A new partitioned stator hybrid excitation flux switching motor with ferrite permanent magnet

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Background

Benefiting from the high energy permanent magnet (PM) excitation and flux-concentration effect, flux-switching PM (FSPM) machines usually possess the advantages of high power density and high efficiency. However, FSPM machines suffer from a limited constant power operation range due to the uncontrollable PM excitation field, which restricts the applications in variable speed drive systems. Therefore, hybrid excitation flux switching (HEFS) machines have been proposed and investigated widely, which combine the merits of both PM machines and electrically excited synchronous machines. Most attractively, HEFS machines can be realized easily without brushes and slip rings because both of the excitation sources and armature windings are located in the stator.

However, all of the existing HEFS machines have a common feature, namely PMs, field windings and armature windings are all located in the single stator, which leads to a serious stator space conflict. So the machine design difficulty is increased and the power density is reduced inevitably. Therefore, a partitioned stator (PS) HEFS (PS-HEFS) machine, which employs two separated stators to respectively accommodate armature windings, PMs and field windings, is proposed in this paper. Due to its special partitioned stator structure, the space utilization of proposed machine can be greatly improved, thus enhancing the electromagnetic performances.

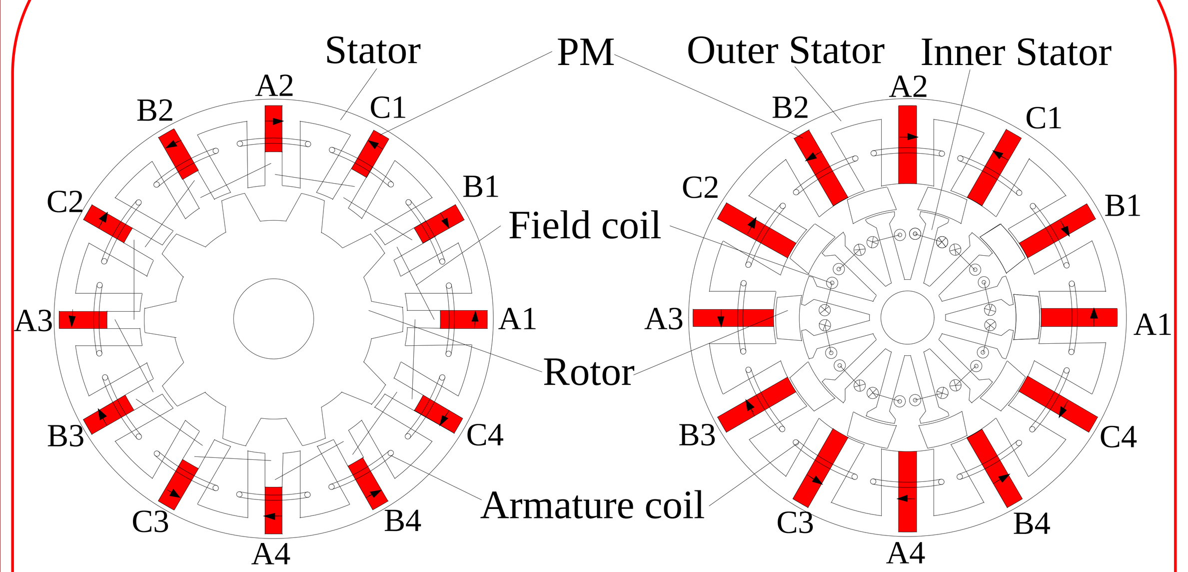
Conclusion

In this paper, a PS-HEFS machine, which employs two separated stators to accommodate armature windings, PMs and field windings, respectively, is proposed and analyzed by using 2-D FEA. Based on the comparison results, it can be summarized as:

- Two PS-HEFS machines possess higher flux density regulation capabilities than two HEFS machines because of the larger field winding slot areas, thus allowing a higher ampere-turn numbers.
- Two HEFS machines exhibit higher cogging torque level due to the smaller air-gap areas than those of two PS-HEFS machines.
- In regard of machines with and without iron bridges, PS-HEFS1 and HEFS1 exhibit wider flux regulation ratio than corresponding machines without iron bridges, though their rated torques is a little lower than that of PS-HEFS2 and HEFS2.

