Nov. 15, 1966 J. E. C. W. WILLIAMS 3,286,014

CRYOSTAT WITH COOLING MEANS

Filed Feb. 24, 1964 3 Sheets-Sheet 1

FIG. 1.

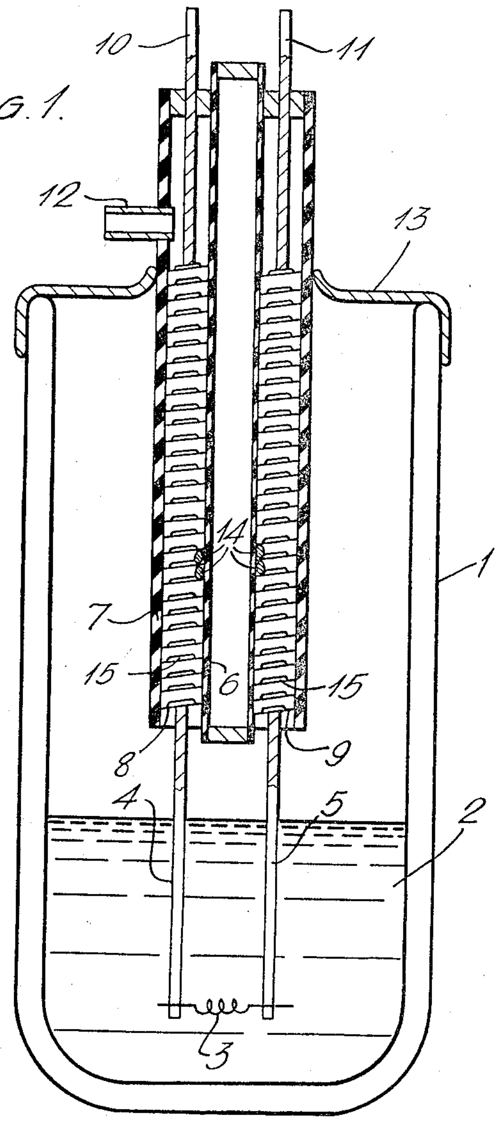

FIG. 2.

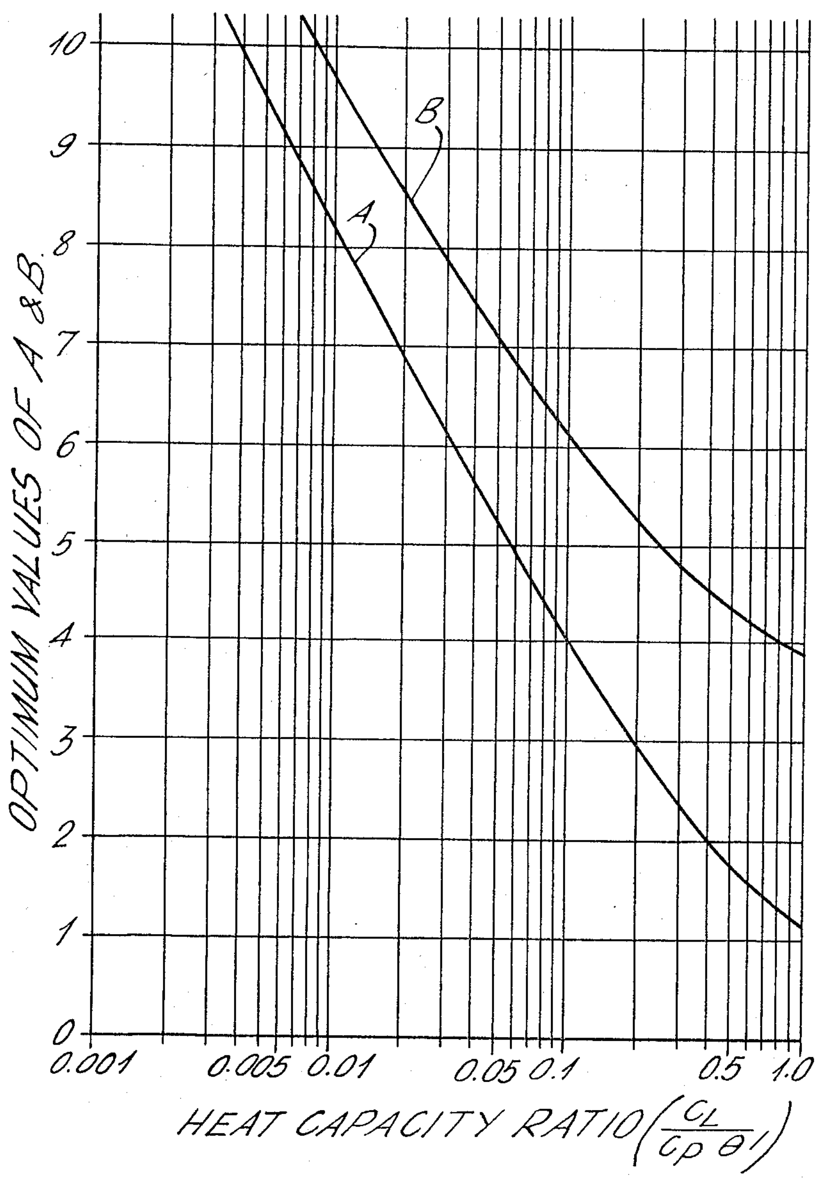
OPTIMUM VALUES OF A & B
10
9
8
7
6
5
4
3
2
1
0
A
B
0.001
0.005
0.01
0.05
0.1
0.5
1.0
HEAT CAPACITY RATIO $\left(\frac{C_L}{C_p \theta 1}\right)$

