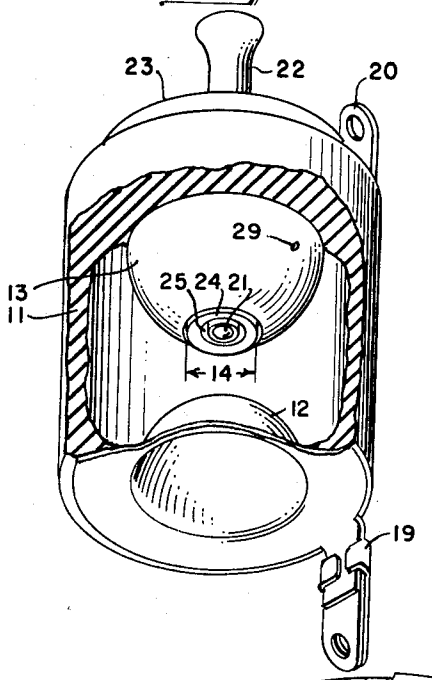
July 17, 1962 J. M. MORGAN ETAL 3,045,093

METHOD FOR CONSTRUCTING ARC DISCHARGE DEVICES

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Fig. 1



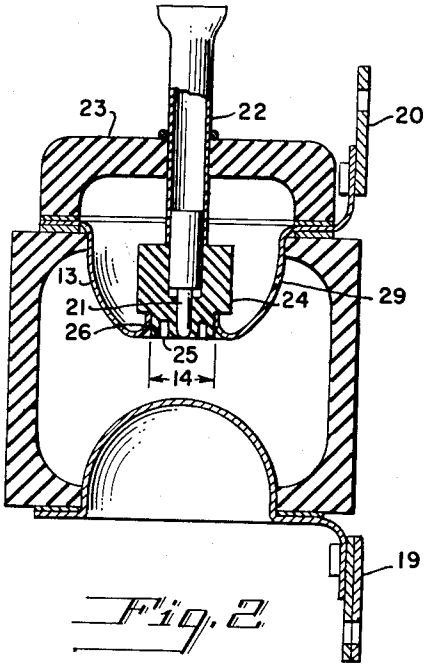
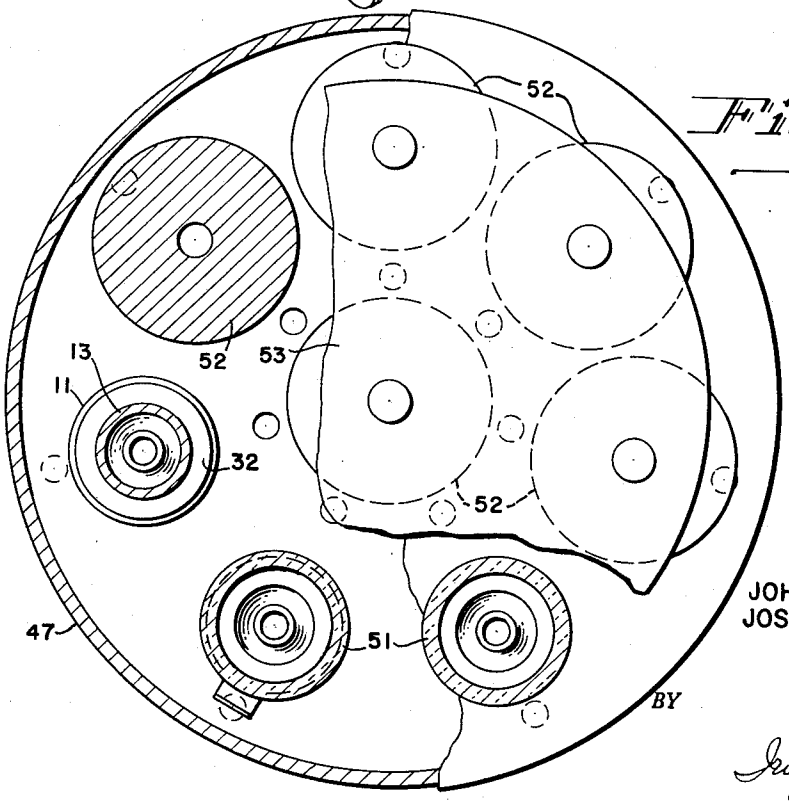


