Case Study: Electric Water Pump

Injection Molded (IM) MQA magnet based surface permanent magnet (SPM) motor to replace Sintered Neo based interior permanent magnet (IPM) motor

Summary

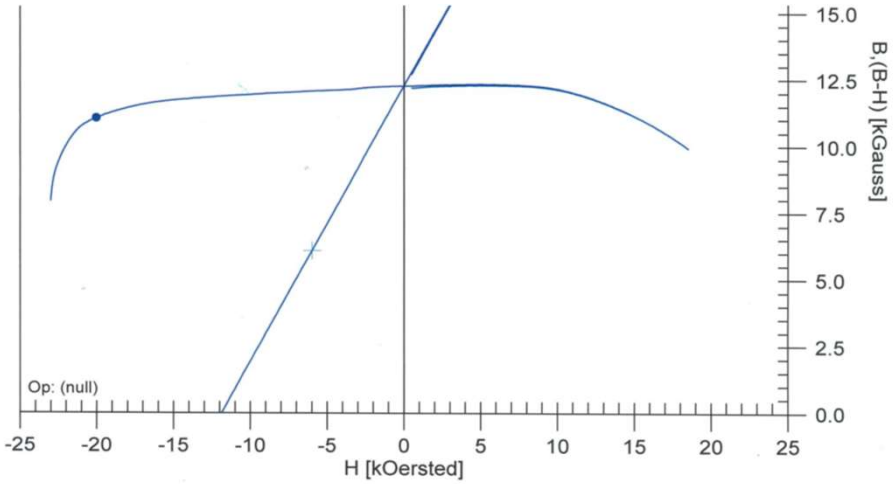
- Use of surface mounted motor structure with MQA magnet can help in achieving the similar motor performance as of equivalent size IPM motor with sintered neo magnet
- The anisotropic bonded magnet doesn’t use any heavy rare earths (HRE) or Cobalt and hence offers price stability

Introduction

- In order to evaluate the performance of anisotropic bonded neo magnet (MQA) in an electric water pump (EWP), we have procured a commercially available EWP
- The procured EWP is used for Engine auxiliary water pump.
- The motor of the procured electric water pump is benchmarked for both the physical dimensions and performance.
  - The motor has IPM structure with sintered neo plate magnets
- An optimal design for a surface mounted PMBL DC using the Injection molded (IM) MQA magnets is arrived at

Benchmarked Magnet Properties

- Magnet Composition
  - Presence of high heavy rare earth content and cobalt
    - High price volatlity
- B-H Curve



