VESI - Demonstrator one

High Performance Ferrite PM Traction Drive

Final presentation by Prof Patrick Luk, Cranfield University

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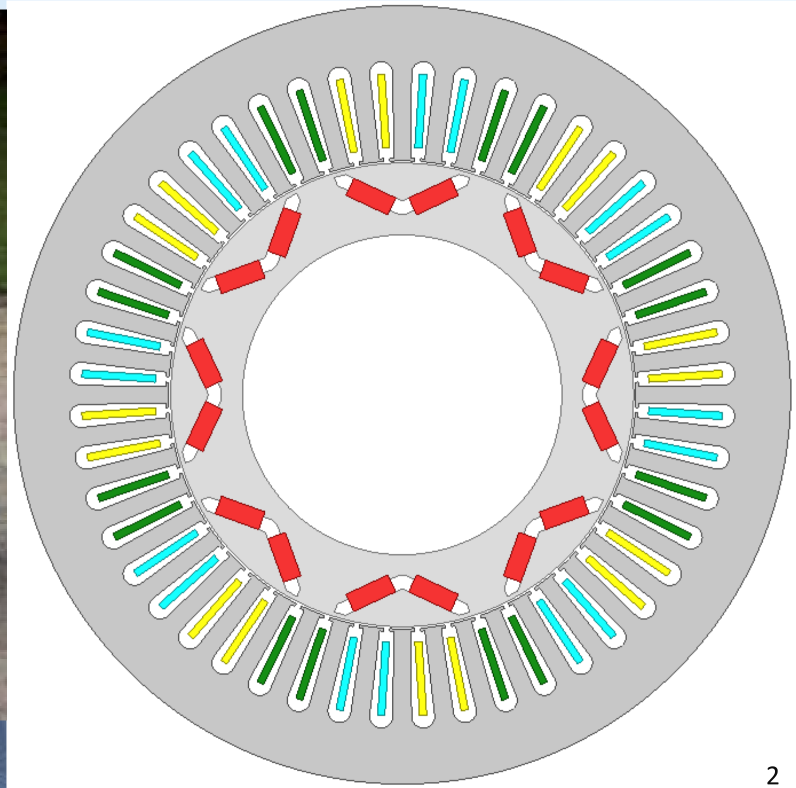
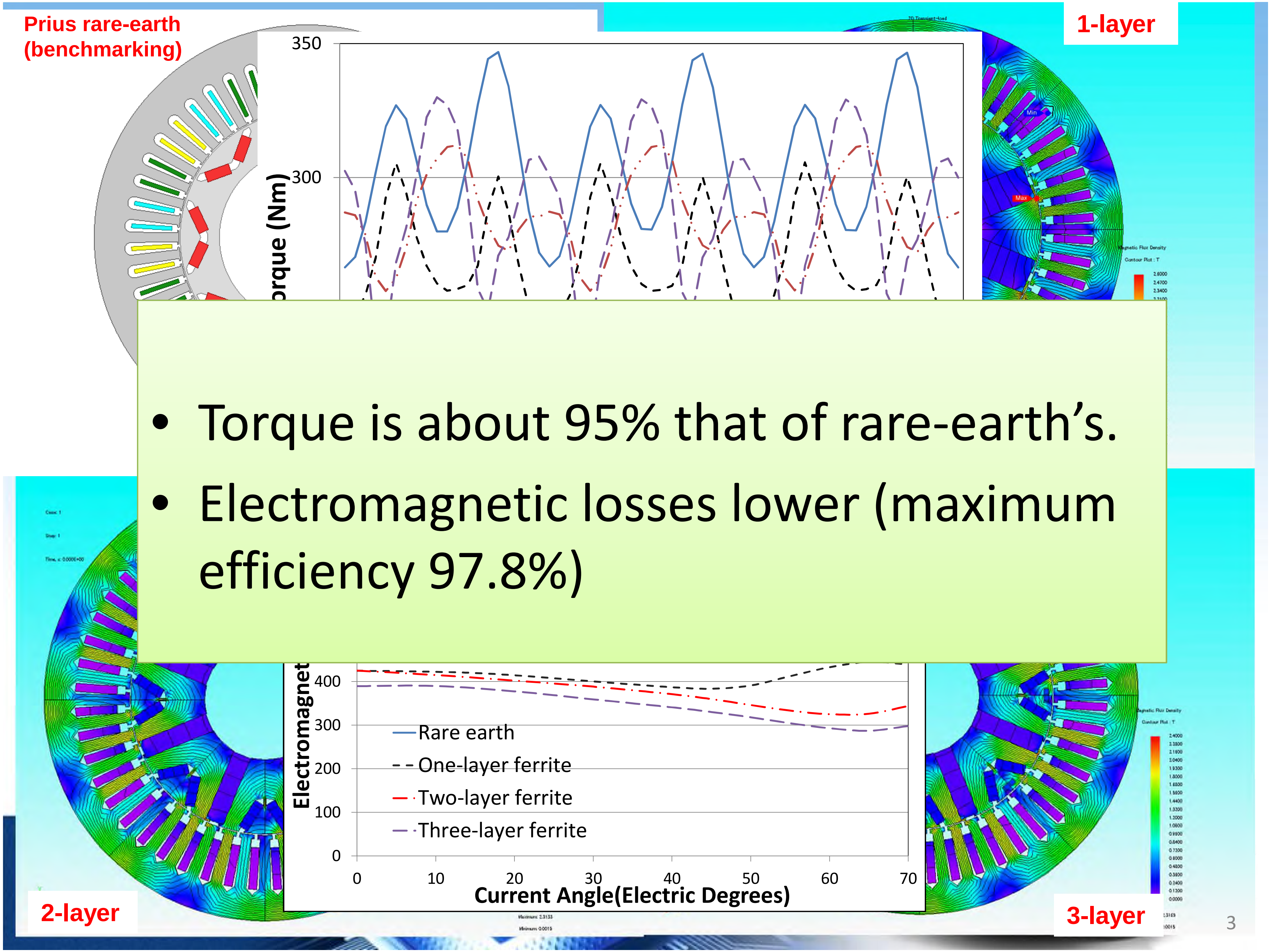
Cranfield UNIVERSITY
Newcastle University
CITY UNIVERSITY LONDON

