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Technique for reduction of mechanical losses in AC superconducting coils due to thermal expansion properties of various FRP bobbins

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Abstract

We reported about reduction of mechanical losses in AC superconducting coils. The method is the use of FRP bobbins fabricated with special fibers. Since their FRPs have negative thermal expansion coefficient to the fiber direction, the FRP bobbins expand to the circumferential direction during cooling down. In case of the superconducting coils with such FRP bobbins, the winding tensions do not decrease during cooling down. Therefore, the mechanical losses are reduced by the suppression of wire's vibration. Their special FRPs are a Dyneema® fiber reinforced plastic (DFRP), a Dyneema and glass fiber reinforced plastic (DGFRP), and a Zylon® fiber reinforced plastic (ZFRP). These materials have negative thermal expansion coefficient to the fiber direction, however, the amplitudes of thermal expansion are various by the quantity or quality of the fiber. In this paper, the values of thermal expansion were actually measured, and it was discussed about the influence on the mechanical losses. At the experimental results, the mechanical loss was small, so that the thermal strain to the circumferential direction on the coil was large. Moreover, in case of the coils with sufficiently strong winding tensions at coil-operating temperature, the mechanical losses vanished.

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Keywords: Mechanical loss; Fiber reinforced plastic; Thermal expansion coefficient; Winding tension

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1. Introduction

Superconducting coils have instabilities caused by moving of superconducting wires. We study about improvement of mechanical instability. Since a winding tension decreases during cooling down in ordinary superconducting coils, the superconducting wire periodically vibrates owing to the electromagnetic force under an AC operation. The wire's vibration constantly generates heat between the wire and the bobbin, and the heat becomes losses. In general, to prevent the movement of the wire, intensification of the winding tension at room temperature or impregnation by applying resins such as an epoxy. However, even if the strong winding tension is applied at room temperature, the winding tension is decreased at coil-operating temperature in the coils with bobbins whose thermal expansion coefficients are positive. Moreover, we can only apply the winding tension up to the limit value of the superconducting wire. About the fixing due to impregnation, it is difficult to apply to complicated shape coils. In this paper, we proposed the simple method to reduce the mechanical losses in AC superconducting coils. The method is to control the winding tension at cryogenic temperature by the use of the special structural materials which have the negative thermal expansion coefficient.

2. Structural materials

A Dyneema® fiber is an ultraoriented polyethylene fiber fabricated by a superdrawing method [1]. The structure of crystalline has an extended chain, and hence the Dyneema fiber has high strength to its longitudinal direction [2]. Moreover, since this extended chain has the negative thermal expansion coefficient longitudinal to the fiber, a Dyneema fiber reinforced plastic (DFRP) expands to the fiber direction during cooling down from room temperature to liquid helium temperature, and the fiber contracts transverse to the fiber direction [3].

The DFRP has relatively the low Young's modulus to the transversal direction to the fiber, and anisotropy of Young's modulus among the longitudinal and the transversal directions is large. Therefore, a Dyneema and glass fiber reinforced plastic (DGFRP) which was compounded the Dyneema and the glass fibers was fabricated to improve the Young's modulus transverse to the fiber. The volume ratio of the Dyneema and the glass fibers (D/G) in the DGFRP is 70/30. However, the DGFRP remains a negative thermal expansion coefficient [4].

A Zylon® fiber is made from poly-*p*-phenylenebenzobisoxazole (PBO) by using a liquid crystalline spinning method, and it has quite high strength and a rigid-rod chain molecular structure with high linearity [5]. The Zylon fiber also has the negative thermal expansion coefficient longitudinal to the fiber. Therefore, a Zylon fiber reinforced plastic (ZFRP) expands to the fiber direction during cooling down from room temperature to cryogenic temperature.

When those materials are used as the bobbins in superconducting coils, the fiber's angle θ wound to an axial direction on the bobbin in the fabrication process of the filament winding method determines the thermal expansion/contraction property to the circumferential direction on the bobbin during cooling down. In case that θ is larger than 45°, the bobbin expands to the circumferential direction during cooling down from room temperature to cryogenic temperature. On the contrary, when θ is smaller than 45°, the bobbin contracts. Therefore, we make it possible to control the winding tensions at cryogenic temperature in superconducting coils in case that such materials are used as coil's bobbin.

3. Experimental procedure

A superconducting wire for the loss measurements is a three-component (NbTi/Cu/CuNi) multifilamentary wire which is allowed for the reduction of AC losses. Specifications of the superconducting wire are summarized in Table 1. All of sample coils were fabricated with the wire. The wire was wound in a U-shape groove on the bobbin with applying a winding tension. Specifications of sample coils are listed in Table 2. The materials of bobbins for superconducting coils are the DFRP, the DGFRP, the ZFRP, and the GFRP.