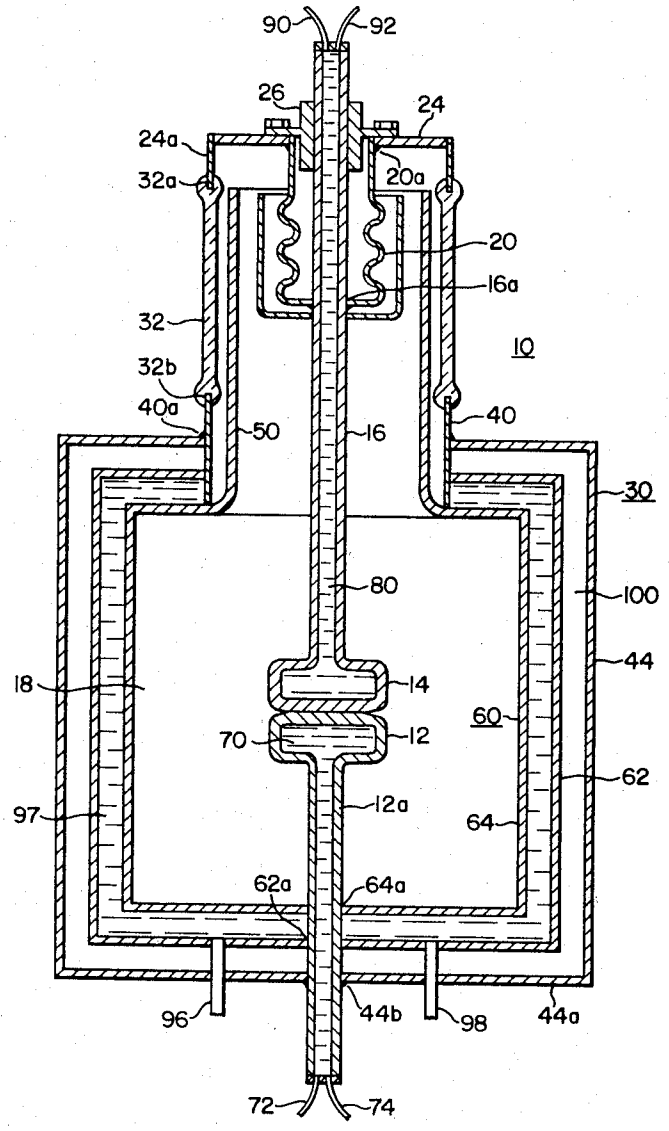
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LOW-TEMPERATURE OR SUPERCONDUCTING VACUUM CIRCUIT INTERRUPTER

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LOW-TEMPERATURE OR SUPERCONDUCTING VACUUM CIRCUIT INTERRUPTER

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ABSTRACT OF THE DISCLOSURE

A vacuum-type circuit interrupter is provided to cool the separate contacts and/or the condensing shield to a low temperature of at least —30° C. The temperature may be even lower to provide superconducting conditions.

This invention relates, generally, to improvements in a vacuum-type circuit interrupter and, more particularly, to improved means for condensing arc-generated metal vapor, released gas, and other arcing products at the electrodes, or contacts, at the shielding structure, and generally throughout the interior surfaces of the interrupter, and is applicable to both alternating current and direct current interrupters.

The usual vacuum-type alternating current circuit interrupter consists of separable contacts in an evacuated chamber. An arc is drawn between the contacts as they are separated to initiate current interruption. The arc is primarily maintained in metal vapor vaporized from the contact material, and in part from gases liberated from the surfaces and interior volume of the electrodes.

Due to the high current density at cathode spots, of the order of 10^5 to 10^6 amperes per square centimeter, there is a strong self-magnetic pressure inside the arc which is proportional to the product of the current and the current density, and which acts to constrict or pinch off the arc in the region of the cathode spot. This magnetic pressure is balanced by the kinetic pressure of the metal vapor and gases within the arc. Near a natural current zero the kinetic pressure decreases allowing the magnetic pressure to constrict the arc which increases the current density which in turn, further increases the magnetic pressure. This leads to two effects. In addition to the runaway pinching off of the arc, the self-magnetic flux in the arc increases very rapidly due to the quickly increasing current density. This latter effect produces an induced back voltage which together with the physical instability produced by the pinch, interrupts the current just prior to the natural current zero.