Magnet Characteristics

Magnetics	
B_r	1.23T
H_{ci}	> 23 kOe
H_c	11.86 kOe
$(BH)_{max}$	36.34 MGOe

Benchmarking

Control electronics

Stator

Rotor

Non-magnetic cap

Teeth

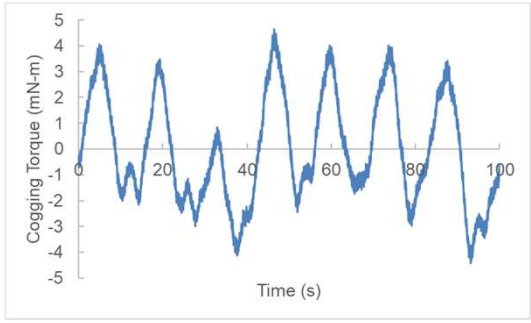
Stator back-iron

Magnet

No-Load and Cogging Torque Measurement

No-load Measurement

Cogging torque Measurement

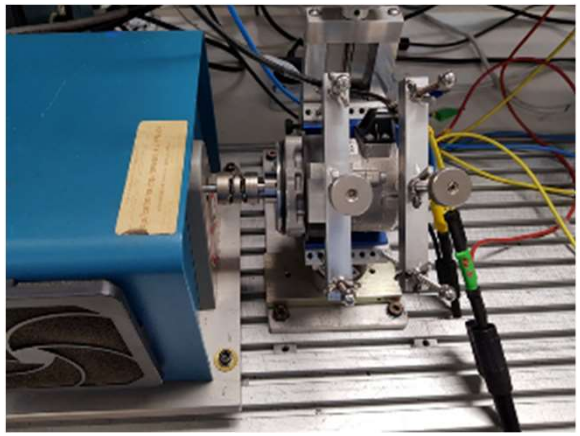


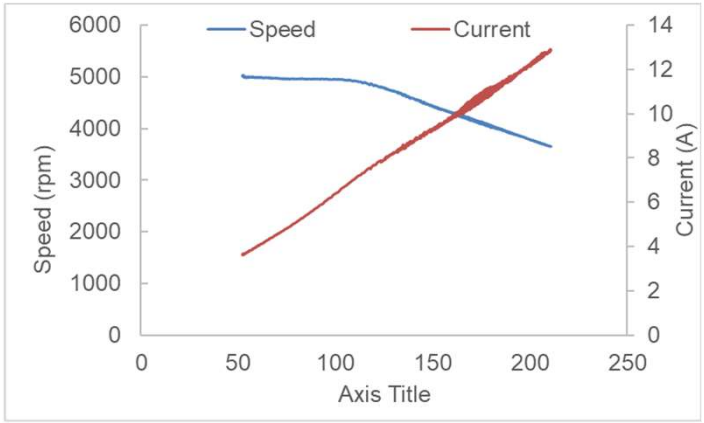
Measured cogging torque

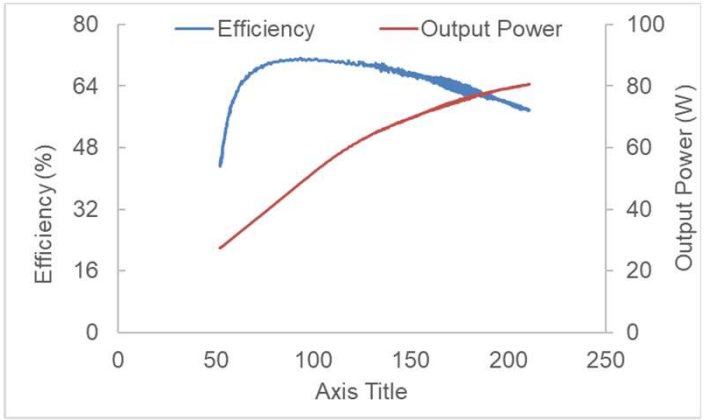
No-load current (A)	No-load speed (rpm)
1.19	6006

$T_{cog\_pk\_pk}$ (mN-m)		$T_{cog\_pk\_pk\_average}$ (mN-m)
CW	CCW	4.04
4.27	3.80	

Load Performance







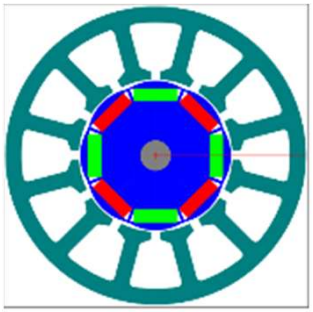
Motor's load performance

Redesign Approach

- Using the commercially available motor design software SPEED, a cost optimal motor is designed.
- The motor topology considered is Surface mounted PMBL DC motor.
  - Injection molded anisotropic bonded neo magnet (MQA) with Halbach magnetization is considered
  - MQA magnet is HRE and Cobalt free
- The motor is designed with following constrains,
  - Same effective airgap (i.e. the actual airgap plus the thickness of PPS overmold on the stator) as benchmarked motor.
  - The stator slot fill is similar or lower than the one in benchmarked motor

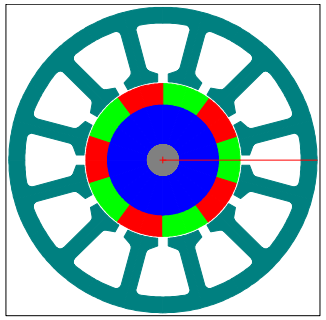
Introduction to IPM and SPM Motor Topologies

- IPM



  - Reluctance torque
  - Complex control
  - Useful in an application where wide speed range is needed
  - Magnet is protected from the opposing field generated by the winding
  - Magnet is away from the airgap
    - Needs stronger magnet to achieve higher airgap flux
    - Higher flux loss in the soft magnetic part surrounding the magnet

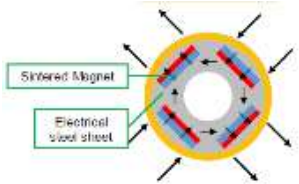
- SPM



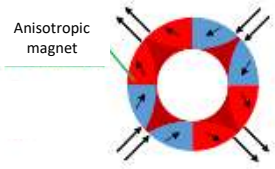
  - No reluctance torque
  - Simple control
  - Magnet is closer to the airgap and hence provides higher airgap flux
  - Useful in an application where wide speed range is not needed

Why a move from IPM motor to SPM motor?

