

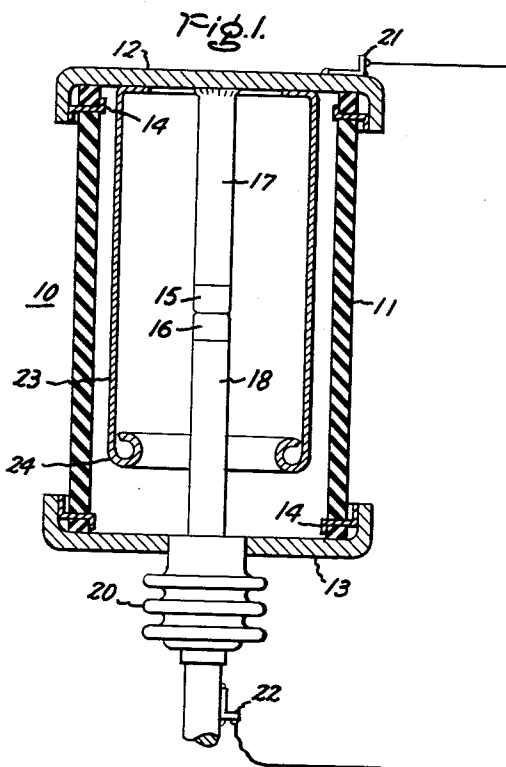
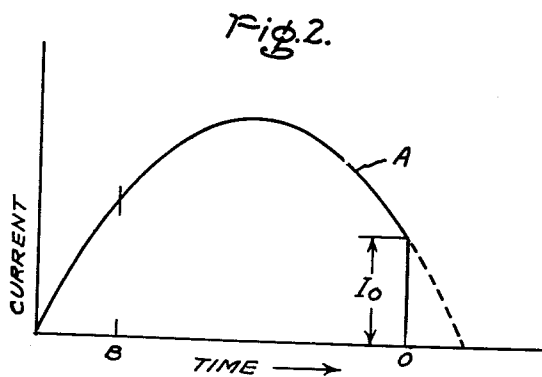
Dec. 19, 1961

J. D. COBINE

3,014,110

ALTERNATING CURRENT VACUUM CIRCUIT INTERRUPTER

Filed Oct. 29, 1959



Inventor:
James D. Cobine,
by John F. Ahern
His Attorney.

1

3,014,110

ALTERNATING CURRENT VACUUM CIRCUIT INTERRUPTER

James D. Cobine, Rexford, N.Y., assignor to General Electric Company, a corporation of New York
Filed Oct. 29, 1959, Ser. No. 849,509
7 Claims. (Cl. 200-144)

The present invention relates generally to vacuum-type electric circuit interrupters uniquely adapted for use in inductive circuits wherein the current interrupted is of low magnitude.

The phenomena of electric current interruption in atmospheric or higher pressures, on one hand, and in high vacuum, on the other hand, are extremely complex and basically different in nature. So also, are the problems which must be overcome in producing operative devices to perform either function. Thus, for example, one great problem in non-vacuum circuit interrupters is the deterioration of the contacts thereof due to the formation of oxides of the contact metal and other chemical compounds due to the presence of atmospheric air, a protective gaseous atmosphere, or an oil bath. Any compound so formed is readily separated from the interrupter contacts. Such a continuous formation and removal of non-metallic compounds rapidly causes the interrupter contacts to erode and deteriorate.

In the vacuum interrupter, on the other hand, the complete absence of gases or liquids in contact with the interrupter contacts virtually precludes the formation of contact-eroding oxides and compounds.

