A long-life, high-capacity and high-efficiency cryogenic system developed for high-Tc superconducting magnet applications

ID: THU-PO3-802
Cryostats and Cooling systems

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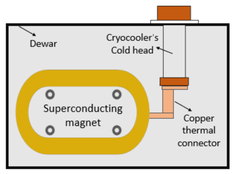
Background

- Cryogenic system plays a vital role in the development of magnet technology. Especially for superconducting magnet, it would be in more widespread use now if it were not for the problems associated with the cryocoolers or cryostats.
- An ideal cryocooler for the magnet applications should have the following features: low maintenance, high reliability, stable operation, long life, high capacity and high thermodynamic efficiency.
- In the authors' laboratory, a cryogenic system based on the Stirling-type pulse tube cryocooler (SPTC) for aerospace applications has been developed and built. The system was designed to be integrated into a new generation of high-temperature superconducting (HTS) maglev prototype train.

Cooling System For Vehicle-mounted Magnet

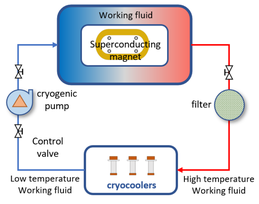
Direct Cooling

➢ The preferred way for in-vehicle cryogenic system of maglev train



- The cryocooler's cold head is directly connected with the low-temperature components of the superconducting equipment through a thermal connector.
- Heat conduction is the main way for heat transfer.
- Independence on cooling media , simple structure, low electricity consumption.

Indirect Cooling

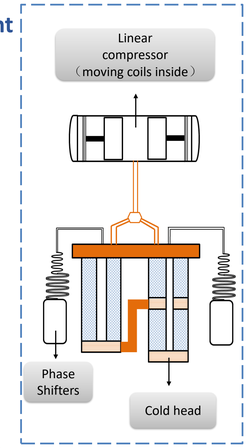


- The cryocoolers and superconducting devices are arranged separately.
- The cooling media (using low Tc working fluid like He & N_2) cooled by the cryocoolers is transferred to the superconducting equipment through the cryogenic fluid circulation pipelines.
- Remote arrangement , complex system, high cost, more space occupation.

Superiorities Of SPTC

Key demands of on-board equipment for HTS Maglev applications

- Designed and manufactured according to vehicle-mounted standards
- Long-time stable operation
- Long maintenance-free period & Low cost
- Modular design & Flexible installation
- Compact size —— Fit for vehicle space
- Excellent electromagnetic compatibility & Good performance in EMC tests



Pulse Tube Cryocooler

Superiorities of SPTC

a promising cryocooler for HTS magnet applications

No moving parts at cold end
- Low vibration：≤ 0.1 Nrms
- Low noise：≤ 45 dB
- Free of abrasion

Inheritance of Aerospace technology
- High reliability
- Long service lifetime (MTTF ≥ 5 years)
- High cooling efficiency
- Low power consumption

Adaptability of vehicle environment
- Compact structure
- Light weight
- Simple magnetic shielding

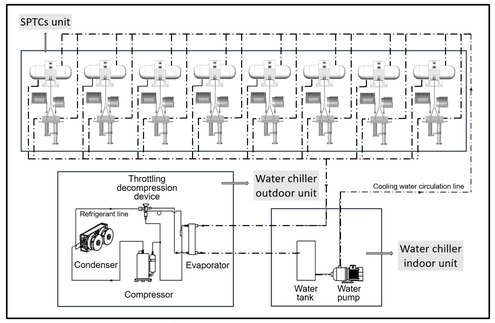
Design Of The Integration System For HTS Maglev Train

Introduction to the system

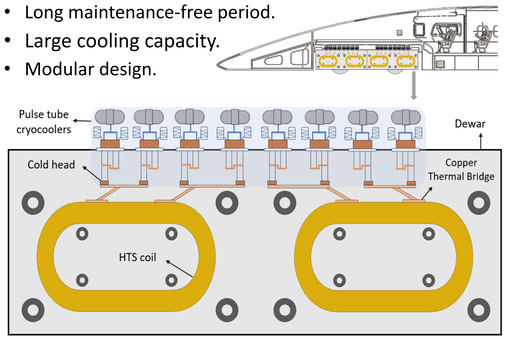
- A HTS coil cool down by 4 SPTCs, and 8 SPTCs are required for one magnet module.
- The heat is transferred by the copper thermal bridges between HTS coil and the cold heads.
- There are four magnet modules on a levitation frame. A large-power water chiller is equipped to provide the cooling water for those SPTCs.