Fig. 2

Fig. 4



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2 Sheets-Sheet 2

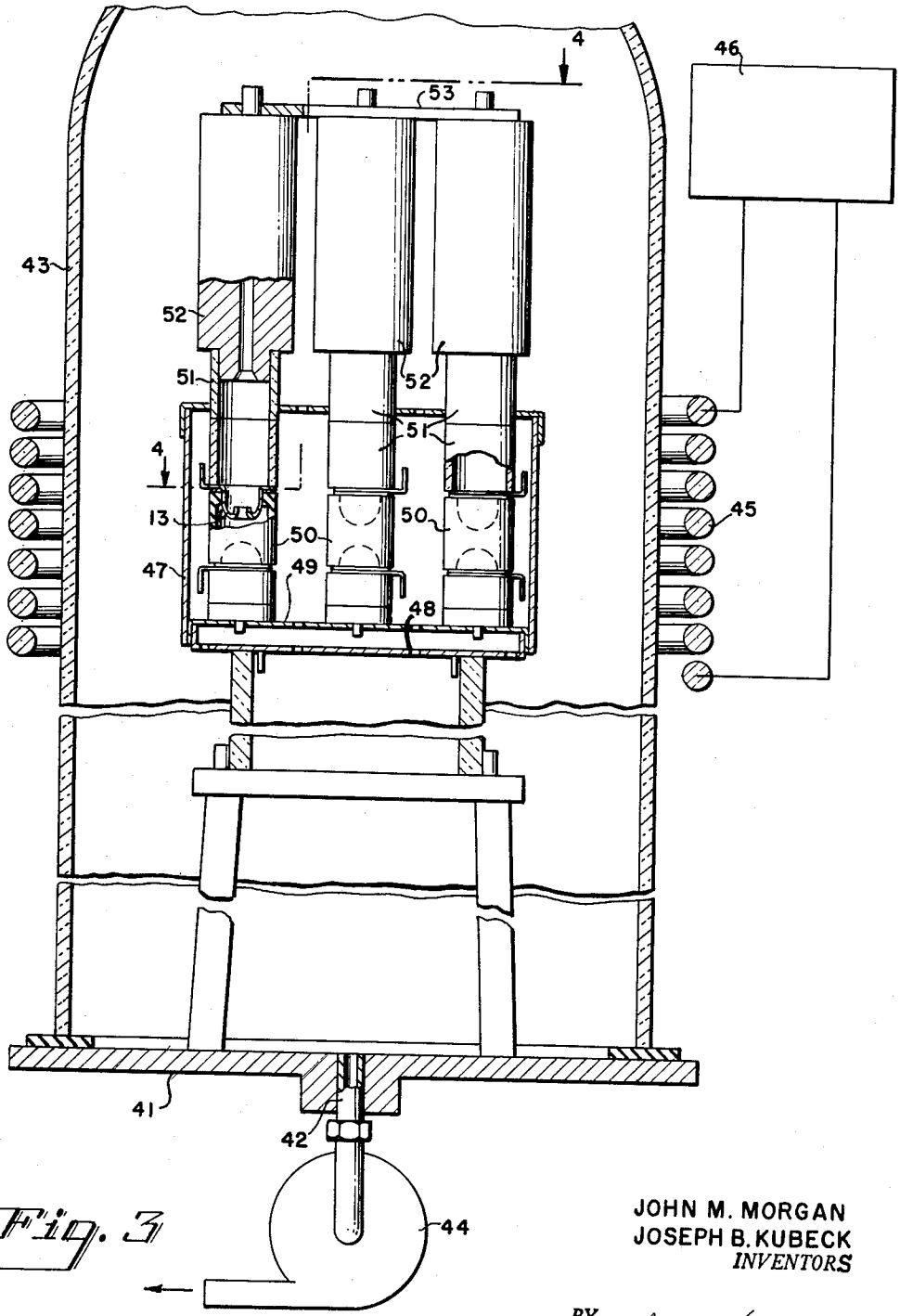


Fig. 3

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3,045,093

METHOD FOR CONSTRUCTING ARC DISCHARGE DEVICES

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Filed Jan. 24, 1961, Ser. No. 84,660
7 Claims. (Cl. 219—9.5)

This invention relates to arc discharge devices and more particularly, to a method for constructing triggered spark gap tubes.

The triggered spark gap is an arc discharge device that functions as a high voltage switch; it employes the electrical breakdown of a gas within the tube in order to provide conduction. Triggered spark gaps have been used for switching up to at least 30,000 volts. They are especially useful in electrical circuits that require extremely fast and very reliable switching functions. Typical applications are those wherein switching times must be less, and often considerably less, than one microsecond. One such application of the triggered spark gap is disclosed in the United States Patent No. 2,867,728 to H. C. Pollock for "Logging Apparatus," which issued on January 6, 1959. Shown therein is a circuit wherein the spark gap is utilized for pulsing a source of neutrons used for litho-logical logging analyses. The specific requirement of the logging apparatus of that patent is for a high voltage pulse which is a small fraction of a microsecond.

