Aug. 4, 1953 D. M. UMPHREY 2,647,973

CIRCUIT INTERRUPTER

Filed July 18, 1949 2 Sheets-Sheet 1

Fig. 1.

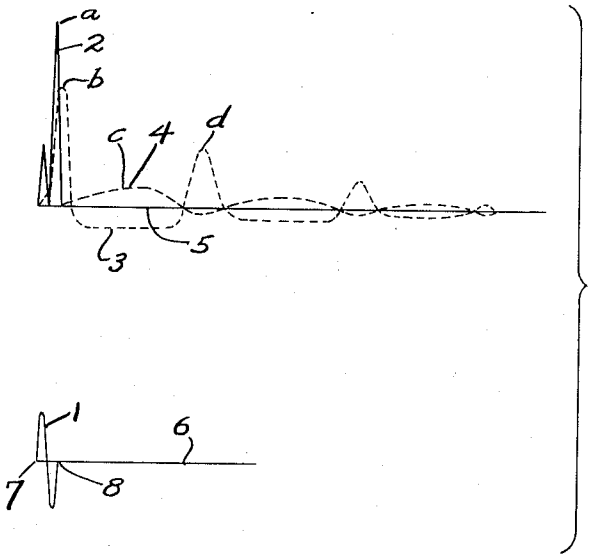


Fig. 10.

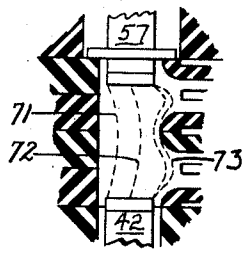
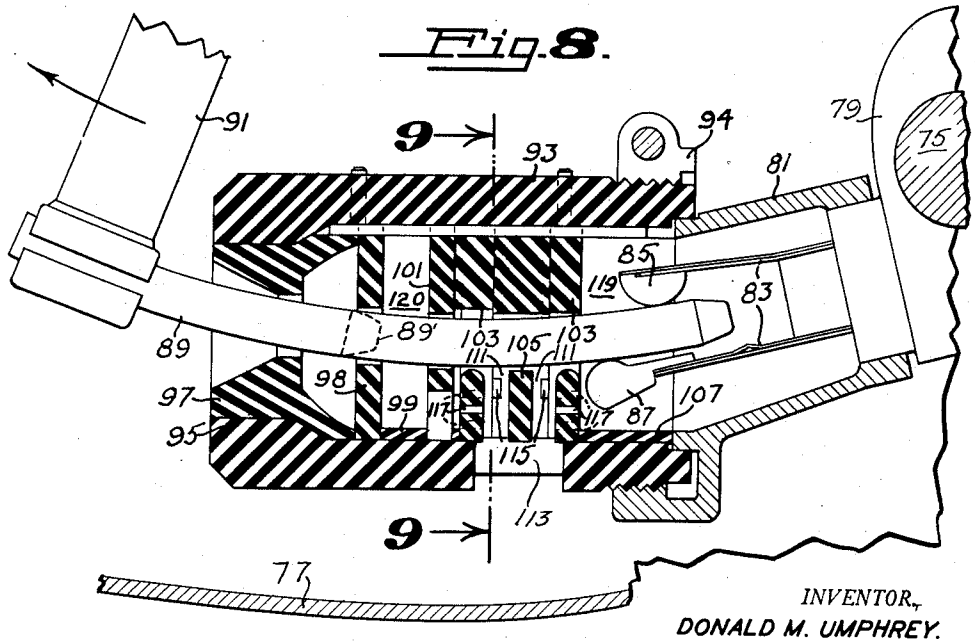


Fig. 8.



INVENTOR,
DONALD M. UMPHREY.
BY Lippincott & Smith
ATTORNEYS.

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Fig. 2.

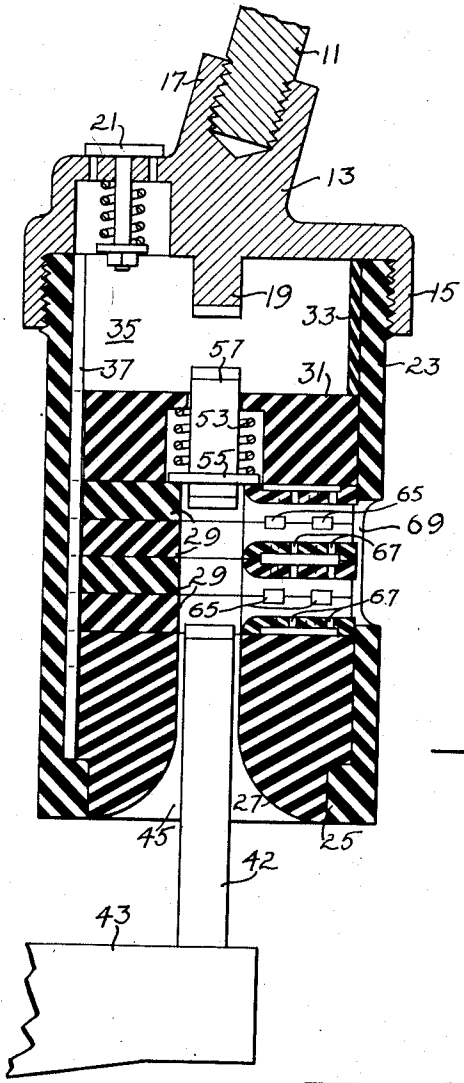


Fig. 3.

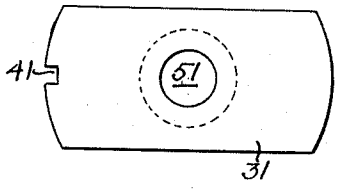


Fig. 4.