Benchmarking our project

- "standing on the shoulders of giants"

Prius HEV rare-earth motor

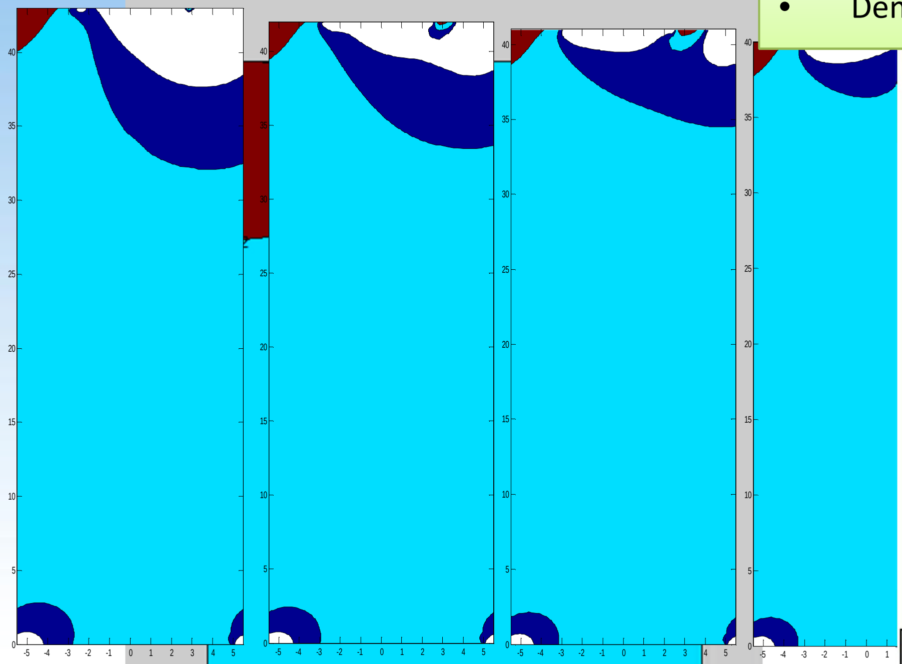




- Torque is about 95% that of rare-earth's.
- Electromagnetic losses lower (maximum efficiency 97.8%)

