

April 13, 1954

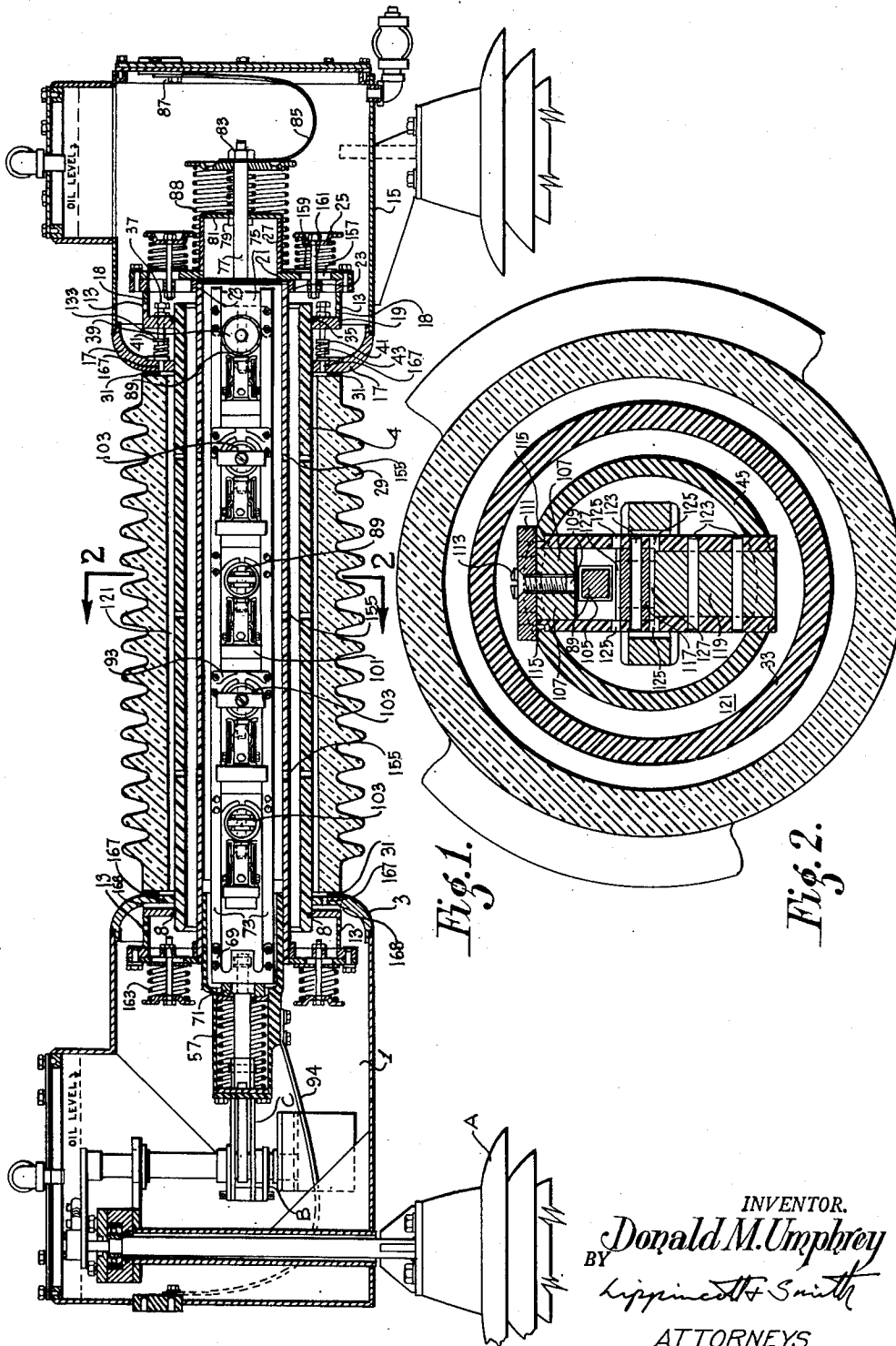
D. M. UMPHREY

2,675,446

CIRCUIT-BREAKER STRUCTURE

Filed July 7, 1951

4 Sheets-Sheet 1



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CIRCUIT-BREAKER STRUCTURE

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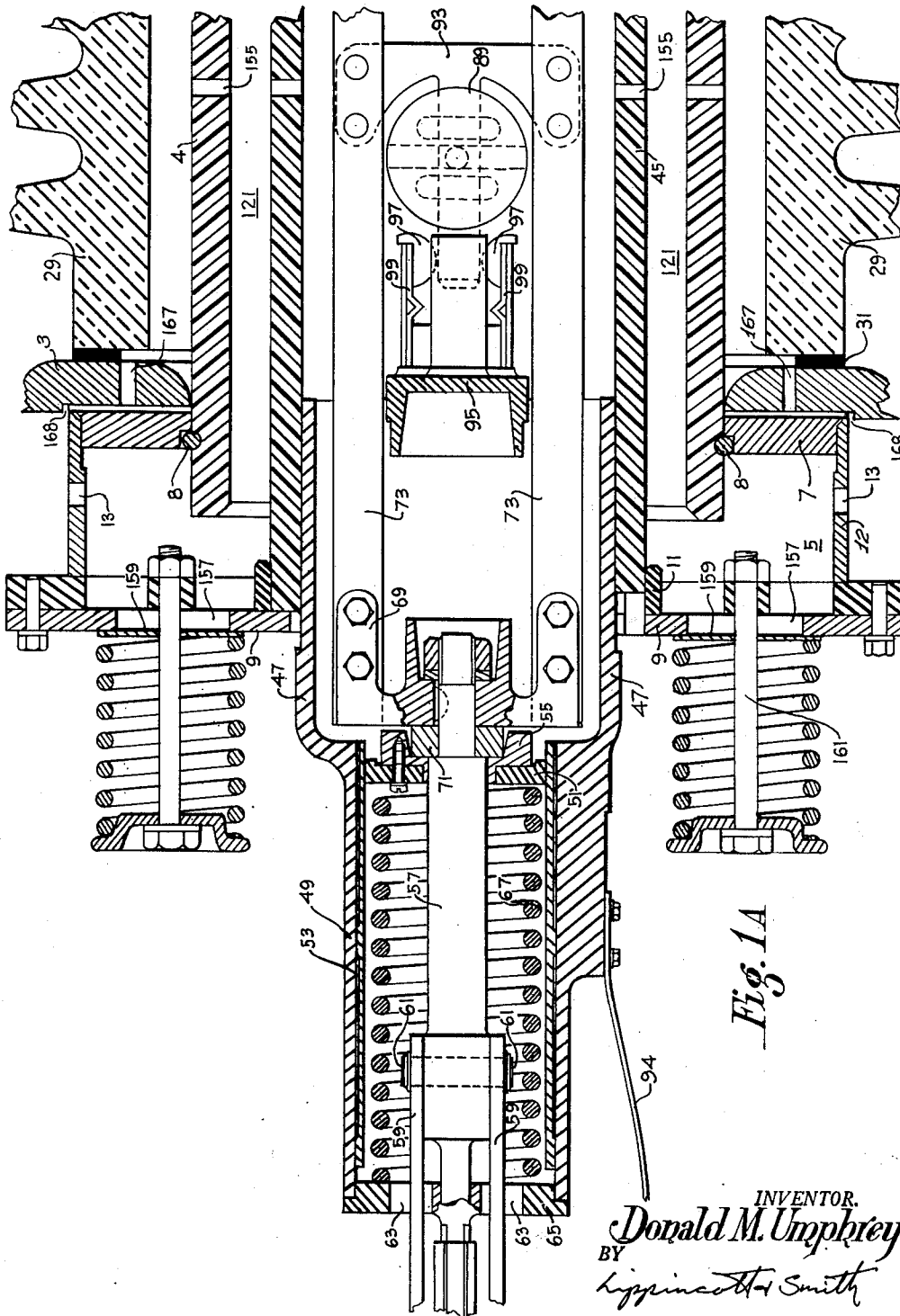


Fig. 1A

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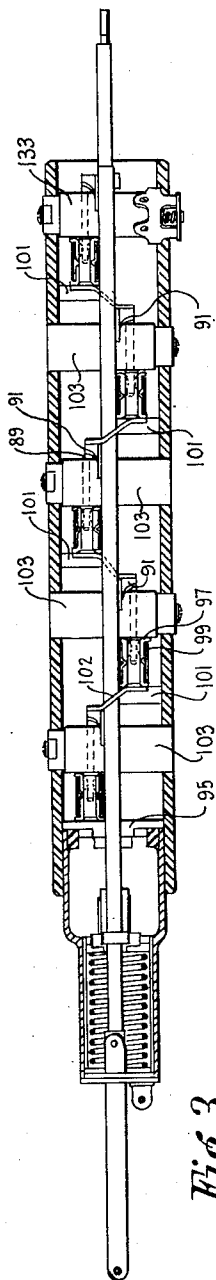
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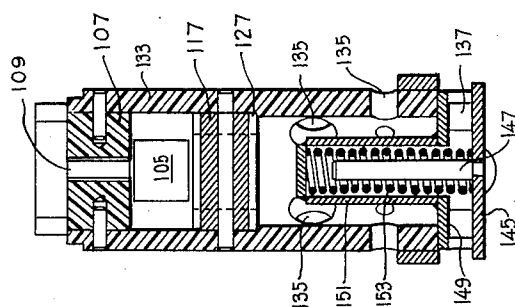


Fig. 6.

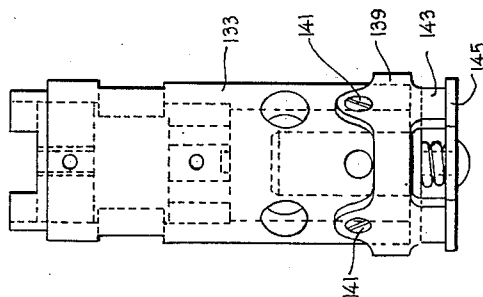


Fig. 7.

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CIRCUIT-BREAKER STRUCTURE

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Application July 7, 1951, Serial No. 235,586

11 Claims. (Cl. 200—150)

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This invention relates to circuit breakers, and specifically to high-voltage, high-power circuit breakers of the oil-break type utilizing in their operation a relatively small quantity of oil or other dielectric liquid; i. e., breakers requiring only something on the order of a hundred gallons of oil instead of several thousand gallons. In this connection it is to be understood that throughout this specification the term "oil" will be used as synonymous with "dielectric liquid" since oil is the liquid most commonly employed for the purpose, and although other liquids may be substituted, their function, if used in the breaker of this invention, would be identical with that of oil.

