Oct. 25, 1966 O. JENSEN 3,281,733

SYNCHRONOUS CIRCUIT BREAKER HAVING A MOVABLE WINDING

Filed Oct. 13, 1964 5 Sheets-Sheet 1

FIG. 1.

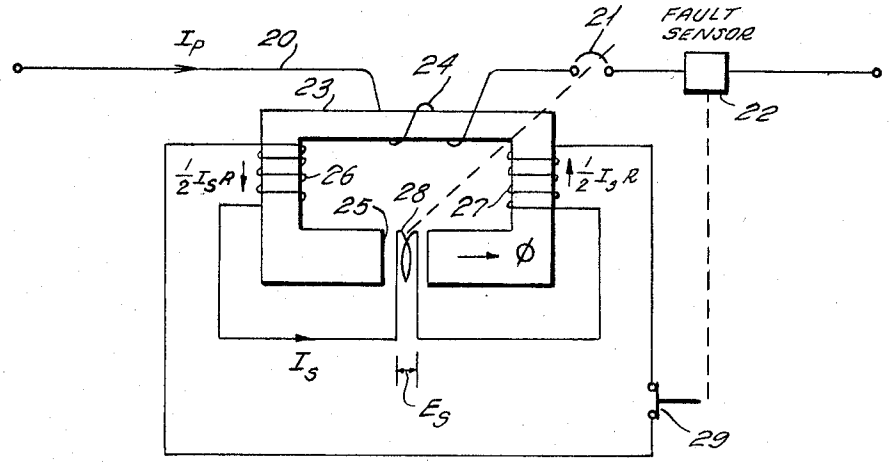


FIG. 2.

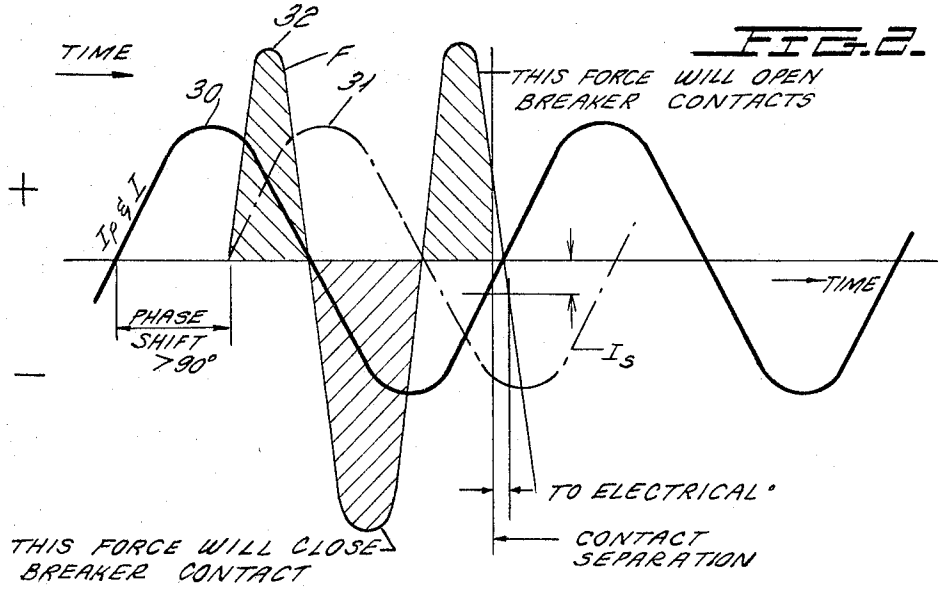
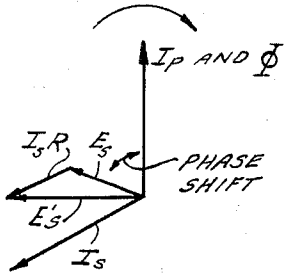


FIG. 3.



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Oct. 25, 1966 O. JENSEN 3,281,733

