

June 2, 1970

R. L. HURTLE ET AL
CURRENT-LIMITING CIRCUIT BREAKER WITH NOVEL ARC
INITIATING AND EXTINGUISHING MEANS

3,515,829

Original Filed May 21, 1965

5 Sheets-Sheet 1

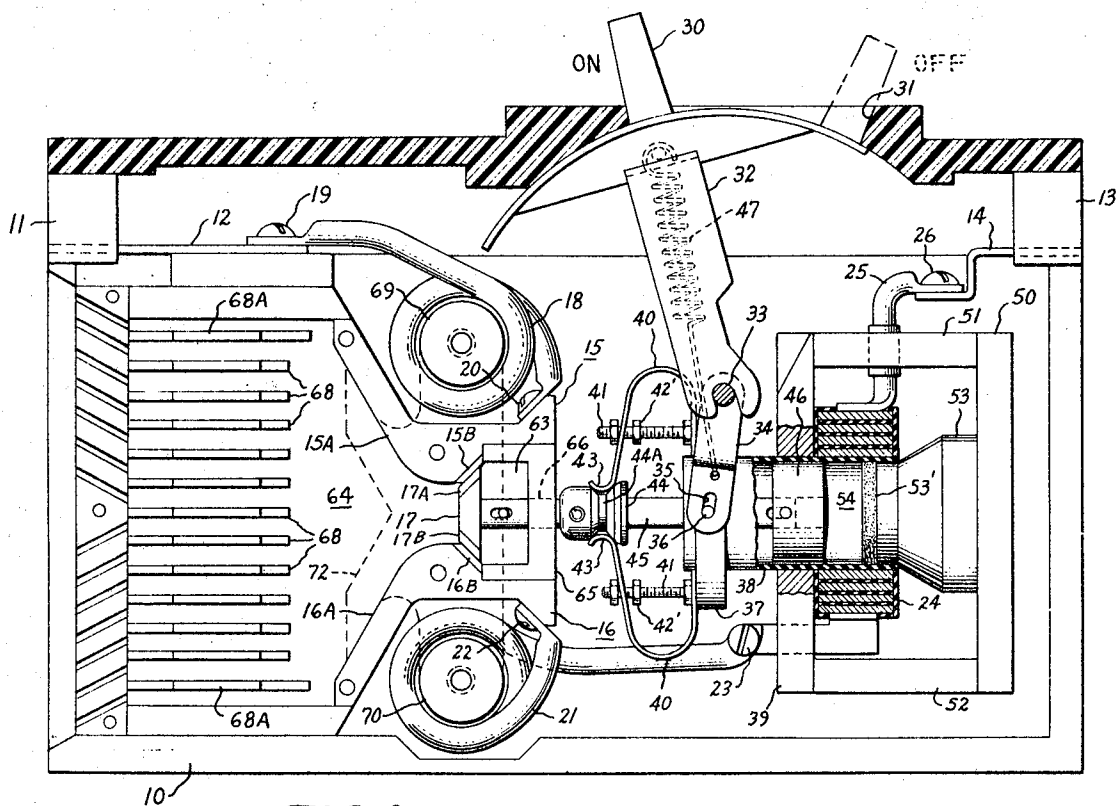


FIG. 1

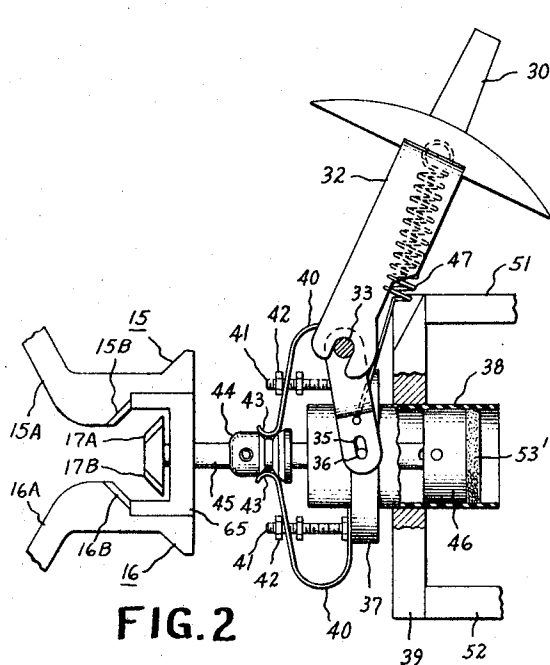


FIG. 2

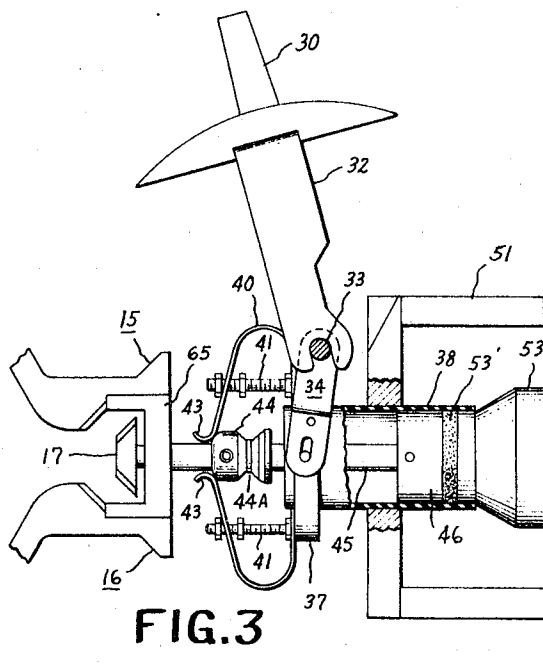


FIG. 3

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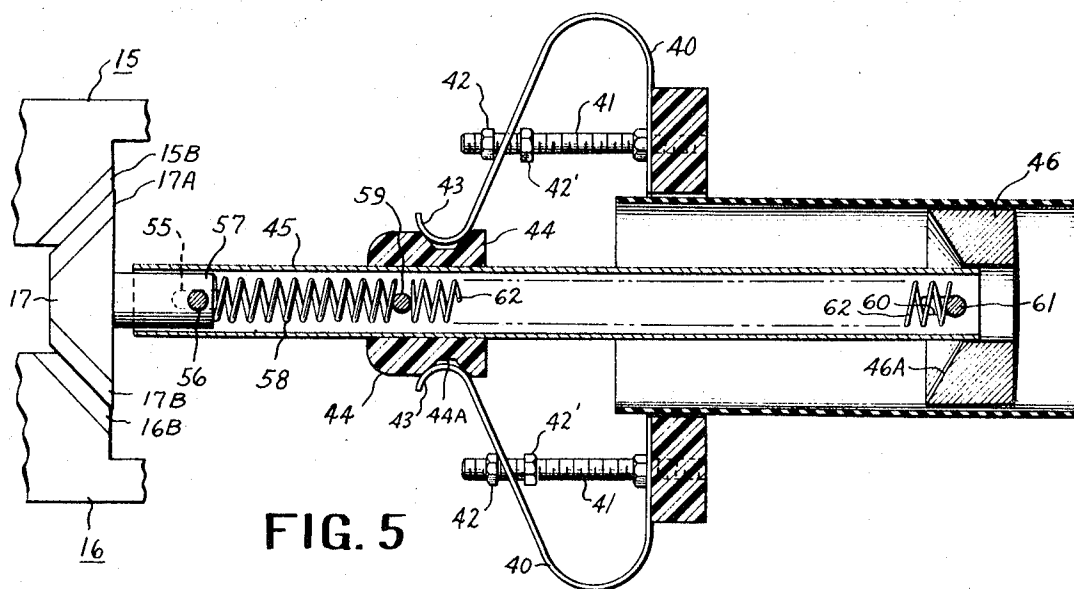


