Aug. 10, 1937. H. MILLIKEN 2,089,286

CIRCUIT BREAKER

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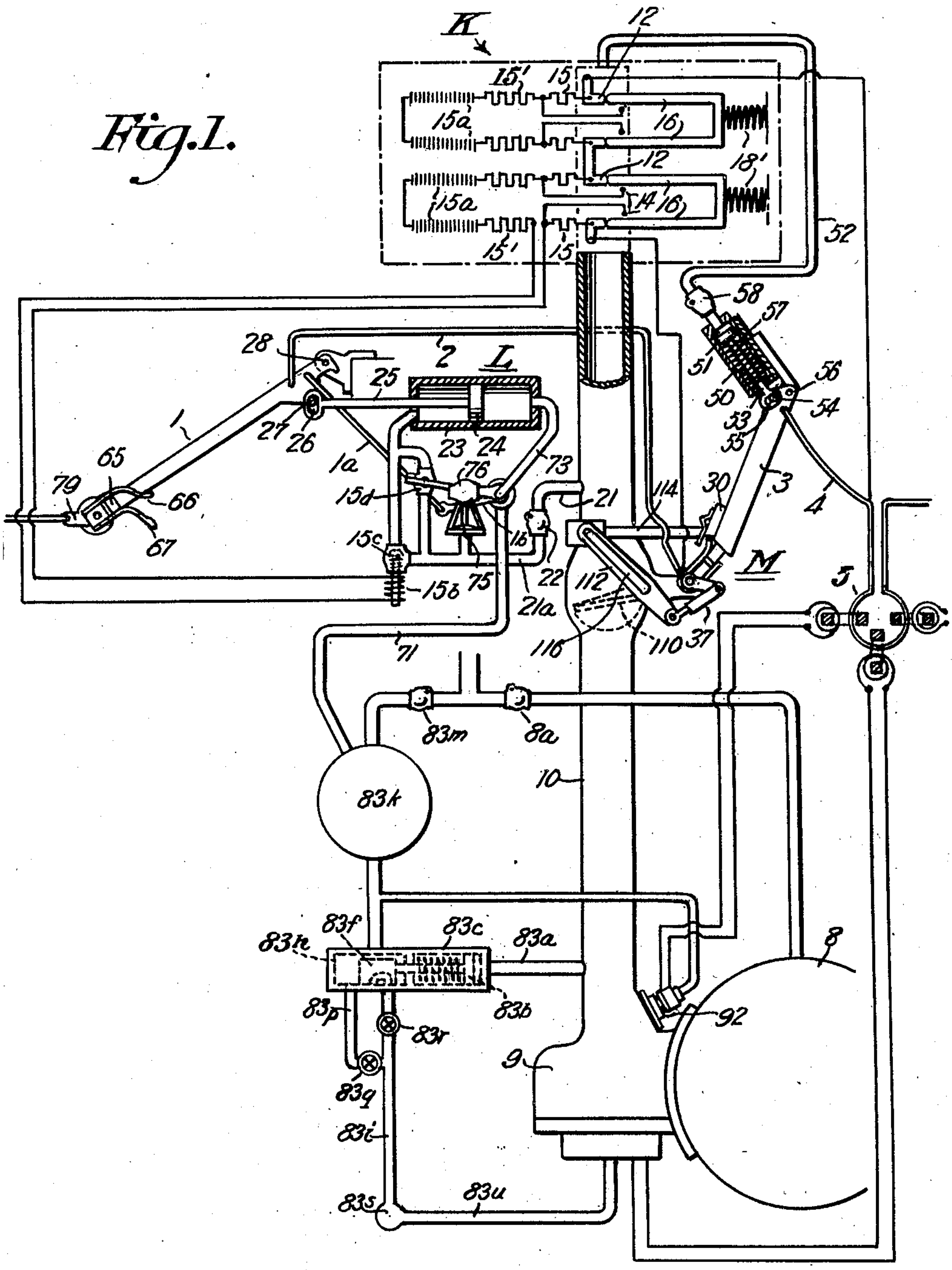
Fig.1.



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CIRCUIT BREAKER

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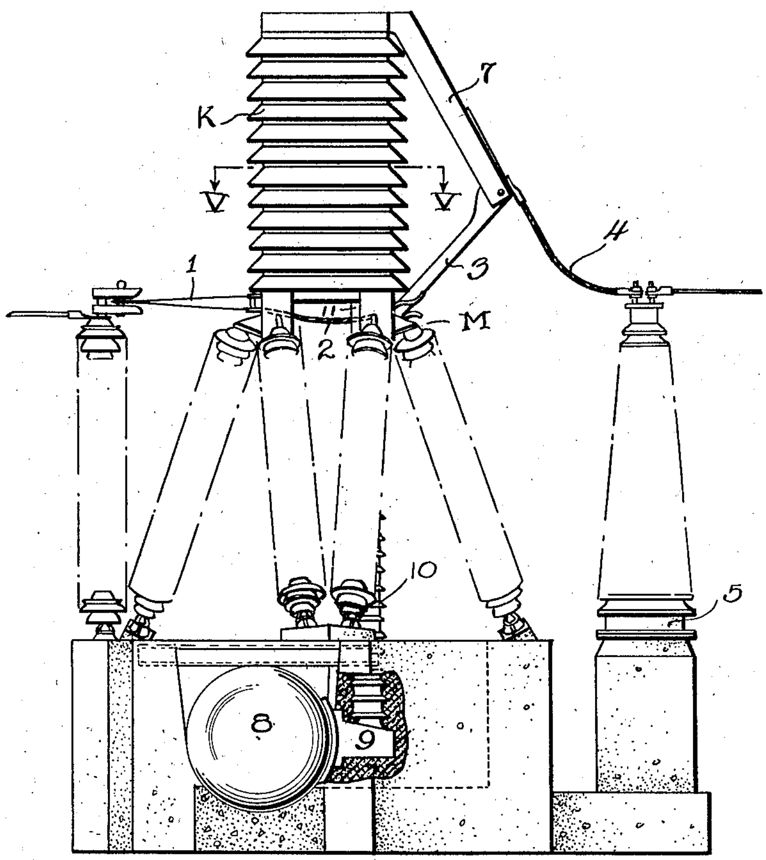
Fig. 2