Topology and Operation Principle

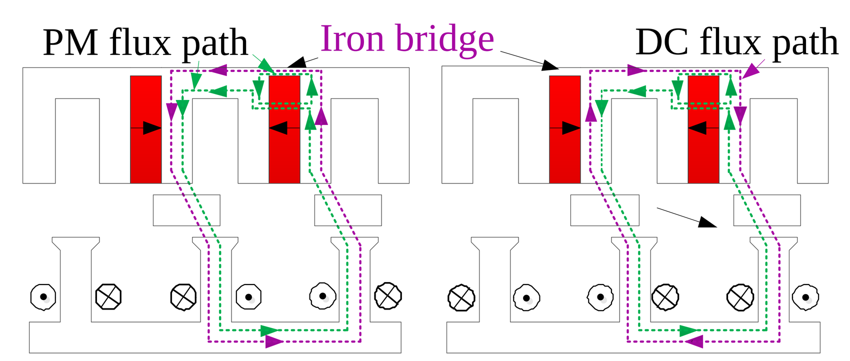
Topology



Existing HEFS machine   Proposed PS-HEFS machine

Compared with existing HEFS machines, the field windings are set in the inner stator, so the inner space of machine rotor can be utilized, and the conflict of location space among three electro-magnetic sources can be relieved.

Operation Principle



Flux enhancing, with iron bridge   Flux weakening, with iron bridge

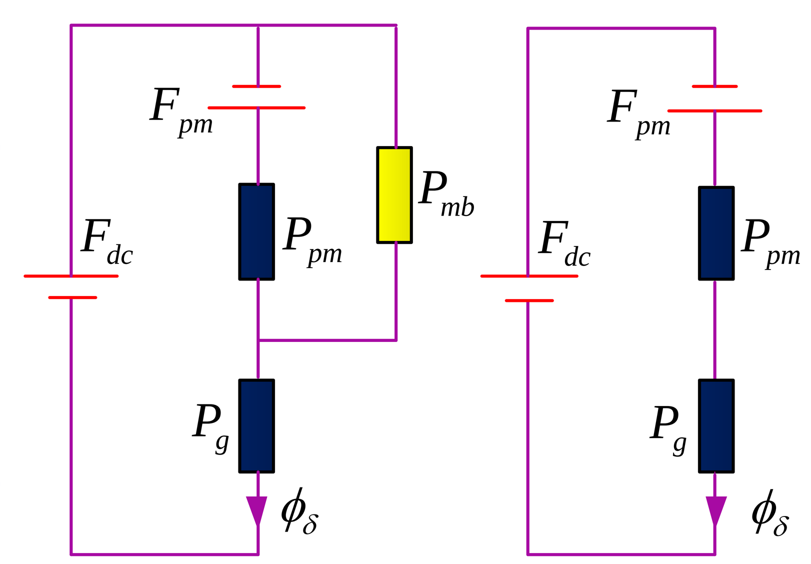
Flux enhancing, without iron bridge   Flux weakening, without iron bridge

It should be noted that an iron bridge is employed between each two outer stator cores, resulting in an unsegmented outer stator lamination to facilitate the manufacture. On the other hand, the iron bridge provides additional magnetic circuit for the magnetic field, which can enhance the magnetic field regulation capability.

Magnetic Circuit Model

An equivalent lumped para-meter magnetic circuit model is developed to qualitative analyze the effect of iron bridges. In order to simplify the derivation, the following assumptions are made:

- The permeability of iron core is infinite except that of iron bridges, which is assumed to be unchanged with the rotor rotation and the variation of excitation sources.
- Finite coercivities are ignored.
- The variation of magnetic field is in the radial direction only.



With iron bridge   Without iron bridge

Defining the flux regulation ratio as

$$\gamma = \frac{\phi_{\delta mx} - \phi_{\delta\min}}{\phi_{\delta PM}}$$

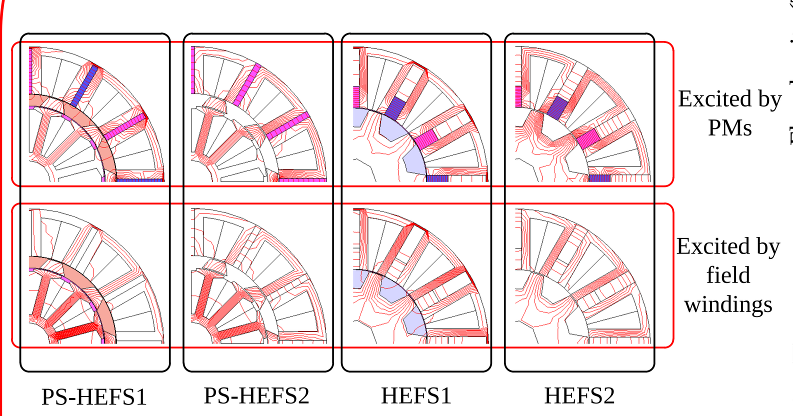
So, the flux regulation ratios of two machines can be calculated as

