MT 26
International Conference
on Magnet Technology
Vancouver, Canada | 2019

Thu-Mo-Po4.10-02

Design and Analysis of Four Different Current Leads for Superconducting DC Energy Pipeline

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***Abstract*——**Superconducting energy pipeline is a new type of hybrid energy transmission cable, Current Leads are an indispensable part of the superconducting device, and their heat leakage can account for 50% of the total heat leakage of the system. In this paper, the process of optimum design, simulation analysis and heat leakage tests of current leads in superconducting energy pipeline are presented. Based on quasi-analytical numerical method, four different structures of current leads have been fabricated and a heat leakage measurement platform was built. The temperature profile of current leads were measured to calculate their heat leakage. The experimental results verify the validity of the design method, prove that the thermal performance of current leads with liquid nitrogen evaporation cooling can be optimized by increasing heat transfer area.

1. The design of current lead

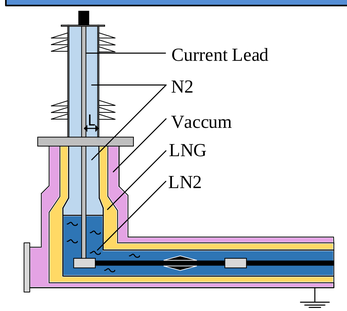

Fig. 1. Structure of the terminal

The structure and function of the SC energy pipeline is:

1) Inner layer (LN_2) provides low temperature environment.
2) Middle layer (LNG) is used to cool the inner layer and transport as fuel.
3) Outer layer (vacuum) reduces convective heat transfer.

The optimum design process of current lead is as follows:

1) Determining rated current and temperature range.
2) Choosing optimization algorithm combining cooling mode.
3) Comparing and selecting suitable materials
4) Calculating the optimum design parameters according to the actual situation

Table I OPTIMAL DESIGN PARAMETERS OF CURRENT LEAD.

Parameter	Value
Rated current	1000A
Material	RRR=30 Copper
Optimal length-to-transverse ratio	3.043
Design length	1500mm
Design cross-section area	450mm^2
Heat leakage	41.352W

2. Design of four current leads and the heat leakage measurement platform

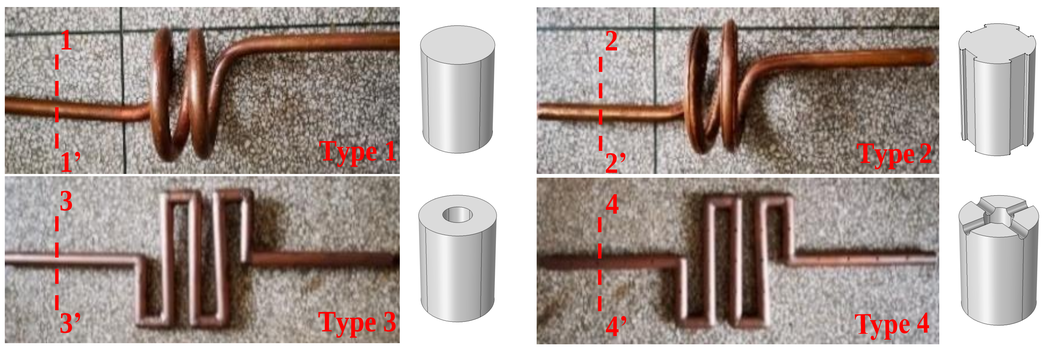

Fig. 2. Pictures of current leads and their cross-section diagrams

3. The heat leakage measurement platform

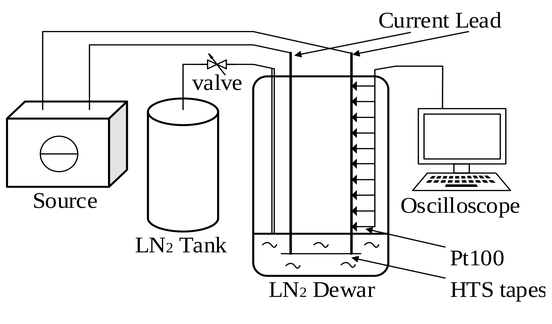

Fig. 3. Schematic diagram and picture of the experimental system

Table II DESIGN PARAMETERS OF FOUR CURRENT LEADS

Parameter		Value
Type 1/2	Radius of current lead	12mm
	Radius of helix	≈71mm
	Interception of helix	50mm
	Number of helixes	2
	Width of groove	6mm
	Depth of groove	2mm
	Total width	142mm
Type 3/4	Outer radius of current lead	13mm
	Inside radius of current lead	5mm
	Radius of hole	2mm
	Distance of openings	50mm
	Number of hole pairs	19
	Total width	200mm

4. Test results

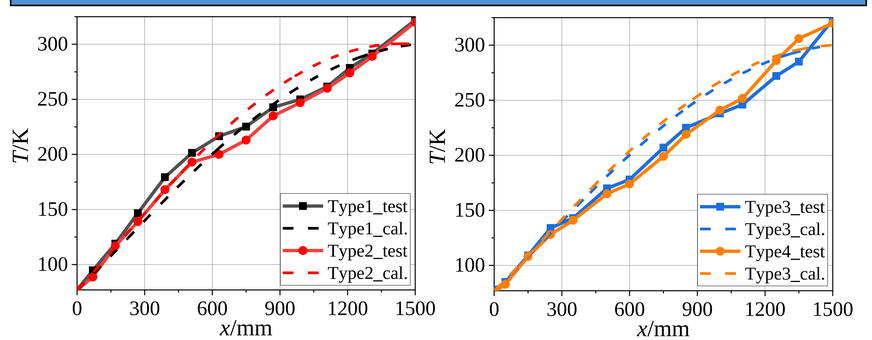

Fig. 4. Comparison of test and calculation results of four current leads

The specific experimental procedures are as follows:

1) Connect the whole system as Fig. 3.
2) Put in 1kA DC current when the lead is completely cooled.
3) Measure the temperature profile of the lead when it is stable.
4) Fit the temperature curve and calculate the heat leakage by conduction heat formula.

Table III CALCULATION AND EXPERIMENT RESULTS OF CURRENT LEADS

Parameter	Type1	Type2	Type3	Type4
Average temp.(cal.)	213.37K	221.72K	213.37K	215.92K
Heat leakage(cal.)	41.088W	41.009W	41.089W	40.953W
Average temp.	217.44K	206.53K	182.54K	203.29K
Maximum positive error	9.87%	6.67%	7.78%	6.67%
Maximum negative error	4.57%	11.1%	11.2%	14.7%
Heat transfer area	0.1124m^2	0.1317m^2	0.1677m^2	0.1766m^2
Cross-section area	452.4mm^2	407.4 mm^2	452.4mm^2	452.4mm^2
Heat leakage	35.14W	33.41W	33.6W	33.19W

5. CONCLUSION

1) When the rated current of superconducting DC energy pipeline is 1kA, the copper current lead with 450 mm^2 cross-section area and 1500 mm long meets the design requirement of minimum heat leakage, at this time, the minimum heat leakage is 41.352W.
2) Among The experimental results of four kinds of current leads with different structures are in good agreement with the calculation results. The maximum error of different measuring points and calculated values are 14.7%.
3) Increasing the heat transfer area can improve the thermal performance of current lead, including reducing the temperature of lead and reducing heat leakage. Among them, tube current lead with openings can reduce the heat leakage about 2W.