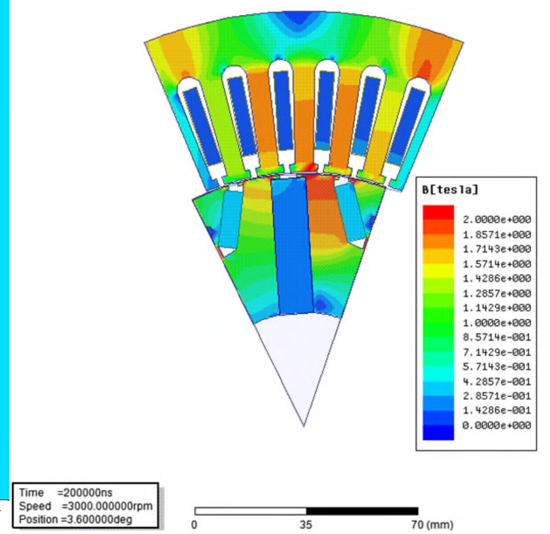
Demagnetization Optimisation

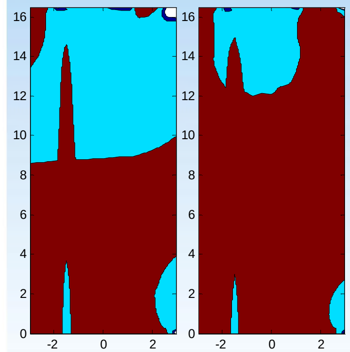
- Torque is about 95% that of rare-earth's.
- Electromagnetic losses lower (maximum efficiency 97.8%)
- Demagnetisation <2%



L=43(depth=1mm) L=42(depth=2mm) L=41(depth=3mm) L=40(depth=4mm)

Main pole demagnetization at different depth and length





(depth=3mm) (depth=4mm)

