Design and Analysis of an Interior Permanent Magnet Synchronous Machine with Multi Flux Barriers Based on Flux-Intensifying Effect

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Background

- The research on a type of new PM machines based on flux-intensifying effect has drawn increasing attention in the machine field. This type of machines has the unique characteristic of $L_d > L_q$, resulting from the innovative design of rotor topology.
- With the price growth of the rare-earth material and its unstable supply chain, the further large-scaled application of rare-earth PM machine is gradually limited. As a result, the studies of a less-rare-earth PM machine or non- rare-earth PM machine has attracted increasing interest and concerns.

Objectives

- Based on flux-intensifying effect, a new less-rare-earth interior PM machine with multi flux barriers will be proposed.
- The proposed machine should have better flux-intensifying effect and excellent flux-weakening capability.

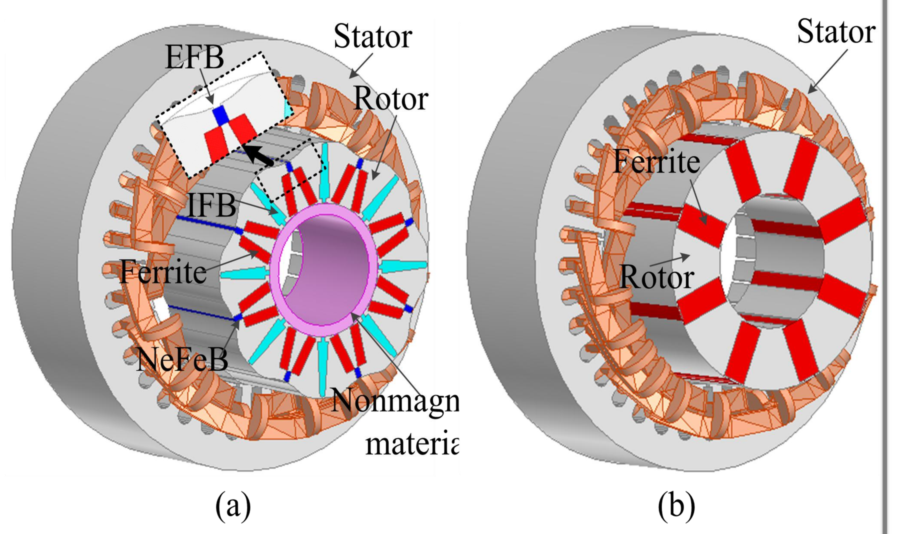
Conclusion

This paper proposes a less-rare-earth flux-intensifying machine with multi flux barriers rotor structure. By establishing the *d*-axis and *q*-axis magnetic circuit model, the flux-intensifying effect of the proposed machine is analyzed in detail. Based on the relevant parameters designs, the reasonable operating points of the PMs, preferable flux-intensifying effect, desirable output torque and low torque ripple are achieved for the machine. Besides, the electromagnetic performances of the proposed machine and the conventional machine are evaluated, which indicates that the proposed machine has better flux-intensifying effect, excellent flux-weakening capability and relatively high anti-demagnetization capability. In conclusion, all the study results reveal that the proposed machine exhibits a potential application prospects in EVs.

Machine Topology

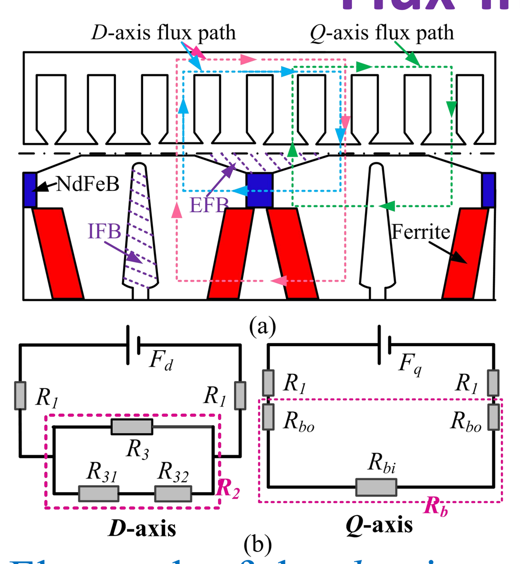
Machine Topology

The proposed machine with three phase 36-slot/8-pole configuration. By the unique rotor design in the flux paths of *q*-axis and *d*-axis, the characteristic of $L_d > L_q$ can be obtained without weakening the torque capability obviously.



Configurations of the machines. (a) MFB-FIPM machine. (b) S-PM machine.

Flux-Intensifying Effect Analysis



(a) Flux path of the *d*-axis and *q*-axis.
(b) Equivalent magnetic circuits.

