§14. A Co-axial Pulse Tube Current Lead Development

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Development of pulse tube cryocooler has been conducted extensively to realize the next generation of cryocooler applications. Since the pulse tube does not possess any moving parts at the low temperature region, which intrinsically has a high potential to be used as a part of applications combined with other apparatus such as current leads for superconducting coils. To demonstrate its potential, we have investigated the possibility to utilize it as a current lead system to improve the reliability of superconducting coil systems. A pair of prototype pulse tube current leads had been fabricated. The integrated current lead (ICL) consists of a co-axial pulse tube cryocooler with a current lead, a copper rod, penetrating its axis. The design work had been performed using a numerical program. The program had been written based upon an Equivalent Pressure-Volume method. The target for the current carrying capacity was 1 kA and the first prototype successfully achieved its goal. Consequently, the integration of a pulse tube refrigerator with a current lead showed the high potential to utilize as a conductively cooled superconducting coil application.

FIGURE 1 shows the schematic of pulse tube cryocooler for the numerical calculation model. In this case, the 4-valve operation scheme is described. A fundamental concept of the model is the existence of a highly elastic gas piston in the pulse tube. The gas piston is assumed to be present in the pulse tube with its ends

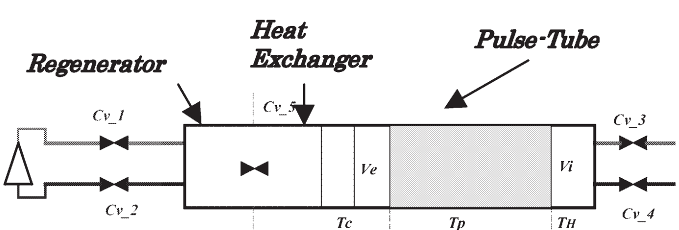

Fig. 1 Schematic of numerical model

displaced as a function of time. Therefore, the "ideal" pulse tube cryocooler cycle can be determined by analyzing gas processes in terms of equation of state. To do so, the system was divided in subsections. Working gases are either flowing in or out to the system via control valves from Cv_1 to Cv_4. Ve indicates the expansion volume, which provides a cooling power. Tc, Tp and TH represent temperature of a cold-end, a pulse tube and the warm end. Pressure of each section was determined by the ideal gas law. The program was designed to determine the position of a gas piston with iterations, using mass and pressure balance within the system. The calculated results reflect the pressure-volume change within the pulse tube which in turn reveals the expansion work at the cold end. Another interesting feature was dividing the regenerator in two-section by a *Cv_5* valve, reducing the computational speed. The computational result does not provide the information of pulse tube dimension. The interaction between the diameter and length of pulse tube to the refrigeration capacity has to be estimated empirically.

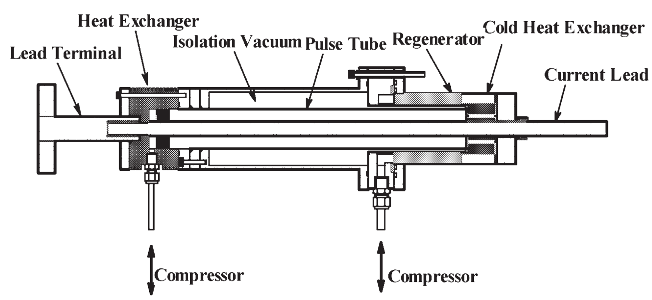

Fig. 2 A prototype pulse tube current lead.

According to the numerical design, a pair of pulse tube current leads was fabricated as shown in Fig. 2. Validation of the prototype was confirmed by the series of performance test: measuring the refrigeration capacities and study current carrying properties. The prototype achieved a steady operation up to 2.17 kA. After that the cold end temperature could not sustain the steady-state condition. This was not the optimum operating condition, however. According to the measured voltage drop across the current-lead, the temperature peak was located close to the warm-end of pulse tube. Optimization of the current-lead length and diameter will improve the current carrying capacity.