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[54] MAGNETICALLY CONTROLLED CROSSED-FIELD INTERRUPTER AND SWITCH TUBE WITH PRESSURE CONTROL FOR LONG DURATION PULES

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 664,722, Aug. 31, 1967.

[52] **U.S. Cl.** **313/161,** 313/231, 313/224, 313/311, 315/111

[51] **Int. Cl.** **H01j 7/16,** H01j 7/20

[58] **Field of Search** 313/231, 161, 311, 224; 331/86; 315/39.51, 111

[56] **References Cited**

UNITED STATES PATENTS

3,566,184 2/1971 Maskell 315/111

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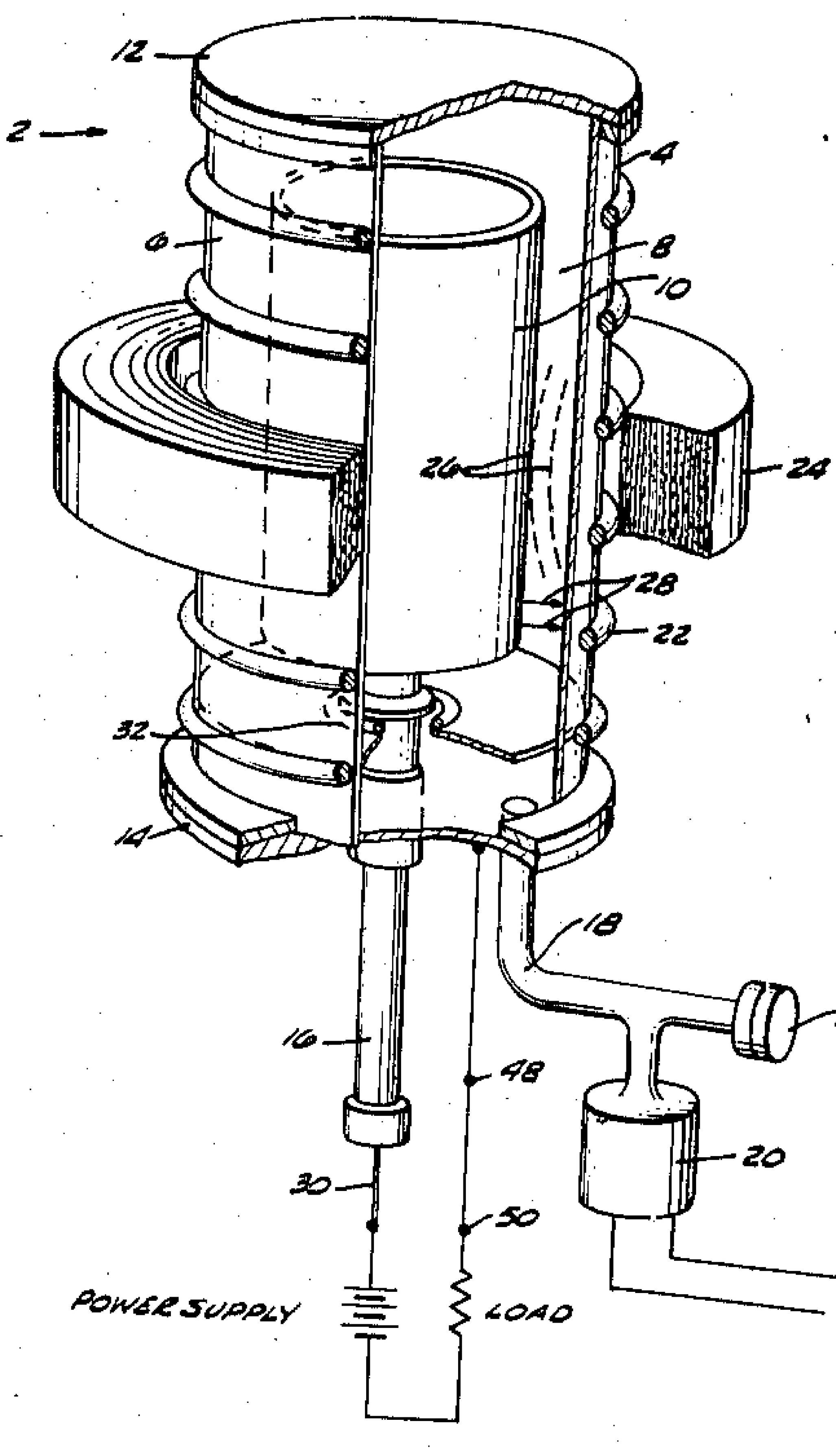
[57] **ABSTRACT**

In the absence of appropriate means for controlling the gas pressure, the time during which a crossed-field electrical switch can conduct is limited by the rapid pumping action of the discharge. The present invention discloses a crossed-field discharge switch in which pressure control is accomplished by selection of gas and electrode materials to minimize gas losses, and means is provided for adding additional gas, if needed. This structure permits a crossed-field electrical switch device to conduct for reasonable lengths of time without off-switching due to gas losses.