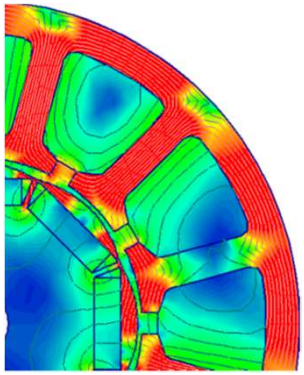
- Type of magnet: Sintered neo plate
- Motor: IPM
  - Wet running motor
  - Need for a overmolding protection (either PPs or steel sleeve) on rotor to protect the magnets
    - The overmolding thickness increases the effective airgap
  - Presence of back iron in rotor
  - Assembly process complexity

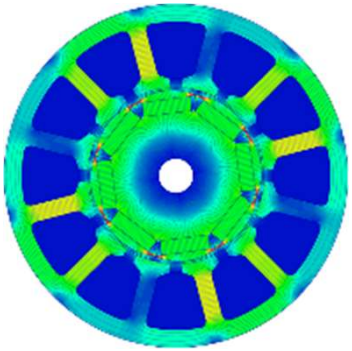


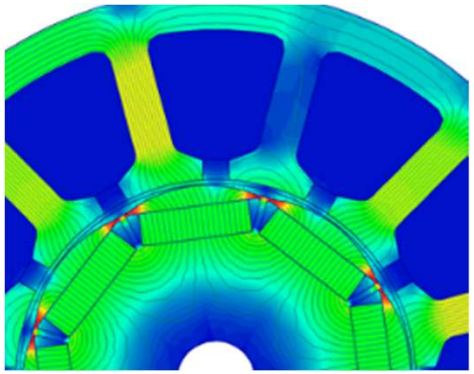
- Type of Magnet: IM Anisotorpic Bonded Neo ring with PPS
- Motor: Surface mounted PMBL DC
  - No overmold on the rotor with IM anisotropic magnet ⟹ Lower effective airgap for motor
  - The anisotropic bonded magnet has Halbach orientation ⟹ No need for the back iron on rotor ⟹ Weight reduction by 25% and lower cogging torque
  - Magnet assembly cost is lower due to IM process for rotor

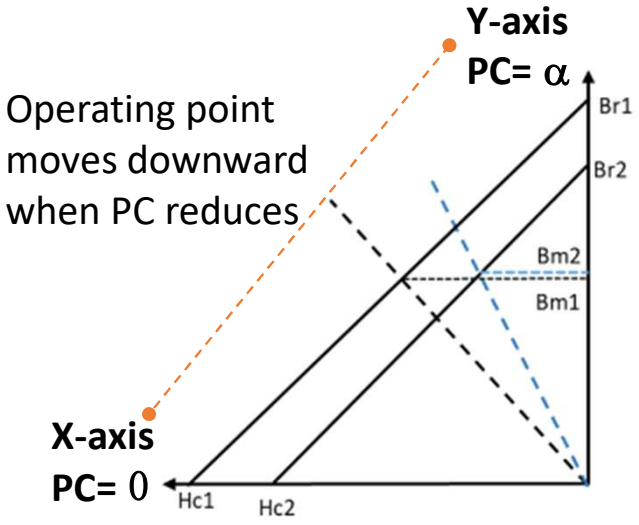


Why a move from IPM to SPM is possible without Increasing Motor Size?



