MQ1™ based Redesign of Electric Water Pump Motor

March, 2018

Benchmarking Process

- A water pump motor is procured from the market.
- The motor is benchmarked
  - Physical dimension benchmarking by measuring the following,
    - Weight of active material
    - Key stator and rotor dimensions
    - Winding pattern and conductor details
    - Magnet composition and magnetic characteristics of magnet
  - Performance benchmarking by measuring the following,
    - Closed circuit mid-airgap flux density
    - Cogging torque
    - No-load and load performance

Benchmarked Motor

- End user: Honda automotive
- Motor manufacturer: Aisin
- Part number: 06100-RDC-A00
- Motor type: Brushless (BL) DC motor
- Motor is wet runner
- Application: Inverter cooling

Motor Assembly and Key Weights




Stator assembly (Epoxy encapsulated)

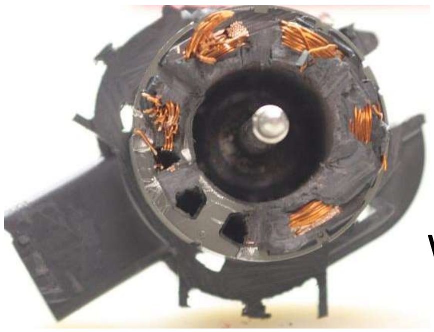
Rotor assembly (with magnet and impeller)

- **Stator**
  - No. of turns/coil: 80 turns
  - Conductor diameter: 0.40 mm (AWG 26)
  - Weight of copper = 40.56 g*

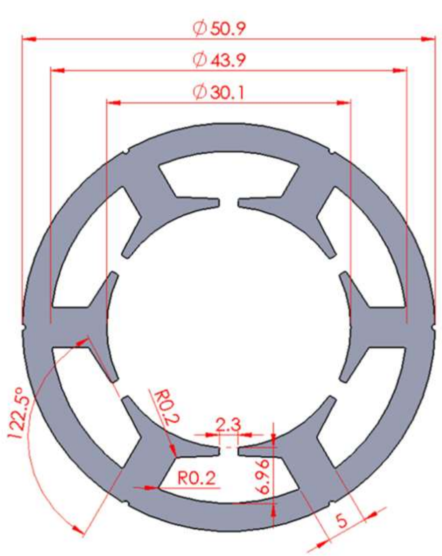
- **Magnet**
  - Material: Injection molded Anisotropic NdFeB (similar to HDDR)
  - Number of poles: 4 poles
  - Magnet weight: 20.2 g
  - Density: 5 g/cm^3

*The total copper weight is estimated from weight of one coil. Weight of one coil = 6.76 g

