

[54] **CRYOGENIC FUSE**

[72] Inventor: **Miner S. Keeler, II**, 2525 Indian Trail S.E., Grand Rapids, Mich. 49506

[22] Filed: **Aug. 18, 1971**

[21] Appl. No.: **172,714**

[52] U.S. Cl. .... **317/13 D, 307/245, 307/306, 317/40 A**

[51] Int. Cl. .... **H02h 3/08**

[58] Field of Search .... **317/13 D, 40 A; 307/245, 306**

[56] **References Cited**

**UNITED STATES PATENTS**

|           |        |               |           |
|-----------|--------|---------------|-----------|
| 3,202,836 | 8/1965 | Nyberg .....  | 307/245 X |
| 3,384,762 | 5/1968 | Mawardi ..... | 307/245   |
| 3,579,035 | 5/1971 | Burnier ..... | 317/13 D  |
| 3,581,113 | 5/1971 | Kafka .....   | 317/13 D  |

*Primary Examiner*—James D. Trammell

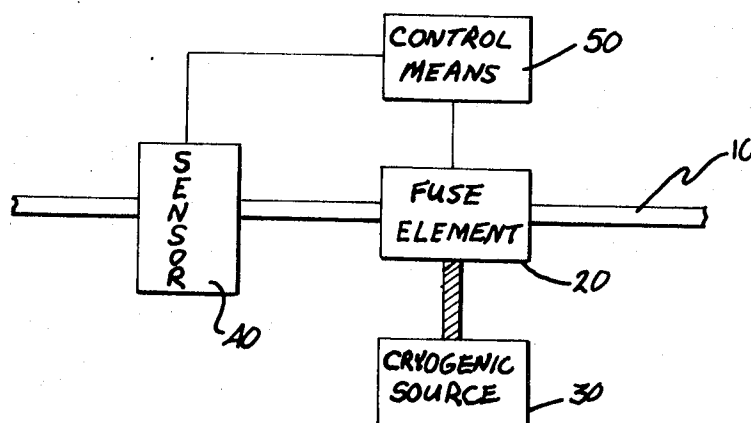
*Attorney*—Price, Heneveld, Huizenga & Cooper

[57] **ABSTRACT**

A fuse element is manufactured of lead or other suitable

material displaying superconductive properties at very low temperatures. A fuse including such an element is employed in a high voltage transmission line by serially inserting the fuse element in the line and maintaining the element in its superconductive state by using a liquified gas to cool the element during normal current levels. A sensor is provided which develops a control signal in the event excessive current levels are reached. The control signal is applied to control means which automatically vents the fuse by allowing the coolant to escape and thereby raises the temperature of the fuse such that its normal resistivity returns. The resulting  $I^2R$  heat developed within the element due to the current flow therein will cause the element to immediately vaporize thereby opening the circuit. In other embodiments the control signal can be employed to provide power to a heating element mounted in thermal proximity with the fuse element to increase its temperature in the event of excessive current. Also the control signal can be employed to cause a magnetic field to be developed which causes the fuse to return to its normal resistivity. The fuse and its related circuitry can be designed to provide either a fast-blow or a slow-blow operating fuse.

**19 Claims, 4 Drawing Figures**



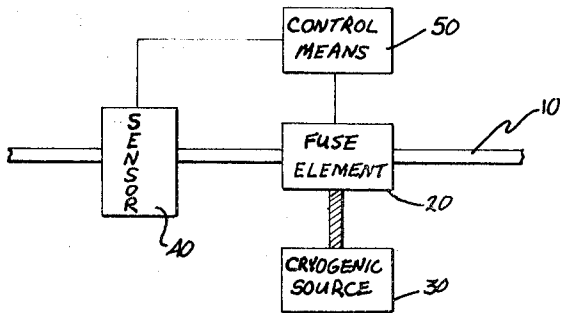


FIG. 1.

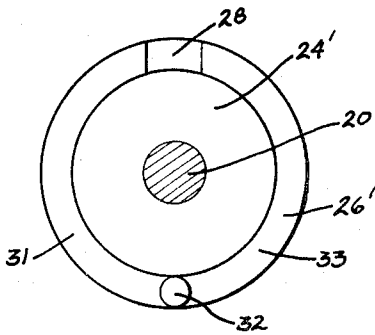


FIG. 3.