Among the objects of this invention, aside from the obvious one of economy of oil, are to provide a circuit breaker of large interrupting capacity which is nonetheless small in size as compared to the more usual tank type of breaker; to provide a circuit breaker in which the pressures developed upon interrupting the circuit on a fault are limited in value, so that the breaker is safe and reliable in operation and is not subject to explosive destruction when operated under maximum short circuit current conditions; to provide a circuit breaker of the oil conserving type which embodies the features disclosed in my copending application Serial No. 105,388 filed July 18, 1949, now Patent No. 2,647,973, dated August 4, 1953; to provide a breaker which will operate satisfactorily upon loads of all values, including the special case of disconnecting an unloaded transmission line; to provide a circuit breaker wherein negative pressures (as referred to as atmospheric pressure) cannot be established in the gases and vapors formed by the arcs consequent upon the interruption of the circuit, but wherein such gases are always maintained at above atmospheric pressure with consequent increase in dielectric strength and resistance to the reestablishment of the arcs after a break has once occurred; and, in general, to provide a circuit breaker of the oil conserving type which possesses the reliability and safety features ordinarily associated with the best of the tank type devices.

Tank types of circuit breakers which are ordinarily used for opening high-voltage, high-power circuits under load or fault conditions have their operating mechanism immersed in large tanks of oil, both for the purpose of electrically isolating the current carrying parts of the mechanism and to supply a body of liquid wherein the pressure wave, resulting from the sudden evolution of a

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large volume of vapor by the arc formed at the break, can expand and thus attenuate the pressure gradient before reaching the walls of the container. In the conventional circuit breakers of the prior art it has been customary to endeavor to extinguish the arc more quickly by injecting into it large quantities of oil, thus raising the arc resistance. If this injection occurs during the period of the alternating current cycle when maximum current is flowing in a high-voltage system, energy is available to convert practically all of the oil thus injected into gas, substantially instantaneously and with explosive violence. The gases and vapors thus produced occupy an enormously greater volume than the oil from which they were formed, and if egress of the gas bubble and the oil surrounding it be restricted, as is practically necessarily the case in breakers of the minimum oil type, the result may well be an explosion of the entire structure, with resultant danger not only from the effect of the blast itself but also of fires resulting from scattering of oil ignited by the arc.

In the copending application above referred to it has been shown that explosive effects from a heavy break can be avoided by keeping the resistance to the arc path as low as possible instead of raising it by the injection of oil, leading the gases and vapors away from the arc path and condensing the vapors by passing jets of oil through them and thus preventing the formation of any material bubble, the arc then extinguishing itself at the first current zero by radiation and self-deionization. By applying this same principle to breakers of the minimum oil type, the dangers of explosion due to the constraint on the liquid are avoided the condensation of the vapor works equally well as with tank type of breakers, and both safety and economy of space and material can be safely accomplished.

It is well known that circuit breakers which operate satisfactorily under short circuit conditions, where many thousands of amperes flow, may fail under the apparently minor duty of disconnecting an unloaded transmission line. Such failures are caused by a number of cooperating causes. First, it must be remembered that the unloaded line looks to the generator supplying it like a practically pure capacity and that the charging current to the line therefore leads the voltage by 90 electrical degrees, reaching its maximum when the voltage is zero and passing through zero when the voltage is at its peak. Even though the current charging the line may be only a few amperes, an arc does form

with a consequent evolution of gas and vapor, even though the volume formed may be relatively small. Although the resistance of such an arc may be relatively high in comparison to that formed on a short circuit, it will still be low in comparison to the impedance offered by the unloaded line, and in a high tension system there is ample potential to maintain the arc during the first half-cycle of the break. Because of the relatively small current, the arc is "thready" or of small diameter; the surface of the arc path is large in comparison. The arc radiates and deionizes rapidly and extinguishes at the first current zero and voltage peak.

During the time of maximum current, however, gases are evolved and expand, imparting to the liquid motional energy in a direction away from the arc path, which, because of the inertia of the liquid, tends to continue even while the vapors formed are condensing. The result is that the former arc path may, under certain conditions, be occupied by gases or vapors under materially less than atmospheric pressure and hence of low dielectric strength. The extinguishment of the arc, however, occurred at an instant of voltage maximum, leaving the line highly charged in one direction. At the moment when the circuit broke the potential on the generator side of the break was equal to that on the line side; half a cycle later, however, the generator potential has reversed while the line has remained charged and there therefore exists, across the break, a voltage which is substantially double the maximum normally existing across the line. If this voltage appears across breaks in low pressure gas, the gaps will again break down and the resulting surge will carry about double the current existing at the initial break. Again a break will occur at the first current zero, but it is possible for the same action to recur and, under conditions of mechanical and electrical resonance, to build up higher and higher voltages and lead to serious trouble. This invention is designed to check any such action at the start and open the circuit, finally and completely, at the first current zero after the breaker opens.

The circuit breaker of the present invention comprises a plurality of tubular casings, one within the other, and connected at at least one end to an oil reservoir. The innermost casing is substantially closed at both ends: within it are a plurality of breaker contacts, fixed contacts secured within the casing itself and movable contacts mounted on an operating rod reciprocally mounted within the casing. A plurality of transverse interrupter tubes are mounted within the casing, one adjacent each of the fixed contacts. Each of these tubes is closed at one end, the other end opening into the next outer casing. Both sides of each interrupter tube are apertured near the closed end to permit the passage of the moving contact through the tube in engaging the associated fixed contact, the parts being so disposed that when the contacts open the gap between the fixed and moving contacts wherein the arc is formed when a break occurs lies almost wholly within the interrupter tube. All of the tubes except one, positioned at one end of the inner casing, are substantially identical. Each is provided with a large number of small apertures in its walls between the openings through which the movable contact passes and the open end of the interrupter tube. Preferably, each of the interrupter tubes is divided by a septum positioned

in a plane transverse to the axis of the casing and longitudinal of the breaker tube.

