

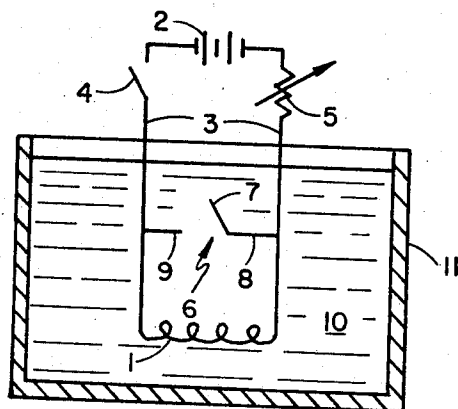
Oct. 24, 1967

J. L. ZAR
CRYOGENIC SWITCH

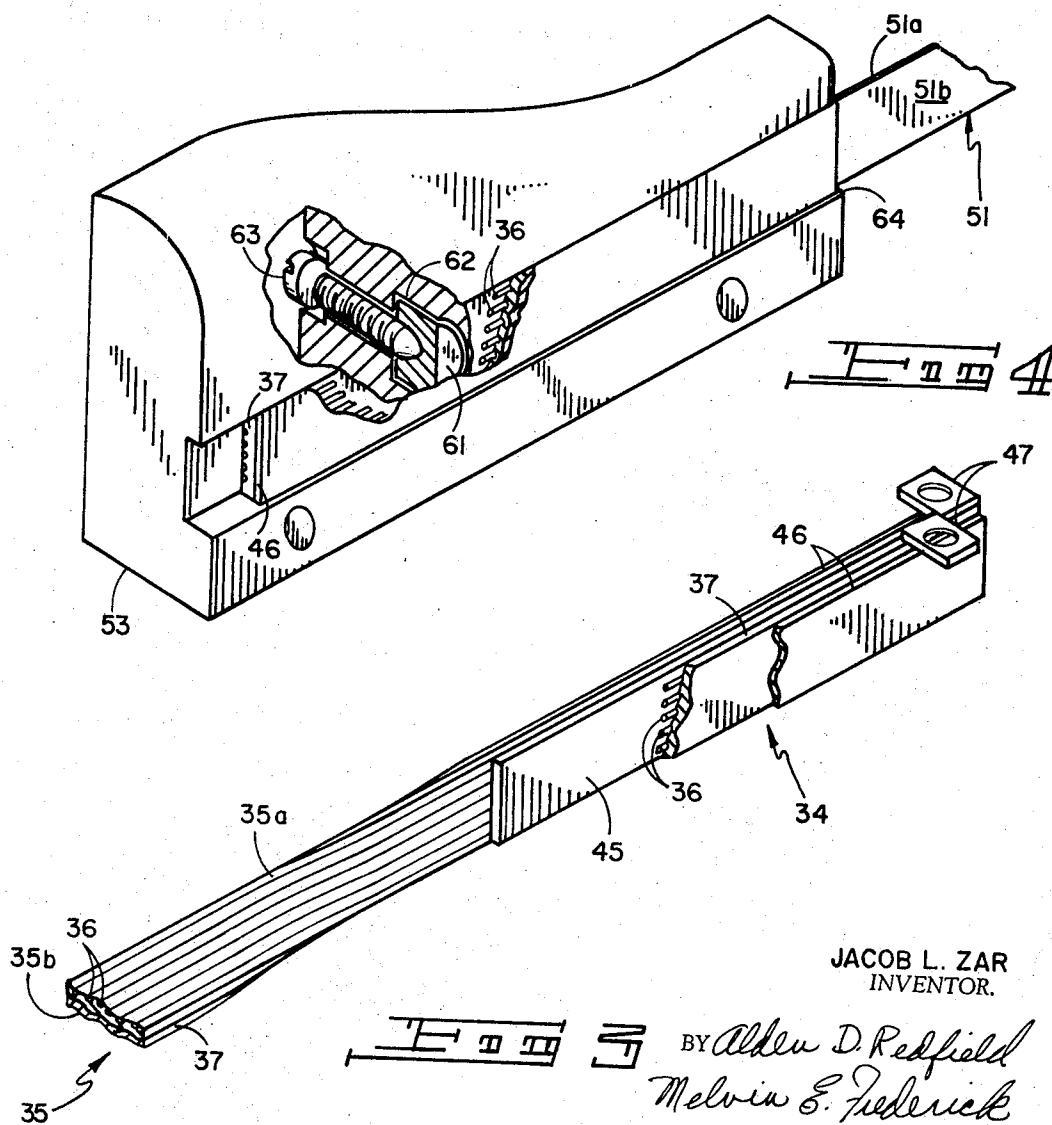
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3 Sheets-Sheet 1