8 Claims, 4 Drawing Figures



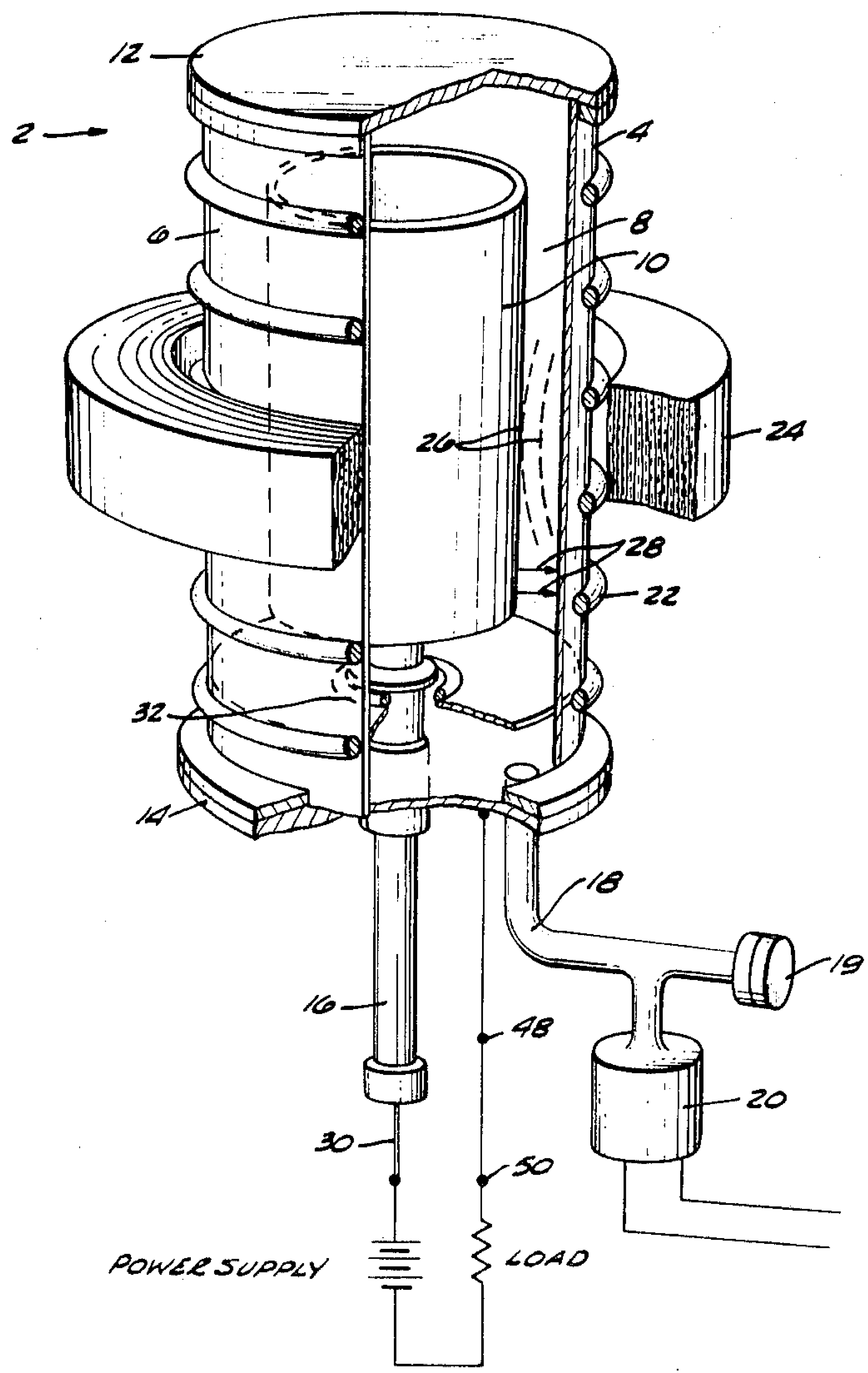


FIG. 1.