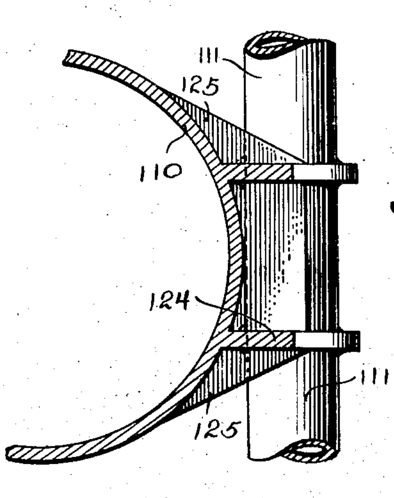


Fig. 10

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Fig. 3

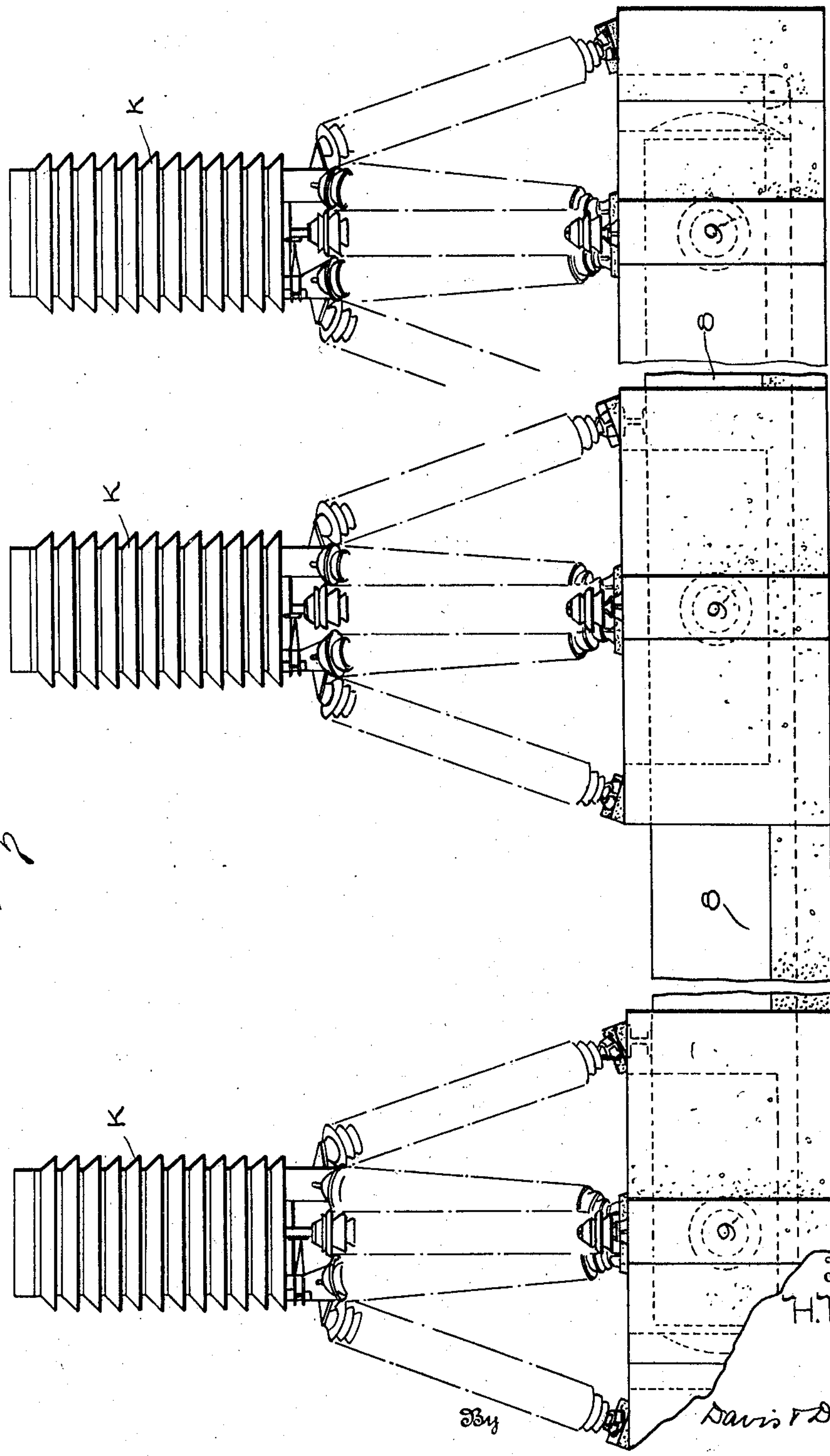

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Fig. 4

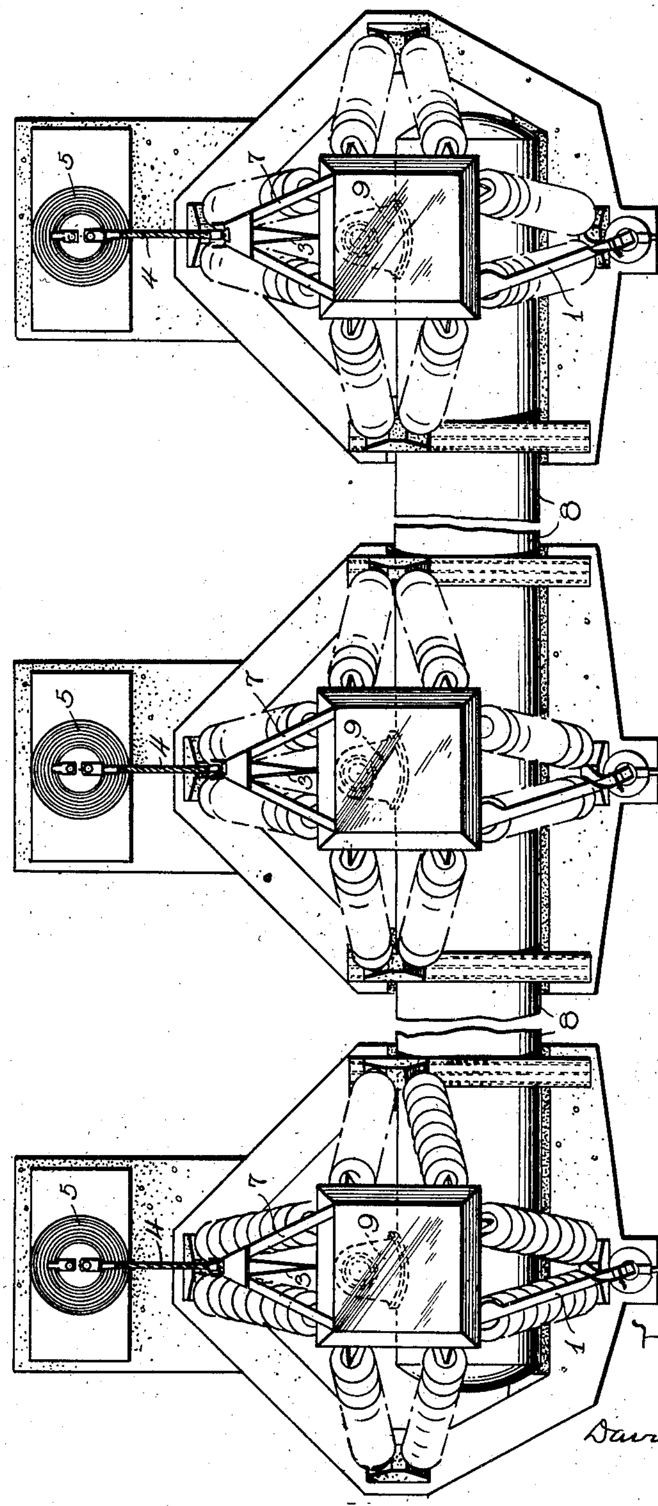

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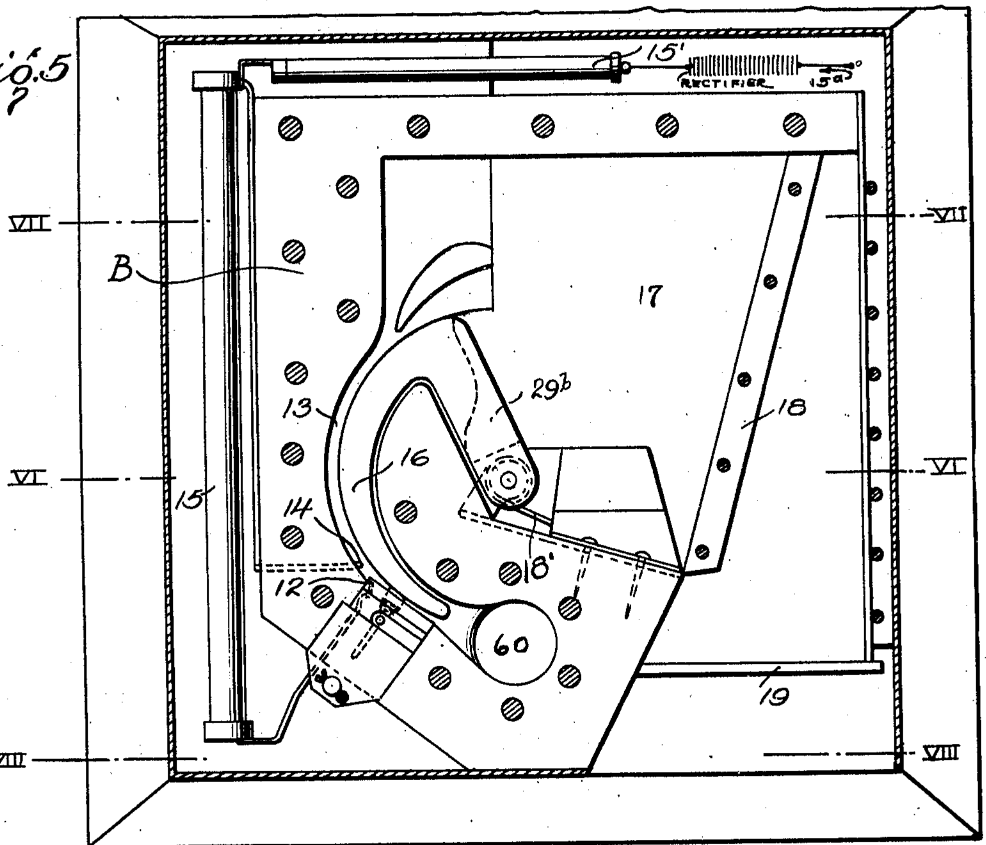
Fig. 5



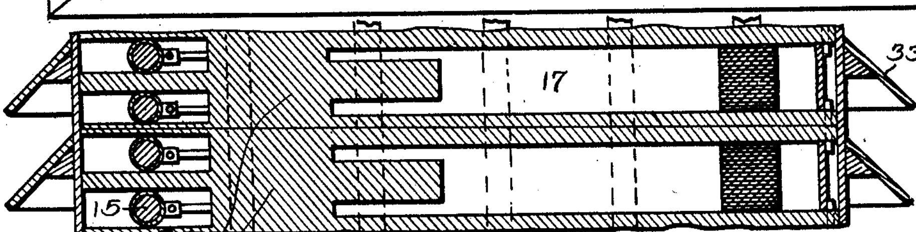


Fig. 7

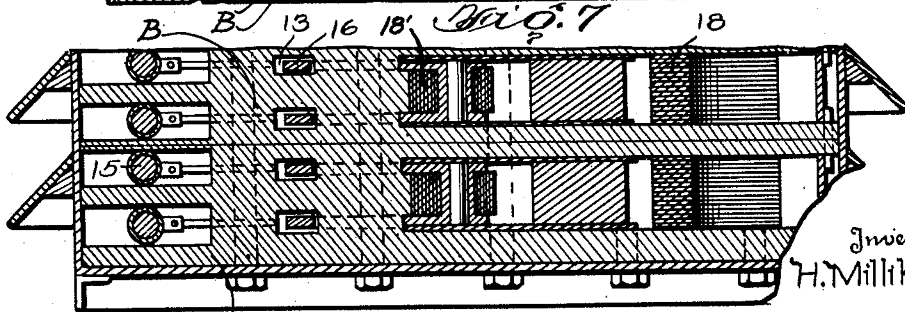


Fig. 6

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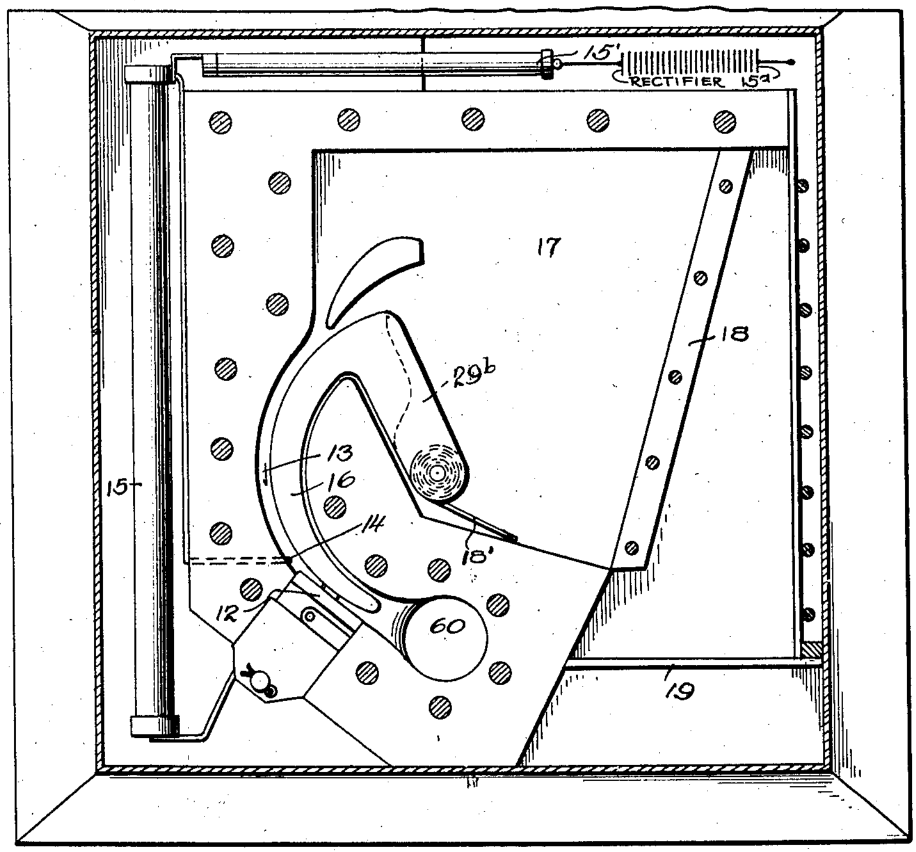

Fig. 9

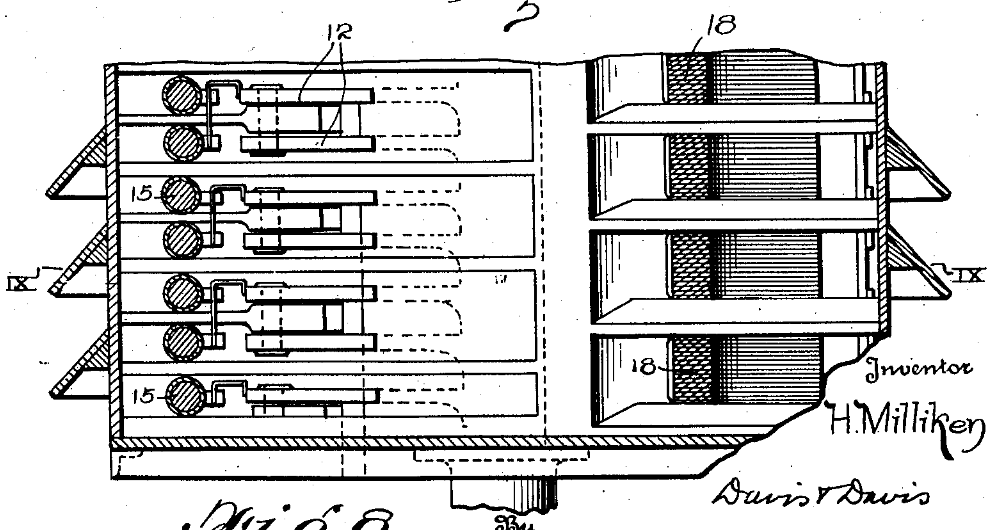

Fig. 8

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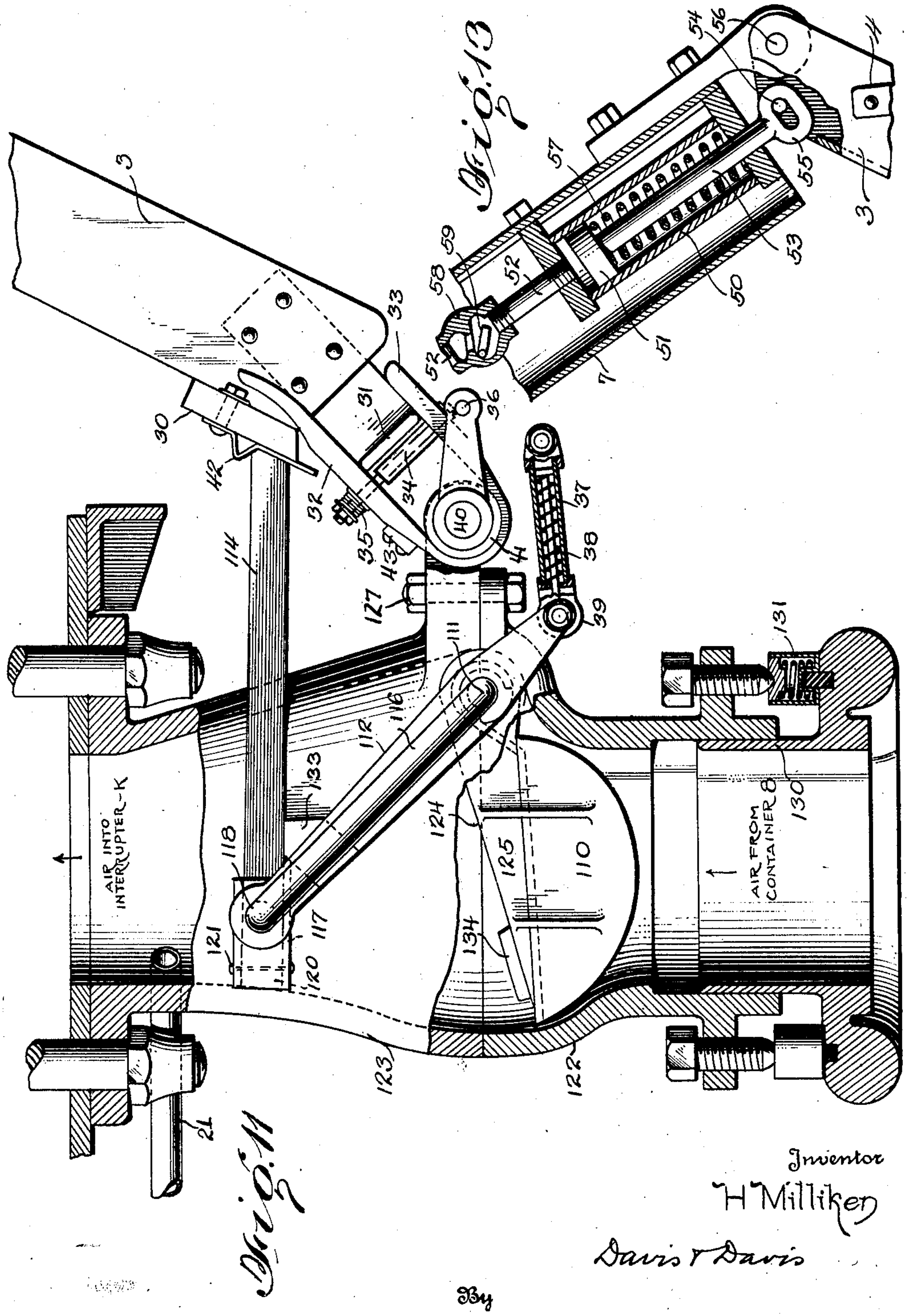

