United States Patent

Doose

[15] **3,686,422**

[45] **Aug. 22, 1972**

[54] **CRYOGENIC CONDUIT ASSEMBLY FOR CONDUCTING ELECTRICITY**

[72] Inventor: **Conrad Doose,** Julich, Germany

[73] Assignee: **Kernforschungsanlage Julich Gesellschaft mit beschrankter Haftung,** Julich, Germany

[22] Filed: **Oct. 28, 1970**

[21] Appl. No.: **84,768**

[30] **Foreign Application Priority Data**

Oct. 30, 1969 Germany.....P 19 54 681.7

[52] **U.S. Cl.**.....**174/15 C,** 62/45, 62/55, 62/514, 174/27, 174/DIG. 6

[51] **Int. Cl.**.....**H01b 9/06**

[58] **Field of Search** .....174/15 C, 24, 16, 21 C, 28; 219/300, 301; 62/52, 53, 514; 335/216

[56] **References Cited**

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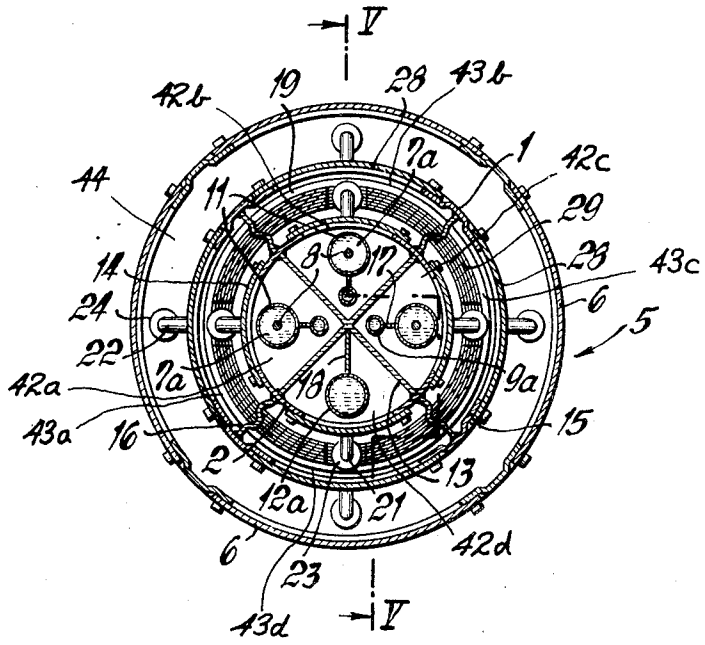
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Primary Examiner—Meyer Perlin
Assistant Examiner—Ronald C. Capossela
Attorney—Karl F. Ross

[57] **ABSTRACT**

A cryogenic conduit assembly for conducting electricity has an outer insulating duct formed by a pair of coaxially nested tubes defining an annular chamber which receives a sleeve of reflective thermal insulation (radiation shield) and is evacuated. The interior of this duct receives a plurality of tubes each subdivided transversely into two longitudinally extending compartments, one used solely for circulation of a cryogen and the other for an electrical conductor. The conductor-receiving compartment is filled with liquid hydrogen (heat-transfer medium) which can be circulated and the other compartment contains rapidly circulating gaseous helium (cooling medium). The assembly is subdivided at joints, the duct having a transverse wall to each side of the joint to hermetically seal off the duct interior. Between these walls at the joint, in addition, there are longitudinally extending walls which define a plurality of zones each receiving one tube, and removable covers are provided for access to each of the zones. These zones can be sealed off from or connected to the duct interior by means of shunt conduits and valves during servicing.

