United States Patent

[11] 3,558,960

[72] Inventors Gunter A. G. Hofmann
Los Angeles;
Ronald C. Knechtli, Woodland Hills, Calif.
[21] Appl. No. 779,341
[22] Filed Nov. 27, 1968
[45] Patented Jan. 26, 1971
[73] Assignee Hughes Aircraft Company
Culver City, Calif.
a corporation of Delaware

[54] SWITCHING DEVICE
6 Claims, 4 Drawing Figs.

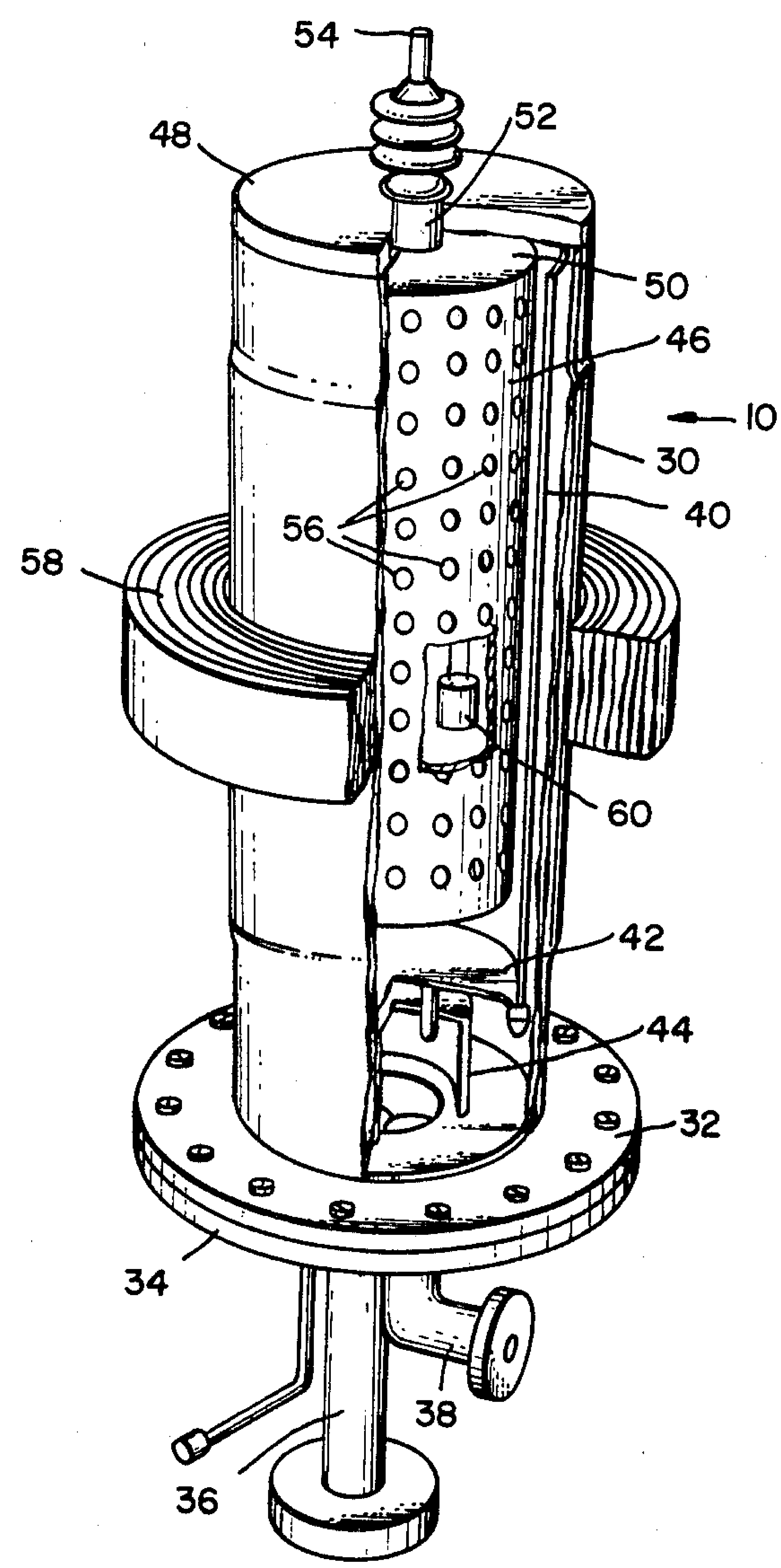
[52] U.S. Cl. 313/161, 313/157; 315/108
[51] Int. Cl. H01j 1/50
[50] Field of Search 313/157, 161, 174, 180; 315/108; 321/2, 11

