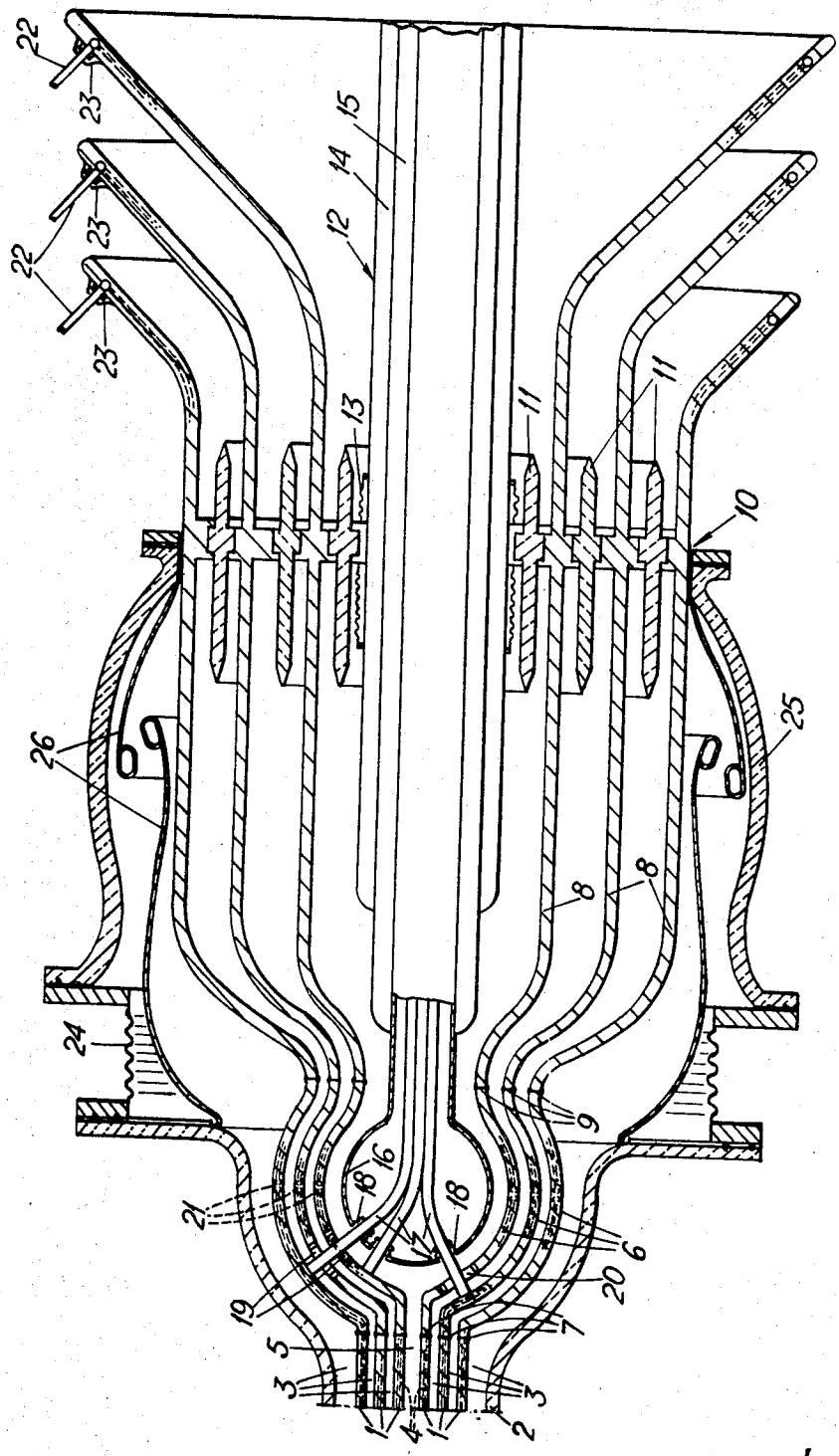
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TERMINATION FOR COAXIAL SUPERCONDUCTING CABLE

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TERMINATION FOR COAXIAL SUPERCONDUCTING CABLE

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ABSTRACT OF THE DISCLOSURE

A termination for a coaxial superconducting cable comprises a tubular insulating envelope sealed at one end to the cryogenic envelope of the cable and at the other end to a coaxial terminal having insulating spacing and vacuum sealing means between its conducting parts. A number of coaxial conductors each connect one of the conducting parts of the coaxial terminal with the corresponding conductor of the cable. Axial movement of the coaxial terminal towards and away from the cable end in response to temperature variation in the coaxial conductors of the termination is allowed for, and a heat shield is incorporated in the connection between the coaxial conductors of the terminal and the cable conductors for obstructing transfer of heat by direct radiation longitudinally from the conductors of the terminal to the cable conductors. The heat shield is preferably formed by shaping the conductors of the termination.