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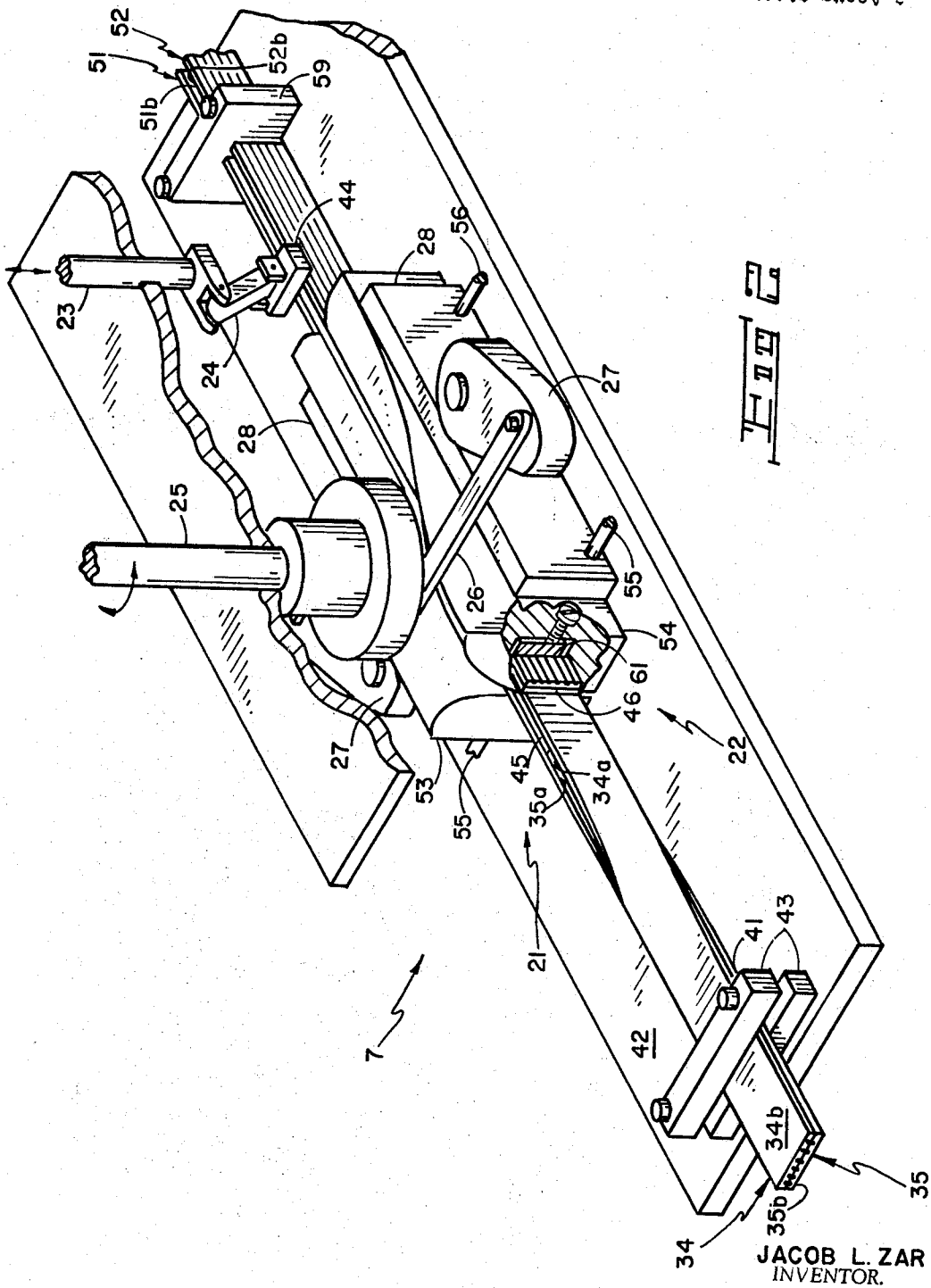
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