If the arc is to remain extinguished from this time on, the gap must have sufficient dielectric strength to withstand the increasing recovery voltage transient without restrike. There is essentially a race, as Slepian has previously described it, between the increasing recovery of dielectric strength and the rising voltage. Whether or not the dielectric strength of the gap will increase sufficiently fast depends to a great extent upon the rate at which metal vapor and gas generated by arcing is removed from the gap. Of course electrical breakdown can also occur in other interior regions of the interrupter when the dielectric strength in these regions is reduced due to the presence of arc-generated vapors and gas. Thus, it is most desirable to condense out these metal vapors and released gas as quickly as possible so that they will not impair the high dielectric strength of the vacuum.

Interruption of direct current is even more difficult, as arc instabilities must be introduced to produce extinction of the arc. In this case it is even more imperative that

the metal vapors and released gas be quickly condensed out, leaving a high vacuum inside the interrupter.

Accordingly, a general object of the present invention is to provide sufficient cooling of the electrodes so that they may more quickly condense arc-generated vapors, thus increasing the rate of dielectric recovery of the electrode gap and the interrupting capacity of the vacuum switch.

Another object is to provide sufficient cooling of the structure surrounding the electrodes that arc-generated vapors striking this structure are more quickly and efficiently condensed, and thus prevented from rebounding from this structure at an excessive rate which might otherwise cause a dielectric breakdown in the gap or in other regions.

Another object of this invention is to reduce contact resistance of the electrodes due to their decreased temperature.

Another object of this invention is to help prevent welding of the contacts.

Another object of this invention is to increase the current-carrying ability of the electrodes, and electrode supports.

Another object of this invention is to reduce the post-arc thermionic emission from the contacts.

Another object of this invention is to increase the withstand voltage of the interrupter in the open-circuit position.

Another object of this invention is to decrease the attrition of the contact surfaces.

Another object of this invention is to increase the interrupting capacity of a vacuum switch made of gassy materials.

Further objects and advantages will readily become apparent upon reading the following specification, taken in conjunction with the drawing, in which the single figure illustrates a vertical sectional view taken through a low-temperature or superconducting vacuum circuit interrupter, the contact structure being illustrated in the closed-circuit position embodying the principles of the present invention.

When the contacts are not sufficiently free of gases dissolved in the material and adsorbed gases and contaminants which are liberated during arcing, the interrupting ability of most vacuum switches is greatly impaired. Constructing a vacuum switch in accordance with the present invention will increase the interrupting capacity of a vacuum switch which is otherwise limited in performance by the gas content of the contacts. This increased performance results from the fact that the released gas is quickly condensed on the cold surfaces as provided in this invention. This helps to maintain a high vacuum.

Even in a highly gas-free vacuum circuit interrupter, a certain amount of gas is liberated from the surfaces and interior volume of the electrodes. In this case the arcing characteristics and interrupting performance of the vacuum switch is primarily determined by the electrode material. Construction of a vacuum switch in accordance with the present invention in which the electrodes and surrounding structure are held at very low temperature also increases the interrupting capacity of a highly gas-free switch by increasing the rate at which the metal vapors are condensed on the electrodes and surrounding structure.

When metal vapors and/or gas strike a surface, a certain number of the incident atoms condense on the surface with the rest of the atoms rebounding from the surface. The ratio of the number of atoms condensing on a surface to the total number striking it, is called the condensation coefficient, the sticking coefficient, or simply the sticking probability. In general, as the temperature of the surface increases, the sticking probability decreases.

The coefficient depends also upon the composition of the vapor or gas striking the surface. The initial temperature and particular material of the surface is an important factor in determining its final temperature when bombarded with metallic vapor or gas.

Langmuir has shown that for metal vapor atoms condensing on a metal surface the sticking probability is very close to 1 when the surface is at room temperature or lower. For most gases the sticking probability is well below 1 at room temperature, and approaches 1 at very low temperatures. In a circuit breaker, the arc-generated metal vapor and gases as well as the radiation produced, heat up the surfaces which surround the arc to high enough temperatures that the sticking probability is significantly reduced. This results in a lowered condensation rate with more and more particles rebounding back into the arc.

