Dec. 3, 1946. G. W. PETERS 2,411,893

METHOD OF CONTROLLING AN ARC

Filed July 8, 1943 3 Sheets-Sheet 1

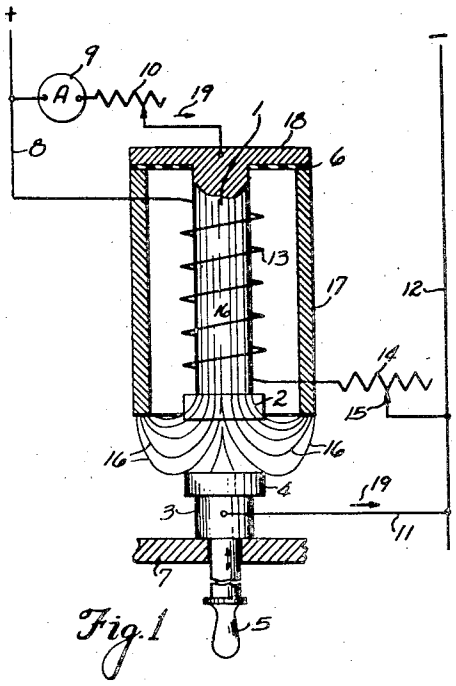


Fig. 1

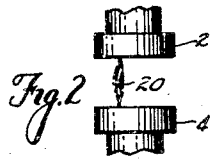


Fig. 2

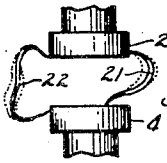


Fig. 3



Fig. 4

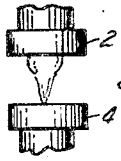


Fig. 5



Fig. 6

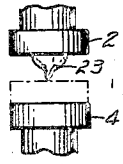


Fig. 7

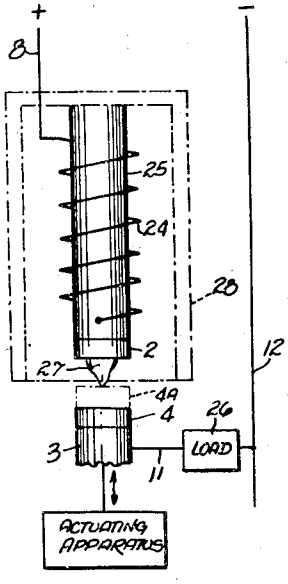


Fig. 8

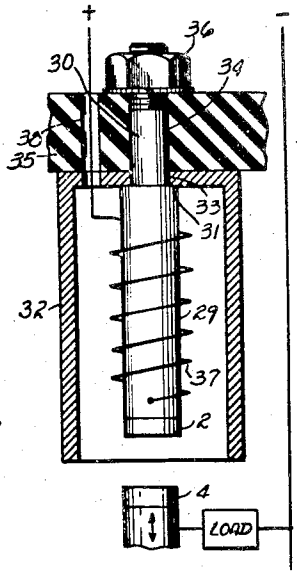


Fig. 9

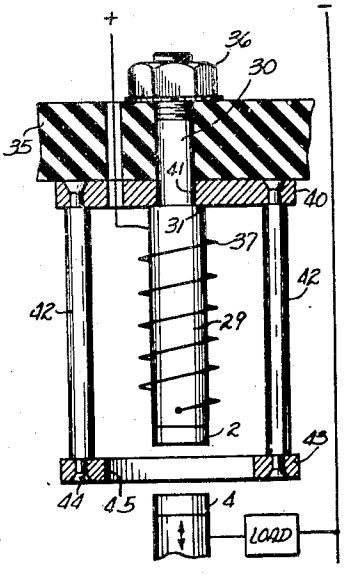


Fig. 10

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Dec. 3, 1946. G. W. PETERS 2,411,893

