The Investigation of Cogging Torque Reduction Technologies

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Background

Cogging Torque is essential torque component on permanent magnet motor having teeth and slots, and also this is an important characteristic of some applications which require precision position control and lower acoustic noise such as electric steering motor.
There had been investigated variety techniques to reduce cogging torque during several decades and most of them show common feature for some reduction of motor performance.

Objectives

- Fault tree analysis of cogging torque and correlation study between cogging torque and design parameters
- Sensitivity comparison for cogging torque and back emf constant according to design parameters
- Provide some guidance for selection of design parameters

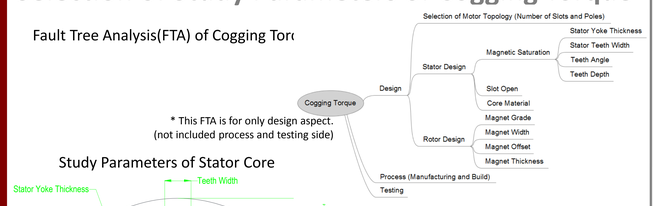
Conclusion

- For better motor design having lower cogging torque and higher Ke performance,
- At stator design aspect, the dimension of parameter for stator core is needed to consider the magnetic saturation effects for lower cogging and higher Ke. Hence, it could be better to be selected as big as possible except for slot open.
- At rotor design aspect, magnet width is needed as 0.92~0.94 pole ratio size. And others are needed to be chosen with optimum value because of trade off relationship between cogging and back emf constant.
- This paper is focused on the design stage, and it could provide some guidance for the selection of design parameters.
- Next plan is to study for cogging torque considering manufacturing process level which could make unbalance of a magnetic circuit or mechanical dimension.

Methods

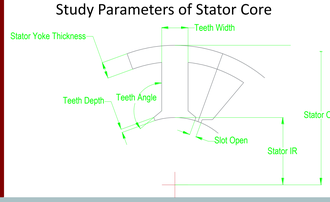
Selection of Study Parameters of Cogging Torque

Fault Tree Analysis(FTA) of Cogging Tor

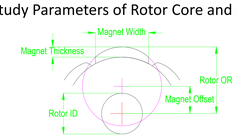


* This FTA is for only design aspect.
(not included process and testing side)

Study Parameters of Stator Core



Study Parameters of Rotor Core and Magnet



Selection of Base Model

- Topology : 9slots 6poles Surface Permanent Magnet Motor
- Stator OD, ID and Stack : 85mm, 41mm and 19.5mm
- Winding : 1.4mm x 26turns, Parallel and Star Connection

Definition of Analysis Range

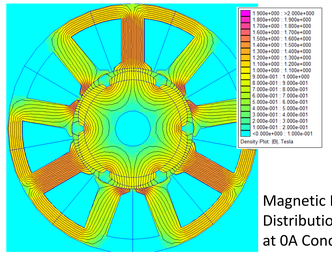
- EM Analysis using with simulation tool with selected parameters
- All study model : 90 models (9 parameters x 10 resolutions)
- The result of cogging torque by parameters could be compared with Ke performance because it could be an index of motor performance capacity.

Study Parameters		Uint	Values	
			Min	Max
Stator Core	Stator Yoke Thickness	mm	3.75	6.25
	Teeth Width	mm	6	10
	Slot Open	mm	1.5	2.5
	Teeth Depth	mm	0.75	1.25
	Teeth Angle	deg.mech.	97.5	162.5
Rotor and Magnet	Magnet Offset	mm	6	10
	Magnet Width	mm	9.36	15.6
	Skew Angle	deg.mech.	4	6.67
	Magnetic Air Gap	mm	0.675	1.125

Samples

Sample Information

- Topology : 9slots 6poles Surface Permanent Magnet Motor
- Stator OD, ID and Stack : 85mm, 41mm and 19.5mm
- Winding : 1.4mm x 26turns, Parallel and Star Connection



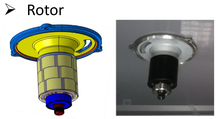
Magnetic Flux Density Distribution of Study Model at 0A Condition