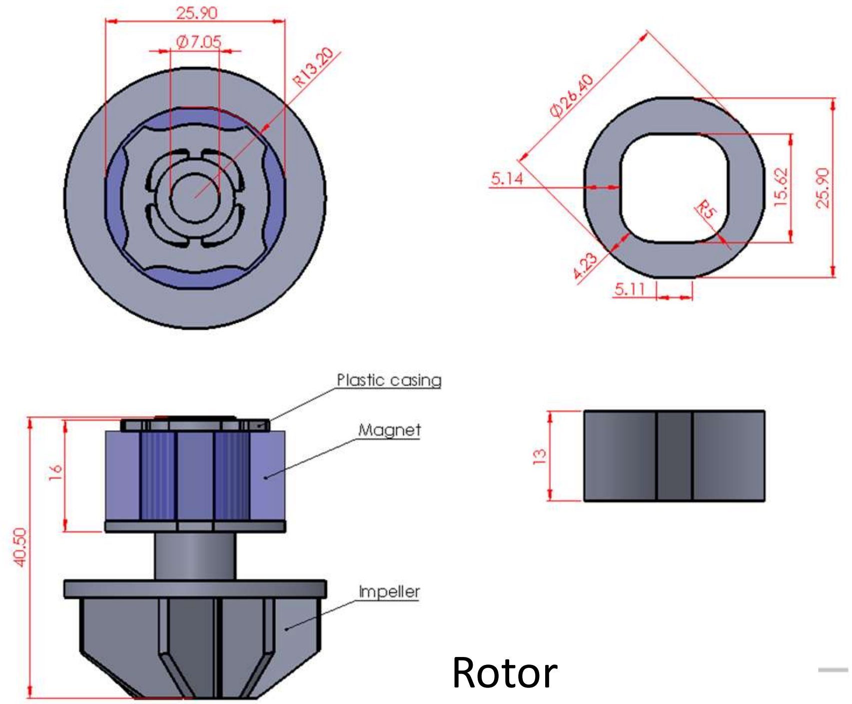
Stator and Rotor Dimensions



Stator
No. of laminations = 26
Lamination thickness = 0.5 mm
Concentrated winding
Whole stator is encapsulated with PPS



Stator



Rotor

The motor is wet runner. Stator is encapsulated to prevent water touching the winding.

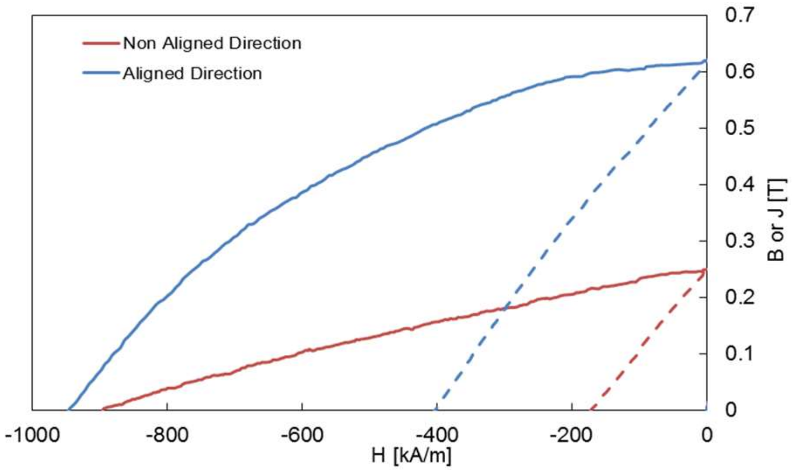
Magnet Analysis: ICP and B-H Characteristics

- ICP results

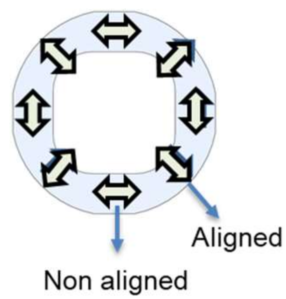
Nd	Dy	B	**Co**	Al	Fe	Ga	Si
28.039	0.699	1.038	**13.486**	0.157	55.622	0.434	0.183

1. **High Cobalt content to increase the curie temperature of compound so it can be use to make IM magnet with PPS**
2. **Cobalt price will fluctuate (increase) with the increased penetration of EV/HEV (Battery).**

- B-H Curve



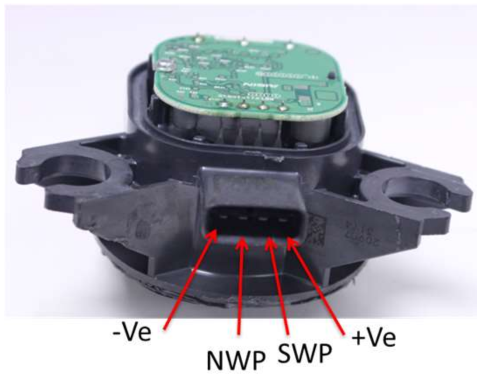
Magnet Characteristics



Halbach orientation on the magnet

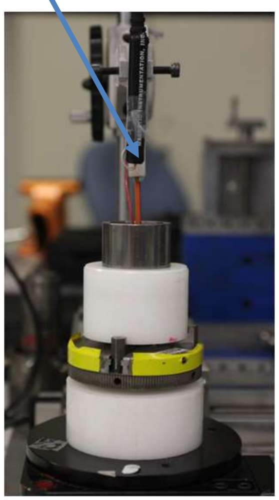
Magnetics	
B_r	0.62T
H_{ci}	950 kA/m
H_c	405 kA/m
$(BH)_{max}$	68.5 kJ/m³

