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HERMETICALLY SEALED HIGH ENERGY SPARK GAP

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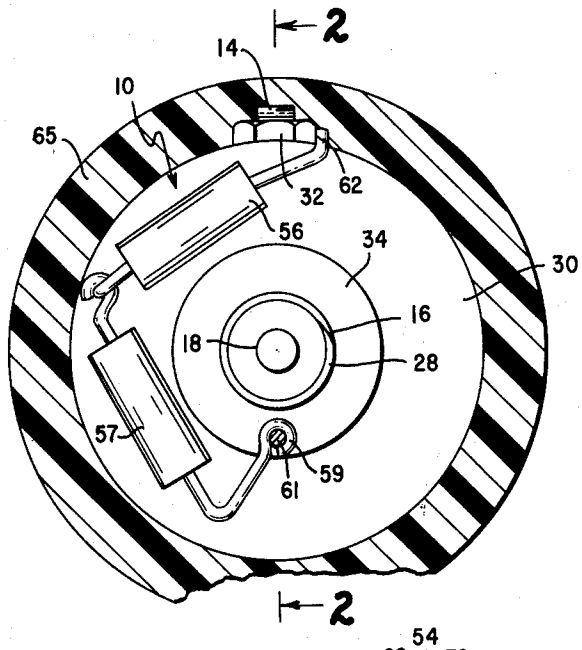


Fig. 1

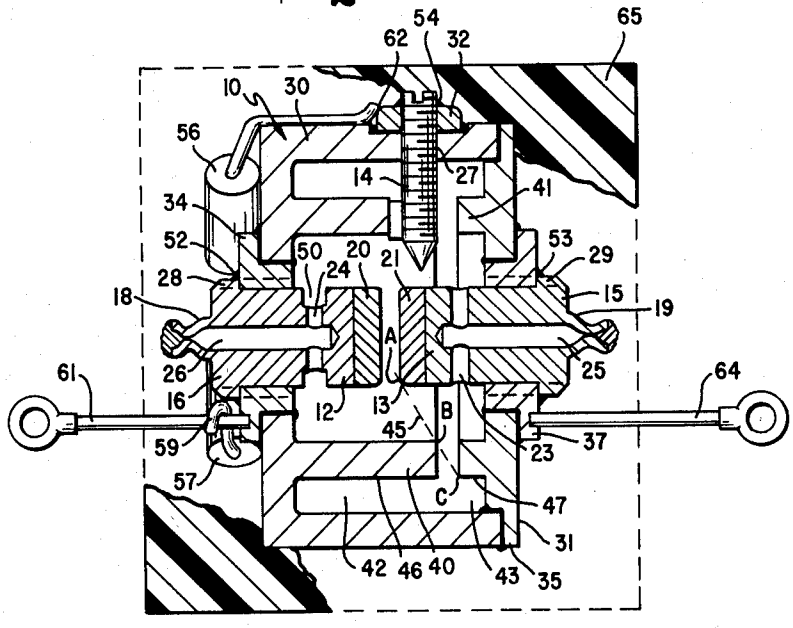


Fig. 2

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HERMETICALLY SEALED HIGH ENERGY SPARK GAP

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This invention relates to electrical apparatus for providing electrical discharges in an electric circuit, and more particularly to the means and method for producing a spark gap device having extremely high order of stability and long-lasting effective life even when operating at high sparking rates in ignition systems for engines.

The invention comprehends the means and method for stabilizing and making highly consistent the electrical potential required to produce an electrical discharge between electrodes by avoiding disturbances of the electrodes surface working function and their spacing while providing very rapid electrical conduction of the gas therebetween.

The invention comprises means located in predetermined position with respect to the electrodes for materially increasing the effective life of a spark gap, preventing its impairment and short-circuiting through the formation of shunting conducting paths between the electrodes.

The invention embraces the provision of means and process of manufacture and assembly of a spark gap device to prevent grease, oil, and other contaminants from collecting on the main components, particularly on the sparking surface of the electrodes, so that, from a mechanical and metallurgical standpoint, an inert assembly is produced.