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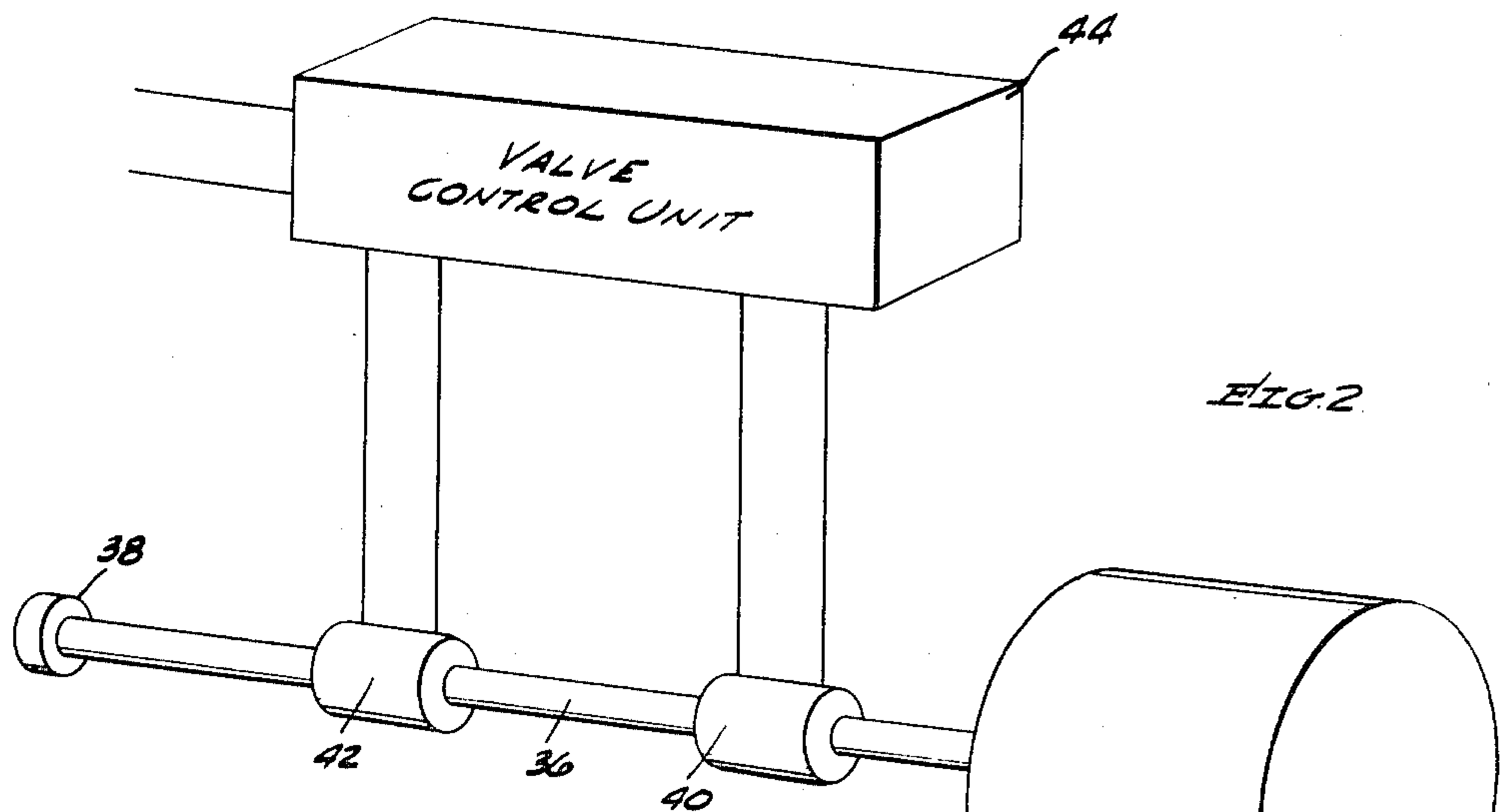