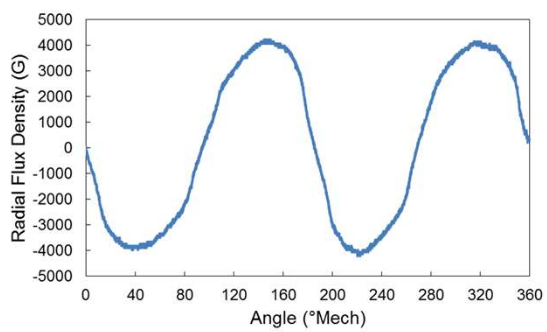
Connections to Control Circuit, Closed Circuit Flux Density and Cogging Torque Measurement

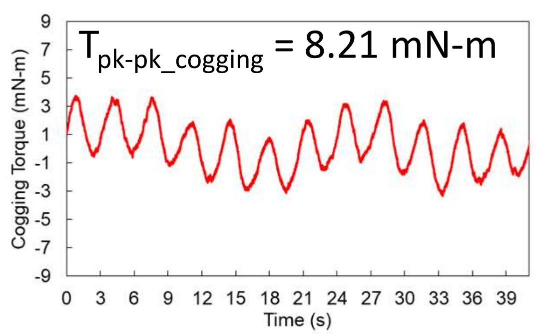


- Supply voltage = 12 V
- SWP ⟹ Output voltage signal corresponding to motor speed