9 Claims, 7 Drawing Figures



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SHEET 1 OF 3

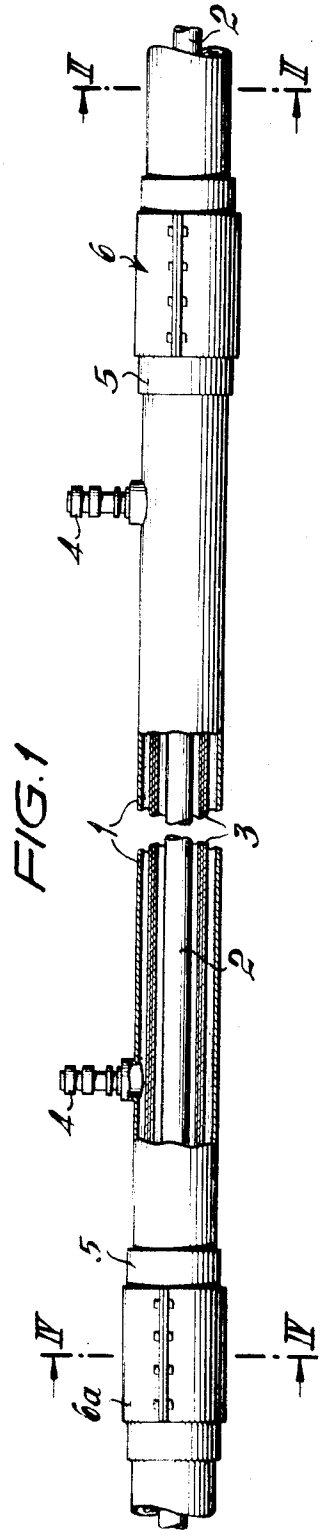


FIG. 1

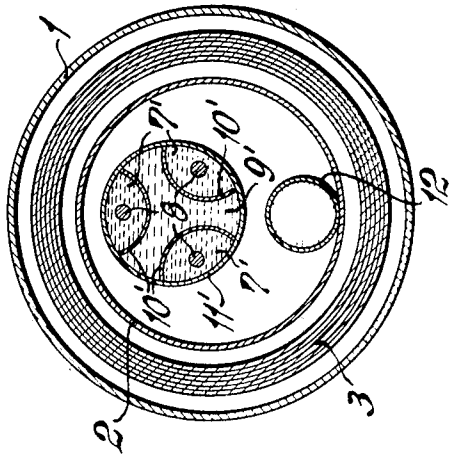


FIG. 3

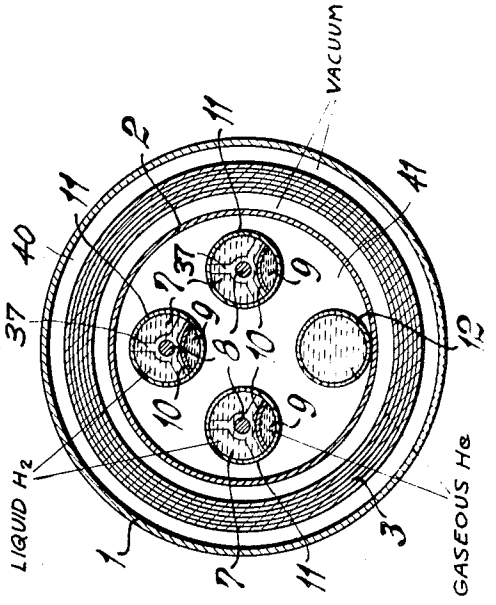


FIG. 2

INVENTOR:
Conrad Doose

By

Karl F. Ross
Attorney

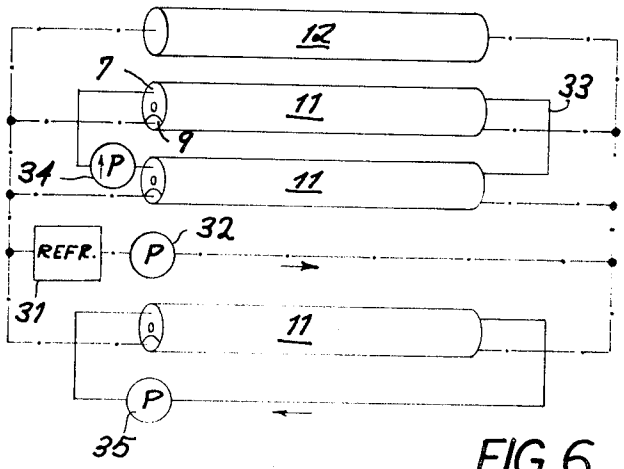


FIG. 6

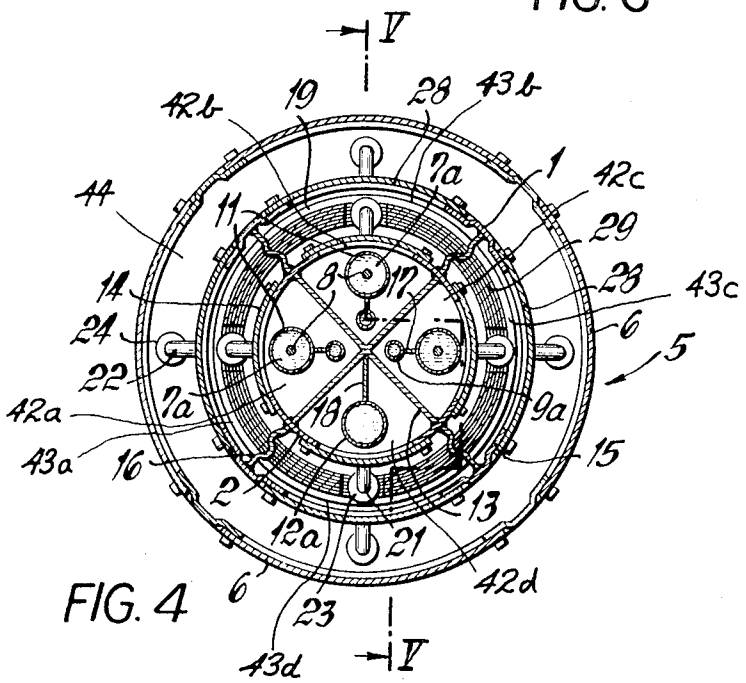


FIG. 4

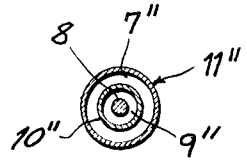


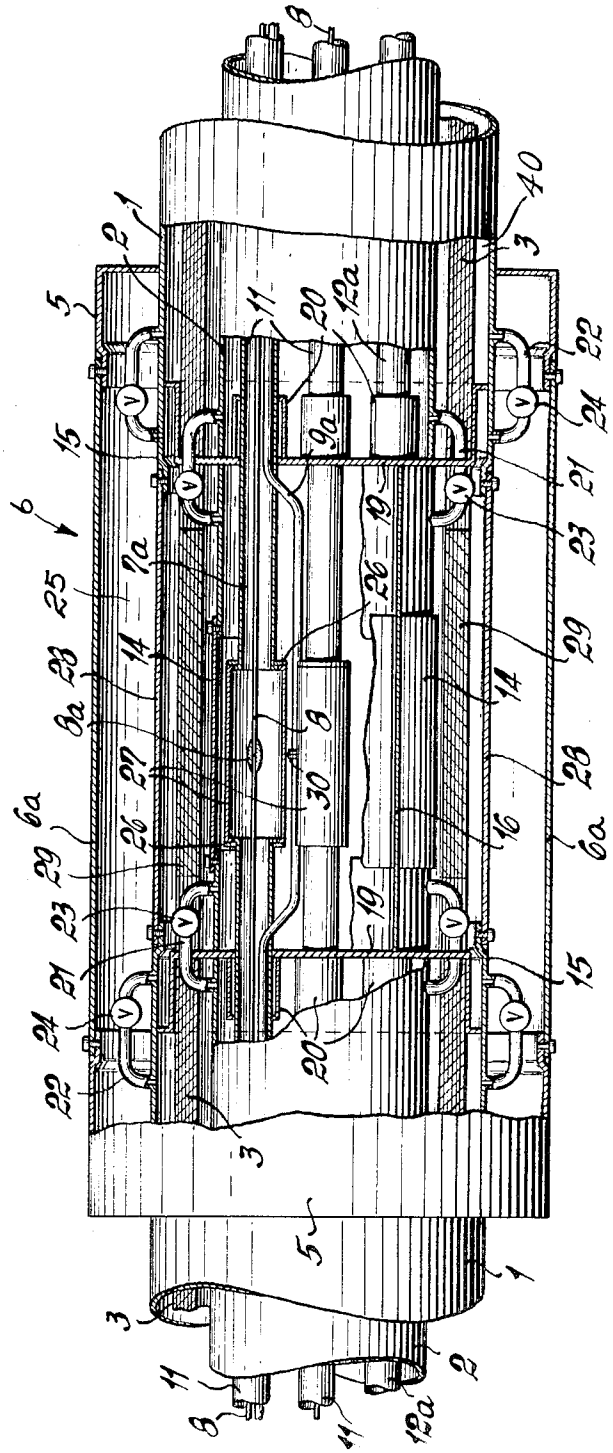
FIG. 7

INVENTOR:
Conrad Doose

BY

Karl F. Ross
Attorney

FIG. 5



INVENTOR:
Conrad Doose

By

Karl F. Ross
Attorney

CRYOGENIC CONDUIT ASSEMBLY FOR CONDUCTING ELECTRICITY

FIELD OF THE INVENTION

The present invention relates to an assembly for conducting electricity and more particularly to a conduit assembly in which an electrical conductor is cooled below its superconducting transition temperature so that it exhibits effectively no electrical resistance and can be used to carry large currents or, more generally, to a low temperature at which normal conduction occurs with greater efficiency.

BACKGROUND OF THE INVENTION

Cryogenic electrical-conduit assemblies usually require cooling of the conductor to below 80° Kelvin, and usually between 4° Kelvin and 20° Kelvin. The conductor can be a wire, a band, or a thin coating of a metal on a flexible or rigid synthetic-resin tube or band. This conductor is cooled by means of a gas (at ambient temperatures) which may be liquefied.