FIG. 5

NOMINAL RATING - AMPS -	DEVICE	INTERRUPTING CAPACITY 3 ϕ -600V.-rms amps	TIME TO INTERRUPT milliseconds	C-L RATIO	VOLUME of 3-POLE ARC CHAMBER	INTERRUPTING CAPACITY per in ³
100	PRESENT INVENTION	280,000	1.28	.24	18	15,500
200	PRIOR ART CURRENT LIMITING CIRCUIT BREAKER	25,000	8.33	.75	123	203
800	PRIOR ART MOLDED CASE CIRCUIT BREAKER	25,000	22.5	1.0	63	400
4000	PRIOR ART AIR CIRCUIT BREAKER	85,000	50.0	1.0	1152	74

FIG. 9

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FIG. 6

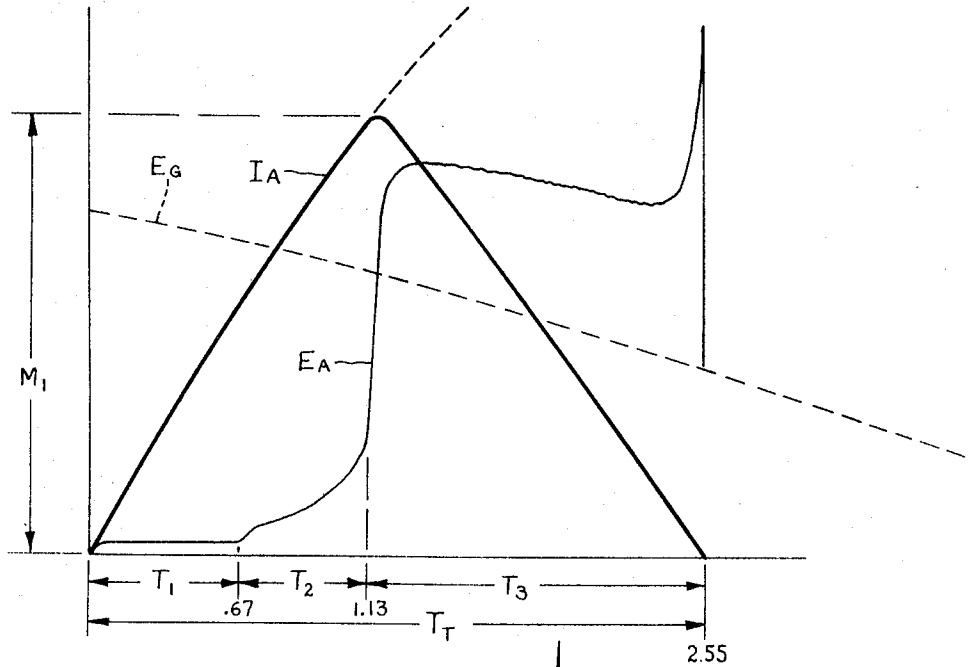


FIG. 7

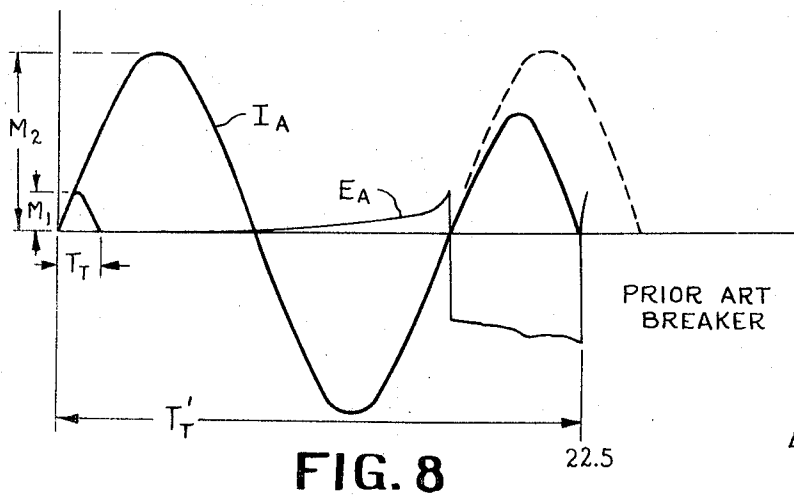
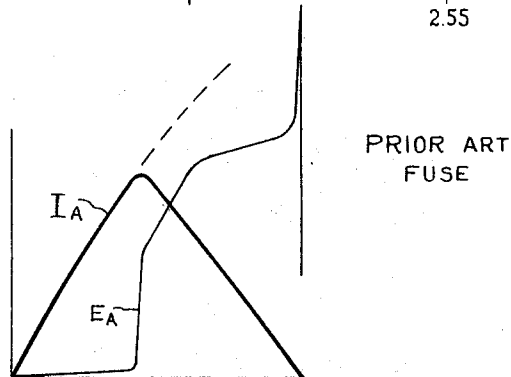


FIG. 8

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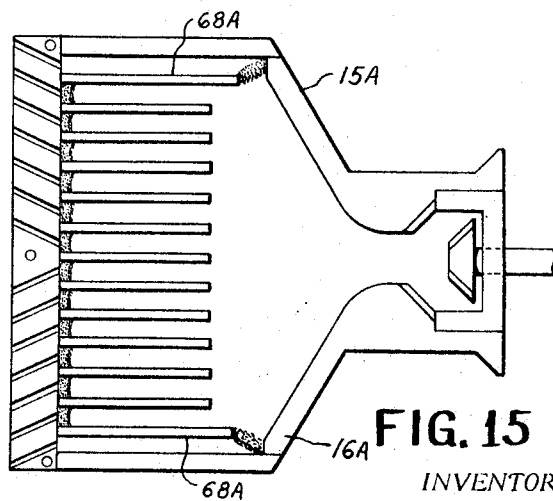
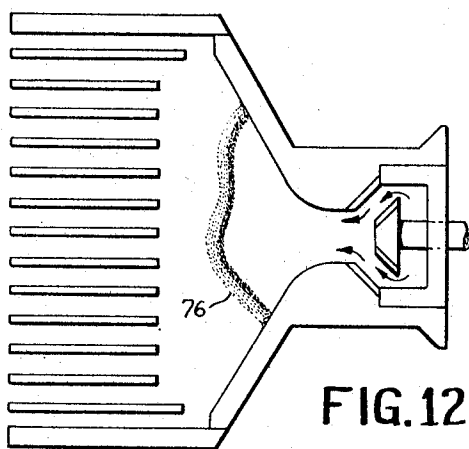
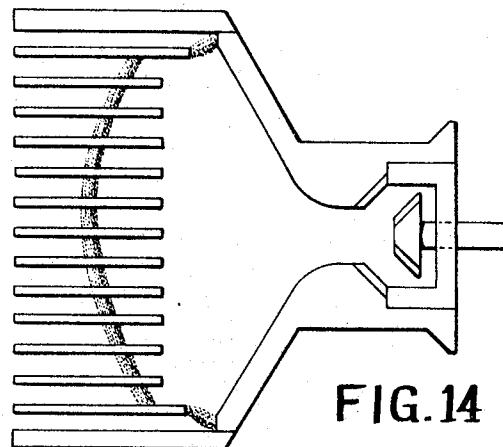
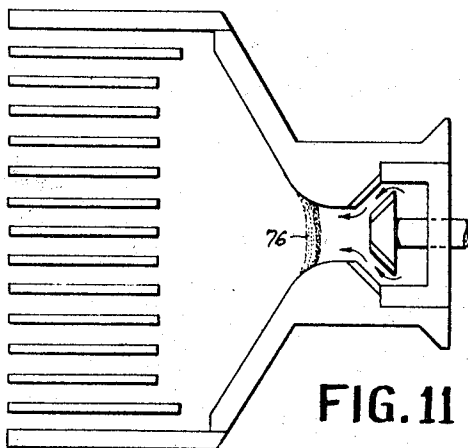
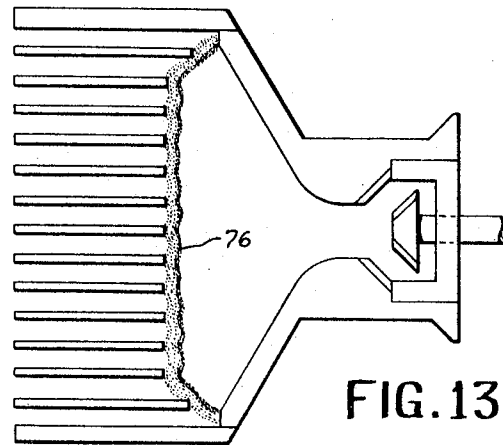
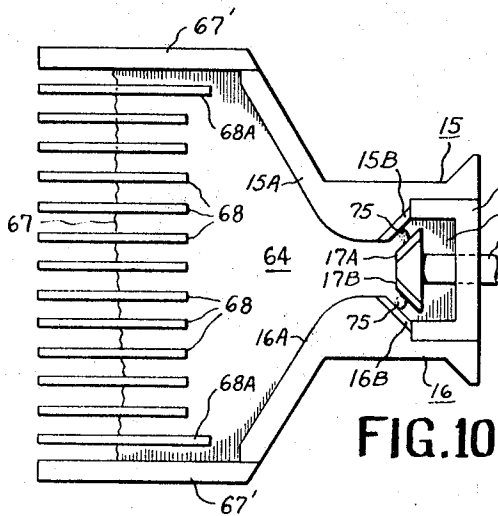
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CURRENT-LIMITING CIRCUIT BREAKER WITH NOVEL ARC INITIATING AND EXTINGUISHING MEANS

