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Radially and tangentially magnetized PMBLDC motor- A comparative analysis using Finite Element Method in COMSOL

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Excerpt from the Proceedings of the 2014 COMSOL Conference in Bangalore.

Presentation Outline

- *Introduction*
- *Objective*
- *Literature Survey*
- *Modeling Using Finite Element Analysis*
- *Surface Mounted PM Motors (SMPM)*
- *Tangentially Magnetized PM Motors*
- *Comparison & Results*
- *Conclusion*
- *References*

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Introduction

- ***BLDC Motor does not use brushes for its operation.***
- ***Electronic commutation using switches.***
- ***Better thermal capability.***
- ***Design is focusing on servo application.***
- ***Different rotor configurations are possible according to applications.***
  - ❖ ***Surface Mounted PM motor***
  - ❖ ***Interior permanent magnet motor***
- ***Finite element analysis (FEA) using COMSOL Multiphysics.***

Objective

- ***Familiarize the permanent magnet BLDC motor.***
- ***Design PM BLDC motor with two different rotor configuration.***
- ***Comparison of Surface mounted PM motor and tangentially magnetized PM motor.***

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Literature review

Permanent magnet Brushless dc motor: (By T. J. E. Miller)

- ***Electric winding on the stator and PMs on the rotor.***
- ***High efficiency***
- ***Higher speed ranges***
- ***Better speed versus torque characteristics***
- ***Long operating life***
- ***Noiseless operation***
- ***Higher dynamic response***

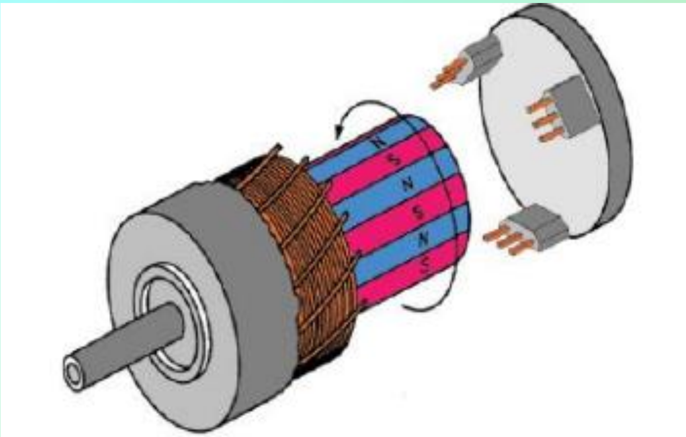

Fig. PMBLDC Motor

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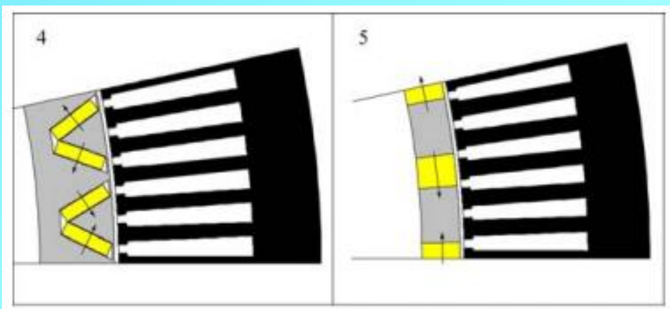
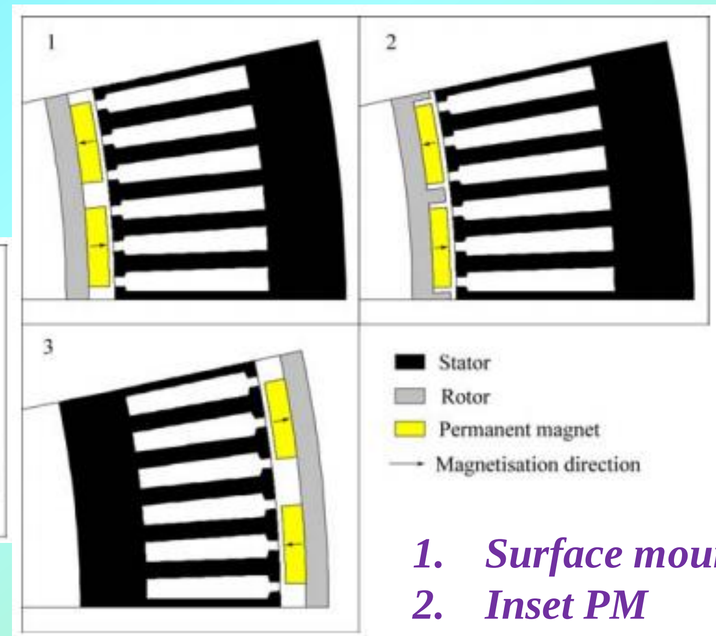
Literature review

Permanent magnet BLDC rotor configurations:

- *Surface mounted PM*
  - *Inset PM*
  - *With external rotor*





- *Interior PM rotor*
  - *V shaped buried PM*
  - *Tangentially magnetized PM*

1. ***Surface mounted PM***
2. ***Inset PM***
3. ***SMPM with outer rotor***
4. ***V shaped buried PM***
5. ***Tangentially magnetized PM***

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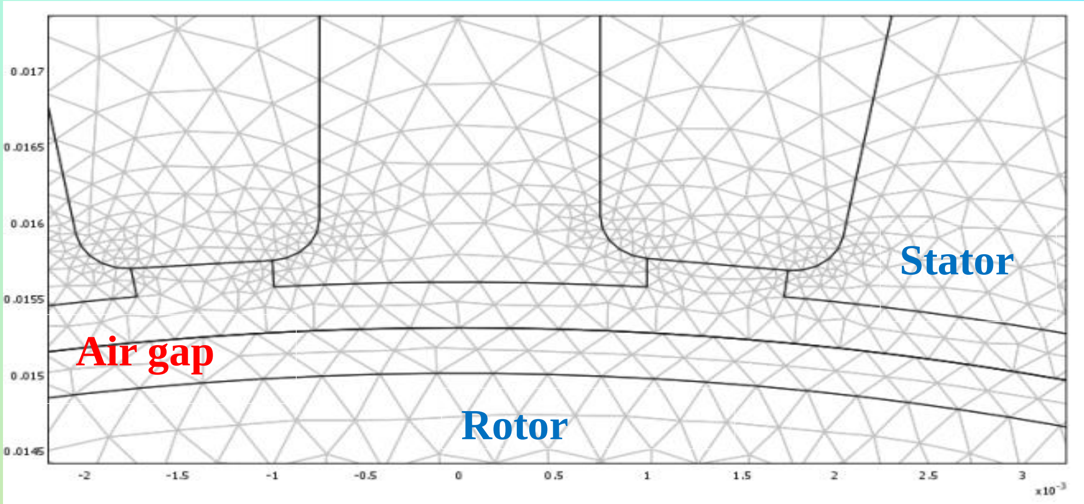
Finite Element Analysis