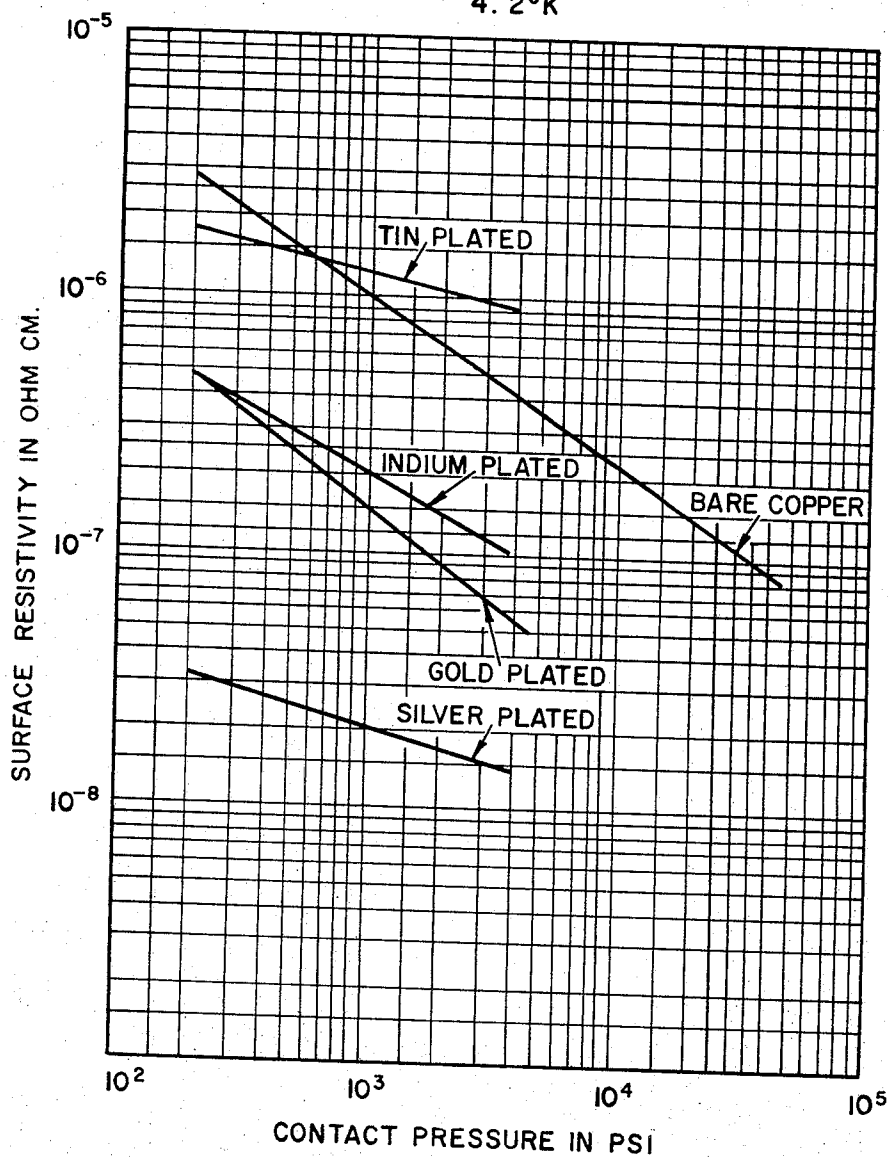
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CRYOGENIC SWITCH

