Study of a Bulk Superconducting Synchronous Machine (バルク超電導同期機に関する研究)

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博士学位論文内容要旨
Abstract

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Due to raising demand for energy and tightening emission legislations, there is a need to improve energy efficiency and also develop new, cleaner power systems. Ship propulsion systems which are at the heart of international trade, account for a considerable share of carbon dioxide, sulfur oxide, nitrogen oxide and particulate matter emissions globally. Among all other ship propulsion systems, electric propulsion emerged as one of the most suitable alternatives toward the reduction of environmental emissions and general improvement fuel efficiency. Ship propulsion requires compact megawatt class motors capable of high output torque density and low speed operation. Output torque is generally increased by increasing the size or the shear stress of the motor. However, shear stress in a conventional machine is limited by permanent magnet (PM) flux strength, copper wire current carrying capacity and iron core saturation. It has thus been challenging to develop compact multimegawatt motors for ship propulsion using conventional technology.

The discovery Low temperature superconductors (LTS) and high temperature superconductors (HTS) opened new possibilities for ship propulsion motor development. Superconductor wires and tapes conduct large dc currents with almost zero joule losses and can thus generate high magnetic fields. HTS can also be used in bulk form as single-grain crystals. Bulk HTS trap and maintain a magnetic flux that is orders of magnitude higher than conventional permanent magnets (PMs). Both superconductor wires, tapes and bulks can be used to develop high power density superconducting machines suitable for ship propulsion.

Current research efforts aim to take leverage of high current carrying capacity and magnetic flux of both LTS and HTS to develop more efficient and high-power density machines for electric propulsion. Considerable research has been conducted on electric machines using superconductor wires and tapes compared to bulks. To explore the potential of bulk HTS machines, we developed a 30-kW low-speed radial-gap synchronous machine with an air-cored rotor and a conventional stator with ferromagnetic teeth. The rotor has 4 field poles. Each pole is a rectangular array of melt-growth $GdBa_2Cu_3O_{7-\delta}$ bulk HTS. The poles are cooled by a 150 W capacity neon thermosyphon which maintains an operating temperature of 30 K. This work studies the aforementioned bulk HTS machine and the thesis is arranged as follows.

Chapter I offers an introduction to the field of superconductivity, including important properties and terminology. A background on general electric machines, design and development of HTS machines and use of cryogenic thermosyphon cooling is also provided.

Chapter II presents a literature study covering development and testing HTS synchronous machines. Cryogenic cooling is an integral subsystem is all HTS machines, therefore a review of recent developments around the electric machine cooling is also given.

Chapter III: HTS cooling system is one of the major enablers as far as HTS application and adoption in industry are concerned. This chapter focuses on a thermal study of a thermosyphon cooling system for HTS machines. The aim is to investigate temperature distribution in a two phase thermosyphon to gauge the performance of a thermosyphon as cooling system of a HTS motor.

Chapter IV presents the study of the bulk HTS machine. Features of the 30-kVA bulk HTS prototype machine and its auxiliaries namely, the cooling, magnetizing systems and data acquisition instrumentation are described.

Chapter V presents the methodology and results of no-load tests, which are the first set of tests conducted on the bulk HTS machine. The main results of generated voltage and core loss at different speeds and field strengths, are presented and discussed. The magnetic flux stability of the rotor is established by comparing flux measurements before and after tests. The presence of harmonics in the output voltage and their effect on as well as the core loss are discussed.

Chapter VI presents the methodology and test results of static load and variable load tests, which are the second set of tests conducted on the bulk HTS machine. The main results output power, torque and speed are presented. The magnetic flux stability of the rotor under operation is established by comparing flux measurements before and after tests. A summary, conclusions and prospects are given in chapter VII.