METHOD OF CONTROLLING AN ARC

Filed July 8, 1943 3 Sheets-Sheet 2

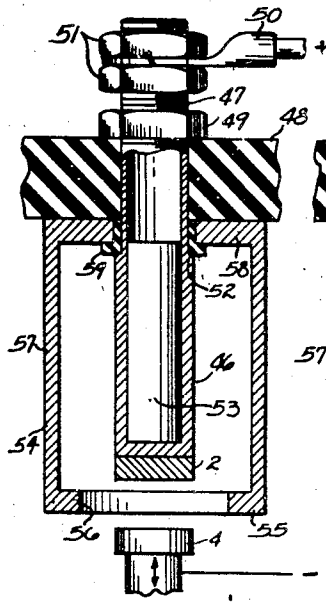


Fig. 11

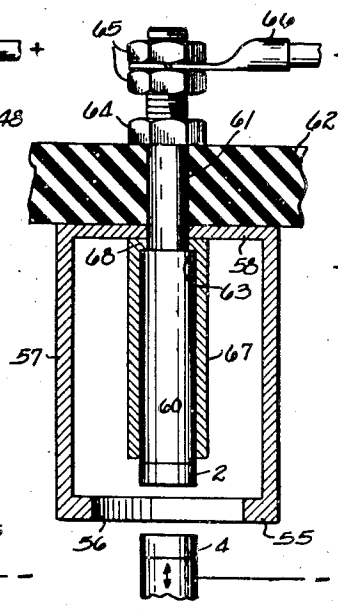


Fig. 12

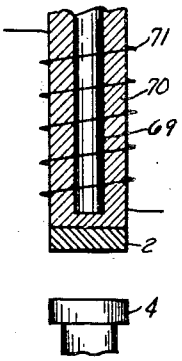


Fig. 13

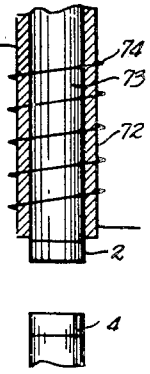


Fig. 14

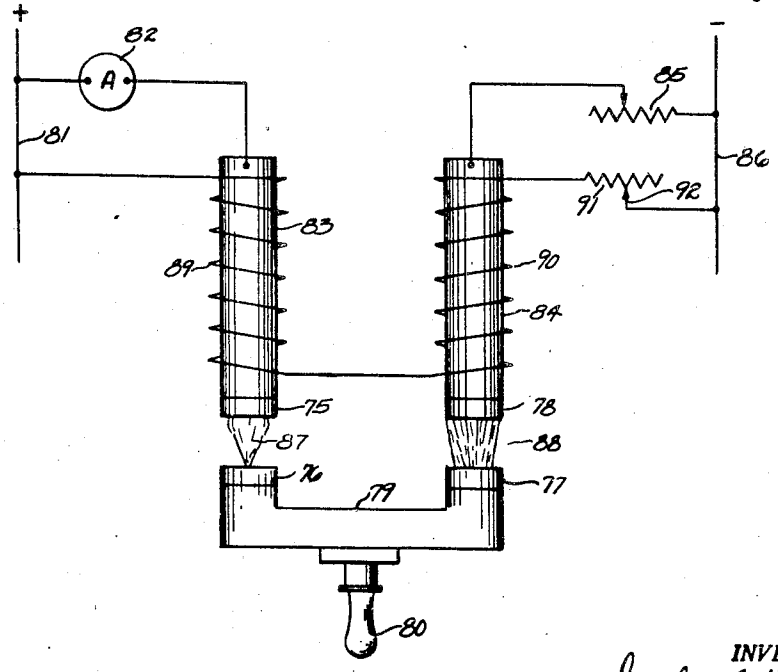


Fig. 15

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Dec. 3, 1946. G. W. PETERS 2,411,893

METHOD OF CONTROLLING AN ARC

Filed July 8, 1943 3 Sheets-Sheet 3

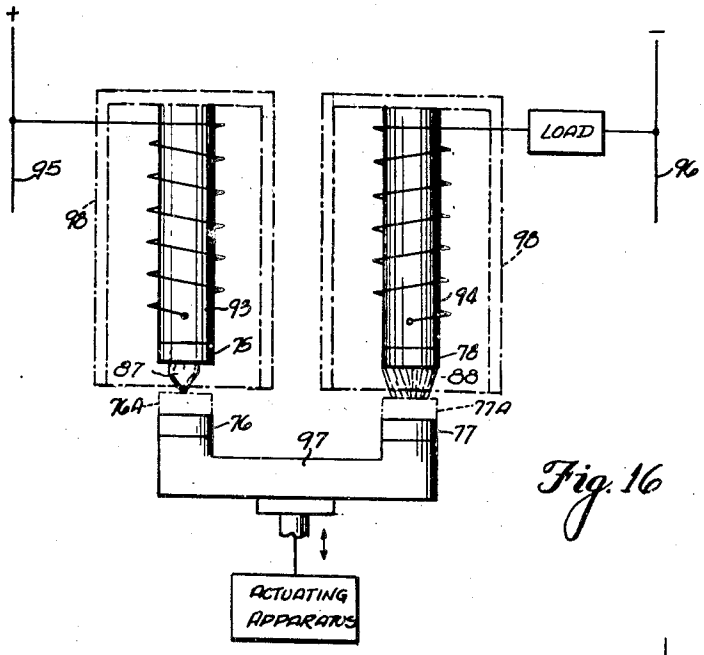


Fig. 16

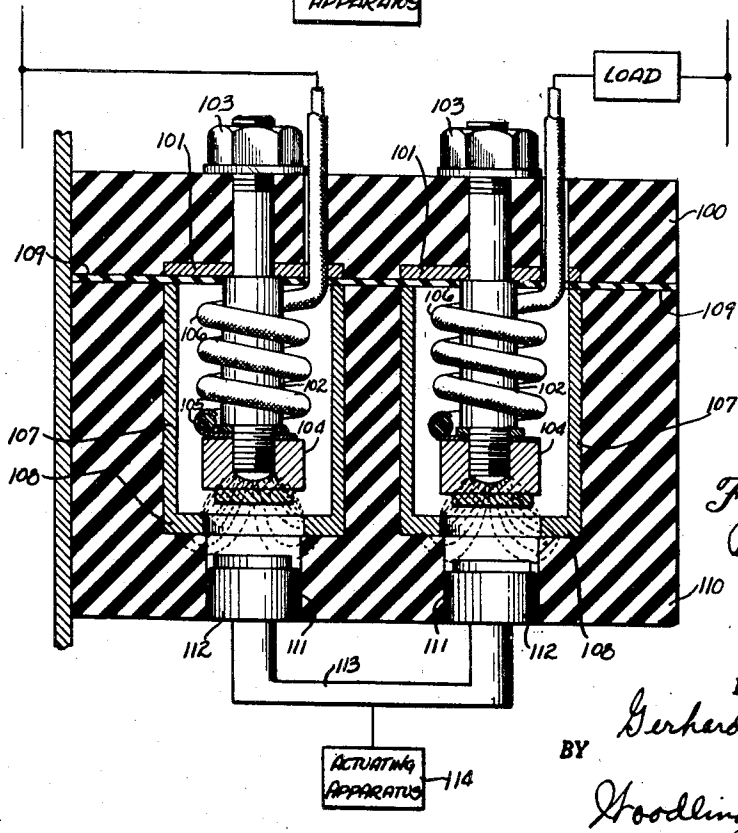


Fig. 17

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UNITED STATES PATENT OFFICE

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METHOD OF CONTROLLING ARCS

Gerhard W. Peters, Akron, Ohio

Application July 8, 1943, Serial No. 493,848

1 Claim. (Cl. 200—147)

1

This invention relates to methods and means for extinguishing the electric arcs drawn between electrodes or contacts in an electric circuit; and particularly to such methods and means that utilize the reaction of the arc on a magnetic field.

The invention is applicable to electric circuit breakers generally. One of its most important uses, however, is in connection with the class of electric contactors whose contacts are frequently closed and opened to make and break, and thereby control, the current in an electric circuit, and hereinafter it will be described in connection with such make and break contactors, and particularly the contacts applicable thereto, as illustrative of one of the uses of the invention.