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3 Sheets-Sheet 3

CLEAN SURFACE RESISTIVITY OF TWO STABILIZED SUPERCONDUCTORS IN CONTACT AT
4.2°K



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CRYOGENIC SWITCH

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13 Claims. (Cl. 200—166)

This invention relates to switches and in particular to switches mechanically operated at cryogenic temperatures such as the temperature of liquid helium.

Typical superconductive devices utilize superconducting conductors in various configurations. Most contemplated uses of such devices are dependent upon the creation of a magnetic field of some magnitude, and in many cases necessitate the flow of currents of as much as 600 amperes or more.

Thus, in the case of superconducting coils which comprise the majority of present day superconductive devices, the coil is generally connected to a direct current external power source by leads which, at least in the vicinity of the coils, are superconducting. Where it is desired to establish a persistent current in the coil, the superconducting leads are connected by a superconducting shunt. When the coil is being charged, the shunt is driven normal and when it is desired to establish a persistent current, the shunt is permitted to become superconductive. In such coils and particularly coils for providing high magnetic fields, the losses originating not only in the power leads that conduct the current from the external circuit to the coil but also the normally superconducting shunt, often represent the principal sources of energy dissipation in the system. Thus, by short circuiting the coil after the desired magnitude of current flow has been established, this current flow can persist for an indefinitely long time. After the superconducting shunt has been established the current from the power supply may be reduced to zero, thereby eliminating the Joule heating in the power leads. Alternately, since the power leads themselves are no longer required to maintain the current, they may be physically removed if desired.

Where the shunt is driven normal by thermal means, the heat generated in the superconducting environment is greatly increased. However, in prior art shunts, which comprise a resistive but unbroken circuit during charging or discharging of the coil, some current will flow in the shunt during charging or discharging and thereby create Joule heating in the shunt. This is due to the low ratio of resistance of the shunt to the coil impedance. The present invention, when used as a shunt, provides for all practical purposes a shunt whose resistance is negligibly small during normal operation while eliminating the generation of heat in the shunt during start up and shut down of the coil.

While the present invention will be explained for convenience in connection with superconducting shunts, it is to be understood that it is not so limited. For example, in the operation of a flux pump which comprises means for magnetically inducing a persistent current flow in a superconducting coil or the like, two switches in accordance with the present invention may be used to permit an increment of current in the flux pump to be added to the current previously built up in the coil that is being charged. Heretofore, it has often been customary to use heaters to drive a portion of the superconducting circuit normal for this purpose. The use of a switch in accordance with the present invention results in a savings in heat energy that is dissipated in the low temperature environment if a thermal switch is used and can permit the reduction in time required for each cycle of the flux pump. Further, in energy storage coils of the superconducting type, it is often desirable to have a switch which

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functions as a low resistance shunt to short circuit the coil so as to allow the magnetic energy to be stored until required in an external circuit and as an open circuit when the energy stored in the coil is delivered to the external circuit. When the switch is opened to permit discharge of the coil, it must not only have a high impedance (preferably infinite), but be capable of withstanding the voltages produced during the discharge. A switch in accordance with the present invention may be used for such purposes at it has good insulation in the open condition and will withstand transient voltages without breakdown.

In accordance with the preferred embodiment of the present invention, there is provided in a switch a switch block member including superconducting wires embedded in a first flat conductor of normal metal, such as for example copper, the exposed surface of which preferably comprises a thin coat of silver; a switch blade member including a second flat conductor substantially the same as the first mentioned conductor, the silver coated face of which is adapted to be brought into register with the silver coated face of the first conductor; and actuating means for moving at least one of the conductors and bringing at least a substantial portion of the silver coated surfaces into contact with each other under pressure.