Each conductor can be received in a tube received in a larger duct, the latter comprising a pair of coaxial and nested tubes defining an elongated annular chamber in which reflective thermal insulation (heat-radiation shield) is provided and which is usually evacuated to preclude heat transfer by conduction or convection. The inner tube is also reflective and is itself cooled, with the conductor-receiving tubes extending through this inner duct.

Of course, such electrical-conduit assemblies are extremely expensive and complicated. Thus they must have long service lives to be economically worthwhile, and their downtime must be held at a minimum. This is very important since any repairs in the known systems usually involve draining them of their cryogen and totally debilitating them for a long period. Shutting down such systems also presents difficulties since the enormous temperature change it thus undergoes causes an inordinate amount of expansion, with subsequent contraction on recooling capable of inducing mechanical strain in the system. It will be recognized that, when cryogenic electrical conduits running over hundreds of meters are provided, both mechanical and electrical failure may be encountered at myriad locations along their lengths, necessitating replacement of wires or pipes. In each case the warming and recooling of the entire length thus take weeks if mechanical stress is to be held to a minimum.

When liquefied helium is used as coolant, it being cooler than 4.1° Kelvin, other problems are encountered. Because of its low latent heat of vaporization, any notable heating of this liquid causes it to vaporize, so that a two-phase cryogen results. It is difficult and uneconomical to circulate a two-phase, gas liquid mixture, especially because turbulence is promoted in constructed or partly obstructed channels, so that the cooling efficiency is greatly impaired.

