§19. Two-Stage Pulse Tube Refrigerator for the Integrated Current Lead System

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The development of an Integrated Current Lead (ICL) system for the cost effective SMES system is being conducted as a national project supported by New Energy & industrial technology Development Organization (NEDO). The project, "Superconducting Power Network Control Technology Development", has two missions; one is SMES system development and the other is to study its applicability to the technical standardization. As for the former case, the final goal is to fabricate the prototype and to demonstrate its validity by the end of 2007 fiscal year.

Our group is responsible for the ICL system development and the priority is to establish a highly reliable system to ascertain the SMES operation. Based upon the previous study [1], the co-axial pulse tube current lead was successfully fabricated and tested in 2004 [2]. To finalize its development, a HTS conductor is utilized to link the copper current lead to the SMES. The interface between the HTS and the coil lead is cooled by the second-stage pulse tube refrigerator. Hence, the successful two-stage pulse tube refrigerator development is crucial to validate the ICL system.

The design concept of ICL system is inherited to the co-axial pulse tube current-lead. As stated earlier, the compactness is a key to apply a relatively simple high voltage tolerance technique which withstands more than 15 kV. Thus, the second-stage was directly connected to the bottom part of first-stage heat exchanger to extend its original configuration. The second-stage consists of a regenerator, a pulse tube and a buffer tank. Its operation mode can be either in the basic orifice pulse tube or the double-inlet type. In both cases, a part of working gas of the first-stage is withdrawn for the second-stage refrigeration cycle, which sustains the compactness of ICL system.

A refrigeration capacity required for the second-stage is determined by the conceivable heat leak during the SMES operation, which is specified as a 0.3 W/kA. This is approximately equivalent to 2 W at 20 K for 3 kA operation, if the link between the copper current-lead and the HTS is maintained about 65 K. Basically, this is our target for the ICL system development. The demand for the first-stage refrigeration is relatively high under this operating condition (~130 W) so that the efficiency of the second-stage refrigeration cycle is designed to be as high as possible. Low efficiency of the second-stage cycle deteriorates overall operation performance of ICL system, which might jeopardize SMES operation.

In general, the two stage pulse tube arrangements is in parallel configuration as shown in Fig. 1a, however, the system requirements demands a confined space. Therefore, the series connected arrangements were applied for this particular case as shown in Fig. 1b. Since the work flow in the second pulse tube has to be consumed as a heat at the first stage, this arrangement leads to additional heat load to the first stage. However, the required refrigeration capacity at the second stage is very small compared with the first stage.

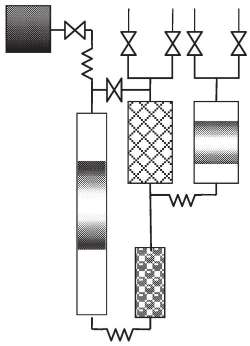

Fig. 1a Parallel arrangement

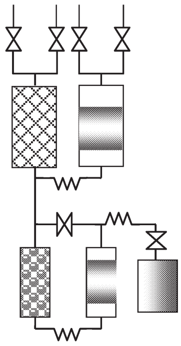

Fig. 1b Series arrangement

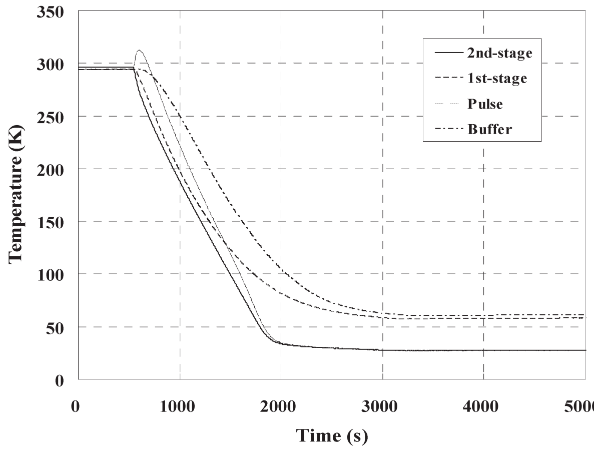

Fig.2 Cooldown curve for the prototype two-stage pulse tube refrigerator.

After optimizing capillary tubes for a double inlet and an orifice, the second stage achieved the lowest temperature of 11.0 K, which validates the series connected arrangement for the ICL system development.

References

1) Matsubara, Y. et al.:19th ICEC (2003) p.625
2) Maekawa, R. et al.:Adv. Cryo. Eng. (2006) p. 553