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Long term operation in 200 m class superconducting DC power transmission test facility in Chubu University

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Abstract. We constructed the 200 m class superconducting DC power transmission test facility (CASER-2) in 2010, and have carried out the cooling down and operation test. The 5th cooling down and operation test was carried out from August to November 2012. Long term current feeding was tested for a month with various currents and temperatures in the 5th test. From the long term current feeding test, the LN2 circulation was clearly affected by the operation of the cryogenic system and the atmosphere, not only by the operation DC current. It was also confirmed that the Peltier current leads worked effectively for the reduction of heat leak at the cable terminal.

1. Introduction

Recently, superconducting DC (SC-DC) power transmission is one of the attractive themes in commercial use of superconductivity, since the SC-DC power transmission is theoretically free from the AC losses, and is able to design the very large current cable for the power transmission. As a practical use, a 380 m/10 kA SC-DC cable was installed in the aluminum electrolysis system of Henan Zhongfu Industrial Co., in China[1]. The Electric Power Research Institute (EPRI) finished a design study of 10 GW SC-DC power transmission over 1000 km in U. S.[2]. Railway Technical Research Institute (RTRI) in Japan started a project to develop SC-DC power transmission system for railways[3].

In Chubu University, the first SC-DC power cable test facility (CASER-1) with a cable length of 20 m was constructed in 2006[4]. Since the first cooling down in October 2006, six cycles of cooling-down were carried out in CASER-1. The performance of the SC-DC cable showed no degradation through these cycles in that the critical currents of the HTS tapes in CASER-1 cable were in the same temperature dependence[5]. Based on the experiments in CASER-1, Chubu University constructed a new test facility of 200 m SC-DC power transmission (CASER-2) in 2010 to establish a power transmission system of a low total cryogenic energy loss[6]. This CASER-2 also has experienced cooling cycles repeatedly, and the 5th cooling cycle of the CASER-2 was carried out from August to November 2012. In this paper, we will describe the results of long term current feeding test for a month with various currents and temperatures in the 5th cooling cycle.

2. Specification of CASER-2

Table 1 shows the electric properties of CASER-2, and Table 2 shows the cryogenic properties to circulate liquid nitrogen (LN2). Figure 1 shows a photograph of a cut-model of a SC-DC cable core fabricated by Sumitomo Electric Industries, Ltd The cable consisted of co-axial three layers of DI-

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BSCCO® HTS tapes; one outside layer of 16 tapes and two inside layers of 23 tapes were insulated by polypropylene laminated paper (PPLP®) for bipolar current feed with an insulation voltage of 20 kV in LN2. All HTS tapes were also insulated by PPLP® from the copper former and shield in the earth potential with an insulation voltage of ±10 kV. Designed total current of the cable was 2 kA at 78 K.

One of the features of CASER-2 is that the cable core was placed in the smooth cryogenic pipe with vacuum insulation[6]. Compared with the corrugated pipe, which is widely used for the cryogenic pipes of superconducting cables, the smooth pipe has the advantage to reduce the pressure drop of LN2 flow[7,8]. Moreover, we employed a zinc-coated carbon-steel pipe (216 mm in outside diameter and 5.8 mm in thickness) as the outside pipe, since the outside pipe is used in the atmosphere to keep the vacuum insulation and an expensive stainless-steel pipe is not necessary. As the inside pipe, a stainless-steel pipe (60.5 mm in outside diameter and 1.65 mm in thickness) was employed from the viewpoint of the low-temperature brittleness in a LN2 temperature. Figure 2 shows a photograph of the cryogenic system of CASER-2. Due to the employment of the smooth cryogenic pipe, low pressure drop along the 200 m cable was achieved; consequently, one Stirling type refrigerator and one LN2 pump are sufficient in CASER-2 to circulate the LN2 along the 200 m cable length.

Table 1. Electric specification of CASER-2

	Specification
Current	DC 2 kA at 78 K
Voltage	DC ± 10 kV
Cable structure	Coaxial, bipolar current feed
SC tape	39 DI-BSCCO® HTS tapes (23 tapes in inside HTS layer, and 16 tapes in outside HTS layer)
Current leads	72 Peltier current leads (46 leads in inside HTS layer and 26 leads in outside HTS layer), and 6 copper leads (all in outside HTS layer)

Table.2 Cryogenic specification of CASER-2

	Specification
Cryogenic system	Coolant is subcool LN2 LN2 was circulated by 1 LN2 pump and cooled by 1 Stirling type refrigerator
Cooling power	1 kW @ 77 K (COP=0.083 @ 77K)
Cryogenic pipe	Vacuum insulated double pipe Outside pipe: Zn-coated steel pipe / Inside pipe: stainless-steel pipe Smooth pipes with several bellows

