Power loss and demagnetization research for high speed permanent magnet electrical machine.

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High speed permanent magnet machines (HSPMMs) have earned extensive interests in industrial application such as compressors, centrifuges and pumps due to their dramatic advantages of high power density, high efficiency and compact size [1-2]. However, high rotating speed and small size also brings challenge, as high frequency magnetic field induces large power loss density, and thermal dissipation condition becomes poorer with the compact size. In this paper, a MW rate, 18000 rpm HSPMM for compressor application is designed and researched by Finite element method (FEM). It is a 27 slots, 4 pole machine structure with high strength carbon fiber sleeve applied around the surface-mounted PM poles for mechanical integrity during high speed rotation. Fig.1 (a) presents the HSPMM cross-section and (b) shows the magnetic flux line distribution in the machine under open circuit condition. Power loss analysis is a key issue for HSPMM design, and steel core iron loss accounts for considerable proportion in the total power loss. Conventionally the iron loss can be calculated by Bertotti's model comprising hysteresis (P_h) and eddy current loss (P_e) which can be expressed as: $P_{fe}=P_h+P_e=k_hf(B_m)^{\alpha}+k_ef^2B_m^2$ (1) where f is frequency; k_h, k_e are the hysteresis loss, eddy current loss coefficient respectively; B_m is the flux density amplitude in the steel core. Such calculation method can be found applied for HSPMM iron loss estimation [3]. Equation (1) considers machine iron loss is relevant to flux density amplitude based on assumption that the flux density in the core is sinusoidal waveform only. However, the practical flux density is not an ideal sinusoidal one with harmonic components; moreover, rotational loss due to rotational magnetization in the core should also be considered. In order to precisely evaluate the iron loss for HSPMM, the magnetic flux density variation in each region of the machine is obtained and decomposed into a series of elliptical loci through Fourier analysis, and the iron loss can be calculated as improved method: $P=k_hkf(B_{kmax}^{\alpha}+B_{kmin}^{\alpha})+k_e(kf)^2(B_{kmax}^2+B_{kmin}^2)$ (2), where B_{kmax} and B_{kmin} are the major and minor axis of k order harmonic elliptical magnetic field locus; Fig 1(c) compares the iron loss at different stator locations calculated by two methods for the HSPMM with rated speed. It can be found the eddy current loss increases more than 20% in the tooth top when considering both harmonics and rotational magnetic field effects, and the total iron loss calculated by improved method is around 15% larger than conventional one. Rotor eddy current loss is mainly induced by the spatial and temporal harmonics in the machine magnetic field. The HSPMM eddy current loss effected by sleeve conductivity is shown in Fig. 1 (d). It can be found with the conductivity increase, the PM eddy current loss slightly reduced due to the shielding effect, but the sleeve eddy current loss increases obviously. So it is desirable to utilize low conductivity material for rotor sleeve with the permission of mechanical constraints. The PM demagnetization results in serious machine performance degradation such as a decrease in output power. The demagnetization can be reflected by demagnetization ratio, defined as the PM remanence flux density loss after demagnetization with the origin one. Shielding effect from high electrical conductivity can be utilized to improve the machine anti-demagnetization capability, by inserting a copper shielding between the PM and sleeve. Fig. 2 (a) compares the PM demagnetization ratio for the HSPMM at short circuit condition. It can be found the rotor copper shielding structure can effectively decrease the demagnetization level for the HSPMM with harsh conditions. The HSPMM is prototyped and Fig.2 (b) shows the picture of HSPMM stator and rotor, more detailed analyses and experimental results will be presented in the final paper.

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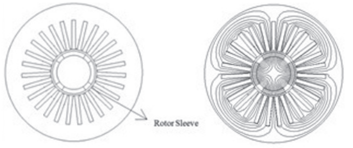
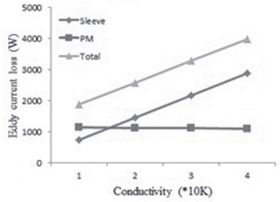


(a) (b)

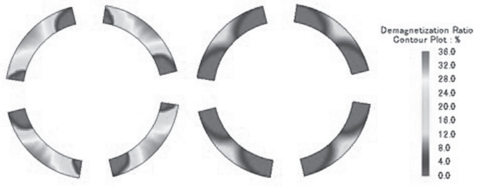
	Conventional (W)			Improved (W)		
	Hys	Edd	Total	Hys	Edd	Total
Tooth top	1399	1105	2504	1538	1341	2879
Tooth Bottom	416	328	744	453	399	852
Yoke	1160	915	2075	1292	1080	2372
Iron Loss		5323			6103	

(c)



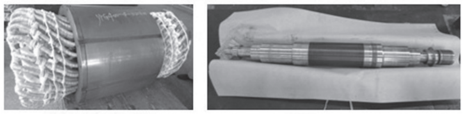
(d)

Fig.1 (a) HSPMM cross-section (b)Flux line distribution (c)Iron loss calculation (d) Rotor eddy current loss with different sleeve conductivity



No copper shielding With copper shielding

(a)



Stator with winding Rotor

(b)

Fig.2 (a) Demagnetization analysis (b) HSPMM Prototype stator and rotor