A superconducting induction motor with HTS armature: electromagnetic theory, design and analysis

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Introduction

Superconducting motors with only high temperature superconducting(HTS) armature can offer the advantages of high reliability, high power density, and high efficiency compared with conventional superconducting motors. In this paper, a novel HTS squirrel-cage induction motor is proposed for high speed operation, which adopts the structure of HTS windings with a certain inclination angle in the stator slots. Due to the limitation of curvature radius of superconducting tapes, pitch of HTS windings can be only set to 1 and adopt the short pitch arrangement structure, which such design details of the HTS motor would ensure the superconducting coils can undertake larger current and reduce AC losses. In order to keep the HTS windings in superconducting state and larger current density, a special fixed cryogenic cooling system below 70K with the method of gas extraction and decompression, which is made of Aramid Fiber, has been fabricated and the whole structure of the stator is placed in liquid nitrogen. According to the motor control principles and electromagnetic field theory, the electrical performances of the novel designed stator-HTS motor, which driven by the VVVF (variable-voltage variable-frequency)inverter, are analyzed including the flux density distributions, the torque, the induced electromotive force, losses and efficiency by using the finite element method. Finally, the components of HTS squirrel-cage induction motor have been manufactured according to the designed parameters. Next step, the motor will be assembled and tested.

I. Electromagnetic Design

A. *Rotor Structure Design*

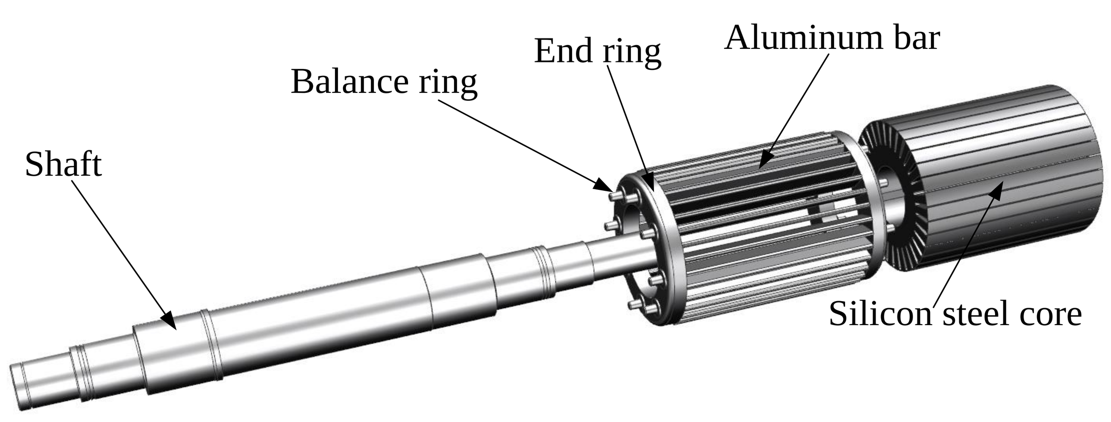

Fig.1 Squirrel cage rotor exploded diagram

TABLE I. Main Structure Parameters of Rotor

Data and parameters	
Outer diameter [mm]	158
Shaft diameter [mm]	60
Active core length [mm]	200
Slot number	33
Slot type	Peariform slot
Rated speed [r/min]	11995
Rotor weight [Kg]	36.8

