Torque Harmonic Analysis of Permanent Magnet Synchronous Machine According to Current Harmonic Order

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Abstract

When motor operating, many harmonic components are included. There are spatial harmonics and current harmonics, and from combination of them torque ripple is generated. Torque ripple causes noise and vibration and has influence on stability of operation system, so torque analysis is important part. If back-EMF and current is ideal sinusoidal wave, torque is constant. However, back-EMF and current is not ideal sinusoidal, and torque ripple is generated by interaction of the back-EMF harmonics and current harmonics. According to order of current harmonic components, torque ripple is shown differently because when time harmonic components are coupled with spatial harmonic components, some of harmonic components are canceled out, as others are intensified due to interaction.
In this paper, effect of current harmonic order on torque characteristic is studied. 3rd, 5th, 7th and 9th harmonic components are considered, and FEA is carried out for torque characteristic analysis according to ratio of each harmonic order.

Conclusion

- Electromagnetic torque harmonic is generated from both EMF harmonics and current harmonics
- Torque harmonic components is intensified or cancelled out according to interaction between two types of harmonics.
- This paper studies about effect of current harmonic order and included ratio to torque harmonic, and 3rd, 5th, 7th and 9th current harmonic components are considered.
- FEA results show that both current harmonic order and amplitude have influence on torque characteristics.
- With combination of current harmonic components, torque harmonic components could be reduced.

Torque Mechanism

Torque Mechanism

Back EMF and current with harmonic components can be expressed,

$$\dot{E} = E_1 \cos(\omega t) + \sum_{v} E_v cos(v\omega t - \varphi_v)$$

$$\dot{I} = I_1 \cos(\omega t - \varphi_1) + \sum_{v} I_v cos(v\omega t - \varphi_v)$$

E_v, I_v: *amplitude* v, v *th harmonic component*
φ_v, φ_v: *initial angle of* v, v *th harmonic component*

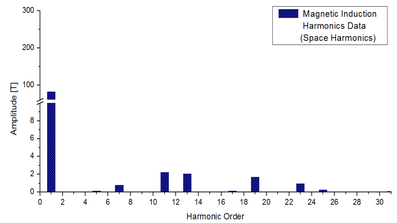
Electromagnetic torque is expressed as,

$$T_{em} = \frac{\dot{E_A}\dot{I_A} + \dot{E_B}\dot{I_B} + \dot{E_C}\dot{I_C}}{\omega_r}$$

$$= \frac{3}{2\omega_r}\left\{ \begin{array}{l} E_1 I_1 \cos(\varphi_1) + \sum_{v} E_v I_1 \cos[(v-1)\omega t + \varphi_1] \\ + \sum_{v} E_1 I_v \cos[(v-1)\omega t - \varphi_v] + \sum_{v}\sum_{v} E_v I_v \cos[(v-v)\omega t + \varphi_v] \end{array} \right\}$$

Base Model

Harmonic Distribution of back EMF

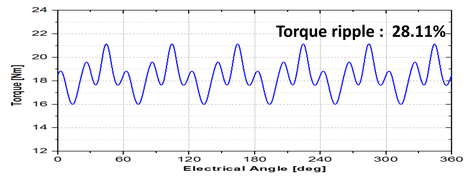


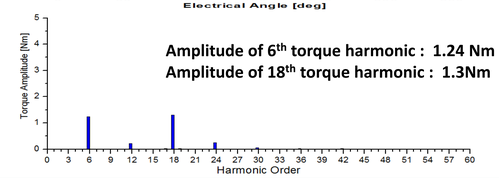
Back EMF harmonic components distribution shows that 7th, 11th, 13th, and 19th harmonic components is large in spatial harmonic.

• **Specification of Analysis model**

Type	IPMSM
Pole/slot	6/18
Stator outer diameter	122[mm]
Rotor outer diameter	58.7[mm]
Air gap length	0.65[mm]

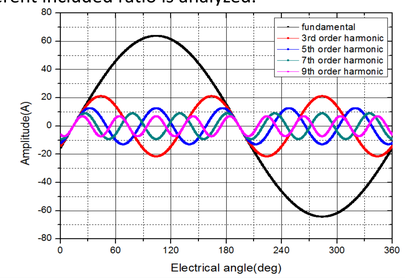
Torque Harmonic Distribution





Current Harmonic

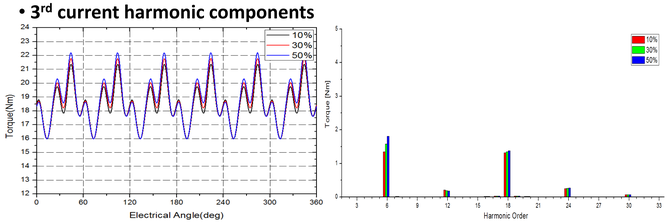
In this paper, we assume that only 1 kind of harmonic order is included in input current. And the cases of different included ratio is analyzed.



FEA Results

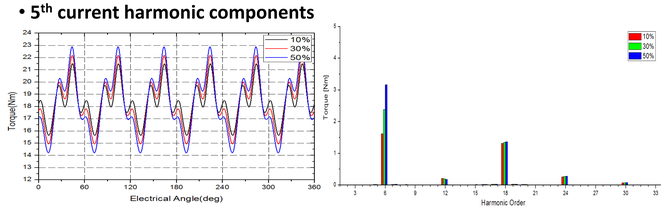
Electromagnetic Torque Characteristics with Current Harmonics

• **3rd current harmonic components**



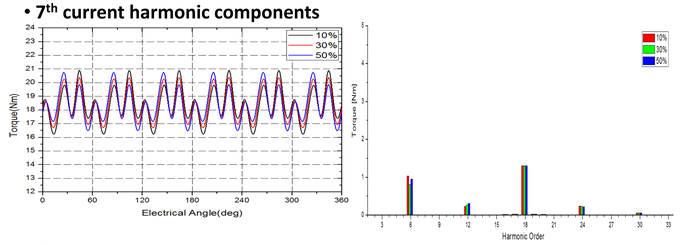
Harmonic Including ratio[%]	10	30	50
Torque ripple[%]	29.11	31.11	33.11

• **5th current harmonic components**



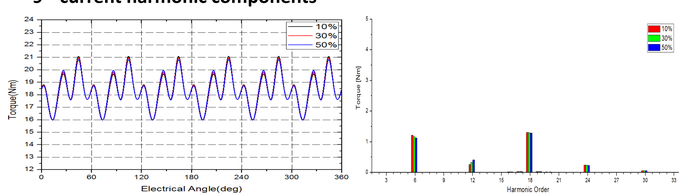
Harmonic including ratio[%]	10	30	50
Torque ripple[%]	31.89	39.58	47.44

• **7th current harmonic components**



Harmonic including ratio[%]	10	30	50
Torque ripple[%]	25.42	20.05	23.31

•**9th current harmonic components**



Harmonic including ratio[%]	10	30	50
Torque ripple[%]	27.75	27.08	26.42

- 6th and 18th harmonic components are dominant in torque harmonic
- When 5th harmonic component is included in current, 6th torque harmonic increases significantly.
- When 7th harmonic component is included in current, 6th torque harmonic decreases. However, torque ripple is lower when harmonic included ratio is 30% than 50%.
- When 3rd or 9th harmonic component is included in current, torque ripple is slightly changed according to harmonic included ratio.

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