Dec. 28, 1965 YASUO KASAHARA 3,226,507

CIRCUIT BREAKER HAVING A PERMANENT MAGNET MADE OF CURIE POINT MATERIAL

Filed Feb. 15, 1963 7 Sheets-Sheet 1

Fig. 1.

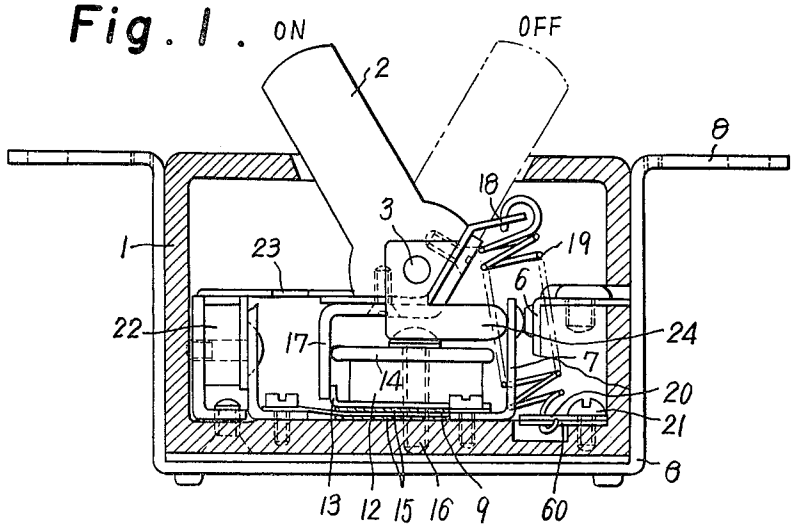
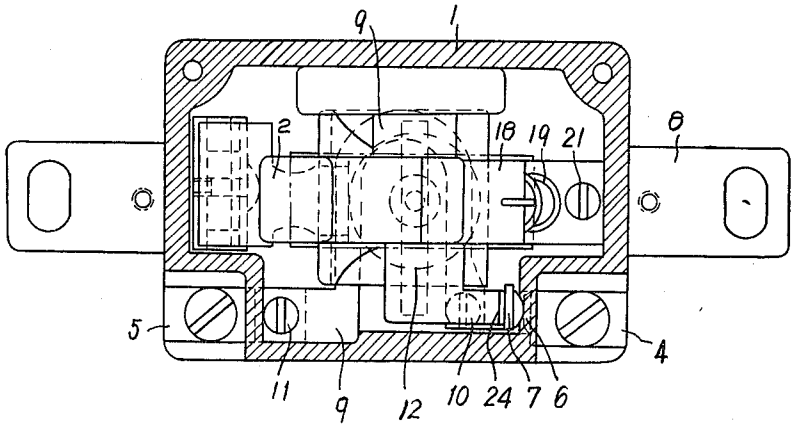


Fig. 2.



INVENTOR

YASUO KASAHARA

BY Irwin S. Thompson

ATTORNEY

Dec. 28, 1965 YASUO KASAHARA 3,226,507
CIRCUIT BREAKER HAVING A PERMANENT MAGNET
MADE OF CURIE POINT MATERIAL
Filed Feb. 15, 1963 7 Sheets-Sheet 2

Fig. 3.

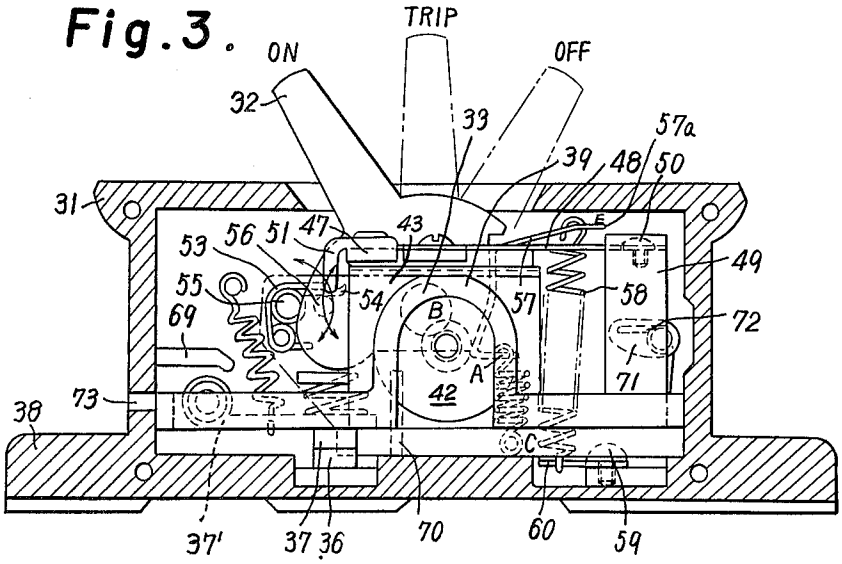
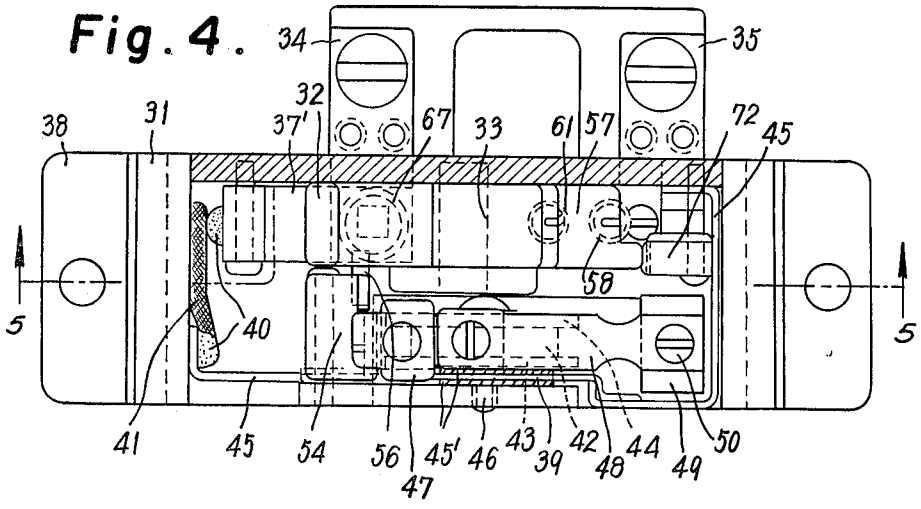


Fig. 4.