Therefore, if the surfaces can be kept cold, this will result in increased interrupting capacity. By maintaining the electrodes and surrounding structure at a temperature well below −30° C. prior to arcing, the resulting temperature rise during arcing will not be as detrimental as if the electrodes and surrounding structure started at 20° C. which they commonly do at present. To be most effective with gassy materials in the interrupter, starting temperatures produced by liquid nitrogen as low as −196° C. are desirable.

In addition to reducing the final temperature of the surface by starting at an initially lower temperature, the final temperature following arcing is also lower because the thermal conductivity is increased at the lower temperature allowing the heat generated at the surface to be conducted away more rapidly to the cooler inside material. Thus, more material shares in receiving the heat which is generated, resulting in a smaller temperature rise than if only a thin surface layer were able to absorb the heat produced during the short arcing time. Of course materials with high thermal conductivity, high mass density, and high specific heat are most desirable.

The lowered temperature of the electrodes and electrode supports also contributes appreciably to their current-carrying ability. Not only is the conductivity of the electrodes and electrode supports increased at the low temperature maintained by the coolant, but the heat generated during normal conduction of current is efficiently extracted by the cooling agent. As a result, a smaller cross-sectional area of conducting material may be used. The lighter mass reduces its cost and the cost of the accelerating mechanism for opening and closure. For additional cost reduction, this invention allows the possible substitution of, for example, aluminum for copper. Cooling the electrodes and electrode supports is more essential in a vacuum interrupter than in other types since the electrodes and supports are virtually isolated by the vacuum, thus causing them to heat up more and take longer to cool for a given temperature rise, than the same size electrodes and supporting members in an oil or gas interrupter.

For certain elements and alloys, the resistivity vanishes if the temperature is reduced sufficiently, i.e., they become superconducting. Liquid helium temperature of −269° C. (4.2° K.) is easily low enough for many of these materials, some of which are listed in the table below.

TABLE OF SOME SUPERCONDUCTING MATERIALS

(x and y are variable percentages)

Material:	Critical Temperature, ° K.
Nb	9.2
Pb	7.2
Ta	4.4
V	5.1
$AlNb_3$	18.0

Material:	Critical Temperature, ° K.
Al_3Os	5.9
AsBiPd	9.0
AsBiPbSb	9.0
AsPb	8.4
$AuNb_3$	11.5
BMo_2	4.7
BNb	8.3
$BaBi_3$	5.7
$BaRh_2$	6.0
$Bi_{0.5}Cd_{0.13}Pb_{0.25}Sn_{0.12}$	8.2
BiCs	4.8
$BiIn_2$	5.6
BiPb	8.8
BiPbSb	8.9
$Bi_{0.5}Pb_{0.31}Sn_{0.19}$	8.5
Bi_3Sr	5.6
Bi_5Tl_3	6.4
CMo	9.3
$C_{0.5}Mo_xNb_y$	~11
$C_{0.5}Mo_xTi_y$	10.2
CN_xNb_y	~17
CNb	10.3
CNb_2	9.2
$C_{0.5}Ta_xW_y$	~10
$CaIr_2$	6.2
CaPb	7.0
CaRh	6.4
$CeRu_2$	4.9
Cr_xV_y	~5
Cu_xPb_y	5.7–7.7
$DNb_{0.13}$	9.12
$Er_{0.01}La_{0.99}$	5.3
$Fe_{0.01}La_{0.99}$	4.9
$Fe_xT_{0.6}V_y$	~6
Ga_2Mo	9.5
Ga_4Mo	9.8
$GaNb_3$	14.5
GaV_3	16.8
Gd_xLa_y	~5
GeIr	4.7
GeV_3	6.0
$Ho_{0.01}La_{0.99}$	5.2
$InLa_3$	10.4
InPb	6.7
In_3Sn	5.5
$IrMo_3$	8.8
Ir_2Nb_3	9.8
Ir_2Sr	5.7
IrTi	5.4
Ir_2Th	6.5
$Ir_{0.1}Zr_{0.9}$	5.5
$La_{0.99}Lu_{0.01}$	5.6
La_xNd_y	~5
$LaOs_2$	6.5
$La_{0.99}Pr_{0.01}$	5.3
$La_{0.99}Sm_{0.01}$	4.5
La_xY_y	~5
$La_{0.99}Yb_{0.01}$	5.5
LiPb	7.2
Mo_3Os	7.2
Mo_3P	7.0
Mo_3Re	10.0
Mo_xRh_y	~7.0
MoRu	9.5–10.5
$Na_{0.28}Pb_{0.72}$	7.2
Nb_3Pt	9.3
$Nb_{0.18}Re_{0.82}$	9.7
Nb_3Sn	18.1
NbSn	17.9
$Nb_{3x}SnTa_{(1-x)}$	6.0–18.0
Nb_xTi_y	~10
Nb_2Zr	10.8
PPb	7.8