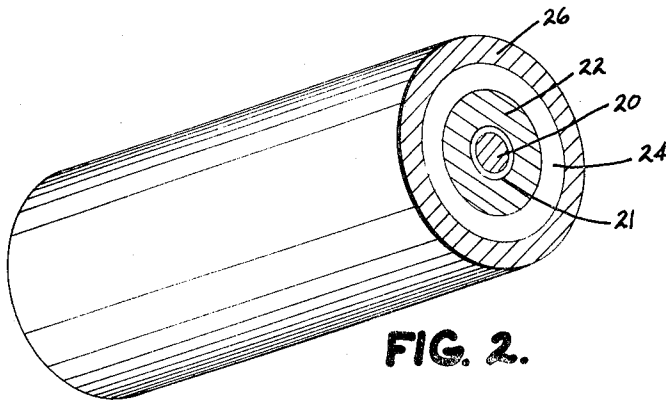


FIG. 2.

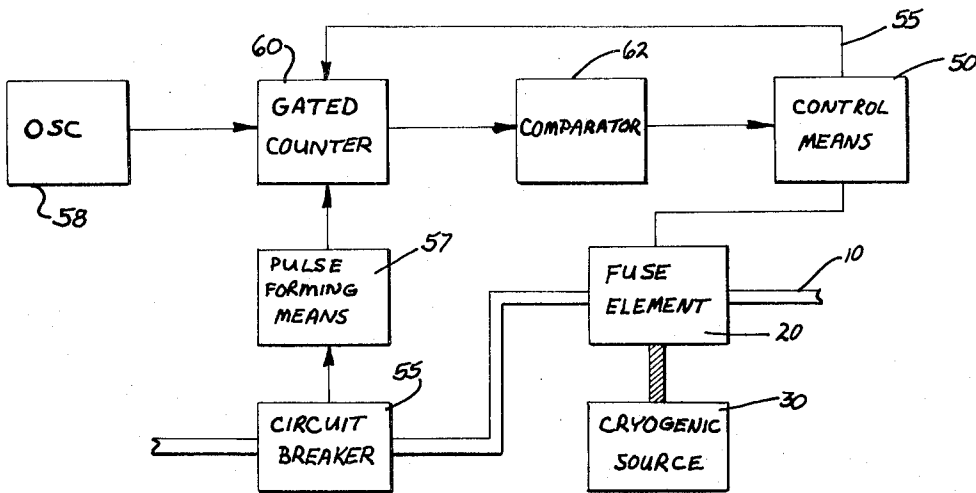


FIG. 4.

## CRYOGENIC FUSE

## BACKGROUND OF THE INVENTION

The present invention relates to fuses and particularly to a fuse suitable for use in a high voltage transmission line which employs a cryogenic source to maintain a normally resistive element in a superconductive state during normal current levels.

Present commercially available circuit breakers for use with high voltage transmission lines are extremely costly due to the complexity of their manufacture which is necessitated by the requirements of reliability of operation under various environmental conditions as well as operating conditions. During electrical storms when voltage or current surges on a transmission line can become rather severe, the circuit breakers have a tendency to interrupt momentarily thereby producing high transient voltages and currents along the transmission line which in some instances can produce considerable damage to transformers or the like. It is desirable, therefore, to provide a relatively inexpensive circuit interrupting means which is positive and fast acting in the event of an excessive current surge thereby eliminating additional current and voltage pulses caused by the presently available circuit breakers themselves. A conventional fuse cannot be employed since the magnitude of current necessary to be carried during the normal operation would necessitate a relatively large fuse element which would not vaporize immediately and thereby interrupt the circuit under overload current conditions. The fuse of the present invention, however, employs the superconductive properties of a material such that the fuse element made of this material will have extremely low conductivity when held in its superconductive state by a cryogenic liquid and which can be rapidly returned to its normal conductivity state in response to excessive current or voltage surges along the transmission line. When inserted in series with the transmission line therefore, the fuse element of the present invention will provide a conduction path which does not interfere with the normal operation of the line. In the event of excessive current flow, however, the fuse element is returned to its normal conductivity state and provides a relatively high resistance. The resulting  $I^2R$  heat rise in the fuse element due to the current therethrough will be sufficient to immediately vaporize the element thereby opening the circuit.