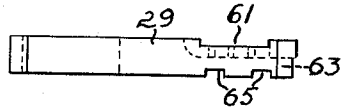


Fig. 5.

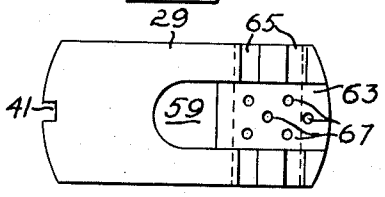


Fig. 6.

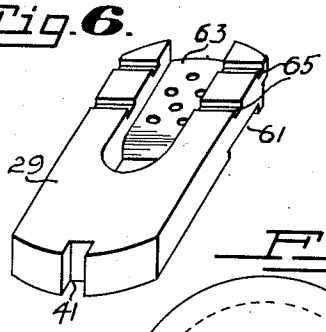


Fig. 7.

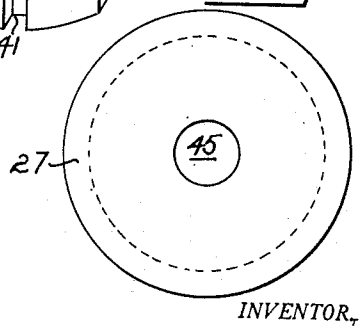
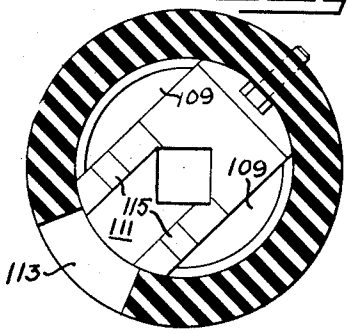


Fig. 9.



INVENTOR,
DONALD M. UMPHREY.
BY Lippincott & Smith
ATTORNEYS.

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CIRCUIT INTERRUPTER

Donald M. Umphrey, Palo Alto, Calif., assignor to Pacific Electric Manufacturing Corp., a corporation of California

Application July 18, 1949, Serial No. 105,388

12 Claims. (Cl. 200—150)

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This invention relates to circuit interrupters or breakers and is particularly adapted to such equipment for use on high voltage high power systems, although it is applicable to use on power circuits where the duty is not so severe.

Interrupting a short circuit on a system of the type for which this invention is primarily designed presents difficult engineering problems. Modern power networks are tending to higher voltages and greater and greater connected loads, with correspondingly greater connected short circuit capacity. On such a system the currents to be interrupted may be as high as 25,000 to 100,000 amperes or more, with voltages in excess of half a million acting to restrike the arc consequent upon the break, once it has been extinguished. In order to reduce the space necessary to withstand the high voltages applied to the interrupters and to assist in quenching the arcs, the interrupters are customarily immersed in oil or other liquid of high dielectric strength, and a number of gaps are opened in series. Even under these conditions the energy liberated in the break is very large, and the period within which it is liberated is so short that the effects are of explosive violence from which very serious chemical and physical effects may ensue.

The temperatures to which the oil or other dielectric liquid is subjected in the arc stream rise to over 6000 degrees Fahrenheit, which tends to cause carbonization or "cracking" of the oil, reducing its dielectric strength and decreasing its effectiveness in withstanding the potentials imposed by future breaks. This effect becomes increasingly serious in accordance with the time that such temperatures are permitted to persist. Such oil as comes within the influence of the arc is almost instantaneously vaporized, resulting in very high pressures and pressure gradients and the generation of serious shock waves which, with interrupters operated under heavy duty, have been felt at distances of half a mile or more from the point at which the interruption occurred. The effects of these waves may manifest themselves in several ways; interrupters have been known to explode and destroy the building wherein they were situated, and since the dielectric liquid used is usually oil, this presents a serious fire hazard, not only to the breaker itself, but to all surrounding property. Upon other occasions the shock has been known to lift a circuit breaker weighing 150,000 pound four inches from its supports, and to stretch as many as four hold-down bolts over one inch in diameter simultaneously.

All of these results, which are manifested to a

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greater or less degree in the best interrupters available to the prior art, are obviously to be avoided if possible. Accordingly, among the objects of my invention are to provide a circuit interrupter wherein the gases and vapors formed in the region of the arc are rapidly cooled and the vapor component thereof condensed, to avoid change of properties of the insulating fluid and thus greatly reduce the degree of deterioration or destruction thereof; to provide a circuit interrupter wherein means are incorporated to reduce greatly the discharge of liquids and gaseous products from the region of the arc into the surrounding vessel, thereby minimizing the disturbance and shock within it and the possible damage to it and to surrounding structures; to provide a circuit interrupter wherein thermodynamic and mechanical means are employed to control gas and vapor pressures and temperatures and minimize their physical effects; to provide means for causing the conducting space occupied by the arc to become non-conducting so rapidly, as the current decreases to zero in the alternating current cycle, that when zero current is reached the region previously occupied by the arc immediately resumes a high dielectric strength, and thus prevents the recovering voltage from reestablishing the arc; to provide a continued high dielectric strength in and around the interrupters after interruption of a fault, by reducing the magnitude of low pressure pulses which usually follow heavy duty interruptions; and to provide a method of circuit interruption which can be adapted to the majority of modern types of high power circuit interrupters with only moderate changes of the mechanical structure.

It has long been recognized that gases and vapors which remain at high temperature become ionized and therefore are conducting, and that an alternating current arc can reestablish itself, after the current has passed through zero and before the rising voltage of the succeeding half cycle has reached the point where it will cause ionization by collision, because of the presence of the ionized molecules within the arc path.