Other problems, however, not generally considered as significant in the non-vacuum circuit interrupter, are of prime importance in the construction of vacuum circuit interrupters. Vacuum interrupters designed to interrupt alternating currents operate substantially as follows:

When an arc is struck between the electrodes of a vacuum interrupter, as for example, by the opening of a pair of switch contacts maintained in a vacuum of 10^{-5} mm. of mercury pressure or less, the arc vaporizes some of the electrode material. If the contacts have been properly processed to remove therefrom all occluded and sorbed gases, only ionized metallic vapor is present in the arc. The arc continues until the alternating current sought to be interrupted falls to a natural zero value, as normally occurs once each alternation. When this occurs, the arc is extinguished, and the ionized metallic particles rapidly diffuse to the cold vacuum chamber walls where they are cooled, de-ionized, and condensed. When the interrupted current seeks to rise again, the arc cannot be reestablished because of the high dielectric strength of the vacuum separating the interrupter contacts. Thus, in a vacuum circuit interrupter, the current is usually completely extinguished at the first naturally occurring instantaneous zero value of current.

The foregoing occurs satisfactorily in vacuum circuit interrupters operating to interrupt alternating currents of high current ratings, namely of 500 amperes or greater. For lower values of alternating current, the phenomenon generally denominated as "chopping" occurs. At these low alternating current values, the arc, rather than persisting until the first natural current zero, is abruptly extinguished at some low current value and falls instantaneously from that value to zero. The value of current at which instantaneous arc extinction occurs is denominated the "chopping current" of the device. Typical chopping currents in prior art vacuum interrupters may be from 10 to 40 amperes. While chopping in vacuum interrupters associated with capacitive circuits may be tolerated, it is unacceptable with inductive loads because of voltage surges induced therein by the high rate of

2

change of current with time (di/dt) when an interrupter "chops." This may be seen from the relationship:

$$V = I_0 \sqrt{\frac{L}{C}}$$

V = the surge voltage induced by chopping

I_0 = the chopping current

L = the equivalent inductance of the circuit

C = the equivalent capacitance of the circuit,

and the fact that the

$$\frac{L}{C}$$

value for many inductive devices may be as high as many tens of thousands ohms.

For most industrial inductive circuit loads, it is necessary to reduce the chopping current level of a vacuum circuit interrupter to a value of below 4 amperes and, in most instances to a value of about 2 amperes.

A second important electrical characteristic of a vacuum circuit interrupter is the voltage recovery characteristic. This characteristic reflects the ability of the interrupter to withstand the rapidly increasing instantaneous electrode-to-electrode voltage following arc interruption. This instantaneous electrode-to-electrode voltage results from the combined effects of the applied system alternating current voltage, and any transient voltages associated with arc interruption, lightning, etc. In any given circuit interrupter application it is essential that the dielectric strength of the electrode-to-electrode space shall at all times exceed the actual voltage appearing across the electrodes. Otherwise the arc may restrike and the basic purpose of the circuit interrupter is defeated.

In accordance with the present invention, the properties of low work function materials are advantageously utilized to minimize the chopping current value of a vacuum switch. Materials of this class include, among others, thorium, caesium, lanthanum, rubidium, barium, and especially thoriated tungsten. All are characterized by the ability to produce electrons in the presence of an electric field, and particularly under the influence of the strong fields and high temperatures at the points of arc contact in a vacuum switch. The low work function material serves this purpose even though the quantity of metallic vapor in the arcing region is otherwise incapable of maintaining the arc. The low work function material is homogeneously distributed throughout the material of at least one of the electrodes, and preferably in both. When the arc is drawn, the low work function material provides a copious supply of electrons at the time chopping would otherwise take place, thereby providing a continued current-conducting path and prolonging the period during which the arc is maintained and thus providing a lower current level at interruption. Insofar as an interruption, or a series of interruptions, may otherwise tend to exhaust the availability of the low work function material at the arcing face of the electrode, diffusion of such material from the more interior portions of the electrode serves to replenish the material available at the point of arcing and thereby provide a long effective electrode life.