- *The finite element modeling includes the Maxwell's equation*
- *Better understanding of the response/behavior of an electromagnetic device*
- *Virtual prototyping ,saving time and cost*



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Motor Specifications

Parameters	Specifications
Supply Voltage	28V
Magnetic flux density, B	0.9 T
Back EMF constant, Kb	0.16
Torque Constant, Kt	0.16
Outer Diameter	52mm
Stack length, L	45mm
Rotor Dia.	30mm
No. of turns, N_t	40
Rated Current, i	9.0 A
Rated Speed	1700 rpm
Rated torque, T	1.45 Nm
Magnet	SmCo5

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Modeling Using Finite Element Analysis

- **Find the no. of turns:**

From Miller's Torque Equation:

$$T = (N_{ph} - 1) N_t K_w \alpha r L B_g i = K_t . i \quad ………(1)$$

where

α = *pole arc coefficient*

$$= \frac{N + 0.14}{\text{No. of slot per pole}} < 1, N \text{ is integer}$$

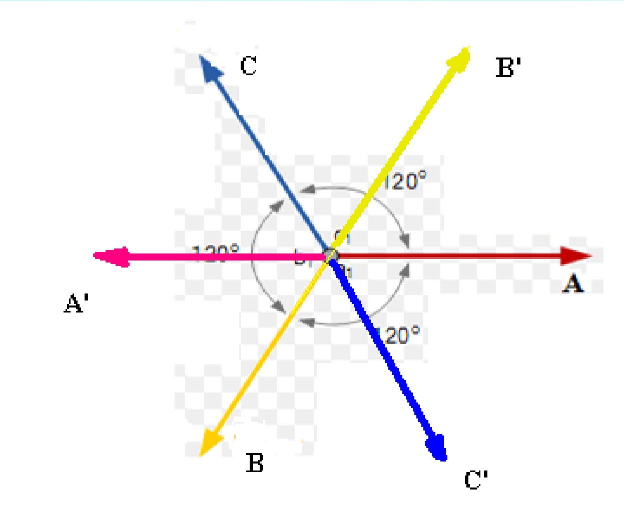
= *0.697*

K_w = *Winding factor (= 0.89)*

- **Hence, No. of turns, N_t = 40 per slot**

Modeling Using Finite Element Analysis

- *Slot/pole = 36/8 = 4.5 (take 4)*
- *Electrical angle = (360*4)/36= 40°*
- *Quadrant Operation*

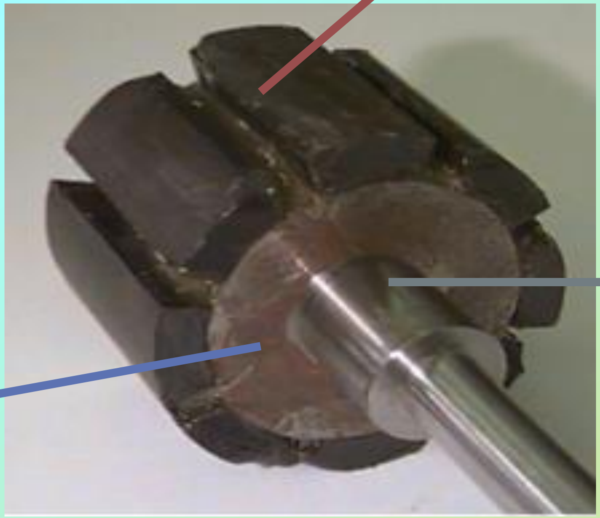


Winding Diagram:

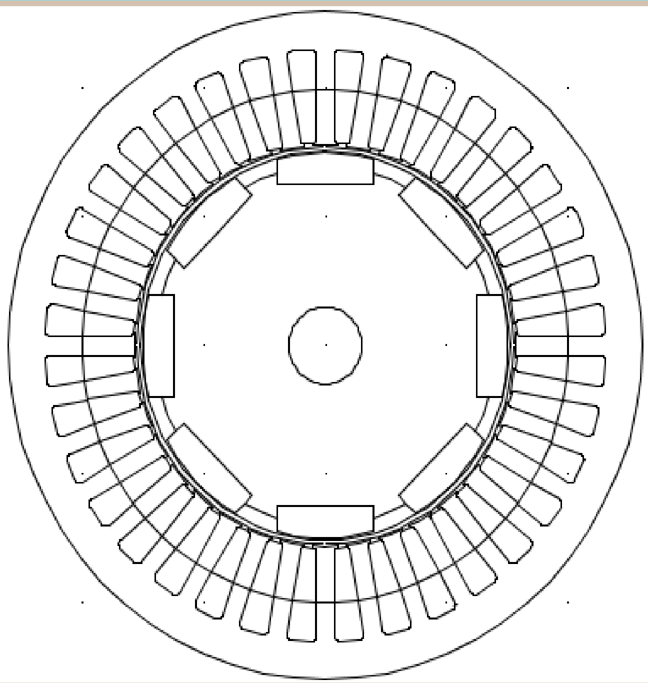
Phases	1	2	3	4	5	6	7	8	9
Electric angle	40°	80°	120°	160°	200°	240°	280°	320°	360°
A	N				S				N
B			N	N				S	
C		S				N	N		

Surface Mounted PM Motors (SMPM)