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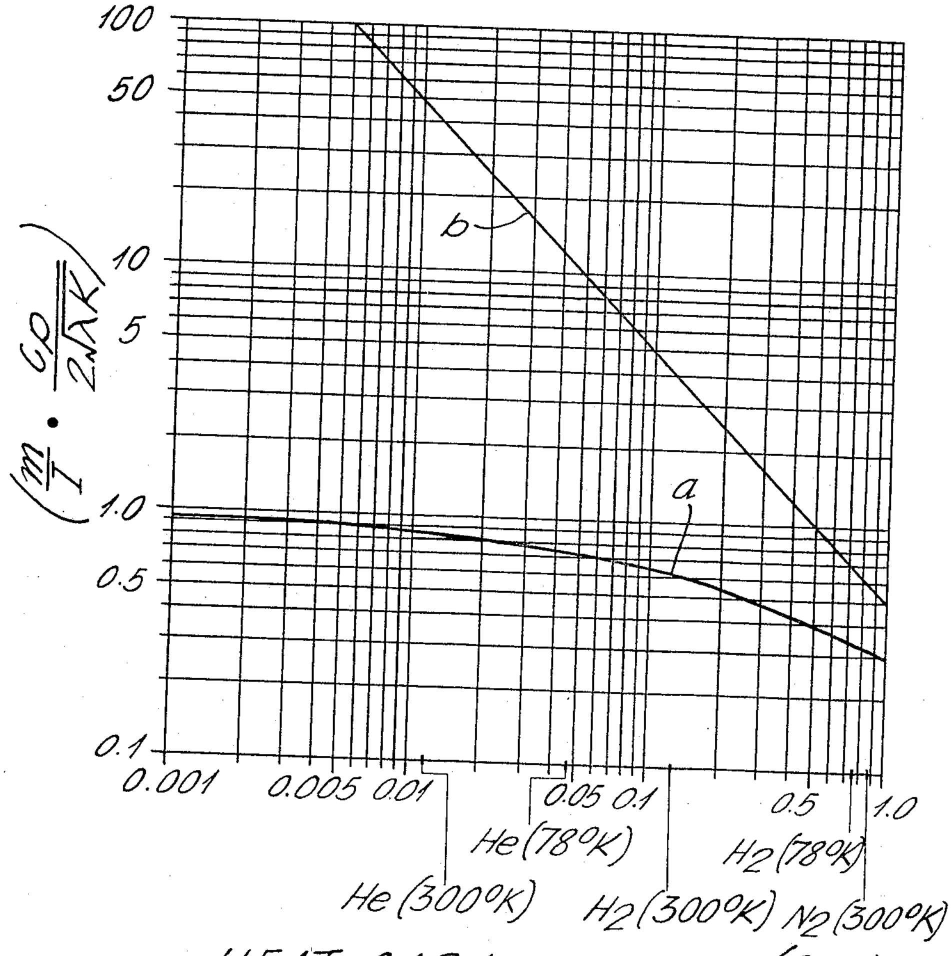
FIG. 3.



HEAT CAPACITY RATIO $\left(\frac{c_L}{c_p \theta'}\right)$

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CRYOSTAT WITH COOLING MEANS

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9 Claims. (Cl. 174—15)

This invention relates to electrical connectors for cryostats.