An important aspect of the vacuum circuit interrupter of the present invention lies in the fact that the electrode is not, in the absence of the low work function material, capable of providing a low chopping current. Preferably the electrode is formed of a refractory matrix impregnated with a low resistance material such as copper. An electrode so formed is characterized by a high degree of resistance to the corroding effects of the arc, by low electrical resistance, and by other desirable charac-

teristics. It is, however, relatively unsatisfactory in terms of chopping current, giving a value of perhaps 6 amperes (which cannot be tolerated in some circuits). This chopping current is due to the inadequate quantity of ionized electrode material available in the arc path when the current falls to about 6 amperes. This same arc starvation in terms of ionized electrode material, however, is desirable in providing a favorable voltage recovery characteristic following interruption. While the low work function material provided in accordance with the present invention serves to maintain the arc to a more satisfactory chopping current value, it does not unduly increase the quantity of vaporized electrode material at the time of interruption. Since the available electrons quickly disperse and disappear upon interruption of the arc, the recovery voltage of the vacuum circuit interrupter of the present invention is of the same order as the same circuit interrupter in the absence of the low work function material.

In accordance with the preferred embodiment of the present invention, at least one electrode of the interrupter is formed from a body of tungsten, serving both as refractory material and as an activating agent for the low work function material. The low work function material in this preferred embodiment is thorium, which has the unusual characteristic of coating with tungsten to provide an even lower work function than that of elemental thorium.

It is therefore a general object of the present invention to provide an improved vacuum circuit interrupter in which chopping current is minimized by the action of a low work function material.

An additional object of the present invention is to provide an improved vacuum circuit interrupter utilizing a low work function material in conjunction with electrode materials that otherwise produce substantial chopping current, to provide both small chopping current and a rapid voltage recovery.

Still another and more specific object of the present invention is to provide an improved vacuum circuit interrupter in which at least one electrode is composed of a refractory material having a high degree of resistance to the eroding action of the arc and coating with a low work function material to activate the same in a manner providing an especially favorable work function value and correspondingly low chopping current.

It is still another object of the present invention to provide an improved alternating current vacuum circuit interrupter characterized by low chopping current, a high recovery voltage rate, ease of manufacture, long life, and is otherwise constructed and arranged to provide a unit having a maximum degree of commercial utility.

The novel features believed characteristic of the present invention are set forth with particularity in the appended claims. The invention itself, however, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the attached drawing in which:

FIG. 1 is a representative view of a vacuum-type circuit interrupter constructed in accord with the present invention and,

FIG. 2 is a graphical representation of a sinusoidal alternating current illustrating the effect of the chopping phenomenon.

In FIG. 1 an interrupter chamber 10 comprises a wall member 11 which may be cylindrical in shape and is constructed of a suitable insulating material, having at the ends thereof a pair of metallic end members 12 and 13 closing the volume therein to form an interrupter chamber. Suitable seals 14 are provided between casing 11 and end members 12 and 13 to render the interrupter chamber vacuum-tight.

Located within chamber 10 are a pair of separable contacts or arc-electrodes 15 and 16 which are shown in their closed circuit or engaged position. Upper contact 15 is

a stationary contact suitably attached electrically and mechanically to a conducting rod 17 which, at its upper end, is united electrically and mechanically with end member 12. Lower contact 16, mounted upon and electrically united with a suitable conducting rod 18, is movable and is connected through bellows 20 or an equivalent vacuum tight member permitting reciprocating motion. Terminal mount 13 projects through a suitable orifice in end member 13, and suitable actuating means may be connected thereto to impart reciprocating motion to rod 18 to cause contact 16 to enter into engagement with, and be removed out of engagement with contact 15. For certain types of interrupters as for example, vacuum fuses and lightning arresters, electrode 16 need not be movable but may be spaced apart from electrode 15 a suitable distance. The electrical circuit which is sought to be interrupted by the interrupter device may be completed by making suitable connections to contact 21, electrically and mechanically mounted upon end member 12 and terminal 22, electrically and mechanically mounted upon rod 18. A suitable insulator shield, such as metallic cylindrical member 23, capped with an arc-preventing ferrule 24 is interposed between electrodes 15-16 and insulator 11 to prevent the latter from becoming coated with metal.