Sample Detail

- Detail Dimension for Parameters

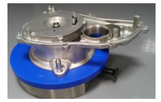
Parameters		Uint	Value
Skew Mothod		-	Rotor 3 stepped
Stator Core	Stator Yoke Thickness	mm	4
	Teeth Width	mm	8
	Slot Open	mm	2
	Teeth Depth	mm	1
	Teeth Angle	deg.mech.	130
Rotor and Magnet	Magnet Offset	mm	8
	Magnet Width	mm	15.6
	Skew Angle	deg.mech.	6.67
	Magnetic Air Gap	mm	0.9

- Rotor



- Stator

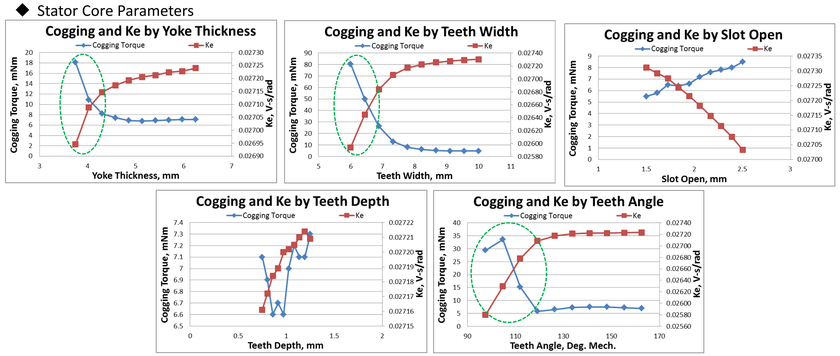
- Motor Outline



Results

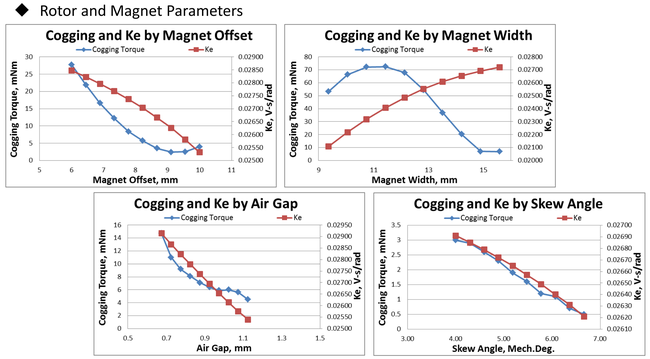
Cogging Torque and Ke by Design Parameters

◆ Stator Core Parameters



- The parameters of the stator core are strongly related with magnetic saturation effect because of its original function as the path of magnetic circuit. Three parameters(yoke thickness, teeth width and teeth angle) as shown with green dot line in above graphs shows magnetic saturation effect when these have not enough dimensions. Therefore it is important to define the parameter as big as possible in order to avoid the magnetic saturation effects and lower cogging and higher Ke performance.
- Not found specific relationship between cogging and teeth depth.
- Smaller Slot open is better for low cogging and higher Ke.

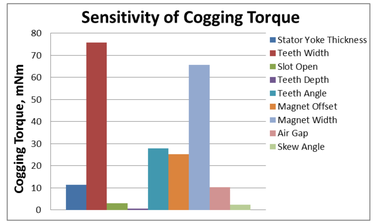
◆ Rotor and Magnet Parameters



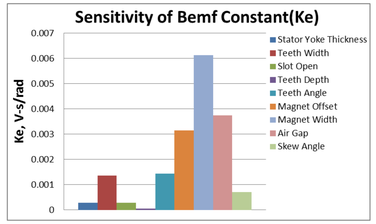
- The parameters related to magnetic flux(magnet offset, magnet width and air gap) from magnet show a strong relationship to cogging and Ke performance. These are needed to select with optimum value because of trade off relationship each other(cogging and Ke)
- The magnet width needs to be selected by optimal value for lowest cogging torque and it could be almost 0.92~0.94 value as pole ratio.
- The skew was considered as 3 step skewed of rotor, and it could be best at 6.67 deg. for low cogging.

Sensitivity Comparison by Design Parameters

Remark : The sensitivity means a deviation from max to min value within the defined parameter ranges.



- Priority of Sensitivity for Cogging Torque
  1) Teeth Width
  2) Magnet Width
  3) Teeth Angle
  4) Magnet Offset



- Priority of Sensitivity for Back EMF Constant
  1) Magnet Width
  2) Air Gap
  3) Magnet Offset
  4) Teeth Angle

- Three parameters(magnet width, magnet offset and teeth angle) needs to be selected more carefully with the optimal value because these are more sensible for cogging and Ke performance compared to others

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