[56] References Cited
UNITED STATES PATENTS

2,528,547	11/1950	Reilly et al.	313/180
2,684,461	7/1954	Busemann	321/11
3,014,857	12/1961	Gow et al.	313/161X

Primary Examiner—Raymond F. Hossfeld
Attorneys—James K. Haskell and Allen A. Dicke, Jr.

ABSTRACT: The switching device has an anode and a cathode with a gas-filled space therebetween. Conduction causes ion implantation into the cathode, sputtering and adsorption pumping, with consequent reduction in gas pressure to result in cessation of conduction when the pressure decreases below the critical value. In the present switching device, this is prevented by providing an auxiliary gas volume which contributes gas as required.



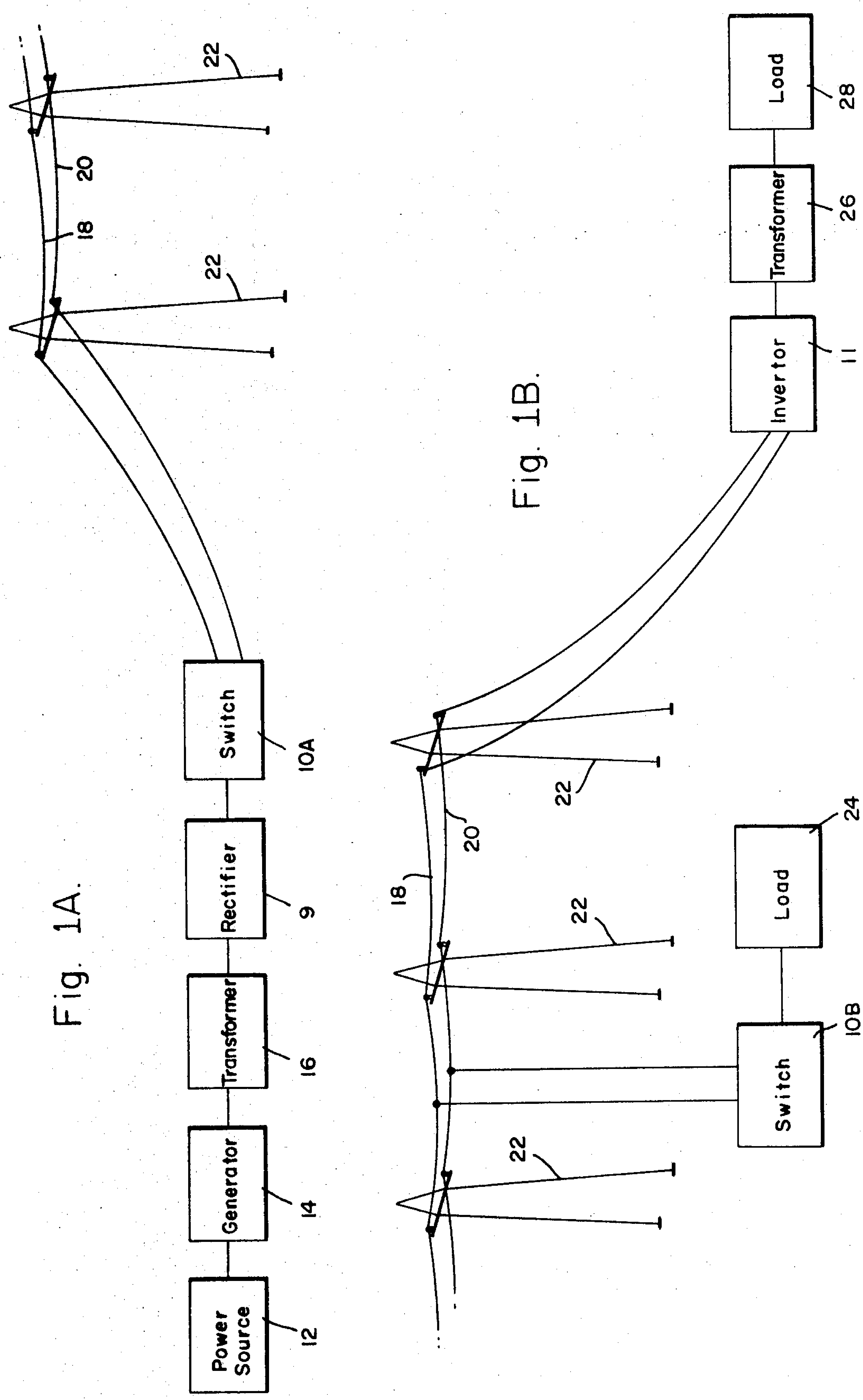
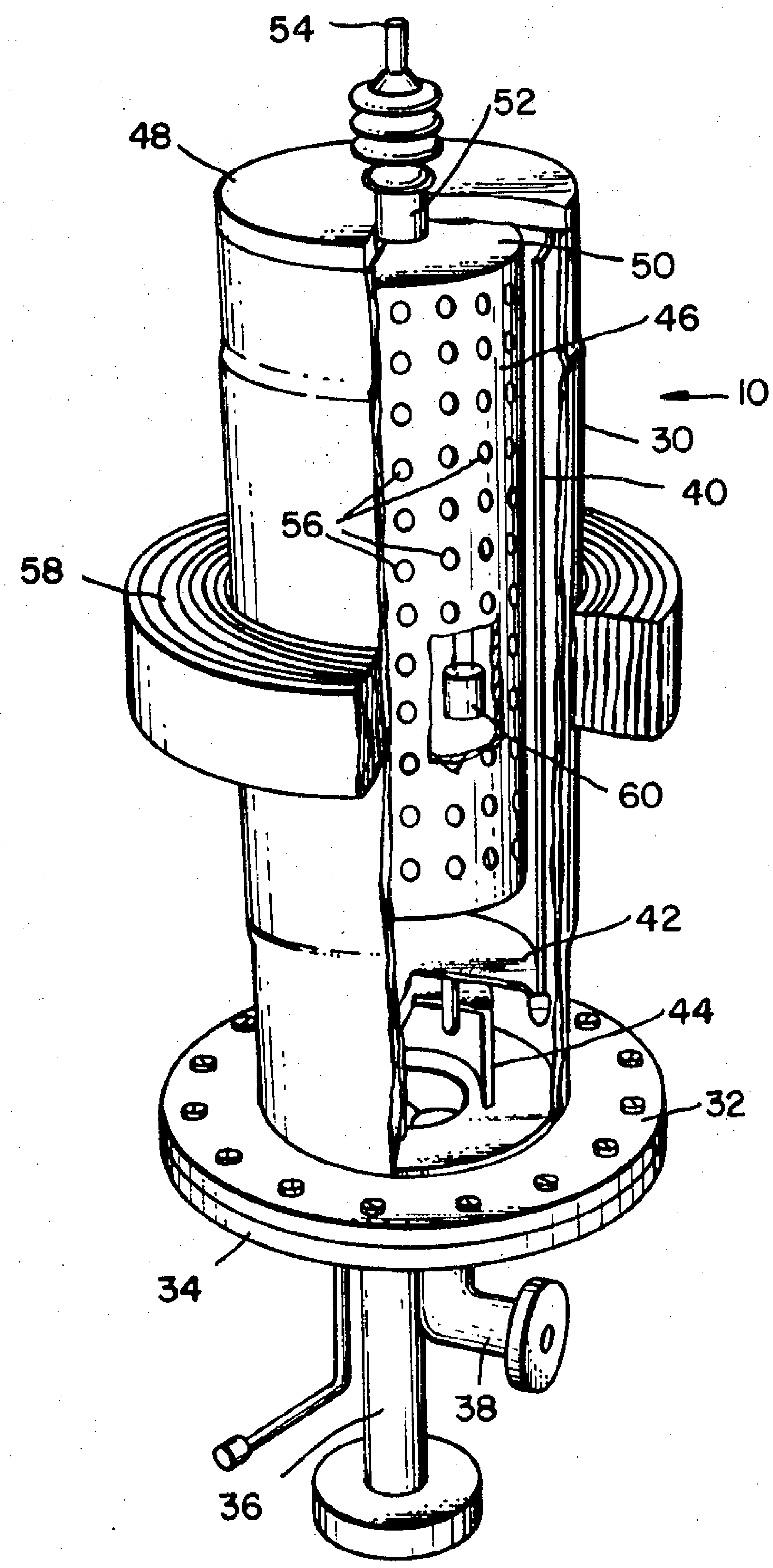