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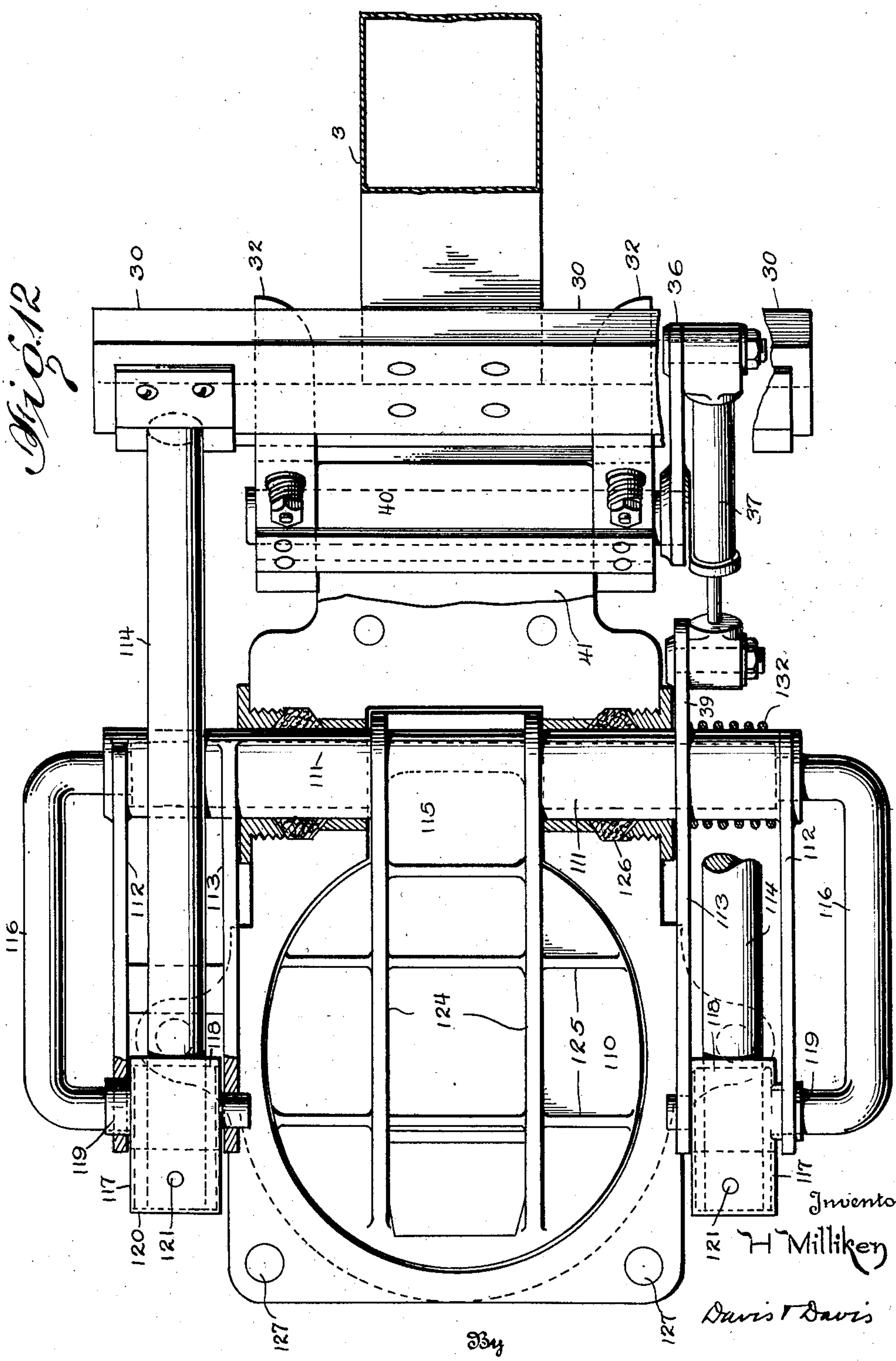
Fig. 12



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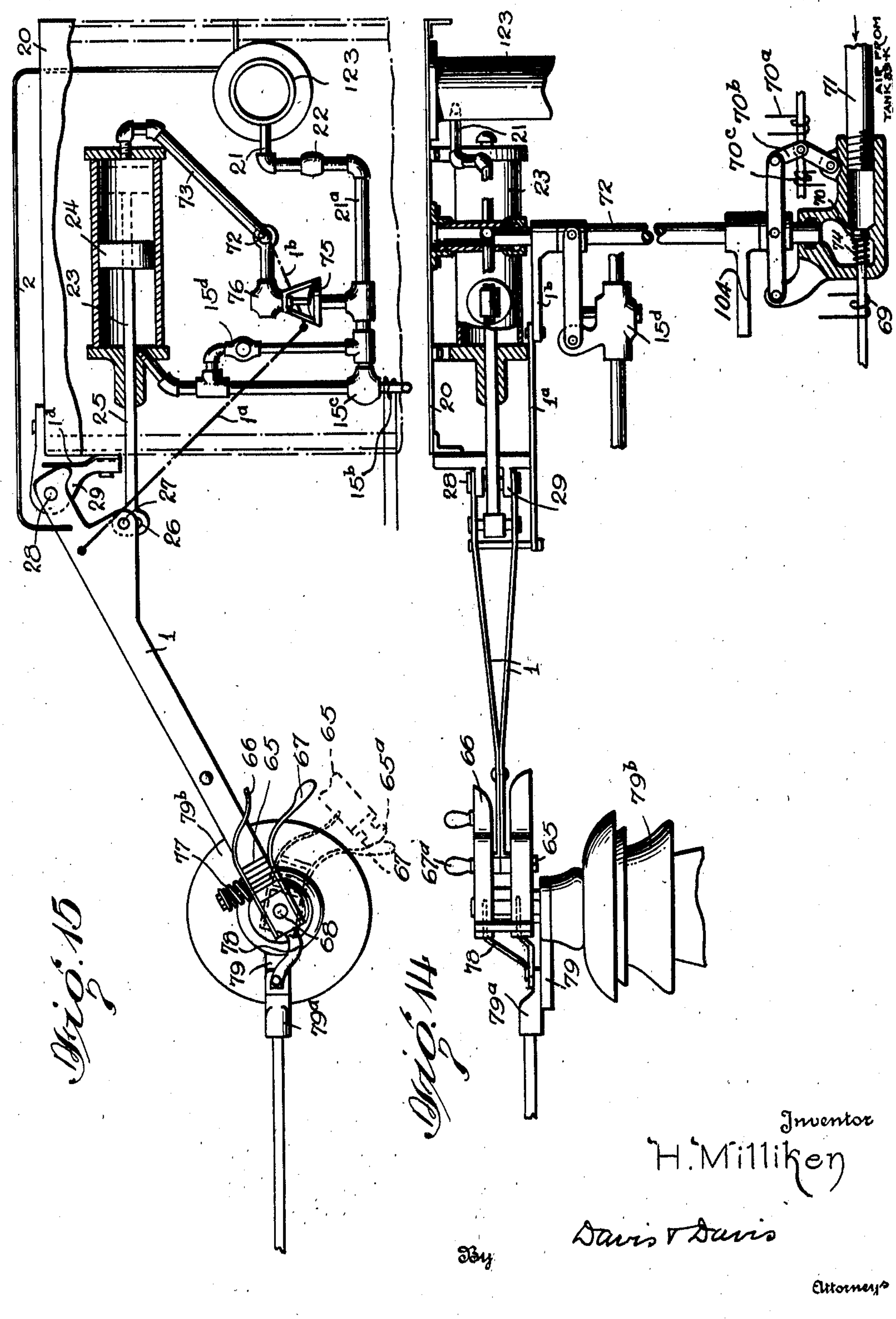

Fig. 15

Fig. 14

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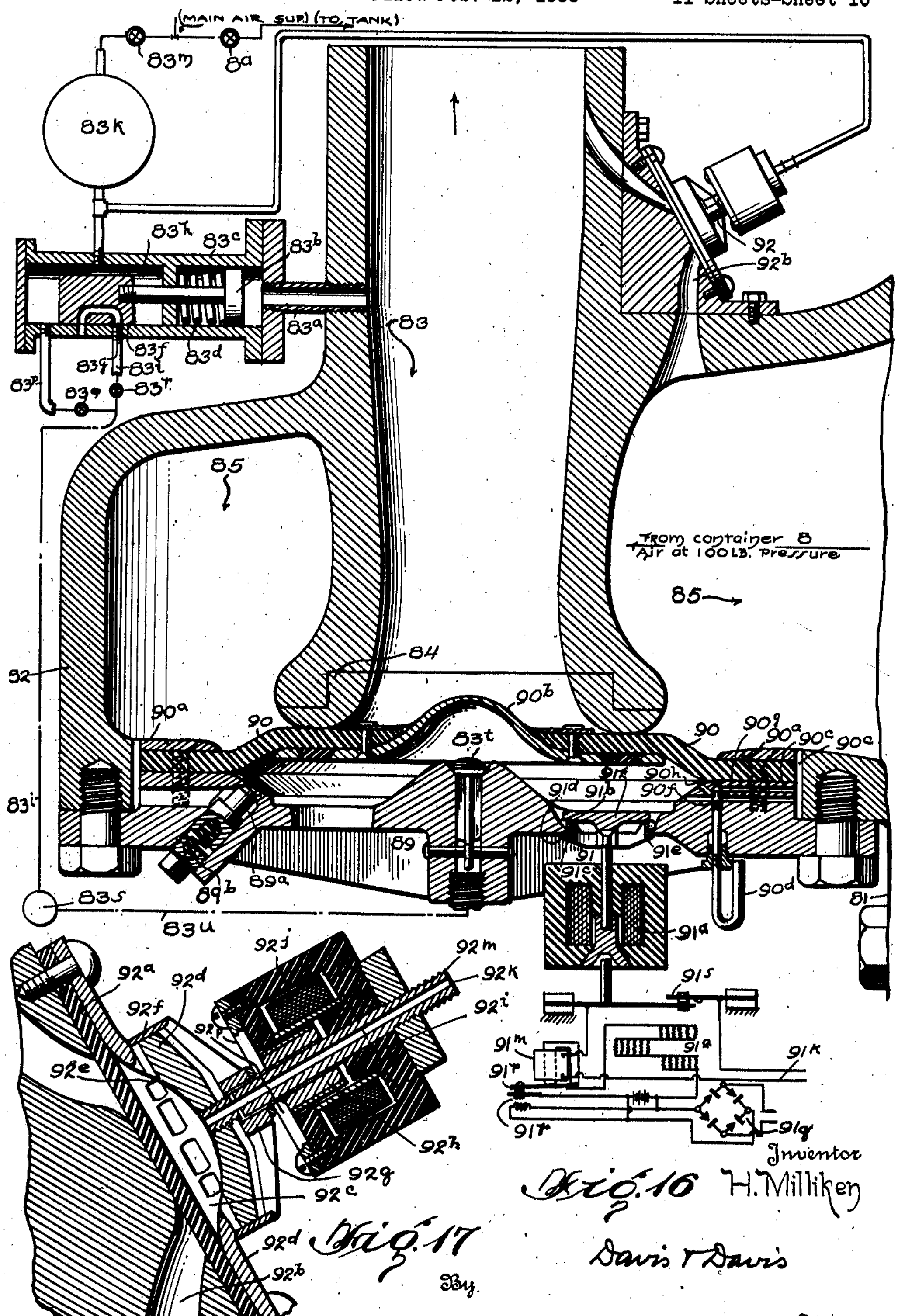