SYNCHRONOUS CIRCUIT BREAKER HAVING A MOVABLE WINDING

Filed Oct. 13, 1964 5 Sheets-Sheet 2

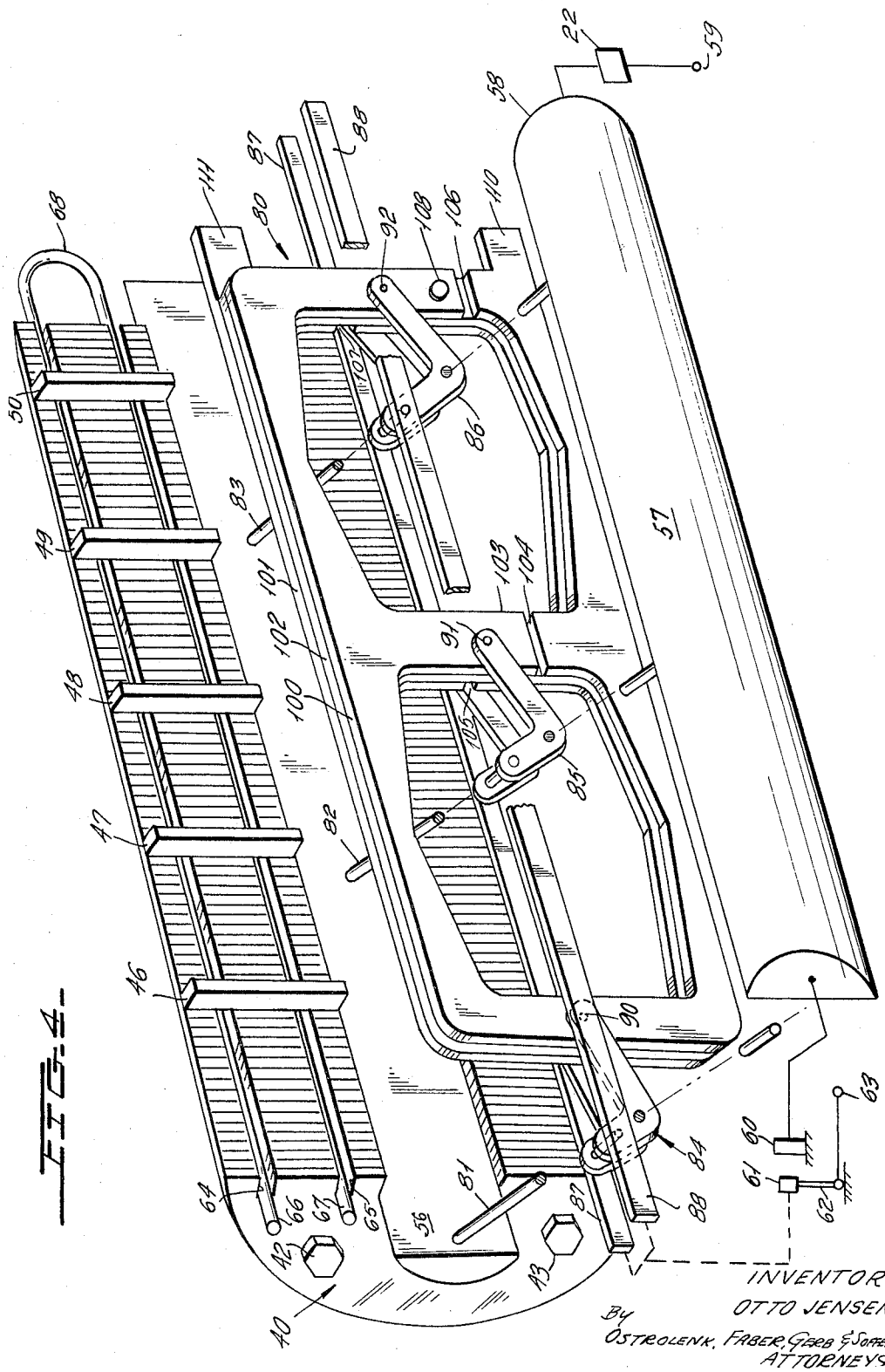


FIG. 4

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Oct. 25, 1966 O. JENSEN 3,281,733