INVENTOR
YASUO KASAHARA
BY Irwin S. Thompson
ATTORNEY

Dec. 28, 1965 YASUO KASAHARA 3,226,507

CIRCUIT BREAKER HAVING A PERMANENT MAGNET MADE OF CURIE POINT MATERIAL

Filed Feb. 15, 1963 7 Sheets-Sheet 3

Fig. 5.

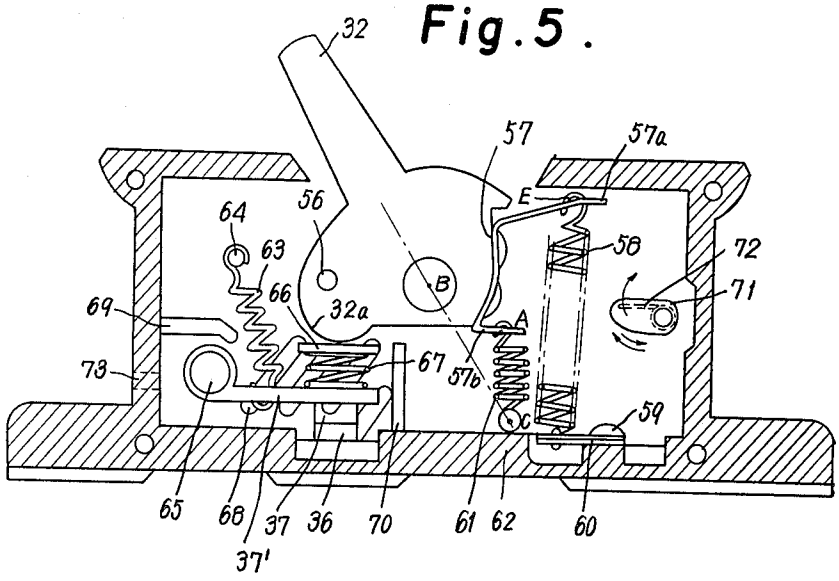


Fig. 9.

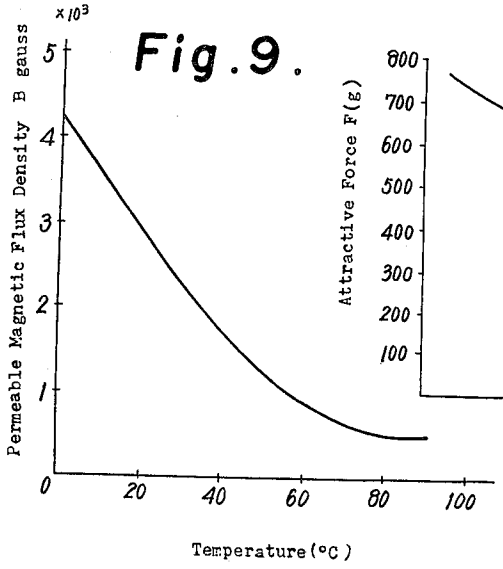
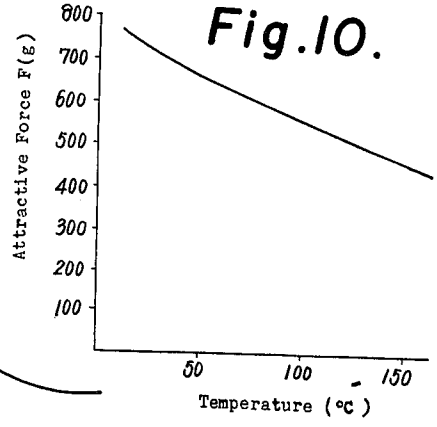


Fig. 10.



INVENTOR

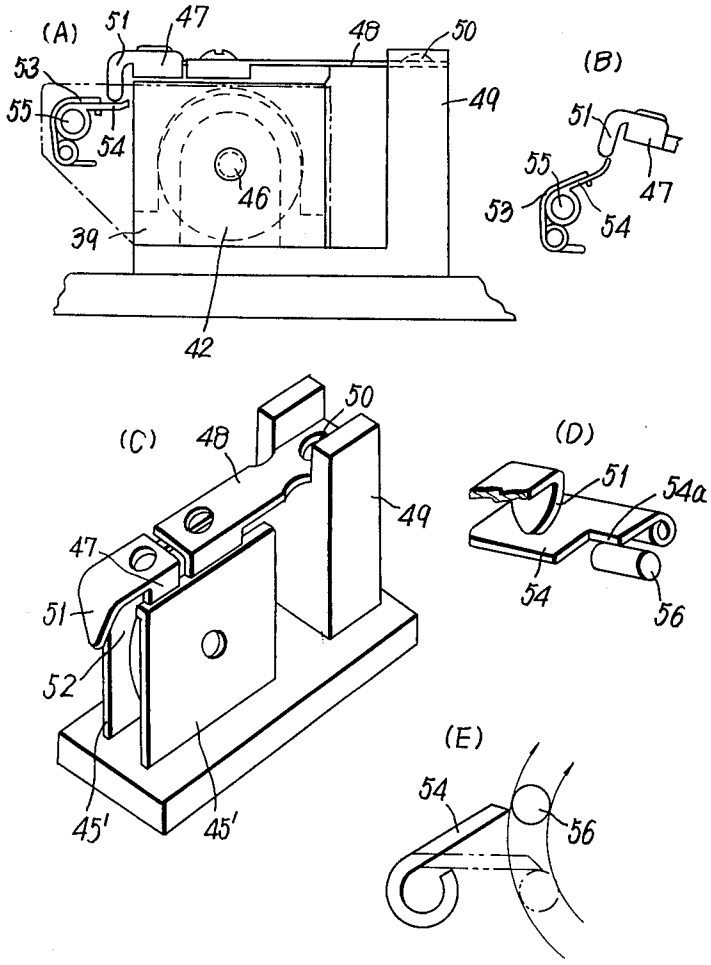
YASUO KASAHARA

BY Irwin S. Thompson

ATTORNEY

Dec. 28, 1965 YASUO KASAHARA 3,226,507
CIRCUIT BREAKER HAVING A PERMANENT MAGNET MADE OF CURIE POINT MATERIAL
Filed Feb. 15, 1963 7 Sheets-Sheet 4

Fig. 6.