Fig. 16

Fig. 17

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CIRCUIT BREAKER

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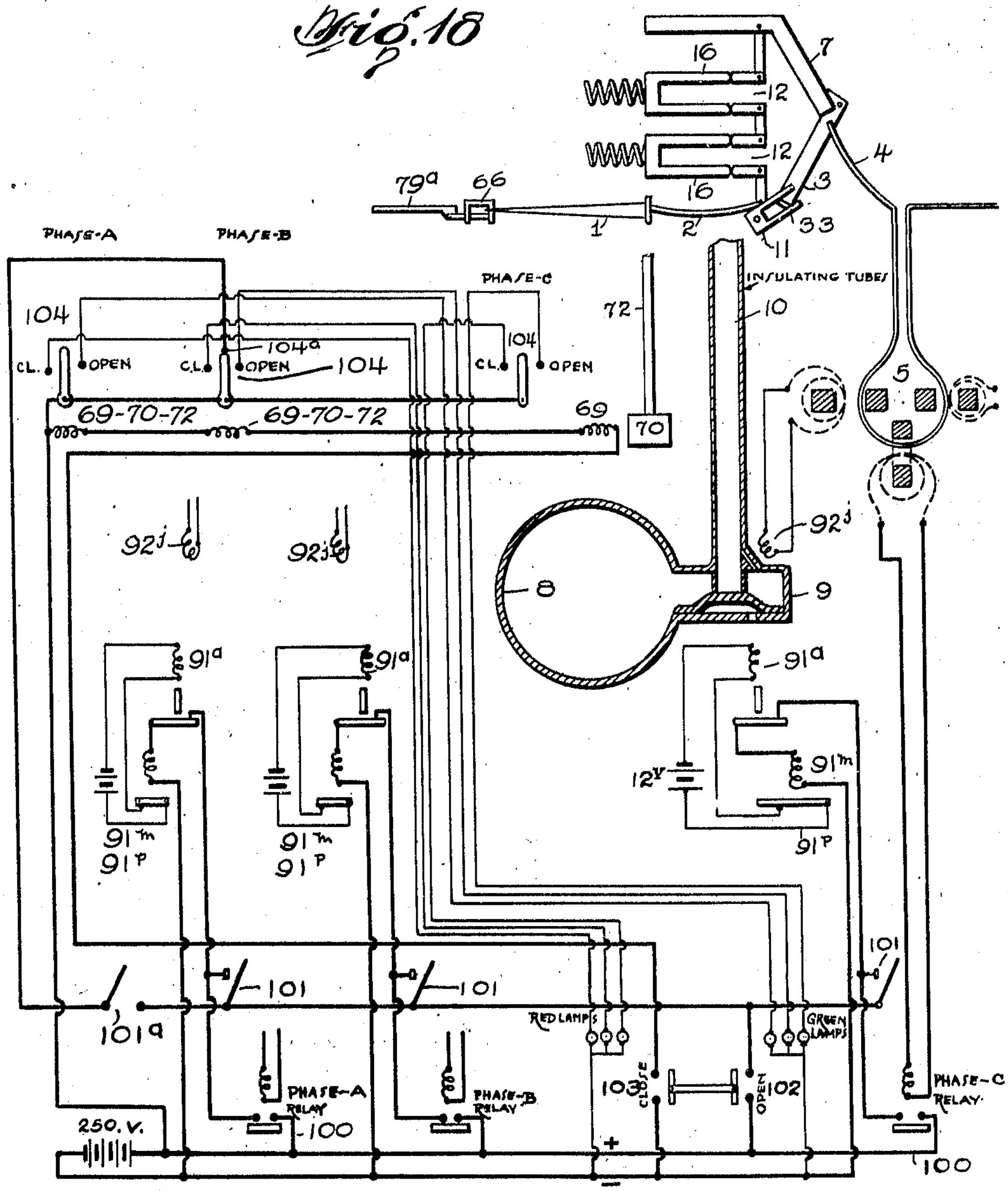
Fig. 18



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Patented Aug. 10, 1937

2,089,286

UNITED STATES PATENT OFFICE

2,089,286

CIRCUIT BREAKER

Humphreys Milliken, Mount Royal, Quebec, Canada

Application February 12, 1935, Serial No. 6,236

20 Claims. (Cl. 175—294)

This invention relates to circuit breakers for interrupting heavy short-circuit currents in large power systems. More particularly the invention relates to improvements in gas blast circuit breakers for interrupting heavy short-circuit currents.

An important object of the invention is to provide improved means for operating such a circuit breaker.

Other objects of the invention will appear hereinafter.

In the drawings, Fig. 1 is a view showing diagrammatically an arrangement of switches, operating mechanism and circuit connections employed in the circuit breaker;

Fig. 2 an end view of the circuit breaker;

Fig. 3 a side view of the circuit breaker embodying three poles for handling a three-phase circuit;

Fig. 4 a plan view of the three-phase breaker;

Fig. 5 a horizontal sectional view of the current interrupter for one of the three-phases of the circuit, taken on the line V—V of Fig. 2;

Fig. 6 a vertical section through the current interrupter, taken approximately on the line VI—VI of Fig. 5;

Fig. 7 a vertical section through the interrupter, taken approximately on the line VII—VII of Fig. 5;

Fig. 8 a vertical section through the interrupter, taken approximately on the line VIII—VIII of Fig. 5;

Fig. 9 a horizontal section through the interrupter, taken approximately on the line IX—IX of Fig. 8;

Fig. 10 a detail cross-sectional view of the rockable impeller for operating the transfer or by-pass switch and showing a portion of the tubular impeller shaft.

Fig. 11 a sectional side elevation of the mechanism for opening the by-pass or transfer switch;

Fig. 12 a sectional plan view of the mechanism for opening the by-pass or transfer switch;

Fig. 13 a vertical sectional view of the mechanism for closing the by-pass or transfer switch;

Fig. 14 a side elevation of the disconnecting switch and showing the operating mechanism therefor, partly in elevation and partly in section;

Fig. 15 a plan view of the disconnecting switch and its operating mechanism, the latter being partly in section;

Fig. 16 a vertical sectional view of the gas blast control valve mechanism and including a portion of the electrical connections for operating said mechanism;

Fig. 17 a detail vertical sectional view of a by-pass valve employed in association with the main gas blast valve; and

Fig. 18 a wiring diagram for the three-phase circuit breaker.

As shown diagrammatically in Fig. 1, the circuit-breaking apparatus for each phase of the circuit includes a current interrupter K, a main disconnecting switch 1 and a by-pass or transfer switch 3. These are all operable in a desired sequence in response to a blast of air or other suitable gas. For supplying said blast, there is provided a storage tank 8 for compressed air. A valve device 9 is secured to said tank, and a blast tube or conduit 10 leads from the valve and is in delivery connection with the current interrupter K. The valve is electrically operable in response to an overload in the main circuit to admit a blast of air from the tank 8 to the conduit through which it is delivered to the current interrupter to open the latter and also extinguish arcs therein. There are also connected to the conduit a mechanism L to open the disconnecting switch 1, and a mechanism M to open the by-pass switch 3. These mechanisms are also operable in response to the air blast in the conduit.

In Fig. 1 the interrupter K, the by-pass switch 3 and the disconnecting switch 1 are all indicated in closed position. High-tension alternating current may be considered as coming in from the main line at the left, through the disconnecting switch 1, flexible conductor 2, the by-pass switch 3, a flexible conductor 4, a transformer 5, and out through the main line at the right. The interrupter is in shunt with the by-pass switch 3, and normally the flow of current is through the switch 3 instead of the interrupter. The transformer 5 has three secondary windings. One winding has a relay connection for operating the valve 9 to open it, in response to an overload in the main circuit, and admit an air blast to the conduit 10. The purpose of the other secondary windings will appear hereinafter. In the conduit the blast first actuates the mechanism M to open the by-pass switch. Thereby the current is shunted to the interrupter K. The latter is next opened and the arcs therein are extinguished by the air blast. After the air blast has opened the interrupter it effects the opening of the disconnecting switch 1, through the mechanism L. The by-pass switch and the disconnecting switch break no current (except that the latter breaks a very small current under conditions hereinafter described). The current is broken by the interrupter K, which is particularly adapted to perform this function.

The air blast also sets in operation a means for closing the air valve 9. The by-pass switch 3 and the interrupter K are returned to closed position by springs. The disconnecting switch 1 is left open. Therefore, as soon as the switch 1 is closed the apparatus will be in condition to reopen properly and immediately in case it is required to open by reason of a fault existing on the power system.

Figs. 5, 6, 7, 8, and 9 show, in detail, the structure of the interrupter. It is a built-up structure comprising a stack of similar, flat, superposed units. Said units may be stacked up in greater or less number, in accordance with the voltage which the interrupter is required to handle. In the present instance, there are twelve of the stacked units in each interrupter. Each unit comprises a body B of insulation recessed to define an aperture or vertical bore 60, a diffusion chamber 17 and a pair of horizontal arcuate passages or arc chutes 13 connecting said bore and chamber. The body B may be formed of groups of horizontal sheets cemented together. All groups are bolted together by twenty vertical rods of insulating material. A pair of arcing horns 16 are pivotally mounted within the diffusion chamber to swing horizontally and they are electrically connected and connected to swing in unison. Each horn comprisese a radial arm leading from the pivotal mounting of the horn and bearing an arcuate portion which extends through one of the arc chutes 13. The bores 60 of the successive interrupter units are disposed in register to form a vertical air conduit leading to the top of the interrupter. The air blast pipe 10 is in delivery communication with the lower end of said conduit, and the conduit is in lateral communication with all of the arc chutes. While the arc chutes, and the members 16 are, in the present instance, curved, they may be rectilinear and the members 16 may move along a straight line instead of an arc.

The insulator bodies of the interrupter units are also recessed to shiftably accommodate contactors 12. The latter are arranged laterally or transversely of the horns 16 and are disposed to project into the arc chutes and bear laterally against one side of the tip portion of the horns, when the horns are in closed-circuit position. Said tip portions are tapered to provide a flare for admission of the air blast from the aperture 60. A spiral spring 18′ at the pivotal mounting of each pair of horns urges the horns to circuit-closing position. Each contactor 12 is also spring-urged laterally into contact with its cooperating arcing horn or electrode. Alternate contacts 12 are electrically joined in pairs to form with the horns a zig-zag current path throughout the full height of the interrupter structure.

The actual arc chute occurs between the outer arcuate wall of the horn 16 and the opposed insulation wall. The chute so defined is quite narrow and its cross-section is only about three quarters of a square inch. This is desirable for the reason that the small cross section of the chute has an important effect upon the efficiency of the arc extinction under the air blast. The horn forms a movable wall of the chute and it is essential that this wall be of conducting material and form part of the high-tension circuit in order that one end of the arc current path shall be swept rapidly away from its other end to stretch its length and reduce its conductivity to zero in minimum time and with minimum air supply to the arc chute. Each arc chute 13 is of about one inch depth vertically, and the horn which moves in it is of about seven-eighths inch depth. Each pair of arc chutes opens into the diffusion chamber 17. The latter is about four inches in depth and has a horizontal area of about six square feet. The diffusion chamber has an outlet to atmosphere, and a cooling grid 18 is disposed across the path of air to the outlet. Said grid may be formed of sheets or strips of copper closely spaced. At the outlet, there is a closure in the form of a hinged damper 19. The latter is normally closed but is adapted to be swung open by the air blast and to be reclosed by its own weight.

The outer stationary insulation wall of each arc chute has a resistor contact 14 spaced inward along the chute from the contactor 12, and out of contact with the horn 16. A current-reducing resistor 15 is connected to each contact 14. There is in the interrupter one resistor 15 for each horn 16. Each comprises granulated carbon packed in insulating tubes and held under compression by a spring. Each of said resistors is also connected to a second resistor 15′ of higher ohmic value.

All surfaces of the interrupter with which the arcs may come in contact are completely fireproof. All of the materials of the structure are treated to prevent absorption of moisture from the air. As a further safeguard, a slight flow of warm, dry air is allowed to pass through the interrupter continuously. Clean, dry air is produced by passing it through a pad of wool which removes the oil vapor (from the compressor lubrication), and then through a bed of activated alumina, which removes the moisture vapor to such a degree that the dew point is reduced to about 35° F. below zero. The wool and alumina are packed in the same container in the power house.

The four sides of the interrupter are covered by vertical sheets of "Armourplate" glass one quarter inch thick, a heat-treated material which is very resistant to shock. This insulating surface is vertical, and has inclined shields, or skirts. It is, therefore, fully protected from the accumulation of a conducting path of snow, dust, soot, etc., which would occur if the surfaces were horizontal, and cause a flashover upon interruption of a short-circuit. The sides are readily removable for access to all interior parts, including the contacts, which can be easily removed when required.

A fundamental advantage of the interrupter is that the entire range of commercial voltages, (from 12,000 upward), can be properly served with one design of interrupting element or unit only six inches high and four feet square. A large number of these elements can be stacked up in a relatively small space; for 138,000 volts, the stack will be only about forty inches high, and for 275,000 volts about seven feet high. When higher voltages are required, they can be served by simply adding more of the same units.

The interrupter assembly K, the by-pass switch 3, and the blade of the disconnecting switch 1 are all supported on eight stacks of standard switch insulators in a zig-zag truss formation around the space beneath the interrupter, to eliminate cantilever stresses on the stacks and to provide rigidity. The stacks rest in a structural steel frame embedded in concrete, for rigid anchorage. The compressed air storage tank 8 rests on the same concrete foundations and has three of the air blast valves 9, one for each phase, connected to the three interrupters K by the three porcelain air blast tubes 10, of six-inch internal diameter. The valves 9 are opened and closed electro-pneumatically, the energizing coils, discussed hereinafter, taking less than ten amperes direct current.

The interrupter operates as follows:

An overload in the main circuit causes the valve 9 to open and admit a blast of air from the tank 8 to the pipe 10. After actuation of the mechanism M to open the by-pass switch, as will be described hereinafter, the air blast flows into the interrupter and is distributed by the vertical conduit to all of the arc chutes. In each arc chute the blast first snaps open the contactor 12, or moves it away from the horn 16 about one-half of an inch. The contactor has less resistance to movement than the horn and, therefore, moves away from the horn before the latter commences to move under the impact of the blast. Separation of the contactor 12 from the horn causes an arc and the blast blows the short arc along the narrow horizontal passage 13. The arc touches the resistor contact 14 and shunts the resistor in circuit. This shunts the current out of the arc, reduces the total current, and brings the current practically into phase with the voltage, facilitating current interruption and practically eliminating voltage surges. While one end of the arc remains on the contact 14, the other end is blown by the air along the metal horn 16. Thereby the arc is stretched and subjected to the conduction-reducing effect of the air blast throughout its length. The conditions at this moment are ideal for the breaking of the arc, viz: The cross section of the arc cannot be greater than that of the narrow arc chute; the length of the arc is relatively great; and the full velocity and pressure of the air blast extend from end to end of the arc, with maximum cooling effect from a minimum quantity of air.