TABLE OF SOME SUPERCONDUCTING MATERIALS—Continued

Material:	Critical Temperature, ° K.
PbSb	6.6
$Pd_{0.1}Zr_{0.9}$	7.5
Re_6Zr	7.4
Rh_xSe_y	~5
Rh_2Sr	6.2
$Rh_{0.1}Zr_{0.9}$	9.0
$Ru_xTi_{0.6}V_y$	~6.0
RuW	7.5
$Ru_{0.1}Zr_{0.9}$	5.7
$SbTi_3$	5.8
SiV_3	16.8–17.1
$Si_{0.9}V_3C_{0.1}$	16.4
$Si_{0.9}V_3B_{0.1}$	15.8
$Si_{0.9}V_3Al_{0.1}$	14.1
$Si_{0.9}V_3Ge_{0.1}$	14.0
$SiV_{2.7}Zr_{0.3}$	13.2
$SiV_{2.7}Nb_{0.3}$	12.8
$SiV_{2.7}Mo_{0.3}$	11.7
$SiV_{2.7}Cr_{0.3}$	11.3
$SiV_{2.7}Ti_{0.3}$	10.9
$SnTa_3$	6.0
Sn_xTl_y	~5
SnV_3	6.0
V_2Zr	8.8

Since part of this invention involves cooling the conducting parts to very low temperatures, it is desirable to gain the added advantage of superconductivity by reducing the temperature to a sufficiently low point. Since good conductors such as copper, silver, and gold, have not yet been found to be superconducting, it is desirable to make the electrodes and electrode supports out of a matrix containing a superconducting material with high critical magnetic field, and a good conductor such as copper. In this way the interrupter will have good conductivity in the normal, nonsuperconducting state. When the superconducting contacts separate during interruption, the contacts go normal, which helps to interrupt the current. A superconducting vacuum circuit interrupter should easily be economical when superconducting transmission lines and other cryogenic systems come into use.

For clean surfaces, contact resistance usually results from the fact that only a small fraction of the area of the two contacts actually makes contact. The contact resistance is proportional to the resistivity of the contact material. Therefore, when the resistivity of the material is reduced with a reduction in temperature, the contact resistance is correspondingly reduced. A reduction in contact resistance decreases the heat generated during normal conduction of current. But more important, reduced contact resistance helps to prevent welding of the contacts when the interrupter is required to remain closed while conducting high over-currents. The ability to maintain low contact resistance and to efficiently remove heat generated at the contact interface is important not only when the contacts are required to remain closed, but also to minimize the temperature rise at the contact interface during the crucial moments when a high fault current is present and interruption is initiated. The speed with which interruption is initiated and at which the electrodes separate is also important in this respect so that sticking or welding of the contacts would be detrimental to the operation of the interrupter. In this respect it is worth pointing out that some welding occurs between very clean contacts in high vacuum due to migration of atoms from one contact surface to the other, and that a low temperature minimizes this effect.

Maintaining the contacts at liquid nitrogen temperature of —196° C. or lower, significantly reduces post-arc thermionic emission from the contacts. Refractory metallic contacts such as tungsten, have been limited in interrupting capacity due to thermionic emission from hot spots on the contact surfaces following arcing. This is more attributable to the high melting point and low thermal and electrical conductivity of these metals than to their work function. Otherwise such metals have the desirable characteristics that they are more easily made gas free than lower melting point metals, and that they have higher breakdown voltages without immediately prior arcing. A lower initial temperature results in greater conductivity and a lower final temperature. Reduction in thermionic emission due to lowered temperature would also benefit non-refractory metallic contacts.