In essence, the triggered spark gap is a tube, the interior of which is filled with a gas which is capable of ionization when an appropriate voltage is applied between certain of the electrodes. The triggered spark gap tube comprises three electrodes. Two of them act as the contacts of a switch, and the third acts to close this elemental switch by virtue of breaking down or ionizing, with a preparatory or initiating pulse, the gas disposed between the third electrode and one of the other two electrodes. The two electrodes which act as the contacts of switch are called dome electrodes because they are hollow hemispherical shapes. The dome electrodes are disposed opposite one another, and are spaced apart (and insulated from each other) by a distance which is appropriate for the voltage of interest. The third electrode (which is shaped like a tube or rod and is called the trigger electrode) projects just through, and is insulated from, the surface of one of the two dome electrodes. When the spark gap is to be switched, a short pulse is applied between the trigger and one of the two dome electrodes. This difference of potential is sufficient to break down the gas between these two closely spaced electrodes, whereby ionization takes place therebetween. One of the theories advanced to explain the triggering of the triggered spark gap is that the ultraviolet radiation which is generated by this localized breakdown serves to trigger the ionization of the rest of the gas between the two dome electrodes. This results in an avalanche breakdown or ionization of the gas between the dome electrodes. The ionized gas serves as a conductor thereby to effectively close the switch. The term "breakdown" as applied to spark gaps means electrical conduction of the gas between the electrodes. In this way, the triggered spark gap acts as a high voltage switch.

Three of the most important conditions for successful operation of a spark gap should be understood for this discussion. The first condition is that breakdown (i.e., conduction) must not occur as long as the potential applied between the dome electrodes is below a certain value. This value is frequently called the "hold-off" value. Spark gaps may be constructed having "hold-off" values ranging from 500 to at least 30,000 volts. The

trigger electrode is not energized while the "hold-off" value is being determined or while the spark gap is being subjected to a specified "hold-off" test.

Secondly, breakdown between the dome electrodes must occur when the potential across them is greater than a certain minimum. In other words, if the difference of potential between the two dome electrodes is great enough, the gas therebetween should break down, and conduction between the electrodes should follow. The value at which the breakdown should occur (keeping in mind that the trigger electrode is not energized at this time either) is often termed the minimum static breakdown voltage. The static breakdown voltage of spark gaps is usually not less than 25% greater than the hold-off value.

Thirdly, the breakdown must occur when the potential applied across the two dome electrodes is within a certain specified range between the hold-off and static breakdown values when the trigger electrode is energized. Furthermore, this breakdown must occur within a certain, and very short, period of time after the trigger electrode is energized. This delay period between application of the pulse to the trigger electrode and the breakdown between the two dome electrodes is called the delay time. This is usually a fraction of a microsecond. The average time variation that a spark gap tube may exhibit in its delay time during a series of pulses is called "jitter."

Not only is the triggered spark gap a high voltage switch, but the current that is switched can be considerable. Since it is an arc discharge device, its conduction current is limited only by the constants of the external circuit. Such operation results in very high temperatures at the cathode dome electrode because of the high current density, and also in intense ionic bombardment of the cathode because of the high voltages. These two effects result in an erosion of the cathode dome electrode due to the vaporization of the cathode metal as a result of the high temperatures and also due to the ionic bombardment. There is a subsequent and inevitable deposition of the vaporized electrode metal elsewhere (and undesirably) on the interior surfaces of the spark gap tube. The combined result of high temperature and ionic bombardment on the cathode dome electrode is, for our purposes here, termed "sputtering."

A metallic coating on the insulating materials that separate the three electrodes within the spark gap affects the electrical characteristics of the spark gap in an undesirable way. Typically, a thin conductive coating forms on the insulator that separates the two dome electrodes, and also on the insulator that separates the trigger electrode with its coupled dome electrode. The dome electrode triggered with the trigger electrode acts as the cathode in normal operation and is usually called the cathode electrode or trigger dome electrode. The other of the two dome electrodes is termed the main dome electrode.

Clearly, the more often the tube is fired or pulsed, the more sputtering results, and as time goes on, the greater the erosion of the trigger dome electrode and deposition of the eroded metallic material on the insulation of the spark gap. In this way, sputtering not only causes unacceptable performance of the tube with respect to the hold-off value and the delay time, but the life of the tube is greatly reduced. The inventions described in the copending applications of Edward E. Hafkemeyer and Robert E. Hueschen for "Arc Discharge Device," Serial No. 87,048, filed December 29, 1960, and Robert E. Hueschen for "Triggered Spark Gap," Serial No. 79,445, filed December 29, 1960, have effectively decreased sputtering and its effects to a point where very satisfactory operation is obtained when no problems are encountered in

terms of interelectrode resistance resulting from the process of constructing the tube itself.

Metallic and other conductive contaminants which may be deposited on the inside surfaces during the construction of the tube also contribute to undesirable performance and decreased life of the spark gap. For this reason, each of the metallic and ceramic tube parts is subjected to several rigid cleaning processes before they are brazed together in their final assembly. For example, each part is vacuum fired, with particular attention to the ceramic elements to insure that all of the adsorbed and absorbed gases are driven off. In addition, each of the parts is ultrasonically cleaned with an appropriate detergent. These careful cleaning procedures prior to assembly help to insure cleaning the inner surfaces of the spark gap.