While the foregoing is taking place, the horn 16 is moving out under the air pressure which overcomes the spiral spring 18'. The horn is fully opened in about one sixtieth of a second, and such velocity requires a bumper 29b of soft material to stop the horn without injury. The interrupter of current occurs before the horn 16 has reached its outermost position. All of the horns are held in that position by the air blast, putting between the twenty-four open contacts an aggregate separation of about twenty-four feet and giving a large factor of safety against restriking of the arc while the disconnecting switch is opening (about one-quarter of a second). When the air blast is shut off, the horns 16 and contacts 12 are returned to their closed position by their respective springs. The cooling grids 18 remove any remaining incandescent heat without impeding the free passage of air.

The duration of the current through each resistor 15 is about one half cycle, and the resistors never rise in temperature more than 10° C. The ohmic value of the resistors is based upon a system impedance corresponding to a maximum (rated) interrupting capacity of the breaker, so that the current is reduced to almost the same value, regardless of the amount of the initial short-circuit current. The second resistor 15' is of much higher ohmic value (about 100,000 ohms). There is one resistor 151 for each resistor 15, all being connected in series to produce a uniform potential gradient through the interrupter and overcome electro-static effects which would otherwise give a non-uniform gradient.

The by-pass or transfer switch 3, and its operating mechanism M are shown in detail in Figs. 10, 11, 12, and 13, and are indicated in Figs. 1 and 2. The switch 3, in its normal closed position is inclined and its upper end is pivotally supported by an inclined conducting arm 7. The latter is in turn supported at its upper end by the interrupter K. The switch is opened by impact of the air blast upon an impeller vane 110. Said vane is pivotally mounted within a casing connected to the blast pipe 10, preferably to the upper end of the latter and forming a direct air flow connection between the pipe and the vertical conduit formed by the vertical bores 60 of the interrupter. As shown in Fig. 11, the impeller casing comprises two parts, 122 and 123, held together by bolts 127. The air blast from the container 8, via the valve 9, passes upward through the casing. Normally the air blast passage is closed by the vane 110. The vane is curved in cross section, as shown in Fig. 10, so that in its open position it will fit snugly against one side of the interior of the casing and offer no obstruction to the passage of the air blast. The casing is bulged out slightly, following the arc of a circle, so that the vane may have a greater area and also maintain its closure of the blast passage through a maximum portion of its upward swing, in order to impart a maximum impulse and open the switch 3 as quickly as possible. At the lower end of the casing section 122 is an expansion sleeve 130, preferably of bronze, to take up slack in the insulating blast tube 10 due to the compressibility of gaskets between sections, of which the tube is forward. Heavy adjustable springs 131 maintain suitable pressure on the gaskets to prevent their being blown out or displaced by the pressure of the air blast.

The impeller vane 110 is welded to a hollow shaft 111 mounted to rotate in two bearings on an axis disposed in the same horizontal plane as the joint between the parts 122 and 123 of the impeller casing. That permits installation and removal of the vane and its shaft together with cranks 112 and 113 which are welded to the shaft outside of the casing. The purpose of the welding is to obtain necessary strength with minimum weight, for maximum acceleration in opening. There are two pairs of the cranks 112 and 113, at opposite ends of the shaft 111. Between the outer ends of each pair there is pivoted a sleeve 117. A rod 114 of insulating material, such as impregnated hickory, is rigidly secured at one end to each sleeve and extends axially therefrom, with the interior of the sleeve vented axially at one end along the rod. At their opposite ends said rods bear against a cross-bar 30 of insulating material, bolted to the switch blade 3. Two contacts 31 are rigidly secured to the switch 3 and each engages a pair of jaws 32 and 33. These are pressed toward each other by a spring 35 on a bolt 34 extending through the jaws. This provides high-pressure electrical contact on both edges of the contact bar 31. The jaws 32 and 33 are secured to a shaft 4 mounted to turn in bearings 41 borne by the impeller casing. A crank 36 is secured to the shaft 40, and an extensible link 37 connects the outer end of said crank to a short crank, extending diametrically from one of the cranks 113. Said link contains a compression spring 38 which is compressed when the link is stretched. The jaws 32 and 33 are shown in the closed position of the by-pass switch, in which position the link 37 is stretched.

The tubular impeller shaft 111 has an air port within the impeller casing, and bent pipes 116 lead from the opposite ends of the shaft 111 to the sleeves 117, surrounding one end of the rods 114. These connections provide for delivery of a blast of air coaxial with each rod 114 along its entire length.

The arm or bracket 7 which hingedly supports the by-pass switch bears an air cylinder 50 and piston 51. The piston has a rod extending from the lower end of the cylinder and provided with a transverse slot 55. A pin 54 borne by the by-pass switch and offset from the pivot of the latter projects through said slot. Between the lower end of the cylinder and the piston, there is a compression spring 57 tending to move the piston upward and swing the switch to closed position. A pipe 52 leads from the upper end of the vertical air conduit of the interrupter to the upper end of the cylinder 50 to lead air pressure to the piston for forcing the latter downward and holding the switch open, against the resistance of spring 57, until the air blast is shut off. In order to delay closure of the switch 3, the pipe 52 is provided with a check valve 58 having a swinging valve disk 59 normally swung downward to open position. Said disk is adapted when closed to permit slow leakage upward through the pipe.

The mechanism M, just described, for operating the by-pass valve works as follows: The air blast released by the valve 9 strikes the vane 110 and swings the latter upward and to the right, with reference to Fig. 11. Cranks 112 and 113 are swung 90° and push the rods 114 against the cross arm 30 and swing the switch 3 to the right. Jaws 32 and 33 are rotated clockwise by the contact bars 31 and the latter are disengaged from said bars. This separation draws only a negligible arc, because the current has a shunt path to follow through the interrupter K. Until the interrupter contacts are open, there is only a negligible difference of potential between the contact bar 31 and the jaws 32 and 33 after the latter separate. When the interrupter contacts open and interrupt the short-circuit current, this potential difference suddenly rises to the full line-to-neutral voltage of the system. The interrupter contacts cannot open until after the vane 110 opens, but they open very quickly after the vane 110 completes its 90° swing, at which instant the rods 114 are still in contact with the arm 30 on the switch 3 and therefore it is essential that the flashover voltage of the rods 114 (lengthwise), plus that of the arms 30, should be safely in excess of the line-to-neutral voltage of the system. An air blast to accomplish this purpose is supplied through the pipe 116 and the sleeve 117 to greatly increase the dielectric strength of the space surrounding each rod 114.

When the rods 114 reach the end of their travel to the right, the switch 3 is moving at a velocity of about fifty to seventy feet per second, or about six inches in half a cycle, when the sixty cycle per second system is used. It is estimated that the short-circuit current will not be interrupted in less than half a cycle after the vane 110 is wide open. Therefore, when the line-to-neutral voltage arrives, there will still be a separation of about eighteen inches of space traversed by the air blast, which provides ample dielectric space to avoid a flashover. The two blasts of air along the rods 114 assist in maintaining the rapid motion of the switch 3 which swings open about forty-eight inches in another two or three cycles and remains wide open until after the air blast is shut off. Furthermore, since ionization of air and other insulation is a function of time, the air will tolerate for a cycle or two many times the voltage which will flash it over if maintained continuously.

The highest commercial voltage at present is 287 kv. Assuming a voltage of 300 kv., the line-to-neutral voltage is 173 kv., which will flash through about eight inches of still air continuously applied, or through a five inch diameter sphere gap, or through about ten inches for the electrodes described in this specification. I have in my device about eighteen inches which would probably flash at about 200 kv. (continuous, still air). The air blast will probably raise it to about 350 kv., and the short time in which it operates will probably raise it to over 900 kv.

In the opening movement of the impeller 110, when the contacts 31 leave the jaws 32 and 33, releasing the tension on the link 37, the jaws 32 and 33 continue their clockwise movement in order to increase their separation from the contacts 31. When the air blast is shut off the vane 110 and all of its connected parts are returned to closed position by a torsion spring 132, one end of which is fastened to the crank 112 and the other end to the casing 122. The jaws 32 and 33, however, stop in horizontal position until the switch 3 releases, when the contacts 31 engage the jaws 32 and 33. The jaws swing up to their closed position, stretching the link 37 and compressing the spring 35 as the contacts 31 turn into their position perpendicular to the jaws 32 and 33. Thereby, there is obtained high-pressure contact with a desirable wiping action which tends to clean the contact surfaces and reduce contact resistance. Rubber bumpers 133 support the rods 114 in proper position to engage the guides 42 on the cross arm 30. A rubber bumper 134 on the vane 110 stops the latter in open position.

Closure of the switch 3 under the influence of the spring 57 is delayed by flow of air from the air blast in the interrupter K through the pipe 52 and the check valve 58 to the upper end of cylinder 50. Pressure of the air upon the piston 51 resists the spring and holds the switch open. The instant the air blast is shut off and air starts to rush out of cylinder 50, it lifts the swinging disk 59 to closed position. Leakage of the air through the check valve, however, slowly reduces the pressure in the cylinder 50 and allows the spring to move the piston upward and move the switch 3 toward closed position. When the pressure in the cylinder 50 has dropped a certain amount, the weight of the valve disk 59 overcomes the air pressure in the cylinder 50, and the disk 59 drops wide open, allowing the remaining air in the cylinder to discharge more quickly and enabling the switch to finish its closing movement more quickly under the action of the spring 57.

The main automatic disconnecting switch and the mechanism for opening and closing it are shown in detail in Figs. 14 and 15. The switch includes a blade 1 pivoted at one end to swing horizontally on a vertical shaft 28, which in turn is borne by a bracket 29 secured to a corner of the bedplate 20 of the interrupter K. The opposite end of the switch has vertical contacts 65 engageable between contact jaws 66 and 67, supported on an insulator stack 19b and mounted to swing on a fixed vertical pivot 68. Arcing tips 65a and 67a are attached to the contacts 65 and the jaw

67 respectively and are positioned so as to cause the arc to strike from the tip 65a to the tip 67a instead of from the contacts 65 to the jaw 67 (or 66), and thus save the latter from burning when the switch blade 1 closes on a short-circuit. Four points or lines of high-pressure electrical contact of low resistance between the contacts 65 and the jaws 66 and 67 are maintained by two compression springs 77, the principle being the same as described in connection with the by-pass switch 3. The jaws 66 and 67 are connected by the flexible copper braids 78 to the stationary lug 79 and the external circuit connection 79a, all being supported on the insulating support 79b. A flexible conductor 2 connects the switch blade with the jaws 32 and 33 of the by-pass switch 3.

The switch 1 is shifted by a pneumatically operated mechanism including a cylinder 23 secured to the under side of the bedplate 20 in a horizontal position. A piston 24 in said cylinder has a piston rod 25 extending from one end of the cylinder and with a transverse slot 26 at its outer end. A pin 27 is borne by the switch blade at a point between its ends, and extends through the slot 26, to operatively connect the piston rod to the blade. An air pipe 21—21a leads laterally from the impeller casing 123 and is in delivery connection with the end of cylinder 23 nearest the switch 1. The pipe 21 has a check valve 22 near the casing 123 and opening away from the latter but permitting slow return leakage to the casing. Beyond the check valve the pipe 21a also has a valve 15c. Normally this valve is spring-closed, but it is adapted to be opened by a solenoid 15b in circuit with the previously described resistor means of the current interrupter K, as indicated in Fig. 1. The pipe 21a also has a by-pass around the valve 15c and provided with a valve 15d.

A vertical insulating tube 72 (see Fig. 14) has, near its upper end, a lateral pipe connection 73 (see Fig. 15) with the end of cylinder 23 remote from the switch. A pipe 71 (see Figs. 1 and 14) leads from a compressed air storage tank 83k (see Fig. 1) and has delivery connection with the lower grounded end of tube 72 through a valve casing. A valve 70 controls air delivery from the pipe 71 to the tube 72. Said valve is normally closed by a spring 74 but has a projecting stem operable by an electrical coil 69 to open the valve. The tube 72 is rotatable and also vertically reciprocable, for purposes which will appear hereinafter, the tube being supported in stuffing boxes for said movements. For rotating the tube there is fastened thereto a lateral crank 1b. A link 1a connects the switch blade 1 to said crank so that when the switch is swung the tube will be rotated. A switch blade 104, borne by the tube, near the grounded end of the latter, and extending radially therefrom, is swung by rotation of the tube, for a purpose which will appear hereinafter. This motion of the tube may also be employed to open the circuit containing the coil 69, after the completion of closing motion of the switch 1.