The employment of a magnetic field to rupture the arc drawn between the contacts of a contactor, is generally old and well known. According to the well known principle, the lines of force of the magnetic field are made to lie in such position and direction relative to the arc, that the current in the arc reacts thereon and moves across or out of the field (in much the same way as the current carrying conductor of an electric motor moves in the motor field); and the movement of the arc and its reaction on the field causes it to lengthen and finally rupture. The arc is usually formed in the air at atmospheric pressure and ionizes the air and produces flame. The flame is one of the arc phenomena and in many instances propagates itself to great length and cross sectional area compared with the arc proper; and the flame must usually be housed or confined by walls or barriers to prevent injury to adjacent parts thereby, and to prevent the flame from bridging metal parts and making a short circuit in the contactor. The flame therefore must be dealt with concurrently with the arc proper.

It has been proposed to destroy or rupture the arc and flame magnetically by first breaking it up into a plurality of smaller arcs; or by forcing it magnetically into the spaces between a plurality of closely spaced fins or plates to thereby break up and deionize the flame. It has also been proposed to cause the arc and flame to rupture more easily by causing the arc to be moved magnetically along a linear conducting path of increasing length and corresponding increasing ohmic resistance.

The present invention makes a radical departure from these and all other prior principles by utilizing a magnetic field in such manner that when an arc is drawn in the field between a pair of contacts, the mutual reaction of the arc and the field causes the arc and any flame which may be initiated, to be drawn inwardly from all

2

sides toward the central or intermediate portions of the contacts. Growth or propagation of flame is thereby prevented. As the contacts, between which the arc is drawn, move apart, the arc appears to be drawn into the general form of a cone, and at its apex, the cone becomes more and more attenuated until continuity of the arc ceases and it "goes out." I am not certain as to the true theoretical explanation of this action, but I believe that the arc extinguishes itself in this manner because its resistance becomes so high due to the decreasing cross-section at its apparent cone apex that the potential across the separated contacts between which it is drawn cannot maintain the current flow in it.

All of the visible phenomena of the rupturing arc are thus confined to the space between the contacts, and to the intermediate portions of the contact surfaces; the evolution of flame is prevented; the explosive sound usually accompanying the rupturing of flaming arcs is absent; the usual provisions for dealing with the destructive and dangerous flame are unnecessary; the burning of the contacts is greatly reduced and their life accordingly prolonged; and an increase in the current that can be carried and interrupted by contacts of a given size is effected.

It is accordingly among the objects of the invention:

To provide generally an improved means and method, utilizing a magnetic field for extinguishing the arc drawn between separable contacts or electrodes;

To provide a means and method for extinguishing arcs, drawn between separating contacts, which progressively transversely constricts the arc as the contacts separate;

To provide an improved method and means for extinguishing arcs drawn between separating contacts which causes the arc to define in space the form generally of a cone as the contacts separate;

To provide a method and means for extinguishing a plurality of arcs, drawn between a plurality of sets of separating contacts, in series relation in an electric circuit, which causes at least one of the arcs to be progressively constricted as the contacts separate and to thereby cause the breaking of the circuit at both contacts to be effected in an improved manner;

To provide a means and method for extinguishing arcs drawn between separating contacts, which causes the arc, and any flame which may be initiated, to be drawn inwardly toward the intermediate portions of the contact surfaces, and to be extinguished thereat;

To provide an improved method and means for breaking an arc drawn between contacts

which causes the arc to be severed at its juncture with one of the contacts while the contacts are separating;

To provide a method and means for breaking an arc drawn between contacts which is applicable with improvement advantages to single-break or to double-break contactors, and to alternating or to direct current circuits;

Other objects will be apparent to those skilled in the art to which my invention appertains.

My invention is fully disclosed in the following description taken in connection with the accompanying drawings, in which:

Figure 1 is a diagrammatic view illustrating an apparatus by which certain principles of the invention hereinafter set forth may be demonstrated;

Figures 2 to 6 inclusive are fragmentary views similar to a part of Figure 1 and showing electric contacts of Figure 1 in fully open position and illustrating the changes which take place in an arc drawn between the contacts concurrently with increasing energization of an electro-magnetic winding of Figure 1;

Figure 7 is a fragmentary view similar to a part of Figure 1 and illustrating the extinguishing of an arc drawn between contacts of Figure 1;

Figure 8 is a diagrammatic view illustrating a practical application of the principles of the invention illustrating the rupturing of an arc drawn between contacts as they separate;

Figure 9 is a longitudinal sectional view of a structure embodying the invention and of a form such as would be suitable to use in some cases in actual practice;

Figure 10 is a view generally similar to Figure 9, but illustrating a modification;

Figures 11 and 12 are views generally similar to Figure 9 or Figure 10 but illustrating modifications using permanent magnets instead of the electro-magnets of those figures;

Figures 13 and 14 are views illustrating further modifications in which the principles of the invention may be embodied;

Figure 15 is a view generally similar to Figure 1, but illustrating two pairs or sets of contacts in series with each other for breaking an electric circuit at two points;

Figure 16 is a view similar to Figure 15, but illustrating the parts more as they would be arranged in practice and showing the arc at the two contacts being broken as the contacts separate;

Figure 17 is a longitudinal sectional view of a double-break contact of the type illustrated diagrammatically in Figure 16 and illustrating the parts more as they would appear in actual practice and including an enclosing housing structure therefor.

With reference to the diagrammatic apparatus of Figure 1, there is illustrated at 1 an electrode made from steel or other ferrous material, having on its lower end a contact or arcing tip 2 of copper or other metal known to those skilled in the art to be suitable for the arcing contacts of make and break contactors.

The electrode 1 is, in this diagrammatic showing, stationary; and at 3 is a movable electrode which may be of any suitable electrically conducting material and having a contact tip 4 thereon confronting the tip 2. A handle 5 is shown for moving the movable electrode 3 toward and from the electrode 1, as indicated by the arrow on the handle to engage the contact tips 2 and 4 to close an electric circuit, and to withdraw the electrode 3 to draw an arc at the contact tips. A stop 7 is

provided to stop the electrode 3 in its downward movement to determine a maximum distance between the contact tips 2—4, for test purposes.