FIG. 2

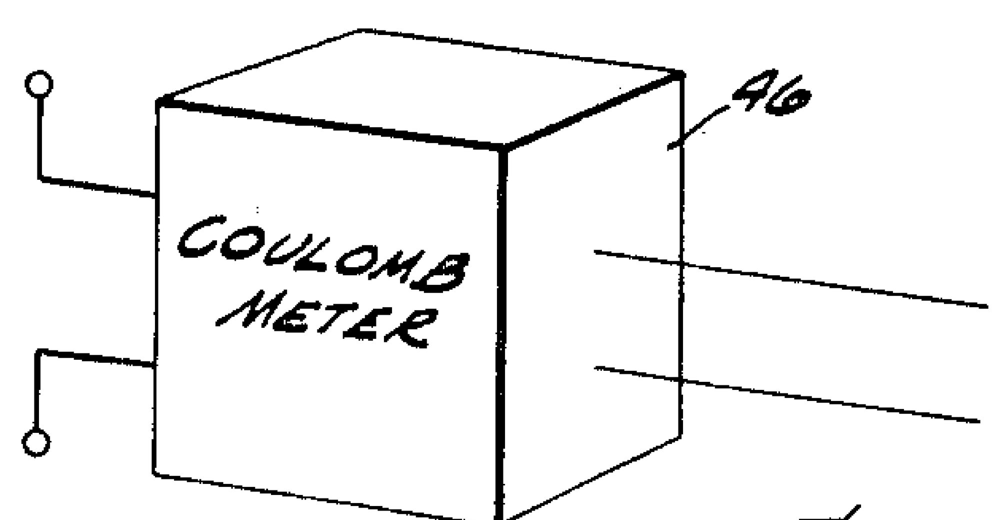

FIG. 3

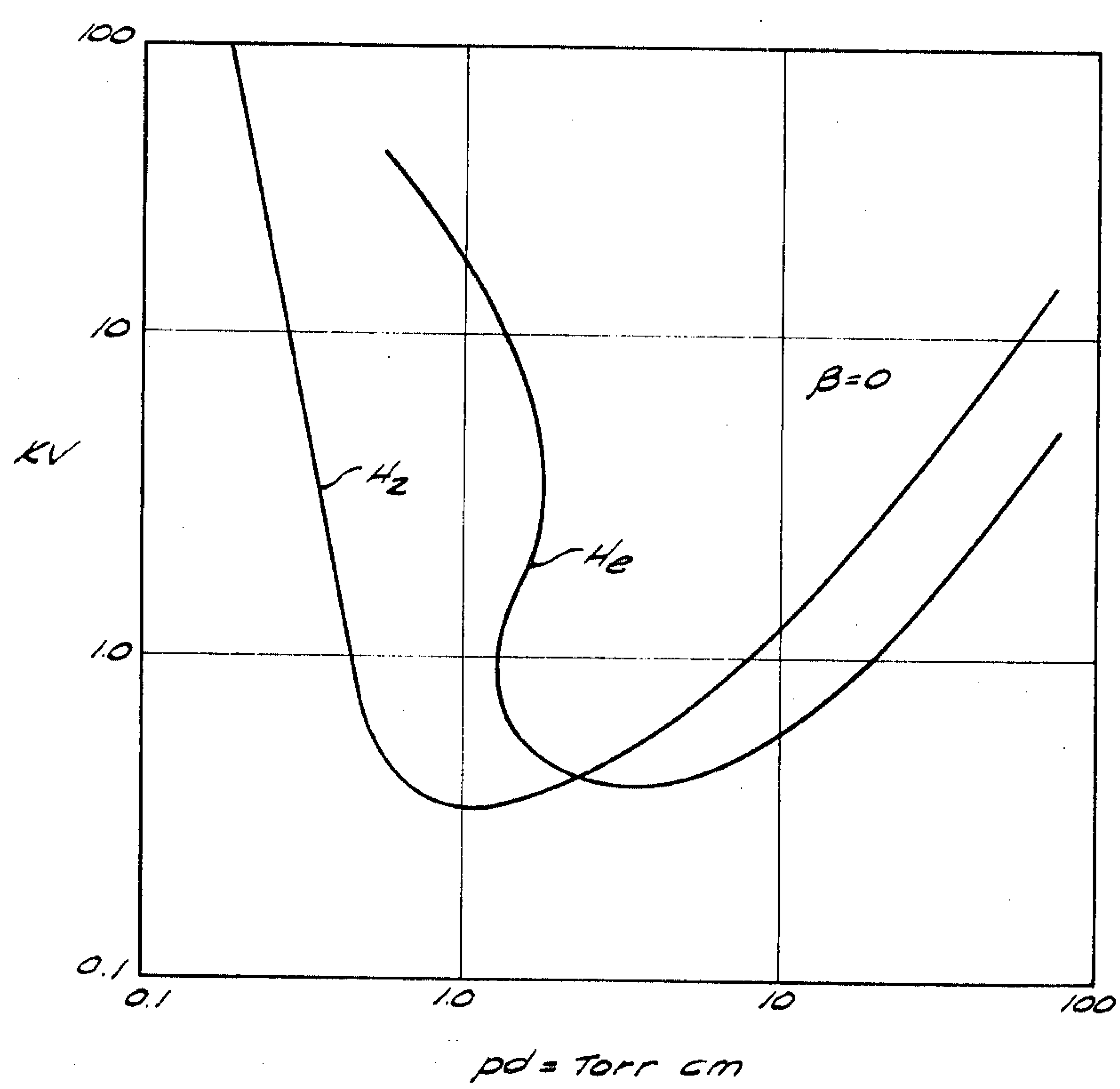

FIG. 4.

