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Multi-channel data acquisition system for a 500 m DC HTS power cable in Ishikari

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Abstract

Reduction of heat penetrating into the cryogenic region is the important method of optimization of superconducting devices. In the cases of short-range power transmission lines and compact HTS devices like magnets, the heat leakage through current leads is relatively large. In order to decrease this contribution, current leads equipped with Peltier elements can be used. The mentioned technology is being actively developed in the Chubu University. Commercial samples of Peltier current leads are installed at the terminals of 500-meter DC HTS cable in Ishikari (Hokkaido). This cable is designed for 5 kA. The inner conducting layer consists of 37 DI-BSCCO HTS tapes from Sumitomo Electric Industries, Ltd. with a critical current of 180 A; and the outer one consists of 35 tapes of the same type. Each end of the cable's tape is connected to the individual Peltier current lead. Accordingly, each of the two terminals is equipped with 72 Peltier current leads, 144 pieces in total. In order to examine behavior of the current leads in detail, each piece is supplied with two thermocouples; there are also voltage taps on feedthrough and on HTS tape end. In addition, current through Peltier current lead can be measured by means of individual current transformer. The hardware part of the data acquisition system includes four Keithley 3706A multimeters equipped with 60-channel model 3724 FET multiplexer cards. Therefore, 144 data blocks are formed. Furthermore, there are 72 measurements of a voltage drop across HTS tape. Sampling period is set to be 3 s. The program part of the data acquisition system was written using LabVIEW software solution (National Instruments Corp.).

Keywords: DC HTS power transmission; Peltier current lead; Current imbalance; Data acquisition system

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1. Introduction

Development of superconducting power transmission (PT) lines that promises great benefits, has a very long history and is associated with overcoming significant engineering problems. The discovery of HTS in 1986 made it possible to simplify the design and reduce the cost of such systems largely. Thereafter, dozens of experimental AC HTS PT lines were created in different countries. Several hundred-meter cable length was achieved. Because DC HTS cables have many advantages, an upsurge in interest in using superconductors for DC power transfer was clearly observed in recent years. However, the number of DC projects in progress is still small [1-5].

One of the important advantages of DC HTS cables is the absence of AC losses. This fact greatly reduces the heat load on the cryogenic system. Since the energy consumption for maintaining the low temperature of the superconductor appears as transmission losses, the refinement of the efficiency of thermal insulation is an obvious way to improve the economic performance of DC HTS PT lines. Short-distance PT lines (for example, intra-plant) are characterized by the significant relative heat leak through the current leads. In the case of the compact systems like magnets, this contribution may be essential. Improvement of the thermal performance of the current lead is mainly achieved by optimizing their geometry and the use of different cooling methods. An alternative way is the application of "active self-cooled" current lead equipped with Peltier element connected in series. In this case, the thermoelectric element operates as a heat pump working against the flow of heat from the outside. Theoretical and experimental researches in the Chubu University allowed us to create commercial samples of Peltier current leads (PCLs) [1, 5-7]. Fig. 1 displays the off-the-shelf PCL design. Current model has four small Peltier elements connected in parallel.

Japanese largest project in the field of DC HTS PT has started in the city of Ishikari in Hokkaido on March 31, 2013. This national project is scheduled for three years. Two cable lines were built by the end of 2015 in the framework of the Ishikari project. 500-meter Line No. 1 connects Sakura Internet Inc. data center to the solar electric plant. 1000-meter Line No. 2 will be used for field study. Lines were designed with the aim of developing new technologies to bring the power transmission distance up to several tens, even hundreds of kilometers. Technical parameters of the Lines are summarized in the Table 1.

Table 1. Specification of the DC HTS PT lines in Ishikari.