Even with these cleaning techniques in the fabrication of the tubes, and with control of the problem of sputtering during the operation of the tube, more is required. Another problem was discovered. In the construction of the tube the brazing technique was responsible for rendering unsatisfactory many of the tubes produced. Construction of the tube involves brazing four separate and distinct joints. Despite the fact that the brazing is performed in a vacuum oven by radiated heat, it was ascertained that deposits of conductive material had been generated during the brazing process which lined the inner surfaces of the tube. A perplexing aspect is that the deposition of conductive material inside the tube was due to vaporization of the brazing alloy because at least two of the braze joints are heated to the melting point of the brazing metal at slightly different times in the firing process. This occurred despite the fact that the distance between the two most widely separated braze joints is less than three-quarters of an inch. A difference of five seconds between the times at which the two joints melt can result, apparently, in sufficient metallic vaporization of the brazing metal to render the tube useless for practical purposes.

It is not fully understood why this time differential between the melting points at the different brazing joints occurs (especially in view of the fact that the brazing is done inside a vacuum oven, and the entire spark gap tube is so small). It has been ascertained, however, that a temperature gradient exists within the vacuum oven in the region of the spark gap tube. This may explain the time differential between the melting points. In addition it may, itself, independently contribute to the metallic deposition inside the tube as may be seen from the hereinafter to be presented explanations.

It is the primary object of this invention, therefore, to provide an improved method for constructing an arc discharge tube characterized by longer life and better performance than has heretofore been possible, and which for any specified performance characteristic, may be manufactured to satisfy those characteristics with a higher production yield than has been heretofore possible.

It is another object of this invention to provide a method for constructing an arc discharge tube which precludes the deposition of electrically conductive matter on the inside surface of the tube.

It is still another object of this invention to provide a method of brazing together parts of a spark gap tube with a minimum amount of vaporization of the brazing metal.

In accordance with the principles of the invention, a method for brazing spark gap joints is followed such that there is substantially no metallic film deposited on the inside surfaces of the tube during the brazing process. The brazing method in accordance with the invention utilizes a two-step technique. The brazing joints that would ordinarily first be heated to the melting point in the old one-step process, are brazed during the first firing step of the two-step method. Advantage is taken expressly of the temperature gradient that has been found to exist in the oven across the tube. The trigger dome electrode which has an aperture through its surface is located toward the lower end of the temperature gradient. As a consequence, metallic vapor generated within the spark gap tube may pass through the aperture and out of the tube to be deposited elsewhere on a cooler surface. After the first-step joints have been brazed, the partially assembled spark gap tube is cooled in the oven in the vacuum system. Then the remaining component tube parts are added, brazing metal is placed at the other two joints, and the entire spark gap tube placed in the oven for the second firing step. The brazing metal applied at the second-step joints has a lower melting point than the brazing metal applied to the first-step joints. Therefore, the second-step joints are brazed without any danger of the brazing metal of the first-step joints vaporizing during the second-step firing.

The novel method believed to be characteristic of the invention is set forth with particularity in the appended claims. The invention itself, however, as to its organization, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings.

In the drawings:

FIGURE 1 is a perspective view with portions cut away of a triggered spark gap tube constructed in accordance with the invention;

FIGURE 2 is a longitudinal cross section of the triggered spark gap of FIGURE 1 taken through a plane including the longitudinal axis of the tube;

FIGURE 3 is a longitudinal cross sectional view of the structure of the brazing oven used in constructing the triggered spark gap tube in accordance with the invention; and

FIGURE 4 is a plan view taken substantially along the line 4—4 of FIGURE 3.

The Structure of the Spark Gap Tube

Referring to FIGURES 1 and 2, there is shown a triggered spark gap tube constructed in accordance with the principles of the invention. So that a frame of reference may be had, the external diameter of the cylindrical body insulator **11** of the tube of FIGURE 1 would be characteristically approximately .675 of an inch for a typical tube. The cylindrical insulating body of tube **11** is preferably a ceramic material to which the metal electrodes may be brazed. A particularly satisfactory type of ceramic comprises ninety-five percent Al_2O_3, with the remaining five percent compisirng Cr_2O_3, SiO_2, MgO and CaO. A commecially avialable ceramic having this composition goes under the trade name of Diamonite P3142–1, although we are not restricting the ceramic either to this type or to this chemical composition. It need only satisfy the requirement that it be a good insulator, strong, and easily adaptable for brazing to metals such as tantalum, molybdenum or Kovar.

