

Cogging Torque Reduction in Double-Rotor Hybrid Excited Axial Switched-Flux Permanent Magnet Machine

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I. Introduction

- Axial switched-flux permanent magnet (ASFPM) machines have attracted a lot of attention, which combine the advantages of the axial flux machine and SFPM machine.
- A novel double-rotor hybrid excited ASFPM (DRHE-ASFPM) machine is presented to broaden the constant power operating range and improve the load capacity.
- In order to reduce the cogging torque and torque ripple, three cogging torque reduction methods are proposed for the DRHE-ASFPM machine.

II. Topology

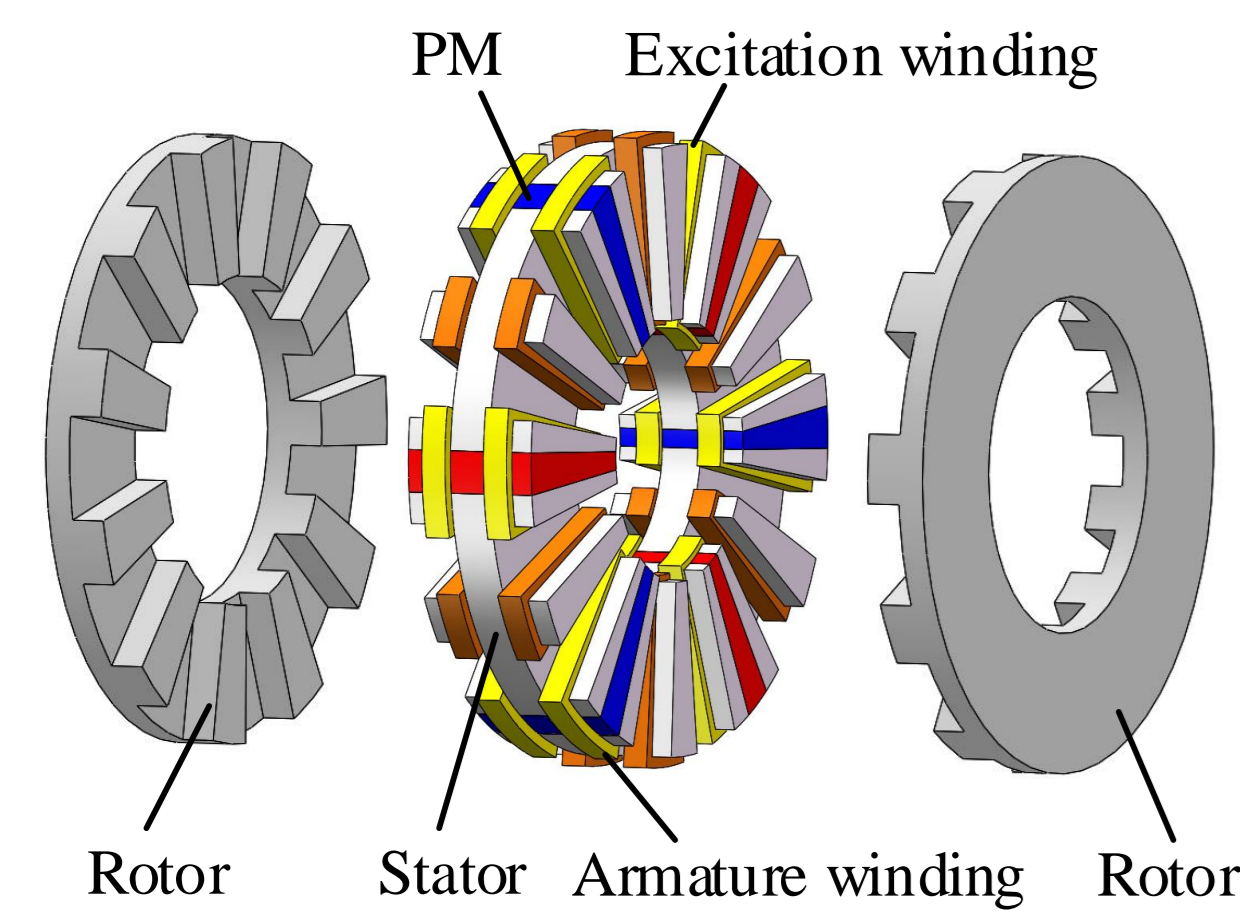


Fig. 1. Topology of DRHE-ASFPM.