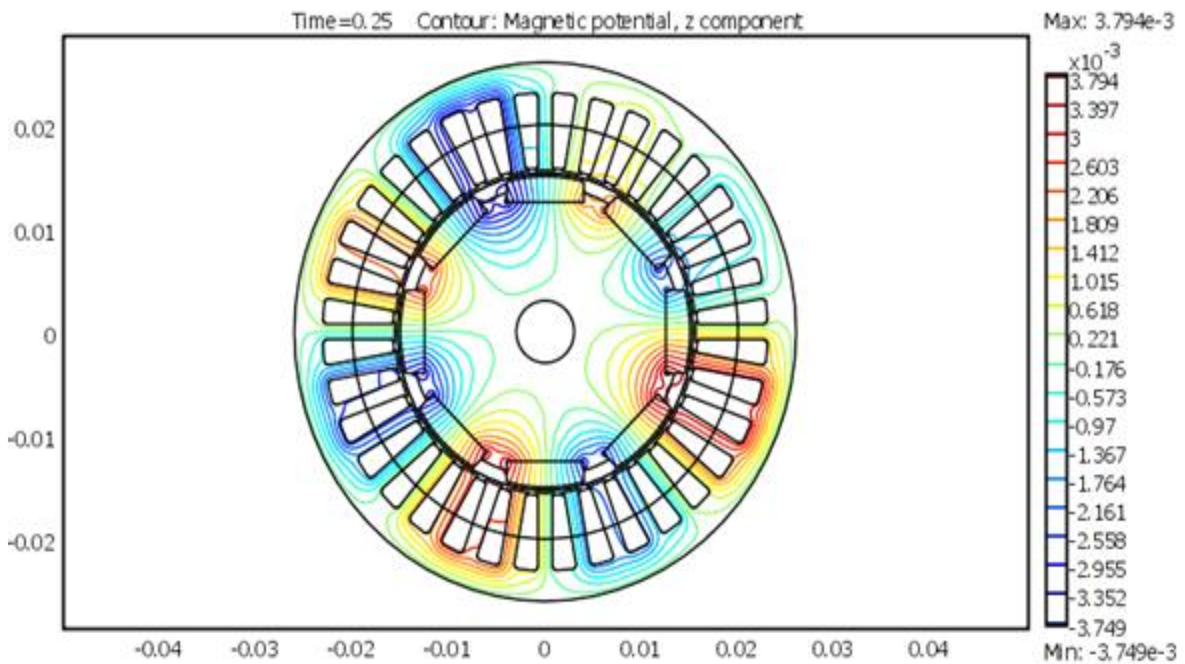
- *Permanent magnets mounted on the surface of the soft iron material.*
- *Produce radially directed flux.*
- *The width of magnet taken to be 8mm.*
- *Height as 2.5 mm.*



Surface Mounted PM Motors (SMPM)

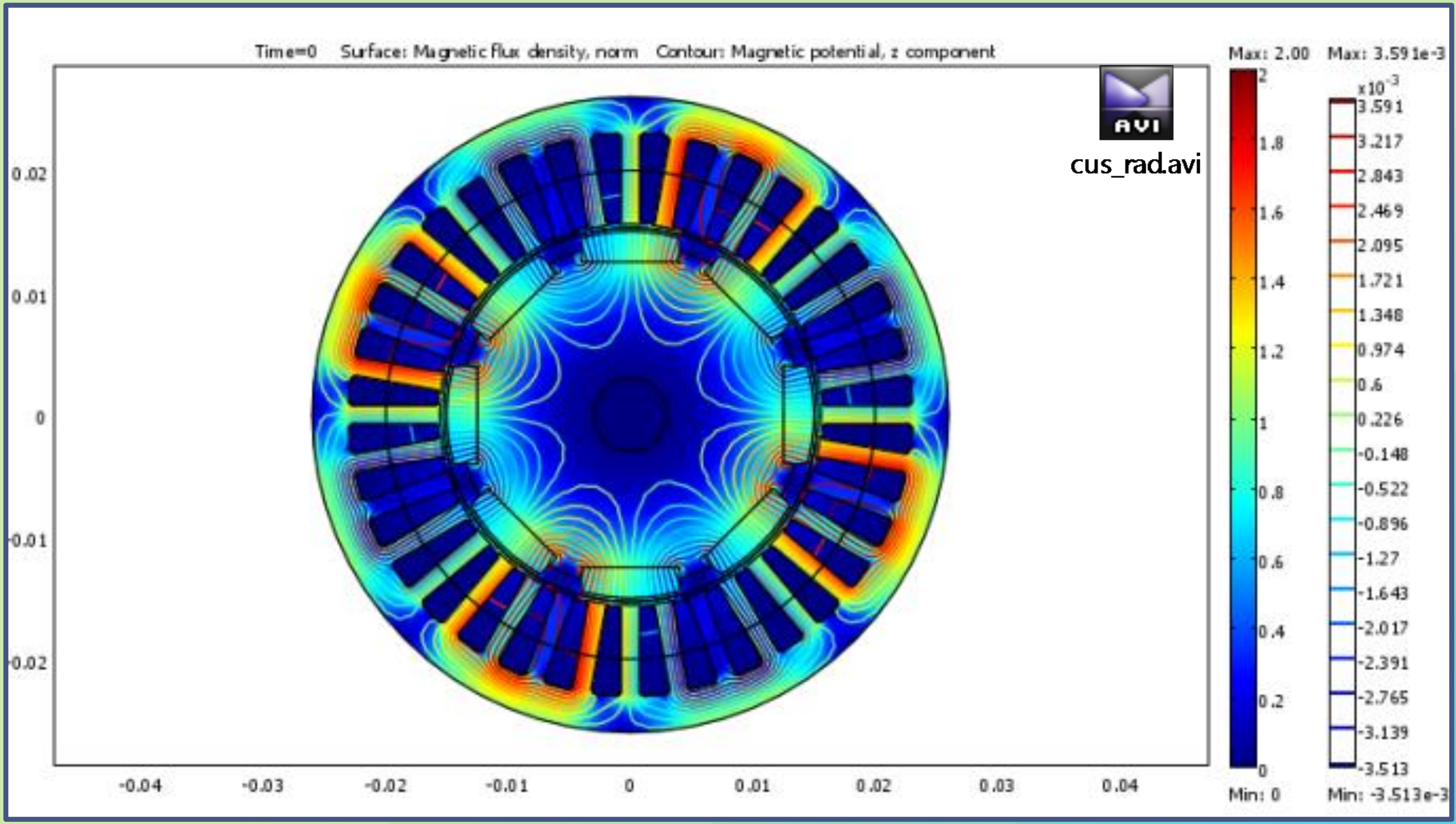


Magnet arrangement



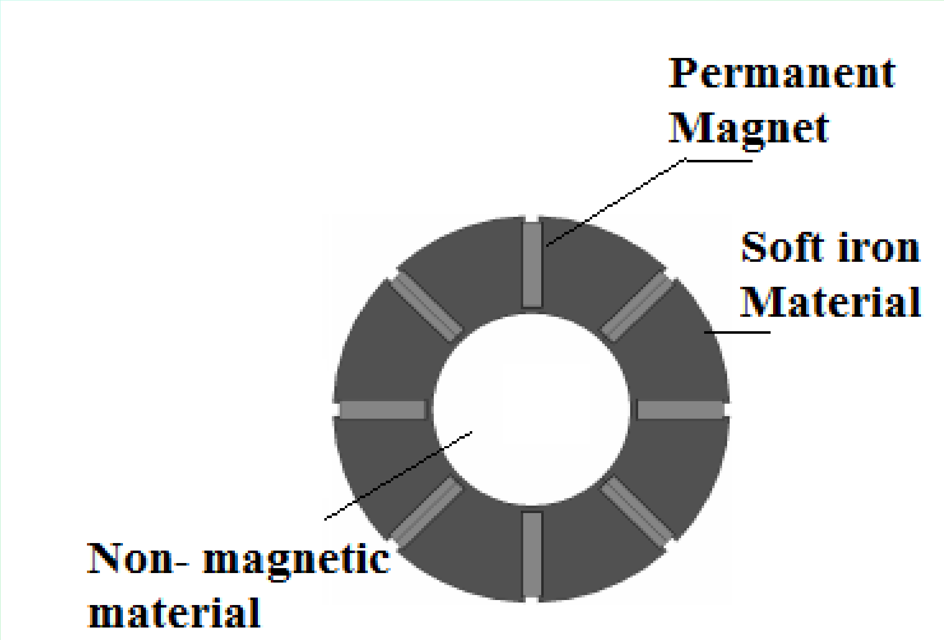
Contour plot

Surface Mounted PM Motors (SMPM)