The major functions of the ceramic body insulator **11** are: the formation of the envelope of the tube so that the gas may be contained therein at a desired pressure; and the electrical separation and insulation of the two dome electrodes **12** and **13**. At the lower portion of the ceramic body insulator **11** is a hollow hemispherical metallic electrode **12**. This is the main dome electrode and in its usual operation normally has applied to it a positive potential relative to the dome electrode **13**. Located at the top portion of insulator **11** is the trigger dome electrode **13** which is in many respects similar to main dome electrode **12**, except that in the central portion of the hemisphere, an aperture **14** is defined therein for purposes that will be described below.

Each of dome electrodes **12** and **13** has a collar forming a base to afford means for brazing to the bottom and top edges of the ceramic body insulator **11**. Disposed between the collar of main dome **12** and insulator **11** is a

thin washer **31** of brazing metal (copper) used for brazing the collar of the electrode **12** to the bottom edge of the cylindrical body insulator **11**. In similar fashion, the collar of the trigger dome is brazed to the top edge of the cylindrical insulator **11** through the medium of a thin metallic washer **32** of the same metal (copper) as that used for securing electrode **12** to the ceramic body insulator **11**.

Except for the aperture **14** located in the center of trigger dome **13**, and a small hole **29** to permit easy loading of gas during the gas filling process, the unitary structure formed by the body insulator **11** and the electrodes **12** and **13** would be air tight. The general configuration resulting is that the two hollow hemispheres **12** and **13** are disposed inside the hollow insulator **11**, with the hollow hemispherical main dome **12** being disposed concave downward and trigger dome **13** concave upward. The distance in the tube between the closest points or the surfaces of domes **12** and **13** determines the breakdown voltage of the tube (in conjunction with the type of gas filling the tube and its pressure).

Attached to the brazed collars of dome electrodes **12** and **13** respectively are electrical terminals **19** and **20** respecively, to which may be applied the potential which is to be switched by the spark gap.

Trigger dome electrode **13** and main dome electrode **12** are made of a material characterized by a high melting point and low vapor pressure. This is necessary, because when the spark gap is activated, its internal temperature may reach to approximately 6,000° C. Tantalum is a metal which well satisfies these requirements and the additional requirement that it be easily brazed to the ceramic insulator **11**. Molybdenum, tungsten and columbium are examples of other metals which may be used because they have similar properties.

The third electrode of the spark gap is the trigger electrode **21** (as distinguished from the trigger dome electrode **13**). It is disposed in the aperture **14** formed in trigger dome electrode **13**. The trigger electrode **21** is disposed coaxially with the cylindrical portion of insulator **11**. Extending upwardly from the trigger electrode **21** is a trigger tube **22** within which the trigger electrode **21** fits. A ceramic cap insulator **23**, with a hole through its center for receiving the trigger tube **22**, is mounted on top of the spark gap, so that the rim portion of cap insulator **23** may be brazed to the top surface of the collar of trigger dome electrode **13**. A thin washer-like element **33** of silver-copper is disposed between the rim of cap **23** and the collar of dome **13** to provide the material necessary for brazing the two together. The hole through the center of ceramic cap insulator **23** is closed by brazing its boundary to the outer periphery of trigger tube **22** with a thin wire **34** of the same silver-copper brazing material. The brazing elements **33** and **34** of the silver-copper depressed solid solution has a melting point which is lower than that of either silver or copper and therefore lower than that of copper brazing elements **31** and **32**. By virtue of the ceramic cap **23** being brazed at these areas, the entire volume within the spark gap body itself is air tight. This volume is filled with nitrogen at a pressure of from approximately one-half of an atmosphere to one atmopshere. The precise pressure of the nitgrogen (in conjunction with the spacing between the trigger dome **13** and the main dome electrode **12**) determines the breakdown potential of the spark gap. Other gases and combinations of gases, such as helium/nitrogen and krypton 85/nitrogen may be used.

Trigger electrode **21** is preferably of tungsten, which also has a low vapor pressure and high melting point. Ceramic cap insulator **23** may be of the same material as the body insulator **11**. The trigger tube **22** is preferably of Kovar or nickel, although materials such as copper or combinations such as copper/Kovar may be used.

Although trigger electrode **21** is disposed in the aperture **14** of trigger dome electrode **13**, it does not fill the aperture. Surrounding trigger electrode **21** and contiguous thereto, and otherwise filling the aperture **14**, is an insulator **24**. Trigger insulator **24** is a ceramic material which may be of the same type as the body insulator **11** and/or ceramic cap insulator **23**.