SYNCHRONOUS CIRCUIT BREAKER HAVING A MOVABLE WINDING

Filed Oct. 13, 1964 5 Sheets-Sheet 3

FIG. 5

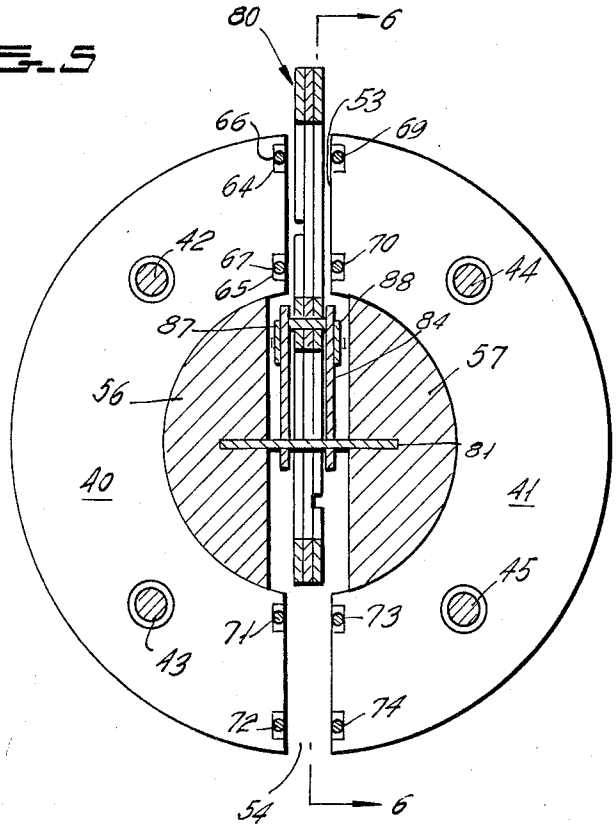


FIG. 7

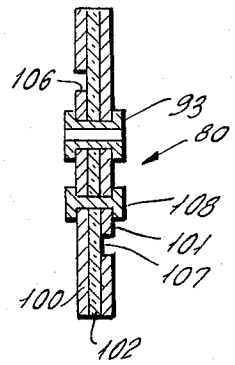
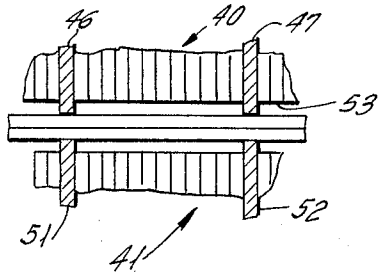


FIG. 8



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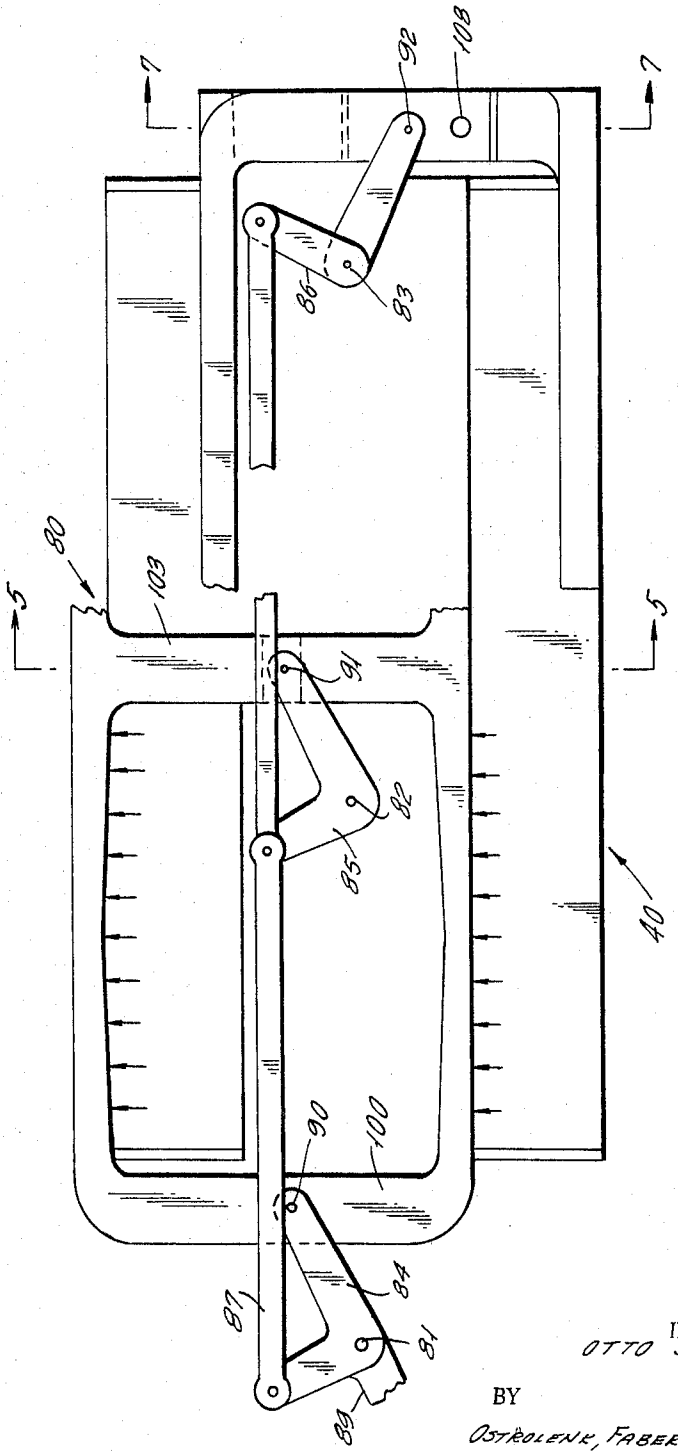
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Oct. 25, 1966 O. JENSEN 3,281,733

SYNCHRONOUS CIRCUIT BREAKER HAVING A MOVABLE WINDING

Filed Oct. 13, 1964 5 Sheets-Sheet 4

FIG. 6.