The interrupter tube at the end of the array differs from those just described in that both ends are normally closed, one end permanently and the other by a relief valve opening into the next surrounding casing and arranged to open when and if the pressure within the interrupter tube exceeds a predetermined, rather high limit. Relatively large apertures open from this last tube into the inner casing.

At the end of the casing opposite this last mentioned interrupter tube there is located a piston which is spring-biased toward the casing. This piston is slidably mounted on the operating rod, or an extension thereof, and is engaged by a collar which further compresses the spring when the contacts are closed. When the contacts open as the operating rod moves away from the piston under the impetus of an opening spring, the piston is free to follow this motion more gradually under the impetus of its own spring, retarded, however, by the oil. The spring pressure on the piston is computed so that when it is released it will maintain, for a brief instance, a pressure of one or several atmospheres upon the oil in the inner casing.

All of the pairs of contacts (i. e., fixed and moving) are connected in series so that when the operating rod moves to open them, a plurality of series gaps is formed. An arc forms in each gap, exerting a pressure on the oil in the inner casing. In the end interrupter, both ends of which are closed, the only escape for oil or gases is into the casing itself. In the remainder of the interrupter tubes the gases have free egress into the next outer casing. In thus escaping, however, they must pass through jets of oil entering the interrupter tube through the small lateral apertures, these apertures being the only material escape for the oil under the pressure developed in the end interrupter. The jets within the remaining tubes cool and condense the vapors formed by the arc so that no material bubble is formed, the vapors being practically entirely condensed by the time that they reach the annular space between the two casings.

In spite of this condensation there is still a body of gas and vapor within the structure that occupies a greater volume than the original oil and therefore an escape passage is necessary, both to accommodate this additional volume and to cause the flow through the jets which accomplishes the condensing action. The second casing opens into the oil reservoir at one or, preferably, both ends of the device through a plurality of relief valves which are set to open at a pressure just slightly greater than that imposed upon the oil by the piston and also through a small bypass vent. Where two reservoirs are used, they are preferably connected through an outermost casing which may be of porcelain and which serves to tie the whole structure together and protect the portions of the device which actively enter into the breaking action.

When the device is operated under fault or heavy load, the pressure developed by the pressure-forming arc at the end of the array is sufficient to actuate the condensing jets and also to hold back the piston and prevent its operation until the breaking operation is substantially complete. Under excessive loads where the pressure develops very suddenly and is very high, the relief valve in the bottom of the pressure-forming arc interrupter tube may open and permit the excess

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volume of gas to escape, but in this case what escapes is only gas and not oil and is only a small part of the total gas and vapor involved, hence practically no oil is discharged without entering into the condensing process.

When operated under light loads, as in the case of an unloaded transmission line, the pressures developed by the arcs may be inadequate to form very powerful jets. In this case the piston exerts the necessary pressure upon the oil to maintain these jets briefly, but particularly it prevents negative pressures developing as a result of oscillation of any gas bubble and, as soon as ionization ceases and the gas becomes non-conductive, it maintains the dielectric strength of the gas at a value slightly, if any, lower than that of the oil itself, thus preventing re-establishment of the arcs under excess recovery voltages as was described above.

All of the above will be more readily understood from the following description, taken in connection with the accompanying drawings wherein:

Fig. 1 is a vertical sectional view through a breaker embodying this invention;

Fig. 1A is a larger scale sectional view of a portion of the structure shown at the left of Fig. 1;

Fig. 2 is a transverse section through the breaker, the plane of section being indicated by the line 2—2 of Fig. 1;

Fig. 3 is a horizontal sectional view through the innermost casing, the operating rod and interrupter tubes being shown in elevation;

Fig. 4 is a sectional view of one of the interrupter tubes, the plane of section passing through the axis of the tube perpendicular to the axis of the casing;

Fig. 5 is an axial section of the interrupter tube shown in Fig. 4, taken in the direction at right angles to the plane of the preceding figure;

Fig. 6 is a section of the end interrupter tube, which encloses the pressure-forming arc; and

Fig. 7 is an elevation of the interrupter tube shown in Fig. 6.

Shown in the drawing is the mechanism, in accordance with this invention, for opening one phase of a polyphase line. In the usual installation three such mechanisms will be used, driven in common from a single reciprocally mounted shaft operated by an actuating mechanism which, as it may be of any conventional type, is not shown. The mechanism associated with each phase is adapted to be mounted upon vertical insulator stacks, one of which, designated as stack A, is journaled for rotation about its own axis. Only the tops of the stacks are shown, as their complete illustration would unnecessarily occupy space better devoted to larger showings of significant features of the invention.

The breaker mechanism proper, with which this invention is particularly concerned, extends horizontally. At each end of the device, and supported by one insulator stack, is an oil reservoir. In the present instance each of these reservoirs is of welded construction, built up from boiler plate. The general construction is believed to be obvious from the drawings and, except for significant features, it will not be described in detail. The reservoir 1, shown at the left of Fig. 1, is the larger of the two. It contains the driving mechanism associated specifically with the breaker for the one phase illustrated. This mechanism comprises a linkage, crank-driven from the rotatable insulator stack A. This linkage connects through a ratchet sector and pawl, not illustrated in de-

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tail, with a crank B. Clockwise rotation of this latter crank retracts a link C to close the breaker. The parts are so arranged that when the common driving mechanism is tripped, and the insulator stack A starts to rotate, the pawl releases and crank B in turn trips free of the remainder of the mechanism, opening under the thrust of a self-contained spring, as will hereinafter be described. This particular operating mechanism is not a feature of the invention claimed herein and the above brief description is believed to supply sufficient background information to permit the invention which is claimed to be understood.

The reservoir 1 is L-shaped, both legs of the L being circular in cross section. The horizontal leg of the L terminates in a heavy annular closing plate 3.