Heretofore spark gap devices, commercially available for use as series gap means to isolate the voltage source from the spark plug while the ignition voltage builds up and for making high frequency systems out of conventional ignition systems, have been unsatisfactory, due primarily to lack of stability and extremely short effective life of such spark gap devices. Many attempts to attain consistent stability and prolongation of the effective life of such spark gap devices have been unsuccessful, so that spark gap devices for such use presently available lack stability and their effective life is of very short duration.

One of the principal objects of the invention is to avoid the foregoing drawbacks and produce a very reliable device for regulating electrical discharge of extremely stable characteristics and of long-lasting useful life, particularly adaptable for use as a series gap in the spark plug circuit of ignition systems for engines.

Another object of the invention resides in the arrangement and construction of the cathode electrode of spark gap to cause its operation at a higher temperature than the anode, and for keeping the cathode relatively hot to prevent hot oxide ions from collecting on its sparking surface and also avoiding disturbances of the electrode surface work function.

Another object of the invention is to provide a barrier or baffle as means to control the deposition of hot oxide ions and metallic particles on the walls of the enclosure of a device for regulating electrical discharge to thereby insure discontinuity in the formation of leakage or shunting conducting paths between the electrodes.

Another object of this invention resides in a hermetically sealed three electrode spark gap assembly providing only a pair of terminal posts to facilitate its rapid connection as a series, or control gap in the spark plug circuit of engine ignition systems.

Another object of this invention is the provision of means for preventing hot oxide ions from condensing and

coating the sparking surface of the cathode to thereby avoid the alteration of its original configuration, as well as changes in the spacing between the electrodes of a spark gap device.

Another object of this invention is to provide in a device for regulating electrical discharge a narrow annular chamber formed between the shanks of the electrodes to insure discontinuity in the condensation and coating on the walls of the chamber of hot oxide ions and metal particles thrown out by the electrical discharge.

Another object of this invention is to provide an improved device for regulating electrical discharge, the break down voltage of which has a voltage variation of less than ±3 percent between consecutive discharges whereby timing jitter, caused by variations in the breakdown voltage is reduced to less than one engine degree when the device is used as a control series gap with the firing gap of engine ignition systems.

Another object of the invention is to provide a hermetically sealed high energy spark gap, in which breakdown of the main spark gap is initiated by the electrical discharge of an auxiliary spark gap and then transferred to the main gap, thus permitting the electrodes to be massive and resist prolonged arcing, avoiding the formation of irregularities in their discharge surfaces as is the case in prior art devices.

Another object of the invention is a device for regulating electrical discharge wherein its enclosure has baffle means separating the shanks of the electrodes to provide a shield against the deposition on its rear wall of material thrown out from the electrical discharge region.

A further object of the invention is a high energy spark gap device wherein the components are bonded to provide a hermetically sealed device and inert assembly is produced by preventing grease, oil, and other contaminants from collecting on their surfaces, particularly on the spark faces of the gap during the manufacture and assembly of the device.

Among other objects of this invention is an improvement of the three-electrode spark gap shown and disclosed in Patent No. 2,963,624 of December 6, 1960, of which I am co-inventor.

Other objects and advantages of this invention relating to the arrangement, operation and function of the related elements of the structure, to various details of construction, to combinations of parts and to economies of manufacture will be apparent to those skilled in the art upon consideration of the following description and appended claims, reference being had to the accompanying drawings forming a part of this specification wherein like reference characters designate corresponding parts in the several views.

Referring to the drawings:

FIGURE 1 is a top plan view of a spark gap incorporating the invention with certain portions of the outer coating being removed; and

FIGURE 2 is a cross-sectional view taken in line 2—2 of FIGURE 1 looking in the direction of the arrows.

The present invention may be incorporated in any suitable device for regulating electrical discharges and for practical application of its principles, the invention is illustrated in the drawings as embodied in a hermetically sealed high energy spark gap, particularly adaptable for use in ignition systems of multi-cylinder internal combustion engines. However, it is to be understood that the invention is not limited in its application to the particular form shown but that it is contemplated that the principles of the invention may be used whenever the same may be found to be of utility.