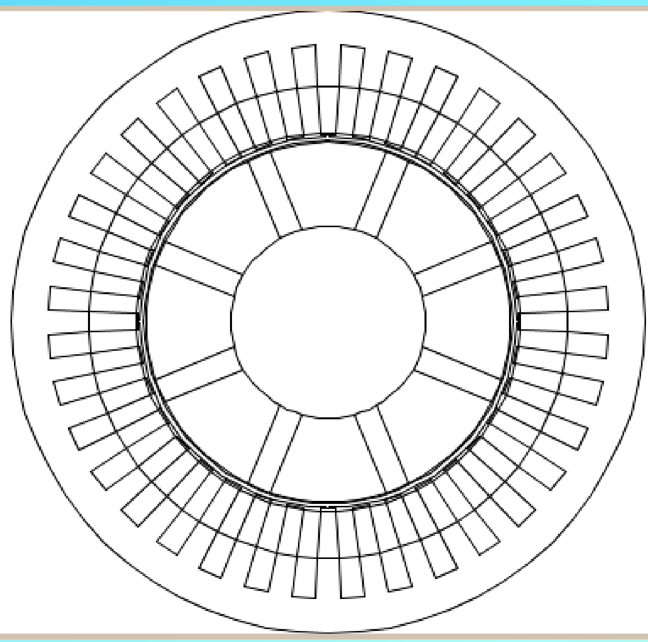


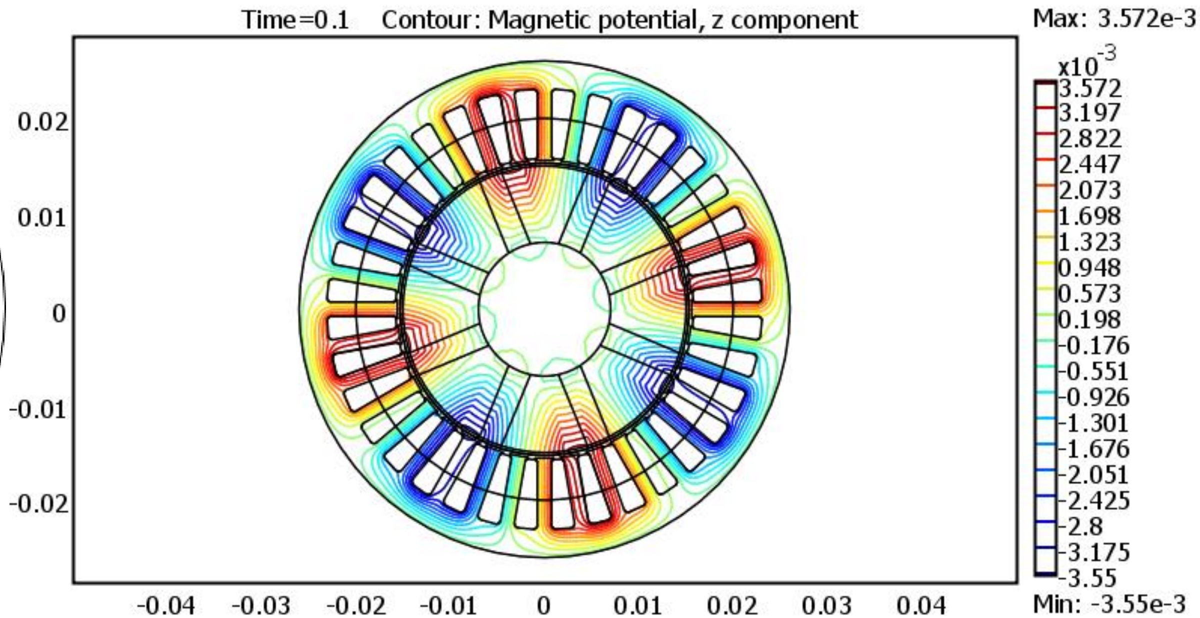
Tangentially Magnetized PM Motors

- ***Each permanent magnet is embedded inside the rotor.***
- ***The magnetic flux density is taken to be at the circumference of the rotor.***
- ***The magnet width of 2.5 mm and depth of 8 mm is taken.***