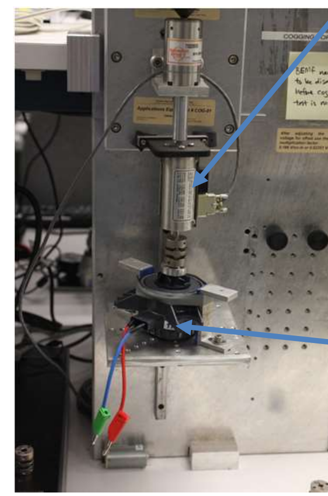
Hall probe







Torque transducer

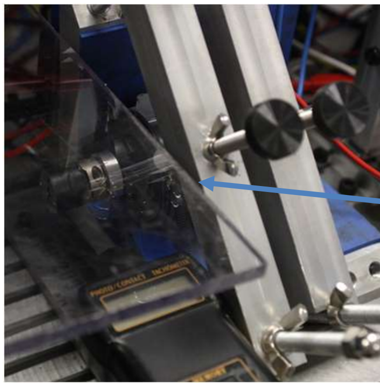


Motor

Closed circuit mid-airgap flux density measurement

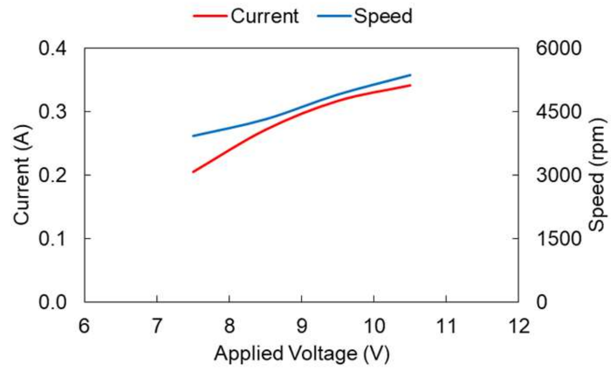
Cogging torque measurement

No-Load and Load Performance Measurement



Motor

No-load Measurement

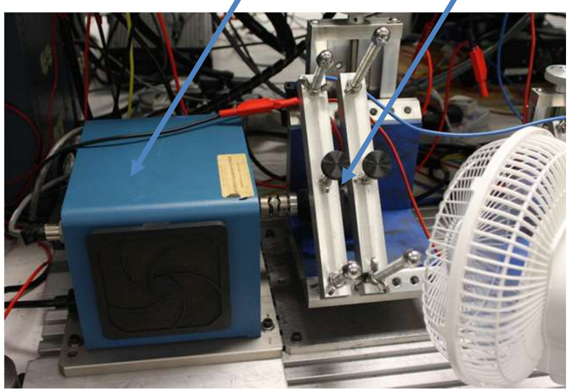


No-load performance of motor

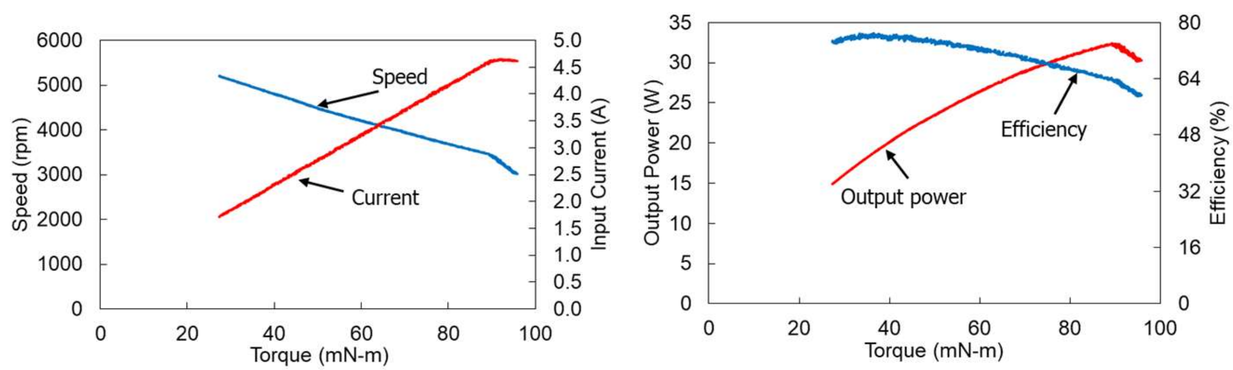
No-load current (A)	No-load speed (rpm)
0.4	6108

Dynamometer

Motor



Load Measurement



Motor's load performance

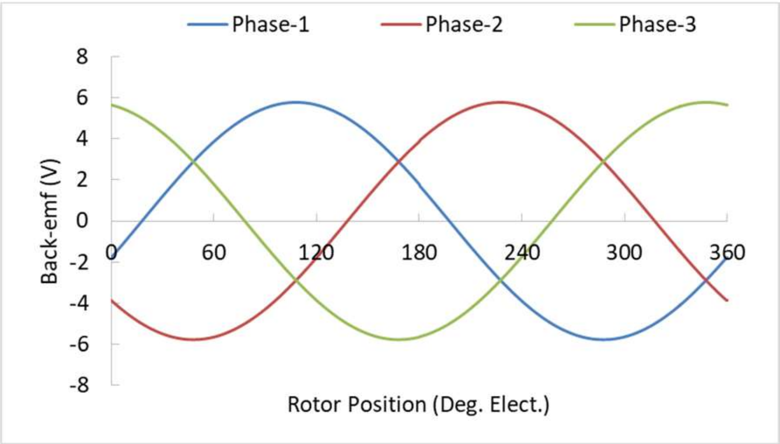
MQ1 based Redesign

Approach to arrive at MQ1 Based Redesigned Motor

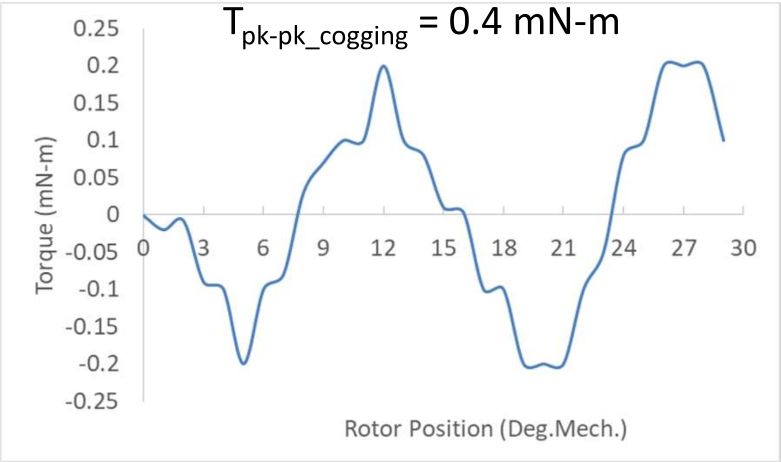
neo Magnequench

- Using the commercially available motor design software SPEED, a motor is designed with injection molded MQ1 magnet.
  - The MQ1 magnet used is Cobalt free, offering stable and lower price compared to anisotorpic NdFeB magnet
- The motor is designed for an optimal active material cost.
- During the design following additional constrains are imposed,
  - The effective airgap for the redesigned motor is same as benchmarked motor (The effective airgap is the actual airgap plus the thickness of PPS overmold on the stator)
  - The conductor current density is similar or lower from the one in benchmarked motor
  - The slot fill is similar or lower from the one in benchmarked motor