An electric circuit is shown as leading from a current supply main 8, through an ammeter 9 and a load resistance 10, to the electrode 1, and from the electrode 3 by way of a flexible connector 11 to the other supply main 12. A winding 13 surrounds the electrode 1 and is connected at one end to the supply main 8, and at the other end is connected, through a rheostat comprising a resistor 14 and a movable contact 15, to the main 12. For any position of the contact 15, the winding 13 will be energized and will produce a magnetic field in the space between the arcing tips 2 and 4. The magnetic flux thus produced is illustrated conventionally by lines 16 and is seen to flow longitudinally through the magnetic electrode 1, and to emerge at its end through the tip 2 into the atmosphere as a magnetic field between the tips 2 and 4. As will be understood this field is generally symmetrical with respect to the axis of the winding 13 although exact symmetry is not essential. The lines within the magnetic electrode 1 flow generally parallel to the axis of the winding, but as they emerge from the lower end of the electrode (downwardly as viewed in the drawings) they bend or curve laterally away from the axis in all directions, toward the right and toward the left in the plane of the paper, and toward and from the observer, etc., as is well known, and thence flow back to the other end of the electrode 1. The field may, for convenience, be referred to as being of funnel form in the space between the contact tips.

A return magnetic circuit is provided for the lines 16, in the form of a tube 17 of ferrous or other magnetic material, surrounding the winding and having its lower annular end generally in a plane with the contact tip 2; and having its other end joined to the core 1 by a connecting element 18. An insulating sheet of insulating material 6 electrically insulates the tube 17 from the connecting element 18.

With the winding 11 energized and the field as described present, if the electrode 3 be raised by the handle 5 to engage the tip 4 with the tip 2, current will flow through the electrodes as described; and, upon withdrawing the electrode 3 by the handle, an arc will be drawn between the tips 2 and 4 which will be in the said magnetic field; and the field and arc will react upon each other as presently to be described.

It is immaterial to this invention whether the lines of magnetic force be considered as flowing downwardly (as viewed in the drawings) and through the electrode 1 and as bending divergingly in all directions laterally away from the axis of the winding; or whether the lines of force be considered as flowing in the other direction and curving or bending inwardly toward the axis. On the other hand, however, it has been discovered that the direction or polarity of the current in the electrodes and in the arc drawn therebetween is of primary importance, and is at the foundation of what is believed to be a discovery in this art. It has been found that if the electrode 1 within the winding 13 is a positive electrode and the other electrode 3 is a negative electrode so that the current flows downwardly (as viewed in the drawings) and as indicated by the plus and minus signs at the mains 8 and 12 and by the arrows 19, the reaction of the magnetic field upon the current in the arc will cause the arc and any flame which may start to de-

velop by ionization of the air, to be drawn inwardly or constricted toward the central axis of the field, and take up in appearance the general form of a cone with the apex pointed downwardly as viewed in the drawings. For this reason the arc will hereinafter sometimes be referred to as a cone-shaped arc.

If the polarity or direction of the current be referred to the direction or movement of the electrons which compose the current, according to more recent physics, then in the practice of this invention, the current would be considered as polarized so that the electrons flow upwardly as viewed in the drawings. The polarity of the current may be considered by either definition, and in either case the base of the cone-shaped arc forms at or on that one of the contact tips (namely, the tip 2 of the drawings) at which the magnetic lines of force in the field are more nearly parallel to the magnetic axis, and the apex of the cone forms in that part of the field where the lines are more divergent with respect to the axis.

In considering the apparatus of Figure 1, it will be assumed first that the rheostat 14—15 has been adjusted to provide a magnetic field of such strength that when the electrode 3 is withdrawn to the maximum distance determined by the stop 7, an arc will be drawn between the tips 2—4 and persist as a standing arc, that is to say, will not be extinguished, in order that the phenomena may be observed. This arc can be further determined by an initial adjustment of the load resistance 10. If now the rheostat 14—15 be adjusted so that there is little or no field between the contact tips, when they are separated, an arc such as is illustrated at 20 in Figure 2 will strike or form as a standing arc between the contact tips. It may strike or form at most any point on the tips probably taking the path of least resistance. With the arc 20 standing, if the strength of the field be gradually increased by moving the rheostat 14—15 to increase the energization of the winding 13, the reaction of the arc and the field will cause the arc to move over to the peripheries of one or the other, or both of the contacts and bulge outwardly laterally beyond the peripheries and become elongated or stretched. Its form is indeterminate and in different instances will have different shapes. For example, it may have the shape shown at 21 in Figure 3 or may have the shape shown at 22 in that figure; and in either case, it will persist as a standing arc accompanied by some flame. If now the field be still further increased by operation of the rheostat 14—15, or if a still stronger field is present when the contacts separate, the arc and whatever flame is present, instead of being driven still farther outwardly laterally from the contacts and becoming larger (as might be expected from a knowledge of prior magnetic arc blowout practice) are drawn inwardly toward the axis of the field and become shorter and stand as a persisting arc, accompanied by some flame, upon the intermediate or generally central portions of the contact tips and become "cone-shaped" as shown for example in Figure 4, with the apex of the cone relatively blunt or truncated. If the field strength be still farther increased, the arc and flame will be drawn inwardly still farther and the apex of the cone and its diameter generally will become smaller as indicated in Figure 5. If the field strength be still farther increased, the diameter of the cone will become very small as shown in Figure 6 and

if the field strength be still farther increased the arc will cease or "go out."