This difficulty is avoided by using liquid nitrogen and/or liquid hydrogen, usually the latter because of its excellent insulating properties. Such a solution, however, is not without its own disadvantages. Hydrogen is a dangerous substance, difficult to contain in its gaseous state and capable of exploding.

Efficient cooling demands, however, that the latent heat of vaporization be utilizable or available in reserve, so that liquid coolants are necessary.

At present new materials have been developed which have superconductive transition temperatures in the vicinity of 14° Kelvin to 20° Kelvin. For such conductors, hydrogen, whose triple point lies around 14° Kelvin, is an excellent coolant, if safety factors are not involved. Also, it is of paramount importance that the coolant contacting the conductor be a liquid since the heat must be removed from the limited surface area of this conductor as rapidly as possible.

OBJECTS OF THE INVENTION

It is, therefore, an object of the present invention to provide an improved cryogenic conduit assembly for conducting electricity.

Another object is to provide such an assembly which overcomes the above-given disadvantages.

SUMMARY OF THE INVENTION

The above objects are obtained, according to the present invention, by a system which is based on two main ideas. The first of these involves the separation of the coolant circulated through the refrigerator from a coolant contacting the conductor. The other new concept, to be combined with the first, is the complete compartmentalization of the separate conductors so that one conductor can be serviced without taking the others out of service and risking all of the thereto inherent difficulties.

