# Thu-Af-Po4.05-19 [77] Investigation of a Surface PM Machine with Segmented-Eccentric Magnet Poles


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## Background

In general, reducing the torque ripple by changing the shape of the permanent magnet (PM) has a negative effect on the electromagnetic torque and increases magnet cost. Magnet segmentation with Halbach array can achieve low total harmonic distribution and reduce torque ripple, which depends on magnet usage. eccentric segmented magnet pole with Halbach array is carried out, which aims to unite the advantages of section Halbach array and eccentric magnets to achieve low torque ripple and high usage efficiency, while avoiding the decrease of the fundamental amplitude of air-gap magnetic flux density and the torque ripple cause by inter-pole leakage flux.

## Objectives

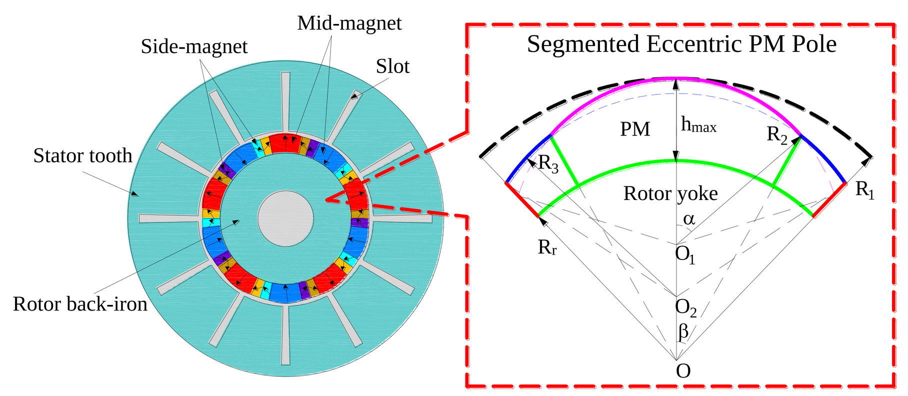
- A 12-slot/10-pole PM synchronous machine.
- There are two types of parameters, one is the magnetization angle $\Delta\theta$, and the other is the offset distances.

## Conclusion

- An unequal-magnet height pole permanent magnet machine has been proposed, which has segmented and eccentric poles.
- It can obtain high amplitude of fundamental air-gap flux density, low cogging torque, high electromagnetic torque and low harmonics.
- The selection method of the polar arc coefficient and the optimum permanent magnet thickness will be further studied in the future.

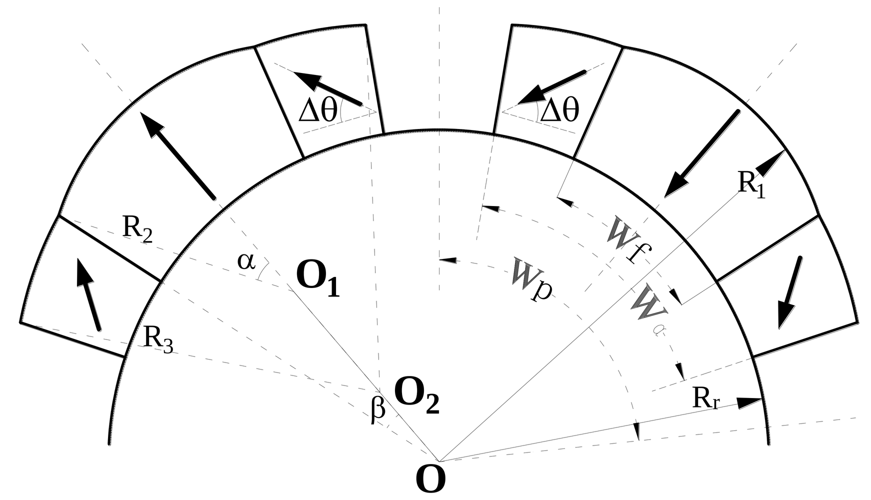
## Structure

### model and magnet pole geometry




each magnet pole is divided into 3 segments, a mid-magnet and two side-magnets which may have different $B_r$ and circular arc centers. The centers of these three parts are on a line and two side-magnets are concentric, not as the mid-magnet.

### magnet poles with eccentric parameters

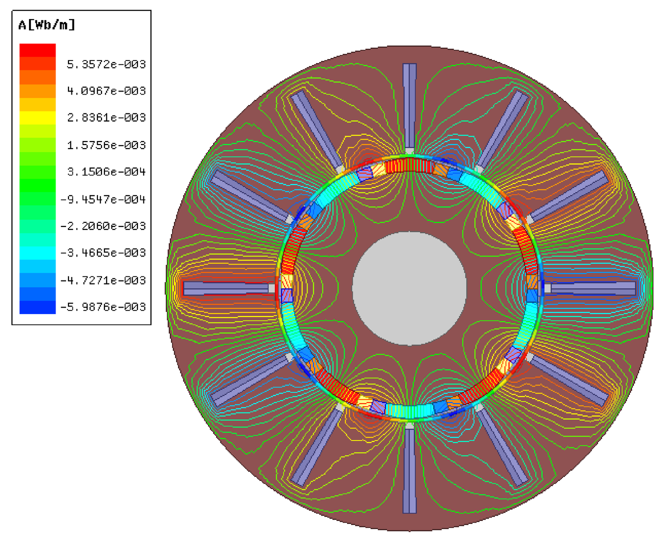


each pole consists of a mid-magnet and two side-magnets. The outer arc center of the mid-magnet and side-magnet are $O_1$ and $O_2$, with radii $R_2$ and $R_3$, respectively. The axis center is $O$.