The volume within interrupter chamber 10 is suitably evacuated through an exhaust tubulation (not shown) during the final assembly thereof. For proper operation of the interrupter as a vacuum-type interrupter of alternating currents, the pressure within chamber 10 must be maintained at a pressure at least as low as 10^{-5} mm. of mercury, but is preferably maintained within the range of 10^{-6} to 10^{-8} mm. of mercury. The foregoing requirement is essential for the operation of the devices as vacuum interrupters of alternating currents. This requirement is necessary because, in order that the current-carrying arc struck between electrodes 15 and 16 be extinguished at the first occurring current zero value, there must be substantially no ionizable gas present within chamber 10. The occurrence of ionization may be substantially prevented if the possible breakdown paths between electrodes 15 and 16, or their respective supports, are small with respect to the mean free path of an electron within the atmosphere obtained with the device. This mean free path is designated as the statistical distance which an electron may travel without colliding with a gas molecule at a given pressure. These conditions may be established in operative circuit interrupters only when the pressure within interrupter chamber is below 10^{-4} mm. of mercury and preferably below 10^{-5} mm. of mercury.

In FIG. 2 of the drawing there is shown, in graphical form, an illustration of the chopping phenomenon. In FIG. 2, the instantaneous value of a sinusoidal alternating current which is sought to be interrupted by a vacuum circuit interrupter is plotted for one-half cycle. As the current depicted by curve A rises from instantaneous value of zero, the contacts, as for example, contacts 15 and 16 in FIG. 1, are separated at point B causing an arc discharge to be established therebetween. Initially, this arc discharge is largely sustained by the metal evaporated from contacts 15 and 16 by the heat generated at the contact surfaces by the arc. The terminal points of the arc are known respectively as cathode and anode spots. As a matter of practice, most of this evaporation occurs at the cathode, or negatively maintained electrode. It is, however, difficult to predetermine which electrode is negative at a particular instance when an alternating current circuit is interrupted. In FIG. 2 the value of current in the arc follows its natural course along the sinusoid of curve A and, for high current arcs (those above 500 amperes) follows the dotted line until a zero value is reached. At this instant the arc is extinguished and the energized metallic ions between the electrodes rapidly diffuse to the cold walls of members 12, 13 and

23 where they are cooled and deionized. The arc remains extinguished because, when a high voltage builds up between contacts 15 and 16, the arc is not reestablished, due to the high dielectric strength of the vacuum separating the contacts.

In the operation of vacuum circuit interrupters wherein the current sought to be interrupted is of a relatively low value, (below 500 amperes) the instantaneous current value does not follow the dotted line continuously to a zero value but, rather, at some low current value, denominated by I_0 and occurring at a time 0, the arc is abruptly and prematurely extinguished. This results in an instantaneous change of current from a value of I_0 to zero. The value I_0 is referred to herein as the "chopping current" value for a particular device. As will be readily appreciated, this almost instantaneous change of current from I_0 to zero results in a high rate of change of current with time (di/dt) and results in the production of extremely high surge voltages and inductive loads which may be connected thereto. These surges may cause the breakdown of insulation and are generally highly injurious to electrical equipment.

In accordance with the copending application of T. H. Lee and J. D. Cobine, Serial Number 750,784, filed June 24, 1958, and assigned to the same assignee as the present invention, the disclosure of which is incorporated herein by reference, the chopping current problem is overcome by an appropriate selection of electrode materials to provide vapor pressure sufficient to counterbalance vapor starvation responsible for such large chopping current values. This general technique can satisfactorily overcome the chopping current problem in many vacuum switch applications. However, in those instances where the chopping current must be reduced to a rather small value this technique also may give rise to a somewhat prolonged availability of vaporized electrode material, and hence a somewhat unfavorable recovery voltage characteristic.

In accordance with the present invention at least one, and preferably both, of the electrode contacts 15 and 16 includes a material having a low work function in conjunction with a major proportion of material otherwise having a relatively unfavorable chopping current. Such materials include thorium, caesium, lanthanum, rubidium, and barium. Thoriated tungsten is an especially preferred material for the reasons described hereafter. These and other materials with work functions less than 3.5 electron volts or below may be used. In the presence of the electric field and temperature conditions existing at the point of arc contact—even at a low arc current—the low work function materials supply electrons in copious quantities. Their action is quite unlike the current conduction resulting from vaporization of the contacts 15 and 16 such as when large arc currents are being carried. In such vaporization the contact materials assume gaseous form and then disassociate into conducting ions and other conduction carriers. In contrast, the low work function material does not necessarily vaporize to provide conduction carriers but instead emits electrons that pass into the vacuum space to conduct the current.