Thus, the assembly according to the present invention comprises an elongated insulating duct, tube means extending longitudinally through the duct and provided with a longitudinally extending heat-conductive partition for subdividing this duct transversely into two longitudinal compartments, one of which receives a conductor and the other of which serves for the circulation of a cryogen.

The heat-transfer medium circulated in the compartment housing the conductor is chosen from among those liquefied gases which have a relatively high heat of vaporization, good electrical insulating properties, and a good heat-transfer coefficient. Liquid hydrogen, according to another feature of the invention, is used here. The coolant (cooling medium) which is circulated through the other compartment is chosen for the ease with which it can be pumped through, and with which it can be cooled for recirculation. Gaseous helium, which provides low temperatures but has a lower heat of vaporization and poorer electrical insulation quality, is used in this case, in accordance with a further feature of this invention. Thus, the heat of the conductor is drawn off by the liquid hydrogen and transferred through the heat-conductive partition to the gaseous helium, whence it is removed by constant circulation and refrigeration of this latter cryogen. Since no conductor is mounted in the compartment through which the helim is circulated, and since none of the conductor supports are in this compartment either, the helium can be pumped through at relatively high speed for extremely efficient heat removal without the danger of electrical breakdown through the helium.

According to another feature of this invention the coolant contacting the conductor is also circulated at slow speed through its compartment, in the opposite direction from that of the cooling cryogen. It is also possible to provide a plurality of such compartments and conductors and to simply circulate the liquid

hydrogen back and forth in the assembly, without ever drawing it out to refrigerate it. Even should the hydrogen vaporize at some point, thereby producing a considerable cooling effect because of its high latent heat of vaporization, it quickly condenses on the compartment walls upon absorption of this quantity of heat through the wall by the helium.

The compartmentalization of the assembly, according to another feature of this invention, is embodied in longitudinally extending and transversely extending dividing walls which subdivide the interior of the duct at the joints between duct sections into a plurality of hermetically independent zones. Each zone is provided with conduit and valve means permitting it to be sealed off at the joint from the duct interior, although under normal operation all the zones and the interiors of the duct sections are interconnected so that they can be evacuated together, or flooded with the same gas. In this manner, for repairs a section of conductor can be removed and replaced without putting the whole assembly out of operation, or even warming up much other than the one zone in which a new conductor is required. The duct is formed in sections separated by joints which can be disassembled to gain access to any of the zones, via removable plates which correspond each to one zone. Of course, the entire tube and its conductor can also be removed and replaced in this manner if necessary.

In accordance with another feature of this invention the duct is provided with a throughgoing conduit in heat-conducting engagement with its wall and through which the gaseous helium is circulated to cool this tube. The duct includes a pair of nested and coaxial tubes defining an elongated annular chamber which is evacuated and which receives reflective insulation.

DESCRIPTION OF THE FIGURES

The above and other objects, features, and advantages will become apparent from the following description, reference being made to the accompanying drawing in which:

FIG. **1** is a side view, partly in section, of an assembly according to the present invention;

FIG. **2** is a section taken along line II—II of FIG. **1**, in enlarged scale;

FIG. **3** is a view similar to FIG. **2** showing an alternative embodiment of the present invention;

FIGS. **4** and **5** are sectional views taken along line IV—IV of FIG. **1** and line V-V of FIG. **4**, respectively;

FIG. **6** is a diagrammatic view illustrating the hookup of the present invention; and

FIG. **7** is a sectional view through another tube structure according to the present invention.

SPECIFIC DESCRIPTION

As shown in FIGS. **1–4** the cryogenic assembly has an outer duct formed by a pair of nested and coaxial steel tubes **1** and **2** defining an annular chamber **40** in which a sleeve of reflective cellular insulation **3**, constituting a mechanical and radiation barrier to heat transfer (see U.S. Pat. No. 3,512,581), is provided. Pumps **4** are provided to evacuate this chamber **40**. The duct is subdivided into sections having ends **5** joined by coupling arrangements **6**. The length of each section is equal approximately to the length of the flexible conductors employed, thereby providing a tube connection wherever the conductors are joined.

Within the inner tube **2**, as best shown in FIG. **2**, are three spaced steel tubes **11** each transversely subdivided into longitudinally extending compartments **7** and **9** by a partition **10**. A conductor **8**, supported on a plurality of three-legged insulating spiders **37** extends longitudinally through each of the compartments **7**.