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Oct. 25, 1966 O. JENSEN 3,281,733

SYNCHRONOUS CIRCUIT BREAKER HAVING A MOVABLE WINDING

Filed Oct. 13, 1964 5 Sheets-Sheet 5

FIG. 9

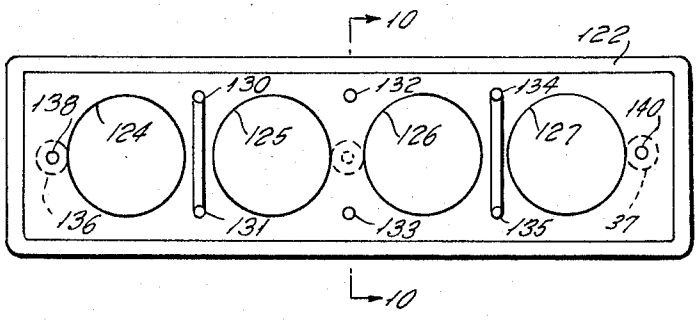


FIG. 10

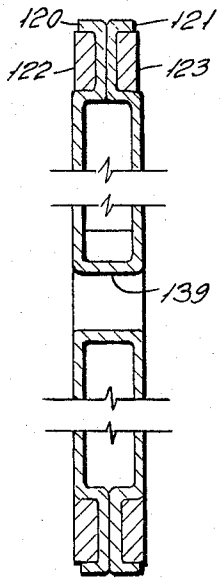


FIG. 11

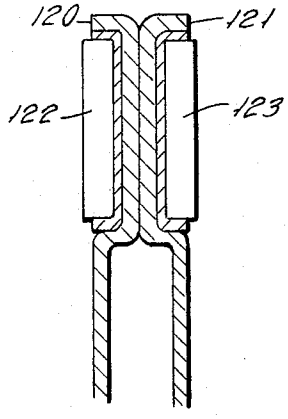
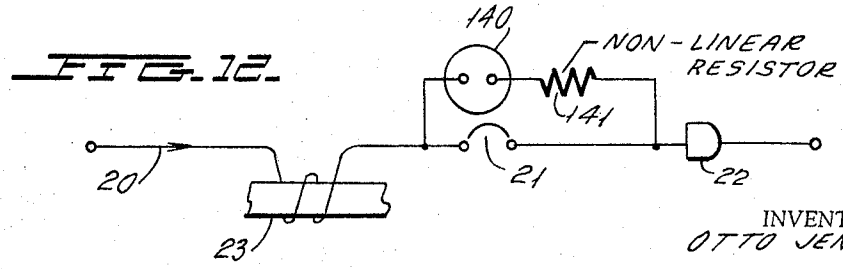


FIG. 12



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3,281,733

Patented Oct. 25, 1966

3,281,733

SYNCHRONOUS CIRCUIT BREAKER HAVING A MOVABLE WINDING

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Filed Oct. 13, 1964, Ser. No. 403,541
5 Claims. (Cl. 335—99)

This invention relates to circuit breakers, and more specifically relates to a novel synchronous A.-C. circuit breaker which interrupts a circuit immediately prior to or at a current zero and automatically recloses upon an unsuccessful interruption to again attempt a subsequent current zero interruption operation.

It is well known that circuit breaker contacts should be separated while the current through the contacts is decaying toward zero and as close to zero current as possible. Under these conditions, only a small arc which is extinguished at current zero, or no arc at all, is formed and no contact erosion takes place.

The present invention is for a novel operating mechanism which generates a contact opening force just prior to current zero and generates a contact closing force in the event of an unsuccessful contact opening operation as evidenced by continued current flow after current zero.

More specifically, and in accordance with the invention, the operating mechanism includes a magnetic flux generating circuit which generates a magnetic flux in phase with the current in the circuit to be interrupted. A movable coil is positioned in this magnetic circuit and a current is supplied to the coil which has a phase shift slightly greater than 90° with respect to the magnetic flux and the current to be interrupted. The interaction of this coil current and magnetic flux then generates a force upon the coil which slightly leads the current to be interrupted. Thus, a positive force appears on the coil slightly prior to the time the current to be interrupted reaches zero. This coil is then connected to the contacts to interrupt the last mentioned current whereby the contacts will be moved toward an open circuit position just prior to current zero.