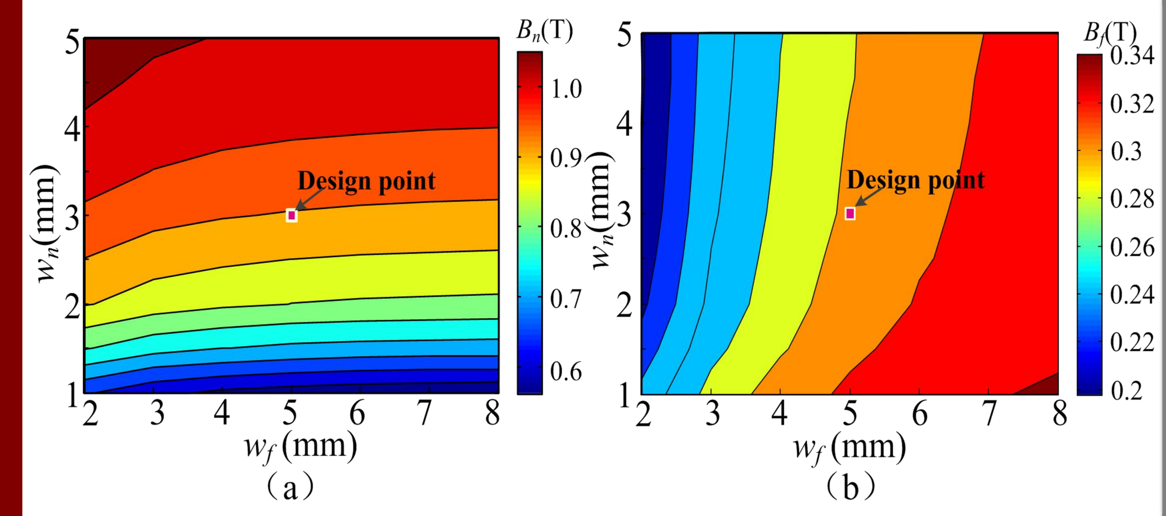
Based on the simplified magnetic circuits, the L_d and L_q of the proposed machine can be deduced and expressed as

$$\begin{cases} L_d = \dfrac{F_d}{i_d[2R_l + R_3(R_{31}+R_{32})/(R_{31}+R_{32}+R_3)]} \\ L_q = \dfrac{F_q}{i_q(2R_l + R_{bi} + 2R_{bo})} \end{cases}$$

The PMs and flux barriers are designed reasonably to achieve the feature of $L_d > L_q$. Thus, the flux-intensifying effect is obtained.

PARAMETERS DESIGN

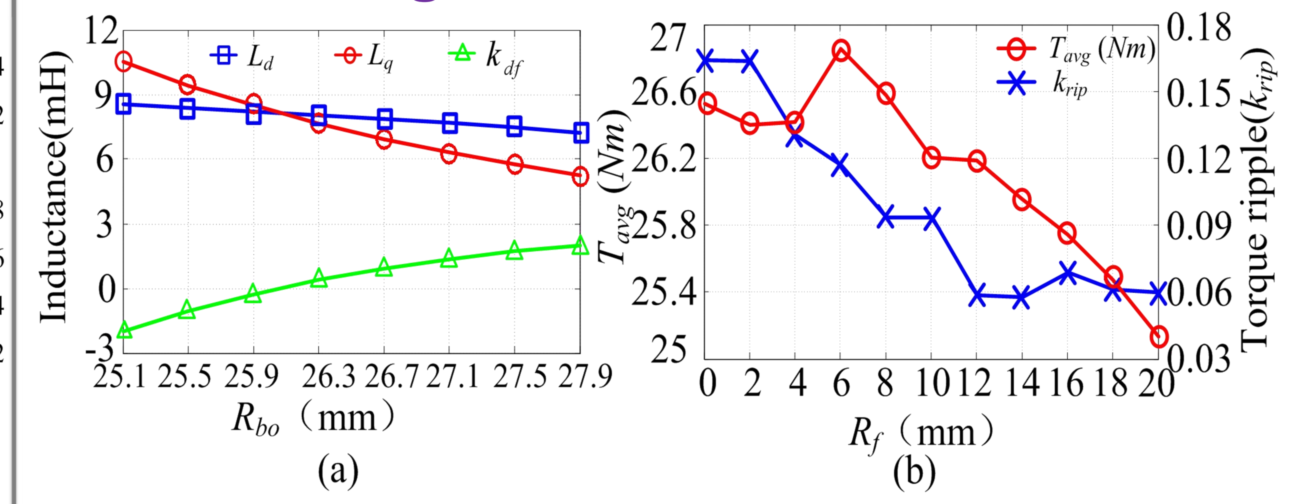
Design of the PMs



Operating point maps of NdFeB and ferrite under different thickness of PMs are given.