- Compact structure
- Short axial length
- High power/torque density
- Robust rotor
- Wide speed range
- Low-speed large torque capability
- Brushless AC operation

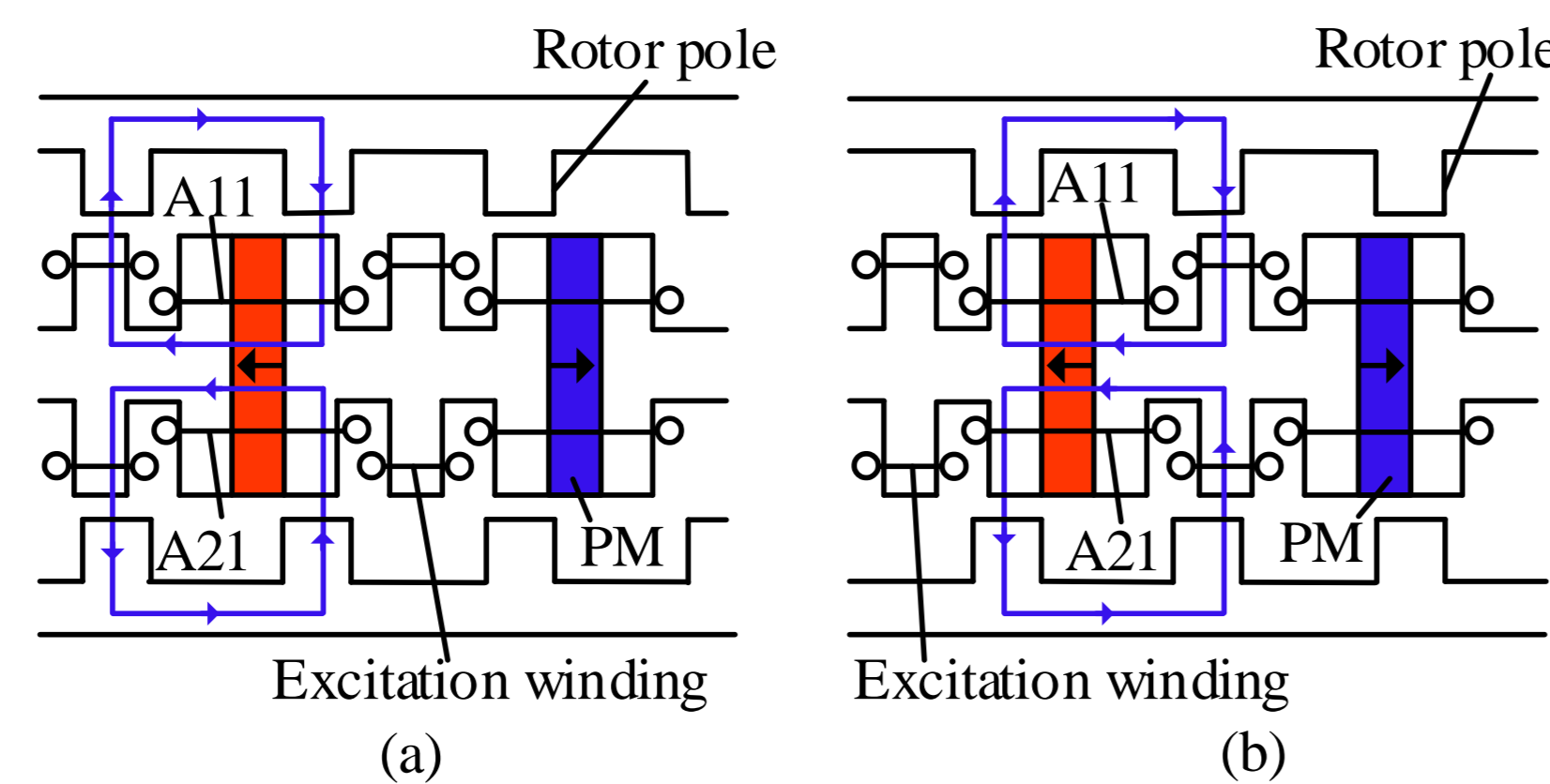


Fig. 2. Operation principle under PM mode. (a) Position 1. (b) Position 2.