In accord with my invention I find that a range of from 2 to 15% by weight of low work junction material is sufficient to achieve the desired results. If less than 2% is used, there is insufficient thermionic emission to sustain the arc. If greater than 15% is used the mechanical strength of the arc-electrodes is adversely affected and excessive eroding results.

By way of a specific and preferred example of the construction of the contacts 15 and 16 the contacts may be composed of a refractory matrix of about 7% thorium, 25% tantalum hydride binder, and the balance tungsten. The matrix may be made by homogeneously mixing these materials, pressing the same to the desired contact shape, and then heating to about 1900° C. in hydrogen for one

hour. The contact matrix thus formed is then impregnated with metallic copper, preferably by heating the same in a vacuum to temperature sufficient to melt copper and permit the same to impregnate itself into the pores of the matrix. Tests have demonstrated that the chopping current of a vacuum switch utilizing a pair of contacts formed in this fashion is of the order of 2.5 amperes. This value should be compared with the value of about 6 amperes for the copper substituent of the electrodes and the very much greater value for the tungsten substituent.

In the above embodiment of the present invention the tungsten serves as a refractory material. That is, it withstands a high temperature before disintegrating and hence resists the eroding action of the arc. It also serves a quite different function in that it coats with the thorium to provide an even lower work function than the low work function of elemental thorium. This action is thought to arise from a very thin surface layer of thorium that is positive in relation to the tungsten body of the electrode. Whatever the reason for this action, the thorium-tungsten electrode is characterized by a more favorable work function than elemental thorium and by the refractory characteristics of the tungsten.

A highly desirable feature of the present invention is that it enables the electrodes to be designed upon the basis of characteristics other than chopping current value. Thus, refractory materials such as tungsten, molybdenum, tantalum, and the like may be utilized for their resistance to the eroding action of the arc, and low resistance low melting point impregnating materials such as silver, copper, etc., may be employed to provide a low electrical resistance. And, since these materials are not relied upon primarily to provide conduction carriers at the moment of arc interruption, it is unnecessary to utilize the very high vapor pressure materials that might otherwise be necessary to reduce the chopping current. Since very high vapor pressure electrode materials are not required it is unnecessary to sacrifice a favorable voltage recovery characteristic in the interest of attaining a low chopping current value. It will be appreciated, however, that in some instances it may be desirable to utilize these materials in conjunction with the low work function materials of the present invention.

While I have shown and described only certain constructions within the present invention it will, of course, be understood that various modifications and alternative constructions may be made without departing from the spirit and scope thereof. I therefore intend by the appended claims to cover all such modifications and alternative constructions as fall within the true spirit and scope thereof.

In the appended claims, the expression "refractory material" is used to designate materials such as tungsten, with melting points in excess of 3000° C. and the expression "low work function material" is used to designate materials such as thorium with work functions of less than 3.5 electron volts.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A vacuum alternating current circuit interrupter comprising: an evacuable envelope evacuated to a pressure lower than 10^{-4} mm. of mercury; a pair of electrical terminals adapted for connection in an alternating current circuit; a pair of electrodes located within said envelope, connected in circuit between said terminals and disposed in spaced-apart relationship during circuit interrupting operation to allow for the establishment of a circuit interrupting arc therebetween, each of said electrodes having a region on which a respective electrode spot for a low current arc may be established; at least one of said electrode regions being formed of a homogeneous porous matrix having a major proportion of tungsten and a minor proportion of thorium.

2. A vacuum alternating current circuit interrupter comprising: an evacuable envelope evacuated to a pressure lower than 10^{-4} mm. of mercury; a pair of electrical terminals adapted for connection in an alternating current circuit; a pair of electrodes located within said envelope, connected in circuit between said terminals and disposed in spaced-apart relationship during circuit interrupting operation to allow for the establishment of a circuit interrupting arc therebetween, each of said electrodes having a region on which a respective electrode spot for a low current arc may be established; at least one of said electrode regions being formed of a homogeneous porous matrix composed of substantially 7% thorium, substantially 25% binding agent, and the balance tungsten, the matrix being impregnated with copper.