Accordingly, it is an object of the present invention to provide an improved electrical switch.

It is another object of the present invention to provide a switch which operates at superconducting temperatures.

It is a further object of the present invention to provide a switch which operates mechanically in a superconducting environment.

It is a still further object of the present invention to provide a switch which for all practical purposes eliminates Joule heating in superconducting shunts.

It is another object of the present invention to provide a switch which eliminates the necessity of using heaters in a superconducting environment to drive a portion of a superconducting circuit normal and/or the generation of heat in a portion of a superconducting circuit which has been purposely driven normal by either thermal or non-thermal means.

The novel features that are considered characteristic of the invention are set forth in the appended claims; the invention itself, however, both as to its organization and method of operation, together with additional objects and advantages hereof, will best be understood from the following description of the specific embodiments when read in conjunction with the accompanying drawings, in which:

FIGURE 1 is a sectional view including a schematic representation of a superconducting coil and is illustrative of the use of the present invention;

FIGURE 2 is a perspective view with parts broken away of a switch incorporating the present invention;

FIGURE 3 is a view showing details of the switch blade member shown in FIGURE 2;

FIGURE 4 is a view showing details of the switch block member shown in FIGURE 2; and

FIGURE 5 is a log-log graph illustrating the variation of surface resistivity with change in pressure for various metals forming the contact surfaces of two stabilized superconductors in contact at 4.2° K.

Referring now to FIGURE 1, there is shown a superconducting coil 1 connected to an external power source, such as a battery 2, by means of leads 3, switch 4 and variable resistor 5. Resistor 5 permits the current from the power source to the coil to be varied. Shunt 6 comprising switch 7 and leads 8 and 9 are connected across coil 1. Coil 1 and shunt 6 are maintained at a temperature below the critical temperature of the superconducting material in coil 1 and shunt 6 by suspending them in

a low temperature environment 10 such as liquid helium contained in a Dewar flask 11.

Coil 1 may be formed of a superconductive wire material exhibiting the requisite critical field and superconductor characteristics for the intended use. Advantageously, superconducting coils are formed of a single strand of a superconducting wire. The consideration dictating the choice of the material for leads 3 are understood by the art. In general, those portions of leads 3 from shunt 6 to coil 1 are formed of a suitable superconducting wire material capable of sustaining the same current flow as the coil. Those portions of leads 3 from the external power source 4 to shunt 6 not suspended in the lower temperature environment are advantageously formed of a low resistance material such as copper which exhibits a lower resistance than the typical superconducting materials in a normal state. Persistent current is established in coil 1 by opening switch 7 and closing switch 4 and varying resistor 5 to establish the desired current flow through coil 1. Thereafter, closing switch 7 and opening switch 4 will result in the establishment of a persistent current through the coil 1, the shunt 6 and the interconnecting portions of leads 3.

FIGURE 2 illustrates a particular embodiment of the switch 7 in the shunt configuration of FIGURE 1. The embodiment is predicated on the desirability of being able to provide in a superconductive shunt a switch that is not only capable of carrying high currents of the order of hundreds of amperes with negligibly small losses but one that can be switched to a completely nonconductive state without the application to or generation of heat in the switch. These considerations dictate the use of a mechanically actuated switch having essentially superconductive characteristics in its closed or current conducting position. Accordingly, the switch is comprised of a switch blade member 21, details of which are shown in FIGURE 3, a switch block member 22, details of which are shown in FIGURE 4, adapted to receive and grip the switch blade member 21, a plunger 23 and a link 24 for bringing the switch blade member into register with the switch block member, and a shaft 25, links 26, cams 27, and pressure plates 28 for bringing the electrically conductive portions of the switch block member and the switch blade member into contact with each other under pressure.