This invention relates to terminations for co-axial superconducting cables for the transmission of very large amounts of power at high voltages, the term "cable" being used herein to include busbars. A superconducting cable is a cable in which, when the cable is loaded, the load carrying conductors are maintained in the superconductive state. Preferred types of coaxial superconducting cable are described in application Ser. No. 730,842 of D. R. Edwards filed May 23, 1968.

The termination in accordance with the present invention can be connected to a superconducting cable in which two or more load-carrying conductors are mounted coaxially within a cryogenic envelope and are separated from each other and from the envelope by evacuated annular spaces. Ducts for a cooling fluid may be formed in or secured to the conductors, and in the latter case they may in some instances act as spacers between the conductors. Where this arrangement is inappropriate, separate thermally and/or electrically insulating spacers are used. The cryogenic envelope may be of the kind described in application Ser. No. 741,932 of J. E. Lawton filed July 2, 1968.

An object of the present invention is to provide a termination having a high voltage end, to which electrical connections can be made, that operates at room temperature.

The termination in accordance with the invention comprises a tubular insulating envelope sealed at one end to the cryogenic envelope of the cable and at its other end to a coaxial terminal, a number of coaxial conductors each connected at one end to or integral with one of the conducting parts of the coaxial terminal and connected at

the other end to one of the conductors of the cable, insulating spacing and vacuum sealing means between the conducting parts of the coaxial terminal, and means incorporated in the tubular insulating envelope of the termination which allows axial movement of the coaxial terminal toward and away from the cable end in response to temperature variation in the coaxial conductors of the termination. The connection between the coaxial conductors of the terminal and the cable conductors incorporates a heat shield for obstructing transfer of heat by direct radiation longitudinally from the conductors of the terminal to the cable conductors; this heat shield will be referred to as the longitudinal heat shield.

The longitudinal heat shield is preferably formed by shaping the conductors of the cable and/or of the termination; the conductors may for example increase in diameter to a maximum and then again reduce in diameter to give each of the annular evacuated spaces between them a sinuous shape such that no unobstructed straight line can lie in the annular space with one of its ends between the cable conductors and the other of its ends between the conductors of the terminal. Normally the conductors of the termination will be of circular cross section, in which case the sinuous shape should be such that no unobstructed right cylindrical or frusto conical surface can lie in the annular space with one of its ends between the cable conductors and the other of its ends between the conductors of the terminal. Since each of the conductors of the terminal will normally be of considerable greater diameter than the cable conductor to which it is connected, the sinuous paths can readily be given an additional curved section by first increasing the diameter of each conductor from the cable conductor diameter and then reducing its diameter in the way described and finally again increasing its diameter to the diameter of the corresponding conductor of the terminal.

The zone of the termination over which the first mentioned sinuous curvature of the annular spaces extends may be an intermediate temperature zone in which the conductor temperatures rise from the cable operating temperature, e.g. 4.5° K., to a temperature at which the superconducting part of the cable conductors would not exhibit superconductivity, e.g. 50–60° K. The remainder of the rise in temperature up to ambient temperature takes place in the second mentioned sinuous zone and in the concentric conductors of the terminal. Although the longitudinal heat shield forms part of the termination, it can be formed partly or wholly by shaping the ends of the cable conductors, provided that these conductors incorporate a sufficient cross section of highly conductive metal to carry the required load at temperatures above the critical temperature for superconduction, or alternatively are at the end of the cable of an alloy that is superconducting within the higher temperature range of the zone.