## SUMMARY OF THE INVENTION

A fuse embodying the present invention comprises a material displaying superconductive properties at extremely low temperatures and relatively high resistance properties at temperatures above its superconductive temperature region. A source of cryogenic liquid is provided to maintain the fuse element in its superconductive state when permissible current levels are flowing therethrough. Additional means are provided for sensing excessive current levels and for returning the fuse element to its normal resistivity state such that it will vaporize due to the heat developed within the device by the current flowing therethrough.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates in block diagram form a fuse including a fuse element inserted in series with a transmission line and associated sensing and control means, and the cryogenic source used therewith;

FIG. 2 is a partial cutaway view of one embodiment of the present invention;

FIG. 3 is a cutaway end view of another embodiment of the present invention; and

FIG. 4 is a diagram in block form showing the use of the fuse of the present invention in conjunction with a conventional circuit breaker and the circuits for providing a control signal which will cause the fuse of the present invention to open in the event the circuit breaker has been interrupted in a predetermined manner.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT OF THE INVENTION

A conductor 10 of a transmission line is shown in FIG. 1. Inserted in series therewith is a fuse element 20 which can be manufactured of lead which displays superconductive properties at or below  $7.2^\circ\text{K}$ . A cryogenic source 30 is associated with the fuse element and supplies a liquified gas such as helium which has a temperature of  $4.2^\circ\text{K}$ . when in its liquid state and which will therefore, when adjacent the fuse element 20, hold the lead element in its superconductive state. Additionally shown in series with the transmission line 10 is a sensor 40 for sensing the level of current in the conductor 10. Although shown in series with the conductor, it is understood that the sensor need not be electrically coupled in series and may sense the current in the conductor 10 by inductive coupling to the magnetic field around the conductor.

The sensor 40 produces an output signal which is applied to a control means 50. The control means can operate in a variety of manners to respond to a signal from sensor 40 which is representative of an excessive current level in a conductor 10 to cause the normal resistivity of fuse element 20 to return. As this occurs, the element 20 is instantly vaporized due to the  $I^2R$  heat developed within the element due to the resistance (R) of the element. Two ways in which the control means can operate to provide this function are shown in FIGS. 2 and 3, respectively.

FIG. 2 shows a partial cutaway view of the fuse element 20 which is surrounded by an electrical insulator 21 and a heating element 22. The annular space 24 adjacent the heating element 22 is filled with the liquified helium and holds the fuse element 20 within the superconductive temperature ranges of lead from which it is made. A thermal and electrical insulating jacket 26 forms the outer surface of the structure. The heating element 22 adjacent the fuse element 20 can be of the woven conductor type which surrounds the fuse element 20 and which is responsive to current from the control means 50 to provide sufficient heat to raise the temperature of the lead fuse element 20 above  $7.2^\circ\text{K}$ .

In this embodiment (FIG. 2) the control means 50 includes a power source such as a battery pack capable of providing sufficient current to the heating element 22 and which is controlled by the signal from the sensor 40 such that current is applied to the heating element 22 in

the event of a current overload in conductor 10. When a current overload occurs, the lead fuse element 20 will be heated above its superconductive region and become relatively resistive. The transmission line current in conductor 10 which also flows through the fuse element 20 will therefore cause a power or  $I^2R$  loss within the fuse element 20 which will generate considerable heat and which will instantaneously vaporize the low melting point fuse element 20, thereby opening the electrical circuit in which the fuse element is placed. It is noted that the electrical insulating layer 21 between the fuse element 20 and heater element 22 must be sufficiently thermally conductive such that it will not interfere with the operation of the fuse.

The length of the thermal jacket and fuse element is dictated by the voltages present along the transmission line. It is necessary that when the fuse element 20 melts, a sufficient gap is formed to prevent breakover arcing which would ionize the surrounding atmosphere and provide a current path across the open fuse. In this regard, the ionization potential of helium is considerably greater than that of nitrogen, the main constituent of air. Thus, by employing helium or the cryogenic medium, the breakover arcing problem due to ionization is considerably reduced.

The control means 50 may include wave shaping and clipping circuitry to vary the shape of the signal from sensor 40. Circuit 50 also will include means for selectively operating the power source employed to activate the heater element 22. For example, a relay may be employed which couples the current from the power supply in the control means 50 to the heating element 22.

Instead of employing a heater element 22, an inductor wound around the fuse element 20 could be employed to provide a magnetic field which would return the element to its normal resistivity in the event of an overcurrent in conductor 10. This phenomenon is well known and will not be described in detail. It is necessary, however, that the magnetic field produced in the induction in response to current supplied thereto from the control means is sufficient to return the fuse element to its normal resistivity.