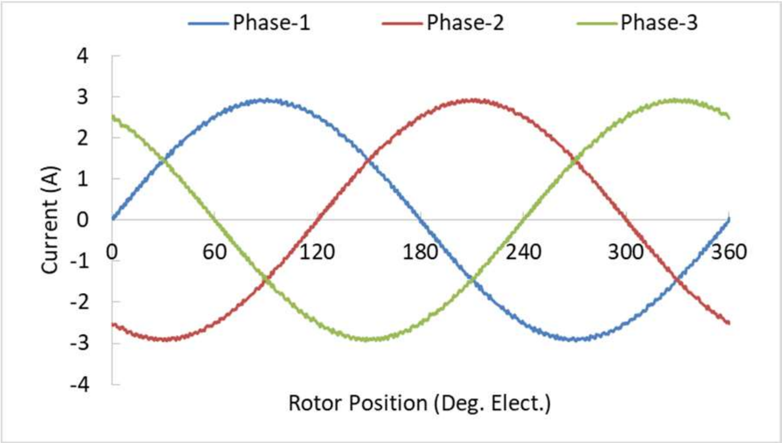
MQ1 Based Redesigned Motor: Performance



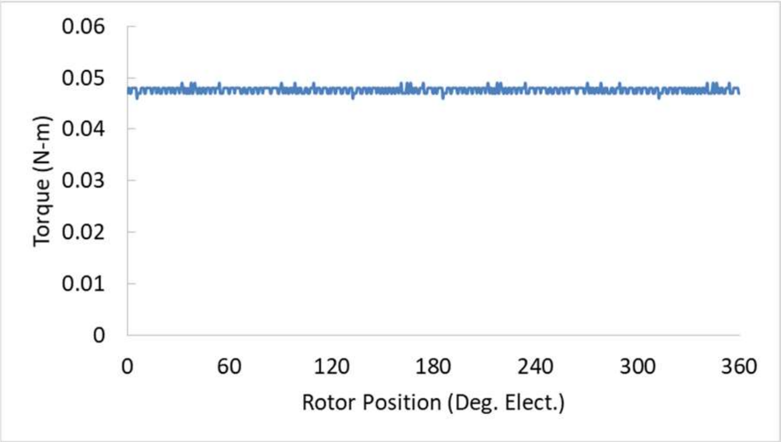
Phase back-emf @ 4803 rpm



Cogging torque

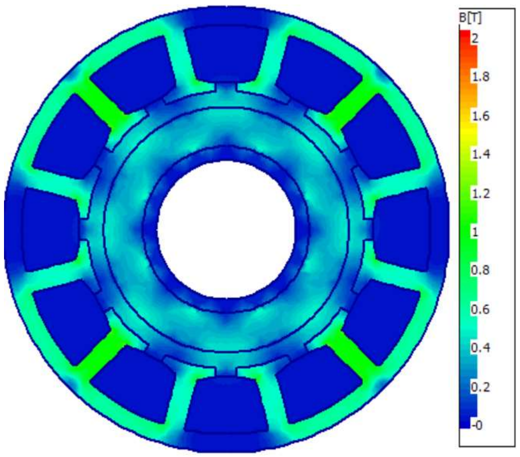


Motor current at T=41 N-mm @ 4803 rpm

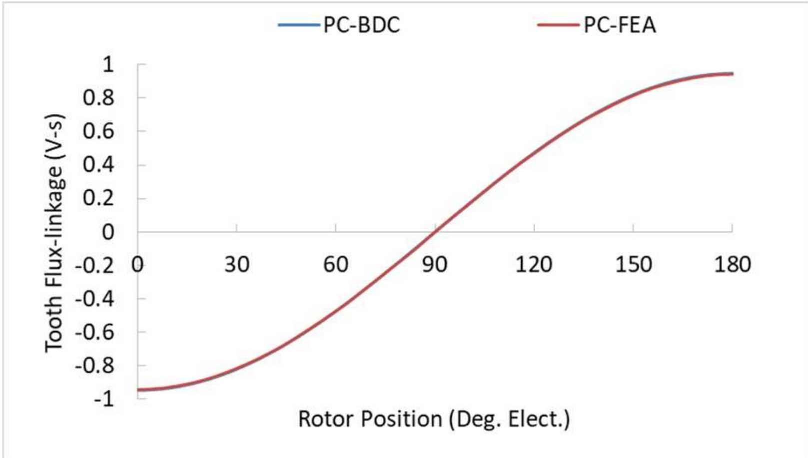


Developed torque @ 4803 rpm

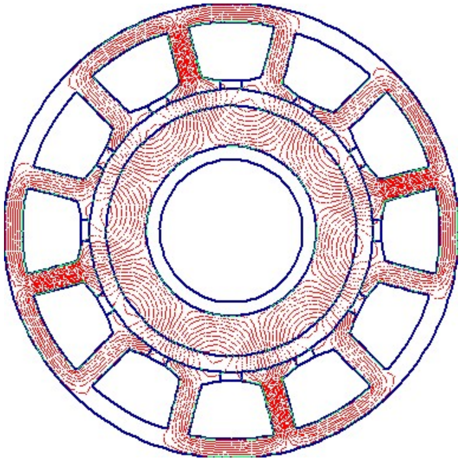
MQ1 Based Redesigned Motor: FEA Validation