Referring to the drawings, the embodiment of the invention illustrated, by way of example, shows a hermetically sealed high energy three-electrode device for regulat-

ing an electrical discharge comprising a main discharge spark gap and a teaser or auxiliary discharge gap in a hermetically sealed envelope or enclosure containing an ionizable gas.

As illustrated in FIGURE 2, the numeral 10 designates a composite housing or enclosure providing a cylindrical closed chamber having comparatively thin wall sections produced from a material having good dielectric constant and suitable insulating characteristics. In carrying the invention into practice consistent with economical manufacture, it has been found advantageous to make or form the housing 10 from suitable ceramic insulating material including porcelain whose dielectric constant is comparatively greater than air which has high insulating qualities, so that the walls of the housing or enclosure are of a minimum cross section, thereby materially decreasing the weight as well as the volumetric space occupied by the device.

The main discharge spark gap is produced by axially aligned electrodes 12 and 13 while the auxiliary spark gap is produced between the main electrode 13 and a right angled or orthogonally disposed third electrode 14 having its discharge face located rearwardly of the discharge face of the main electrode 13.

The main electrodes 12 and 13 are preferably formed of stainless steel or of other suitable conducting non-oxidizable material having cylindrical shanks 15 and 16 with reduced end portions 18 and 19 and are capped at their discharge ends by tungsten discs 20 and 21 which are rounded at their peripheries to minimize sharp edges discharge effects and provide flat or uniplanar electrical discharge faces arranged adjacent and parallel to each other. The portion of the main electrodes located within the interior of the housing 10 is made of a large mass to enhance cooling and each has adjacent to their discharge end transverse openings 23 and 24 in direct communication with the central longitudinal bores 25 and 26 forming passages whereby the interior of the closed chamber containing the three electrodes can be flushed with a suitable ionizable gas such as nitrogen. Thereafter these passages are sealed by crimping as well as sealing the bores 25 and 26 of the electrodes exteriorly of the housing by suitable means such as solder. The shank of each of the three electrodes is provided with threaded portions 27, 28 and 29 in order to facilitate adjustment and setting the spacing of the electrodes for the predetermined breakdown voltage desired.

The composite ceramic housing 10 providing the hermetically sealed enclosure for the three electrodes and the ionizable gas comprises a cup-like member 30 having its walls of thin cross section and a closure 31 cemented to the open end of member 30 in fluid-tight relation. The lateral wall of the member 30 adjacent to its open end is pierced by an aperture to which is cemented in gas-tight manner the threaded member 32 arranged to receive and support at right angles to the axis of the main electrodes the shank 27 of the secondary electrode. The central portion of the bottom wall of member 30 has an opening to which is cemented in gas-tight manner a flanged sleeve 34 having a threaded bore arranged to receive the threaded shank 16 of the main electrode 12.

The closure 31, preferably made of ceramic material, takes the form of a disc-like member having at its periphery a shouldered portion 35 dimensioned to insure an effective fluid-tight bond with the open end of member 30, and has a centrally disposed opening, to which is cemented in fluid-tight relation the flanged sleeve 37 having a threaded bore to accommodate the threaded shank 29 of the main electrode 13 for holding the same in axial alignment with the electrode 12.

According to the principles of the invention, means are provided within the composite housing 10 for materially increasing the effective life of the device for regulating electrical discharge forming barrier or baffle means arranged to control the deposition of hot oxide ions and metallic particles on the walls of the enclosure whereby impairment or short-circuiting of the spark gaps by the formation of leakage or short-circuiting paths between the electrodes is avoided. In the embodiment shown, this means preferably takes the form of an upstanding wall 40 of thin cross section extending from the bottom surface of member 30 arranged to surround the shank of the main electrode 12 and a corresponding wall member 41 in radial alignment with the upstanding wall 40 extending from the inner surface of the closure 31 which, in turn, surrounds the shank of the main electrode 13. The walls 40 and 41 are arranged to form close circular shields surrounding the electrodes and the height of wall 40 is of sufficient dimension to bridge the main spark gap and a portion of the shank of the main electrode 13. In carrying the invention to practice, it has been found advantageous to make the height of the circular wall 40 approximately ¾ of the overall height of the inner chamber provided by the composite housing 10. The wall 40 and the corresponding wall member 41 are preferably spaced with respect to the inner cylindrical wall of the chamber a relatively small distance so as to provide narrow, annular chambers 42 and 43 which further guarantee the discontinuity in the formation of surface leakage or shunting conducting paths between the three electrodes 12, 13, and 14 and thereby increase the effectiveness of wall members 40 and 41 as shields for preventing the impairment and short-circuiting of the spark gaps.