The switch blade member 21, as shown in FIGURE 2 and FIGURE 3, includes two conductors 34 and 35 comprising superconductive material 36 in the form of a plurality of wires embedded in a ribbon 37 of normal metal, such as copper, to provide a "stabilized" superconductor.

A "stabilized" superconductor is one which returns to the superconducting state upon termination of a disturbance that has driven it normal, either self-generated (such as a flux jump) or externally generated (vibration, rapid external field change, temporary excess in current, etc.) without requiring a reduction in excitation current. Broadly, a stabilized superconductor may be provided by disposing superconductive material in good electrical and thermal contact with a substrate whose voltage-current characteristic is that of a simple resistance, the amount of substrate depending on the degree to which the conductor is cooled. Typically, the total cross section of the substrate is substantially greater than that of the superconductive material.

The conductors as shown in FIGURE 2 may, for example, comprise nine copper coated niobium-zirconium wires having a diameter of about 10 mills embedded in a copper ribbon .50" wide x .040" thick and annealed at about 560° C. for about one hour. For a more complete discussion of suitable stabilized superconductors and the fabrication thereof, reference is made to patent application Ser. No. 383,392, filed July 17, 1964, and assigned to the same assignee.

The switch blade member comprising the above described conductors is fixedly attached at 41 to the base 42

as by electrically nonconductive plates 43 and at the other end to the plunger 23 through plate 44 and link 24. The inner grooved surfaces 34a and 35a of the portion of conductors 34 and 35 adapted to fit in the switch block member are bonded as by soft soldering to a metallic strengthening member 45 which is provided to prevent bending or twisting of the conductors adjacent the aforementioned switch block member.

It should be noted that the conductors 34 and 35 are twisted approximately 90° to permit the switch blade member to be moved into and out of the switch block member 22 by plunger 23. It should also be noted that the smooth or ungrooved surfaces 34b and 35b of conductors 34 and 35 are exposed and at least adjacent the switch block member are preferably covered as by conventional electroplating techniques with a thin layer of silver 46. The extreme end of the strengthening member 45 adjacent plunger 23 is provided with ears 47 which are attached as by screws to plate 44. As shown in FIGURE 2, link 24 which is electrically nonconductive is pivotally connected between plate 44 and plunger 23 to permit the switch blade member 21 to be moved into and out of electrical contact with the switch block member 22. Due to the aforementioned 90° twist in conductors 34 and 35, the switch blade member pivots at a point adjacent plates 43 without necessitating a break or interruption of the superconductors.

Directing attention now to the switch block member 22, as shown in FIGURE 2 and FIGURE 4, it will be seen that conductors 51 and 52, which are substantially identical to the conductors of the switch blade member, are respectively carried by oppositely disposed electrically nonconductive blocks 53 and 54 which in turn are movably carried on rods 55 and 56 to permit the blocks 53 and 54, and hence, conductors 51 and 52, to move away from and toward each other, whereby the exposed smooth surfaces 34b and 35b of conductors 34 and 35 may be caused to engage and contact the exposed smooth surfaces 51b and 52b respectively of conductors 51 and 52. The portion of conductors 51 and 52 remote from blocks 53 and 54 are fixedly held and attached to the base by electrically nonconductive support 59. It is significant to note that the smooth surfaces 51b and 52b of conductors 51 and 52 are also coated with, for example, silver, and are respectively parallel with and oppositely disposed from respectively the smooth surfaces 35b and 34b of conductors 35 and 34 when the switch blade member 21 is in the closed or down position. As best shown in FIGURE 4, each conductor 51 and 52 is bonded as by soft soldering two or more metallic holder plugs 61 which are disposed and held in recess 62 by screws 63.