Advantages of the system

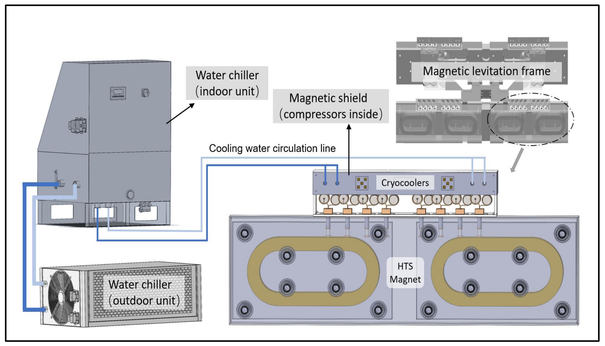
- Using multiple cryocoolers, the coils can be cooled more uniformly.
- When one cryocooler stops working by accident, others can work normally to ensure the reliability of the cryogenic system.
- Low vibration, low noise, light weight.
- Long maintenance-free period.
- Large cooling capacity.
- Modular design.



Schematic diagram of the system



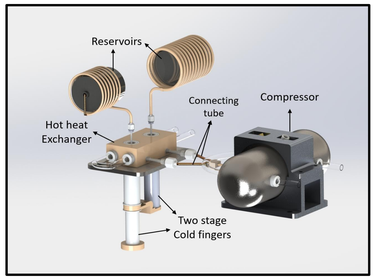
Cold heads and coupling structure design



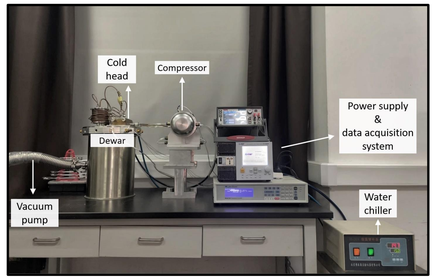
Composition of cryogenic systems

Experimental Performance Of the SPTC

Configuration



Schematic diagram of one SPTC



Experimental setup

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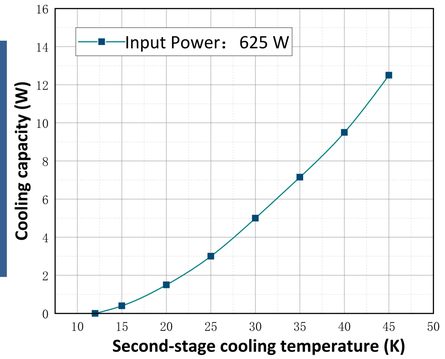

Initial parameters

Working Fluid of SPTC:	**Electrical power consumption:**
High purity helium	625 W
Charge pressure:	**Operating frequency:**
2.8 Mpa	45 Hz

Experimental results

Method for testing the cooling capacity:
- Based on thermal equilibrium
- Use thermal resistance to add heat load to the second-stage cold finger. (No heat load in the first stage)

No-load temperature:
- 12 K

Typical cooling capacity:
- 1.5 W@ 20 K
- 5.0 W@ 30 K
- 9.5 W@ 40 K

Conclusions

- The SPTC is an attractive and excellent cryocooler candidate for HTS magnet system in Maglev.
- The cryogenic system with space SPTC technology is developed and thus has the merits of high reliability and long MTTF. Together with the advantages of structural simplicity, high cooling efficiency and system compactness, it is an appropriate choice for cooling vehicle-mounted HTS magnet .
- The overall design approach and the integration schematic of cryogenic system coupled with magnet is presented and discussed.
- The experimental performance of the SPTC used in the above cryogenic system is described. Typical cooling capacity is 9.5 W @ 40 K with 625W of the input power.
- The above performance indicates that the developed cryogenic system can meet the cooling demand of the HTS magnet applications.