The raising and lowering of tube 72 controls operation of the valve 15d in the by-pass around the valve 15c of the pipe 21a. The valve 15d is of a type common for operating whistles. It is spring-closed and has an upwardly projecting stem depressible to open the valve. A lever is pivotally connected at one end at a fixed point on the casing of valve 15d and at its opposite end is pivotally connected to the tube 72. At an intermediate point, said lever is engageable with the stem of valve 15d to depress it. When the tube is in raised position, the valve is spring-closed. Lowering of the tube causes said lever to depress the valve stem and open the valve. Another lever is operatively connected to the lower end portion of the tube 72 and is operable by a toggle 70b to raise and lower the tube. Electromagnets 70a and 70b are employed to operate said toggle. By energizing the electromagnet 70a the toggle is tripped to permit the tube to drop of its own weight about one inch. By energizing the electromagnet 70c the toggle is operated to raise the tube.

For releasing air from the right hand end of cylinder 23 (with reference to Fig. 15), and enable air admitted to the left hand end to move the piston for opening the switch 1, there is provided a vent valve 76 for the pipe 73. This valve is normally closed, but it has a stem engaged by a diaphragm 75 subject to pressure in the pipe 21a. When air from the air blast flows into pipe 21a, the diaphragm is flexed to open the valve 76 to atmosphere.

After the air blast released by the valve 9 has effected the opening of the by-pass switch and the opening of the interrupter K, it causes the switch 1 to open. Air flows through the pipe 21, the check valve 22, the pipe 21a and the valve 15c to the left end of cylinder 23, with reference to Figs. 1, 15, and 16. Valve 15c is opened by current through the resistor means of the interrupter and the coil 15b connected thereto, by opening of the interrupter. In order to delay opening of the switch 1 until the short-circuit current has been interrupted by the interrupter K, the piston 24 is so located in the cylinder, in the closed position of the switch, as to provide a suitable volume which must be charged before the piston is moved to the right. The cylinder space to the right of the piston is vented to atmosphere by pressure of the air in the pipe 21a which flexes the diaphragm 75 and opens the vent valve 76. Air pressure at the left of the piston then forces the piston to the right and swings the switch horizontally to an open position near the bedplate 20. Opening swing of the switch swings the contacts 66 and 67 to the position indicated by the dotted lines in Fig. 15. The check valve 22 holds air pressure in the left end of cylinder 23 a short time after the air blast has been shut off, in order to ensure complete opening of the switch blade 1. The check valve has however a slow leak in the reverse direction which permits air pressure to escape from the left end of the cylinder after the switch has been opened, so that the switch may be reclosed within a short time if desired.

The switch 1 is reclosed by closing a circuit containing the coil 69 and thereby opening the valve 70. Air is thereby admitted from the compressed air tank 80k through the pipes 71, 72 and 73 to the right end of cylinder 23 to force the piston 24 to the left and reclose the switch 1. As the switch blade recloses, its contacts 65 strike the jaw 66 in a tangential direction in order to relieve the shock of impact and to permit very quick closure of the switch blade, which is very desirable for synchronizing purposes.

In order to prevent the switch blade 1 from drifting away from its open and closed positions after the air pressure is removed a leaf spring 1d is mounted on the bedplate 20 and engages the switch blade, rearward of the blade pivot, in a manner to resist swinging of the blade. A similar spring holds the jaws **66** and **67** in open position and in closed position.

The valve **15***d*, in the by-pass around the valve **15***c*, is also adapted to function in controlling the operation of switch **1**, as will be explained hereinafter.

There are three of the valves **9**, one for each phase of the circuit breaker. The structure of one of these valves is shown in Fig. 16. It includes a hollow cast iron body or casing **82** with a flange **81** bolted to the compressed air storage tank **8**. Said body defines an interior space **85** in constant communication with the interior of the tank **8**. The casing is formed with an outlet nozzle **83** extending downward through the space **85** and in direct delivery communication at its upper end with the air blast tube **10**. Strengthening webs, not shown, preferably integral with the body **82**, may be positioned in the center line of flow of air in the space **85** in such a manner that they do not interfere with the free flow of air. At its lower end the nozzle has a valve seat **84**. A disk-like section **89** preferably a bronze casting, forms the lower wall of the casing and is bolted to the casing. A diaphragm is secured to the lower section or cover **89** and the two define therebetween a shallow air chamber of comparatively small volume. The diaphragm comprises a rubber disk **90** bolted around its margin to the upper face of the cover **89** and having a central portion comprising an upwardly dished steel disk **90***b* riveted thereto. The rubber portion of the diaphragm is held seated upwardly against the valve seat **84** by air pressure in the shallow chamber below the diaphragm, and the dished portion of the disk **90***b* protrudes into the outlet nozzle **83**. A much greater area of the diaphragm is exposed to air pressure in the said small chamber than is exposed to the air pressure in the space **85**, around the outside of the valve seat **84**. The small chamber is normally kept charged with air at sufficient pressure to hold the diaphragm against the seat **84** and keep the nozzle closed against admission of compressed air from the tank **8** and the space **85**. Normally there is only atmospheric pressure in the nozzle, above the diaphragm. Air pressure in the space **85** tending to force the diaphragm downward acts only on the annular area of the diaphragm exposed between the clamping ring **90***a* and the seat **84**.

The diaphragm is forced downward to admit air from space **85** to the nozzle **83** by venting the small chamber beneath the diaphragm. This venting is done very quickly by opening six valves **91** simultaneously. Normally said valves are held closed by electromagnets **91***a* with their magnetic circuits in closed position and therefore exerting maximum force. The breaking of the current through these magnets instantly releases them and each of the valves are blown open downwardly by air pressure in the small chamber. This pressure exerts an unbalanced pressure on each valve, which weighs only a small fraction of a pound, resulting in very high acceleration. Each valve comprises a hollow cylinder whose upper edge bears against a valve seat **91***b*. At its lower edge the valve has an outwardly extending annular flange which bears against another seat **91***d* of annular form and stops passage of air. The internal diameter of the seat **91***d* slightly exceeds the diameter of the seat disk **91***f* and the external diameter of the cylindrical valve so as to afford an annular flange area on which the air pressure exerts an unbalanced force tending to open the valve. A rubber ring **91***e* may be interposed between the flange **91***c* and its seat to reduce leakage and also increase the opening force by its tendency to expand.

The magnet current for the valve **91** is broken by the means shown at the lower right-hand portion of Fig. 16. There, a pair of wires **91***k* coming from an automatic relay are energized, when the relay is closed, with direct current at 125 volts or 250 volts, for the purpose of opening the circuit breaker. This direct current then flows through a very small electromagnet **91***m* which is made so small that it will open in about one-tenth of a cycle or less, and open its contact tip **91***p*. This breaks the circuit through magnets **91***a*, which current is supplied continuously by a small local storage battery, preferably of about twelve volts and located at the circuit breaker. The storage battery is maintained in a charged condition by a small rectifier **91***q*. A small magnectic blowout coil **91***r* reduces duration of the small twelve-volt arc as the current is broken The magnetic blowout coil is continuously energized from the storage battery, with a small fraction of an ampere. Connected to one only of the eighteen electromagnets (six for each phase of the circuit breaker) is a spring contact **91***s* which is opened by the opening of the magnet **91***a*, thereby breaking the current through the magnet **91***m*. This permits the contact **91***p* to reclose, reenergizing the eighteen magnets and closing the eighteen small valves. The air pressure, having been exhausted, is not available to resist such closing.

Air under pressure is supplied from the tank **83***k* to the small chamber beneath the diaphragm through an upwardly opening check valve **83***t*. Air is also fed to said chamber from the valve space **85** through a spring-pressed feed valve to compensate for leakage from the chamber, as will be explained hereinafter.

The diaphragms of the three valves **9** are automatically moved to closed position to shut off the air blast on the three phases by means operable in response to the air blast itself. As shown in Fig. 16, a pipe **83***a* is tapped into the air blast outlet **83**, and is in delivery connection to the right-hand end of a cylinder **83***c*. A piston **83***b* in said cylinder is urged toward the right by a spring **83***d* and has a rod connected to a slide valve **83***f* in a chamber **83***h* of the cylinder. Compressed air is supplied to the chamber **83***h* from the tank **83***k* and the latter is supplied through a pipe and a check valve **83***m* from a main source of compressed air. Said source, not shown, also supplies air to the tank **8** through the check valve **8***a*. Air pressure from the blast forces the piston **83***b* to the left against the resistance of the spring and moves the slide valve to uncover the port **83***g* in the charged chamber **83***h*. Compressed air is thereby admitted through the pipes **83***i* and **83***u* and through the check valve **83***t* to force the diaphragm to closed position and shut off the air blast. The air blast reduces the pressure in the tank **8** by about twenty pounds per square inch in about one second. Hence the pressure per square inch in the tank **83***k* and therefore under the diaphragm is about twenty pounds per square inch greater than that on top of the diaphragm which tends to keep it open. The diaphragm therefore closes promptly.

An air passage connects the small chamber beneath the diaphragm to the space **85** and has a check valve **89***a* opening away from the chamber. An adjustable spring **89***b* urges the check valve to closed position. If the air pressure under the diaphragm exceeds by twenty pounds per square inch that on top of the diaphragm the check valve is forced open and allows air to flow to the space **85**. Thereby the difference in pressure upon the rubber disk is limited to twenty pounds per square inch to prevent injury to the disk. This condition arises only when the tank **8** is being charged after being completely emptied for any purpose. In preparation for recharging, a globe valve **83***q* is opened by hand to admit air from cylinder chamber **83***h* through pipe **83***p* to the pipe **83***i* to hold the diaphragm closed until the tank **8** is recharged to normal pressure, after which the globe valve is closed by hand. Closing by hand of the valve **83***r* prevents air from flowing backward to atmosphere while the valve **83***q* is open. Only one set of parts numbered **83***a* to **83***r* may serve to operate the three air blast valves **9** of the breaker.

A header pipe **83***s* connects the three pipes **83***u* and the check valves **83***t* to one pipe **83***i*. The diameter of said header pipe **83***s* is selected so that its volume will give the correct time delay between the opening and reclosing of the three air blast valves, allowing ample time for the interruption of the main line current, but no unnecessary time which would be wasteful of the air supply and delay restoration of normal pressure to the tank **8**.

After the air blast is shut off the spring **83***d* in the cylinder **83***c* moves the piston **83***b* and the slide valve **83***f* to the right to shut off the air supply from the pipe **83***u* and header **83***s* and exhaust the air in them to atmosphere. This avoids a rush of air through the admission check valves **83***t* of the valves **9** when the vent valves **91** open, which would delay the opening movement of the diaphragms **90**.

In order to further reduce the opening time of each diaphragm the pressure therebeneath may be reduced below the pressure thereabove. Such reduction is permissible because the pressure beneath the diaphragm acts upon a much greater area than the pressure above, in the closed position. The air pressure beneath will be exhausted much more quickly if its initial pressure is less. Hence the diaphragm will start to open earlier and the total opening time of the entire valve will be thereby shortened. The desired pressure per square inch under each diaphragm is maintained automatically by an adjustable pressure-regulating valve which takes air pressure from the main tank **8** through an air duct **90***c* acting on a small piston **90***g* against a spring **90***f* which is adjusted by a screw **90***d*. The air pressure in the duct **90***c* pushes the piston **90***g* down until the air escapes through the duct **90***h* into the chamber beneath the diaphragm. Lowering the screw **90***d* will increase the pressure under the diaphragm and raising the screw will decrease the pressure. There is always a slight unavoidable leakage through the valves **91**. Passage of air through the ducts **90***c* and **90***h* compensates for said leakage, and for a given rate of flow the pressure drop through these ducts depends upon the width of opening of the piston **90***g*, which depends upon the spring pressure.

The opening time of a circuit breaker of this class is universally measured from the instant the switchboard relay contacts close, thereby starting the rise of direct current through the trip coil of the circuit breaker, the opening time ending when at the instant the main contacts of the circuit breaker open and interrupt the high tension current. The fastest relay available for such service, although designated as "instantaneous", actually consumes a minimum of about a sixtieth of a second between the starting current and the closing of the relay contacts. In a large percentage of said cases the so-called "instantaneous" relays cannot be used, such as cases where relays must delay to allow other relays closer to the system fault to open first and clear the fault from the system. Hence, in a large percentage of cases there is a more than one cycle (referring to the common frequency of sixty cycles per second) between the occurrence of the short circuit and the closing of the relay contacts. Advantage may be taken of this fact to start the air blast breaker, of the type herein described, before the closing of the relay contacts, thereby reducing the opening time of the circuit breaker and reducing the total duration of the short circuit. This is accomplished by the coordinated action of the circuit breaker contacts, the impeller vane **110** of the mechanism M, and an auxiliary by-pass valve **92**. The valve **92** is opened by an alternating circuit magnet coil in series with a secondary winding of the main current transformer **5** and therefore is energized at the first half cycle of the short-circuit current, which time is one or more cycles before the relay contacts close and energize the coils **91***a* to open the air blast valve **9**.