MAGNETICALLY CONTROLLED CROSSED-FIELD INTERRUPTER AND SWITCH TUBE WITH PRESSURE CONTROL FOR LONG DURATION PULES

CROSS-REFERENCE

This application is a continuation-in-part of U.S. Pat. application Ser. No. 664,722, filed Aug. 31, 1967, entitled "Magnetically Controlled Crossed-Field Interrupter and Switch Tube."

BACKGROUND

This invention is directed to crossed-field electrical switch devices and particularly for gas pressure control therein.

The prior art includes C. G. Smith U.S. Pat. No. 1,714,405; J. L. Stratton U.S. Pat. No. 2,352,231; G. Boucher et al. U.S. Pat. No. 3,215,893; G. J. Boucher U.S. Pat. No. 3,215,939; and K. Wasa et al. U.S. Pat. No. 3,405,300. These patents teach that a device having spaced electrodes and a low-pressure gas therebetween may be electrically switched by changing the magnetic field strength. By this means, the device is made electrically conductive or nonconductive.

None of the prior art patents has any means for controlling the gas pressure. The Smith and Stratton patents specifically show totally enclosed tubes and do not discuss either electrode materials or the gas fill. Boucher et al. teaches a vessel having a pumpout stem for initially evacuating the enclosure and thereafter filling the space with a gas.

Neither the Boucher nor Wasa et al. patents has any substantial teaching as to the closure of the vessel. Both call for a gastight enclosure or envelope, but do not have any further teaching. This implies that they each have a totally enclosed envelope, but the teaching is not clear.

Whenever current flows through a switch device as described in these patents, sputtering (erosion under by ion bombardment) of the cathode occurs. There is also a smaller amount of anode sputtering. The eroded metal deposits on all adjacent surfaces. This deposited metal forms a film which is highly chemically active, as in a sublimation pump. This film getters reactive gases with very high efficiency.

These prior art patents variously teach the use of hydrogen, neon, nitrogen, argon, Freon and ethyl alcohol as the gas material. Furthermore, they teach the employment of molybdenum, titanium, tantalum, copper, nonmagnetic nonoxidizable steel and platinum as suitable electrode materials. Choosing a popular example of hydrogen as the gas and 304 stainless steel as the electrode material and starting with a gas pressure at such a level that a high-current, low-voltage gas discharge can be obtained, a switching device of the dimensions used in the exemplary embodiment below will off-switch by gas depletion after a charge of less than 1 coulomb has passed therethrough. This amounts to undesired off-switching (by gas depletion rather than by magnetic field change) after 1 millisecond, when passing its rated current of 1,000 amperes. Thus, the device is unsuitable for use as a switching device when conductive periods exceed 1 millisecond. Even if gas were supplied to the device, gas would have to be supplied at the high rate of 50 Torr liters/sec. and carefully controlled for pressure level or the device would be unsatisfactory.

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 crossed-field electric switch device which has pressure control so that the gas pressure therein is managed such as to provide electrical conduction for reasonable lengths of time and predictably manage switching by controlling the applied magnetic field. Pressure maintenance is accomplished by selecting the cathode material from the group consisting of hafnium, tantalum, tungsten and rhenium to result in low-sputter yield cathode material and employing helium as the gas to eliminate gettering and provide fast deionization. Furthermore, for those devices which must conduct an appreciable charge of electricity, a gas supply means to the enclosure is provided. This gas supply means can be responsive to the pressure in the switch device or can be responsive to the amount of charge passed through the device; the amount of charge being substantially directly proportional to the amount of gas cleaned up.

Accordingly, it is an object of this invention to provide a crossed-field electric switch device including means to control the pressure therein. It is a further object to provide pressure control means which includes the elimination of reactive gases combining with freshly sputtered surfaces by employing inert helium as the gas in the crossed-field electric switch device. It is a further object to minimize physical burial of gas during the sputtering activity by selecting the cathode and possibly the anode materials such that sputtering is minimized. It is another object to provide a combination of electrode material and gas which minimizes gas cleanup during electrical conductivity of the electrical switch device.