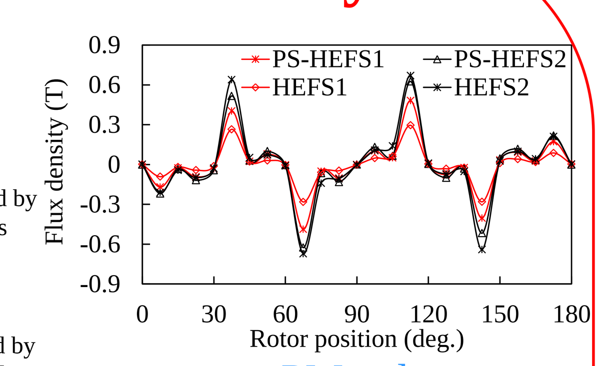
$$\begin{cases} \gamma_1 = 2F_{dc}P_g\left(1 - \dfrac{P_g}{P_{pm} + P_{mb} + P_g}\right) \\ \gamma_2 = 2F_{dc}P_g\left(1 - \dfrac{P_g}{P_{pm} + P_g}\right) \end{cases}$$

It can be found that due to the adoption of iron bridges, the flux regulation ratio can be enhanced under the same magnetomotive force of field windings.

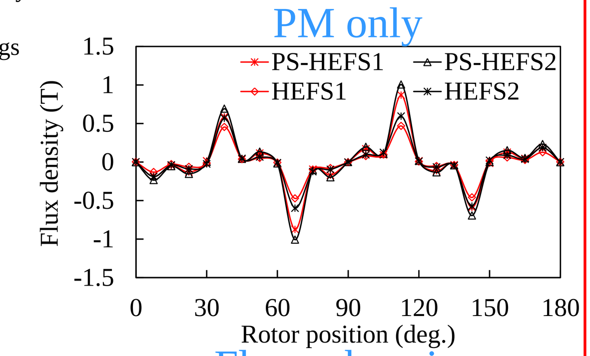
Performance Analysis

Flux Distributions and Density

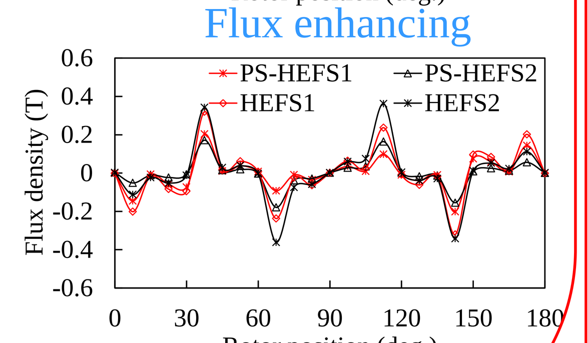




PM only



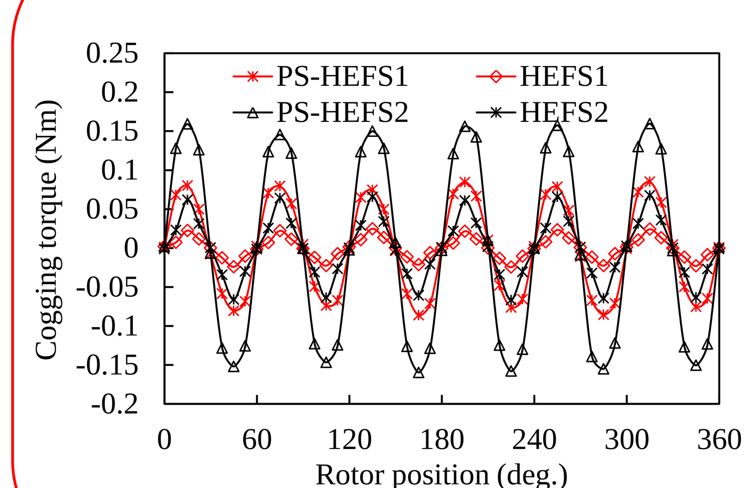
Flux enhancing



Flux weakening

