Torque ripple reduction technique for permanent magnet motors using uneven magnetic pole design

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I. Research background

Cogging torque & torque ripple reduction techniques

PM step skewing

Stator skewing

Notching

Teeth width design

Teeth pairing

PM arc design

PM edge shaping

And more...
II. Uneven magnetic pole design

Principle: Uneven magnetic poles

\[ \frac{Q}{m \cdot t} = \text{Even number} \]

- Q: number of slots, t: GCD (Q, pole-pair), m: number of phase
- 10p12s, 14p12s, 14p18s, 20p24s, 22p24s, 26p24s, 28p24s, 30p36s...

Cogging torque waveform by each pole
(Sensor operation)
II. Uneven magnetic pole design

Principle: Uneven magnetic poles

No load flux density distribution in case of no slot
II. Uneven magnetic pole design

Principle: Uneven magnetic poles

- Magnetic unbalance can be canceled by series connection of the two phase belts even for the uneven magnetic poles
II. Uneven magnetic pole design

Comparative study

Even pole: $\beta = 145$

Uneven pole: $\beta_1 = 130, \beta_2 = 160$

Geometry modeling: Overlay and overlay modification for uneven magnetic pole design
II. Uneven magnetic pole design

Comparative study: Even magnetic pole

Rotor position [Electrical angle]
II. Uneven magnetic pole design

Comparative study: Uneven magnetic pole
II. Uneven magnetic pole design

Comparative study

No load induced voltage: 4-series connection/ph.

![Graph comparing even and uneven rotor positions](image)
II. Uneven magnetic pole design

Comparative study

Peak cogging torque reduction: 97%
II. Uneven magnetic pole design

Comparative study

Same average torque but ripple reduction: 70%
II. Uneven magnetic pole design

Comparative study

Average torque vs. advance angle

- **J=10A_{rms}/mm^2**
- **J=15A_{rms}/mm^2**
- **J=5A_{rms}/mm^2**

Advance angle[Deg.]

Avg. torque[Nm]
II. Uneven magnetic pole design

Comparative study

Torque ripple reduction: about 70%

![Graph showing torque ripple reduction at different advance angles.](image-url)
Uneven magnetic pole design realizes:

- Feasible only for a few special pole/slot combinations
- Cogging torque suppression.
- Torque ripple reduction
- No performance sacrifice

Patents pending

- Kr 10-2016-0064812
- PCT/KR2016/013249
Future work

Rotor design variations

IPM

IPM+SPM

SPM+CP

IPM+CP
Thanks

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