The tubes **11** are not in contact with the tube **2**, but a conduit tube **12** which serves to cool this tube **2** is in heat-exchanging engagement therewith.

FIG. **3** shows how a single tube **11'** can be provided with three partitions **10'** which subdivide its interior up into one conductor-free coolant-circulation compartment **9'** and three conductor-receiving compartments **7'**. In FIG. **7** there is shown how each tube **11''** can be provided in its interior with a coaxial partition tube **10''** subdividing it up into a coolant compartment **7''** and a conductor compartment **9''**. Of course, several tubes **10''** can be provided in one each tube **11''**.

FIG. **6** shows how the compartments are coupled for operation of the assembly. A cryogenic refrigerator **31**, for example of the nitrogen-cooled type, is connected in series with a pump **32** to force cooled gaseous helium rapidly through all of the compartments **9** and through the tube **12** in the same direction, here from right to left. The liquid hydrogen in the compartments **7** can either be circulated slowly countercurrent to the helium by a pump **35** or two of the compartments **7** can be connected together at one end by a conduit **33** and a pump **34** provided at the other end to circulate the liquid hydrogen through one of these compartments **7** in one direction and back through the other in the opposite direction. As mentioned above, the liquid hydrogen serves mainly to abstract the heat away from its conductor **8** and transmit it to the helium in the compartment **9**, so that it need not circulate rapidly, whereas this helium is rapidly circulated and cooled for most efficient operation. The complete lack of obstructions, such as the spiders **37**, in the compartments **9** makes this rapid circulation possible, even where the coolant is present in two phases (i.e., is a gas/liquid mixture).

FIGS. **4** and **5** show the coupling **6** joining the two bell ends **5** of the separate sections of the assembly. The interior **41** of the tube **2** is subdivided in the region of this coupling **6** into four longitudinally extending sectoral compartments or zones **42***a–d* by heat-conducting walls **13**. Arcuate cover plates **14** are hermetically bolted over each of the zones to seal them. Poor heat-conducting serrated walls **16** substantially in line with the walls **13** hermetically divide the annular chamber between the cylindrical extension **15** of the tube **1** and the covers **14** into four compartments or zones **43***a–d* also. The compartments **9** pass through the coupling **6** in the form of independent tubes **9***a* connected to tube ends **7***a* via heat-conducting removable partitions **17**. The ends **12***a* of the tube **12** are connected via a removable heat-conducting web **18** to the crossing point of the walls **13**, to cool them. Each of the three tube pairs **7***a*, **9***a* are in one zone **42***a–c* and the tube ends **12***a* are in a separate longitudinally extending zone **42***d* accessible through respective removable plates **14** which are bolted in place.

The tubes **1** and **2** are each sealed off at the end of each section by a transverse wall **19** provided with feed-through flange sleeves **20** which tightly engage the tubes **11** and **12**. Thus, the interior **41** of the tube **2** is hermetically sealed, except for four conduits **21** communicating with the zones **42***a–d* and provided with shutoff valves **23**. The annular chamber **40** is similarly sealed off by the wall **19** and communicates at each end through conduits **22** provided with shutoff valves **24** to the zones **43***a–d*.

Arcuate reflective insulation plates **29**, corresponding to the insulation **3**, are provided in the chambers **43***a–d* under the removable arcuate cover plates **28** in line with the tube **1**. The annular chamber **25** defined between the plates **6***a* and the plates **1** is hermetically sealed but only filled with normal air at ambient temperature and pressure.

Each of the tubes **7***a* and the tube **12***a* are provided at their ends with small radially extending flanges **26** interconnected by tube sections **27**, all bolted together. The conductors **8** are joined by a weld **8***a*, and the tubes **9***a* are provided at their ends with small flanges **30** adapted to be welded together.

Thus, should one of the conductors **8** fail, the position of the breakdown is located by thermally checking the assembly along its length. Then the cover **6***a* corresponding to the defective conductor **8** at the joint **6** to each side of the breakdown area is removed. This exposes at each joint two valves **24**, which are closed. The cover **28** is unbolted and removed and the insulation plates **29** underneath are lifted out. The two valves **23** thus exposed are then closed and the exposed cover **14** unbolted and removed. The liquid hydrogen in the conductor compartment **7** is advantageously flushed out with some harmless gas as helium, and the tube section **27** is opened to expose the joint **8***a*.