## Parameters

| Quantity | Value | Quantity | Value |
|---|---|---|---|
| Rated speed (rpm) | 600 | Stator yoke height (mm) | 4 |
| Slot opening (mm) | 2 | Rotor outer diameter (mm) | 59 |
| Pole number | 10 | Shaft diameter (mm) | 26 |
| Stator slot number | 12 | Mid-magnet $B_r$ (T) | 1.2 |
| Air-gap length (mm) | 1 | Side-magnet $B_r$ (T) | 1.05 |
| Stator inner diameter (mm) | 61 | Magnet thickness (mm) | 3 |
| Stator outer diameter (mm) | 110 | Eccentricity of mid-magnet (mm) | 11.25 |
| Eccentricity of side-magnet (mm) | 3.75 | | |

## Results

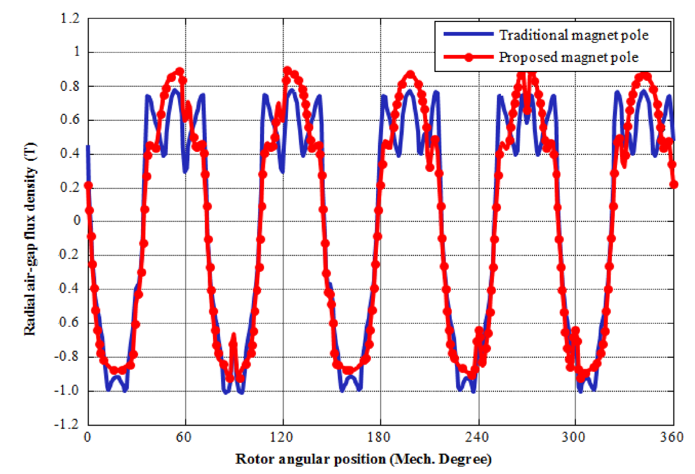


The flux distribution.

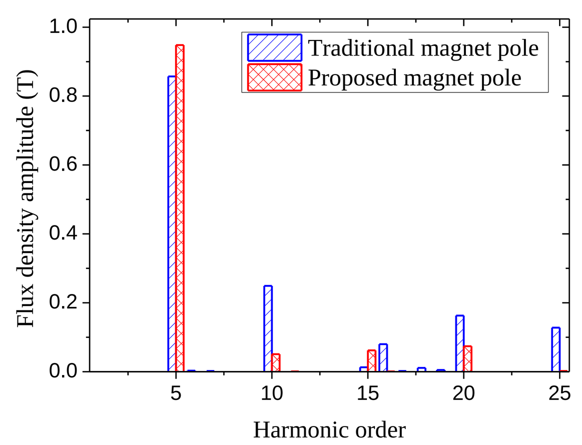
The newly developed magnet pole can decrease the total harmonic distortion (THD)

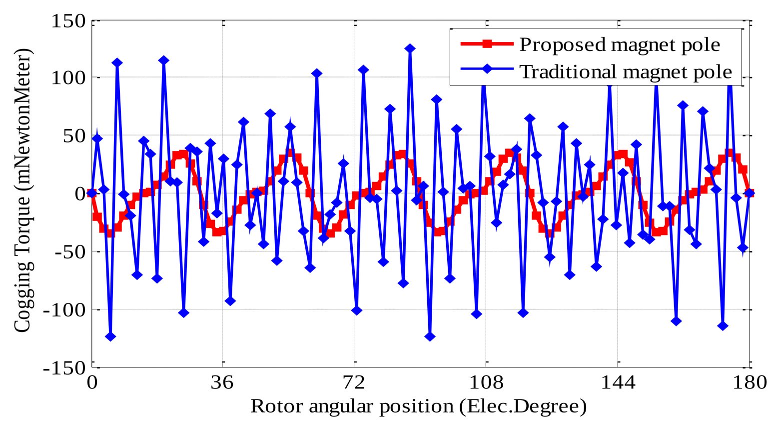
$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} B_n^2}}{B_1}$$

The traditional magnet pole THD is 39.8% and the proposed magnet pole THD is 12.3%.