The effectiveness of the means provided in the embodiment shown for preventing impairment or short-circuiting of the spark gaps can be apprecited when it is considered that the occurrence of an electrical discharge causes partially conductive material, including metallic particles of the electrodes, and hot oxide ions, to be thrown out radially from its discharge region and the tendency of such materials to be deposited on cooler surfaces such as the internal walls of the housing 10. In addition, that if the baffle means of the invention were not used, the deposition of this partially conductive material would not be controlled but allowed to accumulate in sufficient quantities on the internal walls of the housing to form leakage or short-circuiting paths between the shanks of the electrodes. More specifically, the function of the walls 40 and 41, as a barrier against leakage and short-circuiting paths, across the spark gaps can be better understood by examination of FIGURE 2, wherein the extreme boundry or "deposition shadow" of the partially conductive material thrown out radially from the discharge region of the main gap on the walls of the housing is represented by line 45 which is tangent to the tip "A" of the electrode 13 and points "B" and "C" of the walls 40 and 41. The presence of the walls 40 and 41 establish "deposition shadow" defined by the line 45 by intercepting the radial stream of the material thrown out or escaping from the discharge region of the main gap, and thereby forms an effective shield against the collection of such material on the rear surfaces 46 and 47 of walls 40 and 41. In addition, the walls 40 and 41 make it extremely difficult for this partially conductive material to condense and coat the walls of the narrow, annular chambers 42 and 43. The fact that ion condensation and the deposition of the partially conductive material escaping from the discharge region of the spark gaps is controlled by the walls 40 and 41 and the formation of conductive continuous coating is prevented on surfaces 46 and 47, will, in all instances, insure a discontinuity of leakage paths between the shank of the three electrodes and thereby avoid the impairment of the main and auxiliary spark gaps.

Another important feature of the invention resides in the provision of means for avoiding disturbances in the surface work function of the material provided for the discharge face of the electrodes, as well as alterations in its original configuration and changes in the spacing of the spark gaps. In accordance with the principles of the invention, this means finds expression in the arrangement

and configuration of one of the electrodes, preferably the cathode, whereby the same operates at a higher temperature than the other electrode and is kept relatively hot to prevent hot oxide ions and metallic particles from collecting and condensing on its discharge face. This effect is secured by the presence of a heat slot obtained by materially reducing the cross sectional area of a portion of the electrode within the housing. In the embodiment shown, the electrode **12** is constructed to incorporate the heat slot **50** obtained by materially reducing the shank of the electrode rearwardly of its discharge face, whereby the electrode, particularly its forward portion and the tungsten disc **20**, suitably bonded or brazed thereon, operate at relatively high temperature to prevent hot oxide ions from collecting on the discharge face and thus avoiding disturbances of its surface work function, so that spacing of the main gap is not altered but is constantly maintained.

The electrodes **12**, **13** and **14**, as hereinbefore pointed out, are adjustably mounted in the housing by means of threaded connections to facilitate their calibration and setting to the predetermined breakdown voltage desired. The setting of the main electrodes **12** and **13** in their adjusted position is maintained and insured by locking their threaded connections exteriorly of the housing as at **52** and **53** through the use of a suitable bonding material such as solder. The soldered connections **52** and **53** of the electrodes **12** and **13** not only prevent relative rotation with respect to their corresponding supporting sleeves **34** and **37**, but also provide a low resistance path for the flow of electric current and a fluid-tight threaded connection, preventing possible leakage.