Ducts for feeding a cryogenic fluid into ducts located either within the cable conductors or in the evacuated spaces between them may pass through the conductors of the termination or the evacuated spaces between them and these ducts are thermally insulated where necessary to allow for the changing temperature conditions along the termination. When the innermost conductors of the cable and termination are both evacuated tubes, a longitudinal heat shield within the tube at the low temperature end of the termination can be in the form of staggered baffles projecting from the tube wall.

It is however preferred to utilize part of the space

within the inner conductor of the termination to accommodate a common supply duct for feeding cryogenic fluid to cooling ducts within or between the cable conductors or both to such ducts and to cooling ducts within or between the conductors of the termination. The common supply duct preferably terminates in a manifold located within and forming part of the intermediate temperature zone forming part of the longitudinal heat shield, preferably a spherical manifold from which distributing ducts made of insulating material extend radially to the conductors. The manifold forms part of the longitudinal heat shield since it is spaced from, and preferably substantially parallel to, the inner surface of the curved part of the inner conductor in the intermediate temperature zone to provide a vacuum space of the sinuous shape defined above.

From the radial distributing ducts, some of the cryogenic fluid may flow along the cable and some back along the termination (through reducing valves) but separate ducts for distributing the fluid into each of the cable and each of the termination conductors may be provided.

In addition to the means for allowing axial movement between the coaxial terminal and the cable already referred to it is necessary to provide means for accommodating axial movement between various other parts, namely the common supply duct and the gland where it enters the termination and the distributing ducts and the points where they pass through or leave the manifold, and the invention will be further illustrated by a description by way of example of a termination for a three phase coaxial superconducting cable incorporating such means. Reference will be made to the accompanying drawing, which is a diagrammatic longitudinal cross section of the termination.

The termination shown is for a coaxial three phase cable comprising three tubular conductors **1** separated from each other and from an outer tubular cryogenic envelope **2** by annular evacuated spaces **3**. The support (not shown) for maintaining the conductors and the envelope in spaced relationship may be insulated spacers and/or ducts through which cryogenic fluid, for maintaining the conductors at or about 4.5° K., may pass.

Each conductor **1** may for example consist of an annular body of metal which is not superconducting at the operating temperature, coated on one surface only or on both its inner and outer surfaces with a thin metal layer that is superconducting at the operating temperature; a composite conductor in accordance with application Ser. No. 730,842 of Edwards is preferred. Each annular conductor body may be provided witr a number of internal or external ducts for the cryogenic fluid or it may consist of inner and outer shells spaced apart by conducting spacers and between which an annular stream of the cryogenic fluid flows; such coolant passages are diagrammatically indicated at **4**. The central space **5** within the inner tubular conductor is preferably evacuated, and must be evacuated if it communicates with an evacuated space in the termination.

The inner surface of the cryogenic envelope **2** may for example be at a temperature of the order of 60° K., its outer surface being at ambient temperature, for example 293° K.

At the end of the cable to which the termination is attached, each of the three conductors **1** is welded to a separate annular conductor **6** which in the region of the intermediate temperature zone of the longitudinal heat shield is shaped as the frustum of a sphere cut off by planes on opposite sides of the centre, to provide the first curved part of the sinuous passages between the conductors shaped as referred to above, the shape being that of an unsymmetrical frustum such that at the welds **9** where these conductors join the co-axial conductors of the termination their diameter is greater than the diameter of the corresponding conductor of the cable.

The coaxial conductors **8** of the terminal increase in

diameter from the point **9** where they are welded to the conductors **6** forming the intermediate zone of the longitudinal heat shield to a maximum diameter after which, and up to the vacuum seal **10** at the high voltage-ambient temperature end of the termination, they are right cylindrical. For ease of fabrication, the right cylindrical part may be made separately from the tapered part, and welded to it.

The nature and cross-section of the conductors **6** and **8** is such that they will carry the cable load at temperatures rising from 4.5° K. at the welded joints **7** with the cable conductor to about 70° K. at the point where conductors **8** reach their maximum diameter, and to ambient temperature where they emerge from the end of the termination into the atmosphere. At this point the conductors are spaced apart by annular insulating spacers which form vacuum seals between them and between the innermost conductor and a central common supply duct **12** by which cryogenic fluid is fed through the termination into the conductors of the cable and the conductors of the termination. The innermost spacer is connected to the supply duct by a device **1**, e.g., a bellows device, which allows the duct to move longitudinally with respect to the termination.