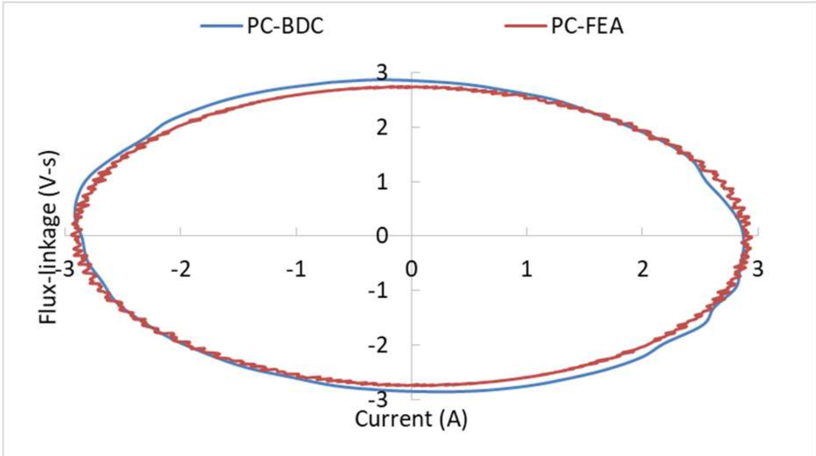
No-load flux density distribution



Teeth flux-linkage

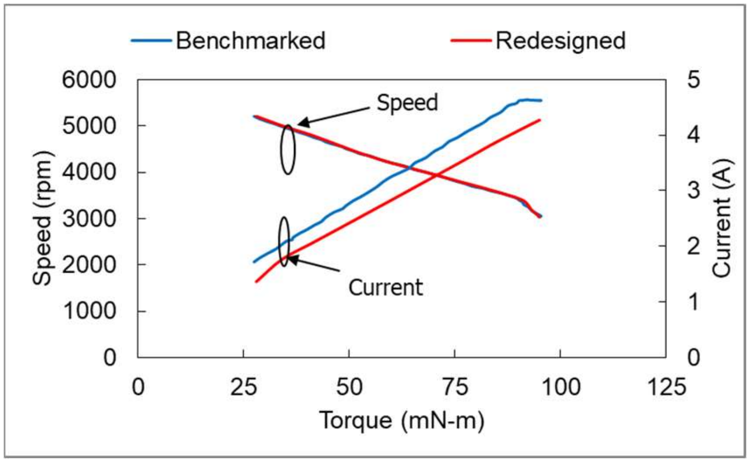


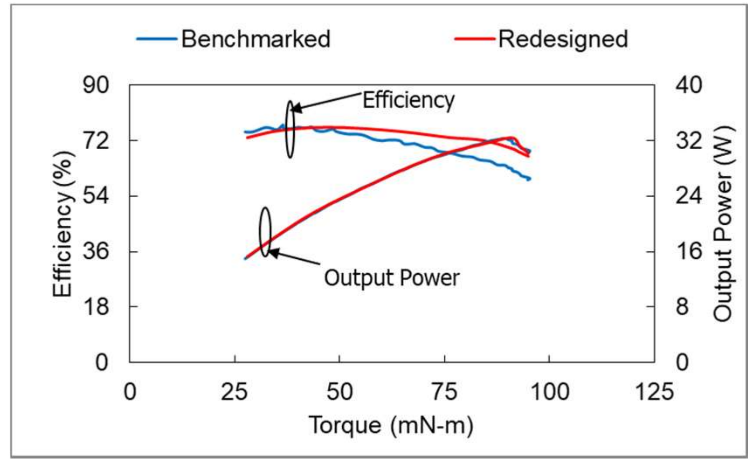
Flux lines



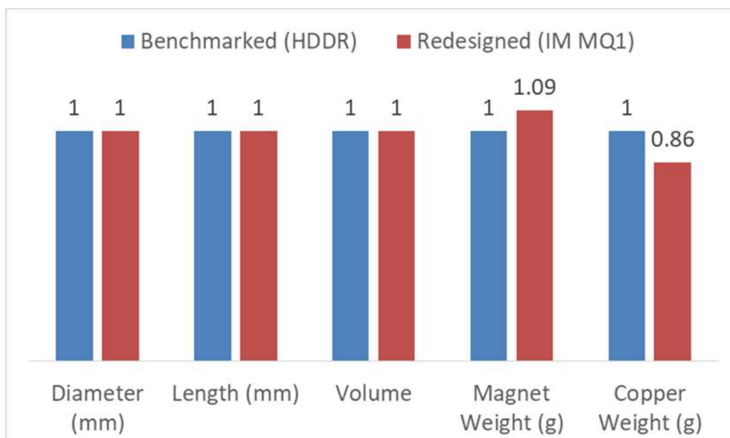
Energy loop

Comparison of Benchmarked and Redesigned Motors





Comparison of benchmarked and redesigned motor performance



Comparison of key physical parameters for benchmarked and redesigned motor

Comparison of Key Physical Parameters for Benchmarked and Redesigned Motors

Parameter	Benchmarked	Redesigned
Magnet	Anisotropic NdFeB	IM MQ1
Magnetization Profile	Halbach	Halbach
No. of pole	4	8
No. of slots	6	12
Outer diameter (mm)	50.90	50.90
Length (mm)	13	13
Length of airgap (mm)*	1.85	1.85
Weight of magnet (g)	20.20	22.00
Weight of copper (g)	40.56	35.00
No. of turns/coil	80	24
Coil Wire diameter (mm)	0.40 (AWG 26)	0.64 (AWG 22)
Current & efficiency (T= 41 N-mm @ 4803 rpm)	2.31 A / 76.20%	2.05 A / 75.91%

Observations

- MQ1 magnet gives relatively stable magnet price as it is **Cobalt free**.
- The cost of active material in IM MQ1 magnet is significantly cheaper compared to benchmarked motor with anisotropic NdFeB magnets.
  - Achieving the Halbach magnetization for an anisotropic NdFeB magnet is challenging while for an MQ1 magnet, it can be achieved by just an appropriate design of the magnetization fixture.
  - The magnet tool cost for the anisotropic magnet is significantly higher due to the need of alignment field
- For an MQ1 magnet, higher no of poles and appropriate slot no can be used to achieve the cost optimized design.
  - The IM MQ1 based motor is having the same size and volume as the benchmarked HDDR motor.
  - The weight of the MQ1 magnet is 9% more but the copper weight is 14% lower.

Questions? Want to know more? Collaborate with us?

Contact us,
research@magnequench.com

Visit our Technical Website
www.mqitechnology.com