B. *Stator Design*

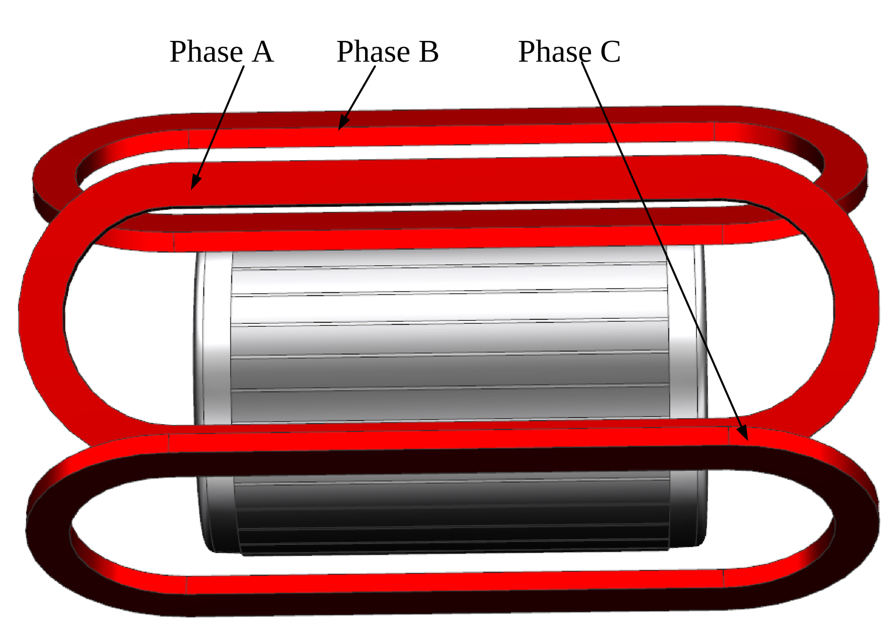

Fig.2 3D configuration of the windings and the rotor

TABLE II . SPECIFICATION PARAMETERS OF YBCO

Data and parameters	
Width of a YBCO layer [mm]	4.8
Thickness of a YBCO layer [mm]	0.18
Ic at 77K, self-field [A]	105
Minimum bend radius [mm]	50
Maximum rated tensile stress [Mpa]	150
Maximum rated tensile strain	0.25%

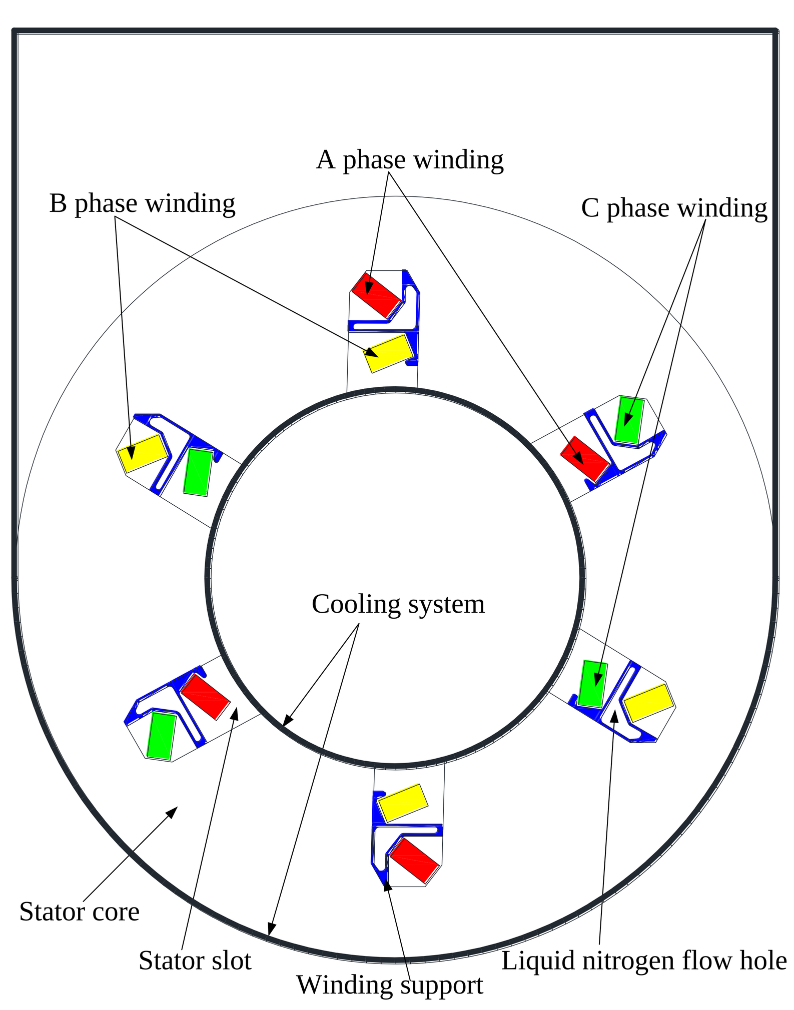

Fig.3 Fundamental structure of the proposed HTS motor stator

TABLE III. MAIN DESIGN PARAMETERS OF STATOR

Data and parameters	
Outer diameter [mm]	345
Inner diameter [mm]	170
Core length [mm]	200
Slot number	6
Slot type	Open slot
Number of parallel branches	2
Physical air-gap length [mm]	0.6
Coil turns	100
Coil straight length(L) [mm]	250
Coil height (H)(with insulation) [mm]	11.3
Coil width(W) (with insulation) [mm]	22.5
HTS material	YBCO-coated conductor
Cryogenic system material	Reinforced aramid fiber
Winding support material	Reinforced aramid fiber
Stator weight [Kg]	106