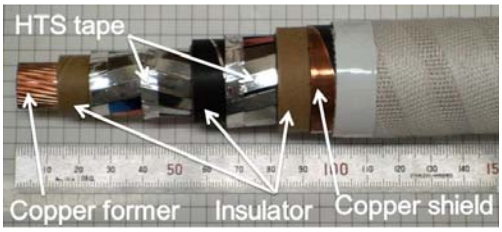

Figure 1. A cut-model of DC superconducting power cable core of CASER-2

Figure 2. Cryogenic system in CASER-2

3. Experimental results in long term operation test

We carried out the 5th cooling down test from August to November in 2012. During the 5th cooling down, we continuously fed the current to the SC cable from September 20th to October 22nd as a long term operation test of CASER-2. We varied operation current and temperature setting of refrigerator as parameters, and kept the speed of the LN2 pump constant, during this long term operation test. Note that the current was limited to 1200 A for the inside layer of the coaxial SC cable and to 600 A for the outside layer, because of the trouble in the connection between the current lead and the power supply.

Figure 3 shows the time evolution of (a) operation current, (b) LN2 temperatures in cryogenic system for the various temperature settings of refrigerator, (c) LN2 flow rate, (d) temperature rise along the 200 m cryopipe as cable line, (e) heat leak on the 200 m cryopipe, (f) temperature rise in and out of the cable terminal B, and (g) heat leak on the terminal B.

From the comparison of figures 3 (a)~(c), the LN2 temperature decreased due to the decrease of refrigerator setting, and increased due to the increase of the operation current. The decrease of LN2 temperature leads to the decrease of the viscosity of LN2. Therefore, the LN2 flow rate also varied following the variation of the LN2 temperature, despite of the constant LN2 pump speed. When the heat leak is stable, the temperature rise along the cryopipe and the cable terminal is inversely proportional to the LN2 flow rate. In figures (d) and (f), the temperature rises shows the undulating