Tangentially Magnetized PM Motors





Magnet arrangement

Contour plot

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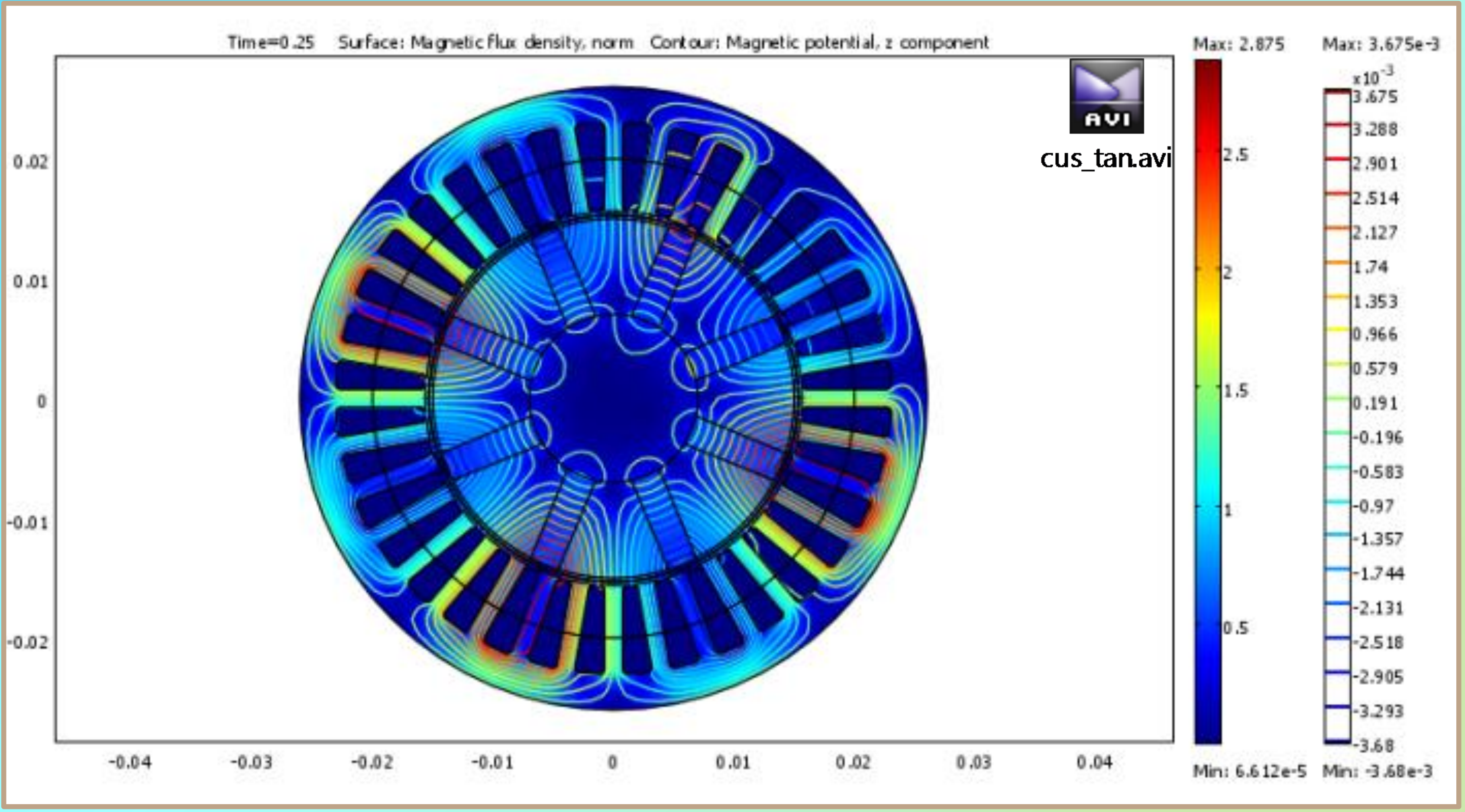
Tangentially Magnetized PM Motors



Vector diagram of magnetic flux density

- ***Surface Mounted PM Motors (SMPM):***

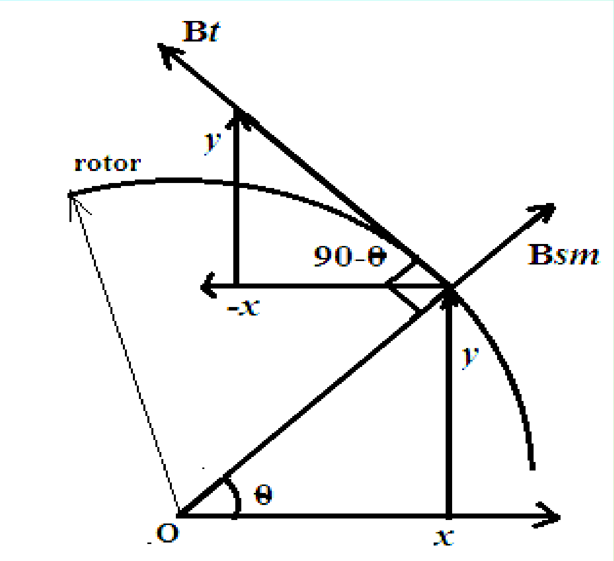
$$\cos\theta = \frac{B*x}{\sqrt{x^2+y^2}}$$

$$\sin\theta = \frac{B*y}{\sqrt{x^2+y^2}}$$

- ***Tangentially Magnetized PM Motors:***

$$\cos\theta = \frac{B*y}{\sqrt{x^2+y^2}}$$

$$\sin\theta = \frac{-B*x}{\sqrt{x^2+y^2}}$$



Vector diagram

Inductance Calculation

- **Magnetic Energy method:**

$$W = \frac{1}{2} L I^2$$

Where W = Magnetic Energy density

- **Virtual work method:**
  - ***Based on Ohm's Law***

$$L = \frac{V(induced)}{i * 2\pi f}$$

V (induced) is not produced by magnetic field due to permanent magnet.

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Comparison based on inductance

❖ ***Difference in air gap inductance:***

Motor type		***With 2 phases excited***	***With R phase excited***
SMPM	***Using Energy Method***	***11.4 mH***	***4.1mH***
	Using Virtual work method	***11.4 mH***	***4.1 mH***
Tangentially Magnetized	***Using Energy Method***	***14.5 mH***	***5.5mH***
	Using Virtual work method	***14.5 mH***	***5.5mH***

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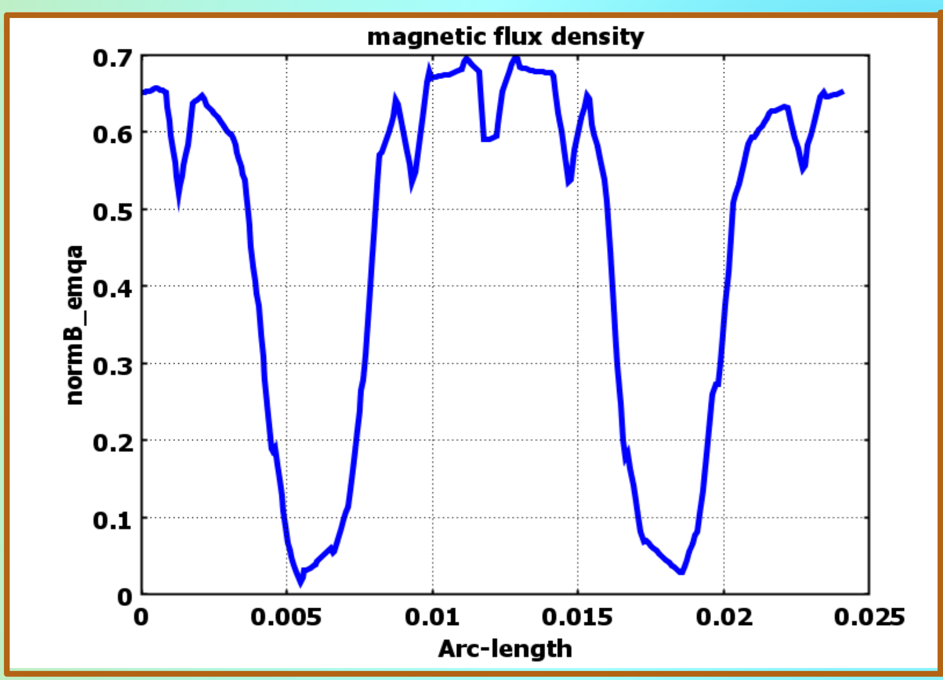
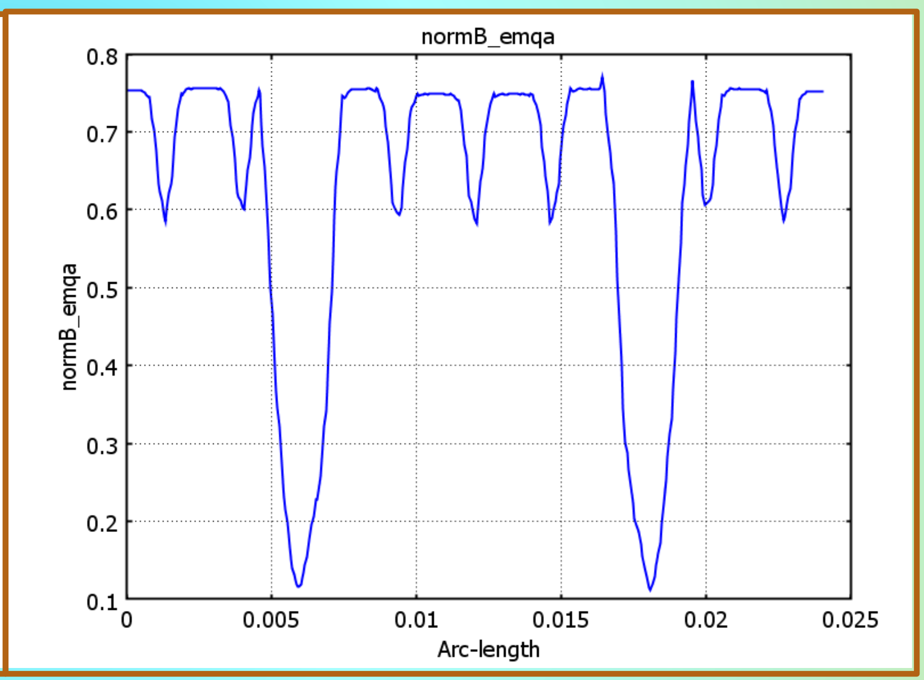
Waveforms