The upper portion of each block 53 and 54 is outwardly beveled to function as guides for the switch blade member and are provided with oppositely disposed shoulders 64 which function as stops to limit the downward travel of the switch blade member such that the conductors 34 and 35 comprising the switch blade member 21 are in substantial register with the conductors 51 and 52 comprising the switch block member 22 when the switch blade member 21 is in its down position.

Shaft 25, cams 27 and links 26 interconnecting shaft 25 and cams 27 function in a conventional manner to bring at least a substantial portion of the conductors 34 and 35 into contact with conductors 51 and 52 under pressure when the switch blade member 21 is in its down position.

As will now be obvious from the preceding description, in order to actuate the switch from its open to closed position, plunger 23 is pushed toward base 42 to bring conductors 34 and 35 of the switch blade member 21 into register with conductors 51 and 52 of the switch block member 22. Thereafter, shaft 25 is rotated to actuate cams 27 and through pressure plates 28 force the blocks 53 and 54 toward the switch blade member 21 thereby bringing at least a substantial portion of the exposed

surfaces of the conductors into good contact with each other under pressure and lock them in this position. The switch is opened by simply reversing these steps. The blocks 53 and 54 may be spring loaded (not shown) to urge them away from the switch blade member 21 when in the unlocked position to eliminate or at least reduce sliding contact between the conductors when the switch blade member is being moved toward or away from its closed or down position. Further, it is not essential that a switch in accordance with the present invention utilize electrically conductive portions (conductors 34, 35, 51 and 52) having the specific configuration shown or use the actuating mechanism shown and described. For example, the switch blade and switch block member may each be provided with a single stabilized superconductor (two conductors merely provide maximum contact surface), actuation of plunger 23 and shaft 25 may be effected by a single operation, or alternately, rather than being moved in a direction parallel to their contacting surfaces as shown in FIGURE 2, one or more stabilized superconductors may be arranged to move in a direction normal to their contacting surfaces (thereby eliminating the necessity of a 90° twist as shown in FIGURE 2) to provide open and closed switch positions.

Since the electrically conductive portions of the switch blade and switch block members each contain superconductive material, the only resistance in the switch is in the resistance of the normal material between the superconductive material and the surface resistivity at the contacting portions of these conductors. Thus, in order to have as smooth a surface as possible between the electrically conductive members, these members are preferably arranged as shown and described so that the substrate sides of the stabilized conductors are in contact. In other words, the side containing the superconductive wires or superconductive strip, as the case may be, face away from the contact surfaces which should be clean before immersion in the superconducting environment.

Reference is now made to FIGURE 5 which illustrates the resistivity of the surfaces between two stabilized conductors at superconducting temperatures wherein the bulk material is copper and these conductors in all but one case are covered with various coatings on their contacting surfaces. All of the curves show that the surface resistivity decreases with the application of pressure. The explanation for this is that the current is conducted across the contacting surfaces through a series of small contact areas. Thus, the cross section for the conduction of current is much less than that of the full contact surface. Under the application of pressure, the areas of contact increase and the resistance of the surface is reduced.

In view of the preceding discussion, the desirability of minimum contact resistance will be evident. However, the choice among metals is not obvious since minimum surface resistivity is required at close to absolute zero temperatures. For example, at these temperatures metals become harder and if the surface is in the nature of a semiconductor, its resistance increases as compared to that at room temperature. Therefore, surfaces which have been found satisfactory for construction of switch contacts at other than superconducting temperatures will not necessarily be satisfactory for use at superconducting temperatures. This was vividly illustrated by tests conducted in the development of the present invention which compared the surface resistivity at superconducting temperatures of clean copper surfaces of a stabilized superconductor in contact and the same surfaces which were allowed to age for two months at room temperature in air. The surface resistivity of the aged surfaces was found to have increased by a factor of fifty compared to fresh surfaces.