The w_f and w_n are chosen as 5mm and 3mm finally.

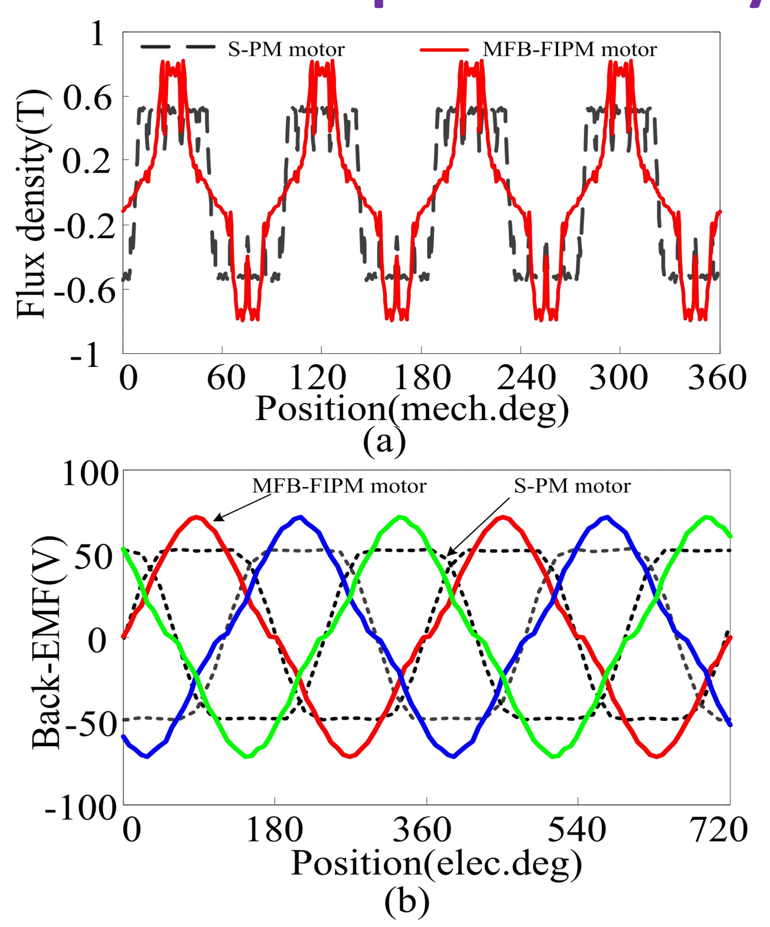
Design of the Flux Barriers



Variation of inductance/ average torque and torque ripple with respect to R_{bo}/R_f .(a) Variation of inductance with respect to R_{bo}.(b) Variation of average torque and torque ripple with respect to R_f.