A major portion of the inventive effort evidenced by the prior art has therefore been directed toward methods of "cooling" or "extinguishing" the arc. In order to accomplish this various expedients have been devised to direct jets of oil into the arc path directly, or, in the alternative, to surround the arc path with an annular jet which will be carried into the arc path by the turbulent gases. It is apparent that these expedients have been used with a degree of success

in the interruption of alternating current arcs. Nevertheless, they are self defeating to a considerable degree and many of the undesirable effects which have been mentioned are actually increased by the methods employed to prevent them.

My invention makes use of the principle that a fluid in the vapor phase is almost instantly condensed upon contact with the liquid phase of the same material below the boiling point. This principle is exemplified in such devices as jet steam condensers, steam ejector pumps and steam boiler injectors. It is also employed in the condensation of the vapors of other fluids, such as mineral oil vapors in petroleum refineries where such vapors have been observed to condense more rapidly even than water vapor, as a result of the very low heat of vaporization and relatively high specific heat inherent in mineral oils.

Considered broadly, the method of my invention comprises the steps of forming the arc by the separation of circuit breaker contacts in the same manner as in all of the prior art devices, and thereafter leaving the direct arc path undisturbed insofar as this is possible, conducting the gaseous and vaporous products generated in the arc in a direction away from the arc path and in a course through which are directed jets or sprays of the cooling liquid, thus cooling and largely condensing these products immediately after they leave the arc path.

From the apparatus standpoint, the invention comprises the means for establishing the arc path, conducting the gaseous products away from it and directing the jets of cooling liquid in such manner that the direct arc path is itself left undisturbed except by means of vapor generated from fluid normally contained in the arc chamber preceding an interruption. Some of the direct effects of immediately cooling and condensing the arc gases and vapors as they leave the arc path are: (1) The fluid vapors remain at or above a possible cracking temperature for less than one two-thousandths of a second so that only a very small fraction of the usual decomposition takes place; (2) all but an extremely small portion of the arc products return to their fluid state as rapidly as they leave the arc path; and (3) energy is synchronously removed from the arc only when the arc current approaches zero and becomes small enough to permit the arc to loop into the exhaust passages where it can be effectively cooled by the jets.

There are many indirect advantages resulting from the action described above. In prior art interrupters the gas bubble which normally develops at the exhaust of the interrupter during arcing is lined with a sheath of permanent hydrogen and acetylene gases and these seriously impair condensation of fluid vapors on the bubble wall. As a result hot gases accumulate at an accelerating rate as long as arcing continues, causing a rapid increase of pressure and bubble size. The sheathing effect mentioned is thoroughly understood in connection with the science of thermodynamics and becomes a serious industrial problem in steam surface condensers where a slight sheath of air on the condensing surface will very seriously impair condensation. However, the cooling and condensing action of the jets of this invention effectively prevents such action.

Additional indirect effects of the cooling jets of fluid in the exhaust passages from the arc chamber are: A reduction of shock pressures in the circuit breaker tank to negligible values, the elimination of a possible ionized gas path between the interrupter and fluid container wall which has on several occasions caused circuit breakers to destroy themselves, the elimination of periodic low pressure surges following an interruption which has on numerous occasions caused the reestablishment of fault arcs in the breaker as late as two cycles following the initial interruptions, and an increase in the ionized gas exhaust velocity from the arcing chamber as a result of the lowered back pressure in the outer container.

The above will be more fully understood by reference to the following description of certain preferred embodiments of the invention, taken in connection with the accompanying drawings, wherein:

Fig. 1 is a graph showing voltage, current and pressure conditions within a circuit breaker of conventional design during the interruption of a short-circuit of a high power system;

Fig. 2 is an axial sectional view through an interrupter, embodying this invention;

Fig. 3 is a plan view of a baffle used in the interrupter of Fig. 2;

Fig. 4 is an elevation, Fig. 5 a plan, and Fig. 6 a perspective view of another type of baffle from which the vapor control elements of the interrupter of Fig. 2 are formed;

Fig. 7 is a plan view of the lower or closing baffle of Fig. 2;

Fig. 8 is an axial sectional view of an interrupter embodying a modified form of the invention;

Fig. 9 is a cross sectional view, the plane of section being indicated by the line 9—9 of Fig. 8; and

Fig. 10 is a diagrammatic cross section of the arc chamber of an interrupter, illustrating the conditions obtaining therein just prior to breaking the arc.

In order that the instant invention may be better understood, it may be well to examine here what occurs when a high power short-circuit is opened by an interrupter of conventional type wherein oil is injected into the arc path in the attempt to extinguish it. In the case of a short circuit the interrupter contacts open in response to the action of a relay and an arc is immediately established. At this stage of the operation the potential drop per inch along the arc is considerably dependent upon the shape and characteristics of the arc chamber and may be as low as 50 volts per inch of arc length for arc chambers of large cross section area or it may be as high as several thousand volts per inch of arc length where violent forced cooling exists even though the current at the instant may be in the neighborhood of 25,000 amperes. The relatively high arc voltage drop in the latter case may be due to one or more of several interrupter characteristics, all of which tend to remove heat from the arc. An unduly small diameter arc chamber causes the arc to come into intimate contact with the cool surface whether it is part of the arc chamber structure or an oil stream which either radially converges upon the arc or flows along its length. The most effective method for removing heat from the arc path, and thus raising its resistance, particularly during the period of heaviest current flow, is that of driving of a cooling fluid at high speed directly into the arc stream.