It has been found that maintaining the electrodes at liquid nitrogen temperature of —196° C. or lower, significantly increases their voltage-withstand ability. This is important to a circuit interrupter because in addition to the requirement that it withstand the normal line voltage in the open position, there is also the requirement that it withstand a much higher impulse voltage without breakdown. The lower the temperature of the contacts, the higher the breakdown voltage becomes. This effect is noticeable at temperatures below —30° C.

Cathode spot motion is still not well understood and is subject to many different views. One point of view is that when magnetic effects may be neglected, the motion of the arc cathode spot is due to the temperature gradient between the cathode spot and the electrode material under it. If this is true, then the lowered temperature of the electrode material, as provided in this invention, gives rise to an even greater temperature gradient giving the cathode spot increased mobility on the cathode surface. This helps to make the erosion of the electrode surface more uniform, avoiding excessive erosion in localized regions. There is also less attrition of the contact surfaces because of the generally lower surface and bulk temperature of the electrodes. The greater condensation rate, as previously discussed, reduces the arcing time and hence the electrode erosion, since it increases the probability that interruption will occur at the first current zero.

With reference to the foregoing principles, attention is directed to the vacuum-type circuit interrupter **10**, more particularly illustrated in the drawing. It will be noted that there is provided a relatively stationary tubular contact **12** cooperable with a movable tubular moving contact **14**, the latter being reciprocally actuated in a vertical direction by a suitable operating mechanism, not shown, which is attached to, and actuates the conducting tubular operating rod portion **16**.

As shown, the two contacts **12, 14** make separable abutting engagement and, for example, may separate a distance of ½ inch in interrupting currents, which may be as high as 30,000 amperes.

To insure a highly evacuated state within the vacuum chamber **18**, such as of the order of 10^{-8} mm. of mercury, the operating rod **16** is sealed, as at **16***a* to the lower end of a flexible metallic bellows **20**. The flexible metallic bellows **20** will insure a permissible vertical operating movement of the movable contact **14**, while at the same time maintaining a highly-evacuated state within the vacuum chamber **18**. It will be noted that the upper end of the flexible metallic belows **20** is secured in a sealing relationship to an upper metallic end cap **24**, as at the point **20***a*. The operating rod **16** is guided by the insulated sleeve **26**. The sleeve **26** is made of insulating material such as Teflon so that current will not be conducted through the bellows **20**, otherwise the bellows may rupture when carrying high currents.

A casing structure **30** may be provided comprising an upper metallic end cap **24**. In addition, the insulating tubu-**32***a*, to a downwardly extending flange portion **24***a* of the upper metalic end cap **24**. In addition, the insulating tubular portion **32** may be sealed, as at **32***b*, to the upper end of a tubular metallic casing member **40**, which is hermetically sealed, as at **40***a*, to a surrounding tubular housing member **44**. The housing member **44** has an inwardly extending lower cap portion **44***a*, which may be hermeti-

cally sealed, as at **44***b*, to the tubular supporting rod portion **12***a* of the lower stationary contact structure **12**.

As well known by those skilled in the art, the arc, which is established across the arcing gap between the separable contacts **12, 14**, vaporizes some of the contact material. The vapors are driven in all directions from the arcing region. The internal insulating surfaces of the tubular insulating casing portion **32** are protected from the condensation of arc-generated metallic vapors thereon by means of the tubular metallic end-shield **50**, and also by the condensation provided by an interiorly-disposed hollow condensing shielding means, generally designated by the reference numeral **60**, and comprising exterior and interior metallic casing elements **62, 64** respectively. The supporting rod portion **12***a* extends through apertures **62***a*, **64***a* provided in the lower end of the shielding means **60**.

In accordance with the principles as set forth hereinabove, the contacts **12, 14** and/or the condensing shield means **60** is cooled to a relatively low temperature, preferably below —30° C. Various coolants may be employed, the table set forth below lists a number of suitable coolants, together with their boiling points at atmospheric pressure.