Referring again to FIGURE 5, inspection of this figure will show that if the contact surfaces of the stabilized conductors are coated with gold as by electroplating, when fresh or clean the surface resistivity of gold is approxi-

mately ten times less than that of a copper surface at liquid helium temperatures. However, as is also shown in FIGURE 5, when the contact surfaces are coated with silver, the surface resistivity can be a factor of six lower than that possible with gold. The graph of surface resistivity for silver was achieved with a silver thickness of about .0004". Furthermore, as will be seen from FIGURE 5, the low resistance of silver plated surfaces can be achieved with minimum contact pressures of the order of 100 lbs. per square inch.

With a surface resistivity of 2×10^{-8} ohm cm. which is achievable with silver, the energy loss in the switch is negligibly small. For example, assuming 5 square inches of contact surface, if such a switch in accordance with the present invention is used to short circuit a superconducting coil having an inductance of one henry, the time constant of the circuit for the decay of the persistent current is about fifty years.

The various features and advantages of the invention are thought to be clear from the foregoing description. Various other features and advantages not specifically enumerated will undoubtedly occur to those versed in the art, as likewise will many variations and modifications of the preferred embodiment illustrated, all of which may be achieved without departing from the spirit and scope of the invention as defined by the following claims.

I claim:

1. In a switch having an open and a closed position, the combination comprising:

- (a) a switch block member including a first conductor comprising superconductive material in electrical contact with an exposed and at least substantially smooth first surface of normal metal;
- (b) a switch blade member including a second conductor comprising superconductive material in electrical contact with an exposed second surface of normal metal, said second surface being adapted to at least substantially mate with said first surface when said switch is in its closed position and at least one of said conductors being movable with respect to the other conductor; and
- (c) actuating means for moving said movable conductor and bring at least a substantial portion of said first and second surfaces into contact with each other under pressure.

2. The combination as defined in claim 1 wherein said first and second surfaces comprise a noble metal.

3. The combination as defined in claim 2 wherein said noble metal is silver.

4. The combination as defined in claim 1 wherein said first and second conductors respectively comprise superconductive material in intimate electrical and thermal contact with a flat member of normal metal.

5. The combination as defined in claim 4 wherein said normal metal has an electrical conductivity of the order of copper at superconducting temperatures and said first and second surfaces comprise a noble metal.

6. The combination as defined in claim 5 wherein said noble metal is gold.

7. The combination as defined in claim 5 wherein said noble metal is silver.

8. The combination as defined in claim 7 wherein said silver has a thickness of about .0004 inch.

9. The combination as defined in claim 8 wherein the pressure applied to said surfaces provides approximately minimal contact resistance between said first and second surfaces.

10. The combination as defined in claim 8 wherein the pressure applied to said surfaces is not less than about one hundred pounds per square inch.

11. In a switch, the combination comprising:

- (a) a base;
- (b) a first electrically conductive member carried by said base comprising superconductive material at least a substantial portion of the surface of which

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is in intimate electrical and thermal contact with a member of normal metal having an electrical conductivity of the order of copper at superconducting temperatures and a smooth exposed first surface at least as great as said surface of said superconductive material;

- (c) a second electrically conductive member carried by said base comprising superconductive material at least a substantial portion of the surface of which is in intimate electrical and thermal contact with a member of normal metal having an electrical conductivity of the order of copper at superconducting temperatures and a smooth exposed second surface of at least approximately the same size at said first surface and adapted to mate therewith, at least one of said members being movable with respect to the other member;

- (d) actuating means carried by said base for moving said movable member and bring at least a sub-

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stantial portion of said first and second surfaces into contact with each other under pressure; and (e) means for electrically insulating said first and second members from said base and said actuating means.

12. The combination as defined in claim 11 including a layer of noble metal on said first and second surfaces.

13. The combination as defined in claim 12 wherein said noble metal is silver having a thickness of the order of 0.0004 inch.

References Cited

UNITED STATES PATENTS

3,096,421	7/1963	Meissner	200—166
3,145,284	8/1964	Laquer	200—166 X

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