- ***Magnetic flux density variation at the air gap***



B_g plot for SMPM motors



B_g plot for tangentially Magnetized PM

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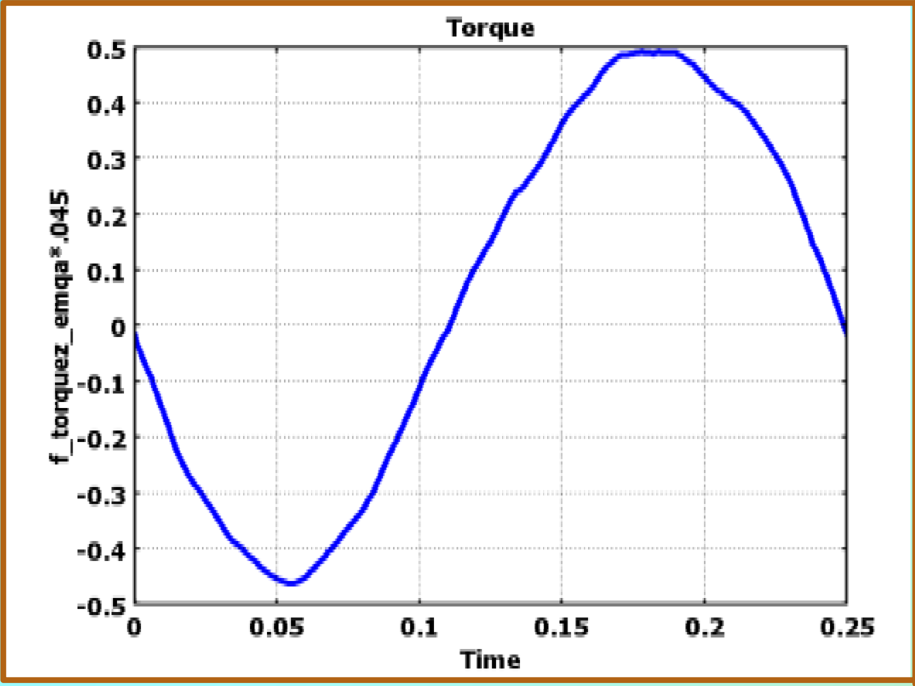
Waveforms

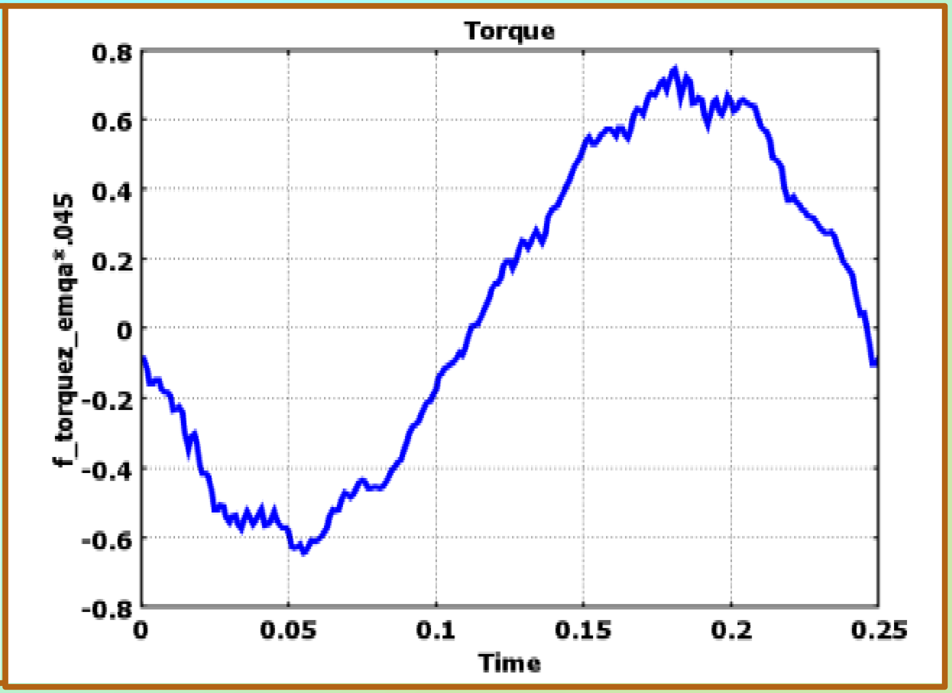
- ***By Maxwell's stress tensor method.***

$$Torque,\ T = \oint_B (r - r_o) \times (n_1 T_2) dS$$

Where r_0 is the point on the axis of rotation and n is unit vector normal to the surface S.