3. A vacuum alternating current circuit interrupter comprising: an evacuable envelope evacuated to a pressure lower than 10^{-4} mm. of mercury; a pair of electrical terminals adapted for connection in an alternating current circuit; a pair of electrodes located within said envelope, connected in circuit between said terminals and disposed in spaced-apart relationship during circuit interrupting operation to allow for the establishment of a circuit interrupting arc therebetween, each of said electrodes having a region on which a respective electrode spot for a low current arc may be established; said electrode regions each being formed of materials incapable of providing a copious supply of vapor under the influence of the arc at least one of said electrode regions having a 2 to 15 weight percent of low work function material homogeneously distributed therein.

4. A vacuum alternating current circuit interrupter comprising: an evacuable envelope evacuated to a pressure lower than 10^{-4} mm. of mercury; a pair of electrical terminals adapted for connection in an alternating current circuit; a pair of electrodes located within said envelope, connected in circuit between said terminals and disposed in spaced-apart relationship during circuit interrupting operation to allow for the establishment of a circuit interrupting arc therebetween, each of said electrodes having a region on which a respective electrode spot for a low current arc may be established; said electrode regions each including a major proportion of refractory material and incapable of providing a copious supply of vapor at the instant of arc interruption, at least one of said electrode regions having 2 to 15 weight percent of a material selected from the class consisting of thorium, caesium, lanthanum, rubidium and barium.

5. A vacuum alternating current circuit interrupter comprising: an evacuable envelope evacuated to a pressure lower than 10^{-4} mm. of mercury; a pair of electrical terminals adapted for connection in an alternating circuit; a pair of electrodes located within said envelope, connected in circuit between said terminals and disposed

in spaced-apart relationship during circuit-interrupting operation to allow for the establishment of a circuit-interrupting arc therebetween, each of said electrodes having a region on which a respective electrode spot for a low current arc may be established; at least one of said electrode regions being formed of a homogeneous coarse matrix having a major portion of a refractory metal selected from the group consisting of tungsten, tantalum and molybdenum, and a minor portion of a low work function material selected from a group consisting of thorium, caesium, lanthanum, rubidium and barium.

6. A vacuum alternating current circuit interrupter comprising: an evacuable envelope evacuated to a pressure lower than 10^{-4} mm. of mercury; a pair of electrical terminals adapted for connection in an alternating circuit; a pair of electrodes located within said envelope, connected in circuit between said terminals and disposed in spaced-apart relationship during circuit-interrupting operation to allow for the establishment of a circuit-interrupting arc therebetween, each of said electrodes having a region on which a respective electrode spot for a low current arc may be established; at least one of said electrode regions being formed of a homogeneous coarse matrix composed of substantially 2 to 15 weight percent of thorium, enough binding agent to allow for the formation of a sintered porous matrix and the balance being tungsten, the matrix being impregnated with copper.

7. A vacuum alternating current circuit interrupter comprising: an evacuable envelope evacuated to a pressure lower than 10^{-4} mm. of mercury; a pair of electrical terminals adapted for connection in an alternating circuit; a pair of electrodes located within said envelope, connected in circuit between said terminals and disposed in spaced-apart relationship during circuit-interrupting operation to allow for the establishment of a circuit-interrupting arc therebetween, each of said electrodes having a region on which a respective electrode spot for a low current arc may be established; said electrode region each including a refractory matrix having a major proportion of refractory material which is incapable of providing a copious supply of vapor at the instant of arc interruption, at least one of said electrode matrices containing 2 to 15 weight percent of a material selected from the class consisting of thorium, caesium, lanthanum, rubidium and barium.

References Cited in the file of this patent

UNITED STATES PATENTS

1,248,621 Cooper ----- Dec. 4, 1917

FOREIGN PATENTS

403,937 Great Britain ----- 1934