Design of Cryogenic Induction Motor Operating Submerged in the Liquid Nitrogen

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This paper presents the design of cryogenic induction motor submerged in liquid nitrogen for operating LNG spray pump. In cryogenic environment, the torque characteristics of induction motor would differ greatly from the operating conditions at room temperature. So, in order to obtain the operating characteristics corresponded with design specifications of the induction motor in cryogenic environment, it is necessary to redesign motor dimensions from the result of conventional design by reflecting changes of material properties under the very low temperature. This paper focused on the design of cryogenic induction motor considering the reduction of resistivity for the stator windings and rotor bars, and the magnetic saturation effect on the steel core under the very low temperature. The proposed VLT(Very Low Temperature) design derived the result that the torque characteristics at cryogenic temperature is similar to that of conventional design operating at room temperature.

***Index Terms*—Cryogenic induction motor, design, liquid natural gas, liquid nitrogen, finite element analysis.**

I. Introduction

Generally, LNG fuels are liquefied at 163 degrees Celsius below zero and are loaded into the cargo ship to be transported. In order to load LNG fuel into the cargo tank efficiently, a small amount of liquid nitrogen must be sprayed by using a pressure pump for cooling inside [1]-[2]. When the pump is operated, the LNG fuels flow through the air gap between the rotor and stator of the induction motor [2]-[3]. Then, the motor is submerged in LNG fuels under the very low temperature, and the torque characteristics at that time are very different from the operating conditions at room temperature [4]. However, most previous researches focused on the conventional design method of the typical three-phase induction motor operating at room temperature or the analysis of the torque characteristics for induction motor according to temperature variations [4]-[5]. In cryogenic environment, the torque characteristics of induction motor would differ greatly from the operating conditions at room temperature. That is because the induction motor consists of copper wires, aluminum bars and ferromagnetic silicon steels so that the electromagnetic characteristics of these materials could be changed with respect to the temperature variation. So, in order to obtain the operating characteristics corresponded with design specifications of the induction motor in cryogenic environment, it is necessary to redesign motor dimensions from the result of conventional design by reflecting changes of material properties under the very low temperature.

This paper focused on the design of cryogenic induction motor considering the reduction of resistivity for the stator windings and rotor bars, and the magnetic saturation effect on the steel core under the very low temperature. The proposed VLT(Very Low Temperature) design could derive the result that the torque characteristics at cryogenic temperature is similar to that of conventional design operating at room temperature.

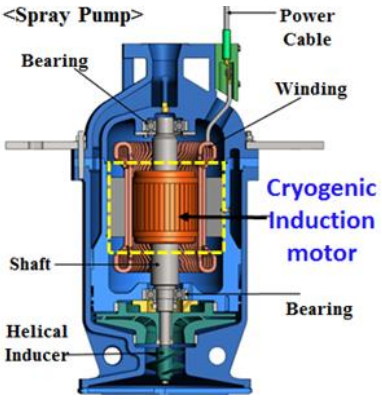

Fig. 1. The diagram of LNG spray pump and submerged induction motor.

II. Variations of Torque Characteristics under the Very Low Temperature

Fig. 2 shows the result of variations of torque characteristics for the induction motor submerged in liquid nitrogen. The torque characteristics of induction motor at very low temperature environment shows a great difference from the operating characteristics at room temperature. Especially, since the resistance of the rotor bars is reduced, the starting torque of induction motor is drastically decreased.

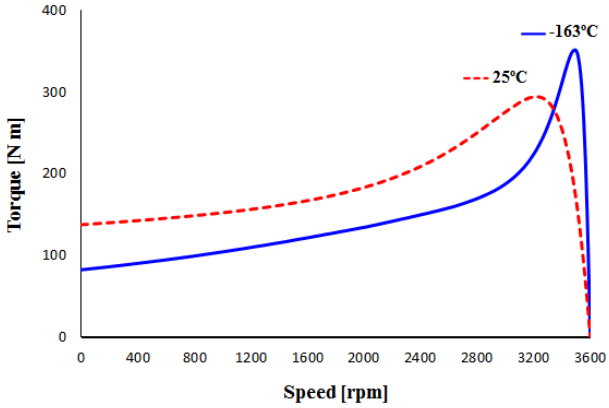

Fig. 2. Variations of torque characteristics under the very low temperature.