In the example being described, this common supply duct is provided with two heat shields: an outer, higher temperature, heat shield **14** which extends only part of the way along the duct within the termination and an inner, intermediate temperature, heat shield **15** which extends along the duct almost as far as the constriction in the inner conductor at the joint **9** between the termination conductors and the conductors of the longitudinal heat shield.

Within the inner conductor, in the region of the intermediate temperature zone of the longitudinal heat shield, the common supply duct feeds a manifold **16** in the form of a stainless steel spherical shell and through the shell wall three glass distributing ducts pass radially to the three conductors. The glands by which the glass ducts pass through the shell wall provide, e.g., by the incorporation of bellows **18**, for relative movement in a radial direction with respect to the manifold between the ducts and the shell wall.

The duct supplying the outer conductor passes through suitable apertures **19** (greater in diameter than the duct) in the intermediate and inner conductors and the duct supplying the intermediate conductor passes through a similar aperture **20** in the inner conductor. The duct connected to each conductor supplies cryogenic fluid both to the cable conductor and to the corresponding termination conductor, a preset valve or valves **21** being provided to ensure that the quantity of fluid flowing through the termination conductor is appropriately related to that flowing through the cable conductor.

The distributing ducts **17** extend into and partly along the common supply duct in a straight or sinuous path to allow sufficient protection against electrical breakdown between the conductors and the earthed manifold **16** through the cryogenic fluid passing through the common supply duct to the conductors.

The three coaxial conductors of the termination extend through the vacuum seal at the high temperature end of the termination into the atmosphere in the form of a coaxial terminal and are each provided with an outlet duct **22** for the cryogenic fluid made of insulating material such as glass and of a length and shape such that it will withstand the potential drop from the conductor voltage at the point where it leaves the conductor to earth potential at the point where it enters refrigerating apparatus for the cryogenic fluid. Glands by which the ducts are attached to the conductors are preferably provided with corona shields **23**. The common supply duct **12** remains axially located between and beyond these extending terminal parts of the conductors.

The cryogenic envelope **2** of the cable is connected by

vacuum seals through an expansion bellows **24** to the low voltage end of a tubular insulator **25** of glass or other suitable material forming the outer envelope for the termination the high voltage end of which supports the coaxial terminal. Thermal and electrical shields **26** or other means for shielding the termination from radiation entering in a radial direction is provided between the inner surface of this envelope and the outer surface of the outer conductor of the termination.

In use, the spaces in the termination between the co-axial conductors, between the outer conductor and the surrounding envelope, and within the inner conductor are evacuated.

What we claim as our invention is:

1. A termination for a coaxial superconducting cable comprising a number of coaxial conductors enclosed in a cryogenic envelope comprising:

(a) a coaxial terminal comprising a number of co-axial conducting parts insulated one from the other;

(b) a tubular insulating envelope sealed at one end to the cryogenic envelope of the cable and at the other end to the coaxial terminal;

(c) a number of coaxial conductors each effecting connection between one of the conducting parts of the coaxial terminal and the corresponding conductor of the cable;

(d) insulating spacing and vacuum sealing means between the conducting parts of the coaxial terminal;

(e) means incorporated in the tubular insulating envelope of the termination which allows axial movement of the coaxial terminal towards and away from the cable end in response to temperature variation in the co-axial conductors of the termination; and

(f) a heat shield incorporated in the connection between the coaxial conductors of the terminal and the cable conductors for obstructing transfer of heat by direct radiation longitudinally from the conductors of the terminal to the cable conductors.

2. A termination as claimed in claim **1** wherein the innermost conductors of the cable and of the termination are both evacuated tubes and wherein a longitudinal heat shield is formed within the tube at the low temperature end of the termination by staggered baffles projecting from the tube wall.

3. A termination as claimed in claim **1** wherein the innermost conductor of the termination is an evacuated tube within which is a common supply duct for feeding cryogenic fluid to cooling ducts within the cable.