INVENTOR
YASUO KASAHARA

BY Irwin S. Thompson

ATTORNEY

Dec. 28, 1965 YASUO KASAHARA 3,226,507
CIRCUIT BREAKER HAVING A PERMANENT MAGNET
MADE OF CURIE POINT MATERIAL
Filed Feb. 15, 1963 7 Sheets-Sheet 5

Fig. 7.

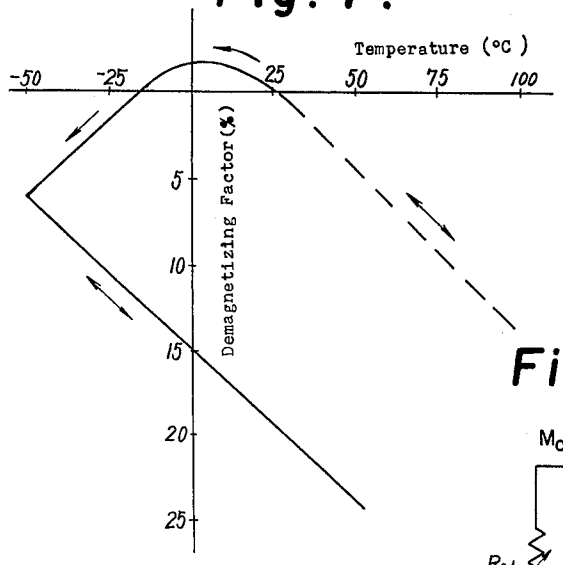


Fig. 11.

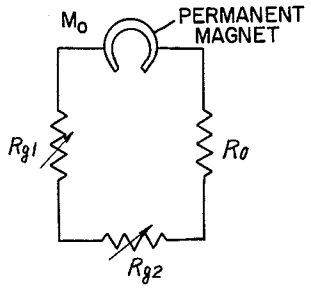


Fig. 8.

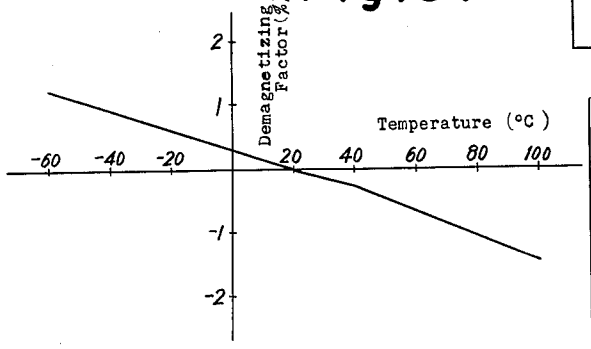
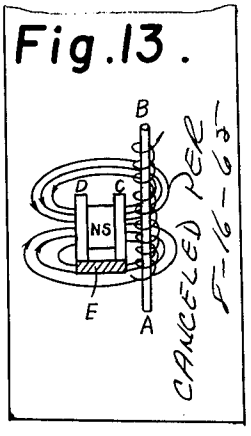


Fig. 13.



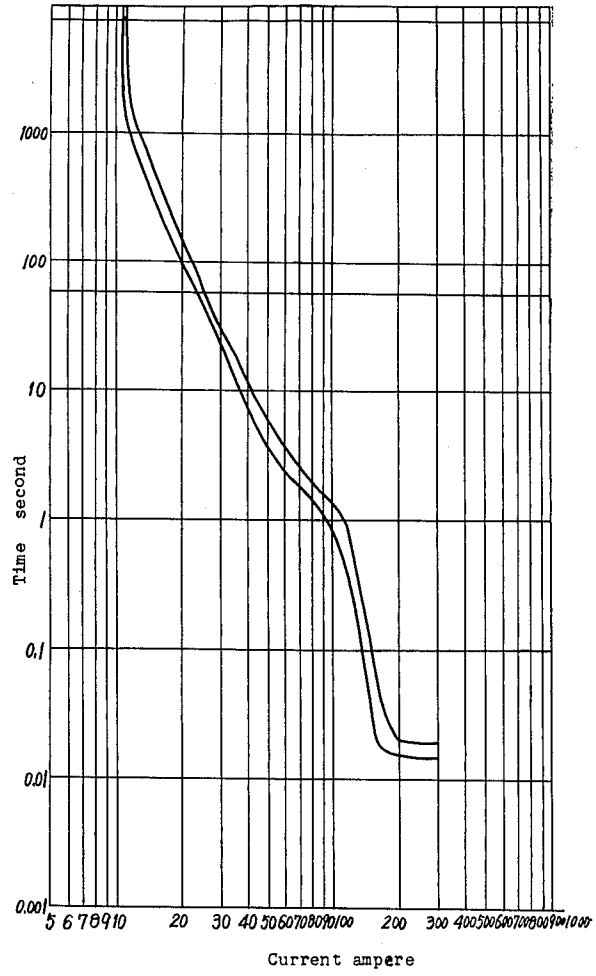
INVENTOR
YASUO KASAHARA

BY Irvin S. Thompson

ATTORNEY

Dec. 28, 1965 YASUO KASAHARA 3,226,507
CIRCUIT BREAKER HAVING A PERMANENT MAGNET MADE OF CURIE POINT MATERIAL
Filed Feb. 15, 1963 7 Sheets-Sheet 6

Fig. 12.