Extensive experiments which I have made confirm the fact that violent cooling of the arc stream at a time when the arc current is high will

actually increase the rate of liberation of heat by as much as 100 times. The gas generated by such rapid liberation of energy can destroy the strongest interrupter structures, making it highly undesirable to incorporate such violent cooling action in the interrupter design if satisfactory operation can be obtained without it.

The energy liberated by an arc contained in an interrupter of the fluid type is manifested in various forms; part of it goes to vaporize the liquid, part goes to superheat and ionize the vapor, and part goes to decompose it chemically, the products of decomposition usually being carbon, hydrogen, and possibly some heavier hydrocarbon oils and lighter vapors which represent only partial cracking of the original dielectric liquid. The net result of rapid cooling action is greatly to increase the resistance of the arc. This increase in arc resistance is, of course, the result aimed at, the idea being that it will cause the arc to extinguish permanently at the instant of zero current. It should be remembered, however, that the effect of the arc resistance is relatively small compared with the impedance of the system in which the short circuit has occurred.

It should also be remembered that in high voltage circuits the resistance of the arc has only a minor effect on the current flow in comparison with the inductance of the system on which the short circuit occurs. The inductance tends to maintain such flow and overcome the increased resistance and hence it is only at the instant when the current approaches zero that high resistance of the arc path can have any appreciable effect.

One hundred volts may appear across an undisturbed arc, as contrasted to several thousand across the arc with oil injection even when the current is relatively large. The overall result of such injection is therefore merely to increase by many fold the amount of energy expended in the arc, with a consequent many fold increase in the amount of gaseous products (including in this term both vapor and permanent gas) which are generated.

The gaseous products generated normally occupy many times the volume of the liquid from which they were produced, and the result is the generation of instantaneous pressures, adjacent the arc path, which are very high indeed. The gases and vapors then expand into the surrounding liquid, and form a bubble which increases in size the more rapidly as more liquid is injected to be vaporized in the arc. The gases travel into the bubble with a speed which is substantially the speed of sound in the medium. They strike against the walls of the bubble and some of them condense. The condensation is, however, limited by the fact that the permanent gases, such as the hydrogen and acetylene, forming a portion of the discharge, tend to form a cushion against the wall of the bubble which acts as a heat insulating sheath, slowing down the cooling of the condensable portion, this action being quite comparable to the effect, in steam engineering practice, of the presence of air in a condenser of the surface type. Moreover, the same thing tends to occur where the vapors and gases contact solid surfaces.

The sudden liberation of a large volume of gas within the liquid means, of course, that the liquid must be displaced. Since the liquid contained in circuit breakers of this type may weigh twenty to thirty tons, its inertia is very great; it must be displaced and the only direction in which it can be displaced is upward into the air space above the liquid. The portion of the liquid above the bubble therefore starts to move upward, at an accelerating rate, but the reaction to this upward acceleration is evidenced as a shock pressure wave which is propagated downward through the liquid. It is this wave which is accountable for the seismic shocks which have been experienced in the neighborhood of such interruptions.

As the size of the gas bubble increases the ratio of its surface to its volume falls, and this, in combination with the thermal insulating effect of the permanent gases formed, renders condensation inefficient. Condensation does, however, occur, and after the arc has been extinguished the pressure in the bubble therefore decreases to a value much below the normal static pressure of the vessel, as the bulk of the condensible gas and vapor condenses. The large mass of liquid above the bubble, however, has been accelerated and it moves up like a piston, despite the relatively negative pressure in the bubble below it, until the increasing pressure above the oil column and the low pressure below it reverses its direction of motion. The result is that the oil column returns at high speed to the lower position and effectively bounces up and down on the small amount of permanent gas remaining in the bubble so that a train of damped oscillations of the oil column is set up. The negative halves of the early waves of such a train are accountable for the stretching of the hold-down bolts in the instance cited above.

The oscillations of the oil column which have been mentioned continue long after the arc has been broken, the latter occurring probably during the first or second one-sixtieth of a second following the parting of contacts if the interruption is successful, while the period of oscillation of the oil column will be something in the order of one-tenth of a second and the total oscillatory time perhaps one second. The effect of these oscillations upon the operation of the breaker is not fully spent, however, even after the arc has extinguished.

If sufficient gas has been generated to accelerate the oil above the interrupters in an upward direction as described, the pressure in the region of the interrupters will reach a very low value in less than one-hundredth of a second following the interruption of current flow. It is well known that the reduction in gas pressure will produce an almost proportionate reduction in the dielectric strength of the gas and it therefore becomes apparent that the recovery voltage following a successful interruption may cause a dielectric breakdown in or about the interrupters, thus producing a breaker failure. This is not an uncommon circumstance when testing circuit breakers near their upper limit of interrupting ability.

Quite customarily automatically reclosing circuit breakers are used which reestablish the circuit at least once after it has been opened, so that in the case the fault is an arcing one which will clear itself if the current is interrupted adequately, there will be no long-continued interruption of service. In the case of a solid fault, however, the contacts will reopen and so remain. When an interrupter opens for the second time the same cycle of operation which has already been described may reoccur, but the effect is complicated by the continuing oscillations of the oil column.

There have been conflicting reports as to the relative difficulty of breaking the circuit on the second operation of such a reclosing circuit

breaker. Some reports have been that the disturbance is less and the interruption easier. Others have stated that the second interruption is much more severe than the first and that complete interruption is much more difficult. Such conflict of testimony, however, is clearly understandable if considered in terms of the oscillations of the oil column within the breaker; the time-setting of the reopening will vary as between breakers of different designs, as will the natural period of oscillation of the oil column. If the interrupter reopens during the half cycle of the oscillation when the pressure is negative, the dielectric strength of the vapors formed in the arc path will be greatly reduced, it being well known that vapors and gases ionize much more readily under reduced pressure, so that the arc can reestablish itself after the voltage reversal much more easily under these conditions. When this occurs the arc will then hold until a positive pressure is reestablished irrespective of the number of times the current may pass through zero in the meantime. If, however, the reopening of the interrupter is so timed that it occurs at a pressure maximum, the effects of the reopening are much less severe.