The Structure of the Brazing Oven

With the presentation of the structure of the spark gap completed, a description of the apparatus used for brazing the component parts of the spark gap tube together is appropriate. In FIGURE 3, there is disclosed a vacuum oven used for the brazing process. Mounted upon a platform **41** which has an exhaust aperture **42** therethrough, is a large bell jar **43** with the bottom rim of the bell jar resting on the platform such that exhaust aperture **42** is enclosed. The rim of bell jar **44** and platform **41** constitute an airtight joint by virtue of appropriate vacuum gasket material disposed therebetween. Underneath platform **41**, and in communication with exhaust aperture **42**, is a vacuum system comprising a standard vacuum pump with appropriate connections to exhaust aperture **42**. The standard vacuum system is represented generically by the block **44**. It should be of appropriate size and capacity for maintaining the inside volume of the bell jar under a vacuum of approximately 5×10^{-5} millimeters of mercury.

Coaxial with and surrounding bell jar **43**, is a radio-frequency coil **45** whose function is to provide inductive heating for the oven. Coil **45** is connected to a source of radio-frequency energy **46**. Typically for an operation of this type, the frequency may be 480 kilocycles per second from a source capable of producing 15 kilowatts of power. A thin walled, hollow cylindrical molybdenum or tantalum susceptor **47** mounted within jar **43** operates to radiate heat within the vacuum of the bell jar. Susceptor **47** is in turn thermally excited by energy induced therein from the RF coil **45**. The combination of tantalum susceptor **47** with its external RF energizing coil **45** is capable of producing temperatures of at least 1100° C. within the bell jar within a relatively short period of time. Susceptor **47** is supported within jar **43** upon ceramic fixturing material. Thus, susceptor **47** is mounted upon a ceramic block **48**, preferably of a porous alumina, and which in turn is supported by a column of the same material resting upon the platform **41**.

Disposed within the hollow defined by cylindrical susceptor **47** and resting upon a small fixture **49** (also of alumina) are eight spark gap tubes **50**, which are to be brazed in the oven. Spark gap tubes **50** are each identically the same as the tube of FIGURES 1 and 2 described above, although during the first firing step in the oven none of the spark gap tubes is completely assembled. The apparatus for holding each of the spark gap tubes in place in the oven will be described at appropriate points below in the explanation of the brazing method.

The Brazing Method

Having described the spark gap tube and the oven for brazing the component parts of the tube, we proceed to a description of the brazing method in accordance with the principles of the invention. Reference will often be made in the following description to the component parts of the spark gap tubes **50**, which are depicted in cross-section in FIGURE 2.

The brazing process is performed in two separate parts. The first part involves a first heating or firing step of certain component elements of the tube so as to make two brazed joints. After this first firing step, the tube is cooled in an argon atmosphere, which is added to the oven, to hasten cooling. Then, as the second part of the process, certain other components of the tube in combination with a different brazing material are added on to the previously brazed structure and the entire structure is reinserted into the oven. The heating process is repeated to complete the last two joints.

The first firing step will now be described. The ceramic cylindrical insulator body **11** of the spark gap tube, in conjunction with the dome electrodes **12** and **13**, are to be brazed together through the medium of the copper brazing metal washers **31** and **32**. Thus, these components are mounted in the same relationship to each other as shown in FIGURE 2, with a titanium hydride slurry applied to the joints wherein copper washers **31** and **32** are disposed. In this first firing step trigger electrode **21**, trigger tube **22**, trigger insulator **24**, and ceramic cap **23** take no part and are in no way involved. However, a hollow ceramic cylinder **51** much like, but longer than, ceramic insulator body **11** is placed over the collar of the trigger dome **13**. A metal, solid cylindrical weight **52** (which may be of stainless steel or copper) is mounted on top of cylinder **51**. Weight **52** has a shoulder cut around the edge of its bottom face so that it is seated securely in the top opening of cylinder **51**. A flat metal disc **53** (also stainless steel or copper) is then placed over the top surfaces of weights **52** so as to align all eight spark gaps. The weights **52** serve to press the components of each spark gap together for the brazing process. The disc **53** further assures that the spark gap tube will be maintained in position during the process. It is desirable in this connection to place a small bore into the top of each of weights **52** and to add eight mating protruding pins from the bottom of disc **53**.

The top portion of cylinder **51**, the weights **52**, and disc **53**, as they are mounted, extend vertically higher than the top layer of RF coil **45**.

The tube structures described for the first step are then mounted in bell jar **43** on the alumina disc **49** within the hollow of susceptor **47**. Coil **45** is then energized such that the inside of bell jar **43**, i.e., the susceptor, is heated gradually to a temperature of approximately 1100° C. and maintained at that temperature for a brief period (approximately fifteen seconds).

After the susceptor has reached its appropriate first-step temperature of approximately 1100° C., brazing occurs. With the spark gap tube parts so heated, the collars of the tantalum domes **12** and **13**, as well as the edges of the ceramic cylindrical insulator **11** are at a high enough temperature such that they are wetted by the melted brazing alloy formed by the copper and the titanium from the titanium hydride. The total heating period is twenty-five minutes. RF power is then turned off and cooling occurs for ten minutes, under vacuum. Then argon is added to the system to hasten cooling. After one hour, the parts are removed.