INVENTOR
YASUO KASAHARA

BY Irvin S. Thompson

ATTORNEY

Dec. 28, 1965 YASUO KASAHARA 3,226,507
CIRCUIT BREAKER HAVING A PERMANENT MAGNET MADE OF CURIE POINT MATERIAL
Filed Feb. 15, 1963 7 Sheets-Sheet 7

Fig_13a

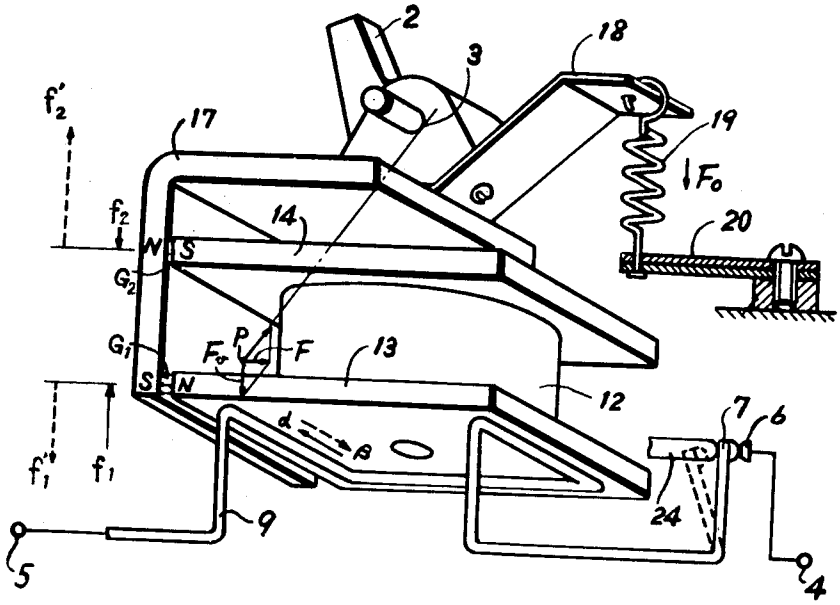
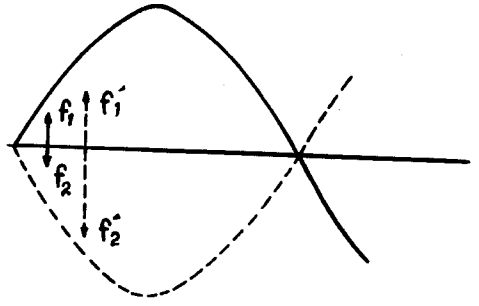


Fig_13b



INVENTOR
YASUO KASAHARA
BY
Irwin S. Thompson
ATTORNEY

United States Patent Office

3,226,507

Patented Dec. 28, 1965

3,226,507

CIRCUIT BREAKER HAVING A PERMANENT MAGNET MADE OF CURIE POINT MATERIAL

Yasuo Kasahara, Tokyo, Japan, assignor to Shoichi Shimada, Tokyo, Japan

Filed Feb. 15, 1963, Ser. No. 258,761
Claims priority, application Japan, Apr. 9, 1962, 37/14,166
2 Claims. (Cl. 200—88)

The present invention relates to circuit breakers, more particularly to automatic electric circuit breakers operable manually to open and close a circuit and also responsive to two kinds of excessive current conditions one of which is overload current condition and the other is short-circuit current condition to open the circuit automatically, independently of the operating handle.

The no-fuse circuit breaker according to the invention is well adapted for use as a miniature tumbler switch having a current rating of the order of about 5–30A and as a no-fuse circuit breaker having a comparatively high current rating of the order of about 30–300A and which comprises a permanent magnet, magnetic shunt material and a yoke or a permanent magnet, soft ferrite and a yoke assembled together to constitute a circuit breaker element, and a conductor connected in series with a switching mechanism and arranged adjacent to the magnetic pole of said permanent magnet, which is constructed and arranged such that an electric circuit is automatically cut off in case of over load by means of the change of the attractive force of the magnetic pole due to the over load current.

For a better understanding of the invention, reference is taken to the accompanying drawings, of which

FIG. 1 is a longitudinal sectional view of a miniature type switch embodying the present invention;

FIG. 2 is its transverse sectional view;

FIG. 3 is a longitudinal sectional view of a second species of a no-fuse circuit breaker embodying the present invention;

FIG. 4 is its transverse sectional view;

FIG. 5 is a cross-section on the line 5—5 of FIG. 4;

FIGS. 6(A)–(E) show the essential parts of the no-fuse circuit breaker shown in FIGS. 3 and 4 in detail;

FIG. 7 is a reversible temperature characteristic curve of barium ferrite;

FIG. 8 is a reversible magnetizing factor-temperature characteristic curve for Alnico V magnet;

FIG. 9 is a permeable magnet flux density-temperature characteristic curve of magnetic shunt steel representing one example of magnetic shunt material;

FIG. 10 is an attractive force-temperature characteristic curve of a movable member of the magnetic circuit shown in FIGS. 1 and 3;

FIG. 11 is an electric equivalent circuit of a thermal magnetic time limit responsive means embodying the invention;

FIG. 12 is time-current characteristic curves for the no-fuse circuit breaker embodying the invention;

FIG. 13*a* is a somewhat diagrammatic view showing the principle of the use of overload current; and

FIG. 13*b* is a force diagram.

Referring to the drawings, FIGS. 1 and 2 represent a tumbler switch embodying a no-fuse circuit breaker according to the invention and having a current rating of the order of 5–30A and adapted for use in the indoor wiring. **1** designates a casing; **2** a hand operating knob; **3** a main shaft for pivoting the hand operating knob to the casing; **4** and **5** wire connection terminals provided at each side of the casing; **6** a stationary contact connected to one of the terminals; **7** a movable contact

connected to the other terminal; and **8** a mounting member projected outwardly from the casing.

In accordance with the invention, the movable contact **7** and one of the wire connection terminals **5** are interconnected through a conductor **9** which serves as a heater. Each end of the heater **9** is connected to the movable contact **7** and the terminal **5** by set screws **10**, **11**, respectively. This heater is extended in the casing towards the opposite side and arranged beneath and in contact through an electric insulating material **15** such as mica, etc. with a magnet means which comprises a permanent magnet **12**, magnetic shunt steel **13** and a yoke **14**, said magnet means being secured to the bottom of the casing by a screw bolt **16**. Provision is made of an armature **17** secured to the inner end of the knob **2** and arranged in opposition to the above mentioned magnet means such that if the knob is moved to on position the armature **17** closes an air gap formed between the yoke **14** and the magnetic shunt steel **13**. Projected from the armature **17** at its side opposing the knob is a spring seat **18**. Between the free end of this spring seat and the free end of bimetal **20** secured to the lower part of the casing by a screw **21**, there is a main spring **19** which serves to normally maintain the knob in its off position.