FIG. 3 illustrates an alternative embodiment of the present invention in which the cryogenic fluid itself is vented from the space between the conductor and the insulating jacket to cause a heat rise in the fuse element instead of applying heat or a magnetic field directly as shown in the embodiment of FIG. 2. In FIG. 3 the lead fuse element 20 is appropriately suspended within an annular shell 26' which is a thermal insulator comprising two halves 31 and 33 which are hingedly mounted by hinge means 32 shown at the bottom of the figure. The enclosure 26' is secured by controllable securing means 28 shown at the top of the figure. Cryogenic fluid in the annular space 24' surrounds the lead fuse element 20 and maintains the fuse element in its superconductive state during normal current levels in the conductor 10 (FIG. 1). In the event, however, that excessive current levels are detected by the sensor 40, the control means can develop a signal which is applied to the securing means 28 to thereby explosively or otherwise open the hinged portions 31 and 33 of the insulating shell 26' and vent to the atmosphere the high pressure cryogenic gas within space 24'. The securing

means 28 may comprise, for example, explosive bolts or the like which respond to an electrical impulse applied thereto by the control means 50 to instantaneously open the halves of the insulating shell. When so opened the temperature of the lead fuse element 20 will rapidly increase thereby rendering the element relatively resistive and as before, it will rapidly vaporize due to the  $I^2R$  heat generated therein.

In place of the securing means 28, an electrically operated valve could be installed on the jacket 26' such that in the event of an over current the valve would open to vent the cryogenic material. In such an arrangement, the hinge 32 would not be necessary.

The embodiments shown in FIGS. 2 and 3 can be mounted in series with the conductor 10 of the transmission line by any suitable means conventionally known in the art. The cryogenic source 30 may in some applications include suitable pump means for circulating liquified helium or the like around and through the fuse. Likewise, the cryogenic source may include a reservoir of such liquified material and the structure shown in FIGS. 2 and 3 may include appropriate means for venting gas vapors as the cryogenic liquid tends to boil off. The fabrication of such equipment is generally well known in the art.

FIG. 4 shows a fuse element and control circuits for providing a slow-blow mode of operation for the fuse. This arrangement may be used in conjunction with a conventional circuit breaker 55 as shown in the figure. In this arrangement an electrical connection is made between the circuit breaker 55 and a gated counter 60. In the event that momentary current surges occur which are not necessarily harmful but which tend to cause the circuit breaker 55 to chatter or otherwise open momentarily, the resultant current interruptions are detected by the circuit. Pulse forming means 57 coupled to breaker 55 provide pulses whose frequency and duration are directly related to the frequency and duration of the circuit breaker 55 interruptions. These pulses are applied to a control element on the gated counter 60 which is also supplied with clock pulses from an oscillator 58. Thus in the presence of the applied pulses from the pulse forming circuit 57 the counter 60 will count clock pulses from the oscillator. The resulting accumulated count represents the total interrupted time of circuit breaker 55 and is applied to a comparator 62.

The comparator is designed such that when the cumulative count from the gated counter 60 reaches a predetermined level the comparator develops a control signal which is applied to control means 50. Thus, when it is desired to cause the fuse element 20 to blow (i.e. open circuit) only after a predetermined number of interruptions of circuit breaker 55 or after a predetermined accumulated interruption time of the circuit breaker 55, the output pulse from comparator 62 is employed to cause the control means 50 to open circuit the fuse element 20 in the same manner described in conjunction with the apparatus shown and described in conjunction with FIGS. 1 through 3.

The control means shown in FIG. 4 additionally may include means for resetting the gated counter 60 periodically by coupling reset pulses to the counter via line 55. In the event that several momentary interruptions of the circuit breaker 55 occur which then cease,

the gated counter 60 can be reset such that the accumulated count over a predetermined period of time will not trigger the comparator 62 and blow the fuse. A suitable reset pulse generating circuit is included within the control means 50 to provide the desired periodic resetting of counter 60. Thus, only current surges on the transmission line which are of a magnitude and frequency against which protective action is desired will cause the fuse element 20 to open.

It is noted that the circuitry shown in FIG. 4 could likewise be used in the circuits shown in FIG. 1 whereby the circuit breaker 55 is eliminated from the circuit and replaced by the sensor 40 shown in FIG. 1. Thus it is seen that the cryogenic fuse of the present invention can be operated in either a fast-blow or slow-blow mode and either singly or in combination with a conventional circuit breaker.

Also it can be coupled in series with a circuit closing device where the voltages are sufficiently high such that the closing device fuses in the closed position due to arcing during closing and, thus, can not be reopened. The cryogenic fuse is then employed as a breaking device to open the circuit. Thus, it is seen that the fuse offers flexible operating characteristics for use in a variety of transmission line applications or in other environments.

