Multi-tube power leads tower for BEPCII IR magnets

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A power lead tower containing the multi-tube power leads is designed and under fabrication for the superconducting IR quadrupole magnets in the Beijing Electron Position Collider Upgrade (BEPCII). The lead tower consists of six pairs of gas-cooled leads for seven superconducting coils at various operating currents. The power lead is designed in a modular fashion, which can be easily applied to suit different operating current. The end copper block of the tube lead has a large cold mass that provide a large time constant in case of cooling flow interruption. A novel cryogenic electrical isolator is used for the leads.

INTRODUCTION

The gas cooled single tube lead was first introduced to the superconducting magnet at the Brookhaven National Laboratory in early 1960s [1]. The gas cooled multi-tube lead was developed at BNL in 1994. Comparing with the single tube leads with a single flow passage, the multi-tube leads consisting of nesting tubes have the advantages of large wetted perimeter and then can carry more current flux with the same cross section area. A pair of multi-tube leads of 6300A for the Muon storage ring magnets and a pair

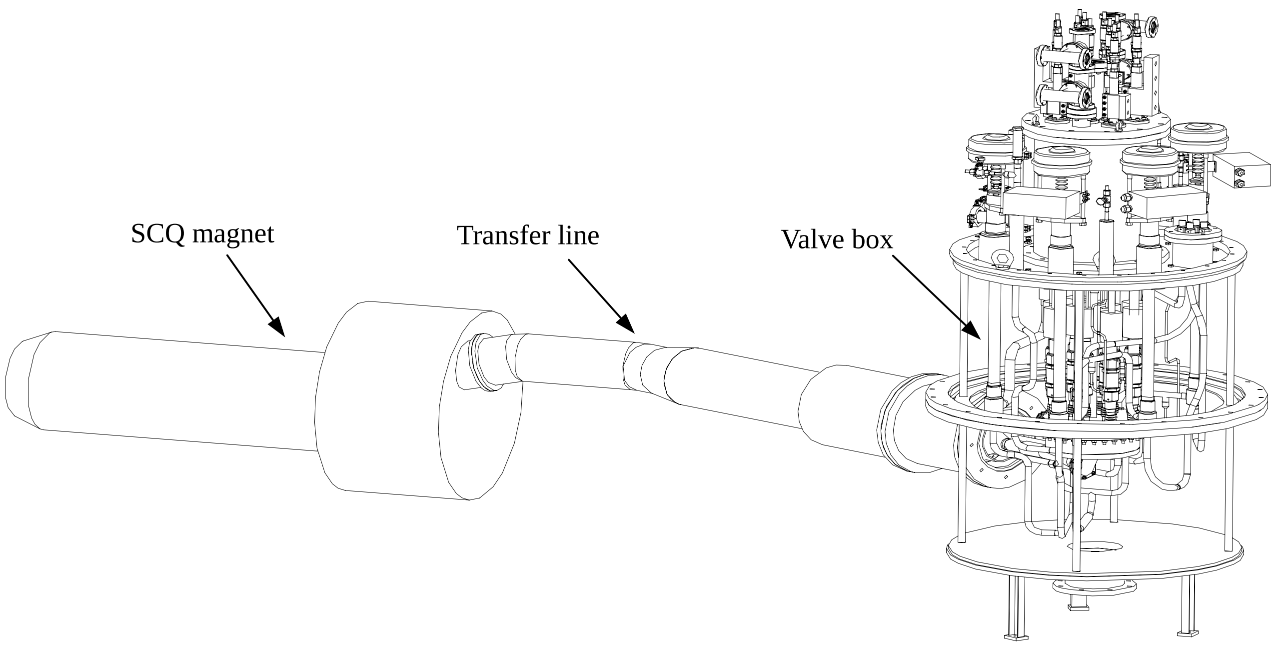

Figure 1 SCQ magnet, transfer line and distribution valve box

of 3300A multi-tube leads for Muon Inflector magnets were installed and operated successfully at BNL in 1994 [2]. The similar design was also applied to the EVA detector solenoid magnet at BNL in 1996 [3]. These magnets were all indirectly cooled by forced flow two-phase helium. For the BEPCII project, because of the similarity between BESIII detector magnet and the EVA magnet, the same design was applied. In the case of the BEPCII quadrupole magnet (SCQ) in the interaction region, which is cooled by supercritical helium, the multi-tube lead is modified. The SCQ magnet has seven coils requiring six pairs of leads. Table 1 gives the parameters of these coils and corresponding tube leads. These 6 pairs of leads are integrated into a lead tower. The superconducting cables run from the magnet end can through the transfer line and valve box to the lead tower (see Figure 1).