Torque produced in SMPM motor



Torque produced in tangentially magnetized PM

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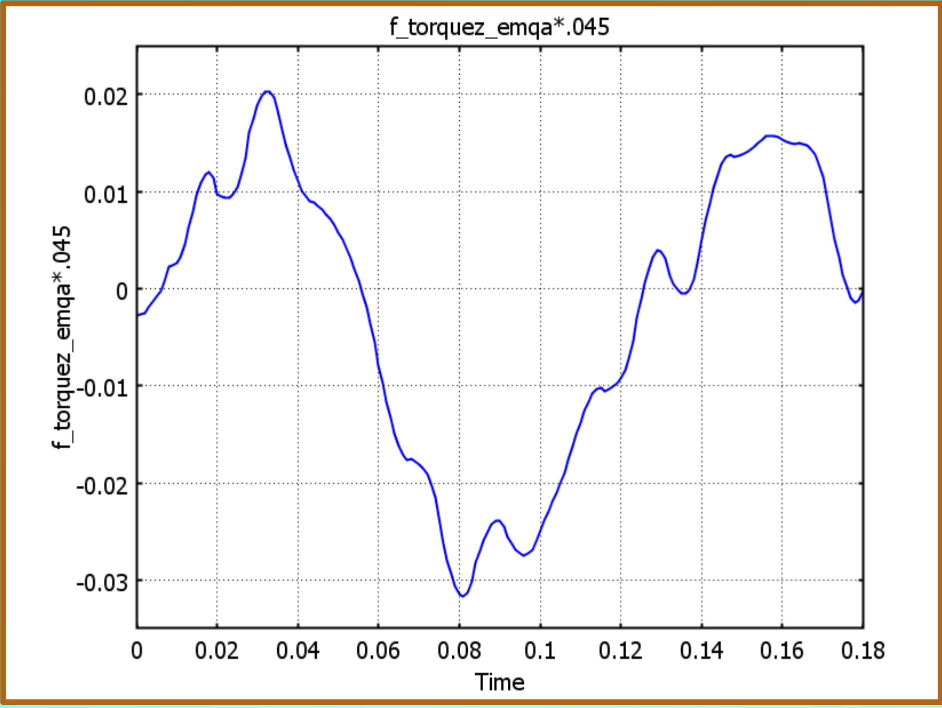
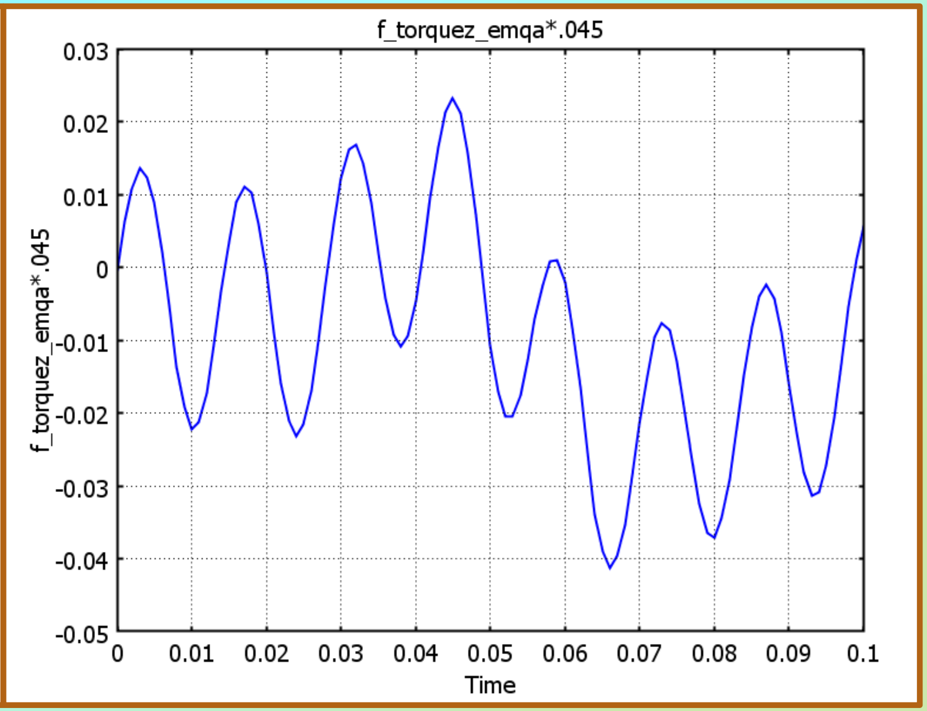
Waveforms

❖ ***Cogging Torque,*** $T = -\frac{1}{2}\Phi^2 \frac{dR}{dt}$



Cogging torque variation for SMPM motor



Cogging torque profile for tangentially magnetized PM motor

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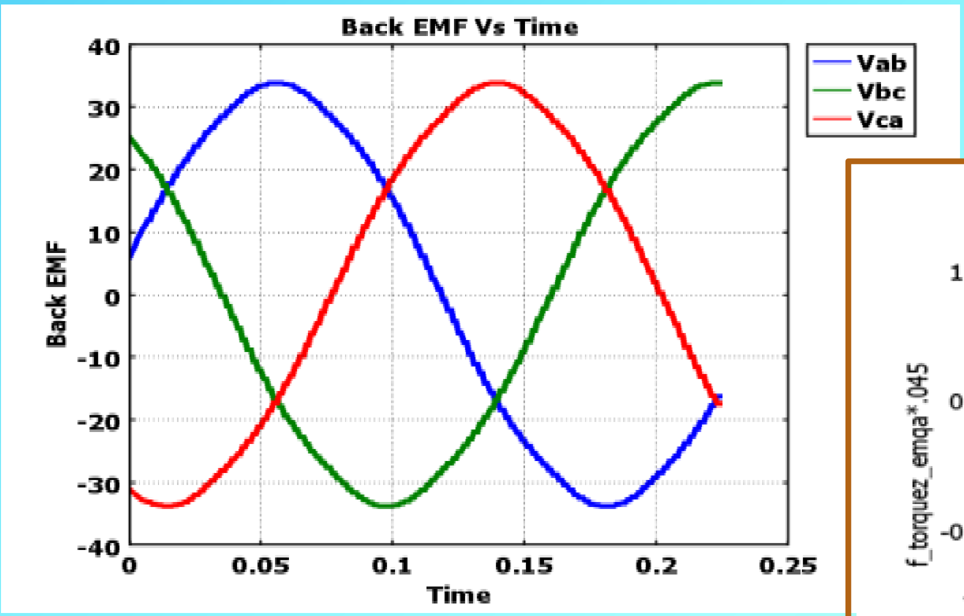
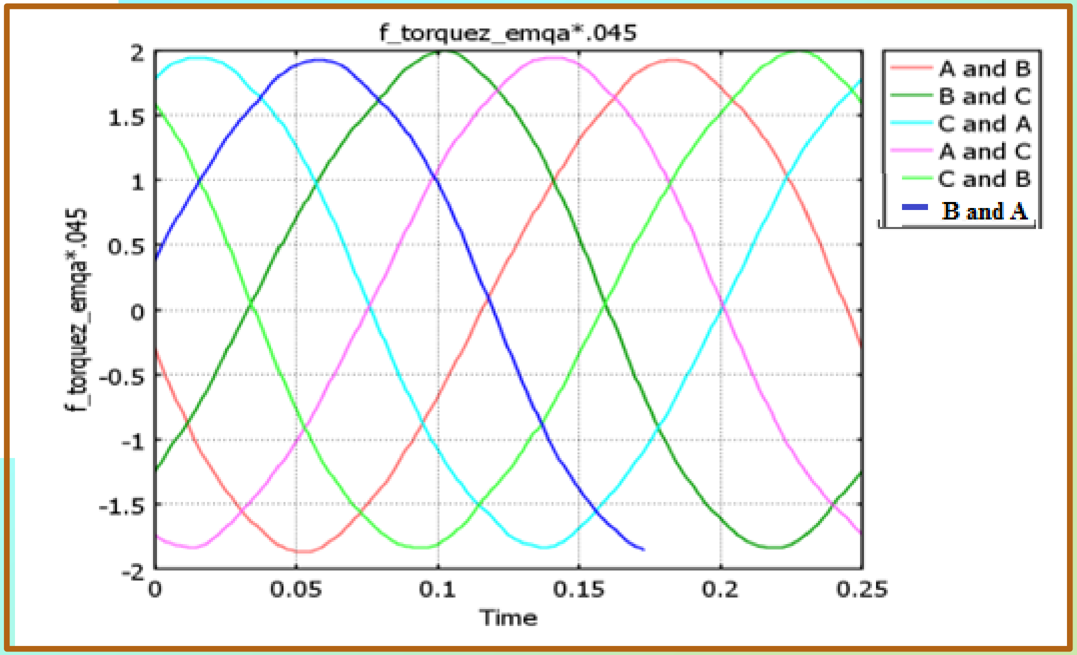
Waveforms



