Magnetization of HTS and design of marine current turbine generator

[課程博士・論文博士共通]

博士学位論文内容要旨
Abstract

専 攻 Major	応用環境システム学	氏 名 Name	李 智
論文題目 Title	Magnetization of HTS and design of marine current turbine generator （高温超電導体の着磁と海流タービン発電機の設計）		

Limited by the magnetic saturation of permanent magnets or the huge Joule heat in copper excitation coils as magnetic field poles, it is evitable to employ high temperature superconductors (HTS) in future large-scale megawatt (MW) electric applications thanks to the superior trapped flux performance (HTS bulks) or current-carrying ability (HTS tapes). To prompt the research and development (R&D) progress of applied HTS technology, this dissertation concentrates on the design and improvement of HTS rotating applications, including a novel magnetization geometry for HTS bulks (Part I) and a prototype marine current generator with HTS tapes in field poles (Part II).

In part I, an off-axis field cooled magnetization geometry is proposed and the trapped flux behavior of $GdBa_2Cu_3O_{7-\delta}$ QMG® samples under off-axis field cooled magnetization is studied.

Thanks to type-II superconducting properties, the melt-growth $REBa_2Cu_3O_{7-\delta}$ (RE denotes rare earth element or Y) bulk is capable of trapping magnetic flux upon cooled below T_c. Coupled with finely distributed second phases like Gd_2BaCuO_5, the trapped magnetic flux has achieved 17.6 T at 26 K under field cooled magnetization. Such superior performance can dramatically increase the torque/power density of rotating machines, igniting the global research on HTS applications using $REBa_2Cu_3O_{7-\delta}$ bulks.

Till now, the majority of magnetization study applies external magnetic field parallel to the crystallographic *c*-axis of HTS bulks. There have been no targeted efforts to magnetize HTS bulks under an off-axis magnetic field with respect to the *c*-axis and the trapped flux behaviour under such magnetization geometry has not been reported. Here, off-axis field cooled magnetization is conducted and trapped flux performance is analyzed. It is found that within finite inclination angle up to 30° ~ 45°, the sample provides superior trapped flux component parallel to the *c*-axis comparable with those obtained by the conventional on-axis field cooled magnetization. Meanwhile, the magnetization is almost parallel to the B_{app}. For large inclination angle, trapped flux lines are meaningful to understand the pinning behaviour of bulk materials in which the trapped flux behaviour is a collection of anisotropic flux pinning and the effect of microstructure on the deformed circulation of supercurrent. The off-axis magnetization geometry makes it more flexible for the design of *in-situ* magnetization systems in HTS electric machines.

In large-scale power applications, a promising solution is to employ HTS technologies. In part II, the design for marine current turbine generator is proposed with a new conceptual structure fitting the marine current energy characteristics. Moreover, two generator topologies are studied and compared at this stage, i.e., conventional PM topology and HTS topology, for the magnetic field poles. Salient-pole marine current turbine generator with iron core of rotor and stator is adopted here considering cost-performance and weight. Analytical model and 3D magnetic field study are combined to design and optimize a 1 MW salient-pole marine current turbine generator with the following main objectives:

1. Develop suitable electrical design methods for salient-pole HTS and PM marine current turbine generators.
2. Optimize main machine parameters based on their influence on the basic performance of marine current turbine generators.
3. For HTS topology, focus on the generator performance at 77 K considering the cooling easement of the cryogenic vessel used for HTS tapes.
4. Compare the performance of HTS and PM marine current turbine generators.

In Chapter IV, a conceptual structure of 1 MW HTS salient-pole marine current turbine generators are presented, and the electrical design method is proposed and its derivation is introduced in details. Based on the initial design, 3D simulation is implemented to calculate the magnetic flux distribution. Integrated magnetic flux in three core parts is emphasized, including the field pole part, armature part and stator part. Some main parameters including the pole pitch, the stator outer diameter, the magnetic flux density in the teeth, and the electric loading of 1 MW marine current turbine generators are optimized considering their effects on the basic generator performance. Here, 77 K is decided as the working temperature for HTS tapes considering the cooling system easement. The corresponding influence on the basic performance (the generator weight, efficiency, and the required HTS length) are studied. In addition, the maximum field current and the refrigerator power required at 77 K are determined. Based on the above calculation and simulation, a suitable structure of a cryogenic vessel used for HTS field coils is proposed and various heat losses in the different positions of the cryogenic vessel are calculated. Then, the required cooling power for the refrigerator is obtained, and its volume and flow rate are calculated. In the end, it is concluded that 77 K is a promising operating temperature for 1 MW marine current turbine generator.

In Chapter V, a conceptual structure of 1 MW PM salient-pole marine current turbine generator is presented, and the electrical design method is proposed and its derivation is introduced in details. The magnetic flux simulation for single pole of PM marine current turbine generator is also performed. The determination methods of two key parameters of the field leakage coefficient and the working condition of PM field poles are presented.

Lastly, in Chapter VI, the dissertation ends with conclusions of present results and discussions for the future work.