Moreover, actual travel of the bubble within the liquid is very slow in comparison with the other effects which have been described; insofar as the effects ensuing upon the single break are concerned, the bubble may be considered as stationary. What occurs upon the reopening depends upon many factors. The second bubble may coalesce with the first, or it may remain separate and set up a series of oscillations of its own which may or may not be in phase with those established by the first bubble and the possibilities are too complex and varied for analysis here. They may be of a catastrophic nature, however, as where the ionized gases in the bubble reach the walls of the container or current carrying parts outside of the interrupter structure, leading to an uncontrollable arc and the destruction of the breaker.

There is a further effect of the bubble formation which is, perhaps, the most important of all. The formation upon the inner surface of an insulating layer of permanent gas has already been referred to, together with its effect upon the slowing down of condensation. The cracking of oils under the effects of high temperature is a function of the time during which such high temperature obtains. If the hydrocarbon vapors are maintained at high temperature for only a few microseconds, very little cracking will occur and only negligible amounts of carbon and hydrogen will be formed, whereas if the gases remain at high temperature for longer periods, cracking occurs at an accelerating rate. It has already been mentioned that the oscillations of the oil column have a period of the order of a tenth of a second, and that several oscillations occur. These oscillations can only continue while the gas bubble persists and the vapor content of the bubble can persist only so long as a high temperature obtains within it. It follows that the vapors are maintained at a temperature at which decomposition can occur for periods of the order of a second, during which period a very large proportion of them can undergo some degree of decomposition.

The steps that have been described are illustrated in Fig. 1, which is a typical pressure-time graph for a conventional high-power circuit breaker. The graphs in the drawing represent, in curve 1, the fault current through the breaker; curve 2, the pressure in the interrupter; curve 3, the pressure below the oil near the interrupters; curve 4, the pressure in the space above the oil. Reference line 5 represents normal atmospheric pressure; reference line 6 represents zero current; point 7 indicates time at which arcing begins, and 8 indicates time at which interruption occurs.

The current graph is included in this figure primarily for purpose of comparison, the interest in the present case being primarily the pressure graphs. It will be noted that as the arcing progresses the pressure in the interrupter chamber itself rises to a very high peak *a*, upon which a similar peak *b* in the general pressure below the oil follows immediately.

Graph 3 shows how, immediately following upon this pressure surge, the pressure below the oil drops below normal, to a minimum which approaches absolute zero. This corresponds with the upward movement of the oil column due to its momentum, and that this is actually the case is shown by the increasing pressure above the oil (*c*). About six cycles, or .1 second later, the pressure under the oil rises to another peak (*d*) as the oil "hits bottom" in the downward motion of its oscillation, this being also indicated by the fact that the pressure above the oil column has dropped to a minimum. Following this pressure maximum the column starts up again, once more reducing the pressure in the region of the interrupters nearly to zero.

The instant invention accomplishes its purposes by preventing the formation of any substantial bubble whatsoever. One equipment embodying the invention is illustrated in Figs. 2 through 5, showing the construction of one contact and the vapor control interrupter unit, of which, it is to be understood, there may be two or more connected in series in a single circuit breaker. The unit is mounted upon a rigid lead-in and support 11, the end of which is threaded to carry an end fitting 13, which should have adequate mechanical strength and therefore is preferably formed of cast bronze, although other materials, of course, can be used. The fitting 13 is preferably generally circular in shape, terminating in a cylindrical flange 15 which is interiorly threaded to receive the other portions of the structure. The boss 17 into which the support 11 is threaded may or may not be offset, as shown, from the center of the fitting, this being a matter of choice depending upon the construction of the remaining portion of the breaker, and not important so far as the present invention is concerned.

Mounted interiorly and centrally of the flange 15 is a contact point 19, and there also is preferably provided, within the fitting, a spring loaded relief valve 21. This relief valve is included as a safety measure, and largely out of deference to past practice.

Threaded into the flange 15 is a tubular casing 23, provided at its lower end with an interior flange or step 25.

The casing 23 is of insulating material, preferably of vulcanized fiber, or of laminated construction impregnated with one of the phenolic resins or the like. Stacked within it and supported by the step 25 is a series of baffles 27, 29 and 31. These may be of the same materials as the casing 23, and the same is true of a cylindrical collar or spacer 33, positioned between the baffle 31 and the interior surface of the fitting

13 so as to press against the stack of baffles and hold them firmly in place, and forming, between the fitting and the baffle 31, a pressure chamber 35. The baffles are held from rotation by a key 37 within the casing 23, which fits into notches 41 formed to receive it in each of the baffles.

Baffles 27 and 29 are centrally apertured to pass the main moving contact 42 of the interrupter. This contact is carried upon a metal contact arm 43, and is movable to make or break contact by any conventional type of circuit breaker mechanism, such as a drop bar, rotary mechanism, or any other which the designer may consider most applicable to the particular duty for which the interrupter is designed.

The baffle 27 is fully circular in section and its central aperture 45 may or may not be flared as shown to facilitate the entry of the blade. Baffles 29 and 31 are shaped as the central zones of circles, and when stacked as shown in Fig. 2, form segmental ducts, within the casing 23, which communicate with the pressure chamber 35.