Both ends of the defective conductor **8***a* are thus exposed, so they need merely be cut so that it can be pulled out, another inserted in its place, and the above operations carried out in reverse to close up the joints. It is important to flush the conduit **9** out with a virtually unfreezable gas such as helium to prevent the formation of solidified air (slush) in this compartment **9**, and the vacuum is restored in each of the zones through opening of the valves **23** and **24** as the joint is reassembled.

Of course, an entire tube **11** or **12** can be similarly replaced. It is necessary to use flexible tubing for such replacement since rigid tubing is impossible to feed in from the side. In this case loosenable seals are provided at the feed-throughs **20**.

It should be clear that with such a system one of the conductors can be replaced without even shutting down the others. The division of the joints into separate zones **42***a–d* makes it possible, with a minimal loss of refrigeration, to replace a conductor without compromising the vacuum of the assembly in general or having to let any unnecessary portions of the assembly warm up. The downtime is cut to the bare minimum. When only two of the conductors are used in normal service, the third one can constitute a reserve conductor to prevent any difficulties in case one of the conductors need be serviced.

I claim:

1. A cryogenic assembly for conducting electricity, comprising:

an outer pipe;

a tubular heat-radiation-blocking shield coaxially received within said pipe and spaced therefrom with all-around clearance;

a tubular body of thermal insulation received within and filling a substantial part of said clearance;

a tube extending longitudinally through said shield in spaced relationship therewith and provided with at least one longitudinally extending heat-conductive partition for subdividing said tube transversely into at least two longitudinal compartments;

an electrical conductor in one of said compartments extending longitudinally through said tube; and

pump means for circulating a cryogen longitudinally through the other of said compartments out of contact with said conductor but in heat-exchanging relation therewith only through said partition, said one compartment being filled with a heat-transfer liquid in direct contact with said conductor.

2. The assembly defined in claim **1** wherein said pump means includes means for circulating a second cryogen forming said liquid through said one of said compartments and means for cooling only the first-mentioned cryogen.

3. The assembly defined in claim **2** wherein the cryogen in the compartment with the conductor is liquid hydrogen.

4. The assembly defined in claim **2** wherein the cryogen in said other compartment is gaseous helium.

5. The assembly defined in claim **1** wherein said tube includes at least four such compartments arranged in pairs and separated by a least two such partitions, said assembly including at least two conductors each passing through one of the compartments of each pair, whereby two conductor-receiving and two cryogen-circulating compartments are formed, said pump means being effective to circulate said cryogen longitudinally through one of said cryogen-circulating compartments in one direction and to circulate the same cryogen-circulating back through the other of said cryogen compartments in the opposite direction.

6. The assembly defined in claim **1** wherein said pipe includes a plurality of sections connected at joints and a pair of longitudinally spaced transverse walls flanking said joint and defining an hermetically closed region in said duct at said joint, said assembly further comprising means at said joint for gaining access to the interior of said region.

7. The assembly defined in claim **6** wherein said tube includes at least four such compartments arranged in pairs and separated by at least two such partitions, said assembly including at least two conductors each passing through one of the compartments of each pair and at least one longitudinal wall extending between said transverse walls and defining a pair of longitudinal zones, each pair of compartments being in one of said zones, said means at said joint including at least two removable covers constituting part of said duct each over one of said longitudinal zones.

8. The assembly defined in claim **6**, further comprising a conduit apart from said tube extending longitudinally through said duct, and means for cooling a cryogen and circulating same through said conduit, said conduit engaging said duct in heat-conducting relationship between said joints, said assembly includ-

ing one such longitudinal wall between said transverse joints defining another longitudinal zone, said conduit passing longitudinally through said other longitudinal zone and being in direct heat-conducting relationship with said longitudinal walls.

9. The assembly defined in claim 6, further comprising respective valve and conduit means between each of said longitudinal zones and the interior of said duct for interconnecting same in an open position and hermetically sealing same off from each other in a closed position.

* * * * *