	Line No. 1	Line No. 2
Length, type	Underground 500 m cable	Overland 1000 m cable
Rated parameters	5 kA, 20 kV, 100 MW	2.5 kA, 20 kV, 50 MW
HTS tapes	BSCCO (Type HT-CA) from Sumitomo Electric Industries, Ltd.	
Cable outer diameter	42 mm	40 mm
Inner conductor	37 HTS tapes (I_c > 190 A)	24 HTS tapes (I_c > 190 A)
Outer conductor	35 HTS tapes (I_c > 190 A)	15 HTS tapes (I_c > 220 A)
Cable insulation	PPLP	PPLP
Cooling system	1 x Turbo-Brayton (2kW@77K), 1 x Stirling (1kW@77K), 2 x Cryopump (40 l/min)	2 x Turbo-Brayton (2kW@77K), 2 x Stirling (1kW@77K), 3 x Cryopump (40 l/min)

Among the differences from the standard HTS PT lines, it should be noted first the use of smooth cryogenic pipes instead of conventional corrugated ones. This approach enables to drastically reduce the hydraulic resistance to flow of the liquid nitrogen and thus to reduce the required power of the cryogenic pumps. Delivery of HTS cable separately from the cryostat and field assembly allows us to increase the drum length up to 5 km, reducing the number of joints and, consequently, reducing the accident risk. Second, the large-diameter outer pipes are utilized in order to improve the air-exhaust condition. Third, preliminary helical layout of the cable core inside the cryogenic pipe was used to prevent undesirable effects related to the thermal contraction. As far as cable is helically coiled along the walls of the inner pipe at the room temperature, and straight at the liquid nitrogen temperature, temperature change does not induce considerable longitudinal displacement. Residual cable strain can be compensated by the adjustment of the terminals are made movable. Fourth, terminals are equipped with PCLs to reduce the local heat leak. Unique feature is the installation of the individual PCLs for each of the cable's HTS tapes [5]. Real-time multi-channel data acquisition system was created to monitor a large array of PCLs that allowed to determine the number of operating parameters, as well as analyze the current imbalance in the cable.

2. Hardware

500 m HTS cable of the Line No. 1 is made of DI-BSCCO tape with a critical current of 180 A available from Sumitomo Electric Industries, Ltd. The inner conductor is composed of 37 tapes wound in 3 layers, and the outer one is of 35 tapes wound in 2 layers. Cable structure is shown in Fig. 2. PPLP is used as electrical insulation. Cable rated current is 5 kA. Since each end of the cable's HTS tapes is connected to the individual PCL, two terminals are equipped with 144 PCL in total. The sketch of PCL and connection diagram are presented in Fig. 3. Photo in Fig. 4 taken during the assembly shows layout of PCLs. In order to study in details the operational performance, each PCL is supplied with two thermocouples. Voltage taps are also available on the feedthrough and on each end of the HTS tapes (see Fig. 3). A set of current transformers can measure the currents through all of PCLs separately.

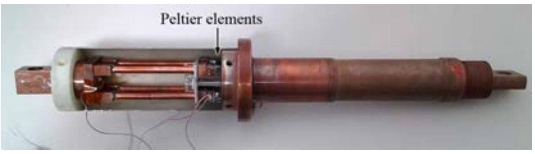

Fig. 1. PCL used in the Ishikari project (uncased).

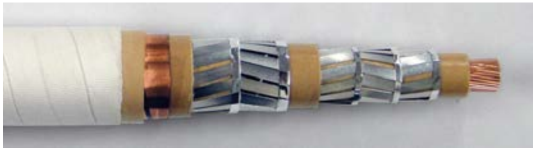

Fig. 2. HTS cable installed in Ishikari (Line No. 1).

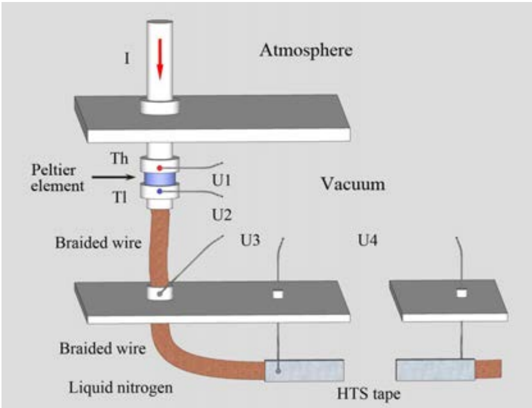

Fig. 3. Sketch of PCL and measurement points.