When current is fed by way of conductors to a current utilisation device immersed in a cryogenic liquid, for example liquid helium, contained in a cryostat, the ohmic heat generated in the conductors tends to pass along them to the liquid and so increases the loss of liquid by evaporation.

It is an object of the present invention to provide a connector of a form which permits this loss to be reduced.

According to the present invention an electrical connector for supplying current to a current utilisation device in a cryostat comprises a duct through which gas evaporating from a cryogenic liquid therein may leave the cryostat, and at least one electrical conductor extending along the duct in such manner as to be in heat-exchange relationship with the gas flowing therethrough.

According to a feature of the present invention an electrical connector supplying current to a current utilisation device in a cryostat comprises two concentric cylinders made of electrically and thermally insulating material, and at least one electrically conducting strip edge-wound between the cylinders to define therewith at least one helical duct through which gas evaporating from the cryostat may flow in heat-exchange relationship with the strip.

The connector may include two or more such strips wound in the manner of a multi-start thread. Preferably the strip is of copper and has a crinkled surface to increase the heat exchange.

A short length at one end of the inner cylinder may be of thermally conducting material and have the turns thereon of said strip thermally connected thereto, whereby heat may be conducted from a body within the cryostat thermally connected to said portion, and removed by the evaporating gas.

An electrical connector for a cryostat, the connector being in accordance with the present invention, will now be described by way of example with reference to the accompanying drawings, in which:

FIGURE 1 is a sectional elevation of a cryostat having such a connector,

FIGURE 2 shows graphs used to optimise the dimensions of the connector, and

FIGURE 3 shows graphs comparing the performance of the present connector with a conventional connector.

Referring to FIGURE 1, a cryostat shown as a Dewar flask **1** contains liquid helium, reference **2**, in which is immersed a current utilisation device **3** whose properties at the temperature of the liquid helium are being measured. Current is supplied to the device **3** by way of twin copper leads **4** and **5**. It is to be understood that although shown as a coil, the device **3** may be of any kind requiring a supply of current.

Above the surface of the liquid helium **2**, the upper ends of the leads **4** and **5** are taken to a connector comprising concentric cylinders **6** and **7** made of synthetic resin bonded paper, which has good thermal and electrical insulating properties, the annular space between which contains two copper strips **8** and **9** helically wound edge-on to the cylinders **6** and **7** in the manner of a two-start thread. Leads **4** and **5** are soldered to the lower ends of strips **8** and **9** respectively, to whose upper ends

are soldered leads **10** and **11** for connection to an external circuit.

The described assembly is constructed by first winding the strips **8** and **9** one the cylinder **6**, the turns being spaced by winding a cotton thread between them (two turns of thread are shown to an enlarged scale at **14**), and then adding the cylinder **7**, which is a tight fit on the outer edges of the strips **8** and **9**. The strips **8** and **9** with the cylinders **6** and **7** therefore define two helical ducts.

The cylinder **6** is closed at both ends as shown, but the annular space between the cylinders **6** and **7** is closed at the upper end only. A vent pipe **12** is sealed into the cylinder **7** above the strips **8** and **9**. The complete connector assembly is sealed to the top of the cryostat **1** by a rubber diaphragm **13** which meets the cylinder **7** just below the vent pipe **12**. The liquid helium siphon or transfer tube is omitted for simplicity.

In operation, the current supplied to the device **3** by way of the strips **8** and **9** inevitably produces ohmic heating therein, and this heat tends to be conducted down the leads **4** and **5** into the liquid helium **2** to increase the loss thereof by evaporation.

In the present arrangement, however the evaporated helium gas leaves the vessel **1** through the two helical ducts, and in so doing extracts heat from the strips **8** and **9** and so reduces the heat conducted to the liquid helium **2**. Some of the evaporated gas also leaves the cryostat via holes (not shown) in the diaphragm **13** after flowing up past the wall of the vessel **1** to reduce the conduction of heat down the wall. The proportions of gas which flow through the connector and diaphragm **13** respectively can be adjusted experimentally to obtain the minimum overall flow-rate. To promote good heat exchange with the ascending gas, the strips **8** and **9** are preferably of the crinkled copper type normally used as heat-exchanger finning, the crinkling being shown at **15**. The gas leaves the connector through the pipe **12**, whence it may be collected if desired.