An insulating tubular casing 4, preferably of a material such as bakelized fiber or cloth having a very considerable mechanical as well as dielectric strength, projects into the reservoir through this opening, this casing providing the principal mechanical support for the breaker itself. This casing is under tension, as will be described hereinafter.

Mounted on the end of the casing, within the reservoir, is an inner chamber 5. The wall 7 of this chamber, facing the plate 3, is an annulus of heavy material which fits closely around the inwardly projecting end of the casing 4 and is secured thereto by a locking ring 8 which fits into a groove in the periphery of the casing and a rabbet in the wall 7. The latter bears against the ring 8. The tension on the casing 4 holds the whole firmly in position.

The opposite wall 9 of the chamber is also an annulus, having a smaller inner diameter and a larger outer diameter than the wall 7. Surrounding the central aperture of the annulus within the chamber is a collar 11. The tubular wall 12, connecting the two end walls of the chamber, is provided with small oil vents 13 at top and bottom to admit oil into the breaker itself and permit the escape of air or other gases or vapors.

The reservoir 15, at the opposite end of the breaker, is very similar in construction to that just described. The wall 17, facing reservoir 1, is a heavy apertured plate similar to the plate 3, through which the other end of casing 4 projects into the reservoir. The second reservoir also contains an inner chamber 18, generally cylindrical in form, borne on the end of the casing 4 and secured thereto by a locking ring in the same manner as chamber 5. The wall 19 of the chamber 18, facing reservoir 1, is formed of a heavy plate, substantially identical to plate 3. The opposite wall 21 is centrally apertured and the aperture is surrounded by a collar 23 of like diameter to the collar 11 already described, and is covered by a cylindrical cap 27.

Reservoirs 1 and 15 are connected by and support three coaxial insulating tubular casings which contain the interrupter mechanism proper. In the device chosen for illustration, the outer casing 29 is formed of electrical porcelain and is supported frictionally, being held in compression between the plates 3 and 17 through gaskets 31. The intermediate casing 4 of this series has already been described; it passes easily through the apertures in plates 3 and 17, but snugly through the apertures in plates 7 and 19. Casing 4 is held in tension, and casing 29 in compression, by means of a ring of compression bolts 37 threaded into plate 19 around the end of casing 4.

The ends of these bolts are of reduced diameter and support and turn within bushings 41 which bear against heavy compression springs 43, these latter, in turn, bearing against plate 17. When the bolts 37 are tightened, the tension exerted on the casing 4 and, accordingly, the compression exerted on casing 29, may amount to several tons. The structure, as a whole, is therefore extremely rigid, the gaskets 31 are under heavy compression so there is no tendency for the oil to leak.

The innermost casing 45, also, in this case, a Bakelite tube, is supported at either end by the collars 11 and 23 respectively. At the driving end of the device the casing 45 has fitted into it a metal bushing 47, the outer end of which is extended and bored to form a pump cylinder 49, which extends into the body of the reservoir 1. Sliding within this cylinder is a piston comprising a head 51 secured to an elongated skirt 53 extending substantially the entire length of the cylinder. The piston head 51 is provided with a bearing bushing 55 which slides upon a piston rod 57. The piston rod is shown in its retracted position; i. e., moved as far as it will go to the left of the figure. It connects with the driving mechanism through link C, pivotally connected to the piston rod by a pin 61, the link projecting into the cylinder through apertures 63 in a piston head 65. A compression spring 67 within the piston skirt bears between the piston head and the cylinder head, tending to force the piston out of the cylinder and into the cavity within the bushing 47, and thus force oil out of the casing 45. The spring is proportioned to exert a pressure of about two atmospheres on the oil in the casing.

The piston rod 57 terminates in a yoke fitting 69, to which it is rigidly secured. Between the fitting and the piston head is a collar 71 adapted to engage the bushing 55 and force the piston into the position shown, compressing the spring. When the piston moves toward the right, however, the collar may move ahead of the piston, leaving the latter to follow under the impetus of the spring. As will become evident hereafter, the motion of the piston is damped by the oil within the casing so that its motion may be relatively slow in comparison with that of the piston rod itself.

The operating rod which carries the moving contacts of the breaker is, in this case, double, consisting of a pair of wooden bars 73 which extend longitudinally through the innermost casing. One end of each of the bars is secured to the yoke fitting 69. The opposite ends of the bars 73 are secured to a yoke 75 mounted on the end of a sliding shaft 77 which extends through a bearing bushing 79 in the end of the cap 27. A flanged disc 81 is secured to the end of the shaft 77 by a suitable nut 83, which also serves to clamp the end of a flexible connector 85 and serves to make positive electrical contact between the shaft 77 and the reservoir, as indicated at the reference character 87.

The main operating spring 88, which opens the breaker when tripped, is of the compression type. It is shown in its maximum stress condition. It surrounds the cap 27 and bears between the plate 21 and the flange on the disc 81, tending to move the operating rod to the right of the drawing.

The moving contacts of the breaker are carried by the bars 73 comprising the operating rod. Each of the moving contacts comprises an elongated finger 89 mounted on a yoke spanning the two bars 73 of the operating rod. Considered from the right hand side of the drawing, the yoke

carrying the first finger 89 is the yoke 75 to which the shaft 77 is attached. In the device illustrated, the contact fingers are of copper and about three and one-half inches long, each being square in cross section. The fingers project from arcuate flanges 91 rising from the yokes which secure them to the bars 73. The yokes 93, following the first yoke 75, are substantially identical and equally spaced along the operating rod. The successive yokes are secured alternately to opposite sides of the rods, bringing the successive contacts quite closely adjacent first to one side of the casing 45 and then to the other.