The third or teaser electrode **14**, with its pointed or needle-like discharge face, which is used to precipitate a corona or static voltage discharge, is readily adjusted and set through its threaded connection with member **32** to provide a discharge across the auxiliary gap before the breakdown voltage across the main electrodes **12** and **13** is reached and is thereafter locked in such position by bonding the threaded connection as at **54** through the use of a suitable bonding material such as solder. The bonded threaded connection **54** effectively prevents change in the setting of the third electrode **14** and possible leakage of the ionizable gap within the housing as well as a high resistance path between the electrode shank and its supporting member **32**.

It should be noted that by the incorporation of the principles of the invention, including, among others, the construction, relative position, and configuration of the electrodes, the discharge of the auxiliary gap not only preionizes the main gap but serves to stabilize to a consistent predetermined value, within very close range, the breakdown voltage, so that variations in the breakdown voltage is less than $\pm 3\%$ three percent between consecutive firings or discharges. Therefore, the timing jitter caused by variations in the breakdown voltage of the device of the invention is reduced to less than one engine degree when the same is incorporated as a control or series gap in the firing circuit of the spark plug of internal combustion engines. It should be borne in mind that the predetermined value of the breakdown voltage of the main gap in the device of the invention is determined broadly by the normal parameters including as factors, among others, the pressure within the enclosure, work function of the metals of the electrodes, configuration of the discharge surfaces, the spacing of the gap, and the kind of ionizable gas used.

In the embodiment of the invention shown, the teaser electrode **14** is connected to the cathode or electrode **12** by interposing very high resistance elements which may take the form of two carbon resistors **56** and **57** having a resistance value which may range from 500,000 ohms to 2 megohms. The carbon resistors **56** and **57** are connected in series and one of their terminals is fixedly secured to the outer surface of the flange of sleeve **34** as at **59**, to which is also connected the terminal lead **61** of the device while the other terminal of the resistors is bonded as at **62** to member **32**. The carbon resistors **56** and **57** and their connection between the teaser electrode **14** and the cathode **12** provide means to attenuate or discontinue the electrical discharge of the auxiliary gap. In order to facilitate proper connection with the other main electrode **13**, the connecting wire forming a terminal lead **64** is bonded to the outer surface of the sleeve **37** to facilitate the rapid connection of the three-electrode spark gap as a series or control gap in the spark plug firing circuit of engine ignition systems.

In order to insure a fluid-tight assembly, and maintain the electrodes **12**, **13**, and **14** producing the main spark gap and auxiliary or triggering gap in a hermetically enclosed space, all components not only are bonded by suitable cementing materials but, in turn, the housing is potted or covered by an epoxy resin coating **65** of comparatively large thickness whereby any leakage between the components and their connections is prevented, so that a hermetically sealed spark gap is permanently insured, irrespective of its environmental conditions.

Another feature of the three electrode sealed spark gap of the invention resides in the process of assembly wherein exacting sterile conditions are called for on the personnel and the materials to produce an inert assembly. Conventional spark gaps become unstable because of the depositions on the surface of the electrodes, which depositions alter the surface work function of the discharge surface of the electrodes, as well as the spacing and thus cause the breakdown voltage of the gap to become erratic. These depositions consist primarily of films, oxides and moisture. By selecting the proper materials, and careful handling, these films are eliminated or minimized to the point of ineffectiveness.

To fulfill the feature of the invention in providing an inert assembly, the shanks of the electrodes are made of stainless steel of a grade which is unaffected by corrosion or materially impaired by electrical discharge. Tungsten is used on the electrode discharge surfaces as it will not volatilize, as does molybdenum, and moreover does not readily form oxides which are only present at very high temperatures. Nitrogen gas is flushed through the longitudinal bores **25** and **26** of the electrodes before the same are sealed to expel and dilute air, thus minimizing oxygen content, thereby reducing possible oxide formation. The dry nitrogen gas helps to remove most of the atmospheric moisture within the hermetically sealed assembly and is retained preferably under atmospheric pressure therein. The ionizable gas is used at a pressure calculated in relation to the spacing of the gaps and the broad characteristics of the voltage employed to give a discharge at a selected potential.