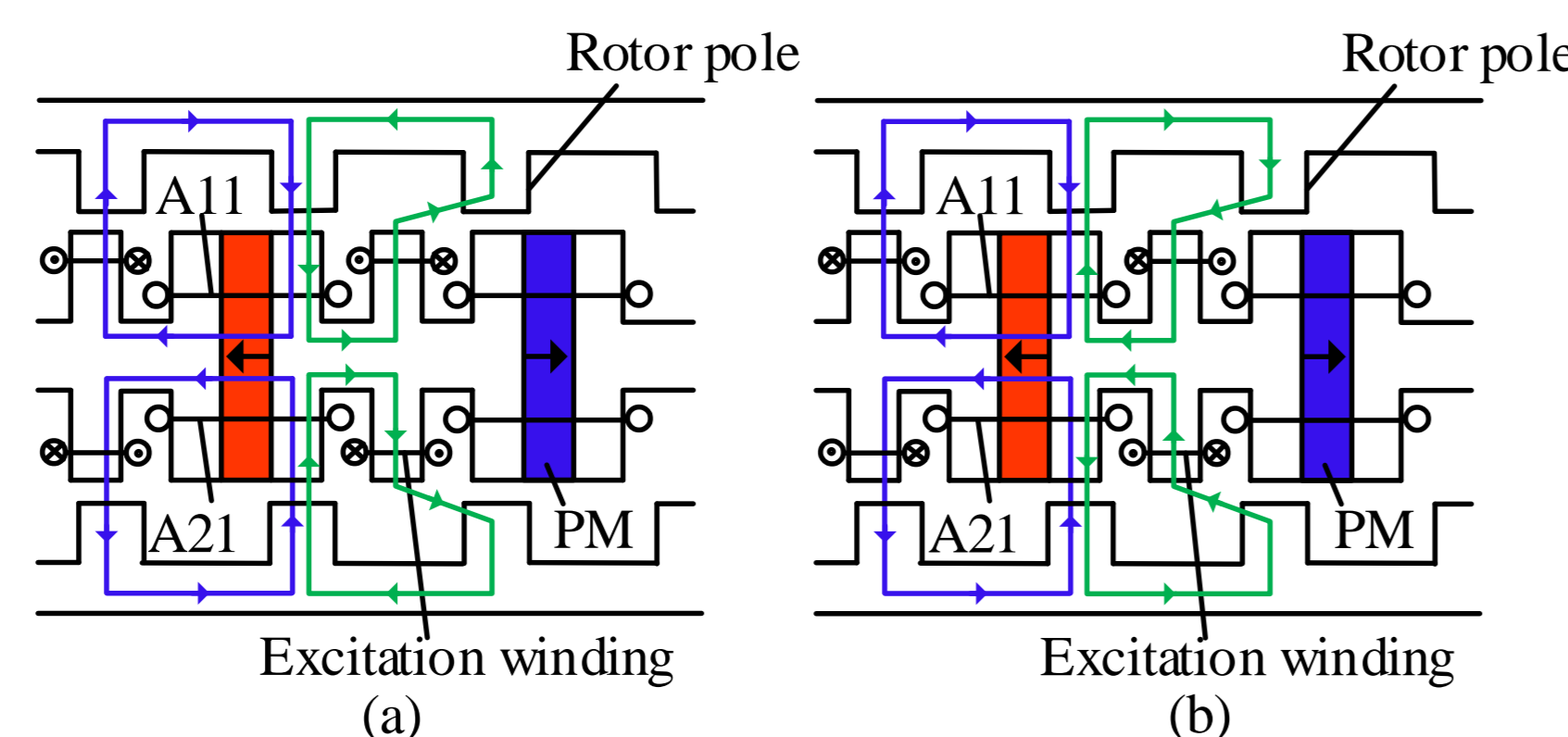


Fig. 3. Operation principle under hybrid excitation mode. (a) Flux-enhancing. (b) Flux-weakening.