C. *Cryogenic Cooling System Design*

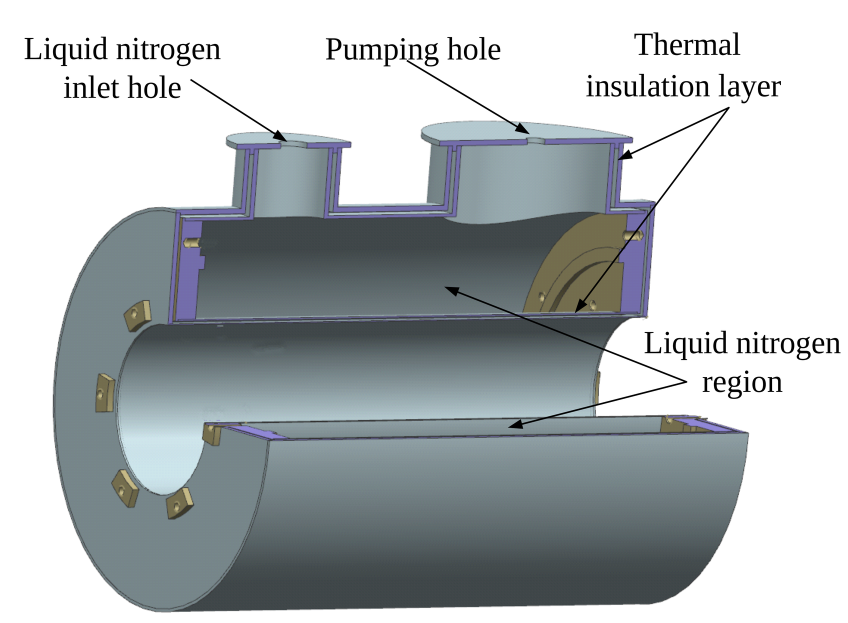

Fig.4 Illustrations for the possible cryogenic system structure

II. Predicted Electrical Performance of HTS Induction Motor

TABLE IV. ELECTROMAGNETIC PARAMETERS OF DESIGNED MOTOR

Data and parameters	
Rated power [kW]	500
Rated voltage [V]	1600
Rated frequency [Hz]	200
Rated power efficiency	97.6%
Rated torque [N.m]	38
Insulation class	F or H
HTS magnet operating temperature [K]	Below 70
Total motor weight [Kg]	151

