3D Multiphysics Modeling of Bulk High-Temperature Superconductors for Use As Trapped Field Magnets

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Abstract

The authors are currently investigating the use of bulk high temperature superconductors as trapped field magnets (TFMs) in order to increase the electrical and magnetic loading of an axial gap, trapped flux-type superconducting electric machine. In electric machines, the use of superconducting materials can lead to increases in efficiency, as well as power density, which results in reductions in both the size and weight of the machine. Bulk superconductors can trap magnetic fields of magnitude over ten times higher than the maximum field produced by conventional magnets, which is limited practically to rather less than 2 T. Indeed, the world record field generated by an arrangement of two bulk superconductors currently stands at 17 T at 29 K.

There are three magnetisation techniques for magnetizing a bulk superconductor that are in common use: zero field cooling (ZFC), field cooling (FC) and pulse field magnetisation (PFM). In all cases, to trap the maximum possible field Btrap, the magnitude of the applied field needs to be at least Btrap, which invariably requires large magnetizing coils, and which is impractical for most applications of these materials. The PFM technique is similar to ZFC, except that the large magnetic field is applied via a pulse on the order of milliseconds, rather than ramped up and down slowly over a period of many minutes, or even hours, as in the ZFC and FC techniques. However, one issue with the PFM technique is that the trapped field is much smaller due to the large temperature rise ΔT associated with the rapid dynamic movement of the magnetic flux in the interior of the superconductor during the magnetisation process. Compared with the record trapped field (the aforementioned 17 T at 29 K), which was generated by FC, the record trapped field produced by PFM is only 5.2 T at 29 K. Therefore, it is critically important to understand the flux dynamics when magnetizing a bulk superconductor using the PFM technique in order to achieve an optimum trapped field profile and investigate how this translates into a practical magnetizing technique for a superconducting electric machine.

In this paper, the PFM of a bulk superconductor is modelled numerically using a 3D finite-element model based on the H-formulation and implemented in COMSOL Multiphysics®. The governing electromagnetic equations are derived from Maxwell's equations (Faraday's Law and Ampere's Law) and the resulting set of partial differential equations (PDEs) are used to directly solve the magnetic field components, Hx, Hy and Hz, using COMSOL Multiphysics®'s General Form PDE interface. To simulate the thermal effects of such an external field on the trapped field, a thermally-isolated model of a bulk superconductor has been used to simulate its thermal

properties. This is carried out using COMSOL Multiphysics®'s Heat Transfer Module coupled with the electromagnetic formulation.

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