22 is a permanent magnet provided within the casing at its side opposite the main spring **19**. Projected from the knob **2** is a leaf spring **23** adapted to be attracted to and in contact with the permanent magnet **22** when the knob **2** is moved to the on position, thereby locking the magnet in its on position. **24** is a switching arm in contact with the inside surface of the movable contact **7** and for opening or closing the movable contact in accordance with the on or off position of the knob.

The operation of the no-fuse circuit breaker shown in FIGS. 1 and 2 will now be described. In FIG. 1 the on position of the knob is shown by the full line, while the off position of the knob is shown by the chain line. If the knob is moved to the on position the armature **17** projected from the knob closes the magnetic circuit between the yoke **14** of the permanent magnet **12** and the magnetic shunt steel yoke **13** while the switching arm **24** pushes the back surface of the movable contact **7** to close the contacts of the electric circuit and at the same time the leaf spring **23** projecting from the knob is attracted by the locking permanent magnet **22**. The main spring **19** at the opposite side of the knob acts to attract the knob from the on position to the off position. In the on position, the resultant force of the attractive forces on the permanent magnets **12** and **22** is in balance with the attractive force of the main spring **19**, thereby maintaining the knob in this on position. The heater **9** connected across the terminals **4** and **5** is arranged in contact with the permanent magnet **12**, so that the excessive current flowing through this conductive path serves to heat the magnetic shunt steel **13** and the permanent magnet **12**. When the permanent magnet **12** and the magnetic shunt steel **13** are heated, the magnetic force thereof is overcome by the attractive force of the main spring **19**, thereby moving the knob from the on position to the off position. In order to maintain the above relation between the magnetic force and the attractive force irrespective to the change of the surrounding temperature, the main spring is associated with the bimetal **20**.

In the embodiment shown in FIGS. 1 and 2, means for locking the knob in the on position comprises the permanent magnet **22**. Alternately, provision may be made of any other locking means comprising a suitable spring means and arranged such that the knob can be locked in the on position without restraining the return movement of the knob towards the off position.

FIGS. 3 and 4 show another embodiment of the no-fuse circuit breaker according to the invention and hav-

ing a current rating of the order of 30–300 A. 31 designates a casing; 32 a hand operating knob; 33 a main shaft for pivoting the band operating knob to the casing; 34 and 35 wire connection terminals provided at each side of the casing; 36 a stationary contact connected to one of the terminals; 37 a movable contact connected to the other terminal; and 38 a mounting member projected outwardly from the casing.

In accordance with the invention, the movable contact 37 and the other wire connection terminal 35 are interconnected through a conductor 39 which serves as a heater. The heater 39 is connected through soldered terminals 40 and a flexible wire 41 to the movable contact 37 and the terminal 35, respectively. This heater is extended upwardly in the casing and arranged in contact through an electric insulating material 45 such as mica etc. with a magnet means which comprises a permanent magnet 42, a magnetic shunt steel yoke 43 and a yoke 44, said magnet means being secured to the side wall of the casing by a screw bolt 46. Provision is made of an armature 47 secured to a movable arm 48 and arranged in opposition to the above mentioned magnet means, one end of the movable arm 48 being secured to a base seat 49 by means of a screw 50. The armature 47 is at its free end provided with an L shaped tag 51 which is extended downwardly so that if the armature 47 closes an air gap 52 formed between the yoke 44 and the magnetic shunt steel yoke 43 the tag 51 is brought into contact with a movable piece 54 having a spring 53 adapted to normally push up the tag 51. 55 shows a shaft of the movable piece 54. 56 is a pin projected from the side surface of the knob 32 to make contact with the movable piece 54 and adapted to open or close the air gap in the magnetic circuit and to set the knob 32 at its on position. Thus, the pin 56 constitutes together with the spring 53 a locking means for keeping the knob 32 at its on position.

As seen from FIG. 5, 57 is a channel arm having two projected arms and arranged at the side opposing the knob. The free end 57*a* of one of the two projected arms is connected to one end of a main spring 58, the other end of which being connected to the free end of bimetal 60 secured by a screw 59 to a base plate 62. The free end 57*b* of the other projected arm is connected to one end of an auxiliary spring 61, the other end of which being secured to the base plate 62. The main spring 58 and the auxiliary spring 61 are so arranged that the knob is stabilized at its on or off position. 63 is a spring for biasing the movable contact 37 into a normally open state. One end of this spring 63 is connected to an arm for supporting the movable contact while the other end of the spring 63 is secured by a pin 64 to the casing. 65 is a pivot for supporting the movable contact. 66 shows a spring washer secured to the upper free end of a spring 67 inserted between the spring washer 66 and the movable contact 37. The spring washer 66 is so arranged that when the knob 32 is moved to the on position a projected part 32*a* formed at one side of the knob comes into contact with the spring washer 66 to push it down. Thus, the movable contact 37 is brought into contact with the stationary contact 36 to close an electric circuit. 68 designates an arc extinguishing means and 69, 70 show arc extinguish chamber walls.

In the embodiment as above mentioned, the base of the main spring 58 is supported by the bimetal 60 for the purpose of maintaining the relation between the magnetic force and the attractive force constant irrespective of the change of the surrounding temperature.