The force applied to the moving coil will reverse after about 90° of current conduction thereby to apply force to the coil in a negative and contact opening direction. Therefore, if the initial current interruption was unsuccessful, the contacts will be closed to await the next current zero time, and a new interruption will take place.

Accordingly, a primary object of this invention is to provide an operating mechanism for circuit breakers which operates at just prior to current zero.

Another object of this invention is to provide a novel synchronous A.-C. circuit breaker mechanism which is operable to open a circuit just prior to current zero and quickly recloses the circuit in the event of an unsuccessful prior interruption.

A further object of this invention is to provide a novel circuit breaker operating mechanism which decreases contact erosion.

Yet another object of this invention is to provide a novel high speed circuit breaker mechanism which operates with high speed and eliminates the need for special arc interruption equipment.

A further object of this invention is to provide a novel circuit breaker which is less expensive than presently available circuit breakers for a given operating duty.

These and other objects of this invention will become apparent from the following description when taken in connection with the drawings, in which:

FIGURE 1 schematically illustrates the operating mechanism of the present invention.

FIGURE 2 shows the operating characteristics of the device of FIGURE 1 as a function of time.

FIGURE 3 shows a vector diagram of FIGURE 2.

FIGURE 4 is an exploded perspective diagram of the novel operating mechanism constructed in accordance with the present invention.

FIGURE 5 is a cross-sectional drawing of the mechanism of FIGURE 4 and is taken across lines **5—5** of FIGURE 6.

FIGURE 6 is a cross-sectional drawing of FIGURE 6 taken across the lines **6—6** in FIGURE 5.

FIGURE 7 is a detailed cross-sectional view of the movable coil of FIGURES 4, 5 and 6.

FIGURE 8 is a cross-sectional view of a detail of FIGURES 4 and 5 showing the use of guide laminations in the magnet structure.

FIGURE 9 is a side plan view of another form which the movable coil could take.

FIGURE 10 is a cross-sectional drawing of FIGURE 9 taken across the lines **10—10** in FIGURE 9.

FIGURE 11 is an enlarged sectional view of FIGURES 9 and 10 to illustrate the bond between various components.

FIGURE 12 shows the combination of a spark gap and non-linear resistor with the main contacts of FIGURE 1.

Referring first to FIGURE 1, I have schematically illustrated therein the principle of the present invention. Thus, a circuit conductor **20** which carries a current I_p is connected in series with a suitable contact means **21**, a suitable fault sensing means **22** and is coupled to a magnet structure **23**, as schematically illustrated, by winding **24**. The magnet structure **23** has an air gap **25** therein, which carries a flux ϕ caused by current I_p and in phase with current I_p. A suitable secondary winding means, shown as series windings **26** and **27**, are then wound on magnet structure **23**. A current I_s is induced in said windings by flux ϕ. Windings **26** and **27** are then connected in series with a movable coil **28** located in air gap **25** and which passes the flux ϕ. The movable coil **28** is then connected to contact means **21**, as indicated by the dotted line, and is operable to move the contact means **21** between a contact engaged and contact disengaged position depending on the direction of motion of coil **28**. The fault sensor **22**, which may be of any desired type, and which may be manually operable, is then connected to a suitable latch means for contact means **21** to be operated by coil **28** when the fault sensing means measures a predetermined condition in line **20**.

The operation of the mechanism of FIGURE 1 is best understood by reference to FIGURES 2 and 3. The current I_p and flux ϕ are shown in phase in curve **30** of FIGURE 2 and in the diagram of FIGURE 3. The flux ϕ induces a total voltage E'_s in windings **26** and **27** which theoretically lags flux ϕ by 90°. However, there is a voltage drop $\frac{1}{2}I_sR$ caused mainly by the resistance of windings **26** and **27** so that the actual driving voltage of

the circuit in series with coil 28 is the voltage E_s. The reactance of coil 28 then causes the current I_s (shown in dotted line 31 in FIGURE 2) to lag the voltage E_s, as shown in FIGURE 3. Therefore, the current I_s lags the current I_p and flux ϕ by more than the theoretical 90°. It is this additional phase shift between I_p and I_s that gives rise to the results of the present invention.