Power Source
12
Generator
14
Transformer
16
Rectifier
9
Switch
10A
18
20
22
Switch
10B
Load
24
Invertor
11
Transformer
26
Load
28

Fig. 1A.

Fig. 1B.

Fig. 2.



Gunter A. G. Hofmann,
Ronald C. Knechtli,
INVENTORS.
BY.

ALLEN A. DICKE, Jr.,
AGENT.

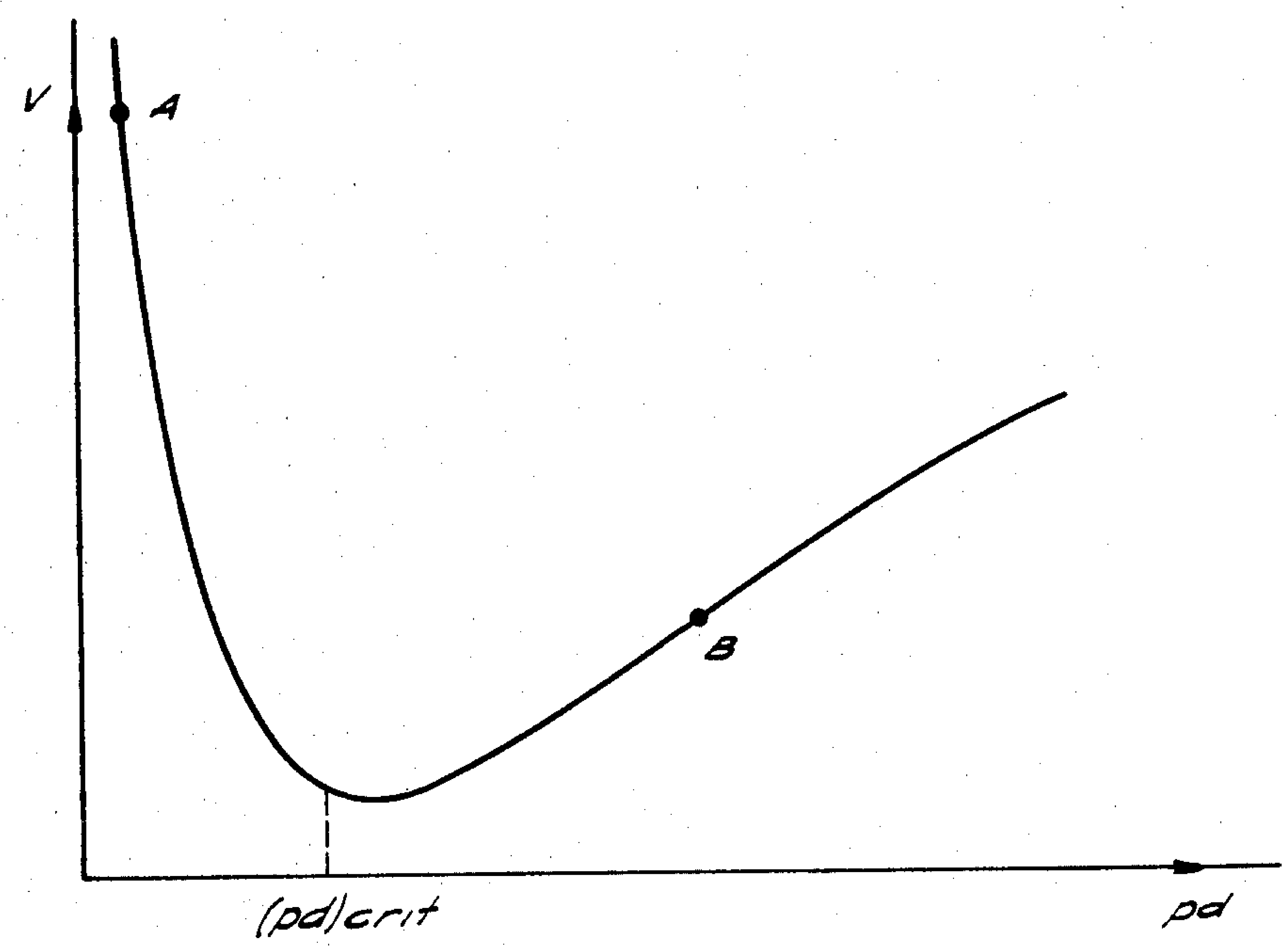


FIG. 3.

SWITCHING DEVICE

BACKGROUND

This invention is directed to a switching device of the crossed field type, employing Penning discharge, wherein regulation of the magnetic field strength controls electron path length so that this path length is above or below a critical value.

Switching devices of a general type are known in the art. Penning U.S. Pat. No. 2,182,736 describes such a switching device, while Boucher, et al. U.S. Pat. No. 3,215,893 and Boucher, U.S. Pat. No. 3,215,939 describe improvements thereon. All three of these devices are primarily directed to rectifier type switching, and the Boucher and Boucher, et al. patents are directed to an improvement wherein the shape of the magnetic field improves rectifying action by providing a lower breakdown voltage in one direction than the other between the two electrodes which form the gas-filled space. However, these devices suffer from the problem that the ions are driven by the electric field toward the cathode and some of them are trapped there by ion implantation in the cathode material. Furthermore, these ions sputter cathode material which may produce adsorption pumping by the freshly sputtered material. These effects result in a reduction in gas pressure with consequent eventual lowering of this pressure below the critical value so that conduction ceases. Thus, these prior art structures are not capable of longterm conductivity. This problem is pointed out in the Penning patent.

With continually increasing electric power demands, there is increased need to exploit sources of power farther away from the users of large amounts of electric power, with the consequent need for transporting the electric power over greater distances. In the United States, a number of our larger electric power-consuming areas are at some distance from primary power sources, such as sites for generation of hydroelectric power, coal deposits and oil deposits. Accordingly, it becomes necessary to transport electricity over greater distances. It is known that to transport high powers over long distances, DC can be economically superior to AC. This has already led to a number of high power DC