The changes in the form of the arc, for example, those which occur in going from Figure 2 to Figure 6, can best be shown by high speed motion pictures projected at low speed. With a standing arc drawn inwardly or constricted until it goes out, it is difficult to ascertain, even with motion pictures, whether the arc extinguishes first at the apex or at the base of the cone, although there is considerable evidence to show that when the arc goes out during the separating movement of the contacts, to be referred to later, the arc extinguishes first at the apex of the cone. Such motion pictures provide substantial evidence to show that the cone-shaped arc is a spinning arc, and practice shows that at least the apex of the arc is at an exceedingly high temperature because if allowed to stand for a substantial length of time, it volatilizes the metal of the contact tips and raises the temperature of these tips quickly to luminous temperature. Based upon the aforesaid evidence that the cone-shaped arc is a spinning arc, it is probable that the arc is actually of linear form and conveys to the observer the impression of cone form because of the high velocity at which the line rotates.

The ammeter 9 in Figure 1 indicates the amount of current flowing in the arc; and as the arc is drawn more and more inwardly toward the axis or center, for example, in going from Figure 4 to Figure 6, the current on the ammeter 9 decreases and when the arc goes out the current abruptly falls as indicated by the ammeter. This has led to the aforementioned hypothesis that as the arc is drawn inwardly its resistance increases, and that it extinguishes or goes out because its resistance becomes so high that the potential across the separated contacts is not sufficient to maintain current flow in the arc therebetween. With the apparatus of Figure 1, if the field strength be stronger than that to produce the standing arc of Figure 6 so that the arc goes out, then obviously when the arc is drawn and the contacts begin to separate, they will reach a point of separation at which the arc extinguishes. This, of course, is the manner in which the invention would be utilized in a make and break contactor for practical purposes.

As is well known in contactor practice, the contacts separate very rapidly. Using the apparatus of Figure 1 to illustrate this, the contact tip 4 would move away from the contact tip 2 very rapidly, and an observer viewing the formation and interruption of the arc would observe visibly a short arc, such as that shown at 23 in Figure 7 of the cone shape with the apex downwardly, and his retina would retain the impression of this short arc with a space between its apex and the tip 4. In Figure 8 is illustrated diagrammatically an arrangement of parts suitable for embodiment in a practical make and break contactor to control a load circuit. Current is supplied by positive and negative supply mains 8 and 12. When the movable electrode 3 is raised to engage the contact tips 2 and 4, current flows from the main 8 through a series winding 24 around a ferrous electrode or core 25 to the contact tip 2 and thence to the tip 4 and to the electrode 3, and thence through a load 26 to the main 12. The winding 24 produces the magnetic field. When the electrode 3 is withdrawn and moves the tip 4 progressively farther from the tip 2, the arc 27 is drawn therebetween. As the contacts separate, this arc takes up the form of a cone as illustrated,

and a point is reached in the movement of the tip 4, namely at 4A, at which the apex of the cone is constricted substantially to a point or to a very small cross-sectional area, this being the position at which the maximum attenuation which the arc apex can attain is reached, so that movement of the tip beyond the position 4A causes the arc to extinguish. It will therefore be readily appreciated that, whereas in prior practice the arc drawn between contacts completely bridges them and stands for an interval of time while it is being extinguished, here the arc never completely bridges the contacts in their open position. As a consequence the arc exists for such a short interval of time—a fraction of the time during which the contacts are opening—that although the arc, particularly at the cone apex is very hot and capable of heating the metal to the volatilization temperature, there is not sufficient time for the heat of the arc to raise the metal of either tip 2 or 4 to the volatilizing or melting point; and as the consequence, the tips, even after thousands of operations, do not develop thereon the pitting and roughening which inevitably occur after a few operations in prior contactors in which the arc completely bridges the contact gap and stands bridging the contacts before it is extinguished. The contacts therefore have a useful life prolonged enormously beyond that of the contacts of prior magnetic arc blow-out contactors.

With an arrangement such as shown in Figure 8 in solid line, the magnetism produced in the core element 25 produces a field between the contacts for extinguishing the arc and returns to the other end of the core 25 through the air; and, with such air return magnetic path, current of great amperage can be broken and the arc extinguished without the development of flame beyond the confines of the contact tips themselves; and the arc goes out without the usual explosive sound; and the provision of an arcing chamber, arc shields, and the like as found necessary heretofore, are not needed; and therefore my invention is not limited to the employment of a ferrous return magnetic path.

As stated above, however, to develop the full advantages of the invention, a suitable density or strength of magnetic field must be provided by the winding, and such field can be produced with fewer ampere turns in the winding if a return path for the lines of force in the field made from ferrous material be provided. Also the form of the field in the arcing gap can be pre-determined more accurately, which in some cases may be found to be desirable, if a return magnetic path is provided; and such a return path is indicated in Figure 8 in dotted lines at 26 corresponding generally to the return path 17—18 of Figure 1.

In Figure 8 is indicated an "actuating apparatus" for causing the electrode 3 and the contact tip 4 to be moved toward the contact tip 2 and retracted therefrom for the purposes described, and this has been done to simplify the drawings and description because such actuating apparatus is so well known in this art; but it may be added here that in practicing the invention with such well known actuating apparatus, it is not necessary to provide any special features in such actuating apparatus to cause the electrode 3 to be retracted more rapidly than in common practice in make and break contactors, nor to separate the contact tips a greater distance than in common contactor practice, to effect interruption of the arc while the contacts are moving apart.

In Figure 9 I have illustrated the parts shown diagrammatically in Figure 8, but more as they would appear in actual practice. A steel or other ferrous core 29 has a shank 30 of reduced diameter thereby providing a shoulder 31. The return magnetic circuit 32 is in the form of a cup, and the bottom of the cup has a perforation 33 through which the shank 30 is projected. The shank is projected not only through the perforation 33 but through a corresponding bore 34 in a supporting panel 35 and a nut 36 on the shank outwardly of the panel, when drawn up tight, mounts both the core 29 and the return magnetic circuit 32 rigidly upon the panel 35. The winding 37 passes through aligned perforations or bores 38 in the panel and in the bottom of the cup and is wound around the core 29 secured at its lower end as viewed in the drawings to a clip device 39 having electrical contact with the arcing tip 2. Other parts and the mode of operation, as will be apparent, will be the same as those of Figure 8.