PERFORMANCES ANALYSIS

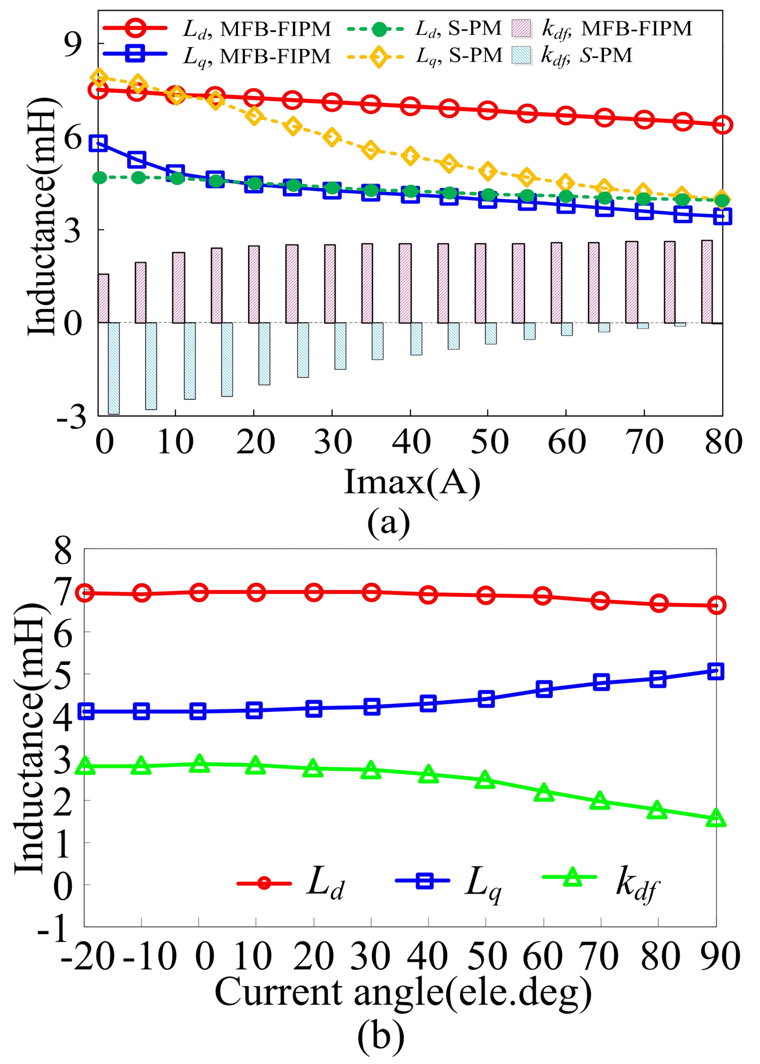
Air-Gap Flux Density and Back-EMF



Air-gap flux density and back-EMF of the machines. (a) Air-gap flux density. (b) Back-EMF.

The proposed machine offers a relatively high airgap flux density. Besides, the back-EMF of conventional S-PM machine is trapezoidal, while the proposed machine is relatively sinusoidal, proving that the proposed machine is suitable for brushless AC operation.

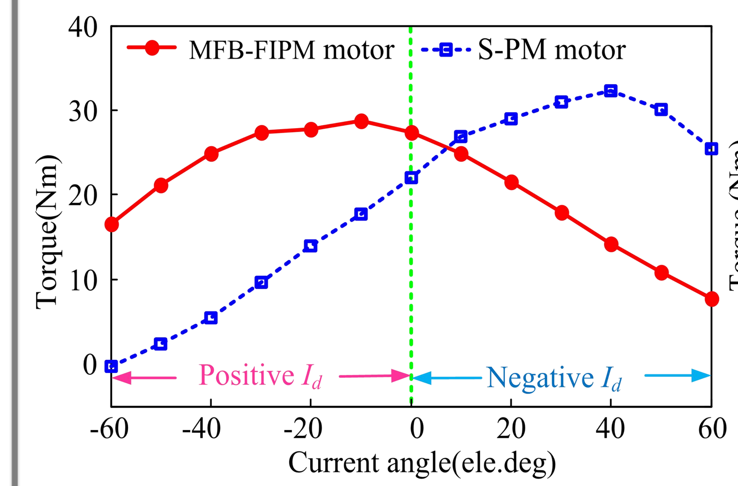
Inductance Characteristics



Inductance characteristics. (a) Inductance varies with current amplitude of the two machines. (b) Inductance varies with current angle of the MFB-FIPM machine.

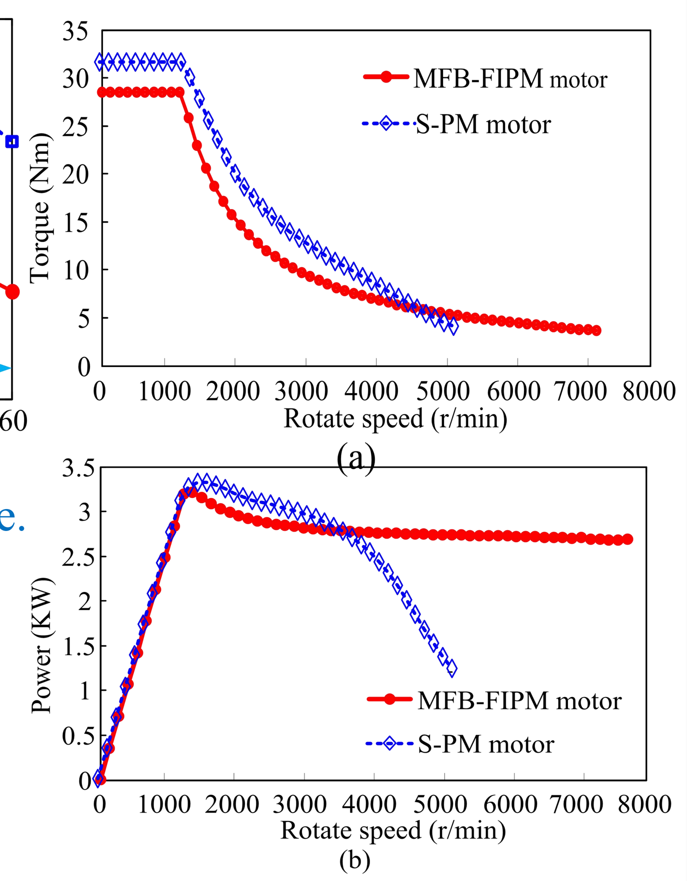
For the proposed MFB-FIPM machine, the L_d decreases slightly with the load current increasing, which is caused by the mild cross-coupling magnetic saturation effect between *d*-axis and *q*-axis. And the characteristic of $L_d > L_q$ is achieved during the all current range.