Cogging torque

$$T_{\text{cog}} = -\frac{g(D_{\text{so}}^2 - D_{\text{si}}^2)}{16\mu_0} \times \int_0^{2\pi} \sum_{n=0}^{\infty} B_m \cos np_s \theta \times \left(\frac{2g(\theta, \alpha) - 1.646\beta_{\text{pm}}}{h_m^2} \right) \frac{\partial g(\theta, \alpha)}{\partial \alpha} d\theta$$

TABLE I
Major Design Parameter

Items	Value
rated output power, P_N (W)	600
rated speed, n_N (r/min)	750
rated armature current, I_N (A)	3.5
rated excitation current, I_e (A)	6
outer diameter of stator, D_{so} (mm)	165
inner diameter of stator, D_{si} (mm)	90
stator length, l_s (mm)	53
stator yoke length, l_{sy} (mm)	11
rotor length, l_r (mm)	15
rotor yoke length, l_{ry} (mm)	6
stator tooth arc, β_{st} (°)	11
stator middle tooth arc, β_{sm} (°)	13.5
stator slot arc, β_{ss} (°)	10
PM arc, β_{pm} (°)	4.5
rotor tooth arc, β_{rt} (°)	16.5
air gap length, g (mm)	1
armature winding turns, N_a	380
excitation winding turns, N_e	960