Sets of fixed contacts are mounted within the casing 45 so as to engage the ends of the moving contacts when the latter are in the closed position. The first set of these contacts, counting this time from the left of the drawing, is in electrical contact with the bushing 47 and thence through a flexible conductor 94, with the reservoir and operating gear at this end of the breaker. A metal support bar 95 is secured across the end of the bushing 47. Copper contact points 97, four in number, to engage each side of the square contact finger, are borne by contact springs 99 suitably secured to the bar 95.

The remainder of the fixed contacts are substantially identical in form, the corresponding parts being indicated by the same reference characters as those of the contacts just described. They are secured, however, to insulating supports 101 fastened alternately to opposite sides of the casing 45 in position to engage the fingers of the moving contacts. Each fixed contact following the first described is connected by a flexible conductor 102 to the moving contact of the preceding pair, so that when the breaker is closed there is a continuous metallic connection through it, but when open the gaps between the contacts of each pair are all in series.

An interrupter tube is positioned immediately adjacent each of the fixed contacts, extending transversely of the casing 45. Each of these interrupter tubes is apertured to permit the finger 89 of the corresponding moving contact to pass laterally through it, and the diameter of the tubes and their position is such that when the breaker opens the arc path between the fixed contact and its associated moving contact lies almost entirely within the breaker tube. All of the interrupter tubes 103 (being all except the last on the right in Figs. 1 and 3) are substantially identical, their construction being substantially as shown in Figs. 4 and 5. One end, immediately adjacent the apertures 105 through which the moving contact finger passes, is closed by a plug 107 secured to the walls of the casing by dowels and having in the center thereof an axial threaded hole 109. The walls of the interrupter tube are notched immediately above the plug 107 to receive a locking bar 111 which is held in place by a screw 113 threaded into the hole 109 in the plug. A shoulder 115 on the outer wall of the interrupter tube fits against the bottom of a counterbore in the inner wall of the casing 45, so that the interrupter tube is rigidly held in place within the casing, clamped between the bottom of the counterbore and the bar 111 bearing against the outer wall of the casing, all as most clearly shown in Fig. 2.

Slightly beyond the aperture 105, on the opposite side from the plug 107, a circular baffle 117 extends across the tube, thus forming an arching chamber in the end of the tube. Slightly beyond the arching chamber, a septum 119 divides

the interrupter tube into two passages which open directly into the space 121 between casings 45 and 4. The baffle and septum are both held in place by dowels 123. The baffle is provided with two passages 125 (see Fig. 4) opening on either side of the septum for the passage of gas and vapor from the arcing chamber into the passages leading into the oil space 121.

A pair of vertical holes 126 extend entirely through the interrupter tube on either side of the baffle 117, these holes communicating with grooves 127 formed in the surfaces of the baffle. Beyond the baffle a multiplicity of much smaller holes 131 (about $\frac{1}{8}$ " diameter) are formed in the sides of the interrupter tubes, these holes being counterbored from without so as to reduce the friction offered to oil which enters these holes and forms jets within the passages on each side of the baffle.

The interrupter tube 133 on the right hand end of the breaker is illustrated in Figs. 6 and 7. It is similar in size and method of attachment to the casing 45 with those already described and the corresponding elements for securing it to the casing 45 are identified by the same reference characters as those already considered. An arcing chamber is formed in the end of the tube but the walls of the tube immediately above and below the baffle are not perforated, although the same type of baffle may be used. Beyond the baffle, however, the construction is quite different; first, the tube opens into the interior of the casing 45 through a plurality of relatively large apertures 135. Second, no septum is provided to divide the tube into two passages, and third, instead of opening freely into the space 121 between casings 33 and 45, the end of the tube is normally closed and held closed by a relief valve generally designated by the reference character 137. The relief valve structure comprises a ring 139 (see Fig. 7) surrounding the ends of the interrupter tube and secured thereto by screws 141. Extending from this ring beyond the end of the tube are a plurality of struts 143 to which a disc 145 is welded or otherwise secured, the whole forming a valve cage. A stud 147 extends inwardly into the breaker tube from the center of the disc 145. The valve itself comprises an annular disc 149 with a cylindrical cap 151 covering its central aperture. The stud 147 projects into this cap and is surrounded by a heavy compression spring 153 which, bearing against the disc 145 and the end of the cap 151, holds the disc tightly against the end of the breaker tube. The strength of the spring is such that the valve will open at about two atmospheres pressure differential.

From the foregoing it will be seen that the only substantial passages, by which any material amount of oil from the interior of casing 45 can be transferred into the space 121 between this and the next outer casing 4, is through the interrupter tubes. Normally none will be so transferred through the end interrupter 133 unless the pressure rises to such a value that the relief valve 137 opens. As will be shown later, however, when this occurs what is discharged will be largely vapor and not oil. There are provided, however, in the top and bottom of the casing 45, a number of small holes 155 (say $\frac{1}{8}$ " in diameter). The total area of these holes aggregates perhaps 1% of the total available passage for oil between the casing; they are provided in order to prevent any possible air or vapor lock in the initial filling of the device and to permit

the escape of any residuum of uncondensed gas after the breaker has operated.

As will be seen from Fig. 1, the oil passage 121 is open at either end into the chambers 5 and 18 respectively. Escape from the inner to the outer compartment of the chambers is provided through a ring of relief valves in each of the dividing walls 9 and 25 respectively, these walls being provided with relatively large openings 157, each of which is covered by a valve disc 159 slidably mounted on a stem 161 projecting into the reservoir from a bar 162 spanning the opening 159. A spring 163 bears between the valve, and a disc 164, carried on the end of each stem 161, and holds the valve closed. The springs are preferably so proportioned that the relief valves will open under a pressure of about three atmospheres.