The weighting and mounting elements **51**—**53** are then removed and the remaining components of the triggered spark gap tube are placed in position for the second firing step. Thus, trigger electrode **21** and trigger insulator **24** are inserted into their appropriate aperture **14** in the trigger dome electrode **13**. Trigger cap **23** is also placed in position with trigger tube **22** appropriately located within its central aperture.

At the edges of the cap **23**, and contiguous thereto as well as to the top surface of the collar of trigger dome electrode **13**, is placed a silver-copper braze washer **33**. This region constitutes the third of the four joints that require brazing. The fourth joint is the region wherein the periphery of the trigger tube **22** meets the boundary of the aperture of ceramic cap **23**. At that region near the top surface of cap **23** is disposed a silver-copper braze wire **34**. Titanium hydride slurry is applied to the third and fourth joints.

The completely assembled spark gap tubes are then placed in the oven and mounted as previously. The susceptor is heated during the second firing step to a temperature of approximately 975° C., which is about 125° C. less than its temperature during the first firing step. The silver-copper eutectic alloy which is used, has a melting point below that of either silver or copper. With the susceptor at this temperature, the spark gap tubes within are subjected to a lower temperature, and in particular lower than that at which copper washers **31**—**32** (now alloyed with titanium) of the first joint can melt; there can be no melting of or vaporization from the first two brazed joints (with the pressure within the oven the same as it was during the first firing step). This temperature, however, is sufficient to melt the silver-copper alloy. After the third and fourth joints are brazed in this manner with the silver-copper brazing material (the 975° C. temperature of the susceptor is also held for a short time, e.g., fifteen seconds, with the total heating time being twenty-five minutes as before), the RF power is removed and the spark gap tubes permitted to cool. They are then removed and are ready to be exhausted and filled with nitrogen at the appropriate pressure.

An important feature of this two-step process may now be comprehended, and its considerable advantages over a one-step process more fully appreciated. It may be recalled that during the first firing step, a ceramic cylinder **51** and metal weight **52** were placed over the partial spark gap structure during mounting to apply pressure during the brazing process. It has been found that the inner surface of cylinder **51** and the bottom face of weight **52** become coated with deposits of copper as a result of the first firing step. These deposits of copper come from copper vapor generated within the volume of the spark gap tube. The copper vapor which is generated rises through aperture **14** of trigger dome electrode **13**. Now, it may be understood, that if prior art one-step rather than two-step firing is utilized, the trigger dome electrode aperture would be filled with trigger electrode **14** and trigger insulator **24**, with the result that the trigger electrode and its insulator would be coated with the copper deposit. When using the two-step method, therefore, it may be seen to be desirable to mount the spark gap tube in the oven (at least during the first firing step), such that trigger dome electrode **13** with its aperture **14** therein is at the top. In this way, the aperture **14** may act as a type of chimney permitting vaporized copper to pass therethrough with relatively little deposition on any of the other surfaces.

The question may well be asked as to why the vaporized copper does in fact rise in the spark gap tube in this manner. It is believed that a temperature differential exists between the bottom of the spark gap tube and the elements **51**—**53** which may account for the fact that the copper vapor rises through aperture **14** of dome electrode **13**. Since the weighting and mounting elements **51**—**53** extend verticaly higher than susceptor **47**, they are in a cooler region of the oven than the spark gaps within the internal volume of the susceptor. As a consequence, any copper vapor that may be generated within the spark gap during the first firing step tends to pass along a straight line up through aperture **14** toward elements **51**—**53**. These latter elements being cooler than those within the hotter region below provide a surface upon which the hot copper vapor can condense.

A possible reason for excessive vaporization during the prior art one-step firing process is related to the geometries of the brazing joints and metal elements. Thus, if solely one type of metal is applied at all of the joints in a one-step brazing process, the different geometries (i.e., washer **31** and wire ring **34** of the brazing elements) may possibly be responsible for a time differential in melting points.

An additional possible explanation for the melting point time differential in the prior art, one-step brazing operation has to do with a possible horizontal temperature gradient between the region of the spark gap tube nearest to susceptor **47** and those regions of the spark gap tube more remote therefrom. Thus, for example, for a spark gap tube mounted in the oven on the right-hand side thereof, the right-hand edges of the brazing washers **31**—**33** (in a one-step operation) would be heated more rapidly than the left-hand side of those

washers. In addition, the right-hand edges of those three washers are closer to the susceptor and tend to be heated more rapidly to higher temperatures than the brazing wire or ring 34 disposed around trigger tube 22 and centrally located on the spark gap tube. The brazing metal 34, therefore, is more remote from the tantalum susceptor than the edges of the brazing washers 31—33, irrespective of whether the tube is mounted on the right-hand or the left-hand side of the oven, or in the center thereof. Presumably, therefore, the washers 31—33 commence melting, at least at some edges, in advance of any portion of the wire 34.