The by-pass valve **92** appears in Figs. 1, 16, and 17 and is shown in detail in the last-mentioned view. The valve includes a rubber diaphragm **92***a* which normally closes a passage **92***b* leading from the constantly charged air space **85** of the valve **9** to the interior of the nozzle **83**. At the outer side of the diaphragm there is a metallic valve body **92***d* which forms with the diaphragm a chamber **92***c*. The valve body has vent ports **92***e* which are normally closed by a movable ring **92***f* fastened to a sleeve **92***g* and an armature **92***h*. The armature is moved by a magnet pole **92***i* energized by an alternating magnet coil **92***j* which is in series with a secondary coil of the main current transformer **5**. Through piping leading from the tank **83***k* to an air duct **92***k* of the valve **92** air pressure is supplied to the chamber **92***c* to hold the diaphragm normally in position to close the passage **92***b*. The air duct **92***k* is in the stationary stud **92***m* secured to the valve body **92***d* and the magnet pole **92***i*. The sleeve **92***g* slides easily on the stud **92***m*. Flat springs **92***p* normally hold the movable ring **92***f* closed. When said ring is moved to open position by the magnet coil **92***j* the chamber **92***c* is vented and the air pressure in the main valve space **85** forces the diaphragm **92***a* to open the passage **92***b* and admit air from space **85** and the connected tank **8** to the nozzle **83**.

The opening of the by-pass valve **92** discharges compressed air from the tank **8** to the nozzle **83** and the connected air blast conduit **10** and starts to build up pressure in the blast conduit. This preliminary pressure starts the opening movement of the impeller vane **110** and the by-pass switch **3**. One or more cycles later, when the diaphragm **90** of the main valve opens, releasing the air blast, there is already a certain pressure in the blast tube **10** and vane **110** has already started to move. This is equivalent to advancing the wave of air pressure by several feet in its upward travel and thereby advancing the instant when the main breaker contacts are blown apart. Circuit breakers of this class should have an opening time of as short as three cycles, or shorter if possible. Therefore an improvement of only a quarter of a cycle, for instance, is of practical importance and commercially valuable.

When the fault on the power system is at such a location that this circuit breaker is required to remain closed even though the short-circuit current passes through it, to allow some other breaker to clear the fault, the by-pass valve 92 will open but will close again at the instant that the short circuit is cleared by the other breaker. The relay controlling this breaker will not close and the main air blast will not be released. The vane 110 will be moved until it opens the air passage in conduit 10 wide enough to relieve the air pressure under it and then stop. When the by-pass valve 92 closes, the vane 110 closes and also the by-pass switch 3. The air admitted by the valve 92 is insufficient to open the breaker contacts in the interrupter K. Even though the switch 3 opens momentarily and recloses no harm is done because the main circuit is not opened. The contacts in the interrupter are shunted around the switch 3 and are capable of carrying the short-circuit current for such a short time without overheating. The main switch 1 does not open because the air connection for opening it is tapped into the air blast tube above or beyond the vane 110, where the pressure from the valve 92 is too slight to open the switch 1.

A general wiring diagram, for the three-phase circuit breaker is shown in Fig. 18. The current flows along the main automatic disconnecting switch 1, the flexible conductor 2, the by-pass switch 3, the flexible conductor 4 and the current transformer 5 and out to the main line. The transformer 5 has three separate magnetic circuits each with one secondary winding. One of these secondary windings is used to operate the coil 92j to open the by-pass valve 92 and expedite the opening of the high-tension circuit by a preliminary supply of air pressure to the blast conduit 10. Another secondary winding is used to operate any well-known type of relay 100, to open the circuit breaker by opening the valve 9. When the valve 9 opens, a blast of compressed air rushes up through the tube 10, blows open the by-pass switch 3, then opens the contacts of the interrupter K (thus interrupting the high-tension circuit) and then opens the main switch 1. The closing of the valve 9 shuts off the air blast, and springs return the by-pass switch 3 and the interrupter horns 16 to closed position. The main switch 1 remains open. The third secondary winding of the transformer is used for additional relaying or metering functions in accordance with common practice.

There are three small knife switches 101. If all of these switches are open each of the three relays 100 for the three phases, will affect only the valve 9 on its own phase and if the short circuit is on only one phase (from line-to-neutral or ground), then only one pole of the breaker will open. If the switches 101 are closed the operation of any relay will open all three valves 9, opening all three poles of the breaker. The three poles of the breaker may also be opened manually by closing the three knife switches 101 and one control switch 102. Or, one pole only may be opened by closing only one of the switches 101 and then switch 102. The three poles of the breaker always close together by closing the control switch 103, energizing the three coils 69 which cause the three main automatic switches 1 to close.

Alongside of the control switches 102 and 103 on the switchboard are three miniature red lamps and three green lamps to indicate whether the switch 1 on each phase is in closed, open or intermediate position (an improper position requiring remedy). A double throw switch 104 is operated by the rotation of the tube 72 on each pole of the breaker to operate the red and green lamps.

In a three-pole breaker of this class it is never desired to close one pole without the other two and it is desirable to close all three poles simultaneously. Therefore the preferred arrangement is to have one coil 69 and valve 70 apply air pressure simultaneously to the three tubes 72, each closing its main switch 1. Under certain conditions, however, it has been considered desirable to have a circuit breaker which could open one pole on a short circuit on that phase (to ground) without opening the other two phases, in order that motors may continue to run for a few seconds until the breaker may be reclosed, as in case the short circuit is only momentary, such as a flashover due to lightning. This circuit breaker, as already described is readily adapted to single-pole opening.

A large percentage of the faults on power systems are of a transient nature, such as a flashover due to lightning. The arc of the flashover being extinguished by the quick opening of the circuit at its source of power, it is very desirable to reclose the circuit as quickly as possible in order to prevent customers' motors from tripping out. With the various types of circuit breakers heretofore used it is necessary to open the circuit breaker completely in order to set in motion the reclosing means. This requires a minimum of about 45 to 60 cycles of time (60 cycles per second). In my circuit breaker the construction is such that the circuit can be reclosed in about 10 cycles of time. This is accomplished by providing the valve 15c (Fig. 15) which is normally held closed by an internal spring, thus preventing the flow of air through the pipe 21a into the cylinder 23 to open the switch 1. The switch 1 thus remaining closed, the interrupter horns 16 are quickly reclosed by their springs when the air blast is shut off, thus reclosing the high-tension circuit quickly. In order to reclose the horns as quickly as possible, the valve reclosing means, from 83a to 83u inclusive, may be provided separately for each of the three poles of the breaker, eliminating the header pipe 83s, with its volume designed to regulate the time of releasing of the main diaphragm 90 (Fig. 16).

If the fault remain on the circuit immediately after the breaker has opened, it is very desirable to avoid reclosing of the breaker and a consequent second shock and disturbance to the remainder of the power system. It is possible to accomplish this by utilizing the circuit through the potential equalizing resistors 15′ (Fig. 5). As previously mentioned, an electromagnet 15b is connected in series with this circuit, as shown in Fig. 1. When this magnet is energized it opens the valve 15c allowing air to pass and open the switch 1 in case the fault is still on the circuit. If the fault has been removed the current through the magnetic coil 15b is insufficient to open the valve 15c, against its spring resistance. Therefore no air passes, the switch 1 remains closed and the horns 16 close, completing the high-tension circuit again.

Long high-tension transmission lines have a relatively large electrostatic capacitance, which, in series with a high resistance such as the resistors 15' would be difficult to distinguish (by the amount of current) from a fault on the circuit. This difficulty is removed by inserting in series with each of the resistors 15' a small current rectifier 15a, preferably of the magnesium-copper sulphide or copper-copper oxide type. The line-charging current is reduced sharply after the first half cycle of unidirectional current so that it will be much less than the current which would continue to flow if there is a fault remaining on the line. The electromagnet can therefore be designed and adjusted to distinguish between charging current and a line fault.

An alternative expedient for distinguishing between fault current and charging current is to reduce the ohms in resistors 15' resulting in increased fault current. This fault current (through resistors 15') must be interrupted by the switch 1 at its contacts 67a. To assist in interrupting this small current, compressed air may be taken from the air blast tube 10 and carried via the switch 1 to the contact 67a.

There are occasions when it is necessary to open the circuit breaker (non-automatically) and leave it open, though there is no fault on the line. The valve 15d is provided to enable this. It bypasses valve 15c and allows air to pass and open the switch 1. The valve 15d, and adjacent parts being at the line potential, its operation is controlled by vertical movement of the insulating tube 72 (Fig. 14). When the tube 72 is in its elevated position the valve 15d remains closed by its spring and the breaker is set for automatic reclosure. To suppress the automatic reclosing feature the valve 15d is held open by energizing the electromagnet 70a to trip the toggle 70b and allow the tube to drop. The automatic reclosing feature is re-established by energizing the electromagnet 70c. The insulating tube 72 thus performs three independent functions: the one just described, and the two other functions previously described. None of these functions interferes with the others. The vertical movement is permitted by link 1a being long in relation to the small vertical movement, the connections not being tightly fitted. The casing of valve 70 is rigidly fastened to the grounded structure supporting the interrupter bedplate 20 on the insulator stacks. That rigidly fixes the distance between the valve 70 and the bedplate 20 with attached parts.

Provision is made for using the circuit breaker to test the line to determine whether there is a fault on the line, without subjecting the remainder of the power supply system to a shock in case there is a fault on the line when so tested. For this purpose there is provided for one of the switches 104 a contact midway between the open and closed positions of the said switch. This contact, designated 104a, is wired in multiple with switch 102, the opening control switch of the breaker. To make the test, the operator closes the switch 103, starting the switch 1 on its closing movement. When the switch 1 reaches its midposition the switch 104 contacts the member 104a tripping open the three air blast valves 9, opening the interrupters and holding them open while the switch 1 completes its closing stroke. If there is no fault on the line the switch 1 remains closed (and the interrupters close in either case). If there is a fault the switch 1 opens before the interrupter K recloses, and there is no shock to the system. After the test the operator opens the switch 101a and leaves it open. The contact 104a is arranged to contact only in the closing direction of the switch blade 104, not in the opening direction.

Certain features of the apparatus disclosed but not claimed herein are claimed in my co-pending patent application Serial No. 732,737 filed June 27, 1934.

What I claim is:

1. In an electrical circuit having control means therefor including a current interrupter operable by a blast of gas to break the circuit and a disconnecting switch in series with the interrupter, a gas-pressure mechanism to operate said interrupter and said disconnecting switch, comprising a gas conduit to deliver a blast of gas to the interrupter to operate the latter to break the circuit, a source of compressed gas in delivery connection with said conduit, normally closed valve means to control admission of gas from said source to said conduit, means responsive to abnormal current in the circuit to cause the opening of said valve means to admit a blast of gas to the conduit, means to control the duration of said blast automatically, a gas-pressure-responsive device to operate the disconnecting switch to open position, and a gas delivery connection between the blast conduit and said device to conduct gas pressure of said blast from the conduit to said device to open the disconnecting switch after the circuit-breaking operation of the interrupter by the blast and during the duration of the blast.

2. In an electrical circuit having control means therefor including a current interrupter operable by a gas blast to open the circuit, a transfer switch in shunt with the interrupter to normally conduct the current past the interrupter, and a disconnecting switch in series with the interrupter, a gas-pressure apparatus for operating said interrupter, said transfer switch and said disconnecting switch, comprising means responsive to abnormal current in the circuit to supply a blast of gas to the interrupter to operate it to open the circuit, means responsive to said blast to open the transfer switch prior to opening of the interrupter by the blast to thereby transfer the current to the interrupter for breaking by the latter, means responsive to the blast to open the disconnecting switch after opening of the interrupter by the blast, means to automatically reclose the transfer switch, and means responsive to the gas blast to delay reclosure of the transfer switch until after the disconnecting switch has been opened a safe distance in response to the gas blast.

3. In an electrical circuit having control means therefor including a current interrupter operable by a gas blast to open the circuit, a transfer switch in shunt with the interrupter, and a disconnecting switch in series with the interrupter, a gas-pressure apparatus for operating said interrupter, said transfer switch and said disconnecting switch, comprising means responsive to abnormal current in the circuit to supply a blast of gas to the interrupter to open it, means responsive to said blast to open the transfer switch prior to opening of the interrupter by the blast to thereby transfer the current to the interrupter for breaking by the latter, means responsive to the blast to open the disconnecting switch after opening of the interrupter by the blast, means to automatically reclose the transfer switch, means responsive to the gas blast to delay reclosure of the transfer switch until after the disconnecting

switch has been opened a safe distance in response to the gas blast, and means responsive to the blast to control the duration of the blast.

4. In an electrical circuit having control means therefor including a current interrupter operable by a gas blast to open the circuit, and a transfer switch in shunt with said interrupter to normally conduct the current past the interrupter, a gas-pressure apparatus to operate said interrupter and said transfer switch, comprising means responsive to abnormal current in the circuit to supply a blast of gas to the interrupter to operate it to open the current, means responsive to said blast to open the transfer switch prior to circuit-opening operation of the interrupter by the blast to thereby transfer the current to the interrupter for breaking by the latter, means to reclose the transfer switch automatically, and means responsive to the gas blast to delay reclosure of the transfer switch.

5. In an electrical circuit having control means therefor including a current interrupter operable by a blast of gas to open the circuit, and a transfer switch in shunt with said interrupter to normally conduct the current past the interrupter, a gas-pressure apparatus to operate said interrupter and said transfer switch, comprising a gas conduit to deliver a blast of gas to the interrupter to operate it to open the circuit, means responsive to abnormal current in the circuit to supply a blast of gas to said conduit, a rockably mounted impeller vane disposed across the path of the gas blast through the conduit to the interrupter and rockable by impact of the blast, and means operable by said vane to open the transfer switch in response to the gas blast prior to circuit-opening operation of the interrupter by the blast and thereby transfer the current to the interrupter for breaking by the latter.