III. Cogging Torque Reduction Method

A. Stator/Rotor Teeth Notching

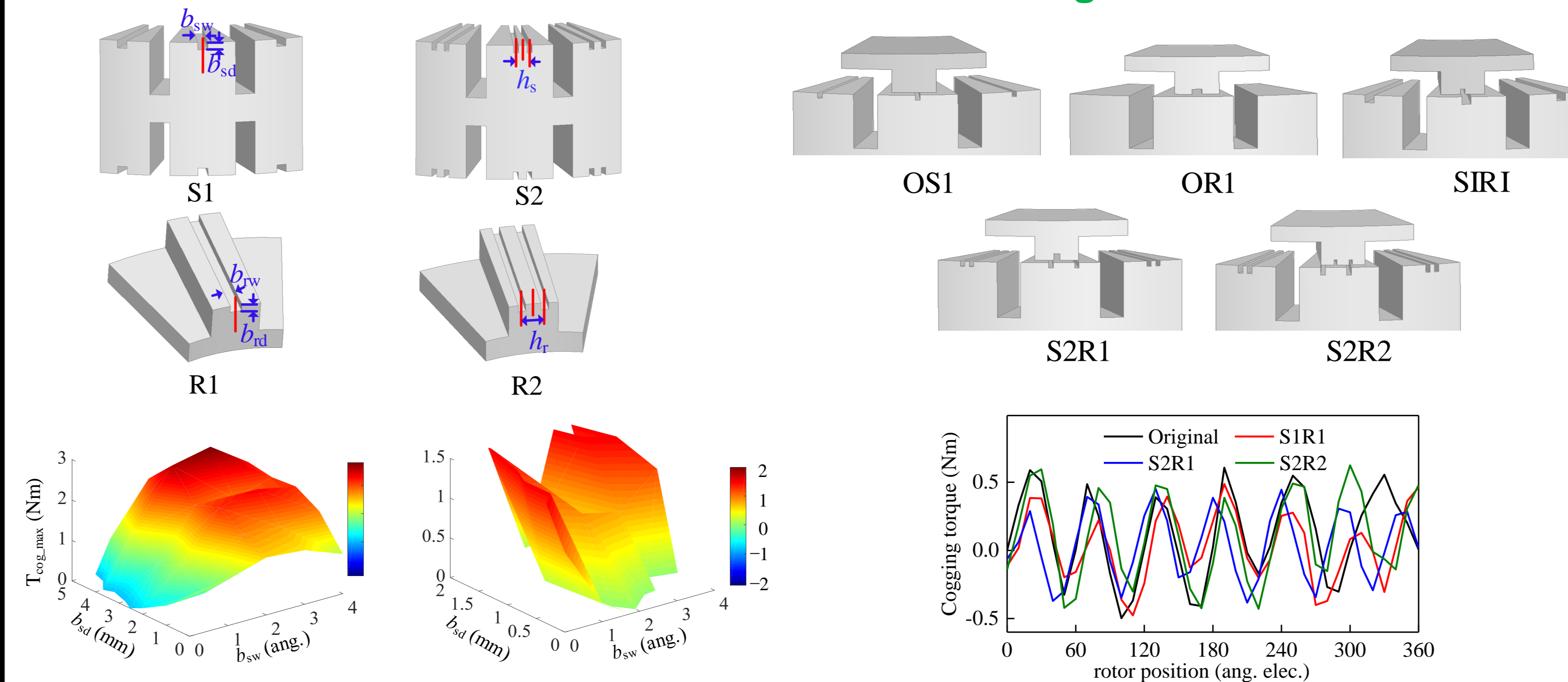


Fig. 4. Various combinations of stator/rotor tooth notching.