transmission lines, such as the Pacific Intertie presently under construction between the Columbia River and Los Angeles. One limitation to the wide use of DC is the lack of practical high power DC switching devices. By making the continuous operation of a Penning discharge device possible over prolonged periods of time, the present invention provides means to make such a DC switch.

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 switching device having first and second electrodes. The interelectrode space is gas filled to such a pressure that the distance between electrodes times the pressure is below a critical value when an electric field is applied without a magnetic field. When a magnetic field above a critical value is applied, the electrons move in a direction generally normal to both the electric and magnetic fields. When the gas pressure exceeds a minimum valve, this results in ionizing collisions of sufficient frequency to sustain a gas discharge capable of conducting a substantial current between the electrodes. In order to maintain the gas pressure above this minimum valve, the device includes a gas supply which will maintain the gas pressure in the interelectrode space within operational limits. Preferably, the electrodes are tubular and concentrically positioned, with the gas reservoir positioned interiorly of the inner tubular electrode, with radial openings through the tubular inner electrode walls to connect the gas reservoir with the interelectrode space.

Accordingly, it is an object of this invention to provide a switching device of the crossed field type suitable for high current capacity and long conduction periods. It is a further object to provide a switching device which has a gas reservoir

therein to maintain the gas at a proper pressure. It is another object to provide a crossed field switch having a concentric tubular anode and cathode with a gas reservoir interiorly of the interior electrode. It is still another object to employ tubular electrodes in a crossed field switching device, with the inner electrode being radially perforated and with the gas reservoir interiorly thereof so that the radial perforations provide for equalization of gas pressure and proper maintenance of gas pressure in the interelectrode space. Other objects and advantages of this invention will become apparent from a study of the following portion of this specification, the claims, and the attached drawings.

