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Coupling loss with long time constants due to large displacement of strands in a large CIC conductor

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Abstract

ac losses consist of both regular losses that are proportional to squared cable twisting pitch and irregular losses that could not be estimated from short conductor sample test results. It was explained from our previous works that irregular loops in the conductor, which are caused by strand displacement as a result of low void fraction of the CIC conductor, produce the losses with long time constants up to several hundred seconds. The observed long time constant indicates that the typical loop length should be about LCM (least common multiplier) of all sub-staged cable pitches, and that contact conditions between the two strands forming the loop should be line contact. In order to investigate the contact conditions in detail, we traced $81(=3\times 3\times 3\times 3)$ strands at intervals of 11 mm along of CIC sample conductor with 1 m in length whose strands are NbTi/Cu without any surface coating. The measured traces of 81 strands show that asymmetric strand positions, in other words, small and large displacements of strands from their original positions due to compressing the conductor provide many line contacts. It is found that the averaged line contact length reaches about 10 mm that is three orders of magnitude larger than the point contact length, i.e. 10^{-2} mm. The time constant of coupling loss is also shown in this paper by estimating the line contact resistance and inductance of current loop.

Keywords: Cable-in-conduit conductor; Strand displacement; Coupling loss; Long time constant

1. Introduction

The superconducting coils wound with cable-in-conduit conductors (CICCs) which are composed of several stages of sub-cable has been applied to large devices such as experimental fusion apparatuses and superconducting magnetic energy storage (SMES) devices because of its high mechanical and dielectric strength. In recent years there has been a growing interest in coupling loss with long time constants which are not observed in test result using short sample conductor [1]. The time constant τ is proportional to the inductance of the current loop and inversely proportional to the contact resistance. Our previous works proved that

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the characteristic length of long current loop estimated from the magnetic field signals which were measured by Hall probes was near the LCM (least common multiplier) of all staged cable pitches [2] and the contact conditions of two strands would be partly line contact due to heavy deformation of triplets which are different from expected point contact conditions [3]. Although these researches can explain the measured time constant of the loss, there is no estimation of the time constant based on actual contact conditions of strands in CICC.

In order to investigate the contact conditions in detail, we identified positions of 81 strands every 11 mm of CIC sample conductor cross section with 411 mm in length, whose strands are NbTi/Cu without any surface coating. In this paper, large displacements of strands from their original positions and contact conditions are investigated in the direction of the CIC axis to estimate the coupling loss time constant.

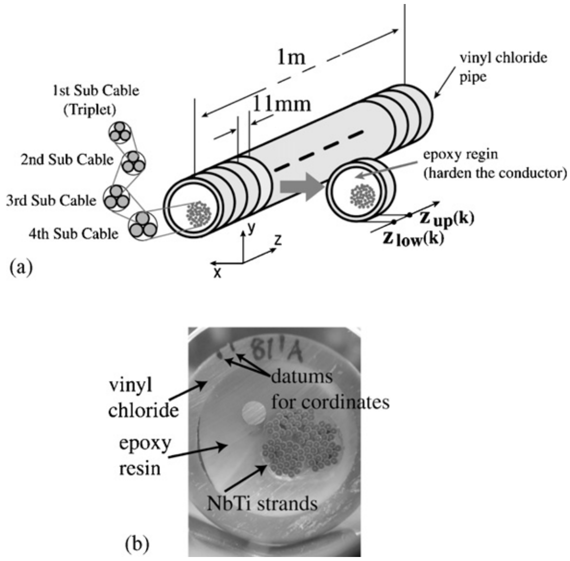

Fig. 1. (a) Schematic of sliced CIC conductor every 11 mm in length and (b) a picture of a section.

2. Experimental details

The sample CIC conductor consists of NbTi/Cu strands of 0.823 mm in diameter without any surface coating. The superconducting strands are cabled with four stages. All sub-cables are compressed in the twisting process to reduce the void fraction and diameter of the conductor (see Table 1). The conductor is not in a conduit, so the void fraction of the sample conductor is slightly higher (42%) than that of typical CICC (36%).

Table 1
Specification of CIC sample conductor

Strand	
Material	NbTi
Strand diameter	0.823 mm
Cu/NbTi ratio	1.95
Surface coating	None
Conductor	
Construction	3 × 3 × 3 × 3 = 81
Conductor diameter	9.73 mm
Void fraction	42%
Twist pitch	
1st	68 mm
2nd	90 mm
3rd	150 mm
4th	270 mm

First, we numbered all strands in order at the end of the twisted conductor and the conductor of 1 m in length is inserted in vinyl chloride pipe without compaction, then hardened with epoxy resin. Second, the conductor in the pipe is cut by a jet of water every 10 or 11 mm in z direction. Fig. 1(a) shows the schematic view of cutting the conductor and Fig. 1(b) the picture of a section.

In order to identify the strands at each section, the resistance of strands is measured at both sides of a section. The resistance of a strand with 11 mm in length is about 0.5 mΩ. The contact resistance between the strand and probe needle is estimated to be about 0.6 mΩ. Hence, the resistance of the corresponding strand is 1.1 mΩ. If the measured resistances are close to 1.1 mΩ, the strands are identified by the careful observation of strand positions at both the cross sections due to only about 60° rotation around the triplet center within 11 mm in length.

3. Experimental results and discussion

3.1. Cross section of CICC and traces of individual strand

The identification of strands has been performed up to 411 mm in length (33 sections). A typical picture is