In order to obtain the main advantages of the invention, every effort should be made to prevent human grease, oil and other contaminants from collecting on the inside surface of the ceramic chamber and on the electrodes used. The general rule which has been followed for securing a spark gap of highly stable characteristics may be expressed as follows: (1) All materials intended to be used internally must be degreased and boiled, (2) Particular care should be taken to use only bonding materials and cements which will not react with the ceramics or the metals of the components. From a mechanical and metallurgical standpoint, the overall result is in effect an inert assembly.

A device regulating an electrical discharge embodying an inert assembly from a mechanical and metallurgical standpoint can be best produced at relatively low cost with high degree of effectiveness by employing the following procedure:

The main electrode assemblies after the tungsten disc forming the discharge faces of the electrodes are brazed or bonded in place are passed with the third electrode through a cleaning agent which would dissolve away all

excessive surface fluxes and oxides resulting from the brazing or bonding operation. The three electrodes are then handled by operators wearing silk gloves so as to prevent contamination by human grease and oils. The solvent used to clean off oxides and fluxes must be one which leaves little or no residual film after drying.

The ceramic members as well as all metal parts including the three electrodes, already cleaned of flux, are passed through another solvent bath wherein all machine greases, oils, and other film-forming deposits are stripped off. This solvent also upon drying should leave little or no residual film.

All components of the three electrode spark gap of the invention are then handled by operators wearing silk gloves which will also prevent lint from sticking to the surfaces. The components are processed and assembled in a room which should be clean and atmospherically controlled so as to minimize dust, grease, and moisture settling on the components.

The cements or bonding agents used in joining the components together into a unified closed housing should be of such a material that will not give off any gases under elevated temperatures as these gases could form contaminating oxides or films on the surfaces of the spark gap structure. The sealed enclosure with the gap assemblies is then flushed with dry nitrogen or some other ionizable inert gas to essentially remove atmospheric oxygen and moisture. The electrodes are then electrically adjusted to the proper voltage setting and stability and thereafter locked or bonded in place by soldering.

The unit is allowed to cool after soldering to come back to room pressure and temperature. The gap is once more flushed with nitrogen and the reduced end portion of the shanks of the electrodes forming the aspirating tubes for the sealed enclosure are crimped over and soldered closed. The unit is then dipped into an air-drying epoxy or plastic material to form a complete hermetically sealed coating over the entire unit. After the coating has dried, the unit is again electrically checked.

It should be noted that the metallic components of the high energy, three electrode sealed spark gap of the invention have substantially the same configuration, and can be produced by screw machine equipment. Moreover, that the main electrode assemblies have interchangeable overall dimensions and that, consistent with economical manufacture, the reduction of the diameter of the shank of the cathode to produce the heat slot of the invention can be secured in any of the electrode assemblies by an additional step in the process of manufacture. In addition, that the production of an inert assembly from mechanical and metallurgical standpoints for the device of the invention is accomplished by a low-cost process without the necessity of special equipment or highly skilled operators whereby the high energy spark gap is highly adaptable for low cost mass production manufacture.

The overall result of the application of the principles of the invention is the production at comparatively low cost, without special equipment or highly skilled operators, of a very stable, high energy, three electrode hermetically sealed gap, nominally rated for more than 1,000 hours with voltage variation of less than $\pm 3\%$ three percent between consecutive discharges or firings having, in effect, less than ± 150 volts variation between consecutive firing for breakdown voltages of 4,000 to 5,000 volts, resulting in a timing jitter of less than one engine degree when the device is used as a control gap in series with the firing gap of spark plugs in engine ignition systems. In actual practice, it has been found that the device of the invention is capable of providing a high energy spark gap having an effective life without impairment in excess of one thousand hours at 200 pulses per second of continuous operation or higher. It should be borne in mind that conventional sealed spark gaps now available have shown very short life expectancy, due primarily to internal shunting or leakage paths across the electrodes. Moreover, that such conventional sealed spark gaps, when used as control spark gap in the firing circuit of spark plugs of an ignition system, load down the source of voltage supply to a point where the voltage will not reach the value required to fire the gap. Therefore, its function in isolating the source from fouled spark plug gaps becomes impaired. However, such is not the case with the device of the invention due to the features hereinbefore described.