DESCRIPTION OF THE DRAWINGS

FIG. 1A is a schematic drawing of a portion of a power system of the nature in which a switch device of this invention is employed.

FIG. 1B is a schematic drawing of another portion of such a power system.

FIG. 2 is a perspective view, with parts broken away, of the switching device of this invention.

FIG. 3 is a graph illustrating the Paschen curve.

DESCRIPTION

The switching device is generally indicated at 10 in FIG. 2. Referring to FIGS. 1A and 1B, which illustrate the manner in which the switching device 10 is employed in a circuit, two different applications of the switching device are indicated at 10A and 10B. In FIG. 1A, power source 12 drives generator 14. Power source 12 can be of any conventional type, including hydroelectric, internal combustion engine, or steam, including nuclear heated steam. Generator 14 generates alternating current electricity of suitable voltage and frequency for that portion of the system. It supplies alternating current transformer 16 which changes the voltage to one suitable for rectification and direct transmission. When direct current is employed for economic, long distance power transmission, this usually requires an increase in voltage at the transformer output, as compared to its input. Transformer 16 supplies rectifier 9, which preferably includes a plurality of rectifiers arranged in bridge form, depending on the plurality of phases at the output of transformer 16.

The rectifier in turn supplies transmission lines 18 and 20, through switch 10A. The presence of switch 10A, which can also serve as circuit breaker in an appropriate circuit combination, permits the use of uncontrolled rectifiers for the rectifier 9. This can lead to substantial savings over the use of controlled rectifiers such as are required by the present state of the art in the absence of a DC switch such as 10A. Transmission lines 18 and 20 are supported on a plurality of towers 22 which support the lines in insulated fashion away from the terrain, from the area of generation to the area where the electric power is to be employed. In some cases, transmission lines 18 and 20 may be buried, and in some cases they will be underwater transmission lines. Furthermore, while two transmission lines are preferable so that the voltage to ground can be divided between them, some systems may employ a ground return, but such is not preferred for high-power systems.

Referring to FIG. 1B, switch 10B is connected between transmission lines 18 and 20 and load 24. While a simple switch and simple load are indicated, there are preferably two switches at 10B, in order to switch the power coming from each of transmission lines 18 and 20. Furthermore, load 24 may be a direct current load operating at transmission line voltage, or it may be an inverter-transformer-load system. Switch 10B, with its load 24, illustrates the use of switch 10B for a tap on the transmission line. In the appropriate circuit combination, switch 10B can also serve as a circuit breaker for the tap.

Referring to FIG. 2, the switch device 10 comprises housing 30 which is carried upon bottom flange 32. Bottom flange 32 is in turn mounted upon base flange 34, and they are secured together to provide a tight seal. Base flange 34 stands upon foot **36** for supporting the switch device structure. Furthermore, vacuum connection **38** is connected to base flange **34** for drawing a suitable vacuum on the interior of housing **30** and then letting into the tube the desired gas (e.g. hydrogen, including its isotope deuterium) at the required pressure. Housing **30**, together with bottom flange **34**, serves as a suitable vacuum tight envelope.

Cathode **40** is in the form of a cylindrical tube. It is spaced inwardly from housing **30**. Cathode **40** has a lower cap **42** by which it is supported from base flange **34** by means of standoff **44**. Lower cap **42** does not need to effect closure, but simply provides mechanical support for the cathode and reduces plasma end losses. By this construction, the entire cathode can be withdrawn through the large opening in bottom flange **32** when the flanges are separated for inspection and service of the cathode and inspection and service of the interior of housing **30**. Cathode **40** is metallic and can be made of stainless steel. The cathode is connected to the foot **36** such as by a metallic strip. Thus, foot **36** provides one of the electrical connections to the switching device **10**. Cathode **40** preferably has an axial slot to prevent the circumferential circulation of current during switching transients, when the axial magnetic field changes with time.

