or by adjustment of the potential applied between the cathode and anode. For example, the relationship between discharge current and applied voltage for several feed gases is shown in FIG. 3. The resultant discharges were very stable even at the low voltage utilized, compared to 1000 volts for the PIG-type arc discharge in the aforementioned Patent No. 2,927,232. In addition, gas utilization in the present invention is more efficient than in the above prior patent, which is evidenced by the low pressure in the present device.

It should be noted that stable hollow arc discharges having diameters up to 2–3 inches may be produced and maintained with the devices of FIG. 1 and FIG. 2 by using a single cathode. However, for arc discharges having diameters substantially larger than 3 inches, two or three off-center cathodes would be required to maintain the hollow discharges. Since the use of more than one cathode restricts the stable operating range of an arc discharge, the use of the least number of cathodes necessary to maintain the discharge is desirable.

The embodiment of the present invention as shown in FIG. 2 may be used as an ion source for a 100 kw. accelerator of the type shown in FIG. 3 of U.S. Patent No. 3,075,115, issued January 22, 1963. In that patent, a relatively small, hollow reflux-type arc discharge was provided and a stream of high-energy electrons were caused to axially penetrate the discharge so as to provide the necessary electrons for space-charge neutralization of the ion beam being withdrawn from the ion source. However, the output of such an accelerator is relatively poor and not very efficient due to poor gas utilization and the requirement of about 1500 volts for stable operation of the arc discharge. Since the reflux-type arc discharge of FIG. 2 of the present invention will operate stably and efficiently with limited power (about 300 volts) and with good gas utilization, it can readily be used with a stream of high-energy electrons in the same manner as in the above U.S. Patent No. 3,075,115 to product more efficiently an energetic, space-charged neutralized ion beam that may be used for propulsion, high-energy injection, etc.

This invention has been described by way of illustration rather than limitation and it should be apparent that this invention is equally applicable in fields other than those described.

What is claimed is:

1. Means for establishing a hollow cylindrical arc discharge comprising an elongated evacuated chamber, a hollow cathode mounted in one end of said chamber, a reflector electrode mounted within the other end of said chamber, an elongated, hollow anode positioned within said chamber between said cathode and said reflector electrode to provide a radial electric field component therewithin, said chamber and anode having a common axis, a source of feed gas, means for feeding gas from said source into the interior of said cathode at a controlled rate, means for providing a magnetic field parallel to said common axis, a source of operating potential connected between said anode and cathode, said cathode being mounted a selected distance from said common axis such that the axis of said cathode is spaced from and parallel to said common axis to establish an off-center refluxing arc discharge parallel to said magnetic field and between said cathode and said reflector electrode, said discharge being caused to rotationally drift by said radial component of electric field to thereby form said hollow discharge symmetrical about said common axis and within said hollow anode.

2. The device set forth in claim **1**, wherein said cathode is mounted on a cathode mounting block and cooling means being disposed about said mounting block, about said reflector electrode and about said chamber.

3. The device set forth in claim **2**, wherein each of said mounting block and said reflector electrode is provided with an axially disposed aperture, whereby high energy electrons may be axially injected into said hollow discharge through said mounting block aperture and a space-charged neutralized beam of electrons and ions may be withdrawn from said chamber through said reflector electrode aperture.

4. The device set forth in claim **2**, wherein said feed gas is selected from a group of gases including argon and hydrogen.

5. The device set forth in claim **2**, wherein said chamber is evacuated to a pressure of 5×10^{-6} Torr, said magnetic field is about 6000 gauss, and said operating potential is about 300 volts D.C., said hollow discharge having a diameter of a selected value in the range from ¾ to 3 inches.

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