The optimum dimensions of the strips **8** and **9**, in relation to a given current, for minimum gas flow from a given cryogenic liquid, can be determined in the following manner.

Making certain approximations and assumptions which turn out to be justified in practice, it is possible to derive two quantities A and B given by the following expressions:

$$A=\frac{mC_P l}{K_a},\quad B=2\sqrt{\frac{\lambda}{K}}I\frac{l}{a}$$

where:

m is the gas mass-flow rate,
C_P is the gas specific heat at constant pressure,
l is the length of each strip,
K is the total effective thermal conductivity of the assembled connector,
a is the cross-sectional area of the strip material,
λ is a mean value of the increase in resistivity per degree Kelvin between the temperatures of the upper and lower ends of the strip,
I is the current flowing in each strip.

In addition,

C_L is the latent heat of evaporation and

$$t'=t_H-t_C$$

where:

t_H is the temperature of the hot (upper) end of each strip **8** and **9**, normally room temperature, and
t_C is the temperature of the liquid helium **2**.

The optimum dimensions for the strips **8** and **9** can be derived from that value of l/a which for a defined current

I and a liquid defined by its heat capacity ratio C_L/C_Pt', makes the mass-flow rate a minimum. Optimised values of A and B as a function of heat capacity ratio are plotted in FIGURE 2. The optimum value of l/a can be derived from the optimum value of B by substituting therein the known values of I, λ and K. By further substituting this value of l/a, together with C_P and K, into the corresponding optimum value of A, the minimum mass-flow rate of gas for the given conditions can be found.

FIGURE 3 illustrates the improvement obtained with the present connector, curve *a*, as compared with "straight" leads, curve *b*, not cooled by the evaporating gas. FIGURE 3 is a plot of the specific flow parameter

$$\frac{m}{I}\cdot\frac{C_P}{2\sqrt{\lambda K}}$$

as a function of the heat capacity ratio. It will be seen that with helium for example, with $t'=300°$ K., the rate of evaporation m for a given value of I can be approximately 40 times as great with "straight" leads as with the present connector.

As an example of the use of FIGURE 2, the optimum value of l/a will be determined for strips carrying 20 amperes. The cryogenic liquid is helium and the hot end temperature (t_H) taken as 300° K.

Taking

$$C_L=0.9 \text{ joules/gram}$$

$$C_P=6.0 \text{ joules/grams/° K.}$$

and

$$t'=295.8°$$

then

$$C_L/C_Pt'=0.012$$

From FIGURE 2, the optimum value of B is 9.4 and of A is 7.85.

Assuming the strip material to be copper and taking

$$K=4.0 \text{ watts/cm/° K. (the value for copper)}$$

and

$$\lambda=0.005\times10^{-6}\Omega\text{cm./° K.}$$

over the temperature range in question,

$$l/a=\frac{B}{I}\cdot\frac{1}{2}\sqrt{\frac{K}{\lambda}}\doteq6700 \text{ cm.}^{-1}$$

whence

$$m=\frac{A.K}{C_P}\cdot\frac{a}{l}\doteq0.00079 \text{ gms./sec.}$$

(This value of m can also be obtained from FIGURE 3).

Using copper strip 1 cm. wide and 10^{-2} cm. thick

$$\begin{aligned} l&=a\times6700 \text{ cm.}\\ &=10^{-2}\times6700 \text{ cm.}\\ &=67 \text{ cms.}\end{aligned}$$

Hence the length of each of the strips **8** and **9**, prior to winding, should be 67 cms. This value only applies accurately where the strips **8** and **9** are wound to a coarse pitch, as explained below. Using pre-curved crinkled heat-exchanger strip, this length is measured along the outside edge of the strips **8** and **9**.

It is found that, if K is taken as the thermal conductivity of the strip material alone, as in the above example, the theory is only accurate when the strips are wound to a coarse pitch, say greater than 45°. This is because the presence of the cylinders **6** and **7** increases the effective thermal conductivity of the connector and in cases where the pitch of the strips **8** and **9** is small, this increase can be quite large. From the quantities, involved in the specific flow parameter, it can be seen that an increase in the thermal conductivity results in an increase in the flow rate. This effect can be reduced by the use of a thin metallic cylinder in place of the synthetic resin bonded paper cylinders **6** and **7**. In this case the effective thermal conductivity of the connector is increased, but now the effective electrical resistivity of the connector is proportionately decreased, so that the product λK is substantially unchanged. A part of the current will of course flow in the metallic cylinders and so the connector can now only contain one of the current leads to the current utilisation device **3**.

