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8:45 CF-02. **Sensorless control of switched reluctance motor based on dynamic thresholds of phase inductance.**
C. Jun [1], D. Zhiquan[1], Z. Dongpo[1] and Z. Jingcheng[1] *1. College of automation, Nanjing University of Aeronautics and Astronautics, Nanjing, China*

9:00 CF-03. **Practical Optimum Design Based on Magnetic Balance and Copper Loss Minimization for a Single-phase Line Start PM Motor.** *S. Baek* [1], B. Kim[2] and B. Kwon[1] *1. Electrical engineering, Hanyang University, Ansan, Gyeonggi, Korea, Republic of; 2. Electrical engineering, Kunsan National University, Gunsan, Jeonbuk, Korea, Republic of*

9:15 CF-04. **Odd stator slot numbers in brushless DC machines as an aid to cogging reduction.** *D.G. Dorrell* [1] and M. Popescu[2] *1. School of Electrical, Mechanical and Mechatronic Systems, University of Technology Sydney, Sydney, NSW, Australia; 2. Motor Design Ltd., Ellesmere, Shropshire, United Kingdom*

9:30 CF-05. **Performance improvement in high-performance brushless rare-earth magnet motors for hybrid vehicles by use of high saturation steel.** *D.G. Dorrell* [1], A.M. Knight[2] and M. Popescu[3] *1. School of Electrical, Mechanical and Mechatronic Systems, University of Technology Sydney, Sydney, NSW, Australia; 2. Department of Electrical and Computer Engineering, University of Alberta, Alberta, AB, Canada; 3. Motor Design Ltd., Ellesmere, Shropshire, United Kingdom*

9:45 CF-06. **Level-set based optimal stator design of interior permanent magnet motor for torque ripple reduction using phase-field model.** S. Lim[1], *S. Min* [1] and J. Hong[1] *1. Automotive Engineering, Hanyang University, Seoul, Korea, Republic of*

10:00 CF-07. **Brushless Permanent Magnet Motor Losses Minimization in Perspective of a Life Cycle Assessment.** T.H. Pham[1], *P. Wendling* [1], P. Lombard[2], V. Leconte[2], J. Coulomb[3] and V. Mazauric[4] *1. Magsoft Corporation, Clifton Park, NY; 2. Cedrat S.A., Meylan, France; 3. G2ELAB, INPG, Saint Martin d'Heres, France; 4. Schneider Electric, Grenoble, France*

10:15 CF-08. **Efficiency Improvement based on New Non-oriented Electrical Steel developed for Universal Motor.** *H. Shim* [1], S. Cha[2], C. Han[2] and G. Kim[1] *1. Products Solution Research Group, Pohang Steel Company(POSCO), Incheon, Korea, Republic of; 2. Electrical Steel Research Group, Pohang Steel Company(POSCO), Pohang, Korea, Republic of*

CF-06

Level-set based optimal stator design of interior permanent magnet motor for torque ripple reduction using phase-field model.

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Automotive Engineering, Hanyang University, Seoul, Republic of Korea

Interior permanent magnet (IPM) motor is widely used for various industrial applications such as power source of hybrid electric vehicle due to its high power density and efficiency. However, the reluctance torque which increases the average torque leads to high torque ripple, the major cause of motor's noise and vibration. Many studies for torque ripple reduction of IPM motor have been performed through the control of parameters representing the geometry of motor configuration. Recently Kwack et al.[1] used the level-set based topology optimization method and obtained the optimal distribution of ferromagnetic material in the stator of IPM motor dropping torque ripple magnificently, but unfortunately having complicated boundaries difficult to manufacture.

To get the optimal stator design satisfying both demanded performance and manufacturability, a new design optimization method using level-set and phase-field approach is proposed in this paper. To distribute the level-set function according to phase-field concept, upper and lower limits are introduced to make the gradient of level-set be zero and then fictitious interface energy can be formulated in terms of the field variable[2]. The fictitious interface energy term so-called Chan-Hilliard energy[3] plays an important role in generating the smooth boundary of the optimal configuration. The optimization problem is formulated to minimize two values, one is torque ripple by adjusting torque values at any rotor angle to the constant target torque, and the other is the fictitious interface energy for making interfacial region to become narrow. The coefficient of complexity(τ) multiplied with the interface energy is employed to control the smoothness of boundary.