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

1. A cryogenic fuse comprising:
  - a fuse element comprising a material displaying superconductive properties at low temperatures, and relatively high resistive properties at temperatures above the superconductive temperature region;
  - a source of cryogenic liquid;
  - means for supplying said cryogenic liquid in thermal communication with said fuse element thereby holding said fuse element in its superconductive state; and
  - means for returning said fuse element to the normal resistivity state in response to predetermined current levels such that said fuse element will vaporize due to heat produced in said fuse element by current flowing therethrough.
2. A fuse as defined in claim 1 wherein said returning means comprises means for venting said cryogenic liquid thereby allowing the temperature of said fuse element to rise above the superconductive temperature region.
3. A fuse as defined in claim 1 wherein said returning means comprises means for applying a magnetic field to said fuse element such that said element will return to the normal resistivity state.
4. A fuse as defined in claim 1 wherein said returning means comprises means for increasing the temperature of said fuse element comprising
  - sensing means for detecting the level of current in said fuse element and for providing signals representative thereof,
  - control means coupled to said sensing means and responsive to signals therefrom such that when excessive current levels in said fuse element are detected, said control means operates to raise the temperature of said fuse element above its superconductive temperature region.

5. A fuse as defined in claim 4 wherein said control means includes a power source selectively operated to apply power to a heating element placed in thermal proximity with said fuse element such that when said power supply is activated, said heating element will raise the temperature of said fuse element.

6. A fuse as defined in claim 5 wherein said fuse element comprises lead and wherein said cryogenic liquid comprises liquified helium.

7. A fuse as defined in claim 4 wherein said control means comprises an insulating sleeve enclosing said fuse element and cryogenic liquid, said sleeve comprising first and second portions hingedly mounted one to another at a first seam therebetween, and bonded to one another by securing means at a second seam thereof, said securing means being responsive to said signals indicating an excessive current level to explosively open said insulating shell thereby venting said fuse element to raise its temperature.

8. A fuse as defined in claim 7 wherein said fuse element comprises lead and wherein said cryogenic liquid comprises liquified helium.

9. A fuse as defined in claim 4 and including further means for selectively causing said fuse element to vaporize only after a predetermined current overload is detected by said sensing means.

10. A fuse as defined in claim 9 wherein said further means includes circuit means for providing a signal to said control means which indicate an excessive current only after a predetermined number of current overload pulses of predetermined duration have occurred.

11. A fuse as defined in claim 10 wherein said circuit means includes:

- a pulse generator,
- a gated counter coupled to said pulse generator and operative to count pulses from said generator only in the presence of a signal from said sensing means which indicates the presence of current overload pulses, said signal from said sensing means being applied to the control element on said gated counter, and
- comparator means coupled to said gated counter and to said control means for providing a signal to said control means when a predetermined number of said pulses from said pulse generator have accumulated in said counter.

12. A fuse as defined in claim 11 and further including means for periodically resetting said gated counter.

13. A fuse comprising a fuse element made of material displaying superconductive electrical properties below a predetermined temperature, said fuse element installed in series with an electrical conductor;

means for maintaining said fuse element below said predetermined temperature when electrical current of a normal level flows through said conductor;

sensing means for detecting an excessive current level in said conductor and for producing a control signal in response thereto; and

control means coupled to said sensing means and responsive to said control signal therefrom to raise the temperature of said fuse element above said predetermined temperature such that said fuse element becomes relatively resistive and vaporizes due to heat generated therein caused by the flow of current therethrough.

14. A fuse as defined in claim 13 wherein said main-  
taining means comprises: a source of cryogenic liquid,  
means for supplying liquid from said cryogenic source  
in thermal proximity with said fuse element, and insu-  
lating means surrounding said fuse element and said

15. A fuse as defined in claim 13 wherein said con-  
trol means comprises means for explosively removing  
said insulating means such that said cryogenic liquid  
will be vented thereby raising the temperature of said  
fuse element such that said material will return to its  
normal resistivity.

16. A fuse as defined in claim 15 wherein said  
material comprises lead and said cryogenic liquid com-  
prises liquified helium.

17. A fuse as defined in claim 13 wherein said con-  
trol means includes a power supply selectively operated  
to apply power to a heating element mounted in ther-  
mal contact with said fuse element.

18. A fuse as defined in claim 17 and further includ-  
ing sensing means for detecting excessive current in  
said fuse element and for providing a control signal in  
response thereto to selectively operate said power  
supply and thereby provide power to said heating ele-  
ment.

19. A fuse as defined in claim 5 wherein said insula-  
tor comprises a sleeve formed of first and second por-  
tions joined at a first seam thereof by hinge means, and  
said means for explosively removing said insulating  
means comprises securing means joining said first and  
second sleeve portions at a second seam, said securing  
means coupled to said sensing means and responsive to  
said control signals developed by said sensing means  
during current overloads to explosively separate said  
first and second sleeve portions in the event a current  
overload is detected.

\* \* \* \* \*

20

25

30

35

40

45

50

55

60

65