Anode **46** is of cylindrical tubular construction and is positioned concentrically with cathode **40** to provide a radial space therebetween having the dimension *d*. The radial space *d* is substantially equal at all facing positions of the anode and cathode. Housing **30** has a top cap **48** upon which anode **46** is positioned. The anode is maintained in position by employing anode cap **50** which is secured to the cylindrical anode **46**, and in turn carries mounting stud **52**. Mounting stud **52** provides both mechanical support by being secured to housing cap **48**, and provides electrical continuity through the cap by connector **54**. Preferably, anode cap **50** is spaced below top cap **48** and connector **54** passes through insulative mounting stud **52** so that connector **54** and the entire anode are electrically separated from the housing. Alternatively, top cap **48** can be of insulative material.

Anode **46** has a plurality of holes **56** therethrough so that the interior space within anode **46** is in communication with the interelectrode space. The volume within the interior of anode **46** is preferably in the order of 10 times the volume in the interelectrode space. Magnet **58** is positioned on the exterior of housing **30** in such a manner as to provide magnetic lines of force in the interelectrode space which are substantially parallel to the axis of the electrodes of switching device **10** over at least part of the electrode length. Magnet **58** is illustrated as being an electromagnet, and such is preferred so that the magnetic field can readily be switched on and off. The power supply to magnet **58** is preferably of such nature as to provide for rapid turn on and off of the field. Its strength is such as to provide a field between 25 and 150 Gauss; 70 Gauss was found to be a preferred value for the dimensions given below used in our experiments to date, considering the turn on and turn off effects, as well as magnet power consumption.

The interior of anode **46**, as well as the interelectrode space, is filled with a gas to an appropriate pressure. Referring to FIG. **3** the Paschen curve is shown therein. This curve illustrates that at a certain critical product of the interelectrode pressure *p* times the interelectrode spacing *d*, the voltage to breakdown is fairly low. It also illustrates at point A that for a lower product, voltage to cause breakdown is considerably higher. This is because at lower pressure, the electron mean-free path exceeds the interelectrode spacing *d*, and the ionization rate decreases, which makes it more difficult to sustain the discharge and makes it possible to withstand higher voltage between electrodes before breakdown occurs.

When the magnetic field is off, electron flow is only under the influence of the electric field from the cathode to the anode so that the average electron path length is substantially equal to the interelectrode space *d*, and is less than the electron mean-free path length. Thus, there is no sustained ionization, electron flow is low, and the switching device can withstand a high standoff voltage, for its operating point lies approximately below point A on the Paschen curve. However, when the magnetic field is applied to the interelectrode space by electromagnet **58**, the axial magnetic field causes the mean-free electron path to be circular until a collision occurs. In this longer path caused by the magnetic field effect, there are sufficient collisions to maintain ionization because the mean-free electron path length is sufficiently longer than the interelectrode spacing *d*. Thus, so long as a sufficient magnetic field is applied, once electrons start flowing, the flow is maintained until the magnetic field is cut off. When cut off, the electrons again flow radially so that ionization is not maintained.

Since the net electron flow is from the cathode to the anode, and flow of electrons through the interelectrode space results in collisions with gas atoms to cause ionization, a certain number of these ionizing collisions cause the ions to be driven into the surface of the cathode. Gas pumping by ion implantation and by adsorption on freshly sputtered material occurs with the result that the amount of ionized and neutral gas decreases after the switching device has been conducting for a period of time to a point where conduction cannot be maintained. This causes unwanted or premature off switching of the device, when the only gas available is that in the interelectrode space. In the present switching device, holes **56** in anode **46** permit the space interiorly of anode **46** to communicate with the interelectrode space. Thus, the gas within the interior of anode equalizes pressure with the gas in the interelectrode space through holes **56**. In order to realize short-time constants, holes are necessary rather than attempting equalization around the ends of the anode tube.