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Continuation of application Ser. No. 457,557, May 21, 1965. This application Oct. 10, 1968, Ser. No. 768,963

Int. Cl. H01h 33/00, 33/18

U.S. Cl. 200—144

6 Claims

ABSTRACT OF THE DISCLOSURE

A current-limiting type circuit breaker including a wedge-shaped bridging movable contact which is drawn from closed position into a generally cup-shaped chamber by a high-speed solenoid. This, together with use of an ablating non-tracking insulation material (e.g. acetal resins) adjacent the closed contacts assists the transformation of the initial two arcs into a single arc which is elongated and moved out onto diverging arc runners into a chamber which has controlled venting, where the arc is extinguished.

This case is a continuation of application Ser. No. 457,557, filed May 21, 1965, now abandoned.

Our invention relates to electric circuit breakers, and more particularly to circuit breakers of the current-limiting type.

The great increase in the use of electric power in recent years has necessitated the provision of electric power supply systems of steadily increasing capacity, with correspondingly greater potential for causing serious damage upon the occurrence of a fault which permits short-circuit currents to flow. It is, of course, the function of electric circuit breakers to interrupt such short-circuit currents. At such increased power supply levels, however, the provision of circuit breakers designed along conventional lines having adequate interrupting capacity presents increasing and at times insurmountable difficulties. In addition, and apart from the matter of interrupting capacity, it is frequently desirable to prevent fault-occasioned currents from attaining a magnitude before interruption approaching the possible maximum short-circuit current of the system. This is because, even though the current may eventually be interrupted by a circuit breaker, the passage of such high currents through other circuit components may cause damage to such components. Accordingly, it has often been necessary in prior art practice to supplement conventional circuit breakers with auxiliary current-limiting equipment.

It is a common practice, in recognition of the need just mentioned, to combine a circuit breaker with a current-limiting fuse, connected in series with it. Such circuit breaker and current-limiting fuse combinations, however, have several disadvantages. The use of fuses, which are one-time operating devices, and must be replaced after a single short-circuit interrupting operation, in a sense defeats the basic purpose of the electric circuit breaker, which is to provide a *repetitively operable* circuit protective device. In addition, the inclusion of current-limiting fuses in such combinations increases the cost of the device to approximately double that of the circuit breaker itself. Furthermore, it has been found desirable to include in such combinations means whereby the blowing of the current-limiting fuse mechanically causes opening of the circuit breaker. This is achieved only by the addition of further mechanism to the com-

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bination, which is expensive and which increases the possibility of malfunctioning of the device.

Although there have been attempts to provide circuit breakers which in themselves perform a current-limiting action as defined above, such attempts have been successful only to a limited extent. Thus the interrupting capacity of prior art current-limiting circuit breakers has not exceeded the maximum short-circuit current interrupting capacity of the afore-mentioned conventional prior art circuit breakers. The effective ceiling of current interruption of prior art contact operating circuit breakers in the commonly used commercial power range, i.e., 600 volts, 60 cycles, prior to the present invention, has been 25,000 amperes, with certain "special," and other large size breakers having interrupting capacities of 50,000 to 85,000 amperes. The interrupting capacity of prior art current-limiting circuit breakers, on the other hand, to our best knowledge and belief, has not exceeded 25,000 amperes at 600 volts.

The term "short-circuit interrupting capacity" is employed in accordance with customary usage in the art, to refer to the capacity of a circuit breaker to successfully interrupt a circuit in which a short-circuit condition exists, wherein the circuit is characterized by having a stated voltage and by having the ability to deliver current of a stated magnitude under such short-circuit conditions. Thus if a given circuit has a voltage of 600 volts, and is capable of delivering 25,000 amperes under short-circuit conditions, then any circuit breaker used in this circuit must have a "short-circuit interrupting capacity" of 25,000 amperes at 600 volts in order to provide effective protection to the circuit. The term "short-circuit interrupting capacity" does not, however, mean that the circuit breaker said to have such capacity must actually interrupt currents of the stated magnitude. This is because (a) the "prospective" short-circuit current is always below the "available" short-circuit current, and (b) a current-limiting breaker, by definition, maintains the let-through current substantially below both the "available" and "prospective" current levels. As used herein, the term "current-limiting" as applied to an electric circuit breaker, means that the circuit breaker is such that current flowing in the circuit during a short-circuit interruption ("let-through" current) is maintained substantially below the current that would flow at such a time if the circuit breaker were replaced by an impedance equal to that of the breaker in its closed condition ("prospective" current).

The term "prospective" current is to be distinguished from "available" current, which refers to the current which would flow if the power source were the only element in the circuit, i.e., if its output terminals were directly connected together by a zero-impedance connecting means ("zero load").

The term "electric circuit breaker" as used herein refers to a device utilizing cooperating contacts for interrupting an electric circuit.

Prior art current-limiting circuit breakers have not been able to achieve short-circuit interrupting capacities of over 25,000 amperes at 600 volts and above primarily because, in circuits having available short-circuit currents above this level, such as 50,000 to 100,000 amperes at 600 volts and above, the rate of rise of the short-circuit current is proportionately greater, and reaches high levels at such speed that the circuit breaker cannot perform a current-limiting action. As a consequence, repeated uncontrollable arc "retrogressions" occur (i.e., the arc, after having been elongated so as to develop an arc voltage opposing the driving voltage, restrikes at some more closely spaced points) the energy developed by the arcing current becomes excessive, and the breaker is destroyed. Such failure, moreover, cannot be avoided by simply

increasing the speed of contact-separation, as will be more fully explained hereafter.

It is a primary object of the present invention to provide a novel and improved circuit breaker of the type utilizing cooperating contacts operating in air which is usable in electric power systems in the range of 600 volts and above and which is able to interrupt available short-circuit currents substantially in excess of available currents which can be interrupted by present circuit breakers, as for example, currents of 100,000 to 250,000 amperes and upwards, with a current-limiting action, maintaining the let-through current at a value substantially below the prospective current maximum, and also maintaining the energy developed by the arc during interruption at a comparatively low level.

It is another object of the invention to provide an electric circuit breaker which is capable of performing a current-limiting function and which also provides the functions of a conventional non-current-limiting circuit breaker in permitting manual "off" and "on" switching operation and in being automatically operable upon the occurrence of abnormal current conditions irrespective of whether the operating handle is forcibly held in the "on" position (i.e., is "trip-free").

It is also an object of the present invention to provide an electric circuit breaker which is manually and automatically operable and which, upon automatic operation in response to the occurrence of short circuit conditions, is capable of separating its contacts at extremely high speed, such for example, as at a rate of acceleration of 1000 or more times the acceleration due to gravity.

