HELIUM VAPOR-COOLED CURRENT LEADS FOR THE RIKEN SRC *

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Abstract

The conventional vapor-cooled current leads have been applied for use in the RIKEN Superconducting Ring Cyclotron (SRC). In particular, two different type current leads have been developed and tested for the relatively small current capacities from 100A to 500 A.

INTRODUCTION

The conventional vapor-cooled current leads are to be used in the RIKEN Superconducting Ring Cyclotron (SRC) [1] – [3]. Six current leads of different current capacities are required to satisfy the requirements for superconducting magnets of the RIKEN SRC. These are listed in Table 1. Current leads are designed to minimize the total heat load on the cryogenic system. This was done by choosing a shape factor defined as LI/A (L: length, A: cross-section, I: current) and a flow rate of GHe [4] – [7]. An operating mass flow of 0.060 g/sec/kA (1.2 W/kA), 20 % above the theoretical minimum flow and heat input of 0.050 g/sec/kA (1.0 W/kA) was expected for SRC current leads. An additional requirement for the 5200 A leads is that the leads must sustain the operating current for 10 minutes after interruption of cooling flow. It was also expected that the frost build-up be kept to a minimum.

INTERRUPTION TIME OF COOLING FLOW

During the cut-off process of the current supply, the current through leads is expressed as follows,

$$I(t) = I_0 e^{-\frac{t}{\tau}} = I_0 e^{-\frac{R}{L}t} \qquad (1)$$

where τ is the time constant, R is the dump resistance and L is the inductance of coil. Therefore, the total energy dissipated on the current lead with resistance of r_L is expressed as follows,

$$E = r_L \int_0^\infty \{I(t)\}^2 dt = r_L \int_0^\infty I_0^{\,2} e^{-\frac{2t}{\tau}} dt = \frac{\tau}{2} r_L I_0^{\,2} \qquad (2)$$

As a result, it is realized that a half time of the time constant corresponds to the interruption time of cooling flow. The time constant, τ = L/R =18.8 H/0.015 Ω = 1250 sec of slow cut-off of the current supply of the SRC main coil results on the interruption time of about 10 min. In addition, the interruption times of 10 min is enough for current leads of other coils with the shorter time constant due to smaller inductances.

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Table 1: Current leads for SRC

Current	Quantity	Length	Function
5200 A	2	≈1670 mm	Main coil
4200 A	3	≈1670 mm	Trim coil
3200 A	2	≈1670 mm	Trim coil
500 A	2	≈760 mm	SBM
400 A	2	≈1270 mm	Trim coil
100 A	11	≈1270 mm	Main & Trim
100 A	-	≈760 mm	Test model

CURRENT LEADS OF 5200, 4200 & 3200 A

The current leads with relatively large current capacities, 5200 A, 4200 A and 3200 A, were not newly developed. Those current leads of cable-in conduit (CIC) type with the specification of 1.4 W/kA were fabricated at the Fuji Electric Co.,Ltd. with the required specifications for the maximum voltage and the sustainable interruption time of GHe cooling flow.

FABRICATION OF CURRENT LEADS

Cable-in-conduit Type

The cable-in-conduit type leads which consists of 2mmϕ phosphorous deoxidized copper wires were applied for leads with the relatively small current capacities of 500 A (with 16 wires), 400 A (with 23 wires), and 100 A (with 6 wires). The electric resistivity of phosphorous deoxidized copper (C1220BD-H) were measured from the room temperature to 4.2 K, with the result of 2.1 × 10^{-9} Ωm @ 4.2 K and 1.77 × 10^{-8} Ωm @ 273 K. This measured electric resistivity of the phosphorous deoxidized copper is much smaller than some references of 6.7 × 10^{-9} Ωm @ 4.2 K, corresponding to LI/A = 286 × $(\rho_{4.2K})^{-0.5}$ = 3.5 × 10^{6} A/m [4], [6]. This means that the phosphorous deoxidized copper (C1220BD-H) in Japan is different from that in the foreign countries. Then, the shape factor LI/A of 7.6 × 10^{6} A/m was applied for this current leads.

The cross-section of 500 A leads for superconducting bending magnet (SBM) of the injection for SRC, which were fabricated at the Mitsubishi Electric Co. are shown in Fig. 1. The cross-sections of 400 A and 100 A leads for SRC had the similar structure. In addition, all soldering is applied with the Ag solder of the rather high melting temperature of about 700°C for safety.