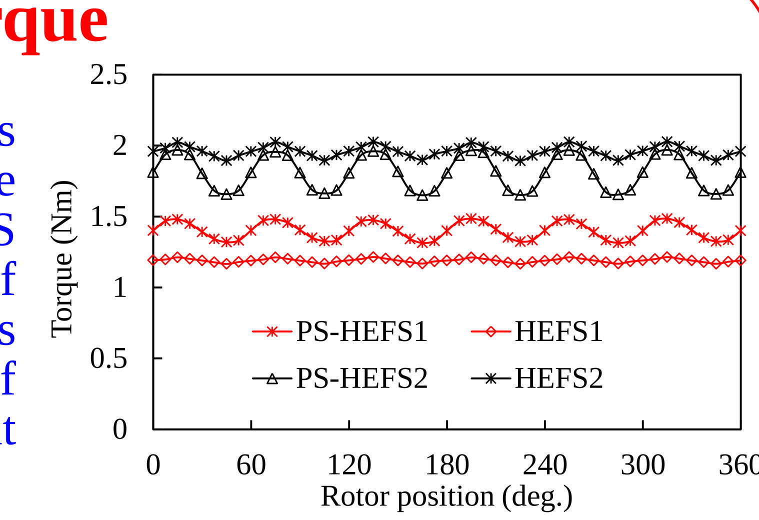
Due to the adoption of iron bridges, some PM fluxes are shorted in PS-HEFS1 and HEFS1, and the winding field is parallel with PM field, and the magnetic field regulation capability can be enhanced compared with those of PS-HEFS2 and HEFS2.

Cogging Torque and Torque



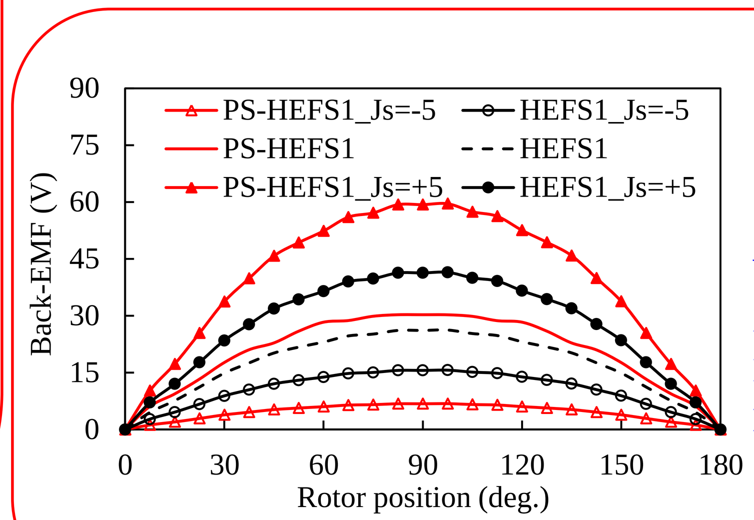
Cogging torque of four machines

The cogging torque peak values of two PS-HEFS machines are higher than those of two HEFS machines, and the values of machines with iron bridges are respectively smaller than those of the corresponding machines without iron bridges.