To state the above-recited objects in another way, it is an object of the invention to provide an electric circuit breaker of the contact-operating type which, in addition to performing the functions of conventional prior art circuit breakers, is also able to perform functions comparable to those of current-limiting fuses.

Additional objects of the invention will in part become obvious and in part be pointed out in the following detailed description, and the scope of the invention will be pointed out in the appended claims.

In accordance with the invention, we provide a current-limiting circuit breaker having means for separating its contacts with an extremely high rate of acceleration. Combined with this high speed separation of contacts, we provide means for quickly elongating the total arc-column thereby generated, to create an arc voltage substantially in excess of the driving line voltage. The combination further includes means operating upon elongation of the arc-column for quickly raising and maintaining at a high-level the dielectric strength of the space previously occupied by the arc in its shorter condition. In addition, the circuit breaker includes means operating simultaneously with the dielectric strength maintenance means, for further increasing the resistance of the arc to current flow, with the result that the current is driven toward zero, resulting in extinction of the arc and complete interruption of the circuit.

In accordance with the invention in one form, the movable contact comprises a bridging contact member, normally engaging a pair of closely-spaced stationary contacts, whereby a pair of closely-spaced serially-related short arcs are created upon initial opening movement of the movable contact. The invention further comprises a two-part arc chamber including a relatively small substantially closed arc-initiation chamber portion and a contiguous relatively large arc-extinction chamber portion. The stationary contacts are positioned adjacent the "throat" or meeting area of the two chamber portions.

The walls of the arc-initiation chamber, and at least significant portions of the walls of the arc-extinguishing chamber are, moreover, constructed of a material having a high rate of "ablation" under the influence of the arc and of generating substantial quantities of gas. The term "ablation" refers to the transformation of a material from

a solid into a gas upon exposure to the action of an electric arc. Accordingly, a high gas pressure is generated in the arc-initiation chamber, which acts on the two short arcs, driving them together to form a single arc of substantially greater total length, and then propelling this elongated arc into the arc-extinguishing chamber and out along a pair of spaced arc runners provided in the arc-extinguishing chamber. This gas flow outward from the arc-initiation chamber, continues, moreover, even after the outward movement of the arc, thereby raising and maintaining elevated, the dielectric strength in the space between the stationary contacts. This outward flow of gas from the arc-initiation chamber is further supplemented by gas generated by the action of the elongated arc on the side walls of the arc-extinguishing chamber to maintain a high pressure of turbulent gas behind the arc, further accelerating its outward movement.

In a particular application of the invention, the outward movement of the arc is also further accelerated and controlled by the action of a magnetic field created by specially formed magnetic field and pole pieces magnetized by passage of current through windings thereon.

In the outer portion of the arc-extinguishing chamber, a plurality of arc-cooling plates are provided, into which the arc is driven. The arc cooling plates further increase the resistance of the elongated arc. The arc is maintained in the outer portion of the arc-cooling plates partly by the magnetic characteristics of its own path, which is generally loop-shaped, and also by continued gas pressure from behind its intermediate portions comprising residual flow of gases from the parts of the arc-initiation and arc-extinguishing chambers previously occupied by the arc, together with continuing generation of gas by the arc itself particularly at its opposite ends, which are "anchored" to the ends of the arc runners, which for this purpose are made to terminate in the arc-extinguishing chamber below the array of arc cooling plates.

In accordance with a preferred form of the invention, the insulation material of the arc-initiation and arc-extinguishing chambers comprises a solid material comprising oxygen, hydrogen, and carbon associated in such a way that when transformed into a gas by the action of an arc, the carbon combines with the oxygen to form carbon-monoxide with substantially no free carbon, and no metallic ions, and a substantial amount of free (uncombined) hydrogen is liberated in gaseous form.

For the purpose of moving the bridging contact in opening direction at high speed upon the occurrence of high short-circuit current conditions, we provide a novel low-reactance magnetic solenoid comprising a ribbon-type winding, acting on an armature which is especially shaped to minimize its mass without loss of magnetic force.

We further provide manually operable switching mechanism for operating the movable contact at will between open and closed circuit positions, and means connecting the switching mechanism to the movable contact in such a way as to permit the movable contact to be moved by the aforesaid solenoid independently of the inertia of the switching mechanism. According to this aspect of the invention, the connection between the switching and the movable contact comprises a "break-away" connection which permits the movable contact member to be completely mechanically disconnected from the switching mechanism upon initial movement of the contact member by the solenoid.

The invention will be more fully understood from the following detailed description, and its scope will be pointed out in the appended claims.

In the drawings,

FIG. 1 is a side elevation view of an electric circuit breaker incorporating the invention, certain portions of the enclosing casing and the magnetic pole structure being removed to show the parts, and certain portions being shown broken away for clarity;

FIG. 2 is a side elevation view, showing movable portions of the structure of FIG. 1 in a manually-operated "open" condition;

FIG. 3 is a side elevation view showing the moving parts in the condition which they assume upon operation by high short-circuit current;

FIG. 4 is a perspective view of the circuit breaker of FIG. 1, certain portions, including the manually operable handle, being omitted for clarity;

FIG. 5 is a view of a portion of the mechanism of FIG. 1, showing particularly the structure of the movable contact operating rod and its associated parts;

FIGS. 6, 7, and 8 are graphical representations of the arc current and arc voltage conditions of the circuit breaker of the present invention, of prior art current-limiting fuses, and of prior art conventional circuit breakers, respectively, during short-circuit interruption;

FIG. 9 is a chart showing certain electrical and physical parameters of the circuit breaker of the present invention as compared to prior art devices;

FIGS. 10 through 15 are semi-diagrammatic illustrations showing what is believed to be the behavior of the arc during the interruption of a short-circuit current by the circuit present invention.

Referring first to FIG. 1, the invention is shown as incorporated in an electric circuit breaker comprising an insulating casing 10 which is generally box-shaped, the side toward the observer being removed to show the interior. An incoming line terminal 11 is supported in the casing 10 by suitable means, not shown, and has connected thereto a conducting strap 12. A load terminal 13 is also supported in the casing 10 by suitable means, not shown, and has connected thereto a conducting strap 14.

Supported within the insulating casing 10 is a pair of stationary contact assemblies 15 and 16. Each of the stationary contact assemblies 15 and 16 comprises a main portion including outwardly diverging arc runner portions 15A and 16A. A stationary contact 15B is carried by the stationary contact assembly 15. Likewise, a stationary contact 16B is carried by the stationary contact assembly 16. A generally wedge-shaped movable contact member 17 is provided, having movable contacts 17A and 17B for cooperating with the stationary contacts 15B and 16B respectively.

The stationary contact assembly 15 is electrically connected to the strap 12 and the line terminal 11 through a coil 18 which is connected at one end of the conductive strap 12 by a screw 19 and at the other end of the stationary contact assembly 15 by a screw 20. A second coil 21 is connected at one end to the stationary contact assembly 16 by means of a screw 22 and at the other end is connected by means of a screw 23 to a solenoid winding 24. The solenoid 24 is connected at its other end by means of a conductor 25 to the conductive strap 14 by means of screw 26.

The current flow path through the circuit breaker is therefore as follows: beginning at line terminal 11, to strap 12, to blowout coil 18, to stationary contact assembly 15, to movable contact assembly 17, to stationary contact assembly 16, to blowout coil 21, to solenoid winding 24, to conductor 25, to conductor 14, to load terminal 13.

Referring particularly to FIGS. 1 and 2, manually operable switching mechanism is provided for moving the movable contact 17 at will into and out of engagement with the stationary contacts 15B, 16B. The switching mechanism in the embodiment illustrated comprises a manually engageable handle member 30 projecting through an opening 31 in the top of the casing 10. A generally U-shaped handle support member 32 is pivotally supported at each of its ends on a pair of fixed pivot pins 33, each fixedly supported in a corresponding side wall of the casing 10. Also supported on the pivot pins 33 are a pair of operating links 34, each having an elongated slot 35, receiving corresponding pins 36 carried by a generally toroidal or ring-shaped operating yoke 37.