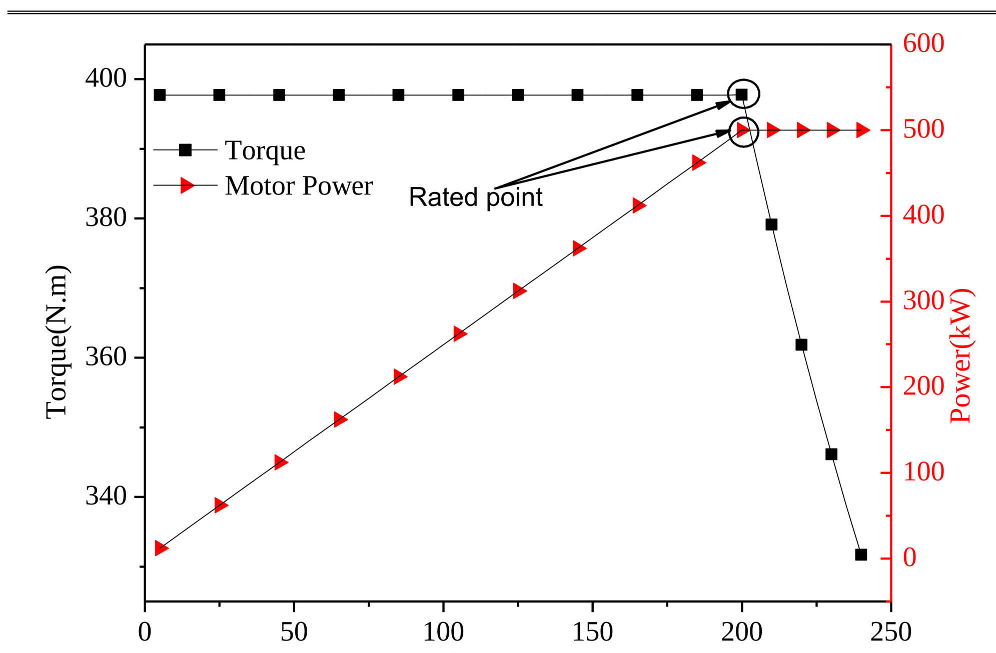

Fig.5 Operating characteristics of HTS induction motor

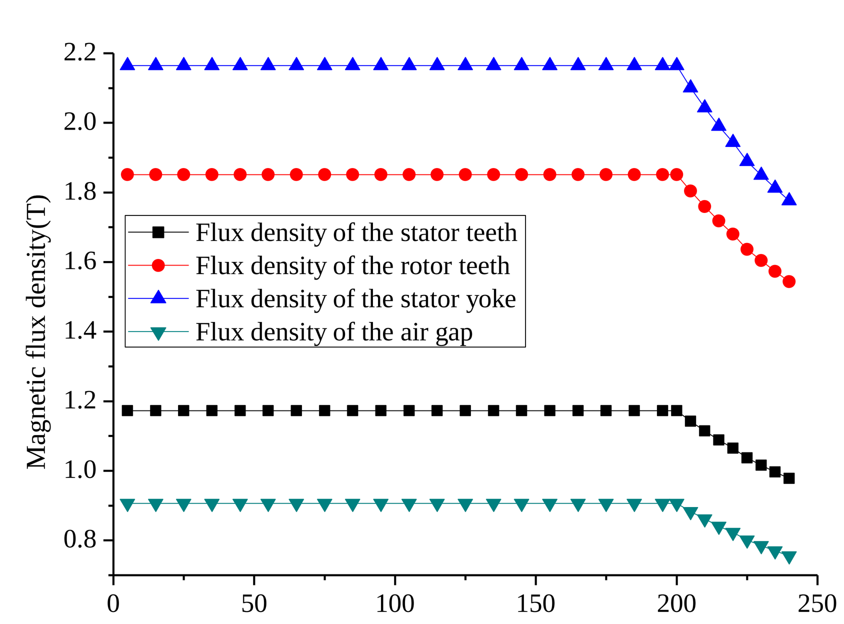

Fig.6 The curves of the magnetic density of each part with the supply frequency

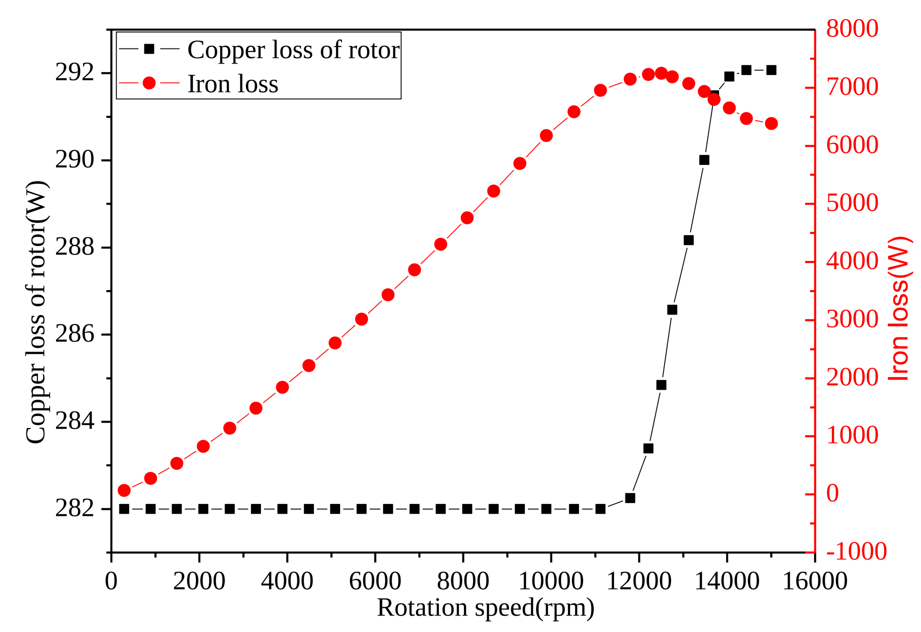

Fig.7 The curves of rotor copper consumption and stator iron consumption vs rotation speed