It is still another object to provide means attached to the electrical switch device which supplies additional gas as needed to make up for losses of gas. It is still another object to alternatively measure the pressure or measure the charge through the electrical switch device to determine when additional gas is required and appropriately activate the gas supply means. Another object is to provide long life by minimizing sputtering, for sputtering coats surfaces and, when too much sputtering has occurred, material flakes off and may destroy the insulating properties of the tube. It is a further object to employ helium as the fill gas, for helium is so light it sputters the quoted metals less than any other inert gas. As another object to make the voltage hold-off strength of a single tube as high as possible, helium is used because of its superior Paschen curve which is better than all other gases. 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, with parts broken away and partly shown in section, of the crossed-field electrical switch device of this invention.

FIG. 2 shows a gas supply means for connection to the electrical switch device.

FIG. 3 illustrates a means for actuating the gas supply means.

FIG. 4 illustrates the Paschen curve for hydrogen and helium.

DESCRIPTION

An embodiment of the crossed-field electric switch device is shown in FIG. 1. The device can operate either to turn a circuit on or off and, thus, its description as being a switch device includes the function of interrupting circuit current.

The device **2** comprises a cylindrical cold cathode **4**, which in this embodiment also forms the cylindrical wall of the interrupter envelope **6**, and a cylindrical anode **10**. The cylindrical electrodes **4** and **10** are coaxial and together define a gas-filled interelectrode space **8**. The envelope **6** is closed at each end by end plates **12** and **14**. Alternately, it is understood that both the cathode **4** and the anode **10** could be surrounded by a separate vacuumtight envelope **6**, this envelope being not necessarily identical with the cathode **4**. It is furthermore understood that, when the vacuum tight envelope **6** is physically distinct from the outer electrode shown here as cathode **4**, the latter can be slit in a substantially longitudinal manner to prevent the induction of eddy currents in the outer electrode **4** when the applied magnetic field is rapidly charged for switching purposes. Such eddy currents, if permitted to flow, result in a delay between an applied change in current in the solenoid generating the magnetic field, and the change of this magnetic field in the interelectrode space. By making the envelope **6** out of electrically insulating or relatively high-electrical resistivity material, and by providing said slit in the outer electrode 4, said switching delay can be substantially eliminated.

The top end plate 12 is closed, while the bottom end plate 14 carries a support post 16. The support post passes through the bottom metal closure plate 14, but is electrically insulated therefrom. The support post 16 thus physically supports the bottom plate 14 and the structure supported thereon, and it physically supports anode 10 by physical connection thereto. Support post 16 also acts as an electrical connection to anode 10. Tube 18 is connected to the interior space. Tube 18 is flanged off by flange 19 and can have a pressure gauge 20 connected to tube 18 by means of a tee.

A water-cooling coil 22 can optionally spirally encircle the outer wall of the envelope 6. A magnetic field coil 24 is mounted externally of the envelope 6 for use in applying a magnetic field (indicated schematically by the dotted lines 26) having at least one component perpendicular to the electric field (indicated schematically by the arrows 28) between the anode 10 and cathode 4. The inlet, outlet, pump, and heat exchanger for the water-cooling coil 22 have been omitted from the drawing in the interest of clarity. The electrical lead 30 to the anode extends through the plate 14 and the anode mount 32. The cathode lead 34 is attached to the metal plate 14.

Moderately large cathode surface areas are required to carry sizable currents at current densities small enough (<25 A/cm.^{2}) to avoid arcing because an arc is not extinguished by off-switching the magnetic field.

The maximum voltage hold-off capability of the apparatus of this invention can be determined by the use of a Paschen curve. One such curve is shown in FIG. 4 for both hydrogen and helium. Each curve predicts the breakdown voltage for a pair of electrodes immersed in a specific kind of gas, the electrodes being separated by a distance "*d*," and the gas being at a pressure "*p*," (and with no magnetic field in the interelectrode space). The apparatus of this invention operates to the left of the Paschen minimum. That is, if it is desired that the interrupter or switch tube of this invention be able to hold off 25 kv., the product "*pd*" must be made less than about 0.8, if helium, for example, is the ambient gas. If the electrodes are parallel and spaced-apart 2 cm. or less, the maximum pressure which can be used is about 0.25 Torr, if breakdown in the absence of the magnetic field is to be avoided.