The operating yoke 37 is slidably supported on a generally tubular fixed support 38 mounted in a hole in a generally planar fixed member 39, to be further described.

The operating yoke 37 carries connecting means shown in the form of a pair of elongated resilient return-bent spring clips or fingers 40 mounted thereto by threaded studs 41 which carry adjustable stop nuts 42 and 42' adjacent the outer ends thereof for adjustably positioning the free ends of the clips 40. The spring clips 40 terminate in return-bent end portions 43 providing cam-follower portions which releasably engage a grooved portion 44A of a boss or enlargement 44 fixedly attached to contact carrying means in the form of movable contact operating rod 45, to which the movable contact 17 is attached in a manner to be described. The portion 44A provides a detent or cam surface for the portions 43. The contact operating rod 45 has a solenoid plunger or armature 46 attached thereto in a manner to be described and slidably supported within the tubular member 38. The resilient fingers 40 thus serve to releasably connect the switching mechanism to the contact carrying rod 45.

A pair of operating springs 47 are provided which are connected at their upper ends to the upper portion of the handle support member 32 and are connected at their lower ends to pins 48 carried by the operating links 34 respectively. When the parts are in the "on" condition, as shown in FIG. 1, the line of action of the operating springs 47 lies to the left as viewed of the pivot pin 33, and therefore the springs 47 bias the operating links 34 clockwise about the pivot pins 33, and urge the yoke 37 to the left as viewed. This force is transmitted through the clips 40 to the operating rod 45 and the movable contact 17.

When the operating handle is moved clockwise to the "off" position as shown in FIG. 2, the line of action of the operating springs 47 lies to the right as viewed of the pivot pin 33, and biases the operating links 34 counterclockwise moving the yoke 37 and the contact operating rod 45 to the open position.

Automatic opening of the contacts takes place independently of the manual operating mechanism just described in the following manner. On the occurrence of sufficiently high over-load conditions, the overload current traversing the solenoid winding 24 establishes sufficient magnetic flux to draw the solenoid plunger 46 to the right as viewed in FIGS. 1-3 at high speed. Although the force of the solenoid under such conditions is much greater than that of the operating springs 47, the operating mechanism is not moved to the open circuit position when this occurs. Instead, the plunger 46, the operating rod 45 and the movable contact 17 move without being impeded by the inertia of the manually operable mechanism parts, by reason of the resilient action of the spring clips 40 which permits the boss or enlargement 44 to spread the spring clips 40 slightly by cam action and to pass therebetween although the spring clips remain in substantially the same position, the parts then moving to the automatically opened condition as shown in FIG. 3. It will be observed that when this occurs, the forward ends 43 of the spring clips 40 close around the forward end of the boss 44, and retain the movable contact assembly from moving back or rebounding toward closed circuit position. By means of high-speed moving pictures, it has been determined that the gripping portions 43 of the clips 40 are actually thrown apart by the high acceleration of the movable contact assembly, so that during the opening movement of the movable contact they present no impedance whatever thereafter to the motion of the contact member in opening direction. They return to closed condition, however, before the movable contact assembly rebounds toward closed condition.

Following automatic opening, the mechanism may be

reset to permit reclosing simply by moving the operating handle 30 to its normal off condition, thereby returning the ends 43 of the spring clips 40 into engagement in the groove 44A of the boss 44. The circuit breaker may then be reclosed by returning the handle to its on position as shown in FIG. 1.

Certain aspects of the operating mechanism of the circuit breaker disclosed herein are also disclosed and claimed in co-pending application Ser. No. 801,883, filed Oct. 10, 1968, said application also being a continuation in part of the aforesaid application Ser. No. 457,557, filed May 21, 1965, and now abandoned.

For the purpose of maintaining the reactive impedance of the solenoid coil 24 at a minimum, this coil is wound from a conductor in the form of a relatively wide thin ribbon, as shown in FIG. 1. The reluctance of the path for the flux associated with the solenoid 24 is furthermore made extremely low by a box-type low magnetic reluctance field structure comprising the front plate 39, a corresponding back plate 50, top and bottom plates 51, 52, and a generally right circular cone-shaped intermediate field piece 53. It will be observed that the flux path associated with the solenoid 24 extends entirely through low magnetic-reluctance material throughout its closed loop except for the small gap provided by the tubular member 38 extending between the front plate 39 and the solenoid plunger 46, and the air-gap 54 existing between the solenoid plunger 46 and the adjacent surface of the truncated conical field piece 53.

With the novel solenoid construction shown and described, movable contact acceleration forces have been achieved which are calculated to be at least 1500 G's, or 1500 times the acceleration due to gravity.

For the purpose of arresting the high speed travel of the solenoid plunger 46, a stop cushion 53' is provided on the face of the conical field piece 53, preferably constructed of a durable resilient material such as neoprene.

As shown particularly in FIG. 5, the solenoid plunger 46, although generally cylindrical in shape has one end face thereof provided with a generally conical recess 46A. It has been found that this configuration affords the maximum effective distribution of the mass of the plunger 46. In other words, although the provision of additional low magnetic reluctance material in this region might be expected to reduce the total reluctance and therefore increase the effective flux of the solenoid, it has been found that the addition of this material and its inertia, at the ultra-high speed opening rates achieved, is deleterious rather than helpful.

The design and construction of the contact operating rod 45 and its connection to the movable contact member 17 is also such as to afford the maximum contact opening speed. Thus the operating rod 45 preferably comprises a relatively thin-wall tubular member thereby maintaining its mass at a minimum for the strength required. The rod 45 is connected to the contact member 17 by lost-motion connecting means, and the forward end of the operating rod 45 is provided with a pair of elongated slots 55, which receive outwardly directed pins 56 carried by a projecting stem 57 attached to the movable contact member 17. A light compression spring 58 is also provided within the forward part of the operating rod 45 between the end of the stem 57 and a pin 59 which serves to attach the boss 44 to the rod 45. In the "on" condition of the circuit breaker, the spring 58 is slightly compressed by the action of pin 59, so that the rod 45 is biased away from the contact 17 and the pin 56 is normally spaced to the right of the left end of the slot 55. This permits a small amount of pretravel of the operating rod 45 in opening direction before it engages the pins 56, thereby providing an "impact opening" action. This action permits the operating rod 45 to achieve an initial momentum in the opening direction which is transferred to the movable contact with impact action.

The rod 45 is also connected to the armature 46 by lost-motion connecting means. For this purpose, the right hand end of the operating rod 45 is also provided with a pair of elongated slots 60 which receive a pin 61 carried by the solenoid armature 46. A light compression spring 62 extends between the pin 59 and the pin 61 to bias the armature 46 away from the rod 45. This construction permits a small amount of overtravel of the operating rod and the movable contact 17 beyond the point where the motion of the solenoid armature 46 is arrested. By this means, the total travel of the solenoid armature 46 is slightly less than the total contact opening movement of the movable contact 17. In other words, the movable contact and its operating rod 45, are in a sense, "thrown" to the full open position.

It will also be observed that the final position of the solenoid armature 46, as shown for example in FIG. 3, is *not* the position which establishes the maximum-flux, minimum-reluctance, condition of the solenoid parts as might be expected. Instead, the maximum-flux, minimum-reluctance condition is established by an armature position *intermediate* the normal position shown in FIG. 1 and the final full operated position shown in FIG. 3. With this arrangement, the solenoid 24 develops its maximum opening force at a time when the movable contact assembly comprising the rod 45 and the movable contact 17, is in motion, and susceptible of increased acceleration. In other words, maximum acceleration of the movable contact during its initial travel, when it is most important, is achieved by this arrangement. The remaining desired travel of the movable contact is achieved by the "throwing" action just described.

It will be observed that by means of the solenoid construction, with low reactance and low mass of moving parts, and minimum required travel, combined with the novel low inertia construction of the means connecting the solenoid to the movable contacts, and further combined with the means for moving the movable contact assembly independently of the inertia of the manual operating mechanism, the structure disclosed and described achieves a basic requirement of a highly efficient current-limiting circuit breaker, that is, ultra-high speed opening of the contacts upon the occurrence of short-circuit conditions.

