§32. Development of Current Leads Combined with the Pulse-Tube Cryocooler

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In operating usual large superconducting magnets such as LHD coils, the high current of 10 kA class is supplied through current leads into the cryogenic region from a power supply located at room temperature. The heat leak from the current leads causes a large load of the refrigeration system. Therefore it is necessary to reduce the heat leak from the current leads with a minimum refrigeration load for a low cost and stable operation of the superconducting magnet system. Several types of high temperature superconducting (HTS) current leads were developed for further reduction of the heat leak. The HTS conductor is employed in the HTS current leads in the temperature region below 50K, while the copper conductor feeds the current from a room temperature to the HTS conductor. Although a large reduction in the heat leak has been demonstrated in the operation of the HTS current leads, large heat load to the refrigeration system is still generated in the conventional copper conductor part.

In this work, we apply advantageous characteristics of a pulse-tube cryocooler to the copper conductor region of the 3kA HTS lead system for a reduction of the refrigeration load caused by with a compact structure.

Fig. 1 shows a schematic drawing of a pulse-tube current lead. The pulse-tube cryocooler consists of a pulse tube, a regenerator and warm-and cold heat exchangers without moving element in the cryogenic region. The copper-rod conductor is concentrically inserted into the pulse-tube. In this work, a calculation code was produced for briefly designing the pulse-tube current lead. In a calculation model, the pulse-tube current lead is divided into the conduction cooled current lead with the adiabatic condition and the pulse-tube cooler. The generalized one-dimensional heat conduction equation is solved for obtaining optimum values of the geometrical dimension and the heat leak at the cold end of the conduction cooled current lead. The geometrical dimension of the conductor is expressed by Il/s, where I, l and s are the operational current, length and cross-sectional area, respectively. The boundary values of temperatures at cold and warm ends are taken to be 60 and 300 K, respectively. In the code, values of the thermal conductivity and the electrical resistivity at any temperature are provided by approximate expressions for the copper material with various RRR number. The heat leak Q_c and Il/s are estimated to be 41W/kA and 3.64×10^6 A/m for the optimum current lead of copper with RRR of 80.

The cooling power of the pulse-tube cooler was estimated by using the equivalent *PV* method. In the equivalent *PV* method, an imaginary gas piston moves with expansion and compression motion in the pulse-tube by the open-close operation of 4-valve. Fig. 2 shows the *P–V* diagram in the cold and warm ends of the pulse-tube with the effective inner volume of 623cm^3. The temperatures of the cold and warm ends are maintained to be 60 and 300K, respectively. The cooling power is estimated to be 97W at 60K. The operational current is designed to be 2kA for the pulse-tube current lead with the condition of $Q_c = 41\mathrm{W/A}$.

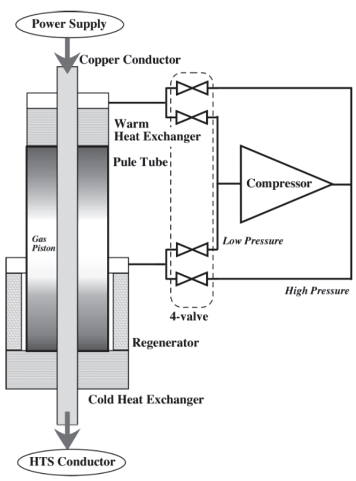

Fig. 1 Concept of the pulse tube current lead.

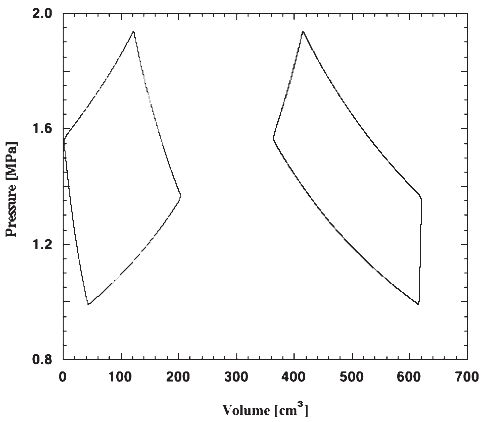

Fig. 2 *P–V* diagram of the pulse-tube