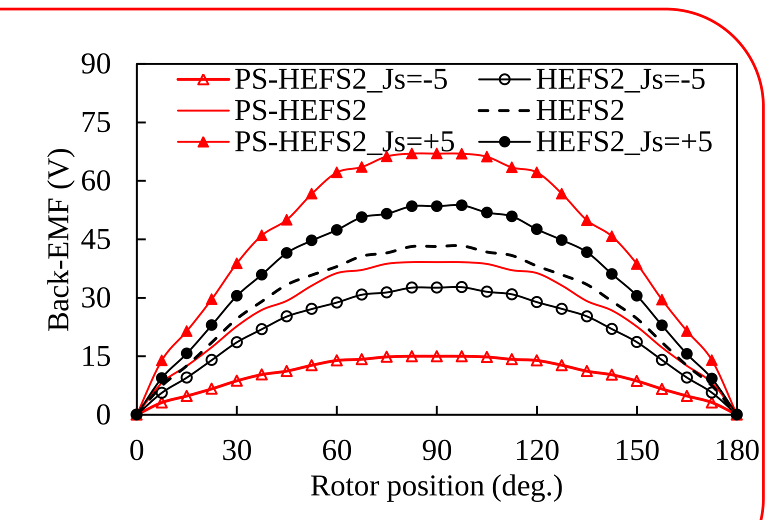
Torque waveforms of four machines

Back-EMF



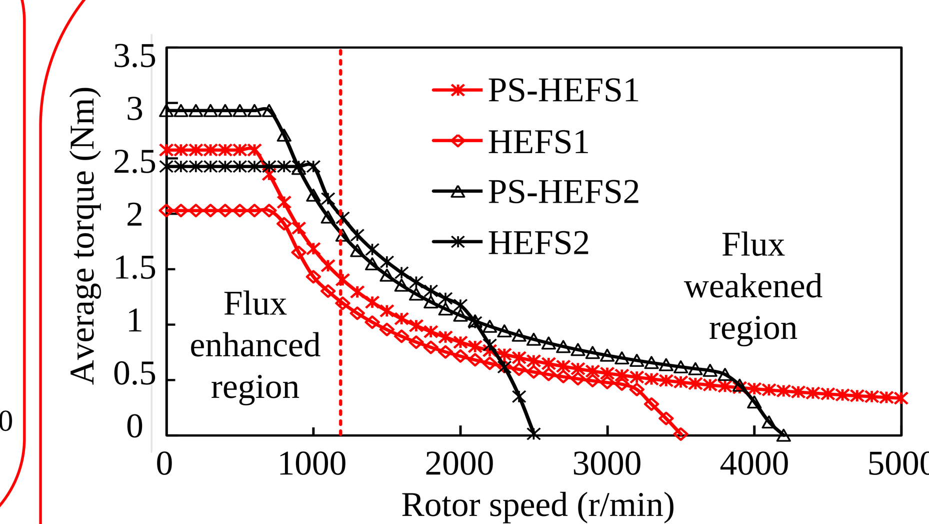
Back-EMF, with iron bridge

The labels of “Js = −5” and “Js = +5” represent the hybrid excitations with the current density of 5 A/mm^2 in the field winding slots, with negative and positive polarities respectively.

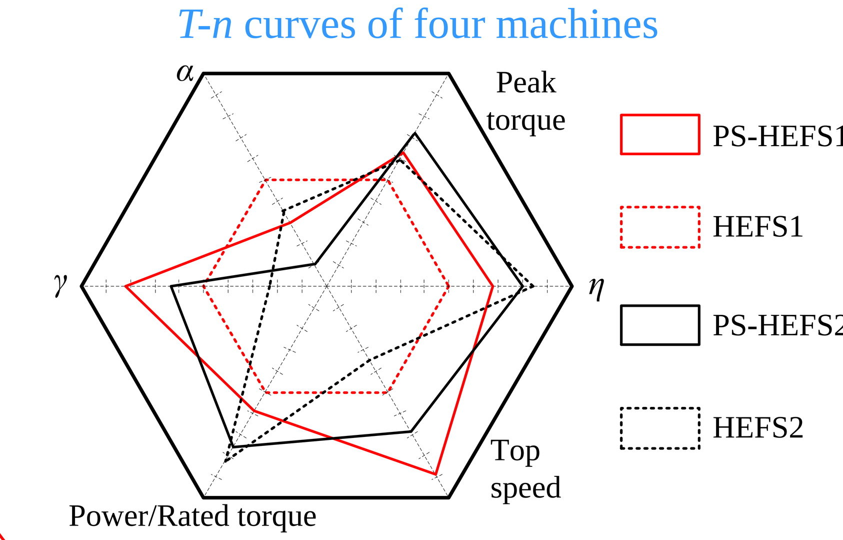


Back-EMF, without iron bridge

Speed *VS* Torque



T-n curves of four machines



Comparison of six key performances

The CPSR can be significantly extended under flux weakening operation, while the flux enhancing operation is beneficial to improve torque output and response speed in the low speed region. With the identical limitation of bus voltage and phase current peak value, the torque-speed curves of four machines are calculated by using the flux-linkage method.