B. Stator Slot Chamfering

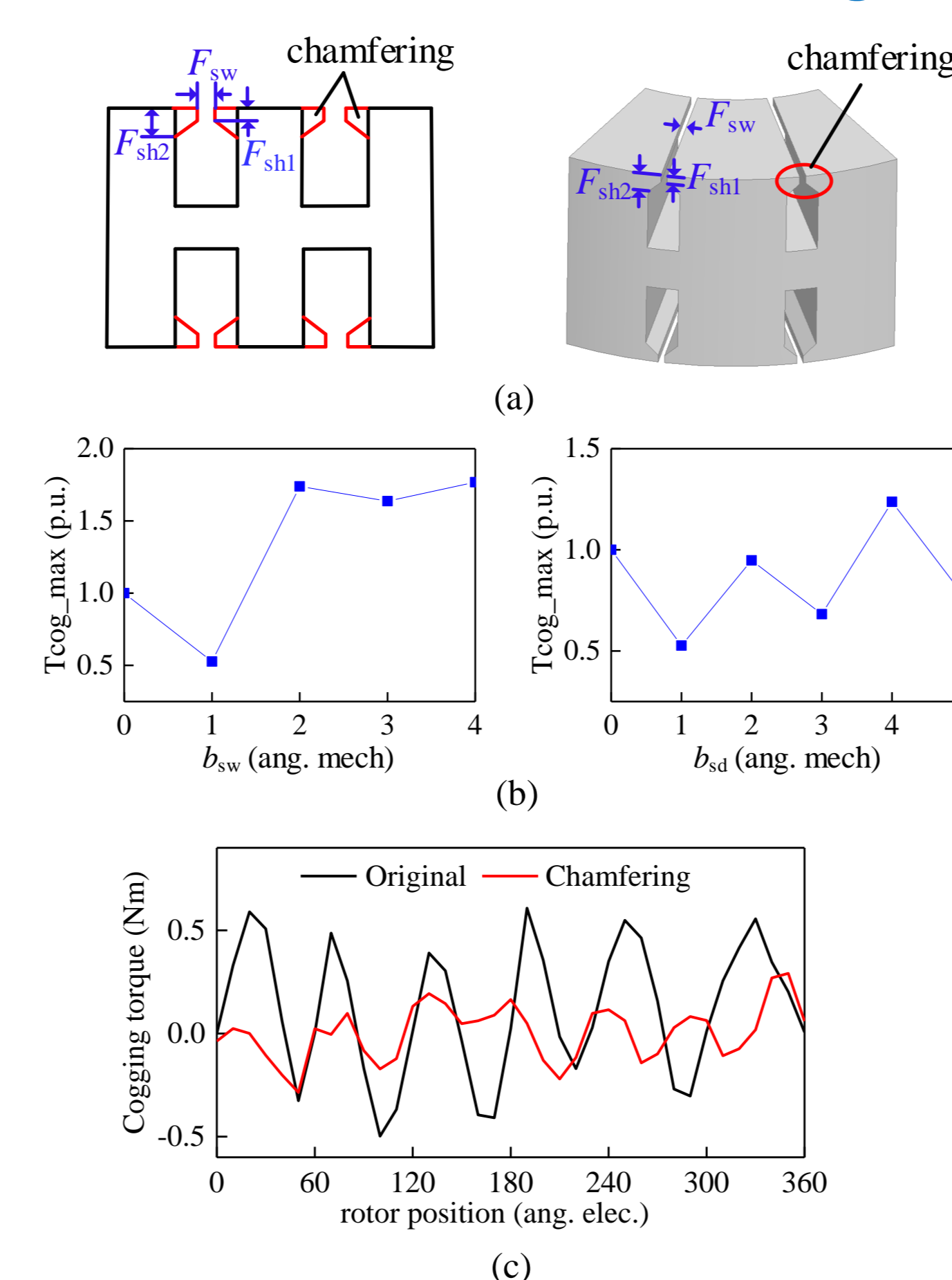


Fig. 6. Stator slot chamfering.