The axial opening 51 within baffle 31 is counterbored to receive a spring 53 which works against a flange 55 on a movable auxiliary contact 57, the latter being adapted to engage the contact 19 when the spring 55 is fully compressed, as will occur when the contact 42 bears against its lower surface.

Movement of the spring-loaded contact 57 is limited by the flange 55 bearing against the rim of central aperture 59 in the upper of the baffles 29. As shown, there are four of the latter type of baffles, which face alternately up and down within the stack. Considering the upper one of these baffles as facing "up," it will be seen that it is provided with a transverse groove 61 across its outer end at the right of the illustration. Extending radially beneath this groove is a second groove 63, which increases in depth at its inner end where it communicates with the central aperture 59. Transverse grooves 65 extend across the lower side of the baffle intersecting the groove 63, which also communicates with groove 61 through holes 67 formed in the septum between the two grooves. It will be seen that when these baffles are stacked alternately face up and face down, as shown in Fig. 2, the grooves 65 cooperate with the adjacent baffles to form transverse oil conduits or channels connecting with the principal conduits or ducts within the body of the casing.

The grooves 65 likewise cooperate with their counterparts on adjacent baffles to form ducts leading from the conduit into the grooves 63. Grooves 65 cooperate in a similar manner to form channels leading outwardly from the central aperture into the body of the circuit breaker, casing 23 being apertured as indicated at 69 to complete the passageway.

It will be seen that when the contacts of the interrupter are closed by raising the arm 43, the contact point 42 will force the auxiliary contact 57 against contact 19, completing the circuit to the lead 11. When the circuit breaker trips the arm 43 starts to move downward, followed by the auxiliary contact 57 under the impetus of the spring 53. An arc therefore immediately starts to form in the pressure chamber 35, and establishes pressure within this chamber before the motion of the auxiliary contact is stopped by the flange 55 and the main gap between contacts 42 and 47 starts to open. The pressure within the chamber 35 is immediately communicated to oil in the ducts. Since the latter are blocked at the bottom by baffle 27, the oil is forced through the passageways which have already been described and is ejected as jets into the channels formed by the grooves 63.

In the meantime an arc has formed between contacts 42 and 57, vaporizing the oil in the space between them and ejecting the vapors at very high velocity through the channels formed by the grooves 63 where they meet the intersecting jets from the channels 65 and holes 67.

The liquid in these jets is cold, they are small in cross section and hence relatively large in surface area. The action is very much the same as that in a jet type of steam condenser; the efficiency of condensation is very high since there is no opportunity for a film or layer of fixed gases to form to prevent the heat transfer which is also facilitated by the high velocities involved. In addition the high velocity of the hot gas stream disrupts the cold oil jets into a multitude of minute droplets with a further increase in combined surface area, each droplet acting as a nucleus of condensation with the result that heat is exchanged most effectively. Because of the speed with which the vapors have been condensed, very little cracking takes place and the formation of fixed gases is so small as to be practically negligible, and such small quantities of gas as are formed are carried into the body of the oil adhering to the droplets in such finely divided form that they cannot coalesce into any large bubble which can give rise to the effects discussed above. By the time the discharging material has reached the aperture 69 in the casing, practically all of it has returned to the liquid phase and any bubble which does form is so small that no noticeable shock effects occur.

Direct passage of the liquid from the pressure chamber 35 into the arcing chamber is substantially prevented by the flange 55, while that entering through the various jets is carried by the momentum of the escaping fluid outwardly into the enclosing receptacle, and hence there is no new oil or other cold liquid injected into the arc to raise its resistance and increase the liberation of energy therein.

After the first peak of current has passed and it starts to fall off toward zero, the rate of energy liberation within the direct arc path decreases. At this point the conditions within the arcing chamber are somewhat as is illustrated in Fig. 10. With falling current the arc dwindles in intensity and becomes "thready," tending to move toward the discharge side of the chamber. Although the temperatures developed within the arc are very high, the major portion of the gaseous products have been removed from the chamber as rapidly as produced and condensed so that the total mass of the material at this high temperature is small and is located near the discharge side. The time involved has been very brief, and the walls of the chamber are still relatively cool so that the rate of radiation of energy from the arc is high. The gases on the non-discharge side of the chamber therefore deionize by expansion and radiation and become non-conducting in a zone delimited by the dashed line 71 of the figure. Beyond this zone is a transitional zone, shaped somewhat as is illustrated by the dashed line 72, where the gas is only partially ionized, while beyond this again is the actual arc 73. With falling current the size of this arc becomes rapidly smaller so that at a time very near current zero it will loop into the passages containing the fluid jets. Thus the arc will be

completely cooled only at or near the time of current zero and without having extracted large quantities of heat from the arc while the current magnitude was large. The effect is to synchronously cool the arc only when such cooling is desirable. Finally at the time of a few microseconds preceding current zero, the liberated arc energy becomes extremely small relative to the surface area of the arc so that heat is radiated more rapidly than it can be supplied electrically with the result that effective ionization disappears completely and the circuit becomes interrupted.

In the meantime, the limits 71 and 72 of the deionized and transitional zones have been moving across the chamber at a velocity which will actually exceed the speed of the gas in which deionization is progressing as a result of cooling due to gas expansion and due to radiation. The pressure within the chamber drops; it does not assume a negative value, but remains at the norm established by the atmospheric and liquid pressure within the receptacle. There is, therefore, no diminution of the dielectric strength of the vapors within the gap due to rarification, and the arc therefore does not reestablish itself.