As is well known, the interaction of current I_s in coil 28 and the flux ϕ through coil 28 gives rise to a force perpendicular to the interacting current and flux. It will be seen later that coil 28 is not circular so that a net force moving the coil up or down is generated. This force is shown in FIGURE 2 as line 32 which encloses a shaded area and is positive (in a direction to open contact means 21) when ϕ and I_s are both either positive or negative, and is negative (in a direction to close contact means 21) when I_s and ϕ are of opposite polarity. Thus, the force varies with twice the frequency of the current I_s or flux ϕ. Moreover, and due to a phase shift of greater than 90° between current I_s and flux ϕ, the negative closing force magnitudes are higher than the positive opening force magnitudes.

In operation and assuming that contact means 21 is closed and a fault causing increasing current I_p is measured by fault sensor 22, the latch means of contact means 21 is released. The current I_s at this time will be negative so that the force acting on coil 28 is negative thus holding the contact means 21 engaged with high pressure. Some time after the fault current has reached its peak value and has started to decay, the force on coil 28 reverses and coil 28 will move to open the contacts just prior to zero current for current I_p. Thus, in FIGURE 1 it is seen that contact separation occurs 10° prior to current zero for current I_p. Note that there has been a time delay in FIGURE 2 from the zero force time to actual contact separation time. This time delay is due to the inertia of the moving contact members and mechanical linkages and the lost motion which is inevitable in such mechanical structures. By proper selection of lost motion, mass, and force, the contact separation can be made to take place at high velocity at some predetermined time.

When contact separation occurs, an arc will be established which will burn until actual current zero is reached and the arc will extinguish. If the movable contacts have sufficiently separated at this time, there will be no restrike and the current I_p is successfully interrupted.

However, if a restrike should occur as due to late fault occurrence and thus an insufficient force pulse during the opening stroke, the force pulse will reverse and a negative force pulse is applied to the contact means 21. The contact means 21, which is conducting through an arc, will therefore reclose with great force and will remain closed until the current I_p again decays toward zero.

Clearly, with this type arrangement the arc energy will be reduced to just a few percent of the energy in a conventional breaker with random contact separation.

FIGURES 4–8 show a novel manner in which an operating mechanism can be built to carry out the operation schematically described in FIGURE 1. More specifically and as best shown in FIGURES 4 and 5, the magnet structure 23 of FIGURE 1 is formed of opposing stacks 40 and 41 of semicircular magnetic laminations which are held together by suitable bolts or clamps such as bolts 42 and 43 for stack 40 and bolts 44 and 45 (FIGURE 5) for stack 41. The opposing lamination stacks may have interposed therein extending guide laminations such as laminations 46 through 50 in stack 40 (FIGURES 4 and 8), and opposing laminations such as laminations 51 and 52 in stack 41 (FIGURE 8) which serve to guide a movable coil, as will be described later.

The opposing lamination stacks 40 and 41 define upper and lower air gaps 53 and 54 which each serve the purpose of gap 25 of FIGURE 1.

Each of stacks 40 and 41 then receive semicircular bus conductors 56 and 57 respectively which constitute two halves of a slotted circular conductive bar and are in parallel with one another. Conductors 56 and 57 correspond to the winding in line 20 of FIGURE 1 and serve as a single turn primary winding for magnetic structures 40 and 41. Thus, in FIGURE 4 conductors 56 and 57 are electrically connected from a first terminal 58, through the fault sensing mechanism 22, to a line terminal 59. At the other end conductors 56 and 57 are electrically connected to a suitable stationary contact 60. Stationary contact 60 cooperates with a movable contact 61 suitably carried on a pivotally mounted contact arm 62. The contact arm 62 is then connected to a second line terminal 63.

Each of the magnet structures 40 and 41 then receive secondary windings, equivalent to windings 26 and 27 of FIGURE 1 in their pole faces. Thus as shown in FIGURES 4 and 5, the upper portion of stack 40 has two elongated slots 64 and 65 therein which receives the upper and lower sections 66 and 67 of winding 68 (FIGURE 4). The opposite pole face in stack 41 has a similar winding having upper and lower sections 69 and 70 in suitable slots, as shown in FIGURE 5. The two windings 68 and the winding having sections 69 and 70 may then be connected in series relation. Note that any number of turns could be used.

The lower air gap 54 has a similar secondary winding arrangement in its pole faces, as shown by winding halves 71–72 in stack 40 and winding halves 73–74 in stack 41. Clearly, all of the secondary windings are connected in series with one another.