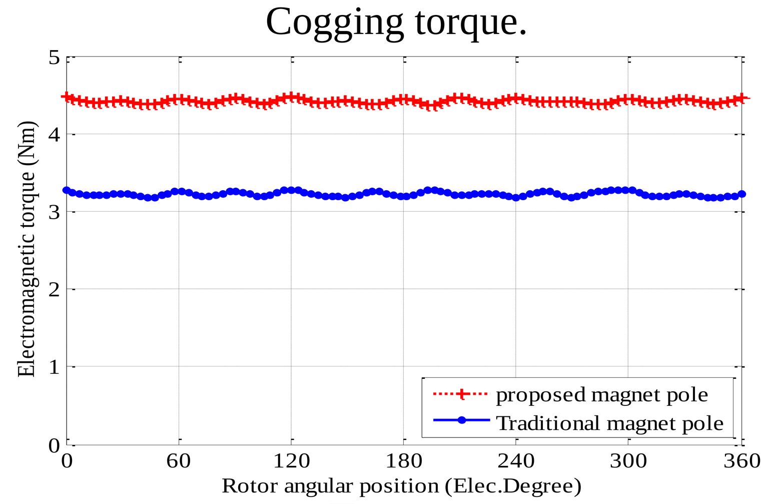



flux density



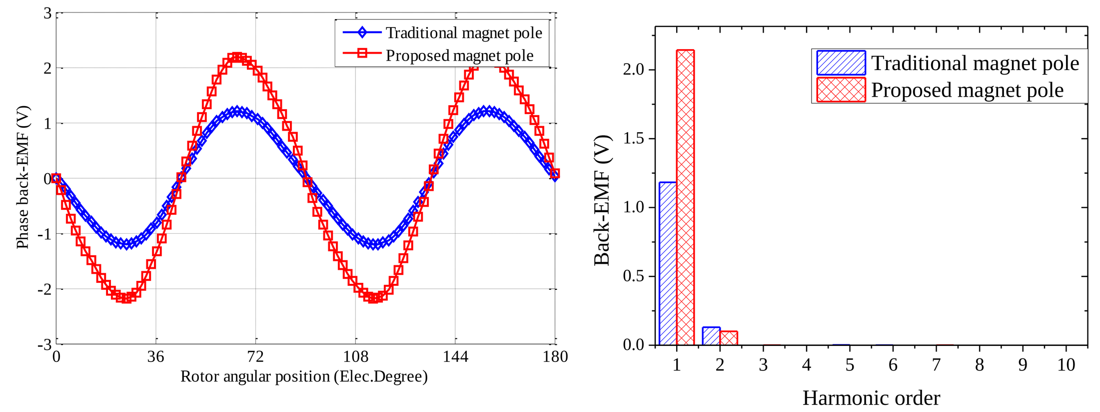




Cogging torque.




Torque

The average torque values are 4.47 Nm and 3.35 Nm, respectively.

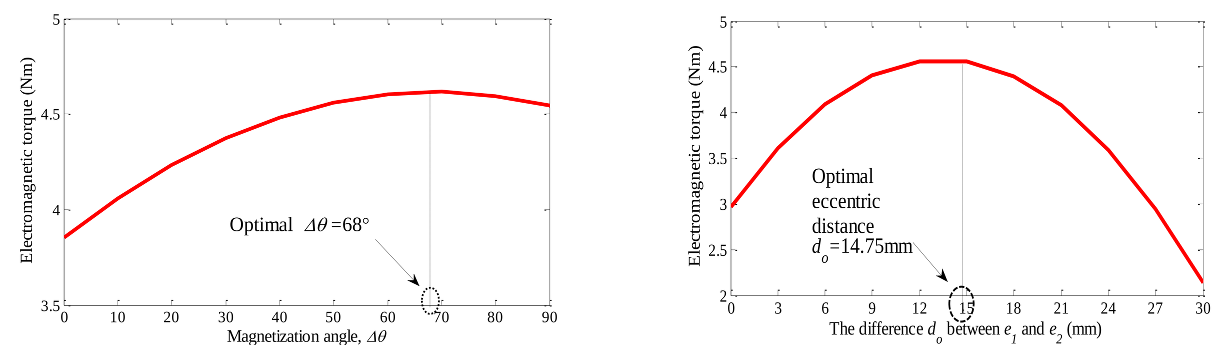



Back-EMF and harmonic

The phase back-EMF amplitude of proposed magnet pole and traditional pole are 2.26 V and 1.33 V, respectively.

From the FEA results, the advantage of the proposed magnet shaping technique is validated. It can obtain high amplitude of fundamental air-gap flux density, low cogging torque, high electromagnetic torque and low harmonics. The following is further optimization of the shape and direction of magnetization.

### Optimized design




The electromagnetic torque has a tendency to rapid increase with the increase of magnetization angle and the optimal angle is $\Delta\theta$=68°, while the machine can deliver optimum electromagnetic performance with the optimized Halbach magnetization array. The electromagnetic torque increases first and then decreases with the increase of eccentricity, it shows the optimal difference between $e_1$ and $e_2$, $d_o$=14.75mm.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