Back EMF variation for both rotor configurations



- ***Induced Voltage,*** $V = N \sum \frac{L}{A} \int E_z dA$

Torque waveforms for estimating the ripple torque

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Conclusion

- ***A three phase 36 slot, 8 pole BLDC motor applied for aero space applications was used for analysis.***
- ***Comparison was done for Surface mounted, radially magnetized motor and tangentially magnetized motor using COMSOL Multiphysics 3.5a.***
- ***Main difference was found in air gap inductance .***
- ***The interior permanent magnet design gave desirably more inductance than surface mounted PM design.***

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[4] Tayfun, Gundogdu, Guven Komurgoz, "Design of Permanent Magnet Machines with Different Rotor Type" *World Academy of Science, Engineering and Technology* Vol:4 2010-10-29.

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[8] Why do infinite Element Analysis-NAFEMS

[9] COMSOL3.5a manual

THANK YOU

Questions???

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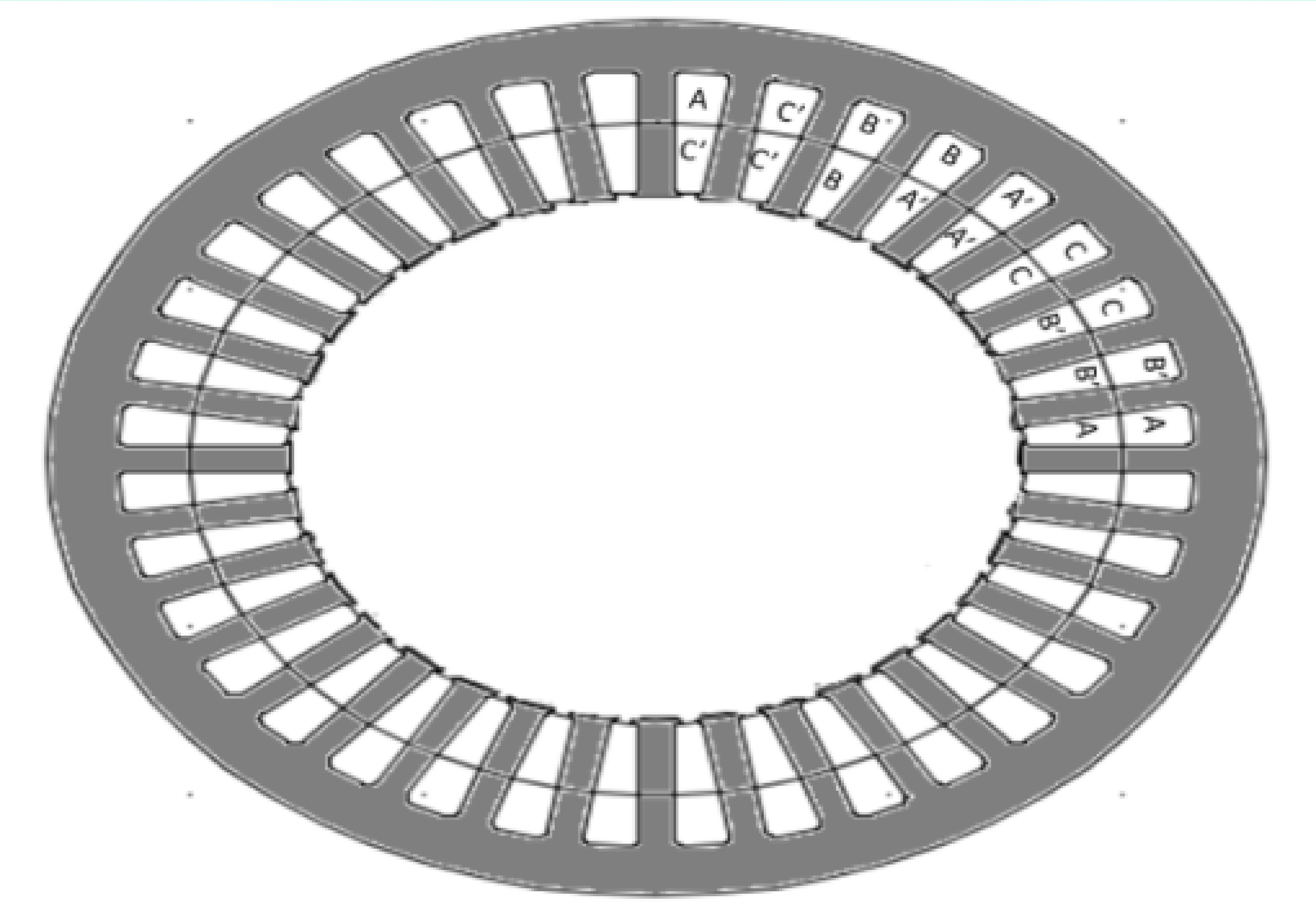
Winding Pattern



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