It should be noted that much the same effects will occur even in structures where the gas discharge is symmetrical. The arc path is unstable; if it wanders toward one side of the ar chamber where the exit velocity is high, pressure will increase on the other (although not to the same extent as with a unilateral discharge) and the same process will cause the final break of the arc.

It has been stated and it should again be emphasized that during this process no oil has been injected into the arc chamber or the direct arc path proper. The extinguishment of the arc has been entirely due to the normal process of displacement and radiation, all processes which have been carried out in the process of extinguishment being directed to the vapors which have escaped from the direct path. The distinction between "direct arc path" and "arc" is made because the temperature of the vapors escaping through the channels 63 during the major portion of the process is still so high that they may be ionized up to the moment when they actually impinge upon the oil jets. Since they are ionized and since they are in contact with a conducting body of gas, some very minor percentage of the arc current is carried by them at a time when the amount is rather large, just as some portion of the current carried by a metallic conductor theoretically flows through the outer periphery of a large thin metallic flange surrounding and connected to such conductor. The increase in resistance of the conductor as a whole which would attend the removal of such a flange is far too small to be measured by ordinary methods, and the same holds true of the increase in arc resistance which occurs due to the deionization and condensation of the escaping vapors. An actual measurement in such a case is, of course, practically impossible, but the increase in the resistance can be estimated as, perhaps, two or three per cent, as contrasted with an increase of several hundred per cent which may be occasioned by injecting oil into the arc or the somewhat smaller increase which occurs by an axial flow which is incorporated into the arc path by turbulence. The difference in the two effects is so great as to constitute a difference in kind, and the phrase "direct arc path" is used in this specification and claims to emphasize this fact.

Moreover, in the final stage of the break the current may be carried by ionized vapor escaping through the channels 63, the arc looping into these channels and away from the space between the contacts just before the final break. When this occurs, however, the current is approaching zero, and injection of oil into this indirect path does not result in the release of excess energy and does not result in increased heat.

In the embodiment just described the pressure for forcing the condensing jets through the escaping vapors is derived from the auxiliary arc formed in the pressure chamber 35. It is to be understood that this is merely one way of supplying such pressure which has been used frequently in the prior art for directing oil jets into the arc itself. Other means of supplying this pressure are equally applicable to this invention, and the auxiliary arc chamber is the equivalent of piston pumps, rotary pumps, and various other devices which are well known in the circuit interrupter art.

A different embodiment of the invention is illustrated in Figs. 8 and 9. Considering first Fig. 8, the fixed contacts of the interrupter and the arc control structure which is associated therewith are mounted on an insulating bushing which extends vertically downward from the cover of the tank or receptacle within which the interrupter is mounted and a portion of the wall 77 whereof is fragmentarily indicated on the drawing. A clamp 79 grips the bushing 75, and is preferably formed integrally with an end fitting 81 (corresponding roughly with the end fitting 13 of the first embodiment described) within which are mounted a plurality of springs 83 carrying on their free ends contact tips 85 and 87 respectively.

Although they do not show in the figure, there are preferably provided additional springs and contact tips corresponding to those designated 83 and 85 respectively, these being positioned in planes above and below the plane of the figure so as to make contact on all sides of an arcuate moving contact 89 which is carried upon the rotating contact arm 91 and actuated by a type of mechanism well known in the art.

A tubular insulating casing 93 is threaded into the end of the fitting 81 and locked in place by a split clamp 94.

As in the previous example the outer end of the casing is provided with an inwardly projecting flange or step 95, against which rests the stack forming the arc control structure, and comprising, reading successively from left to right, a throat plug 97, a barrier 98, a spacing collar 99, baffles 101 and 103, a barrier 105, a second baffle 103, and a final spacing collar 107. All of the elements 97 to 105 inclusive are apertured to permit passage of the movable breaker contact 89, but these apertures are not axially located except in the case of the throat plug 97; instead the apertures are displaced from the axis to accommodate the curvature of the contact.

The elements 97, 98 and 105 are completely circular, so as fully to block the interior of the casing 93 except for the apertures through which the contact passes. Baffles 101 and 103, however, are zonal in form, to form segmental oil conduits 109 as indicated in Fig. 9. The baffles 103 and the barrier 105 are radially grooved to form passageways 111 for the outwardly flowing gases, these passages connecting with an aperture 113

in the casing 93. The passageways are transversely intersected by grooves in the barrier 105 forming channels 115 connecting with the oil conduits 109 for admitting condensing oil jets to the passages. Additional apertures 117 for forming such jets are drilled or otherwise formed in the baffles 103.

In this structure the pressure to force the condensing jets of oil through the escaping gaseous products of the arc is not produced by an auxiliary arc, but by the main arc itself. The contact points 85 carry the normal load current of the device, supplemented, of course, by the contact 87. The latter, however, is provided primarily to take the arc when the interrupter opens and thus prevent pitting of the main current carrying contacts 85. A portion of the arc is formed in the pressure chamber 119 within the fitting 81, and the resulting pressure can only relieve itself by forcing the main body of oil in the chamber through the aperture 117, the conduit 109 and channels 115 into the escaping gases from the main body of the arc. When the interrupter is fully opened the tip of the contact 89 lies approximately in the position indicated by the dotted lines 89', and that portion of the main arc formed within the chamber 120 between baffles 98 and 101 forces oil through the slots 110 in baffle 101 and the apertures 117 in baffle 103, and so through the gases escaping through channel 111.

