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Design and Performance Analysis of an Iron Core-based No-Insulation HTS Magnet for HTS DC Induction Heating Machine

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Abstract

An energy efficiency of a high temperature superconducting (HTS) DC induction heating machine is improved up to 80~90%. The core technology in the machine is to ensure its thermal stability during operation. In this paper, we presented design details and performance analysis results of no insulation HTS magnet with an iron core for an HTS DC induction heating machine. The HTS magnet was simulated by a finite element method and an equivalent circuit analysis. In order to confirm physical performances, the magnet was fabricated and experimented with an iron core as well as without an iron core. The simulated and experimented results were analyzed in detail.

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Keywords: Cryogenic; FEM; HTS; Induction heating; Iron core; No insulation

1. Introduction

Despite of government policy on an energy saving in industrial fields, primary metal industries including extrusion plants, melting and hardening furnaces and forging facilities, are still using conventional atmosphere furnaces with very low energy efficiency of 20-30% [1]-[3]. As one of the counterplans, high temperature superconducting (HTS) technology enables a system's energy efficiency up to 80~90% by using lossless

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superconducting magnets [4]-[7]. The core technology in an HTS DC induction heating machine is to guarantee its thermal stability of HTS magnets during operation.

In a conventional insulated coil magnet, a quench may lead to severe damage to the magnet and thus a protection scheme is necessary. One of the protection schemes, a ‘no insulation (NI)’ winding technique for HTS magnets was presented [8]. Particularly in the event of a quench, it was confirmed that the magnet current was automatically bypassed through turn-to-turn contact layers [9].

In this paper, we presented design details and performance analysis results of a NI HTS magnet with an iron core for an HTS DC induction heating machine. To maximize the thermal stability, the NI HTS magnet was adopted. An iron core was applied to the magnet to minimize the amount of HTS wires. Prior to the fabrication of the NI HTS magnet with an iron core, a finite element method (FEM) analysis model and equivalent circuit model were investigated and the design specifications through their results were deduced. In order to confirm the simulation results, the HTS magnet was fabricated and tested with an iron core as well as without an iron core. The performance results were analyzed in detail. The results will be used for the practical design of an HTS DC induction heating machine.

2. Development of an HTS magnet analysis model

2.1. Application of NI HTS magnets

If a thermal runaway of the HTS coils happens at a high current density, a hot spot temperature quickly exceeds its critical limit and results in serious damage, and thus a protection method is required. As one of the solutions, the NI winding method for HTS magnet was adopted. This method not only maximizes the thermal stability of HTS magnets, but also has simple stages to fabricate HTS magnets [10].

In this paper, the HTS magnet was wound by only copper laminated HTS wire with the thickness of 0.1 mm. The thickness of the copper lamination layer is about 30-40 μm. After the winding, the surface between the HTS coil wound and bobbins was painted with STYCAST instead of the epoxy impregnation to improve the thermal contact.

2.2. Equivalent circuit and FEM model of the NI HTS magnet

The equivalent circuit of the NI HTS magnets was referred to [9]. In the circuit, the charging and discharging characteristics of the NI HTS magnet depends on the R_p, the NI HTS coil’s characteristic resistance. The R_p causes power consumption and it makes the coil temperature increases. If the coil temperature increases, the critical current of the coil decreases and thus it diminishes the magnet performance. An appropriate value of the R_p should be examined in the design stage of NI HTS magnets.

For the FEM analysis, the 3D FEM analysis model of the NI HTS magnet was designed as depicted in Fig. 1(a), (b), and the critical current curve to the perpendicular magnetic flux density of the NI HTS magnet were predicted as shown in Fig. 1(c). The iron core was modeled with a non-linear relative permeability and simulated. The base frame and the billet supporter are made of the iron material, S45c were applied at the design stage to secure the metal billet’s rotating axis and support the HTS magnet and the HTS induction heating machine. However, because

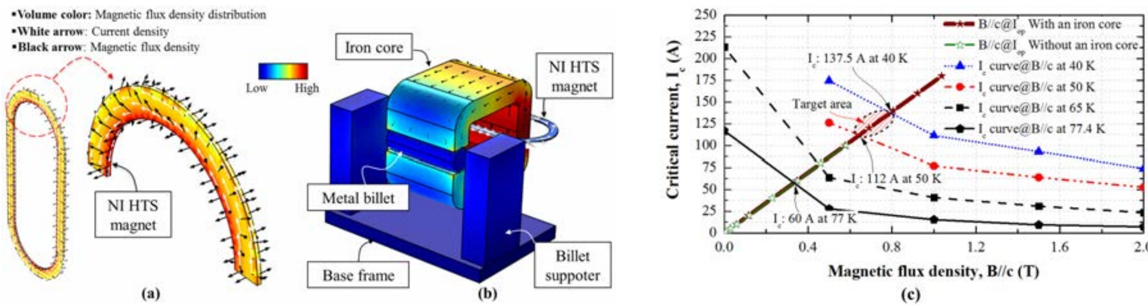

Fig. 1. 3D FEM analysis models of the NI HTS magnet; (a) without an iron core, (b) with an iron core (St10); (c) The critical current characteristic curves