TABLE OF SUITABLE COOLANTS

Coolant	Chemical symbol	Boiling point at 1-atmosphere ° C.
Liquid ammonia	NH_3	−33.3
Liquid radon	R_n	−61.8
Dry Ice	CO_2	[1] −78.5
Liquid xenon	Xe	−107.1
Liquid krypton	Kr	−152.9
Liquid argon	A	−185.7
Liquid nitrogen	N_2	−195.8
Liquid neon	Ne	−245.9
Liquid helium	He	−268.9

[1] Sublimates.

Liquid oxygen and liquid hydrogen with boiling points of —183.0° C. and —252.8° C. respectively were not included in the table because of their potential combustibility.

The coolant entering the space **70** interiorly of the lower relatively stationary contact structure **12** may enter by means of an inlet port **72** and be exhausted by an outlet port **74**. Likewise the coolant entering the space **80** interiorly of the upper hollow tubular movable contact **14**, may enter by means of a suitably provided inlet port **90** and exhausted by a suitable outlet port **92**. In addition, the hollow shielding means **60** may be supplied from an inlet port **96** and the coolant utilized in the annular space **97** exhausted by means of an outlet port **98**.

It will be obvious that by a circulation of the coolant the temperature of the contacts **12, 14** and/or condensing shield **60** may be maintained at the low temperature provided by the coolant. The annular space **100** surrounding the metallic casing **62** is evacuated to provide heat insulation for the interior cold metallic casings **62** and **64**. Cooling may also be provided by thermo-electric effect, by use of powdered Dry Ice, or by other means.

The advantages of utilizing a separable contact structure **12, 14** maintained at the relatively low temperature, preferably below —30° C., has been set forth above and not only reduces the resistance, but also prevents welding and facilitates condensation of the metallic and gaseous atoms.

The provision of the tubular shielding means **60** cooled to a low temperature by the coolant also, in a manner as described above, assists in a rapid condensation of the metallic vapor and gaseous atoms emitted during the interrupting operation.

Although there has been illustrated and described a specific structure, it is to be clearly understood that the same was merely for the purpose of illustration, and that changes and modifications may readily be made therein by those skilled in the art without departing from the spirit and scope of the invention.

I claim as my invention:

1. A vacuum-type circuit interrupter having a high vacuum including means defining an evacuated envelope, a pair of relatively movable contacts that are separable to establish an arcing gap therebetween disposed within said evacuated envelope, and means for cooling at least one of said separable contacts to a relatively low temperature of at least —30° C. to facilitate condensation of metallic vapor during the interrupting operation.

2. A vacuum-type circuit interrupter having a high vacuum including means defining an evacuated envelope, a pair of relatively movable contacts that are separable to establish an arcing gap therebetween disposed within said evacuated envelope, a condensing shield structure disposed within said evacuated envelope for condensing metallic vapor emitted from the contacts during the opening operation, and means for cooling said condensing shield structure to a relatively low temperature of at least —30° C. to enhance the condensing capacity of the condensing shield structure during the opening operation.

3. The combination according to claim **1**, wherein a coolant is circulated within said one contact.

4. The combination according to claim **2**, wherein a coolant is circulated within said condensing shield structure for the cooling thereof.

5. The combination according to claim **1**, wherein said one contact is rendered superconductive.

6. A vacuum-type circuit interrupter including means defining an evacuated envelope having a high vacuum, a pair of relatively movable contacts that are separable to establish an arcing gap therebetween disposed within said evacuated envelope, and means for cooling at least one of said separable contacts to a relatively low temperature of at least —30° C. to facilitate condensation of metallic vapor during the interrupting operation, a condensing shield structure disposed within said evacuated envelope for condensing metallic vapor emitted from the contacts during the opening operation, and means for cooling said condensing shield structure to a relatively low temperature of at least —30° to enhance the condensing capacity of the condensing shield structure during the opening operation.

7. The combination according to claim **3**, wherein the coolant is a liquified gas.

8. The combination according to claim **4**, wherein the coolant is a liquified gas.

9. A circuit interrupter including separable contacts, and means for cooling one of the contacts to a low enough temperature to appreciably lower the resistance thereof.

10. A vacuum-type circuit interrupter including means defining an evacuated envelope, a pair of relatively movable contacts that are separable to establish an arcing gap therebetween disposed within said evacuated envelope, and means for cooling at least one of said separable contacts to a relatively low temperature of at least —30° C.

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