The effective thermal conductivity of the connector is also increased by the presence of the gas flowing in the helical ducts. Since this gas is essential to the action of the connector, some increase in the effective thermal conductivity above that of the strips **8** and **9** alone is inevitable, but it is desirable that this increase be minimised. The gas is normally turbulent and in this state constitutes a partial thermal short circuit between adjacent turns of the strips **8** and **9**, this being particularly pronounced when the pitch is small. In a two duct connector as described above the effect is reduced by blocking one of the helical ducts from end to end with a loose matrix of material of low thermal conductivity, such as glass fibre. In this way a barrier of stagnant gas, of much lower thermal conductivity than turbulent gas, is interposed between every other turn of the strips **8** and **9**. However, turbulent gas flows over one surface of each of the strips **8** and **9**, giving good heat exchange between the strips **8** and **9** and the gas.

The effective thermal capacity (K) of an actual connector is given more accurately by:

$$K_1+K_2\frac{l_1}{a_1}\cdot\frac{a_2}{l_2}+K_3\cdot\frac{l_1}{a_1}\cdot\frac{a_3}{l_3}$$

the subscripts 1, 2 and 3 referring to the strips **8** and **9**, the cylinders **6** and **7**, and gas, respectively.

It is not essential for the strips **8** and **9** to be wound helically as they may be arranged to be straight, so as to define straight ducts for the gas.

In a modified form the present invention can be used to reduce the quantity of cryogenic liquid needed to cool down a large body. In this modified form a short length at the lower end of cylinder **6** is replaced by a copper tube to which the lowermost turns of one of the strips **8** or **9** are soldered, the corresponding turns of the other strip **9** or **8** being electrically insulated thereform. The copper tube is thermally connected to the body to be cooled so that heat is conducted from the body to the turns soldered thereto. The evaporating gas absorbs this heat in the small heater-exchanger thus formed at the lower end of the connector.

Normally the connector contains both of the current leads to the specimen, but as mentioned above it may contain only a single lead, in which case two such connectors may be sealed into the cryostat to supply the specimen. Alternatively the connector may contain three or more leads as required.

Connectors as described above may be used with advantage in open and closed loop systems, that is to say, irrespective of whether the evaporated gas is lost to the atmosphere or is re-used.

I claim:

1. In a cryostat containing a cryogenic liquid, an electrical connector for supplying current to a current utilization device immersed in said cryogenic liquid, comprising, two concentric cylinders made of electrically and thermally insulating material, and at least one electrically conducting strip edge-wound between said cylinders to define therewith at least one helical duct through which gas evaporating from said cryogenic liquid leaves the cryostat and in so doing flows in heat exchange relationship with said strip.

2. A cryostat as claimed in claim **1** wherein the said strip has a crinkled surface to increase the heat exchange.

3. A cryostat as claimed in claim **2** wherein the said electrically conducting strip is copper.

4. In a cryostat containing a cryogenic liquid, an electrical connector for supplying current to a current utilization device immersed in said cryogenic liquid, comprising, two concentric cylinders made of electrically and thermally insulating material, and at least two electrically conducting strips edge-wound between said cylinders as a multi-start helix to define therewith at least two helical ducts through which gas evaporating from said cryogenic liquid leaves the cryostat and in so doing flows in heat exchange relationship with said strips.

5. A cryostat as claimed in claim **4** wherein the said strips have a crinkled surface to increase the heat exchange.

6. A cryostat as claimed in claim **4** wherein the said electrically conducting strips are copper.

7. In a cryostat containing a cryogenic liquid, an electrical connector for supplying current to a current utilization device immersed in said cryogenic liquid, comprising inner and outer concentric cylinders, said inner cylinder having an end portion made of thermally conducting material, said outer cylinder and the remaining portions of the inner cylinder being made of electrically and thermally insulating material, an electrically conducting strip edge-wound between said cylinders to define therewith a helical duct through which gas evaporating from said cryogenic liquid leaves the cryostat and in so doing

flows in heat exchange relationship with said strip, said device and that part of said strip which is wound on said end portion of the inner cylinder being thermally connected to said end portion.

8. A cryostat as claimed in claim **7** wherein the said strip has a crinkled surface to increase the heat exchange.

9. A cryostat as claimed in claim **7** wherein the said electrically conducting strip is copper.

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