Table 1 Parameters of the coils and corresponding leads for the SCQ magnet in BEPCII

Magnet Circuit	SCB (HDC)	SQC	SKQ	VDC	AS1,AS2,AS3
Nominal Current (A)	550	550	65	65	1150,65,65
Design Current (A)	630	630	150	150	1600,150,150
Nominal Lead (#×A)	2×630	2×630	2×150	2×150	2×1600,2×150

Table 2 Dimensions of each copper tube for the BEPCII SCQ magnet leads
(OD: outer diameter; T: thickness; S: total area)

Leads	OD1 (mm)	T1 (mm)	OD2 (mm)	T2 (mm)	OD3 (mm)	T3 (mm)	OD4 (mm)	T4 (mm)	S (mm^2)
1600A	28.6	0.9	25.4	0.9	22.22	0.9	19.05	0.5	207.9
630A	19.05	0.65	15.88	0.65	12.7	0.7	9.52	0.5	95
150A	7.94	0.65	4.76	0.6					22.7

The multi-tube lead composes a set of concentric thin wall copper tubes. Copper tubes carry electrical current and the annular spaces between adjacent tubes provide helium flow channels. For the 1600A leads the four tubes are used, three are current carriers and the very inner one is used to only constitute the flow channel and filled with glass wool to dump the possible acoustic oscillation. The optimized wall thickness of copper tube and the annular space are configured according to the numerical computational simulation, which provides the guidance in selecting the commercial copper tubes [3]. Table 2 gives the dimensions of each copper tube for the BEPCII SCQ magnet leads.

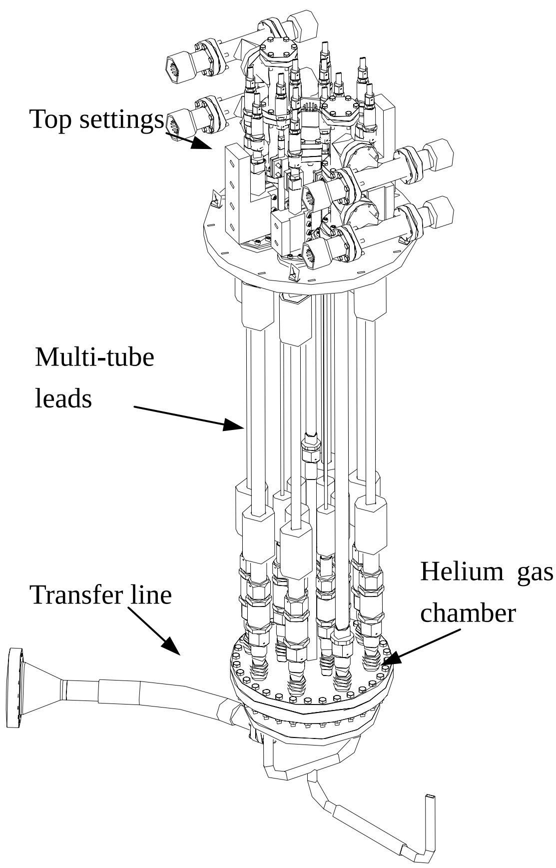

Figure 2 Lead tower of SCQ magnet

MULTI-TUBE LEAD TOWER

The lead tower is constructed as a single unit that is installed at the center of the valve box (see Figure 2). The lead tower can be disassembled from the vacuum chamber of the valve box. On the top warm flange of the lead tower, the six pairs of leads are mounted with the G-10 electrical insulators. Its top setting includes the copper bus bars in different sizes and currents, the helium cooling tubes electrically insulated through the G-10 tube insulators to the refrigeration system, and the electrical feedthroughs for the voltage tap wires from each coil and bus work in the cable transition lines. At the cold end, each tube leads are connected to the helium gas chamber that provides the helium cooing fluid. Each tube lead is electrically insulated to the helium chamber through the G-10 electrical insulators. The solder joint of the superconducting cable and tube lead is built in the helium chamber. All the tube leads are designed in the same length and connected to the common helium chamber regardless their operating currents. To compensate the differences of possible thermal stresses in different tube sets, the flexible sections are used in each tube lead.