C. Stator Slot Chamfering and Tooth Notching

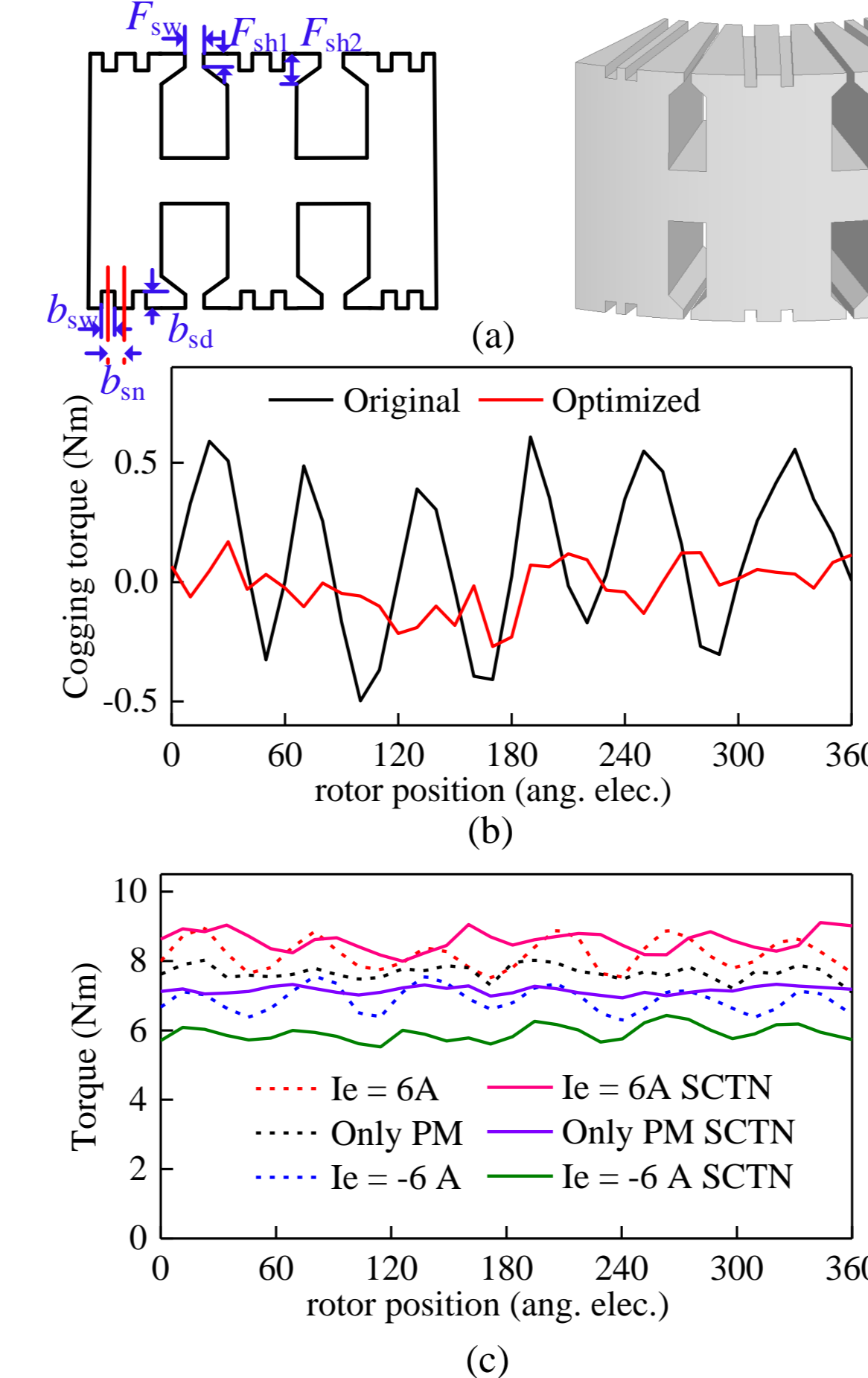


Fig. 7. Stator slot chamfering and tooth notching.