The proposed method is applied to obtain the optimal stator design of 12 pole-18 slot IPM motor designed for a traction motor of hybrid electric vehicle. The reference design of which the average torque is 58.2Nm and the torque ripple is 91.3% is illustrated in Fig. 1 with the design domain. The volume fraction is fixed to 0.8 and τ is varied from 0 to 1×10^-7 for controlling smoothness of optimal configuration. Fig. 2 depicts the optimal stator design of IPM motor according to each τ and the corresponding torque curves are shown in Fig. 3. It is noted that the boundary of optimal stator shape becomes simpler to ensure manufacturability as τ increased within a little loss of torque performance. It is summarized in Table 1 that optimal rotor shape with the control of τ provides 13.1%, 12.7%, 13.2%, and 14.9% increase in the average torque and the torque ripple measured by the difference between maximum and minimum torque is decreased to 9.6%, 13.2%, 16.3% and 18.5%, respectively. It is expected that the proposed method provides flexible representation of structural boundaries for the design of IPM motor.

[1] J. Kwack, S. Min and J.-P. Hong, Optimal Stator Design of Interior Permanent Magnet Motor to Reduce Torque Ripple Using the Level Set Method, IEEE Trans. Magn., 46, 6, 2108-2111, 2010

[2] T. Yamada, S. Izui, S. Nishiwaki, K. and A. Takezawa, A topology optimization method based on the level set method incorporating a fictitious interface energy, Comput. Methods Appl. Mech. Engrg., 199, pp. 2876-2891, 2010

[3] J. W. Cahn and J. E. Hilliard, Free Energy of a Nonuniform System. I. Interfacial Free Energy, J. Chem. Phys., 28, 2, 258-267, 1958

	Reference design	Optimal design			
		τ=0	τ=1×10^-8	τ=5×10^-8	τ=1×10^-7
Average Torque [Nm]	58.2	65.8 (13.1%↑)	65.6 (12.7%↑)	65.9 (13.2%↑)	66.9 (14.9%↑)
Torque Ripple [%]	91.3	9.6 (89.5%↓)	13.2 (85.5%↓)	16.3 (82.1%↓)	18.5 (79.7%↑)

Table 1. Comparison between reference and optimal design

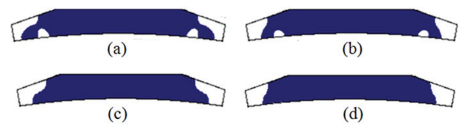

Fig. 2 Optimal stator design: (a) τ=0 (b) τ=1×10^-8 (c) τ=5×10^-8 (d) τ=1×10^-7

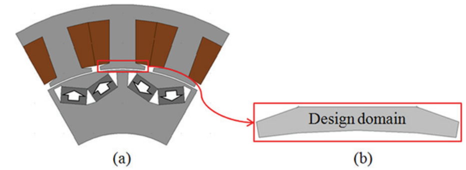

Fig. 1 Configuration of IPM motor: (a) reference design (b) design domain

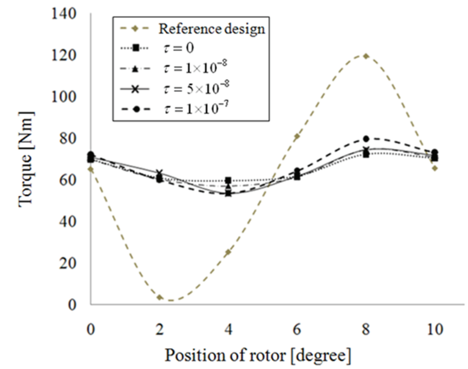

Fig. 3 Torque curves of optimal design