4. A termination for a coaxial superconducting cable comprising a number of coaxial conductors enclosed in a cryogenic envelope comprising

(a) a coaxial terminal comprising a number of coaxial conducting parts insulated one from the other;

(b) a tubular insulating envelope sealed at one end to the cryogenic envelope of the cable and at the other end to the coaxial terminal;

(c) a number of coaxial conductors each effecting connection between one of the conducting parts of the coaxial terminal and the corresponding conductor of the cable;

(d) insulating spacing and vacuum sealing means between the conducting parts of the coaxial terminal;

(e) means incorporated in the tubular insulating envelope of the termination which allows axial movement of the coaxial terminal towards and away from the cable end in response to temperature variation in the coaxial conductors of the termination, and

(f) a heat shield formed by shaping the coaxial conductors of the termination so as to obstruct transfer of heat by direct radiation longitudinally from the conductors of the terminal to the cable conductors.

5. A termination as claimed in claim **4** further comprising means for evacuating the spaces between the coaxial conductors, wherein the conductors of the termination are of circular cross section and the longitudinal heat shield is formed by increasing the diameters of the conductors to a maximum and then reducing their diameters to give each of the evacuated spaces between them a sinuous shape such that no unobstructed right cylindrical or frusto-conical surface can lie in the annular space with one of its ends between the cable conductors and the other of its ends between the conductors of the terminal.

6. A termination as claimed in claim **5** wherein the said sinuous shape comprises an additional curved section formed by again increasing the diameter of each conductor to the diameter of the corresponding conductor of the terminal.

7. A termination as defined in claim **4** wherein

(a) the innermost conductor of the termination is a tube;

(b) a common supply duct for feeding cryogenic fluid to cooling ducts within the cable is accommodated within the innermost conductor of the terminal and terminates in a spherical manifold;

(c) distributing ducts made of insulating material extend radially from the manifold for feeding cryogenic fluid to the conductors;

(d) the coaxial tubular conductors of the termination each comprise a frustum of a sphere concentric with the spherical manifold and cut off by planes on opposite sides of its centre to provide between the conductors and between the inner conductor and the manifold spaces of sinuous shape such that no unobstructed right cylindrical or frusto-conical surface can lie in any of the annular spaces with one of its ends between the cable conductors and the other of its ends between the conductors of the terminal, and to form a heat shield for obstructing transfer of heat by direct radiation longitudinally from the conductors of the terminal to the cable conductors, and

(e) means for evacuating the spaces between the conductors and between the inner conductor and the manifold.

8. A termination as claimed in claim **7** comprising means for causing some cryogenic fluid from the radial distributing ducts to flow along the cable and some back along the termination.

9. A termination as claimed in claim **8** wherein the common supply duct terminates in a manifold located within and forming part of the intermediate temperature zone forming part of the longitudinal heat shield.

10. A termination as claimed in claim **7** wherein separate radial ducts are provided for distributing cryogenic fluid into each of the cable conductors and into each of the termination conductors.

11. A termination for a coaxial superconducting cable comprising a number of coaxial conductors enclosed in a cryogenic envelope comprising

(a) a coaxial terminal comprising a number of coaxial conducting parts insulated one from the other;

(b) a tubular insulating envelope sealed at one end to the cryogenic envelope of the cable and at the other end to the coaxial terminal;

(c) a number of coaxial conductors each effecting connection between one of the conducting parts of the coaxial terminal and the corresponding conductor of the cable;

(d) insulating spacing and vacuum sealing means between the conducting parts of the co-axial terminal;

(e) means for evacuating the spaces between the co-axial conductors;

(f) means incorporated in the tubular insulating envelope of the termination which allows axial movement of the coaxial terminal towards and away from the cable end in response to temperature variation in the coaxial conductors of the termination, and

(g) a heat shield for obstructing transfer of heat by direct radiation longitudinally from the conductors of

the terminal to the cable conductors, which heat shield is formed by increasing the diameters of the conductors to a maximum and then reducing their diameters to give each of the evacuated spaces between them a sinuous shape such that no unobstructed straight line can lie in the annular space with one of its ends between the cable conductors and the other of its ends between the conductors of the terminal.

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LARAMIE E. ASKIN, Primary Examiner

U.S. Cl. X.R.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,539,702 Dated November 10, 1970

Inventor(s) Derek Reginald Edwards et al.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 4, line 22,"1" should read -- 13 --.

Signed and sealed this 26th day of January 1971.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

WILLIAM E. SCHUYLER,
Commissioner of Paten