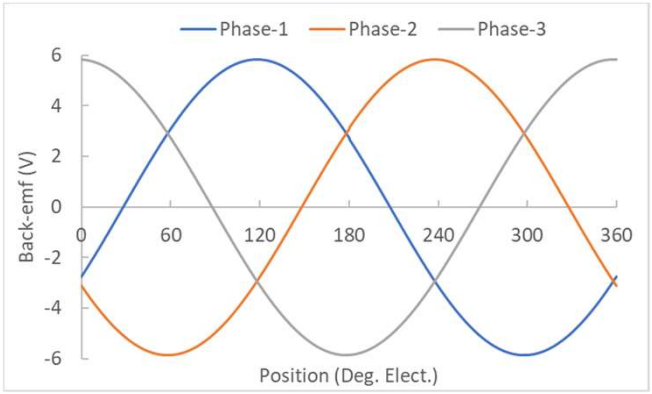




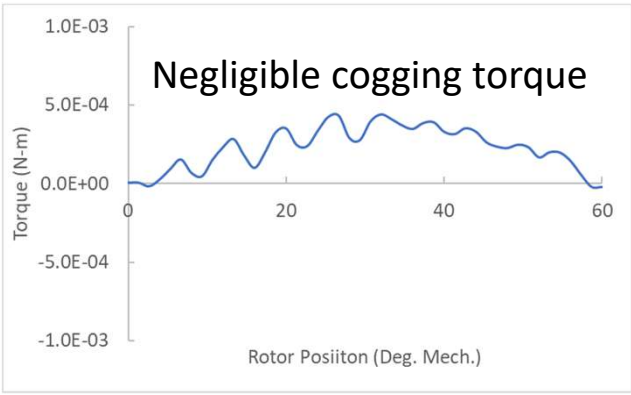


- For sintered neo magnet based IPM motor
  - Presence of overmolding on rotor ⟹ Increase in effective airgap ⟹ Permeance co-efficient ↓
    - The magnet operating point is B_{m1}
- For IM anisotropic ring based motor
  - Removal of PPS overmolding on the rotor ⟹ Reduction in effective airgap ⟹ Permeance co-efficient ↑
    - The magnet operating point is B_{m2}

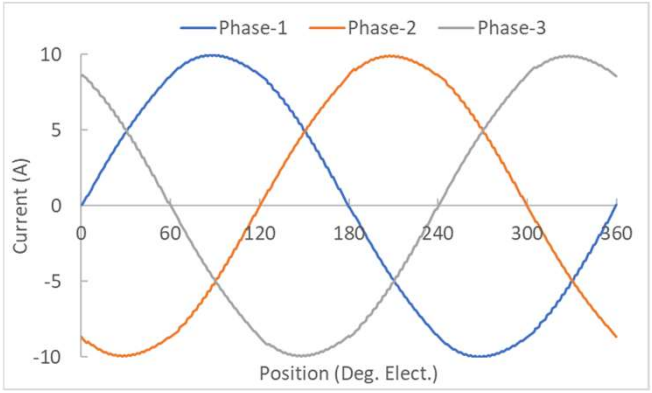
Injection Molded MQA Magnet based Redesigned Motor-Performance