The operation of the no-fuse circuit breaker shown in FIGS. 3–6 will now be described. In FIG. 3 the on position of the knob is shown by the full line, while the off position of the knob is shown by the chain line. If the knob 32 is moved to the on position the pin 56 projecting from the knob is lowered over a notch 54*a* of the movable piece 54 to a position below the movable piece 54 as shown in FIG. 6D. Thus, the knob 32 is set to the on position by the spring 53 acting on the movable piece 54. In this case, the armature 47 supported by the plate spring 48 operates to close the air gap 52 of the magnetic circuit of the permanent magnet 42, whereupon the downwardly extending tag 51 formed at the end of the armature 47 tends to push downwards the movable piece 54. In this case, the attractive force of the magnet for attracting the armature 47 also attracts the lower end of the tongue 51, thereby producing thrust force for pushing downwards the movable piece 54. The pin 56 projecting from the knob 32 is acted upon by the pulling back force of the main spring 58 provided at the opposite side of the knob 32. If the attractive force of the magnet is balanced with the pulling back force of the main spring 58, the on position of the knob 32 can accurately be defined and stabilized. If the knob 32 is moved to the on position, the protruding part 32*a* formed at one side of the knob causes to push down the spring washer 66 of the spring 67 for supporting the movable contact 37, so that the movable contact 37 comes into contact with the stationary contact 36. Thus, a conductive path across the wire connection terminals 34 and 35 is closed, which results in a current flow through the above conductive heater 39. If the current capacity of the current flowing through this conductive path is within a rated range the permanent magnet 42 is heated but still sufficiently magnetized so that the knob is kept at its on position without being influenced by the spring force. If an excessive current flows through the heater conductor the permanent magnet 42 and the magnetic shunt steel yoke 43 are heated to a given critical temperature (for example, 60–80° C.). Then, the magnetic force of the permanent magnet 42 is rapidly decreased owing to the synergestic effect of the thermal reversible change of the coercive force of the permanent magnet and of the change of the thermal reversible permeability of the magnetic shunt steel yoke or soft ferrite yoke or owing to the sole thermal reversible effect of the coercive force of the permanent magnet (in case of without using the magnetic shunt steel yoke). Consequently, the attractive force of the main spring 58 overcomes that of the permanent magnet, so that the knob 32 is pulled by means of the main spring 58 and moved back to the off position. Then, the pin 56 projecting from the knob pushes the movable piece 54 and, consequently, the tongue 51 formed at the end of the movable yoke upwards to open the magnetic circuit. At the same time, the knob 32 is moved to the off position to release the pressing force of the protruding part 32*a* against the spring washer 66 and the spring 67. Thus, the movable contact 37 is sprung up by means of the tension spring 63 to automatically cut off the electric circuit formed between the movable contact 37 and the stationary contact 36. When the knob 32 is moved to the off position a connection point A between the auxiliary spring 61 and the leg projected from the knob 32 moves over a center line from a pivot center B of the knob to a point C for supporting the auxiliary spring to a position D opposing the point A, while a connection point E between the free end 57*a* and the main spring 58 moves to a point F far below. Thus, the main spring and the auxiliary spring cause to stabilize the knob 32 by applying forces in opposite directions with respect to the line BC, so that the knob is stopped at the off position.

The movable contact 37 and the stationary contact 36 are surrounded by the arc extinguishing walls 69, 70, so that the no-fuse circuit breaker shown in FIGS. 3–6 renders it possible to automatically cut off the current of the order of 30 A.–300 A. The no-fuse circuit breaker according to the invention, therefore, may be applied to a temperature relay, alarm detector, D.C. reverse current relay, A.C./D.C. over current relay, short-circuit protective circuit breaker, over-heating protective relay, and magnetic valve etc.

The no-fuse circuit breaker according to the invention may also be applied to automatically cut off the heavy cur-

rent of the order of 300–1,000 A. if provision is made of an arc extinguishing chamber for improving the arc extinguishing character of the arc extinguishing means.

71 is trip indicating restraining cam and **72** shows its reset spring. In the automatic cut off operation, the cam **71** and its reset spring **72** serve to restrain the rotation of the free end **57***a* of the spring supporting arm **57** and also restrain the knob at its trip position, thereby indicating the trip position. This trip position of the knob **32** is shown by chain lines and designated by "Trip" in FIG. 3. **73** designates a gas outlet opening formed in the arc extinguishing chamber wall.

A conventional automatic circuit breaker has to be provided with bimetal and an electromagnetic tripping means for the purpose of obtaining the delayed character and also the minimum time limit character, respectively. Thus, if the current directly flows through the bimetal, the temperature thereof is raised due to Joule heat generated by the specific resistance of the bimetal, which results in a mechanical displacement of the bimetal in proportion to the value of the current flowing through it in order to obtain the reverse time limit character. Alternately, the bimetal is indirectly heated so as to make use of its mechanical displacement. In the case of the direct heating of the bimetal, since the bimetal consists of two different kinds of metals laminated one upon the other the current is distributed in the two layers in unbalanced state owing to difference in the specific resistance of each metal, thereby causing temperature difference in each metal. The ideal operative condition of the bimetal lies in the mechanical displacement occurred by the difference of the coefficient of expansion of two kinds of metals at equal temperature, so that if the bimetal is directly heated by the current it is necessary to use the bimetal having an excellent property in order to overcome the above disadvantage. Such bimetal, however, is very expensive. On the other hand, the bimetal adapted to be indirectly heated is complex in construction if compared with one to be directly heated, so that the bimetal to be indirectly heated is not generally used. Moreover, the mechanical displacement of the bimetal is slow and of very minute change. Such bimetal per se is not suitable for cutting off the electric circuit, so that it is generally used in combination with a rapidly acting trip mechanism. As above mentioned, the bimetal makes use of the mechanical displacement occurred between two kinds of metals heated, so that its immediate insertion in the circuit after its operation is not possible owing to its permanent deformation. If the circuit breaker comprising the bimetal is combined with an electromagnetic tripping means, heavy current such as short-circuit current flows temporarily through the bimetal. The bimetal, thus, is subjected to heat shock, which results in a permanent deformation of the bimetal owing to its balance or contact with the other mechanism, thereby requiring frequent adjustment of the dial each time the circuit breaker is used.

The circuit breaker according to the invention can obviate the above disadvantages due to the heat shock of the bimetal without necessitating any special mechanism such as the electromagnetic tripping means and any complex structure such as a plunger with oil damping type circuit breaker. The circuit breaker according to the invention operates very rapidly based on the magnetic snap action of the switching element itself, so that a number of short circuits can positively be cut off within any desired minimum duration without impairing the reverse time limit character.

The no-fuse circuit breaker having the current rating of the order of 5 A.–30 A. shown in FIGS. 1 and 2 is suitable for a switch embedded in the wall in case of household and factory wirings. The no-fuse circuit breaker having the current rating of the order of 30 A.–300 A. shown in FIGS. 3–6 is far superior in character if compared with the conventional no-fuse circuit breaker and can be applied to the temperature relay, fire detector, D.C. reverse current relay, A.C./D.C. over current relay, short-circuit protective relay, over heat protective relay, magnet valve etc.