All of the above factors may contribute individually or in combination to account for the excessive metallic deposits within the spark gap characteristic of a one-step brazing operation.

Although the brazing elements 31 and 32 were described as being copper, other brazing metals have also been found to provide excellent results. The main requirement for the metal of washers 31 and 32 is that it melt at a higher temperature than that of the brazing elements 33 and 34. It has been found that a gold-copper eutectic in the ratio of fifty percent gold to fifty percent copper provides an excellent brazing metal which will melt at a temperature higher than that of the silver-copper used for elements 33—34. The silver-copper is preferably in proportions of seventy-two percent silver to twenty-eight percent copper. This eutectic has a melting point of 779° C. at 5×10^{-5} millimeters of mercury.

While we have shown particular embodiments of our invention, it will be understood that many modifications may be made without departing from the spirit thereof, and we contemplate by the appended claims to cover any such modifications as fall within the true spirit and scope of our invention.

What we claim is:

1. The method of constructing a spark gap tube having a given number of metallic and ceramic parts forming a plurality of joints to be brazed comprising the steps of: assembling a plurality, but less then all, of said given number of parts to form at least one of said joints; placing said given number of parts in an induction heating oven and forming a vacuum in said oven; brazing said one joint with a first brazing metal having a given melting point; assembling the remainder of said given number of parts upon the previously brazed parts to form at least a second joint spaced from said first joint by a distance of approximately an inch or less; and brazing said second joint with a second brazing metal having a lower melting point than that of said first brazing metal.

2. The method of constructing a spark gap tube having a given number of metallic and ceramic parts forming a plurality of joints to be brazed comprising the steps of: assembling a plurality, but less than all, of said given number of parts to form at least one of said joints; placing said given number of parts in an induction heating oven and forming a vacuum in said oven; brazing said one joint with a first brazing metal of copper; assembling the remainder of said given number of parts upon the previously brazed parts to form at least a second joint spaced from said first joint by a distance of approximately an inch or less; and brazing said second joint with a second brazing metal of silver and copper in solid solution.

3. The method of constructing a spark gap tube having two metallic dome electrodes and a ceramic body insulator for spatially and electrically isolating said dome electrodes from each other comprising the steps of: forming an aperture through one of said electrodes; assembling

said dome electrodes and said body insulator together to form a volume that would be closed except for said aperture; placing brazing metal between said electrodes and said ceramic insulator so that each of said electrodes can be brazed to said insulator; placing the assembly of said electrodes, insulator and brazing metal within a brazing oven within which a temperature gradient exists when the temperature of said oven is raised; disposing said assembly within said oven with said apertured electrode closer to the lower temperature end of said gradient than the other of said electrodes; forming a vacuum within said oven and brazing said electrodes and said insulator by raising the temperature within said oven to the melting point of said brazing metal at said vacuum.

4. The method of constructing a spark gap tube having two metallic dome electrodes and a ceramic body insulator for spatially and electrically isolating said dome electrodes from each other comprising the steps of: forming an aperture through one of said electrodes; assembling said dome electrodes and said body insulator together to form a volume that would be completely closed except for said aperture; placing brazing metal between said electrodes and said ceramic insulator so that each of said electrodes can be brazed to said insulator; placing the assembly of said electrodes, insulator and brazing metal within a brazing oven within which a temperature gradient exists when the temperature of said oven is raised; disposing said assembly within said oven with the axis of said aperture through said electrode parallel to the direction of said temperature gradient; forming a vacuum within said oven and brazing said electrodes to said insulator by raising the temperature within said oven to the melting point of said brazing metal at said vacuum.

5. The method recited in claim 4 including the steps of brazing an additional element to said brazed assembly with another brazing metal different from said brazing metal.

6. The method as recited in claim 5 wherein said other brazing metal has a melting point lower than that of said brazing metal at the same pressure.

7. The method of constructing a spark gap tube having two metallic dome electrodes and a ceramic body insulator for spatially and electrically isolating said dome electrodes from each other comprising the steps of: forming an aperture through one of said electrodes; assembling said dome electrodes and said body insulator together to form a volume that would be completely closed except for said aperture; placing brazing metal between said electrodes and said ceramic insulator so that each of said electrodes can be brazed to said insulator; placing the assembly of said electrodes, insulator and brazing metal within a brazing oven within which a temperature gradient exists when the temperature of said oven is raised; disposing said assembly within said oven with the axis of said aperture through said electrode vertically oriented and with said apertured electrode above said other dome electrode; forming a vacuum within said oven and brazing said electrodes to said insulator by raising the temperature within said oven to the melting point of said brazing metal at said vacuum.

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