§21. Research and Development of High Temperature Superconducting Induction/ Synchronous Machine for Liquid Cryogen Circulation Pump

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Our research group has carried out research and development of high temperature superconducting induction /synchronous machine (HTS-ISM) for highly efficient liquid cryogen circulation pump.

Fig. 1 shows a schematic diagram of the rotor (cage) windings. The rotor bars are installed in slots of a rotor core, and the end rings short-circuit all of the rotor bars. By applying the rotating magnetic field to the windings, the current is induced in the windings, and then the torque is generated in the rotor correspondingly. Our motivation is to fabricate the above windings with the use of the HTS tapes. When the induced current is less than the HTS rotor bars' critical current, the interlinked magnetic fluxes will be trapped in the windings. Therefore, the magnetic poles are equivalently formed in the windings, and the synchronous operation is possible even the structure of the motor is the same as that of the simple structured induction motor [1,2].

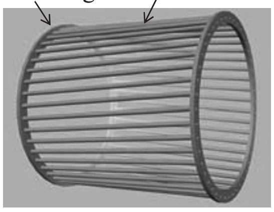

Fig. 1. Schematic diagram of rotor (cage) windings

We have firstly designed the 5 kW class HTS-ISM based on our theoretical expression. The maximum synchronous torque, τ_{sm}, is expressed based on the nonlinear electrical equivalent circuit as follows[1)].

$$\tau_{sm} = \xi \frac{p}{2} \phi_s' I_c' \tag{1}$$

where, ξ (= 3) and p(= 4) denote the phase number and the pole number, respectively. As this equation shows, τ_{sm} is determined by the primary converted trapped magnetic fluxes, ϕ_s', and the critical current of one rotor bar, I_c'(= I_c/N_{eff}). The value of ϕ_s' is expressed as follows.

$$\phi_s' = \frac{\sqrt{V_1^2 - [\omega(l_1 + l_2')I_c']^2} - r_1 I_c'}{\omega} \tag{2}$$

where, V_1, l_1+l_2' (= 9.63 mH), r_1 (= 0.12 Ω@77 K), and ω (= 2πf; f: primary frequency) are, correspondingly, input phase voltage, total leakage inductance, resistance of the primary windings and the angular frequency.

Fig. 2 shows the designed result by using eqs. (1) and (2). From this figure, the critical current of one rotor is decided to 415 A@77 K for 5 kW.

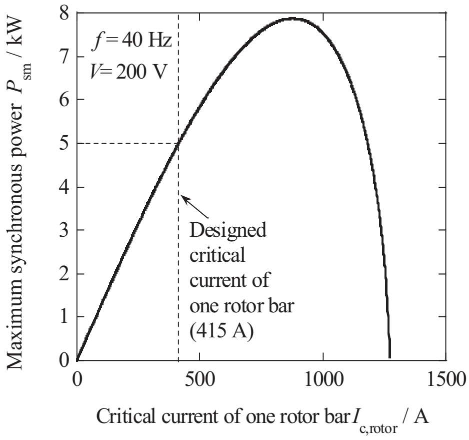

Fig. 2. Designed result of 5 kW class HTS-ISM

(a) Original motor

(b) Fabricated Gd rotor bar

Fig. 3. Photographs of original motor and Gd rotor bar

Fig. 4. Motor control system

Fig. 3 shows a photographs of the Cu stator and the rotor core. We have purchased second generation HTS coated conductors from SuperPower Inc. (Average critical current: 85 A, Average n-value: 30, Width: 3.02 mm, Thickness: 0.064 mm, Total length: 44 m), and 7 pieces of the tapes are stacked for one rotor bar. In this case, total critical current of such rotor bar is 416.5 A (= 85 A×7× 0.7; factor 0.7: reduction rate of critical current due to self-field). We will complete the rotor soon, and then test in liquid nitrogen. Fig. 4 shows a photograph of a motor control system (National Instruments).

1) Morita, G. et al.: Superconductor Science and Technology **19** (2006) 473.
2) Nakamura, T. et al.: Superconductor Science and Technology **20** (2007) 911.