Consider now the device 2, with no voltage applied across the electrodes, but with an applied magnetic field having a magnitude above a critical value, which may fairly uniformly occupy the entire interelectrode space, and having at least one component extending parallel to the electrodes. A voltage applied now will drive an electron in a cycloidal path with a drift perpendicular to both the electric and magnetic fields. A suitable geometry will allow this motion to continue unhindered until the electron makes a collision. The electrons are then said to be "trapped" under the influence of the crossed electric and magnetic fields. The magnetic field has prevented an electron from going directly from the cathode to the anode and has, therefore, considerably increased the length of the electron trajectory. The increase in path length is such that the average electron makes at least one collision with the gas in the interelectrode space before it is captured by the anode. The collision produces more electrons so that avalanche is quickly established. With respect to ionization, this is equivalent to an increase in pressure. Hence, a device of suitable design at a pressure below the critical pressure can be made to conduct with a modest (~300 volts) discharge conduction drop by the application of a magnetic field of suitable orientation and magnitude.

Now consider that such a gas discharge device is operating in the above manner and the magnetic field is suddenly switched below the critical magnitude required for conduction. At this time, the electrons in the interelectrode space are no longer trapped and, because of the low gas pressure in the device, the electrons are drawn directly to the anode in substantially collisionless trajectories (the positive ions are essentially unaffected by the magnetic field because of their large masses). This leads to recovery rates (i.e., of the insulating strength) which are very fast; for example, on the order of 1 kv. per microsecond.

The design criteria for a 25 kv. sealed-off switching device described in FIG. 1 are the following: select a suitable pressure at which a high-current, low-voltage crossed-field discharge can be maintained. This is typically 0.05 Torr for either hydrogen or helium, this pressure being relatively independent of gas type. From the Paschen curve for the gas selected, determine the maximum interelectrode space *d* which will keep the *pd* product to the left of the curve at the desired maximum hold-off voltage. From FIG. 4, this *pd* value for a 25 kv. tube is 0.26 Torr-cm. for hydrogen and 0.80 Torr-cm. for helium. Since *p* has been selected independently to be 0.05 Torr for both gases, this means *d* must be less than 5.2 cm. for hydrogen and *d* must be less than 16 cm. for helium. There is another restriction on *d;* namely, *d* must exceed some minimum spacing to avoid field emission between cathode and anode when the tube is holding off the full voltage (magnetic field off). The rule is to allow about 50 kv./cm. for well-arced surfaces. Hence, the minimum *d* for a 25 kv. tube is one-half cm. independent of the type of fill gas. It is, thus, clear that a value of *d* somewhere between these two limits will provide successful operation and that there is no conflict between the lower and upper limits. As the desired hold-off voltage is raised, however, such a conflict can occur. Much above 100 kv., for example, the minimum *d* requirement meets the maximum *d* requirement and further voltage hold-off in a single gap becomes impossible. It is at this high voltage that the improved Paschen curve for helium is advantageous over hydrogen (and all other gases) in that the maximum *d* for helium is greater than the maximum *d* for any other gas, enabling the highest voltage hold-off capability to be found in a helium filled tube.

When a switching device of the dimensions given by this example is employed to pass current, two principal phenomena result in the removal of the gas from free activity in the device. The first phenomenon is chemisorption. Sputtering erosion of the cathode, and to a lesser extent the anode, under ion bombardment causes deposition of the eroded metal on all adjacent surfaces. This deposited metal forms a film which is highly chemically active. The use of refractory metals for low-sputter yield and greater arc resistance is incompatible with reactive gases from a chemisorption point of view.

In addition to the loss of reactive gas from the device by chemical reaction at the freshly sputter-deposited surfaces, the sputter deposition of cathode material on adjacent surfaces buries considerable amounts of gas, if the deposited layers are being simultaneously bombarded by energetic ions or neutrals. This is strictly a physical phenomenon and is unrelated to the chemical reactivity between the gas and the sputtered material, but is directly related only to the discharge intensity, the amount of material being sputter-deposited, and the potential of the surfaces on which the sputter-deposited material lands. To minimize this effect, the electrode material is selected to have a minimum sputtering rate.

In accordance with this invention, helium is employed as a nonreactive gas fill and a cathode (and most desirably, also an anode) material (selected for low-sputtering rate) from the group consisting of hafnium, tantalum, tungsten, and rhenium is employed. In the exemplary switch device described above, employing a helium gas fill at 0.05 Torr and tantalum as an electrode material, a charge of 250 coulombs can be passed before the pressure decreases to an extent that the switching device uncontrollably off-switches due to pressure loss. This corresponds to conduction for one-fourth seconds at 1,000 amperes. This is sufficiently long to be useful as a switching device. Thus, in accordance with this invention, it is critical that helium be employed as the fill gas in the switch device and at least the cathode electrode, and preferably both electrodes be made from a material selected from the group consisting of hafnium, tantalum, tungsten and rhenium.