ARC HANDLING: CREATION, MAINTENANCE, ELONGATION, PREVENTION OF RETROGRESSIONS, AND EXTINCTION

In accordance with the invention, we have discovered that virtually ideal current-limiting interrupting action may be achieved in a contact operating device operating in air, only when the following objectives are achieved: (1) high speed creation of an arc following the incidence of a short-circuit; (2) transformation of the initially created arc to an arc of substantial length with accompanying development of an arc voltage-drop substantially *greater than* the driving line voltage within 3 milliseconds from incidence of a short-circuit; (3) maintenance of an arc voltage-drop substantially greater than the applied line voltage until the current is reduced to zero and extinguished. In accordance with the invention, we provide a structure which achieves the aforesaid objectives in a manner and to a degree not approached by prior art "current-limiting" contact operating devices. The structural means for achieving objectives (2) and (3), is embodied in the novel contact chamber and arc-chute construction to be described. In this connection, reference will be had particularly to FIGS. 1 and 4 and the semi-diagrammatic FIGS. 10-15.

As previously described, the stationary contact assemblies 15 and 16 comprise main body portions supporting stationary contacts 15B and 16B respectively, and including outwardly diverging arc runner portions 15A and 16A. In accordance with the invention, these assem-

blies are associated with a two-part arc chamber comprising, referring to FIG. 1, an arc-initiation chamber 63 includes a generally C-shaped enclosing member 65 of insulating material of a nature to be described, having an opening 66 in the back wall thereof which closely receives the operating rod 45. The opposite sides of the arc initiation chamber 63 are closed by portions of a pair of insulating arc chute side wall members comprising a pair of plates of insulating material 67 to be described. It will be observed that the arc-initiation chamber 63 is entirely enclosed except in the direction of the arc-extinguishing chamber.

The arc-extinguishing chamber portion 64 is formed by portions of the side plates 67, which close its opposite sides, and also by the arc runners 15A, 16A, and by insulating pieces 67' (see FIGS. 10-15). Supported between the arc chute side plates 67, are a plurality of arc cooling plates 68, all of which are substantially the same length, except, as shown in FIG. 1, the end plates 68A, which are slightly longer than the remaining plates, for a purpose to be described. The arc cooling plates 68 are preferably constructed of copper or brass, since it has been discovered that the use of these materials greatly reduces the throwing off of molten metallic particles as compared to similar plates of iron or steel.

The arc chute side plates 67 are preferably backed up by a pair of reinforcing plates 67C (only one shown in FIG. 4). The arc chute side plates 67 are also provided with inwardly extending portion 67A at the front part thereof which include outwardly diverging slots 67B. The inwardly extending portions 67A abut each other and form a barrier between the arc extinguishing chamber 64 and the outside, the slots 67B acting as restricted outlets to provide controlled venting, as will be further described in connection with FIGS. 10-15. The arc chamber parts described, including the stationary contact assemblies 15 and 16 are maintained strongly in assembled relation by suitable bolting means not shown, extending through openings 67D.

In accordance with one aspect of the invention, the arc chamber enclosing insulating elements comprising the generally C-shaped member 65 and the arc chute side plates 67 are constructed of a material, to be described more fully hereinafter, having a high rate of gas generation by ablation when exposed to the intense heat of an electric arc. Furthermore, the material ablates without any observable residue or by-products left on the surface thereof or on adjacent metallic parts, and without dielectric deterioration of the remaining surface. It is important to note that no ceramic or refractory materials are used in the arc chute area. This is because such materials commonly comprise oxides of aluminum which, when vaporized by the action of the arc, liberate gases which include atoms of aluminum. Such metallic atoms are readily ionized, and therefore make it more difficult to avoid arc retrogressions.

Novel magnetic arc blow-out means is also provided, as shown particularly in FIGS. 1 and 4, comprising the coils 18 and 21 previously described and magnetic core pieces 69 and 70 extending through the coils 18 and 21 respectively. The cores 69 and 70 are interconnected by a pair of field or pole pieces 71 and 72, bolted thereto through the openings shown. Each of the magnetic field pieces 71 and 72 is of generally Y-shaped configuration and is provided with a pair of outwardly diverging angularly directed pole extensions 73, as shown particularly in FIG. 4. The pole extensions 73 are tapered in thickness from a relatively thick portion adjacent the corresponding field pieces 71, 72 to a relatively thin outer portion as shown, the pieces being shaped so that the surfaces adjacent the arc chute side plates 67 are substantially co-planar therewith, and the outer surfaces are tapered inwardly. This shaping of the pole pieces 73 serves to concentrate the generated magnetic flux at the region which is most critical to the proper handling of the created arc, in a manner

to be described. In addition, each of the pole pieces 72 includes generally lozenge-shaped bosses or flux-intensifiers 72A which project very close to the points of initiation of the two original arcs.

5 SHORT-CIRCUIT INTERRUPTION BY THE CIRCUIT BREAKERS OF THE PRESENT INVENTION

The operation of the circuit breaker of the present invention in interrupting a short-circuit current, together with the presently conceived theory applying thereto, will be described in connection with FIGS. 10-15. Following description of this interrupting operation, the theory will be correlated with a reproduction of an actual oscillogram of a short-circuit interrupting operation achieved by the circuit breaker incorporating the invention. It must be appreciated that the process of electric current interruption by the creation and control of arcing in a gas such as air, is, at the present stage of the technology, an art, rather than a science. There is much about the subject which is not fully understood, and many of the advances which have been made have been achieved primarily by strictly empirical methods. The discussion of the operation of the circuit breaker of the present invention, insofar as it relates to arc behavior and control, must therefore be considered in this light. The interpretations put herein upon the remarkable results obtained by the present invention, accordingly, may be subject to later correction or modification in the light of possible more elaborate future analysis of the operation of the circuit breaker of the invention which may be made possible by removing or decreasing the limitations of presently available test instrumentation.

FIG. 10 shows the condition of the contacts which is believed to exist immediately following initial opening movement of the movable contacts 17. At this time a pair of serially related arcs 75 are created between the corresponding movable and stationary contacts 17A-15B, 17B-16B. The presence of these arcs causes the adjacent material of the side plates 67, and of the member 65 to ablate, i.e., to be transformed into a gas. Since the adjacent space is enclosed in all directions except the left direction as viewed, a relatively high pressure is developed in the arc-initiation chamber 63. At the same time, the ionized gases associated with the arcs 75, radiating in all directions, cross each other in the throat region between the stationary contacts 15 and 16. The presence of these ionized gases, combined with the force exerted on the arcs 75 by the pressure in the chamber 63, immediately transforms the two arcs 75 into a single substantially longer arc 76 as shown in FIGURE 11. This action achieves another basic necessity of an ideal current-limiting circuit breaker, that is, high speed creation of an arc of substantial length. It has been found to be of critical importance that the arc be created of substantial length at ultra-high speed, not only because such longer arc has a greater arc voltage drop, but because it then enables the associated magnetic blow-out means to act effectively, since the effect of such magnetic blow-out means is directly proportional to the length of the arc upon which it acts.

As shown in FIG. 12, the substantially longer single arc 76 is maintained, although the arc voltage drop across such longer arc is greater than the voltage which was previously sufficient to maintain two shorter arcs, and restriking of the shorter arcs is prevented (1) by the build-up of high dielectric strength between the movable and stationary contacts 17A-15B and 17B-16B, and (2) by the continuing flow of gases generated in chamber 63. Such continuing flow of gas is thought to be partly due to the pressure previously stored therein, as well as to a continuing ablating action because of the high heat of the movable and stationary contacts at this time, which, by radiation and conduction, acts on the insulating parts to continue the ablating action.