III. Design of Cryogenic Induction Motor

A. Variations of material characteristics

The induction motor consists of copper wire, aluminum and ferromagnetic silicon steels so that the electromagnetic characteristics of these materials would be changed in very low temperature. In cryogenic temperature, the resistivity of copper windings and rotor aluminum bars is reduced about 0.25 times that of room temperature as shown in Fig. 3. On the other hand, the magnetization characteristics of steel plates used for the rotor and stator core is not varied significantly in cryogenic temperature.

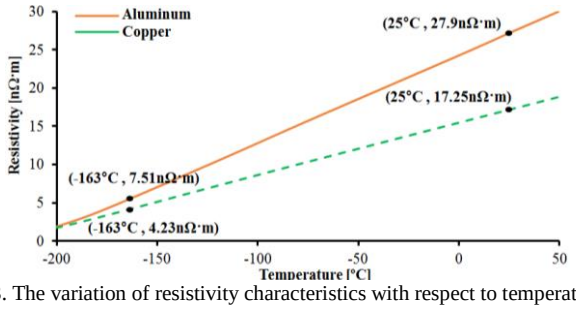

Fig. 3. The variation of resistivity characteristics with respect to temperature.

B. Design of induction motor for cryogenic temperature

Under the very low temperature, the reduction of resistances for copper windings and rotor bars affects the overall torque characteristics of induction motor so that excitation currents and leakage reactance of the motor are changed. Therefore, it is possible to reduce the total volume of induction motor by reducing the slot area of stator and rotor comparing to conventional design with same resistance. In Fig. 4 shows the drawing result of VLT design for cryogenic temperature. As shown in Fig. 5, the proposed VLT design could derive the result that the torque characteristics in very low temperature is similar to that of conventional design operating in room temperature corresponded with design specification.

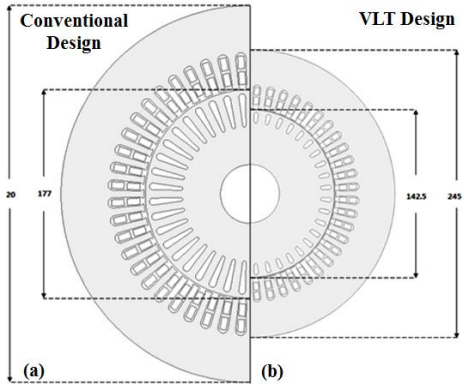

Fig. 4. Design of cryogenic induction motor. (a) Conventional. (b) VLT design.

TABLE I
Design Specification of Induction Motor (3-Phase, 2 Poles)

Specification	Value
Voltage / Frequency	440V / 60Hz
Rated Output / Torque(running)	37kW / 90.2Nm
Stator diameter(maximum)	320mm
Efficiency	87.9%
Temperature	-163℃ (Submerged Liquid Nitrogen)

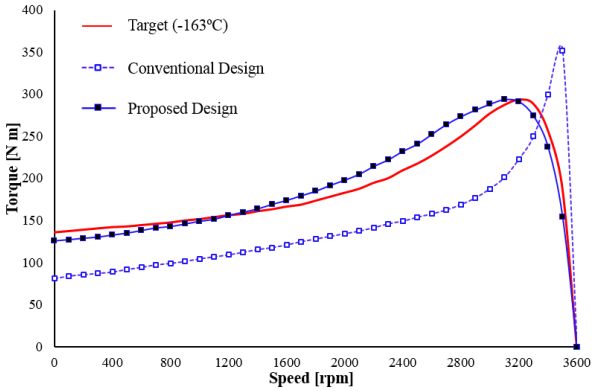

Fig. 5. Results of variations for torque characteristics each type of design.

IV. Verification

It is necessary to verify the performance test from the experimental setup of induction motor operating in submerged liquid nitrogen. From both simulated results and measured results, we can predict the torque characteristics of induction motor designed by the proposed method.

V. Conclusion

This paper presented the design of cryogenic induction motor submerged in the liquid nitrogen. In cryogenic environment, the torque characteristics of induction motor would differ greatly from the operating conditions at room temperature. So, this paper proposed redesign method of induction motor to derive the torque characteristics corresponded with design goals at cryogenic temperature.

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