At each end of the breaker the small openings 13 connect the chambers 5 and 18 with the main body of the receiver, bypassing the relief valves. As will be seen, the combined areas of these openings are very small in comparison with the aggregate areas of the relief valves with which they are in parallel. At high rates of oil flow, openings 13 will offer a very material degree of friction so that the most of the moving oil will prefer to pass through the relief valves.

Passage of oil into the interspace between casings 4 and 29 is provided for by ports 167 in plates 3 and 17, just within the periphery of the outer casing 29. At the driving end of the breaker these ports connect with grooves 168, formed in the plate 7, which form passages into the reservoir. The oil in the interspace between casings 4 and 29 does not enter into the normal operation of the breaker. It does add to the insulation of the device, and the interspace permits passage of oil between the two reservoirs and equalization of oil level as between them.

Operation of the breaker is accomplished by a longitudinal motion of the operating rod. The breaker is closed by traction on the piston 57; it is opened by spring 38 when the closing mechanism is tripped free. As the breaker contacts start to open under the impetus of the spring, an arc is formed in each of the gaps between the fixed and moving contacts, the arc drawing out within the arcing chamber between the plug and the baffle in each of the interrupter tubes. At least a portion of the oil in each of these chambers is immediately vaporized, expanding and forcing oil out of the interrupter tubes into the interspace 121 and out of the latter through the chambers 5 and 18 into the reservoirs. Owing to the very sudden development of the pressure and the relatively large aggregate of passages between the innermost and intermediate casings, the opening of the bypass ports 13 is entirely inadequate to relieve the pressure developed, which is accordingly established as approximately three atmospheres as it appears in the chambers 5 and 18.

The vapor in interrupter tube 133 has no direct escape into interspace 121, but must pass, instead, through openings 135 into the inner casing 45 unless and until the pressure within the interrupter rises to two atmospheres above that in the interspace and causes relief valve 137 to open. The oil in casing 45 is therefore subjected to a differential pressure of two atmospheres above that in the interspace, which is itself under a pressure of three atmospheres above normal, so that the arcs are formed under a pressure of about 90 pounds absolute. At such pressures oil

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vapor has nearly the dielectric strength of oil itself, and, therefore, when the arcs are once extinguished, it is practically impossible for them to restrike, even at potentials greatly in excess of normal line voltage.

When the relief valve 137 does open, the only oil that is discharged into the interspace is that remaining unvaporized in the interrupter tube itself. This oil and the vapors that are discharged from the interrupter tube can pass cut through the ring of relief valves into reservoir 15, and the body of oil in casing 45 is still available for condensing the vapor formed in the other tubes.

As there is a two-atmosphere differential between the pressure in casing 45 and that in the interspace 121, the oil in the innermost casing is forced through the apertures 131 in the interrupter tubes 103 as a large number of jets of relatively high velocity. In addition, oil is forced through the holes 125 on each side of the baffle 117 and into the grooves 127, spreading over the surface of the baffle and preventing its charring from immediate contact with the hot vapors. The arcing chambers in each of these interrupter tubes open freely into the interspace 121, and the evolved vapors pass through the openings in the baffle and into the passages toward the interspace. In so doing, however, these vapors must pass through the multiple jets of oil, which, acting like the jets in a jet type of steam condenser, effectively cool and condense the vapors. Experiments have shown that before they can reach the interspace 121 they have undergone practically complete condensation and have returned to the liquid phase. Continuation of the arcing within the chambers within the interrupter tubes therefore contributes little or nothing toward increased pressure. Nevertheless, however, the highest pressure within the interrupter tubes is in the arcing chambers themselves immediately surrounding the arc, and very little oil filters into the chambers through the apertures 105. What little does enter is around the arc path instead of through it, so that it has a minimum effect toward cooling the arc and raising its resistance.

The pressure developed by the pressure-forming arc under a heavy short is sufficiently high so that it prevents the pump piston 51 from following the operating rod after the circuit starts to open, for although the initial stress on the pump spring will apply two atmospheres pressure to the oil, this pressure will drop somewhat as soon as the piston has moved. After the arcs are extinguished, however, the piston will follow the operating rod and maintain the pressure for a short period, perhaps $\frac{1}{4}$ second, and the actual time required for this being determined by the pressure drop in the jets between the inner and intermediate casings and by the size of the bypass ports 13. This is a relatively long time in comparison with that required to break the circuits and extinguish the arcs. The latter operation requires approximately 3 cycles after the gaps start to open: in a 60 cycle circuit it takes about 2 cycles from the time the fixed and moving contacts start to separate to the time when opening is complete. The next half cycle will usually be sufficient completely to break the circuit. Experience indicates that the particular breaker shown will open any load within its capacity in 5 to 5½ cycles after the trip coil is first excited to its operating point. The inertia of the mechanical parts accounts for the remaining

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time between the first application of a fault load and a complete break in the circuit.

Where the breaker is used to open a purely capacitive load, as in the case of disconnecting an unloaded transmission line, the operation may be slightly different. As was pointed out above, the current to be broken may be very small and consequently the evolution of gas may be no more than sufficient to empty the arcing chambers in the ends of the interrupter tubes of oil in the liquid phase. Consequently, after the first surge of pressure, no more vapor may be evolved in the pressure forming arc. The pump at the driving end of the breaker, however, continues to apply a pressure of about two atmospheres to the oil. The pressure of approximately two atmospheres is therefore maintained in the arcing chambers, raising the dielectric strength of the vapor to nearly that of the oil itself and preventing the arc from re-establishing and building up excess voltage, as was explained above. Furthermore, owing to the constriction of the passages through which any interchange of oil between the innermost and outer casings must take place, any hydraulic oscillation which may tend to occur is highly damped, and it is practically impossible to develop the negative pressures which are indirectly the cause of the effect which has been described.