IV. Experiment Validation

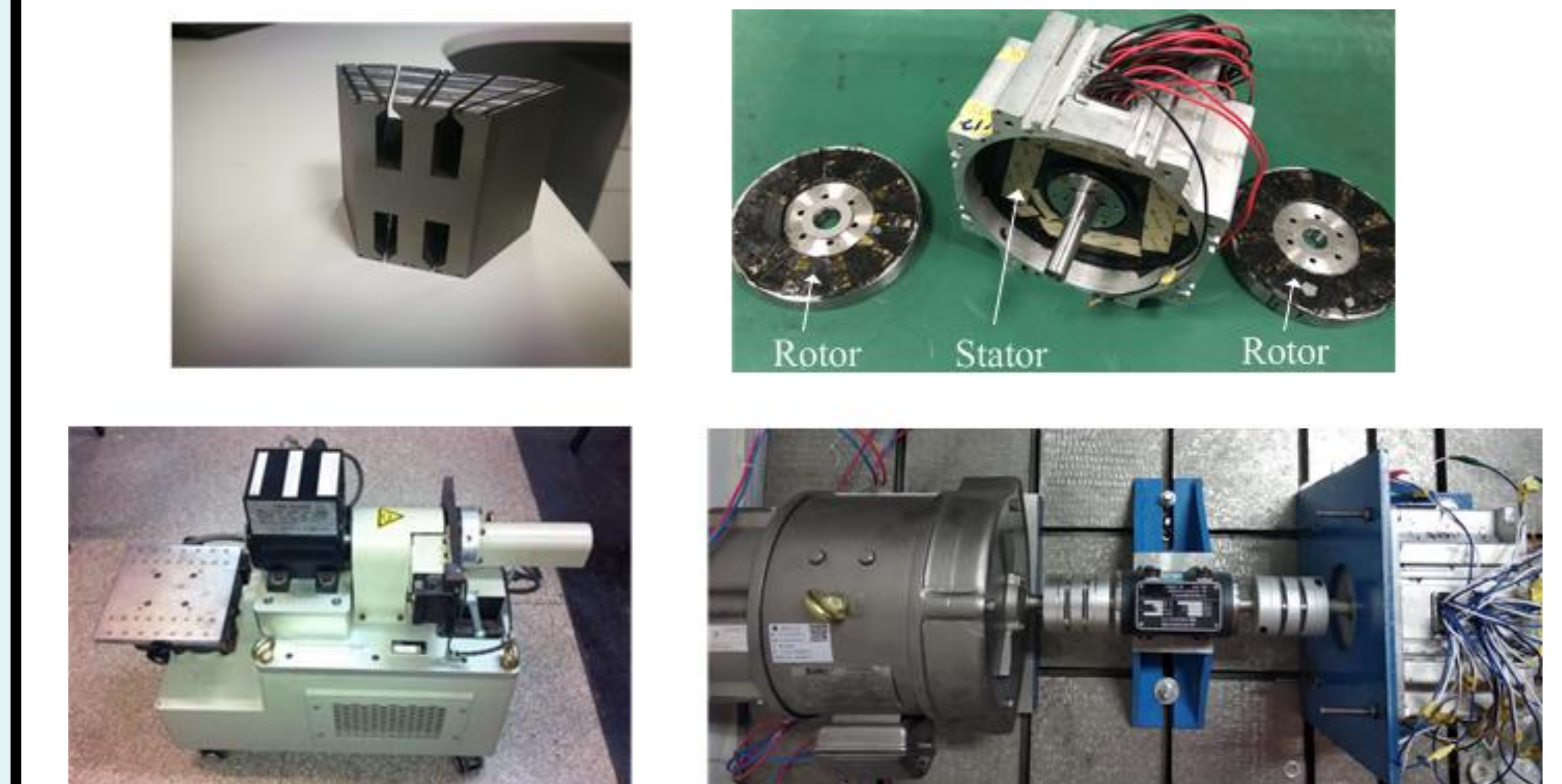


Fig. 8. Experimental platform.

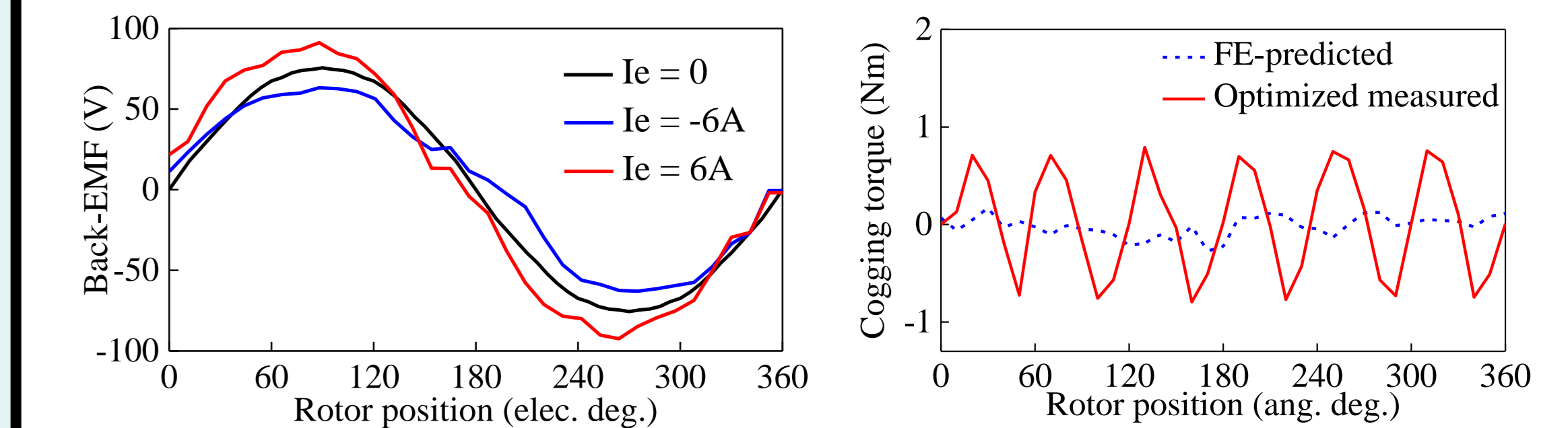


Fig. 9. Experimental results. (a) Measured back-EMF. (b) Measured cogging torque.

V. Conclusion

- A novel DR-HEASFPM machine is proposed, and the wide-speed operating range is achieved and the load capacity is enhanced.
- Three cogging torque reduction methods are proposed for the DRHE-ASFPM machine, such as the stator/rotor teeth notching and stator slot chamfering. Finally, the cogging torque is reduced and the torque ripple is decreased.
- The proposed DRHE-ASFPM machine is suitable for the electrical vehicles.