A movable winding 80, corresponding to winding 28 of FIGURE 1, is then disposed in the air gaps 53 and 54. More specifically and as shown in FIGURES 4, 5 and 6, three pivot pins 81, 82 and 83 are fixed in opposing conductor halves 56 and 57. Pivot pins 81, 82 and 83 then carry double crank arms 84, 85 and 86. The upper ends of crank arms 84, 85 and 86 then externally pivotally receive operating rods 87 and 88 by a suitable pin engagement arrangement.

Operating rods 87 and 88, as schematically shown by dotted lines in FIGURE 4, are then connected to movable contact 61. Alternatively and as shown in FIGURE 6, crank 84 can have an extending arm 89 which can be connected to the contact drive structure.

The movable coil 80 is then disposed between the double crank arms 84, 85 and 86 and is secured thereto by suitable pivot pins, such as pins 90, 91 and 92 respectively, in the rightwardly extending portions of the cranks 84, 85 and 86. As shown in FIGURE 7, a suitable insulation washer, such as washer 93, can be embedded in the portion of winding 80 which receives pins 90, 91 and 92.

Movable coil 80 is shown to be a two turn structure in the drawings and is comprised of a multilayer construction including outer aluminum conductors 100 and 101 which are bonded together in high strength insulated relation by a central epoxy layer 102 (FIGURE 7). Conductors 100 and 101 may be of the order of 0.01 inch thick. The strength of the winding is further increased by a central leg section 103 (FIGURES 4 and 6) which has air gaps 104 and 105 in layers 100 and 101 respectively to prevent a short circuiting turn. Similarly, the right-hand leg of winding 80 has air gaps 106 and 107 in conductors 100 and 101 respectively to prevent short circuiting.

In order to form a two turn device, a conductive rivet 108 (FIGURES 4, 6 and 7) connects aluminum conductors above gap 106 and below gap 107. Thus, current flow from winding sections 64–65, 69–70, 71–72 and 73–74 is connected by suitable flexible conductors (not shown) to terminal 110 (FIGURE 4) of conductor 100. The current then flows around conductor 100 to rivet 108 and through to conductor 101. Thereafter current flows

around conductor **101** to terminal **111** (FIGURE 4) and back to the other terminal of the driving windings.

The operation of the structure of FIGURES 4–8 is similar to that described for FIGURE 1 in FIGURES 2 and 3. Thus, when there is a fault, or some other signal requiring the contacts **60** and **61** to be opened at current zero, a latching mechanism is opened to permit contact **61** to be moved solely by operating rods **87** and **88**. The current flow through conductors **56** and **57** causes a flux ϕ in phase therewith to be set up in air gaps **53** and **54**. This induces a voltage E'_s (FIGURE 3) in winding sections **64**, **65** and **69–74** which causes a current I_s to flow in the two turn winding **80**.

When the breaker is closed, winding **80** will be in its lowest position, shown in the right-hand side of FIGURE 6. The interaction of the curernt I_s in winding **80** and the flux ϕ in the air gaps **53** and **54** will then cause a force on winding **80** which drives it upward to the position at the left-hand side of FIGURE 6 and in FIGURE 5. Note that this force is such that contact separation will occur just prior to current zero through contacts **60** and **61**. The upward motion of winding **80** will cause cranks **84**, **85** and **86** to rotate counterclockwise about pivot pins **81**, **82** and **83** respectively, thus thrusting rods **87** and **88** to the right to cause the opening of contacts **60** and **61**.

The reclosing operation due to failure to extinguish the arc is the same as described for FIGURE 1.

The construction of movable winding **80** is made as strong and as light as possible. This is required to obtain sufficient contact motion in the last 10 electrical degrees prior to current zero and to withstand the recovery voltage across the contacts immediately after successful current interruption. Moreover, to keep the magnetizing current required to drive flux across gaps **53** and **54** as small as possible, these gaps must be narrow. Thus, the movable winding **80** must be very thin but with enough strength to withstand the bending forces created by the electromagnetic forces involved.

It will also be noted that at the end of the operating stroke the electromagnetic drive is no longer needed. Therefore, coil **80** can be moved out of the air gap with a substantial savings in material.

An alternate form for the movable winding **80** is shown in FIGURES 9, 10 and 11 wherein two magnesium plates **120** and **121** serve as a support frame for a two turn winding formed of aluminum conductors **122** and **123**. More particularly, magnesium plates **120** and **121** may have a thickness of the order of 0.005 inch and are stamped to have aligned openings, such as openings **124**, **125**, **126** and **127** therein. The two plates are then secured to one another as by spot welding around their peripheries and at locations, such as locations **128–137** (FIGURE 9). Suitable bushings **138–140** are then formed in the plates to receive pins **90**, **91** and **92** (FIGURE 6). The main aluminum conductors **122** and **123**, which may have a height of 0.250 inch and a thickness of 0.01 inch, are then placed in stamped peripheral depressions in plates **120** and **121** respectively and are secured therein as by an insulating epoxy adhesive. The conductors **122** and **123** are then suitably connected in series and used as described in FIGURES 4 through 8.