Fin Type

As another candidate, the fin-type leads which had the straight thread cut into a conductor, were applied. The 100 A leads with the length of 760 mm were fabricated at RIKEN, as shown in Fig. 2. The shape factor LI/A of about 1.2 - 1.5 × 10^6 A/m is applied for these current leads made of brass (C1220BD-H).

EXPERIMENTAL SETUP FOR QUALITY MEASUREMENT

The experimental setup for the quality measurement of the current leads is shown in Fig. 3. In particular, the heat input due to the current leads was measured from the decreasing rate of the LHe level, using the measured relation between the LHe decreasing rate and the heater power in the LHe on the condition without the U-spahed conductor connecting both current leads. The measured results are shown in Fig. 4. The total heat input relating to the decreasing rate of the LHe level is the sum of the heater power and the heat leak into the LHe chamber due to the thermal conduction through the dewar wall, etc, which is decreased by the increase of the evaporated GHe. In Fig. 4, it is shown that the decrease of the intrinsic heat leak saturates at the heater power of about 1.9 W. The uncertainty of the measured relation between the LHe decreasing rate and the heater power, which is the main cause for the error of the measured data of the heat input due to the current leads, will attribute to the fact that the helium evaporation by heater is not in a completely steady state and the time constant to the quasi-steady state is long.

EXPERIMENTAL RESULTS

500 A, 400 A & 100 A Leads (cable-in-conduit type)

For a pair of 500 A leads, the heat input, pressure drop, voltage drop, etc. as a function of the He vapor mass flow were measured. The measured results are listed in Table 2. Measured heat input characteristics together with the self-cooling line expressed by $w = C_L m$, where w is the heat input, C_L (= 20.90 kJ/kg) is the latent heat of evaporation of liquid helium, and m is the mass flow rate, are shown in Fig. 5. It is also implied that the efficiency of heat transfer (or exchange) to evaporated He gas is about 50 %. Furthermore, the sustainable time of 10 minutes after interruption of cooling flow was confirmed experimentally.

The similar measurements for a pair of 400 A and three pairs of 100 A leads were made. The measured results are also listed in Table 2. The differences of the electrical

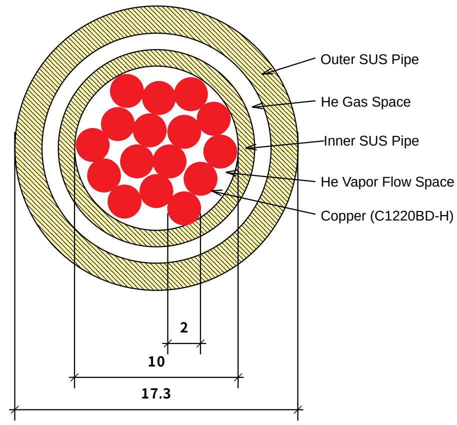

Fig. 1. Cross-sectional view of 500 A leads for SBM (cable-in-conduit type).

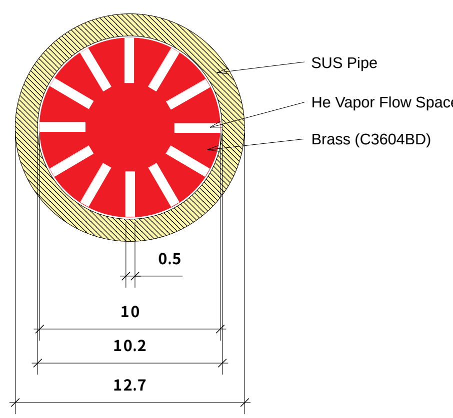

Fig. 2. Cross-sectional view of 100 A leads (fin-type).

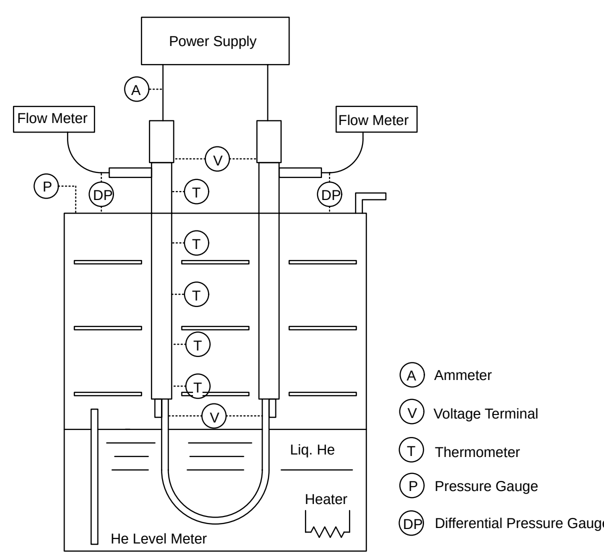

Fig. 3. Schematic layout of experimental setup for the quality measurement of the current leads.

and thermal characteristics among three pairs of 100 A leads were small.