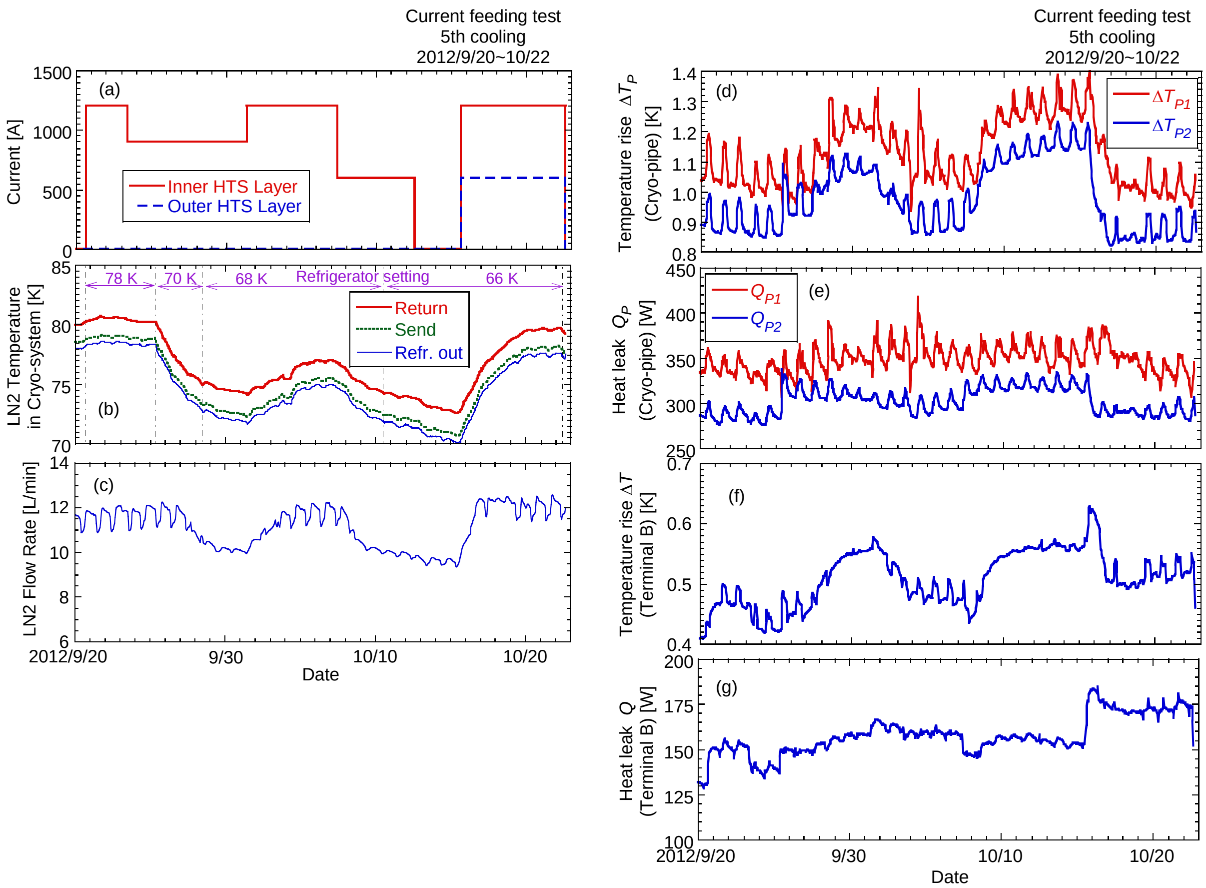

Figure 3. Time evolution of (a) operation current, (b) LN2 temperatures in cryogenic system (refrigerator out, send into and return out of the cable) for the various temperature settings of refrigerator, (c) LN2 flow rate, (d) temperature rise and (e) heat leak along the 200 m cryopipe as cable line, (f) temperature rise and (g) heat leak on the terminal B. In (d) and (e), suffixes 1 and 2 show the data derived from the temperatures of the top and bottom of the cryopipe, respectively.

time evolutions inversely following the variation of the LN2 flow rate.

Figures 3 (c) ~ (g) also shows the spike-like variations with the cycles of 1 day, in particular for (d) and (e). In CASER-2, 80% of the cryopipe was placed outside of the building, and then the temperature of the cryopipe surface was affected by temperature of atmosphere. This variation of the cryopipe temperature led to the daily variation of the heat leak into the cryopipe, in particular as the radiation heat, and also affected to the temperatures of terminals and the LN2 flow rate; consequently, they showed the spike-like daily variations.

The heat leak in the terminal B (figure 3 (g)) slightly increased when only the inside HTS layer operated with a current to 1200 A. This is because the Peltier heat of the Peltier current leads (PCLs) [9] in the cable terminal (Table 1) suppressed the Joule heating due to the operation current. Contrastingly, the heat leak in the terminal B clearly increased when a 600 A current was fed to the outside HTS layer. This was because the current leads in the outside HTS layer included 6 copper leads and Joule heating of copper leads led to the increase of the heat leak in the cable terminal.

4. Conclusion

We carried out the 5th cooling down in 200 m class SC-DC power transmission test facility（CASER-2) from August to November in 2012. During the 5th cooling down, a long term current feeding test was continued for 1 month with varying the operation current and the temperature setting of the refrigerator in the cryosystem. This long term operation clearly showed the relationship of the operation current, the operation temperature of the cryogenic system and the LN2 circulation. In addition, the LN2 circulation was affected by the atmosphere, in particular in the heat leak at the cryopipe; therefore, the LN2 circulation showed the daily variations. It was also confirmed that the PCLs worked effectively to suppress the heat leak at the cable terminal.

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References

[1] Liang XM, Dai ST, Gao ZY, Song NH, Wang YS, Zhang D, et al., 2010 Design of a 380 m DC HTS power cable. *IEEE Trans. Appl. Supercond.* **20** 1259–62.
[2] Hassenzahl W, Daneshpooy A, Eckroad S, Grant P, Gregory B, Nilsson S 2009 Program on Technology Innovation: A Superconducting DC Cable. *EPRI Report 2009*; 1020458.
[3] Tomita M, Suzuki K, Fukumoto Y, Ishihara A, Muralidhar M 2011 Next generation of prototype direct current superconducting cable for railway system. *J. Appl. Phys.* **109** 063909.
[4] Yamaguchi S, Hamabe M, Yamamoto I, Famakinwa T, Sasaki A, Iiyoshi A, et al., 2008 Research activities of DC superconducting power transmission line in Chubu University. *Jour. of Phys.: Conf. Ser.* **97** 012290.
[5] Hamabe M, Fujii T, Sugino M, Sasaki A, Sugimoto T, Watanabe H, et al., 2010 Cooling cycle test of DC superconducting power transmission cable. *Jour. of Phys.: Conf. Ser.* **234** 032019.
[6] Yamaguchi S, Kawahara T, Hamabe M, Watanabe H, Ivanov Yu, Sun J, et al., 2011 Design and construction of 200-meter high temperature superconducting DC power cable test facility in Chubu University. *Proc. the 23 Int. Cryogenic Eng. Conf. and Int. Cryogenic Mat. Conf. (Wroclaw, Poland, 18-23 July 2010)*, (Wrocław: Oficyna Wydawnicza Politechniki Wrocławskiej) 1041-47.
[7] Weisend II JG, Van Sciver SW 1990 Pressure drop from flow of cryogens in corrugated bellows. *Cryogenics* **30** 935-941
[8] Sasaki A, Hamabe M, Famakinwa T, Yamaguchi S, Radovinsky A 2008 A Numerical Analysis in LN2 Channel for DC-SC Power Transmission Line *Adv. in Cryogenic Eng.* **53A** 75-82