As shown in FIG. 13, the single arc 76 is further greatly elongated and moved outwardly toward the plates 68 by the magnetic blow-out action. When the arc reaches the position shown in FIG. 13, it engages the edges of the arc cooling plates 68, and thereafter, as shown in FIG. 14, the arc enters the series of plates 68 and becomes a series of short arcs. It will be observed that, in accordance with the invention, the arc cooling plates 68A at each end of the assembly are extended slightly and brought relatively close to the end portions of the arc runners 15A and 16A respectively. It has been determined by examination of samples following short-circuit interrupting operations, that a large amount of ablation of the side-plate material occurs at these points, indicating that the ends of the arc remain anchored at these points, contributing a substantial amount of stability and symmetry to the arc during the final stages of the interrupting process.

As shown in FIG. 15, the final condition of the arc is adjacent the outer ends of the cooling plates 68, with the ends of the arc remaining anchored between the inner ends of the plates 68A and the outer ends of the arc chute runner 15A, 16A. The arc (or series of arcs) is maintained in the position of FIG. 15 throughout its intermediate portion by the "baffle" provided by the meeting parts 67A, previously described. The outer edges of the plates 68 are closely adjacent the portions 67A, at points between adjacent slots 67B. Although the edges are preferably very close to the parts 67A at these points, they may not be directly in contact, since the arc will not readily strike through a greatly restricted space such as a crack. The "baffle" 67A also serves an important function in controlling the speed of egress of gases from the chamber 64.

Although the arc interrupting process has been described in a number of separate steps, it will be appreciated that the entire interrupting time, from the point of incidence of a short-circuit condition to the point of zero current, that is, complete extinction, requires only the time in the neighborhood of 1.3 milliseconds, or about one thirteenth part of a complete cycle in a conventional 60 cycle AC current. By comparison, and as indicated in the chart of FIG. 9, the shortest interrupting time achieved by prior art non-current-limiting circuit breakers is 22.5 milliseconds, and by prior art current-limiting circuit breakers, 8.33 milliseconds, or over 6 times as long.

Because of this ultra-high speed opening action it has been found that, contrary to accepted prior art circuit breaker practice, the contacts need not be of highly refractory material. In addition, the arc cooling plates 68 and 68A are preferably constructed of brass, rather than steel, since, as previously mentioned, it has been found that brass, in contrast to steel which is commonly used in prior art circuit breakers, does not have the characteristic of "sputtering" or throwing off hot molten particles when subjected to the action of a high current arc.

Ultra-high speed of opening and interrupting of the arc also permits the use of a material for the arc enclosing box portion 65 and the arc chute side plates 67 which has an extremely high rate of ablation under the effects of an arc. If the interruption were not achieved in the extremely short time described, material of such high ablation rate would be substantially completely destroyed by the arc, and would not be serviceable for repeated operations.

Finally, the initiation and extinction of the arc at the extremely high speeds achieved in accordance with the present invention has the highly important advantage of reducing to a minimum the length of time during which actual arcing occurs. This is important, from the point of view of keeping to a minimum the amount of energy which must be absorbed or dissipated, and equally importantly, it reduces to a minimum the factors which tend to cause retrogressions of the arc, that is restriking

of the arc after an initial elongation, back at a point where its voltage is lower. Thus the present invention deals with the problem of preventing retrogressions, firstly, by reducing the length of time during which the factors tending to cause them exist, and secondly, by quickly removing any contaminating or ionized gases from the point of initial arc inception and by keeping this area free from such contamination until the arc is finally elongated and extinguished. This is achieved, moreover, without the necessity of stored pressurized gases, dielectric liquids, or other extraneous media often used in prior art breakers.

The material used in the arc chute area may be any suitable material having the ablating characteristics described. Thus embodiments of the invention have been constructed using vulcanized fiber material in the arc chute area. These devices successfully interrupted available short circuit currents at 600 v. of about double the value which can be interrupted by conventional circuit breakers. Thus, for example, a circuit breaker constructed in accordance with the invention successfully interrupted short circuit current on a 600 volt system having an available short circuit capacity of 50,000 amperes. As previously noted, conventional breakers are usable to successfully interrupt more than 25,000 amperes at 600 volts.

It has been discovered, however, that when a particular type of material is utilized, the ability of the circuit breaker of the invention to interrupt available short circuit currents is increased by a factor of about 6 times over conventional breaker ability. The type of material referred to is that designated generally by the chemical name of acetal resins, and particular "polyoxymethylenes." Thus in the form of the invention the short circuit current interrupting action of which is illustrated in FIG. 6, the insulating material for the arc chute sideplates and for the arc chute pressure chamber comprises a material such as described in Pat. No. 2,768,994 issued Oct. 30, 1956. This material is a polyoxymethylene polymer having recurring $-\text{CH}_2\text{O}-$ units. When transformed into a gas by the action of an electric arc, it is believed that the carbon atoms combine with the oxygen atoms to form carbon-monoxide, leaving substantially no free carbon atoms, and liberating a substantial amount of hydrogen in gaseous form.

Although this material is a thermoplastic material, and would ordinarily not be considered suitable for use in an open arc chute construction, it has been found that in the current-limiting circuit breaker of the present invention, the interrupting process takes place with such speed that no perceptible thermal distortion and no excessive ablation takes place. Thus, circuit breakers in accordance with the invention, incorporating this material have been successfully operated repeatedly on systems having available short-circuit current values of 100,000 amperes at 600 volts.

In such tests, it has been found that on the first operation of the circuit breaker one or two arc retrogressions may occur, but such retrogressions are quickly corrected, and the successful interruption results. On tests immediately following the initial test, no retrogressions occur. After the material has been allowed to stand for a substantial period of time such as two weeks, retrogressions have been found to occur on the first test, but such tests are nevertheless successful. On successive tests, no retrogression occur.

The following chart indicates the performance of the circuit breaker of the invention in comparison with prior art breakers, in terms of ability to interrupt "available" short circuit currents at 600 volts:

Device	"Available" short-circuit current
(1) Prior art molded case circuit breaker	25,000
(2) Circuit breaker of the present invention using vulcanized fiber arc chute material	50,000
(3) Circuit breaker of the present invention using acetal resins	150,000

It will be observed that (1) the circuit breaker of the present invention, even with conventional materials used in the arc chute area, has *double* the short-circuit interrupting capacity of prior art breakers, and that (2) the circuit breaker of the present invention, with acetal resin arc chute material, has *six times* the interrupting capacity of prior art breakers, and *three times* the capacity of the circuit breaker of the present invention using conventional arc chute materials.

In accordance with the presently conceived analysis of the operation of the invention, it is believed that the exceptional performance of acetal resin is due primarily to their characteristic of producing uncontaminated hydrogen gas upon exposure to an arc. By "uncontaminated" is meant that (1) there is a minimum of uncombined or free carbon, and (2) there is a minimum or total absence of other ionizable gaseous components, and (3) there is a total absence of metallic vapors. In addition, acetal resins produce such hydrogen at relatively high rates under the action of the arc. Using this material, pressures within the arc chamber have been achieved which are calculated to be in the neighborhood of 1000 p.s.i. during the arc interruption process. It is important to note, however, that the liberation of a large quantity of gas does not in itself result in the exceptional performance levels achieved with the use of acetal resins. Other materials, such as vulcanized fiber, also liberate gases in large quantity under the influence of the extremely intense arcs produced by the invention. Such materials, however, as noted above, while giving performance far exceeding that achieved by conventional circuit breakers, do not approach the high values achieved with acetal resins.

Acetal resins have been used in the prior art in certain arc extinguishing devices, notably fuses, lightning arresters, and also in movable-contact type devices comprising oil-immersed circuit breakers. By means of the combination of such materials with the novel arc-producing and controlling means and gas-controlling structure of the present invention, however, a true current-limiting action has now been achieved in air circuit breakers, capable of operating at power magnitudes previously achieved only by current-limiting fuses.

The current-limiting short-circuit interrupting action of the circuit breaker of the present invention is shown in FIG. 6, which is a reproduction of an oscillogram showing arc current and arc voltage conditions during the process of interruption of a short-circuit current by a circuit breaker constructed in accordance with the invention.