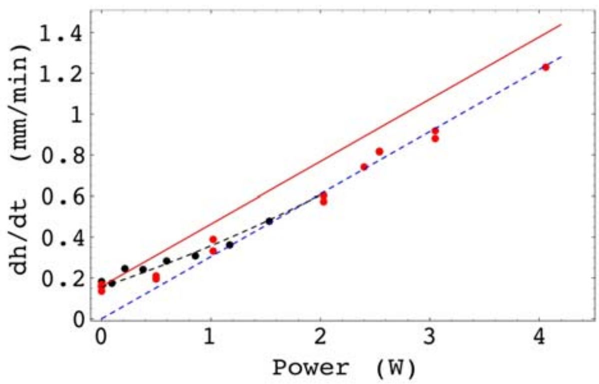

Fig. 4. Heater power v.s. decreasing rate of LHe level.

100 A Leads (fin type)

Similar measurements for a pair of 100 A leads of fin type were made. However, the measured results were scattered due to the small heat input compared to the background heat input of cryostat of about 1 W. The sustainable time of 10 minutes after interruption of cooling flow was also confirmed experimentally.

CONCLUSION

Both of cable-in-conduit and fin types of current leads were experimentally confirmed to be reliable for use in the SRC, and less sensitive to excess current with enough safety margin in the event of cooling gas flow stoppage. Unfortunately, it is implied that the heat leak is larger than the expected one. In addition, it is shown that the measurement accuracy for the heat leak has to be improved.

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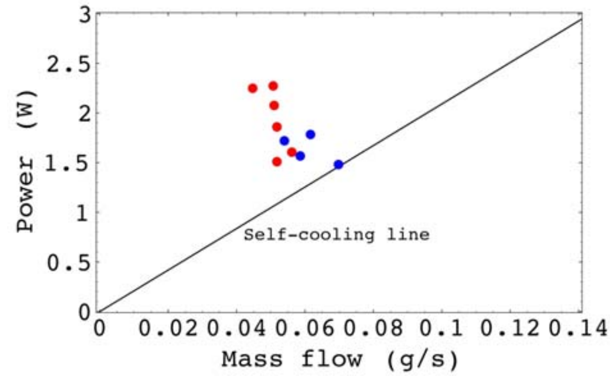

Fig. 5. Measured heat input characteristics for a pair of 500 A current leads (cable-in-conduit type).

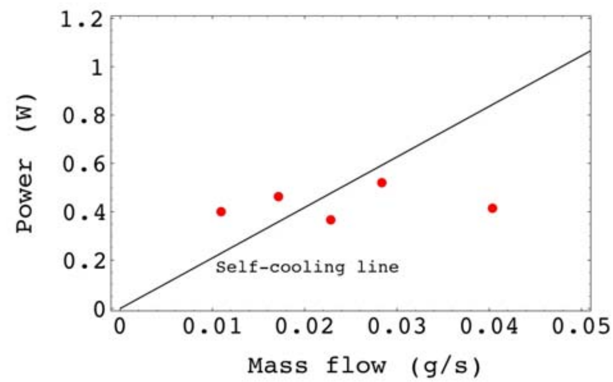

Fig. 6. Measured heat input characteristics for a pair of 100 A current leads (fin type).

Table 2: Measured Results of Current leads for SRC

Current capacity	**Heat input @mass flow**	**Pressure drop**	**Voltage drop**
3200–5200 A (CIC-type)	(1.4 W/kA*)	-	-
500 A (CIC-type)	1.6 W @0.059 g/s	0.7, 1.7 kPa	≈62 mV
400 A (CIC-type)	2.0 W @0.050 g/s	0.5, 0.5 kPa	≈80 mV
100 A (CIC-type)	0.5 W @0.015 g/s	0.3, 0.3 kPa	≈80 mV
100 A (fin-type)	0.4 W @0.012 g/s	0.5, 0.5 kPa	≈70 mV

* Designed value