In Figure 10 is illustrated a modification of the form of Figure 9, showing a different construction of return magnetic circuit. A disc 40 of ferrous material has a perforation 41 therein through which the shank 30 of the core 29 is projected whereby the nut 36 will mount the core and the disc 40 on the supporting panel 35. Riveted or otherwise secured to the disc 40 is a plurality of ferrous rods or posts 42—42 projecting therefrom in the general direction of the core 29. A ring of ferrous material 43 is secured to the outer ends of these posts in any suitable manner, for example, by screws 44 projected through the ring and threaded into the ends of the posts. The ring 43 has a central perforation or opening 45 surrounding the magnetic axis and preferably, but not essentially, coaxial with the magnetic core 29 and disposed so that the flux emanating from the lower end of the core 29 as viewed in the drawings will form a funnel field in the arcing space between the contact tips 2 and 4 having the characteristics above described. By changing the lengths of the posts 42, the position of the ring 43 may be varied. The position for this ring illustrated in Figure 10 will be suitable and the principles of the invention will be expressed with it in this position, but because of variable quantities, which inevitably will be present in such a structure, the optimum position for this ring may be nearer to or farther from the end of the core 29. In some cases, the magnetic field which can be produced by a permanent magnet will be sufficient to draw the arc inwardly and to extinguish it, and in Figures 11 and 12, I have indicated a structural arrangement by which this may be accomplished. In both figures, as will be obvious, the winding to produce the field is not needed and has been omitted.

Referring to Figure 11, there is shown generally at 46 an electrode of copper or other electrically conducting material, in tubular form, closed at its lower end (as viewed in the drawings) and having a contact tip 2 thereon. The electrode 46 has a shank 47 projected outwardly through a perforation in the supporting panel 48 and threaded to receive a nut 49; and outwardly beyond the nut 49, a terminal 50 may be mounted on the shank by nuts 51. The reduction in diameter to provide the shank 47 provides a shoulder 52. Within the tubular electrode 46 is a permanent magnet 53, the line of force emanating from the lower end of which provide the arc extinguishing field above described. A return magnetic cir-

cuit is provided shown generally at 54 comprising a relatively thickened ferrous disc 55 having a perforation 56 therein preferably co-axial with the magnet 53; and a tubular ferrous side wall 57 connected thereto and extending upwardly to and connected to a ferrous disc 58 which has a perforation therein encircling the shank 47 of the electrode. A thimble of electric insulation material 59 lies between the disc 58 and the electrode 46 and is engaged by the shoulder 52. As will be apparent, when the nut 49 is drawn up tight, the shoulder 52 draws the thimble against the disc 58, and both the electrode 46 and the return magnetic circuit 54 are thereby rigidly mounted upon the panel 48 in functioning positions. In explanation of the insulation 59, it should be pointed out here that, in all of the arrangements herein illustrated having return magnetic circuits, the outer or movable electrode is illustrated as below the magnetic circuit; but that the arrangements will function just as well in any other position, for example, upside down; in which latter instance the return magnetic circuit may be a lodging place for foreign matter or objects from any source, which might electrically bridge the movable electrode and the magnetic circuit; and if the said insulation were absent, a short circuit between the electrodes through the return magnetic circuit might be set up. It will be noted that the insulation 59 is located so remotely from the movable electrode and in a sense within structure, that it cannot be unintentionally bridged; but since its function can be performed by a suitable gap in the return magnetic circuit at almost any other point, the exact location given it in Figure 11 is not essential.

In Figure 12 a copper or like electrode 60 is provided having the arc tip 2 thereon, and at its upper end is of reduced diameter to provide a shank 61 projected outwardly through the supporting panel 62 and providing a shoulder 63 on the electrode. A nut 64 is threaded on the shank 61 and outwardly beyond it are nuts 65 for mounting a terminal 66 on the electrode. A permanent magnet 67, in this figure in the form of a tube, is telescoped over the electrode 60 and the upper end (as viewed in the drawings) is formed with a flange 68 which fits over the shoulder 63. A return magnetic circuit is again provided comprising, as in the form of Figure 11, a disc or head 55 having a perforation 56, and connected to a side wall 57 which may be tubular, and which at its upper end is provided with a disc or head 58 encircling the shank 61, between the flange 68 of the magnet and the panel 62. When the nut 64 is drawn up tight, it will mount the magnet 67 and the return magnetic circuit and the electrode 60 rigidly upon the panel 62 with the magnetic circuit and the field in functioning positions. As will be apparent in both the forms of Figures 11 and 12, the magnetic field produced by the permanent magnets will have the form described in connection with Figure 1 for causing the arc to be drawn inwardly and take up the form of a cone between the arcing tips 2 and 4 and to be extinguished thereby.

As stated hereinbefore, the return magnetic circuit is in all cases not essential and therefore with the permanent magnet forms of Figures 11 and 12, it may be simply omitted; and the making of any structural changes occasioned by its omission is believed to be well within the knowledge of those skilled in the art. It is believed that Figures 11 and 12 and their descriptions disclose sufficiently the utilization of a permanently energized magnetic circuit for producing the arc interrupting field and that other forms of such permanent magnets will now readily occur to those skilled in this art; for example, in Figure 9 or Figure 10, those parts, or some of them, which are referred to above as comprised in the return magnetic circuit may be made from permanently magnetized metal for this purpose. In some of the foregoing figures, where windings are utilized to produce the magnetic field, the magnetic core within the winding has been shown to be of approximately the same cross-sectional area as that of the contact or contact tip. These figures therefore might be thought to suggest that the field produced by the winding should emanate equally or substantially equally through all parts of the contact tip. This is not essential as has been indicated generally by the arrangements of Figures 11 and 12 utilizing permanent magnets; and is further shown not to be essential by the arrangements of Figures 13 and 14 which have been found to be practicable and to satisfactorily embody and express the principles of the invention.

In Figure 13 the iron core 69 is of reduced cross-section and lies longitudinally within an electrically conducting electrode 70 through which the current from the positive main flows on its way to the contact tip 2. The field producing winding 71 surrounds the electrode 70. Here as will be apparent, the greater part of the field producing flux flows out of the lower end of the core 69 and therefore in general through the central or axial portion of the contact tip 2.