It will be noted that all of the pressures involved are generated in the main arc. The gases formed within the pressure chambers 119 and 120, however, are in immediate contact with relatively large volumes of relatively cool oil. Their expansion forces the oil in the chamber away from the aperture parallel to the arc's path and prevents the injection of oil into the direct path of the arc itself. Owing to the condensation of the vapors in the ducts 111, however, there is a very steep pressure gradient through these ducts. Except for the method of generating the pressure for circulating the condensing liquid the operation of the modification last described is practically identical to that which has been described in detail in connection with Figures 2 through 6, and hence need not be repeated here.

It may be well to note that the only difference between the structures here described and those operating on the principle of injecting oil into or along the surface of the arc is a relatively slight change in the ducting of the baffles. Except for this one factor, these interrupters are precisely similar to others which may have been commercially marketed. The interrupting capacity of the device has, however, been increased many fold, and the violence of the physical effects ensuing upon the interruption has been reduced to a point where it is no longer of importance. The device last described has successfully interrupted with no discernible breaker disturbances, a three and one-half million kva. circuit at 115 kilovolts, six series breaks being used to accomplish this.

Upon another occasion an interrupter built in accordance with this invention has interrupted a circuit carrying nine million six hundred thousand kva. at two hundred forty kilovolts, this being the largest amount of power which has successfully been broken by any interrupter to date, so far as records are available. The interruption was accomplished in forty-two hundredths of a cycle of arcing and without appreciable disturbance. As the test referred to was made on a power system at the Grand Coulee Dam, which is the only place known to the inventor where power is available for a test of this character, it seems improbable that this performance has been exceeded anywhere in the world.

One of the difficulties that has been encountered in prior art interrupters has been that those which operated satisfactorily upon full load short circuits have not always been as successful when used to switch currents of normal value, and vice versa. The duty upon a breaker of this kind in interrupting normal currents is not so severe, and in some cases, at least, no extraordinary precautions are needed to extinguish the arc. Interrupters designed for breaking short circuits, however, have in some cases relied on the extremely high pressures produced to accomplish the interruption, and in normal switching operations have not had available the pressures required for their operation. In the device of this invention, however, the arc extinguishes itself, as has been described, and the device will condense the gases produced whether they be large or small in volume.

As has already been indicated, nearly all modern types of oil immersed circuit breakers utilize jets to direct the oil flow and accomplish extinguishment of the arc. It is apparent, therefore, that such devices can be readily modified to redirect this oil flow so as to operate in accordance with the invention here described. Details of the structures referred to are so various that it is clearly impossible as well as undesirable to attempt here to consider even a fraction of such modifications. For these reasons the detailed descriptions of interrupter structure here given are considered to be illustrative merely and in no sense limiting, and protection is desired as broadly as possible within the scope of the appended claims.

I claim:

1. An interrupter for use immersed in a dielectric liquid comprising a pair of current carrying contacts relatively movable to separate and establish a direct arc path therebetween, means for directing gases and vapors generated in said arc path in a direction away from said path, and means for forcing a plurality of jets of said liquid through said gases and vapors in a direction transverse to their direction of flow.

2. Apparatus in accordance with claim 1 wherein said course comprises a channel extending in one general direction away from said arc path, to establish a differential pressure between the sides of said path.

3. Apparatus in accordance with claim 1 including an arc-confining shield surrounding said arc path and having at least one lateral channel formed therein to define the course of said gases and vapors, and transverse holes formed in the walls of said channel to direct said jets thereacross.

4. Apparatus in accordance with claim 1 wherein said jets are so directed as to avoid impinging on said arc path.

5. Apparatus in accordance with claim 1 wherein said jets are substantially parallel to said direct arc path but entirely clear thereof.

6. Apparatus in accordance with claim 1 wherein said jets are directed approximately perpendicularly to a plane containing the axis of said arc path.

7. An interrupter for use immersed in a dielectric liquid comprising a pair of current carrying contacts relatively movable to separate and establish a direct arc path therebetween, a

shield surrounding said path, a baffle positioned within said shield to form a conduit separate from said path and apertured to provide a course away from said path for gaseous products generated therein, said baffle having holes formed therein connecting said conduit with said course and transverse of the latter, and means for applying pressure to liquid in said conduit to force it into said course.

8. An interrupter for use immersed in a dielectric liquid comprising a pair of current carrying contacts relatively movable to separate and establish a direct arc path therebetween, a conduit for said liquid, a baffle structure surrounding said path apertured to form a channel for gaseous products generated in said path away from the same, said baffle structure having openings therein connecting said conduit with said channel and transversely directly with respect to the latter, and means for forcing liquid from said conduit through said openings to form jets.

9. Apparatus in accordance with claim 8 wherein a plurality of similarly directed channels are formed in said baffle structure with openings connecting said conduit with each of said channels.

10. The method of interrupting an arc formed with a dielectric liquid which comprises the steps of directing gaseous and vaporous products of said arc in a course away from the path of said arc, and forcing jets of said liquid across said course in a direction transverse the direction of flow of said products to condense said vaporous products before a substantial bubble can be formed.

11. The method of preventing the reestablishment of an arc formed within a dielectric liquid which comprises the steps of conducting the vaporous products away from the direct path of said arc, and cooling and condensing said products so rapidly as to prevent the formation of any substantial bubble thereof within said liquid while preventing any material encroachment of said liquid upon the arc path or reduction of pressure therein below atmospheric pressure.

12. A circuit breaker comprising a receptacle for containing a dielectric liquid, an interrupter mechanism mounted beneath the liquid level comprising a pair of contacts mutually movable to separate and establish a direct arc path therebetween, means for directing gaseous products in a course away from said path, and means for forcing a jet of said liquid across said course and through said gaseous products in a direction transverse to their direction of flow.

DONALD M. UMPHREY.

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