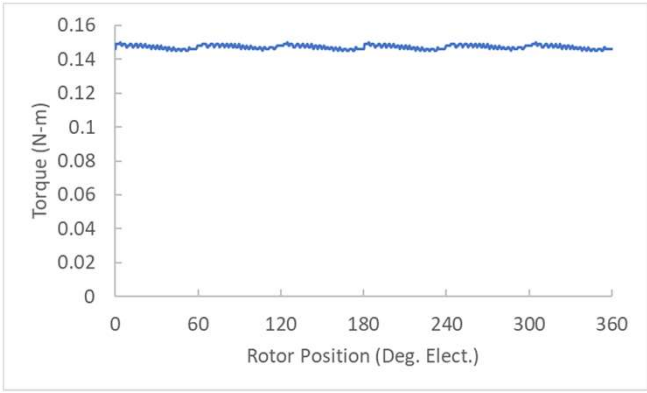
Phase back-emf @ 5000 rpm



Cogging torque

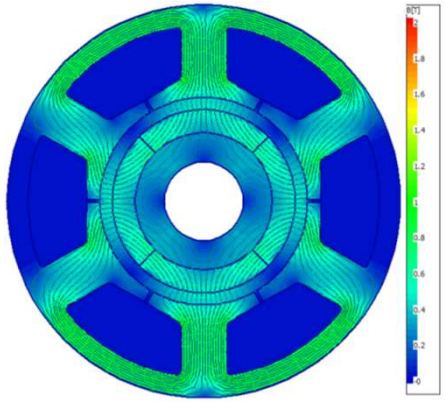


Motor current at T=125 N-mm @ 5000 rpm

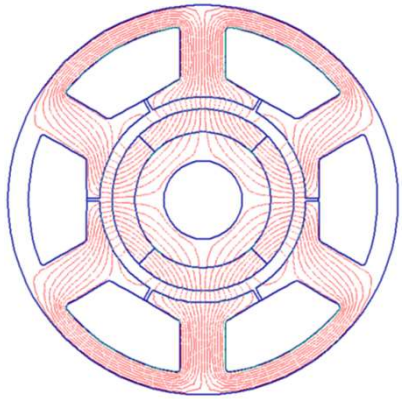


Developed torque @ 5000 rpm

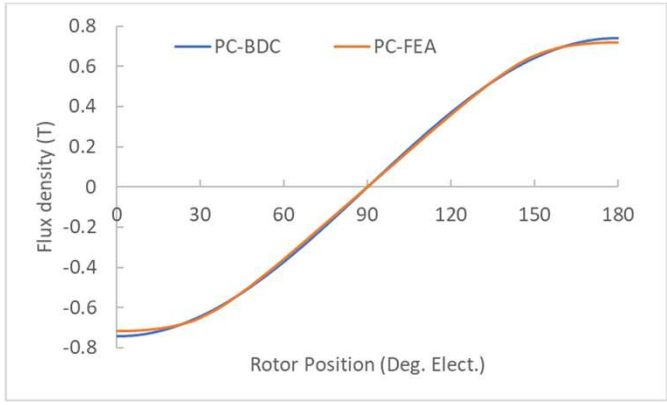
Injection Molded MQA Magnet based Redesigned Motor- FEA Validation



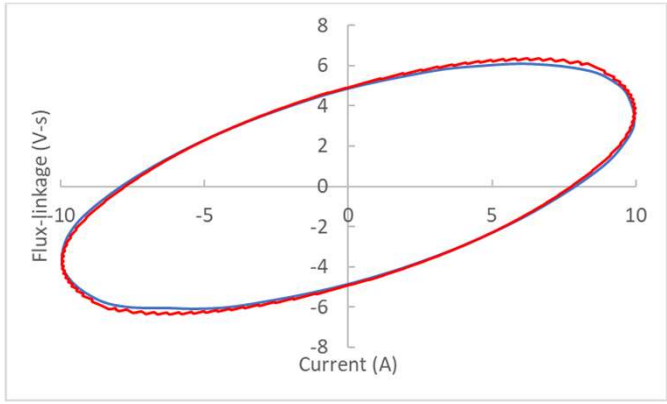
No-load flux density distribution



Flux lines

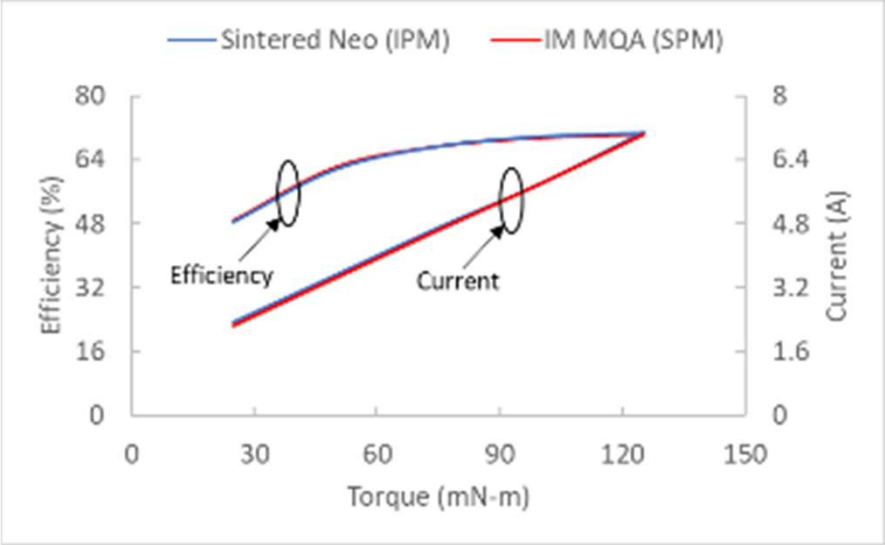


Teeth flux-linkage



Energy loop

Comparison of Benchmarked and Redesigned Motors



Parameter	Benchmarked Motor	Redesigned Motor
Motor Topology	**IPM**	**SPM**
Type of magnet	Sintered Neo	IM Anisotropic bonded neo (IM MQA)
Magnet shape	Plate	Ring
Dy and Co in magnet	**Yes**	**No**
No. of slots/poles	6/4	
Airgap (mm)	1.875	
Outer diameter (mm)	60	60
Active length (mm)	22	22
Magnet weight (g)	27.26	27
Copper weight (g)	65.30	65
Total weight (g)	386	362

Conclusion

- Use of surface mounted motor structure with MQA magnet can help in achieving the similar motor performance as of equivalent size IPM motor with sintered neo magnet
- The anisotropic bonded magnet doesn’t use any HRE or Cobalt and hence offers price stability

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