As a further feature of the invention, it has been found useful to combine a jump gap and non-linear circuit in parallel with the interrupter contacts of a synchronous circuit breaker. Thus, as shown in FIGURE 12, which shows a modification of the circuit of FIGURE 1, adds a spark gap **140** and a series resistor **141** in parallel with contact means **21**. The resistor **141** is one of such nature that its resistance increases with temperature. Thus, the resistor is non-linear.

When the contact means **21** opens by the synchronous mechanism of FIGURE 1, just before zero current in line **20**, an arc of low intensity is established which extinguishes of its own accord at the first current zero. It is however possible that the recovery voltage across opened contact means **21** will tend to reignite an arc after it extinguishes. In accordance with the additional feature of FIGURE 12, the gap **140** is designed to have a lower flashover voltage than the gap of contact means **21**, so that flashover action will prefer the gap **140**.

Resistor **141** in series with gap **140** will then conduct fault current. The resistor, whose resistance increases with temperature will then limit fault current and at the first voltage zero, the resistor current will reach zero. The recovery voltage now sinusoidal so that the arc gap **140** is extinguished without high recovery voltage.

It is to be noted that resistor **140** is fabricated of any material, such as pure iron wire, which has a positive temperature characteristic. By way of example, in a pure iron wire, the resistivity will be of the order of 0.0048 at 100° C. and increases approximately linearly to 0.18 at 850° C. From 850° C. to its melting point of 1500° C. it decreases from 0.18 to .0068.

As a typical example, a resistor can be made of 32 meters of 0.7 millimeter diameter pure iron wire. This resistor will have a cold value of 10 ohms which within ¼ cycle on a fault condition in a circuit of the type shown in FIGURE 12 will be heated to approximately 550° C. and increase in resistance to approximately 35 ohms whereupon the resistor current will be successfully limited and interrupted without excessive recovery voltage.

Although there has been described a preferred embodiment of this novel invention, many variations and modifications will now be apparent to those skilled in the art. Therefore, this invention is to be limited, not by the specific disclosure herein, but only by the appending claims.

The embodiments of the invention in which an exclusive privilege or property is claimed are defined as follows:

1. A synchronous circuit breaker comprising a magnetic structure, an elongated air gap in said magnetic structure, a pair of cooperable contacts, a first winding wound on said magnetic structure and connected in series with said pair of cooperable contacts, operating means connected to one of said pair of cooperable contacts and movable for moving said pair of cooperable contacts into and out of engagement with one another, a second winding wound on said magnetic structure, and a third winding connected in series with said second winding; said second winding coupled to said third winding by the flux in said magnetic core, thereby to energize said third winding responsive to the current in said first winding; said third winding being positioned in said air gap and being in a plane substantially perpendicular to the magnetic flux across said air gap; said third winding being movable in a direction perpendicular to the direction of the magnetic flux across said air gap at a predetermined time with respect to the phase of the current in said first winding; said third winding mechanically connected to said operating means; said first winding comprising first and second parallel spaced elongated conductors; said magnetic structure comprising a first and second stack of magnetic disk sections and a slotted elongated conductor; said first and second stack of magnetic disk sections partially enclosing a respective half of said slotted elongated conductor; the opposing surfaces of said first and second stack of magnetic disk sections defining said air gap and being aligned with the space between said first and second elongated conductors.

2. The device substantially as set forth in claim **1** wherein said third winding is a thin rigid rectangular conductor elongated in the elongated direction of said elongated conductors.

3. The device substantially as set forth in claim **1** wherein said second winding is carried around the air gap defining the surface of said first stack of magnetic disk sections extending above said first elongated conductor.

4. The device substantially as set forth in claim **2** which further includes guide surface means connected in the opposing air gap defining surfaces of said first and sec-

ond stacks of magnetic disk sections for guiding the motion of said third winding.

5. The device substantially as set forth in claim 1 wherein said third winding comprises a first and second parallel frame of thin rectangular conductors, an insulation layer; said insulation layer being connected to opposing sides of said thin rectangular conductors; and connection means extending between said thin rectangular conductors for defining at least two electrical turns.

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