The switch device is described as having a cathode electrode 6 and anode electrode 10, strictly for convenience of description. With appropriate shaping of the magnetic field, either electrode can operate as the cathode, depending on applied polarity. Furthermore, the device can be employed in AC-circuits, with reversing polarity.

FIG. 1 illustrates the switch device 2 as being totally closed off, with the blank flange 19 closing the pipe 18 by which the switching device is initially evacuated and refilled to the proper initial helium pressure. For longer life operation, a gas supply is employed. FIG. 2 illustrates reservoir 34 which contains helium under pressure and which is connected by tube 36 to flange 38. This flange is connected to tube 18, instead of the closure flange 19. Valves 40 and 42 are electrically operable and are normally closed. They are serially mounted in tube 36 and define a known volume in the tube therebetween.

When valve 40 is open, the tube 36 between the valves is charged to the pressure of the reservoir 34. Thereupon, when valve 40 is closed, followed by the opening of valve 42, the pressurized volume of the space between the valves is discharged through tube 18 into the interelectrode space. By this means, a known amount of helium gas can be quickly discharged into the switch device. Valve control unit 44 controls the sequence of valve operation.

The actuation of the valve control unit 44 to discharge helium into the switch device 2 can be accomplished by detecting the pressure by pressure sensor 20 and actuating valve control unit 44 when the pressure decreases to a predetermined value. By this means, gas resupply is accomplished.

Another way of determining when gas resupply is required is by the employment of a coulomb meter 46, see FIG. 3. The coulomb meter is connected to the terminals 48 and 50 in FIG. 1 in place of the shunt illustrated therebetween. The coulomb meter measures the charge which is passed through the switch device and, when the amount of charge passed reaches a predetermined amount, a connection between the coulomb meter and the valve control unit 44 actuates the valve control unit to deliver gas to the switch device.

These resupply means are operable, when helium is employed as the fill gas and at least the cathode electrode is made of material selected from the group consisting of hafnium, tantalum, tungsten and rhenium, because of the relatively slow rate of gas loss. If hydrogen is used as the fill gas and 304 stainless steel is used as the cathode material, a gas supply means, as illustrated in FIG. 2, would not be sufficiently fast to overcome the gas loss. Similarly, titanium hydride ribbon and sponge would not be able to supply hydrogen at an adequate rate to maintain a sufficient pressure level for maintenance of conductivity under the conditions described above.

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.

What is claimed is:

1. A switch device of the gas discharge type comprising:

a first tubular electrode, a second tubular electrode insulatingly mounted with respect to said first tubular electrode and mounted within said first tubular electrode in spaced-apart relationship, defining an annular gas discharge region in the interelectrode space;

means for maintaining helium gas in said annular gas discharge region below the critical pressure required for low-pressure electric discharge between the electrodes at the voltage to be applied across said electrodes;

means for producing a magnetic field in said annular gas discharge region above a critical value required to provide sufficient electron trapping to sustain current between said electrodes when said voltage is applied, the invention comprising:

said gas being helium and at least the one of said electrodes acting as a cathode in the electric discharge being made of material selected from the group consisting of hafnium, tantalum, tungsten and rhenium for minimizing gas loss due to chemisorption and burial.

2. The device of claim 1 wherein the helium gas pressure is about 0.05 Torr and the interelectrode spacing is less than 5 centimeters.

3. The device of claim 2 wherein said electrodes are positioned within an envelope that is totally sealed.

4. The device of claim 1 wherein said electrodes are positioned within an envelope that is totally sealed.

5. The device of claim 1 wherein gas supply means is connected to said interelectrode space to supply helium to said interelectrode space to aid in preventing off-switching due to gas losses from said interelectrode space due to electric discharge in the interelectrode space.

6. The device of claim 5 wherein said gas supply means comprises a helium reservoir and a helium gas supply tube connected between said reservoir and said interelectrode space, first and second valves in said tube defining a gas volume therebetween, valve-operating means connected to said first and second valves for alternately opening said first and second valves so that the volume between said first and second valves is alternately connected to said helium reservoir and to said interelectrode space so that gas is discharged from said reservoir to said interelectrode space upon operation of said valve-operating means.

7. The switch device of claim 6 wherein a pressure sensor is connected to said interelectrode space, said pressure sensor being connected to said valve-operating means so that upon detection of low pressure in said interelectrode space, said valve-operating means is operated to discharge helium into said interelectrode space.

8. The switch device of claim 6 wherein a coulomb meter is connected to one of said electrodes, said coulomb meter being connected to said valve-operating means so that, upon passage of a predetermined charge through said switch device, said coulomb meter actuates said valve-operating means so that said gas supply means discharges helium gas into said interelectrode space.

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