It is to be understood that the above detailed description of the present invention is intended to disclose an embodiment thereof to those skilled in the art, but that the invention is not to be construed as limited in its application to the details of construction and arrangement of parts illustrated in the accompanying drawings since the invention is capable of being practiced and carried out in various ways without departing from the spirit of the invention. The language used in the specification relating to the operation and function of the elements of the invention is employed for purposes of description and not of limitation, and it is not intended to limit the scope of the following claims beyond the requirements of the prior art.

What is claimed:

1. A device for regulating electrical discharge comprising in combination spaced electrodes in axial alignment having their discharge surfaces arranged adjacent to each other to provide a spark gap therebetween, a sealed enclosure of dielectric material containing the electrodes and ionizable gas, and baffle means in said enclosure to control the deposition of hot oxide ions on the walls of the enclosure to thereby insure discontinuity in the formation of leakage paths between the electrodes.

2. A device for regulating electrical discharge comprising two electrodes axially aligned having substantially flat discharge surfaces in spaced relation, means arranged rearwardly of the discharge surface of one of said electrodes for causing its operation at higher temperatures than the other and for keeping said electrode relatively hot, and a sealed enclosure containing said electrodes and an ionizable gas.

3. A hermetically sealed high energy spark gap including two electrodes axially aligned, said electrodes having substantially flat imperforated discharge faces arranged in spaced relation to provide a spark gap, a sealed enclosure of ceramic material containing said electrodes and ionizable gas, means in said enclosure to control hot oxide ions from collecting on the discharge face of one electrode, and baffle means in said enclosure to control material escaping from the discharge region of the spark gap from collecting on the rear walls of said baffle means to prevent short circuiting of the spark gap.

4. A hermetically sealed high energy spark gap including two main electrodes, said electrodes having substantially flat imperforated discharge faces arranged in spaced relation and parallel with each other to provide a main spark gap, a third electrode having a discharge face orthogonally disposed with respect to the axis of the main electrodes, the discharge face of the third electrode located to the rear of the discharge face of one of the electrodes and spaced apart to provide an auxiliary spark gap, and a sealed enclosure of insulating material supporting the three electrodes and containing an ionizable gas, said enclosure having baffle means to control material escaping from the discharge region of the spark gaps from collecting on portions of the walls of said baffle means to prevent impairment of the spark gaps.

5. A device for regulating electrical discharge comprising main electrodes axially aligned, said electrodes having their discharge faces arranged in spaced relation to provide a spark gap, a secondary electrode having its discharge face orthogonally disposed with respect to the axis of the main electrodes to the rear of the discharge face of one of the electrodes and spaced to provide an auxiliary gap therewith, a sealed enclosure of dielectric material containing said electrodes and ionizable gas, means on

one of said main electrodes to control material escaping from the discharge region of the spark gaps from collecting on the discharge face of said electrode, and means in said enclosure to control material escaping from the discharge region of the spark gaps from collecting on the walls of the enclosure to thereby insure discontinuity in the formation of conducting paths across the spark gaps.

6. A device for regulating electrical discharge comprising two main electrodes, said electrodes having their discharge faces arranged in spaced relation to provide a main spark gap, a third electrode having its discharge face located to the rear of the discharge face of one of the electrodes and spaced apart to provide an auxiliary spark gap therewith, a sealed enclosure of dielectric material containing the three electrodes and an ionizable gas, and means including a narrow annular chamber within said enclosure to control material escaping from the discharge region of the main spark gap from collecting on the walls of the enclosure to thereby insure discontinuity in the formation of leakage paths across the main spark gap.

7. A device for regulating an electrical discharge comprising in combination two main electrodes having their discharge faces arranged adjacent to each other to provide a spark gap therebetween, a sealed housing of dielectric material containing the electrodes and ionizable gas, slot means formed on the shank of one of said electrodes to control material escaping from the discharge region of the spark gap from collecting on its discharge face, and a narrow annular chamber integrally formed in said housing to control material escaping from the discharge region of the spark gap from collecting on the walls of the housing to thereby prevent the formation of leakage surface paths between the electrodes.

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