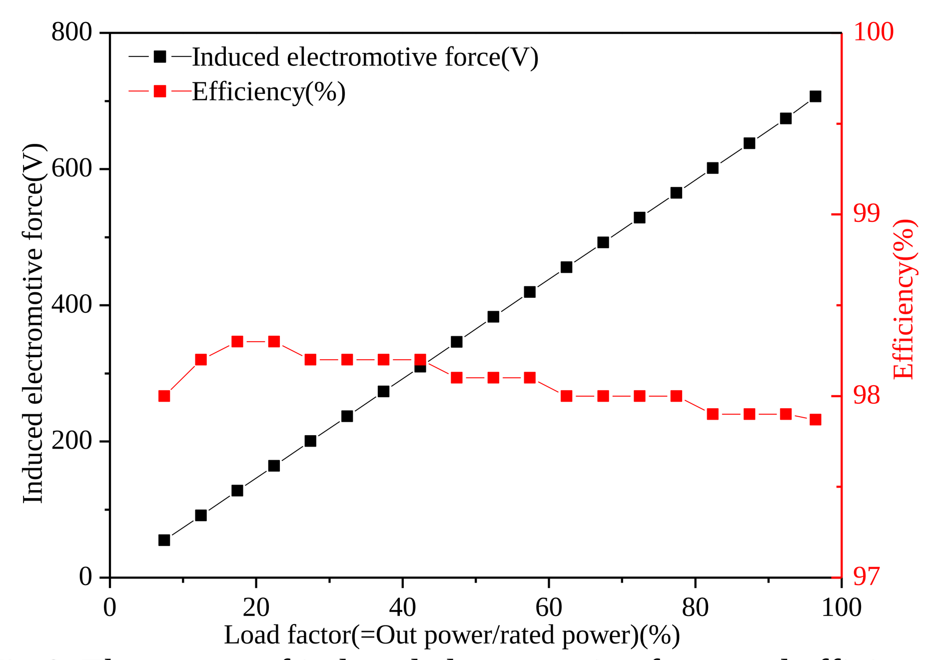

Fig.8 The curves of induced electromotive force and efficiency with load factor

III. Fabrication

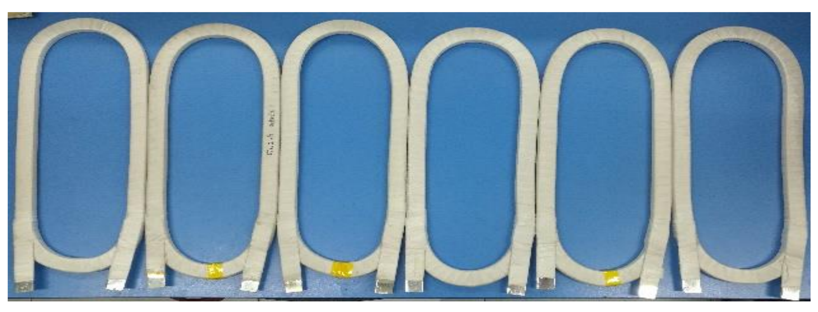

Fig.9 The fabricated HTS racetrack-shaped coils with the insulation material

Fig.10 Photographs of the fabricated rotor

Fig.11 Photographs of the fabricated stator core with mold

IV. Conclusion

In this paper, a novel HTS squirrel-cage induction motor with HTS armature for high speed operation was proposed. According to the engineering experience and electromagnetic design program, the rotor, stator and cooling system were designed in detail respectively. Based on the electromagnetic structure parameters designed, an electromagnetic model representing the cross section of the HTS induction motor is developed to predict electrical performance, including power, voltage, torque, efficiency, load factor, induced electromotive force and magnetic density. At present, the components of HTS squirrel-cage induction motor have been manufactured and the motor will be assembled and tested in next stage.

V. Acknowledgment

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