In the present invention, the pole face of the permanent magnet having the thermal reversible property is provided with the magnetic shunt steel and yoke or the soft ferrite and yoke or with the yoke only and makes use of the synergetic effect of the thermal reversible change of the magnetic force of the permanent magnet and of the change of the thermal reversible permeability of the magnetic shunt steel or soft ferrite or the sole thermal reversible effect of the magnetic force of the permanent magnet. In the magnetic circuit constructed as above mentioned is heated directly or indirectly by the current flowing through the conductive path inclusive of the switching contacts, the magnetic force decreases in inverse proportion to the time elapsed, so that the attractive force of the magnetic circuit heated to a temperature corresponding to the suitable current value and the pulling force of the main spring becomes unbalanced with the attractive force of the magnetic circuit whereby to open the contacts. Thus, the no-fuse circuit breaker according to the present invention makes it possible to operate the responsive element in response to the magnetic force to be produced at any desired temperature in a rapidly snap manner, so that it is particularly suitable for opening the electric contacts.

The reason why the minimum time limit character of the no-fuse circuit breaker according to the invention can be obtained will now be explained. If the heavy current such as short-circuiting current flows through the heater **39** which is in parallel with and separated from the magnetic pole of the magnetic circuit, the magnetic fields produced inter link each other. The magnetic field produced by the permanent magnet is constant and similar to the magnetic field condition produced by D.C. except its transient phenomena. If heavy A.C. current flows through the heater, the magnetic fields produced by this A.C. current and those produced by the permanent magnet mutually react each other, thereby producing repulsive force or attractive force between the heater and the magnetic circuit. This causes disturbance in the permeability of the magnetic shunt steel or of the soft ferrite to cancel the magnetic flux in one direction while increasing the magnetic flux in the opposite direction. This increase of the magnetic flux reaches the magnetic saturation point owing to the character of the magnetic shunt steel or of the soft ferrite. The alternating magnetic field induces in the armature eddy current which produces magnetic flux to be added to the magnetic flux produced by the permanent magnet. If the armature is used as a part of the magnetic circuit and subjected to the pulling force thereof, this pulling force and the attractive force of the spring acting upon the armature become unbalanced to operate the knob, thereby opening the electric contacts. The minimum time limit character of the no-fuse circuit breaker according to the present invention may also be obtained by causing the direct current to flow through the heater and by determining the direction of flow by properly selecting the polarity of the terminals.

The reason why use is made of the magnetic breaking mechanism in place of the bimetal will now be explained. The time delay character of the bimetal is attained by the use of the mechanical flexure displacement produced in response to the temperature rise or drop of the bimetal. The time delay character is called also as reverse time limit which means that the more the driving force is increased the lesser the time required to initiate the operation.

The permanent magnet has two different effects of non reversible and reversible changes of the magnetic flux density in dependence with the temperature change.

In the present invention the magnetic character of the magnet that its coercive force or residual magnetism is reversibly increased or decreased with respect to the

change of temperature is combined with the magnetic character of the magnetic shunt steel or of the soft ferrite that the magnitude of its permeable flux is increased or decreased in dependence with the change of temperature or use is made of the reversible character only of the permanent magnet that its coercive force or residual magnetism is increased or decreased in dependence with the change of temperature in order to obtain the reversible character of the increase or decrease of the flux with respect to the temperature rise or drop, thereby obtaining the reverse time limit character. The demagnetizing factor-temperature characteristic curve of the permanent magnet such, for example, as barium ferrite magnet having compositions of $BaO \cdot 6Fe_2O_3$ is shown in FIG. 7 in which either one of the two directions of the change of the demagnetizing factor is shown by the arrows.

The inventor has found out by the test of such barium ferrite magnet that if this magnet is subjected to certain heat treatment it shows the reversible change at a temperature range between +350° C. to −50° C.

FIG. 8 shows one example of a reverse magnetic change factor-temperature characteristic curve of a magnet made of Alnico V lying in a temperature range between −60° C. and +100° C., the test being carried out for a magnet having a length to diameter ratio of 4:1. A representative composition of the Alnico V is 24% of Co, 14% of Ni, 3% of Cu, 8% of Al and the remainder of Fe. The Curie point is about 450° C. for barium ferrite and about 860° C. for the magnet of the Alnico V. The important point of the present invention is that use is made of the magnetic reversible character of the magnet instead of the Curie point thereof.

In considering FIG. 8, it must be remembered that FIG. 8 does not indicate a Curie point at 20° C., but only a flux point in the demagnetizing factor curve at 20° C.

The magnetic shunt steel used in the present invention is steel containing about 29% of Ni and having a temperature character in which the saturated magnetic flux density decreases in accordance with the temperature rise. Such magnetic shunt steel has heretofore been used for the temperature compensation of the magnetic circuit.

FIG. 9 shows a permeable magnetic flux density-temperature characteristic curve of the magnetic shunt steel containing 29% Ni and having a coercive force of about 6 oersteds, the curve being measured in an electric field of 200 oersteds.

If the magnetic circuit consisting of a permanent magnet having the above mentioned reversible character with respect to the temperature and of the magnetic shunt steel or soft ferrite or consisting of the permanent magnet and its yoke is subjected to the temperature change by means of an electric current heating means, the amount of heat generated is determined by I^2R in which I is current flowing through the conductive path from one of the breaker terminals to the other terminal and R is the resisance of the heater included in the conductive path when the temperature of the magnetic circuit is raised, the magnetic flux density is decreased in accordance with this temperature rise. The heavier the current, the shorter the time required for the temperature rise. Thus, the increase of the current causes the elevation of the temperature which then serves to decrease the magnetic flux density. The time required to decrease the magnetic flux density to any desired given amount in accordance with the increase of the current becomes shortened, thereby obtaining the reverse limit time character or delay time character. Since this character is of thermal reversible change, this principle may be applied to various kinds of machines and instruments. The inventor has applied said principle to a miniature type switch or a no-fuse circuit breaker, which permits it to effect the role of the delay time circuit breaker for heavy current and of a breaker for heavy current shock during short circuiting.

The automatic circuit breaker embodying the present invention comprises a magnetic circuit consisting of a permanent magnet, magnetic shunt steel or soft ferrite and a yoke or consisting of a permanent magnet and a yoke, a part or whole of said magnetic circuit being constituted by a movable mechanism. The driving force to be applied to this movable mechanism is assumed to be F_0 and provision is made for a heating means for directly or indirectly heating the magnetic circuit near the latter.