In Figure 14 the magnetic core 72 is in the form of a sleeve, surrounding an electrode 73 through which the current flows to the tip 2; and here as will be apparent the flux producing the arc extinguishing field emanates from the end of the sleeve at portions of the contact tip 2 generally near its periphery. In both Figures 13 and 14 the field producing windings 71 and 74 are shown, as a further modification, as energizable independently of the main current through the arc.

The invention as described above relates to the breaking of a circuit at a single pair of contacts. The structure of the means or mechanism for moving the contacts to close the circuit and separate them to break it, have not been shown inasmuch as such means are so common-place and so well known in the art. In most cases as is well known, the electrical connection to the movable electrode for example, the electrode 3 in Figure 8 or Figure 1, must be a flexible connection as indicated at 11. To avoid the necessity of such flexible connection, there has been developed in the art numerous types of construction by which the electric circuit is broken concurrently at two points in series with each other in the circuit. Figure 15 illustrates such an arrangement embodying my invention in an apparatus by which the action may be observed. Shown generally at 75 and 76 is one pair of contacts and at 77 and 78 another pair, the contacts 76 and 77 being mounted upon a connector 79 and reciprocable by a handle 80 connected to the connector 79. When the connector 79 is moved upwardly to effect engagement of the pairs of contacts, current in a circuit to be controlled flows from a positive main 81 through an ammeter 82, to a magnetic pole piece or core 83 and thence through the contacts 75 and 76, through the connector 79, through the contacts

77 and 78, and through a second magnetic pole or core 84, thence through a current limiting load 85 to a negative main 86; and when the connector 79 is retracted, arcs as indicated at 87 and 88, are drawn between the respective pairs of contacts.

Magnetic fields in the arcing gaps between the contacts are produced by windings on the said cores, the energizing current flowing from the main 81 through a winding 89 on the core 83, and thence through a winding 90 on the core 84, and thence to the negative main 86, through a rheostat 91—92. At suitable load 85 initially adjusted and at suitable energizations of these windings, the arcs 87 and 88 will be standing arcs and may be observed. The arc 87 will again be drawn inwardly and become cone-shaped with its apex pointing downwardly as described hereinbefore, but the current is flowing in the opposite direction through the arc 88, and its form and characteristics will be different.

The present invention has thus far been described as relating particularly to the formation and extinguishing of an arc to interrupt a circuit at one point, or at one pair of contacts. In the embodiment of Figure 15 where the circuit is interrupted at two points, or two pairs of contacts, the invention relates particularly to the production and extinguishing of the arc 87 as drawn between one pair of contacts, and its functions in breaking the circuit in cooperation with the arc 88 drawn at the other pair of contacts; and therefore only a brief discussion of the arc 88 will for this reason be given in this patent. A more complete discussion of arcs corresponding to the arc 88 will be found in my copending application, Serial No. 493,847, filed July 8, 1943. For purposes of economy in manufacture, convenience of making replacements, repairs, etc., it is desirable for the structure and arrangement of parts at both pairs of contacts to be duplicated structures as nearly as practicable.

The two arcs 87 and 88 will therefore usually be produced under like conditions; and because of the remarkable extinguishing characteristics of the cone-shaped arc 87, both structures will be predetermined to meet the optimum requirements of that arc. Under such equivalent or duplicate conditions, and proceeding experimentally with the apparatus of Figure 15, and producing standing arcs, and gradually increasing the strength of the fields by the rheostat 91—92, the arc 88, at low field strength will tend to be repelled outwardly away from the space between the contacts somewhat as illustrated in Figure 3 and described above for the cone-shaped arc. As the field strength is increased, the arc 88 is drawn inwardly and stands or persists in the space between the contacts. While this is going on, the arc 87 has been drawn inwardly and acquired its cone form, and it becomes more and more attenuated as described above in going from Figure 4 to Figure 6. As the cone-shaped arc 87 thus becomes more and more attenuated, the ammeter 82 indicates that the current in both arcs is falling just as when the cone-shaped arc was alone in the circuit; and the current on the ammeter ultimately abruptly falls to zero and both arcs go out. Since the arc 88 is substantially confined to the space between the contacts, as referred to, and since the current flowing in it has ben reduced as described, its extinguishment also occurs without the usual explosive sound and without the usual flame attendant upon breaking an arc in prior devices in which the arc is ruptured by elongating or stretching it until it breaks; and this improvement is believed to be due to the fact that the two arcs are in series.

In Figure 16 is illustrated diagrammatically a general arrangement of parts which might be used in an actual double-break contactor wherein it is intended that the arc shall be extinguished each time that the contacts separate and not persist or stand at any time. Here windings on cores 93 and 94 are in series in the main circuit between mains 95 and 96, and in series with the arcs, and the ampere turns thereof are predetermined so that there will be a sufficiently strong field to extinguish the arcs in every case. When the connector 97 has engaged the contacts, and then withdraws the contacts 76 and 77, the arcs 87 and 88 form as described above, but by the time the contacts 76 and 77 reach the positions indicated generally at 76A and 77A, the arcs are extinguished. The arc 87 becomes cone-shaped as illustrated and as described more completely above, the cone apex of which is to the eye of the observer, spaced from the contact 76.

The foregoing description has been directed to the utilization of the invention with uni-directional or direct current, but it is applicable also to making and breaking alternating current circuits. In connection with alternating current, the double-break arrangement shown diagrammatically in Figure 16 is preferred because the current periodically changes in direction. When the current is flowing in one direction, the cone-shaped arc forms at one pair of contacts. When the current reverses and flows in the other direction, the cone-shaped arc obviously will be formed at the other pair of contacts. Thus the advantages described above of having the cone-shaped arc in series with the other arc to contribute to the improved breaking of both arcs are always present at both pairs of contacts. The observable visible character of the arcs with alternating current introduces evidence to show that the self-extinguishing characteristics of the cone-shaped arc predominate when the two arcs are in series because the arcs that are visible to an observer appear as cone-shaped arcs at both pairs of contacts when the current is alternating. Similarly, when a single pair of contacts is used to break an alternating current circuit, a cone-shaped arc corresponding to the arc 87 tends to develop during one half cycle, and an arc corresponding to the arc 88 tends to develop during the succeeding half cycle. The effect is difficult for the eye to observe, but in general it is believed that the arc extinguishes upon the development of the cone-shaped arc.