In a particular example, the interelectrode radial distance *d* is about 15 millimeters, with an anode diameter of 90 millimeters and axial length of 300 millimeters. Holes **56** are present in such quantity and size as to provide about 30 percent of overall anode area as communication space. With such dimensions, and with a switching device **10** capable of holding off 25 kilovolts, normal gas pressure in the interelectrode space and in the anode interior, when the switching device **10** is new, is about 0.04 millimeters of mercury. Hydrogen is the preferred gas, including its isotope deuterium, in the switch of this example. If it were not for the gas within the interior of the and anode being in communication with the interelectrode space a charge of 0.4 Coulombs is approximately sufficient to reduce the interelectrode space gas pressure to a point where the switching device will off switch, due to gas loss. However, with the indicated interior anode volume available to the interelectrode space, a charge greater than 2.4 Coulombs can be passed before the gas pressure decreases sufficiently to cause danger of off switching. The conduction period can be further extended by providing an auxiliary gas source such as titanium hydride ribbon or sponge **60** at an appropriate temperature, inside of the anode volume or in communication with it. Titanium metal in such a form that it has a large surface area, for example as ribbon or sponge, has the property that, at elevated temperature and in a hydrogen atmosphere, great quantities of hydrogen are absorbed. While maintaining an appropriate temperature, a reduction in the hydrogen pressure thereabound results in discharge of hydrogen from the metal in an attempt to maintain an equilibrium pressure. Such large quantities of hydrogen can be absorbed that, under the pressure and volume considerations of the structure of this invention, the titanium hydride source functions virtually as an infinite source to maintain the equilibrium pressure. It should, however, be noted that such an auxiliary gas source alone, without the holes providing fast communication for the gas between the interelectrode volume and the gas-filled volume inside the anode, would not suffice to prevent self-interruption of the gas discharge due to gas depletion in the interelectrode space under passage of a high current. Under such conditions, the time constant of a conventional auxiliary gas source would be too long compared to the gas depletion time constant of the interelectrode space. In this example, a magnetic field in the order of 70 Gauss is provided in the interelectrode space. The holes **56** in the anode do not limit current-carrying capacity, because discharge is cathode area limited, rather than anode area limited.

With the dimensions illustrated, the switching device **10** is capable of off switching DC loads of 1,000 amperes, and hold off 25 kilovolts within a recovery time on the order of about 25 microseconds. Thus, it is useful as a DC switch or element of a DC circuit breaker, as illustrated in FIGS. 1A and 1B.

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.

We claim:

1. A switching device, said switching device comprising:

An envelope arranged to maintain a subatmospheric pressure within said envelope, gas at a subatmospheric pressure within said envelope;

a cathode electrode within said envelope, said cathode electrode having an active cathode face;

an anode electrode positioned within said envelope, said anode electrode having an active anode face facing said active cathode face, and defining an interelectrode space;

electrical connections on said anode electrode and said cathode electrode, said gas pressure within said envelope in said interelectrode space being sufficiently low so that, upon application of a direct voltage between said anode and said cathode to produce an electric field therebetween, there is substantially no electric current conduction therebetween in the absence of a magnetic field;

an electromagnet on said envelope, said electromagnet, when energized, supplying a magnetic field in the interelectrode space at an angle with respect to the electric field so that, when the electromagnet is energized, ionization takes place in the interelectrode space to permit electric current to flow between said anode and said cathode and, upon cessation of the magnetic field, ionization ceases so that there is substantially no electric current conduction between said anode and said cathode so that control of the magnetic field switches the electric current, the improvement comprising:

perforations in at least one of said electrodes, a gas space on the other side of said perforated electrode opposite said active electrode face so that gas can communicate through said perforations into said interelectrode space, said gas space having a greater volume than said interelectrode space.

2. The switching device of claim 1 wherein said anode electrode is perforated and said gas space is on the opposite side of said anode electrode from the active face thereof.

3. The switching device of claim **2** wherein said cathode is tubular and said anode is tubular and said anode is positioned within said tubular cathode so that the space between said anode and said cathode is substantially uniform.

4. The switch of claim **3** wherein said anode and said cathode are each cylindrical tubes, said cylindrical tubes of said anode and said cathode each having an axis, said axes being substantially coincident, the interelectrode space being measured in a distance perpendicular to said axes, and the electric field being applied in a direction perpendicular to said axes, said magnetic field being applied in a direction substantially parallel to said axes.

5. The switching device of claim 1 wherein an auxiliary gas source is positioned on the side of said perforated electrode opposite said active electrode face.

6. The switching device of claim **5** wherein the gas is hydrogen and said auxiliary gas source is a metallic hydride.