CONFIGURATION OF TUBE LEADS

To provide the electrical carrier and the cooling flow passage through the multi-tubes is not a simple task. At lead ends, both at the top warm side and the bottom cold side, each tube must have large enough weld surface with a copper bock to reduce the electrical resistance. The copper block services as a tube holder. The stack of the copper blocks must be arranged as to provide a large enough internal flow cross section area for each annular cooling flow. And these copper blocks must be welded as a single unit to hold the tube set. Therefore, the welding procedure becomes critical in fabrication of the leads. A copper insert with a long tail at the cold end is used for attaching the superconducting cable. The smallest tube made of stainless steel provides an annular space at its outside. There is no cooling flow inside of this stainless steel tube. Figure 3 shows the configuration of the 1600A power lead for the SCQ magnet.

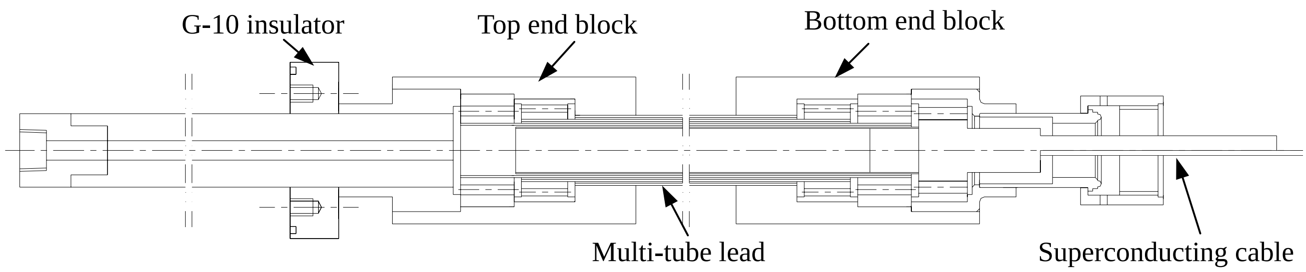

Figure 3 Configuration of 1600A power lead for SCQ magnet

The function of the bottom copper block is also to provide a large mass cold sink, which can stabilize the temperature in case of thermal disturbance. It can also delay the thermal run-away for a long enough time in case of cooling flow interruption. The whole copper block comprises four small cylindrical blocks which splice one by one and the most upper block envelopes the below ones with the hatch directing down. A group of holes is drilled on each small block, and a concaved room is provided to constitute the flow passages.

For electrical insulation to the cooling pipes connecting to the refrigeration system, the G-10 cryogenic tube insulators, instead of the ceramic ones, are used to prevent from crack failure due to thermal stress at low temperature. A cryogenic tube fitting is also used at the cold end for the convenience of reassembling the lead tower or replacing the lead set if a failure of a single lead occurs. Another feature of the design is to use a flexible section in each lead to compensate the differential stress among the tube sets.

The difficulties of fabricating the power lead tower are how to solder the copper block, especially the bottom block. Special attention should be pay to the soldering quality in the following aspects: 1) large contacting surface to reduce the electrical contact resistance; 2) the effective soldering strengths to withstand the thermal stress when being cooled down from the room temperature to the operating temperature; 3) good tightness for the outer soldering area to prevent helium leak.

CONCLUSION

The multi-tube power leads are used for the BEPCII superconducting magnets, including the IR quadrupole magnets and the detector solenoid magnet. The lead tower for quadrupole magnets consists of 6 pair of leads made in multi-tube sets. The leads was designed and under constructed at the Institute of Cryogenics and Superconductive Technology of HIT.

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