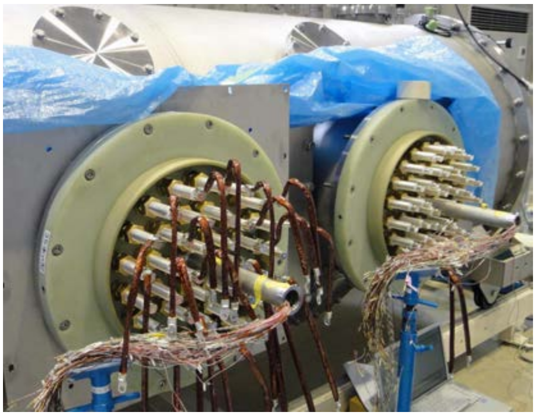

Fig. 4. Layout of arrays of PCLs (Line No. 1).

Additionally, in the Ishikari project a great attention is paid to the protection of cable and construction elements of the mechanical strains due to thermal contraction. Two cryogenic load cells are install inside terminals in order to monitor HTS cable strain. One of the supports located inside elbow segment of the cryogenic pipe is supplied with thermometer and three pairs of strain gages. We use four Keithley 3706A multimeters each equipped with five 60-channel model 3724 FET multiplexer cards to digitize raw signals. Multimeters communicate with single PC via LAN. Connection via LAN allows us to read data from four spaced devices.

3. Software

In accordance with Fig. 3, each PCL data block contains temperatures of the upper (Th) and the lower (Tl) terminals of the Peltier element, a voltage at the Peltier element (U1), voltage drops across the braided wire connecting PCL and feedthrough (U2), and connecting feedthrough and HTS tape (U3), and an individual current through the PCL (I). Therefore, 144 data blocks are created after each sampling. Furthermore, we have 72 measurements of the voltage drop across HTS tape (U4). In total, there are 936 PCL data channels to be analyzed and recorded. The program part of the data acquisition system was written using LabVIEW software solution (National Instruments Corp.). As mentioned above, the program has an additional option to acquire and display data on mechanical strains, and store this information in separate files. The measured data were recorded at time intervals of 3 s. Due to the large volume of data (about 250 Mb/day), visualization used two monitors with a resolution of 1920x1080 pixels. Data can be displayed in different modes, both graphically and digitally. The output files are written to disk once an hour. A quick real-time data recording is also provided, allowing fully restore the information in case of power failure. One of screenshots of the program is shown in Fig. 5. Frequency distribution of the temperature difference across the Peltier elements (ΔT=Th-Tl) at a maximum current of 5.0 kA is presented in Fig. 6 as an example of acquired data analysis.

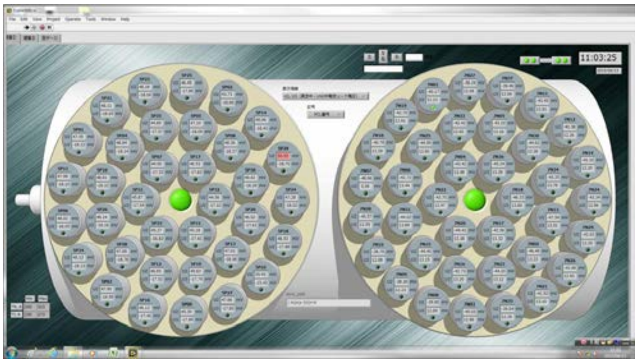

Fig. 5. One of screenshots of the PCL data acquisition program.

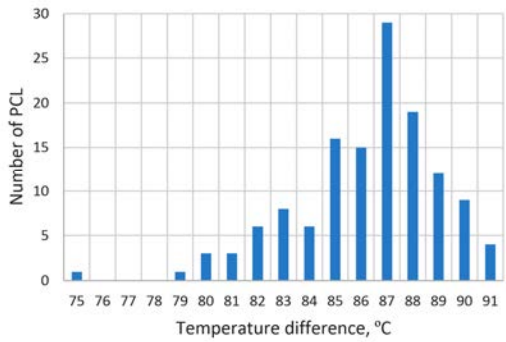

Fig. 6. Frequency distribution of ΔT across the PCL at 5 kA.

4. Results

Construction of 500-meter Line No. 1 was completed in the spring of 2015. First cooling down was carried out successfully in May and June. PCL data acquisition system was tested for stable operation both during energization test when the transport current achieved 6 kA, and during idling. No software malfunction was observed. The system allows to carry out cable critical current measurement safely for PCLs. Moreover, the measurement of the critical current of each HTS tape is also available. The program will be used in the Line No. 2 after appropriate adaptation.

Acknowledgements

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