In the test, the results of which are shown in the oscillogram of FIG. 6, the circuit breaker was connected to a power source of 600 volts and having an available short-circuit current of 32,000 amperes.

Time lapse from the incidence of the short-circuit condition is indicated in milliseconds on the abscissa of FIG. 6. Curve I_A represents the instantaneous current value of the arc. Curve E_A represents the instantaneous voltage as read between the stationary contacts. Curve E_G is drawn in to represent the instantaneous value of the source voltage.

Measured from the instant of incidence of the short-circuit condition, the movable contact required only 0.67 millisecond (time T_1) to move far enough to draw a pair of arcs.

The two arcs were transformed into a single arc having an arc voltage drop substantially exceeding the source voltage in 0.46 additional millisecond (time T_2). Specifically, the arc voltage reached a value of about 1050 volts at this time, exceeding source voltage by about 300 volts.

It will be observed that at this point the rising current I_A was halted and its slope was reversed. The arc was maintained in a high resistance condition from this point until it was completely extinguished in 1.42 additional milliseconds (time T_3).

The entire time required from incidence of short-circuit condition to complete extinction of the arc was about 2.55 milliseconds. Parenthetically, it will be noted that the time to interrupt, in this instance, is longer than the time to interrupt in the case for which figures are listed in the first line of the chart of FIG. 9. This is explained by two differences in these tests. Firstly, the test involved in the FIG. 9 chart (line 1) is a 3-phase test, which for certain technical reasons is an "easier" test than the single-phase test illustrated in FIG. 6. Secondly, the circuit involved in the FIG. 9 test having 280,000 amperes available at 600 volts is necessarily a less inductive circuit than the circuit of the FIG. 6 test which has only 32,000 amperes available at 600 volts since both have about the same power factor (about 15%). A less inductive circuit is much easier to interrupt, since the inductive voltage opposing interruption is much lower. This explains the apparent paradox of a higher magnitude available short-circuit current being interrupted in a lesser time, a phenomenon which is characteristic of true current-limiting devices.

In tests comparable to that of FIG. 6, prior art current-limiting fuses perform their interrupting action in about the same total time, while conventional non-current-limiting circuit breakers, as illustrated in FIG. 8, require about 22.5 milliseconds to interrupt, or about 8 times as long.

It will be seen that the current and voltage conditions during interruption by the circuit breaker of the present invention, as shown in FIG. 6, resemble quite closely the corresponding conditions existing during interruption by a current-limiting fuse, shown in FIG. 7.

For further comparison, corresponding current and voltage conditions during interruption by a conventional, non-current-limiting circuit breaker is shown in FIG. 8. On the scale of FIG. 8, the time T_T represents the time required for interruption in accordance with the present invention, which compares to T'_T the time required by a conventional circuit breaker.

Likewise, the magnitude of let-through current for the present invention is represented by M_1 , while the magnitude reached in a comparable interruption by a conventional circuit breaker is represented by M_2 .

It will be further observed that in an interruption by a conventional circuit breaker at the currents and voltages involved here, the contacts of a conventional circuit breaker do not separate to draw an arc until about 8.6 milliseconds, or about one-half cycle of a 60-cycle wave. By contrast, the breaker of the subject invention opens its contacts and draws an arc in about 0.67 millisecond, or about one twenty-fifth of a 60-cycle wave, as indicated at T_1 in FIG. 6.

Although the short-circuit interruption action of the circuit breaker of the present invention causes the arc current and voltage to closely follow a pattern similar to that of a current-limiting fuse, the mechanism by which this is achieved is quite different from that operating during interruption by a current-limiting fuse. Thus, in a current-limiting fuse, a pulverant filler or powder of siliceous material is utilized, which is melted and fused by the action of the arc into a solid glassy body known as a "fulgerite." This action absorbs much of the energy of the arc. It will be observed that this mechanism is, by its nature, a one-time operating phenomenon, and that the control and extinction of the arc in air, as described previously herein, is repetitively operable, and quite different from the fuse operation.

While the invention has been described in only one particular form, it will be appreciated that many modifications thereof may be made without departing from the spirit of the invention. Thus, for example, the manually-operable handle 30 may be replaced by an automatically-operable member, to provide a remotely operable device or "contactor." Likewise, such operating means may be supplemented by means causing opening operation of the handle 30 or an equivalent member automatically upon the occurrence of abnormal current conditions through

the circuit breaker which are below the "short-circuit" level.

We therefore intend, by the appended claims, to cover all such modifications as fall within the true spirit and scope of the invention.

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

1. A high-speed current-limiting electric circuit interrupter which is capable of operating with current-limiting action at substantially high available short circuit current values such as 10,000 to 100,000 or more amperes at substantially high voltages such as 200 to 600 or more volts and of the type having contacts operating in air comprising in combination:

- (a) a pair of elongated electrically conductive arc runners having first end portions spaced relatively closely together, said arc runners diverging outwardly from said first end portions to relatively widely spaced second end portions;
- (b) insulating means including side wall members extending between said arc runners and defining with said arc runners a generally V-shaped relatively large arc extinguishing chamber;
- (c) enclosing means defining a relatively small arc extinguishing chamber adjacent said first end portions of said arc runners, said arc initiation chamber having all sides thereof substantially closed except the side thereof communicating with said arc extinguishing chamber;
- (d) said first end portions of said arc runners extending into said arc initiation chamber, each of said first end portions carrying a stationary contact thereon within said arc initiation chamber;
- (e) a movable contact-bridging member having a pair of contact surfaces, means supporting said contact-bridging member in said arc initiation chamber for movement toward and away from said side of said arc initiation chamber communicating with said arc extinguishing chamber between a closed circuit position in which said contact surfaces thereof engage said stationary contacts respectively and an open circuit position in which said contact surfaces are out of engagement with said stationary contacts, there being a relatively small clearance between said movable contact bridging member and said arc initiation chamber, and said movable contact bridging member in said closed circuit position substantially closing said open side of said arc initiation chamber;
- (f) magnetic field producing means for moving an arc drawn between said arc runners outwardly along said arc runners from said first end portions toward said second end portions;
- (g) said side walls of said arc extinguishing chamber and at least a portion of said sides of said arc initiation chamber being composed of an insulating material generating arc extinguishing gas when subjected to the action of an electric arc, and
- (h) high speed electromagnetic operating means connected to said contact-bridging member for operating said contact-bridging member from said closed

to said open circuit position on the occurrence of current of predetermined value.

2. A high-speed current-limiting electric circuit interrupter as set forth in claim 1 wherein said interrupter also comprises an insulating baffle member closing the outer opening of said arc extinguishing chamber adjacent said second ends of said arc runners, said baffle member having a plurality of relatively narrow slots extending therethrough in the direction of flow of arc gases from said arc extinguishing chamber.

3. A high-speed current-limiting circuit breaker as set forth in claim 1, said circuit interrupter also comprising a plurality of metallic arc cooling plates supported in said arc extinguishing chamber, said arc cooling plates being aligned in equally spaced apart relation in a row adjacent said second ends of said arc runners.

4. A high-speed current-limiting circuit breaker as set forth in claim 2, said circuit interrupter also comprising a plurality of metallic arc cooling plates aligned in equally spaced relation in a row adjacent said second ends of said arc runners, each of said plates being positioned between a corresponding pair of slots in said arc baffle, and the width of said slots being substantially less than the spacing between said arc cooling plates.

5. A high-speed current-limiting electric circuit interrupter as set forth in claim 3, wherein the end plates in said row of plates have portions thereof extending in a direction toward said stationary contacts substantially below the line defined by the lower edges of the remaining plates to a point closely adjacent said arc runners.

6. A high-speed current-limiting circuit interrupter as set forth in claim 1 wherein each of said stationary contacts is positioned at an angle to its respective arc runner in diverging relation to the other of said contacts, and wherein said bridging contact comprises a generally wedge-shaped contact member having contact bearing surfaces inclined toward each other in the direction of said arc extinguishing chamber.

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