In practice, upon breaking an alternating current circuit by the utilization of my invention, even when the current amperage is as high or even higher than the maximum continuous current carrying capacity of the closed contacts, the arc or arcs extinguish so "easily" and with so little observable phenomena of any kind, that it is difficult in some instances to describe from observation the character of the arc or arcs at the instant of rupture.

Among the foregoing forms and modifications of the invention, it is shown that the arc field may be produced by a winding energized independently of the arc or by a winding in series with the arc. In the latter case, as the resistance of the arc increases, the current reduces and the field will weaken. In some cases, therefore, it

may be desirable to utilize in the magnetic core or magnetic circuit, steel having a substantial degree of magnetic retentivity to insure that there will be a strong enough field even at the moment of extinction of the arc.

A gap in the magnetic circuit such as that provided at the insulation 59 of Figure 11 can be provided in any of the forms having return magnetic circuits, if for any reason it is found to be desirable. Obviously, return magnetic circuits, such for example, as those described may be provided for the forms of Figures 13 and 14 and also for the double contact forms of which Figures 15 and 16 are illustrative examples, and as indicated in dotted lines at 98 for the form of Figure 16. In use with alternating current circuits it may be desirable to laminate or slot the ferrous parts of the magnetic circuit to reduce the generation of eddy currents therein. This is so well understood in this art as not to warrant complications in the drawings or prolixity in the specification to illustrate and describe it.

It will be apparent from the foregoing that in order to draw the arc inwardly and extinguish it, there must be a field strength above a certain minimum; and that this minimum field strength is in general greater than has usually been employed heretofore in prior arc interrupters. A field strength greater than this minimum is, as a fact, not detrimental. The field strength therefore does not have a critical value.

In practice there will, therefore, be an optimum field strength which will lie between this minimum and a maximum, which maximum, will be determined by economical considerations represented by the size and cost of the winding and associated parts. Even this optimum field strength will be different in different structures and for different amounts or amperages of current to be interrupted. My invention, therefore, is not limited to any particular field strength, inasmuch as in any instance, all of the advantages thereof will be expressed with a considerable range of field strengths. In order, however, to make this disclosure definite and sufficient as to the field strength (to comply with the statutes), I have illustrated in Figure 17 a contactor drawn to scale (in the original drawings) from a working specimen embodying the invention, and it will now be described.

The contactor of Figure 17 is a double break contactor, the two halves of which are duplicates, and either half of which may be used alone as a single break contactor. A supporting panel 100 has recesses in its face in which are seated ferrous discs 101—101. Ferrous cores 102—102 extend through the panel 100 and by means of nuts 103—103 on threaded shanks of the cores, the cores and the discs are rigidly mounted upon the panel. Contact tips 104—104, mounted on the lower ends of the cores, have electrical connection with clip devices 105—105 to each of which one end of a winding 106 is connected, the winding helically surrounding the core and the other end of the winding passing outwardly through the panel 100 where it may be connected to an electric circuit as described hereinbefore. A return magnetic circuit, comprising a sleeve 107 and having on its lower end a ring 108, surrounds the winding and at its upper end is spaced from the disc 101 by an insulator 109. As will be seen, the disc 101 is a part of the return magnetic circuit. An external enclosing housing 110 made from insulating material is provided having recesses telescoped over the sleeves 107 and detachably secured by means, not shown but well known in the art, to the panel 100. The housing thus holds the insulator 109 and the sleeves 107 in position. The housing 110 is provided with bores 111—111 axially aligned with the cores 102—102 which function as guides for guiding the reciprocatory movement of the lower contacts 112—112. The contacts 112—112 are electrically connected by a connector 113 and means is shown at 114 for reciprocating the connector 113 and the contacts 112—112. The contacts are illustrated in the fully open positions. The arrangement will be seen to be similar to that of Figure 16 and its operation to be substantially the same as that of the apparatus of Figure 16.

Using this contactor as a double-break direct current contactor, either one of the windings may be connected to the positive supply main, and the two windings will be in series. There are approximately three-and-one-half turns in each winding. The field strength at each set of contacts will be determined by the amperage flowing in the windings. With a non-inductive load circuit at 230 volts across the supply mains, the above described cone-shaped arc will be developed and extinguished at one of the sets of contacts as the contacts move apart when the field strength is that produced by 30 amperes in the circuit, and therefore, in the windings. In other words, approximately 105 ampere turns are enough in this contactor to provide a cone arc producing and extinguishing field strength. This field strength is in the above mentioned optimum field strength range, and accordingly, this field strength may be decreased substantially (by fewer turns or lower amperage) without losing the arc forming and extinguishing characteristics described.

For higher load currents in the circuit, stronger fields will be produced and the larger amperages will accordingly be interrupted in the same manner. For repeated intermittent operation currents as high as one hundred or more amperes may be successfully interrupted for thousands of operations before impairment of the carrying capacity of the contacts becomes perceptible.

Subject matter illustrated and described herein but not claimed is being claimed in my copending application, Serial No. 493,847, filed July 8, 1943.

Although I have described my invention with a certain degree of particularity, it is understood that the present disclosure has been made only by way of example and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and the scope of the invention as hereinafter claimed.

I claim as my invention:

In a magnetically quenched circuit breaker having two relatively movable contacts, the method of quenching the arc created when said contacts open, said method comprising magnetically forcing the arc at the instant of its creation inwardly toward a central zone between the separated contacts thereby preventing the arc from materially lengthening itself by flaring outwardly beyond the sides of the contacts, and magnetically restricting the cross-sectional area of the said arc and thereby increasing the resistance of the said arc without materially increasing the length thereof for extinguishing the arc.

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