Torque Performances and speed range



Torque varies with the current angle.

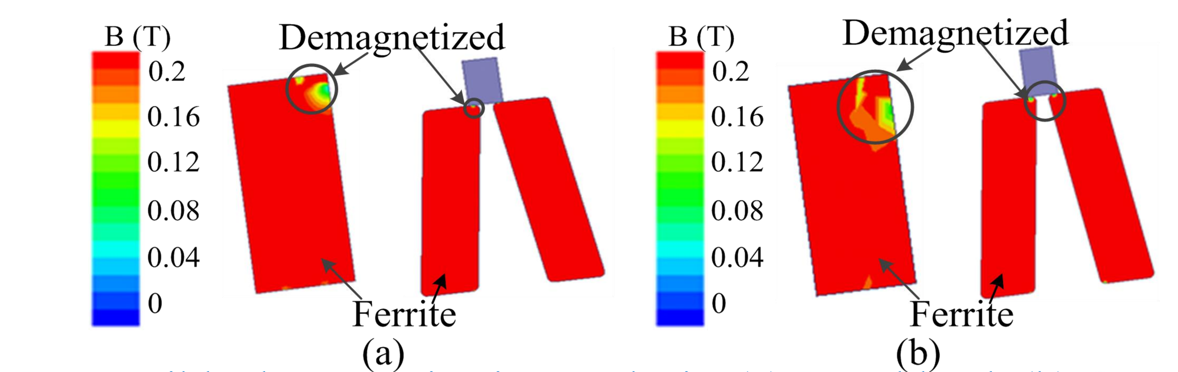
The maximum total torque of the MFB-FIPM machine is acquired with positive I_d, And when the positive I_d is applied, positive reluctance torque is achieved.



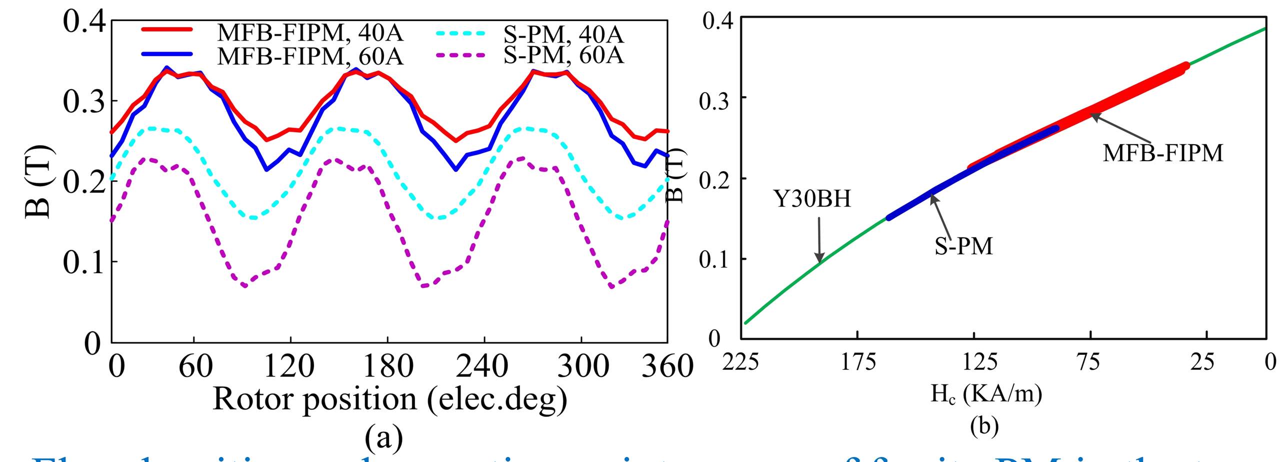
Operation characteristic curve.

The MFB-FIPM machine owns excellent flux-weakening capability and wide speed range.

Demagnetization Analysis



Irreversible demagnetization analysis. (a) Rated load. (b) Overload.



Flux densities and operating point ranges of ferrite PM in the two machines. (a) Flux densities. (b) Operating point ranges.

The operating points of ferrite PM is increased and partial demagnetized risk is mitigated in the MFB-FIPM machine.

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