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Thermal insulation test of new designed cryogenic pipes for the superconducting DC power transmission system in Ishikari, Japan

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Abstract

New cryogenic pipes were designed for the superconducting DC power transmission systems constructed in the Ishikari area in Japan. In the designs two inner pipes, for the cable and for the return of liquid nitrogen, are installed in a single outer pipe for the circulation of liquid nitrogen. In contrast to the cryogenic pipes commonly used for the superconducting power transmission, in which corrugated pipes are used, straight pipes are adopted to reduce pressure loss of the circulation of the liquid nitrogen. A radiation shield to reduce heat leak to the inner pipe for the cable is adopted in one of the designs.

Two types of test pipes with and without the radiation shield were constructed and heat leak of these pipes was measured to evaluate the efficiency of the test pipes. The lowest heat leak of 0.73 W/m was measured for the test pipe with the radiation shield.

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Keywords: Cryogenic pipe; Superconducting DC power transmission; Heat leak;

1. Introduction

The superconducting DC power transmission has been developed intensively and it is going to be applied to actual power transmission and distribution systems for its high efficiency coming from smaller energy loss by the zero electrical resistance of the superconductivity in combination with the nature of the DC power transmission [1,2,3]. A cryogenic pipe is one of the primary components of the superconducting DC power transmission system. Low heat leak cryogenic pipes are demanded, because the energy to pump out the heat by the heat leak of the cryogenic pipes is a main source of the energy loss and, eventually, determines the efficiency of the entire transmission system.

In addition to the low heat leak, low pressure loss is an expected property of cryogenic pipes for the circulation of refrigerant [4]. The pressure loss is originated from the friction between the inner surface of the cryogenic pipe and the circulating refrigerant, which is closely connected with the structure of the cryogenic pipe [5]. If the pressure loss

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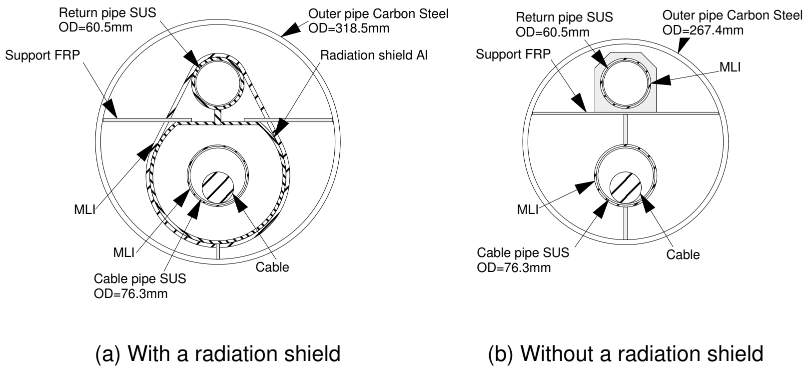

Fig. 1. Schematic drawings of the cryogenic pipes with a radiation shield (a) and without a radiation shield (b)

is large, a large pump with high discharge pressure will be required. The pressure loss increases with the increase of the flow rate of the refrigerant, which is almost proportional to the second power of the flow rate [4]. However, if the heat leak is small, the flow rate can be reduced, because the temperature rise of the refrigerant between terminals can be limited. Therefore, to reduce the pressure loss, a low heat leak is also expected for the cryogenic pipes. From these points of view, we have designed new cryogenic pipes. Test pipes were constructed and heat leak of these pipes were measured to evaluate the efficiency of these pipes. The designs will be applied to the cryogenic pipes for the superconducting DC power transmission project which was launched in 2013 in the Ishikari area in Japan and will be also applied, we expect, to the cryogenic pipes in future superconducting DC power transmission systems.

2. Structure of test pipes

We designed new cryogenic pipes and made test pipes to measure heat leak to evaluate their efficiency. In our designs, two inner pipes, one for the installation of the cable (the cable pipe) and another for the return of liquid nitrogen (the return pipe), are installed in a single outer pipe for circulation of the liquid nitrogen. Straight pipes, in part bellows pipes for the compensation of thermal shrinkage, are used for the inner pipes. This makes the reduction of the pressure loss possible in comparison with corrugated pipes which are commonly used for the cryogenic pipes for the superconducting power transmission [6,7]. A radiation shield, which surrounds the cable pipe, is adopted to reduce the heat leak to the cable pipe. We made two different types of test pipes, with and without the radiation shield, to compare the effect of the radiation shield.

Fig. 1 (a) shows a schematic drawing of the cryogenic pipe with a radiation shield. One unit of the pipe is 12 m, which comes from the limitation of transport. The 12 m unit pipes will be connected on site. The outer pipe is a carbon steel pipe with the nominal diameter of 318.5 mm. The inner pipes are stainless steel pipes with the nominal diameter of 76.3 mm for the cable pipe and of 60.5 mm for the return pipe. The cable pipe is surrounded by the radiation shield made of aluminum and supported to the radiation shield by plates made of fiber reinforced plastic (FRP). The return pipe is held by the radiation shield. Therefore almost all the radiation heat incident on the radiation shield is taken away by the liquid nitrogen flowing in the return pipe. Multi-layer insulation (MLI) is wrapped around the radiation shield and the cable pipe to reduce the radiation heat transfer. The radiation shield is separated from the outer pipe by FRP rods.

Fig. 1 (b) shows a schematic drawing of the cryogenic pipe without a radiation shield. One unit of the pipe is also 12 m. The outer pipe is a carbon steel pipe with the nominal diameter of 267.4 mm. The sizes and the materials of the cable pipe and the return pipe are the same as for the test pipe with the radiation shield. These pipes are supported by FRP rods and plates to the outer pipe. Layers of MLI are applied to the cable pipe and the return pipe.