In the circuit breaker as above mentioned, if the movable part of the magnetic circuit is subjected to a given temperature or the force F_0 which is in balance with the attractive force produced by the magnetic flux density of the magnetic circuit corresponding to the above temperature, the heat generated by the current and conducted to the magnet serves to elevate its temperature. When the temperature of the magnetic circuit reaches the given temperature, the force applied to the movable part becomes unbalanced with F_0, so that the movable part is reversed in position by the spring force to rapidly open the electric contacts. A relation between the attractive force subjected to the movable part and the temperature is shown in FIG. 10. FIG. 11 shows an electric equivalent circuit for the magnetic circuit consisting of the permanent magnet and of the magnetic shunt steel, where M_0 represents the internal magnetomotive force of the magnet, R_0 the internal resistance of the magnet, Rg_1, Rg_2 the equivalent resistance of the magnetic shunt steel. The present invention makes use of the reverse character of the change of Rg_1, Rg_2 and of the change of M_0 with respect to the change of temperature, which causes the change of the magnetic flux density of the magnetic circuit consisting of M_0–R_0–Rg_1–Rg_2. Thus, the change of the attractive force or the repulsive force due to the change of the magnetic flux becomes unbalanced with the driving mechanism such as the spring, thereby producing the mechanical operation for carrying out the switching operation.

In the present invention, the movable part is subjected to the force F_0 which is in balance with a suitable temperature which is higher than the saturation point of the temperature rise of the magnetic circuit at more than 100% of the current value. The temperature rise range of the heater is selected by the amount of heat generated I^2R for the passed current. If the current capacity to be generated at the magnetic circuit is properly determined, an excellent reverse time limit character necessary for the no-fuse circuit breaker can be obtained. FIG. 12 shows a time-current characteristic curve for the circuit breaker embodying the invention and having a current capacity of 10 A. In this circuit breaker, the compensation for the atmospheric temperature may be carried out by a combination of the bimetal **60** and the main spring **19**, which permits the circuit breaker to operate for a wide temperature range and within the shortest time duration. The inventor has proved theoretically and experimentally the above fact.

In FIGS. 13*a* and 13*b*, if the overload current flows through the heating conductor **9** which is parallel to the air gap forming side edge of the yoke **13**, and perpendicular to the magnetic lines of forces produced by the permanent magnet **12**, the yoke **13** and the permanent magnet **12** are heated by this overload current. The magnetization of the permanent magnet **12** or the permeability of the yoke **13** made of magnetic shunt material or soft ferrite is decreased in response to the temperature rise thereof, so that the attractive force F acting on a point P on the armature **17** and hence its downwardly acting magnetic component force F_v becomes less than the spring force F_0 of the main spring **19** ($F_v < F_0$). The knob **2** is, thus, caused to be rotated in a clockwise direction to retract the switching arm **24** from the movable contact **7**, thereby opening the main contacts **6** and **7** with the aid of the spring action of the movable contact **7**.

In FIGS. 13*a* and 13*b*, if the short-circuit current flows in a direction shown by an arrow α during a positive half cycle through the heating conductor **9** which is perpendicular to the direction of the magnetic lines of forces produced by the permanent magnet **12** in the air gaps G_1 and G_2, this short-circuit current reacts with the magnetic fields produced by the permanent magnet **12**, which results in an application of forces f_1 and f_2 ($f_1 > f_2$) against the armature **17** in opposite directions. This produces a downwardly acting magnetic component force F_v due to the magnetic force F produced by the permanent magnet **12** at any point P on the plane of the armature **17**. If $f_1 + F_0 > f_2 + F_v$ (F_0 is a downwardly acting force of the main spring **19**), the knob **2** rotates in a clockwise direction to retract the switching arm **24** from the movable contact **7**, thereby opening the main contacts **6** and **7** with the aid of the spring action of the movable contact **7**.

If the short-circuit current flows in a direction shown by an arrow β during a negative half cycle through the heating conductor **9** which is perpendicular to the direction of the magnetic lines of forces produced in the air gaps G_1 and G_2 by the permanent magnet **12**, this short-circuit current reacts with the magnetic field produced by the permanent magnet **12**, which results in an application of forces $f_{1'}$ and $f_{2'}$ ($f_{2'} > f_{1'}$ for the air gap G_2< the air gap G_1) against the armature **17** in opposite directions. If $f_{2'} + F_o > f_{1'} + F_v$, the knob **2** rotates in a clockwise direction to retract the switching arm **24** against its spring action, thereby opening the main contacts **6** and **7**.

If the overload current or the short-circuit current ceases to flow through the heating conductor **9**, all of f_1, f_2, $f_{1'}$ and $f_{2'}$ become zero and $F_v > F_o$, so that the knob **2** is rotated in a counterclockwise direction, thereby closing the main contacts **6** and **7** with the aid of the switching arm **24**.

Though the invention is described by means of embodiments as shown in the drawings, yet various modifications can of course be made without departing from the scope of the following claims.

What I claim is:

1. A circuit breaker comprising conductor means, switching means movable to complete a circuit through said conductor means in one position thereof and to interrupt a circuit through said conductor means in another position thereof, first means biasing said switching means toward said one position, second means biasing said switching means toward said another position, said first biasing means including magnet means, said switching means including armature means normally attracted by said magnet means, and means responsive to overload current in said conductor means for reducing the biasing effect of said magnet means to the extent that the biasing effect of said second biasing means becomes greater than the biasing effect of said first biasing means under conditions of overload current thereby to move said switching means from said one position to said another position to interrupt said circuit, said reducing means comprisng means in said circuit for applyng the magnetic flux of short-circuit current to said armature means in a direction at least partially to counter the flux of said magnet means.

2. A circuit breaker as claimed in claim **1**, said magnet means having reduced permeability at elevated temperature, said reducing means comprising electric resistance heater means in said circuit for heating said magnet means.

References Cited by the Examiner

UNITED STATES PATENTS

2,182,864	12/1939	Frank	200—88
2,184,372	12/1939	Von Hoorn	200—88
2,751,483	6/1956	Keen, et al.	200—88 X

BERNARD A. GILHEANY, *Primary Examiner.*

ROBERT K. SCHAEFER, *Examiner.*

ROY N. ENVALL, *Assistant Examiner.*