6. In an electrical circuit having control means therefor including a current interrupter operable by a gas blast to open the circuit, and a transfer switch in shunt with said interrupter to normally conduct the current past the interrupter, a gas-pressure apparatus to operate said interrupter and said transfer switch, comprising a gas conduit to deliver a blast of gas to the interrupter to operate it to open the circuit, means responsive to abnormal current in the circuit to supply a blast of gas to the conduit, a shiftable actuator for the transfer switch disposed in the path of said blast through the conduit and shiftable by impact of the gas, a pusher element operatively connected to said actuator and operable upon the transfer switch to open the latter by shift of said actuator by the blast prior to circuit-opening operation of the interrupter by the blast to thereby transfer the current to the interrupter for breaking by the latter, and means to conduct gas from said blast and deliver a gas blast along said pusher element as the latter is actuated to open the transfer switch, for the purpose set forth.

7. In an electrical circuit having control means therefor including a current interrupter operable to open position by a gas blast, and a hinged transfer switch in shunt with the interrupter to normally conduct the current past the interrupter, a gas-pressure apparatus to operate said interrupter and said transfer switch, comprising a gas conduit to deliver a blast of gas to the interrupter to open it, means responsive to abnormal current in the circuit to supply a gas blast to said conduit, a rockably mounted impeller vane disposed in the path of the blast through the conduit and rockable by impact of the blast, a crank arm external to the conduit and operatively connected to said vane and rockable thereby, a pusher element operatively connected to said crank arm and operable thereby upon the transfer switch to swing it to open position to thereby transfer the current to the interrupter for breaking by the latter, and means to conduct gas from said blast outside of the conduit and deliver a blast of gas along said pusher element, for the purpose set forth.

8. In an electrical circuit having control means therefor including a current interrupter operable to open position by a gas blast, and a hinged transfer switch in shunt with the interrupter to normally conduct the current past the interrupter, a gas-pressure apparatus to operate said interrupter and said transfer switch comprising a gas conduit to deliver a blast of gas to the interrupter to open it, means responsive to abnormal current in the circuit to supply a gas blast to said conduit, a rockably mounted impeller vane disposed in the path of the blast through the conduit and rockable by impact of the blast, a crank arm external to the conduit and operatively connected to said vane and rockable thereby, a pusher element operatively connected to said crank arm and operable thereby upon the transfer switch to swing it to open position to thereby transfer the current to the interrupter for breaking by the latter, means to conduct gas from said blast outside of the conduit and deliver a blast of gas along said pusher element, for the purpose set forth, means to reclose the transfer switch automatically, and means responsive to the interrupter-opening gas blast to delay reclosure of the transfer switch.

9. In an electrical circuit having a plurality of control switches therefor operable in response to a blast of gas, a gas blast supply apparatus for said switches comprising a gas delivery conduit having an inlet orifice to receive the blast for operation of the switches, a source of compressed gas in delivery connection with said orifice; a valve mechanism to control admission of gas from said source through said orifice to the conduit and comprising a casing, a diaphragm in said casing normally closing said orifice, the casing defining a chamber at the orifice-closing side of said diaphragm in constant communication with said gas source, and a chamber at the opposite side of the diaphragm, means to charge the latter chamber with gas to hold the diaphragm normally closed, the diaphragm having an area around said orifice exposed to the gas pressure in the first chamber, and a larger area exposed to the pressure in the second chamber, normally closed vent valve means for said second chamber; and means operable in response to abnormal current in the said circuit to cause said vent valve means to open and vent said second chamber and permit the pressure in the first chamber to shift the diaphragm to open the orifice and admit a blast of gas from said source to the conduit.

10. In an electrical circuit having a plurality of control switches therefor operable in response to a blast of gas, a gas blast supply apparatus for said switches comprising a gas delivery conduit having an inlet orifice to receive the blast for operation of the switches, a source of compressed gas in delivery connection with said orifice; a valve mechanism to control admission of gas from said source through said orifice to the conduit and comprising a casing, a diaphragm in said casing normally closing said orifice, the casing defining a chamber at the ori-

fice-closing side of said diaphragm in constant communication with said gas source, and a chamber at the opposite side of the diaphragm, means to charge the latter chamber with gas to move the diaphragm to closed position, the diaphragm having an area around said orifice exposed to the gas pressure in the first chamber, and a larger area exposed to the pressure in the second chamber, a gas pressure feed connection to supply gas from said first chamber to said second chamber, valve means to control flow through said feed connection and automatically maintain the pressure in the first chamber in excess of that in the second chamber, normally closed vent valve means for said second chamber; and means operable in response to abnormal current in the said circuit to cause said vent valve means to open and vent said second chamber and permit the pressure in the first chamber to shift the diaphragm to open the orifice and admit a blast of gas from said source to the conduit.

11. In an electrical circuit having a plurality of control switches therefor operable in response to a blast of gas, a gas blast supply apparatus for said switches comprising a gas delivery conduit having an inlet orifice to receive the blast for operation of the switches, a source of compressed gas in delivery connection with said orifice; a valve mechanism to control admission of gas from said source through said orifice to the conduit and comprising a casing, a diaphragm in said casing normally closing said orifice, the casing defining a chamber at the orifice-closing side of said diaphragm in constant communication with said gas source, and a chamber at the opposite side of the diaphragm, means to charge the latter chamber with gas to hold the diaphragm normally closed, the diaphragm having an area around said orifice exposed to the gas pressure in the first chamber, and a larger area exposed to the pressure in the second chamber, normally closed vent valve means for said second chamber; means operable in response to abnormal current in the said circuit to cause said vent valve means to open and vent said second chamber and permit the pressure in the first chamber to shift the diaphragm to open the orifice and admit a blast of gas from said source to the conduit; and means operable in response to said blast to cause recharging of the second chamber to shift the diaphragm to close the orifice.

12. In an electrical circuit having a plurality of circuit-breaking devices operable in response to an air blast to break the circuit, a gas blast supply apparatus for said circuit-breaking devices, comprising a gas delivery conduit, a source of compressed gas in delivery connection to said conduit, valve means operable in response to abnormal current in the circuit to admit a blast of gas from said source to the conduit for operation of the circuit-breaking devices, and auxiliary means to supply a charge of gas to the conduit and including auxiliary valve means also operable in response to abnormal current in the circuit to admit to the conduit a charge of gas prior to admission of said blast and insufficient to open the circuit-breaking devices.

13. In an electrical circuit having a plurality of circuit-breaking devices operable in response to an air blast to break the circuit, a gas blast supply apparatus for said circuit breaking devices, co... ising a gas delivery conduit, means responsive to abnormal current in the circuit to supply a blast of gas to said conduit for operation of the switches, and auxiliary means also responsive to abnormal current in the circuit to supply to the conduit a preliminary charge of gas prior to supply of said blast to the conduit and insufficient to open said circuit-breaking devices.

14. In an electrical circuit having control means therefor including a disconnecting switch, a current interrupter in series with said disconnecting switch and operable by a gas blast to break the circuit, and a transfer switch in shunt with said interrupter to normally conduct the current past the interrupter and operable independently of the disconnecting switch, a gas-pressure mechanism to operate said interrupter, transfer switch and disconnecting switch, comprising means responsive to abnormal current in the circuit to supply a gas blast to the interrupter to operate it to break the circuit, means responsive to said blast to open the transfer switch independently of the disconnecting switch and prior to the circuit-breaking operation of the interrupter by said blast to thereby transfer the current to the interrupter for breaking by the latter, and means responsive to the gas blast to open the disconnecting switch subsequent to the circuit-breaking operation of the interrupter by the gas blast.

15. In an electrical circuit having control means therefor including a disconnecting switch, a current interrupter in series with said disconnecting switch and operable by a gas blast to break the circuit, and a transfer switch in shunt with said interrupter to normally conduct the current past the interrupter and operable independently of the disconnecting switch, a gas-pressure mechanism to operate said interrupter, transfer switch and disconnecting switch, comprising means responsive to abnormal current in the circuit to supply a gas blast to the interrupter to operate it to break the circuit, means responsive to said blast to open the transfer switch independently of the disconnecting switch and prior to the circuit-breaking operation of the interrupter by said blast to thereby transfer the current to the interrupter for breaking by the latter, means responsive to the gas blast to open the disconnecting switch subsequent to the circuit-breaking operation of the interrupter by the gas blast and during the duration of the blast, and means responsive to the blast to terminate the blast.

16. In an electrical circuit having control means therefor including an automatically reclosing current interrupter and a disconnecting switch in series with the interrupter, and in which the interrupter is operable by a blast of gas to break the circuit, a gas-pressure mechanism to operate said interrupter and said disconnecting switch comprising means responsive to abnormal current in the circuit to supply a blast of gas to the interrupter to operate it to break the circuit, a resistance means, means to cause current in the circuit to be shunted through said resistance as the interrupter is operated by the gas blast to break the circuit, means responsive to said gas blast for opening the disconnecting switch after the circuit-breaking operation of the interrupter by the blast, and means responsive to a predetermined current shunted to said resistance means during the opening operation of the interrupter to cause said gas responsive means to open the disconnecting switch if said current through the resistance means is sufficient and to leave said switch closed if the current is insufficient.

17. In an electrical circuit having control means therefor including an automatically reclosing current interrupter and a disconnecting

switch in series with the interrupter, and in which the interrupter is operable by a blast of gas to break the circuit, a gas-pressure mechanism to operate said interrupter and said disconnecting switch comprising means responsive to abnormal current in the circuit to supply a blast of gas to the interrupter to operate it to break the circuit, a resistance means, means to cause current in the circuit to be shunted through said resistance as the interrupter is operated by the gas blast to break the circuit, means responsive to said gas blast for opening the disconnecting switch after the circuit-breaking operation of the interrupter by the blast, means responsive to a predetermined current shunted to said resistance means during the opening operation of the interrupter to cause said gas responsive means to open the disconnecting switch if said current through the resistance means is sufficient and to leave said switch closed if the current is insufficient, and means adjustable to permit opening of the disconnecting switch in response to the gas blast independently of said resistance-current-responsive means.

18. In an electrical circuit having control means therefor including an automatically reclosing current interrupter and a disconnecting switch in series with the interrupter, and in which the interrupter is operable by a blast of gas to break the circuit, a gas-pressure mechanism to operate said interrupter and said disconnecting switch, comprising means responsive to abnormal current in the circuit to supply a blast of gas to the interrupter to operate it to break the circuit, a resistance means, means to cause current in the circuit to be shunted through said resistance as the interrupter is operated by the gas blast to break the circuit, a gas-pressure-responsive device to operate the disconnecting switch and having a gas delivery connection to conduct gas from said blast thereto to operate said device for opening the disconnecting switch in response to the gas blast after the circuit-breaking operation of the interrupter by the blast, a normally closed valve to control flow through said gas delivery connection, and electrical operating means for said valve in circuit with said resistance means of the interrupter and responsive to current shunted to said resistance means during the opening operation of the interrupter to open the valve and thereby cause the disconnecting switch to open if said current in the resistance means is sufficient, and to leave the valve closed to prevent opening of the disconnecting switch in response to the gas blast if said current is insufficient, for the purpose set forth.

19. In an electrical circuit having control means therefor including an automatically reclosing current interrupter and a disconnecting switch in series with the interrupter, and in which the interrupter is operable by a blast of gas to break the circuit, a gas-pressure mechanism to operate said interrupter and said disconnecting switch comprising means responsive to abnormal current in the circuit to supply a blast of gas to the interrupter to operate it to break the circuit, a resistance means, means to cause current in the circuit to be shunted through said resistance as the interrupter is operated by the gas blast to break the circuit, means responsive to said gas blast for opening the disconnecting switch after the circuit-breaking operation of the interrupter by the blast, means responsive to a predetermined current shunted to said resistance means during the opening operation of the interrupter to cause said gas responsive means to open the disconnecting switch if said current through the resistance means is sufficient and to leave said switch closed if the current is insufficient, and current rectifying means in series with said resistance.

20. In an electrical circuit having a plurality of control switches therefor operable in response to a blast of gas, a gas-pressure apparatus to control the operation of said switches, comprising a conduit to deliver a gas blast for operation of the switches, a source of compressed gas, a valve device to control admission of gas from said source to said conduit and including a closing member comprising a diaphragm normally subjected on one side to fluid pressure to hold it closed against said admission of gas, means responsive to abnormal current in the circuit to relieve said closing fluid pressure and to admit pressure to the opposite side of said diaphragm to move said diaphragm to admit a gas blast to the conduit; means responsive to the said gas blast for restoring fluid pressure to reclose the valve and shut off the gas blast, said responsive means comprising a fluid pressure delivery connection leading from a fluid pressure source to said valve device, a valve spring-urged to normally close said connection, and a gas communication from the said blast conduit to admit gas from the blast to shift the spring-urged valve to open said fluid pressure delivery connection.

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