The breaker which has been described in detail herein is designed to function on a 115 kilovolt circuit carrying up to 1½ million kilovolt-amperes. Relative proportions of the parts shown are therefore those appropriate to phase voltages, to ground, in the neighborhood of 65,000 volts, and phase currents of 7,500 amperes. Generator reactance will limit the current on a solid fault to about three times full load value, or between 20,000 and 25,000 amperes.

The total volume of oil required for the breaker illustrated is between 130 and 150 gallons. That required for one commercial tank-type breaker of comparable capacity is 3,150 gallons. The saving in oil is therefore approximately in the ratio 20 to 1 as compared to breakers of the tank type. Size and cost of structure are correspondingly reduced.

Breakers of this same general type can, of course, be constructed in other sizes for other specific applications. Design for such purposes will usually permit or require modification in detail, and, possibly, the omission of features desirable in a breaker of the capacity here considered or the addition of features not here shown. It is therefore desired that the protection accorded the invention shall not be limited to the specific device herein described, but only by such limitations as may be expressed in the following claims.

What is claimed is:

1. A circuit breaker structure comprising a plurality of tubular insulating casings mounted one within the other and all adapted to hold an insulating liquid, an insulating operating rod reciprocally mounted within the innermost of said casings, a plurality of elongated moving contact elements mounted on said rod, a like plurality of fixed contact elements mounted within the casing and engageable by said moving contact elements, a plurality of tubular interrupter elements mounted transversely of said inner casing adjacent said fixed contact elements and apertured in a direction parallel to the axes of said casings to permit the passage of said movable contact elements therethrough in engaging said fixed

elements and cause any arc formed when said contact elements are separated to occur within said interrupter elements, each of said interrupter elements being closed at one end and opening into an outer one of said casings at the other end, said interrupter elements forming the only substantial passage outward from said innermost casing and having a plurality of relatively small apertures in the sides thereof between said contact-passing apertures and the open ends of said interrupter elements, and means operative upon disengagement of said contact elements for establishing a pressure within said innermost casing tending to drive liquid therefrom through the apertures in said interrupter elements toward said outer casing.

2. A circuit breaker in accordance with claim 1 wherein said pressure establishing means comprises an additional fixed contact element and an additional movable contact element engageable therewith coincidentally with the engagement of the aforementioned contact elements, a transverse tube apertured to pass said additional movable contact element, and closures at both ends of said tube, said tube being laterally apertured into said innermost casing.

3. A circuit breaker in accordance with claim 2 wherein the closure at one end of said transverse tube includes a relief valve opening into an outer casing.

4. A circuit breaker in accordance with claim 1 wherein three casings are employed, said interrupter elements opening into one of said outer casings, a passage connecting said one outer casing with the second of said outer casings, and relief valve means interposed in said passage and adapted to open when the pressure in said one outer casing exceeds that in the second of said outer casings by not more than a few atmospheres, said second outer casing being open to atmospheric pressure.

5. A circuit breaker in accordance with claim 4 including additional means operative upon disengagement of said contact elements for establishing in said innermost casing a pressure less than that required to operate said relief valve means.

6. A circuit breaker in accordance with claim 5 including a bleeder passage connecting said outer casings and so restricted as to maintain the pressure established by said additional means for a period of the order of seconds.

7. A circuit breaker in accordance with claim 5 wherein said additional pressure establishing means comprises a pump cylinder opening into said innermost casing, a piston within said cylinder, a spring adapted to urge said piston toward the opening into said casing, and means con-

nected to said operating rod and unconnected to said piston to thrust said piston away from said opening upon engagement of said contact elements, so that said piston actuated by said spring alone empties said cylinder into said innermost casing upon operation of said rod to disengage said contact elements.

8. A circuit breaker in accordance with claim 5 wherein said additional pressure establishing means comprises a pump cylinder substantially coaxial with and opening into said innermost casing, an extension of said operating rod passing longitudinally through said cylinder, a piston slidably mounted on said extension within said cylinder, a spring adapted to urge said piston toward said casing, and a collar on said extension and positioned to bear against said piston and stress said spring when said contact elements are engaged and release said piston upon operation of said rod to disengage said contacts.

9. A circuit breaker structure comprising a first casing adapted to hold a dielectric liquid, a fixed contact within said casing, a movable contact within said casing engageable with said fixed contact and separable therefrom to form an arc path therebetween, a reservoir for dielectric liquid, a second casing having an opening into said reservoir and adapted to be filled with said liquid, an arcing chamber substantially surrounding said arc path and opening into said second casing, means operative upon separation of said contacts for establishing pressure on liquid in said first casing, and a relief valve substantially closing said opening between said second casing and said reservoir for retaining pressure in said second casing up to a limited value.

10. A circuit breaker in accordance with claim 9 including means for limiting the pressure differential between said first and second casings.

11. A circuit breaker in accordance with claim 9 wherein said pressure establishing means comprises an additional pair of fixed and moving contacts operative coordinately with said previously identified contacts to form an additional arc path, an arcing chamber within said first casing substantially surrounding said additional arc path and opening into said first casing, and a relief valve connecting said last mentioned arcing chamber and said second casing for limiting the pressure differential between said casings.

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