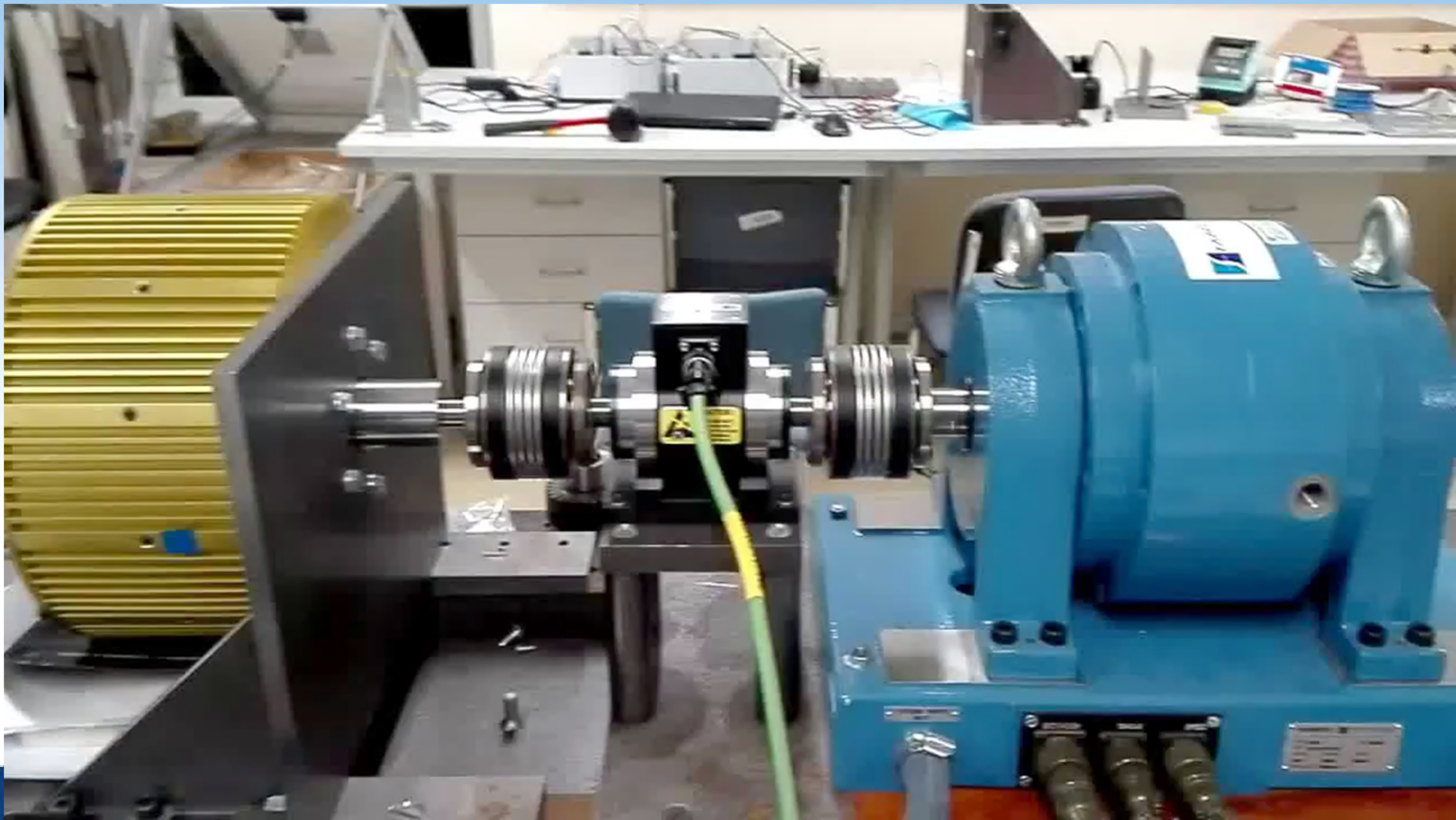
zation at different depth

Demagnetized area /%	6.37	4.31	2.51	1.86
Torque /Nm	89.88	89.11	88.20	87.07

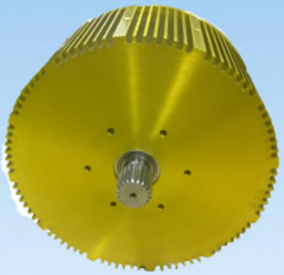
Demagnetized area %	1.47	0.84	0.6	0.16
Torque /Nm	90.21	89.88	89.47	88.57

Deeper magnet insertion will reduce the demagnetized area at the cost of reduced torque output.

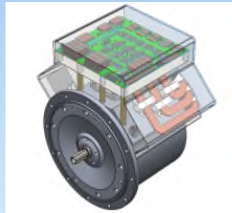
https://www.youtube.com/watch?v=WcpE0ITSIJM



Technology Demonstrator



Ferrite PM Motor → Ferrite PM Drive



Aim: Showcasing a ***viable and sustainable alternative EV traction technology*** *that is critical for the uptake and penetration of the EVs in future automotive market*.

Objective: Developing a high performance ferrite motor with full functional integration with its converter.

- \$12/kW; 1.2 kW/kg; 3.5 kW/L; Efficiency 93%; Cooling 70°C inlet temperature at 8 l/min water/glycol 50/50 mix

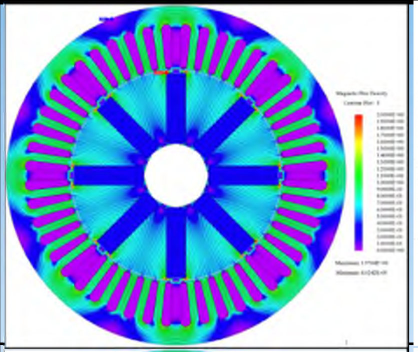
Design Rationale

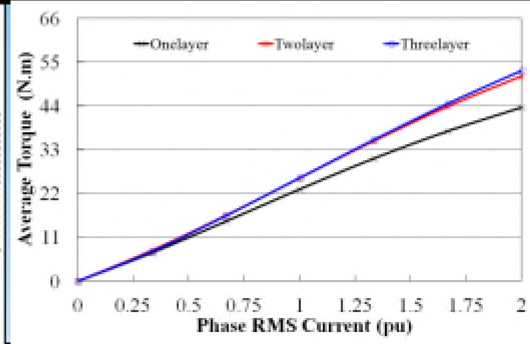
- Flux focusing to maximize PM torque --> high rotor pole number (>6)
- Saliency to boost reluctance torque--> multilayer interior magnets
- High power density --> high rotational speed
- Limited switching frequency --> low rotor pole number, low rotational speed
- Rotor integrity limitation --> low rotational speed, simple rotor structure

Estimated real power	20kW
Rotational speed	**10,000rpm (rated); 20,000rpm (max)** **5,000rpm (rated) (lower speed version)**
Efficiency	>93%
Nominal Bar Bus Voltage	300V
Ambient temperature	60 degrees
Pole Pairs	4
Cooling	Water cooled

Magnet Layer Optimisation

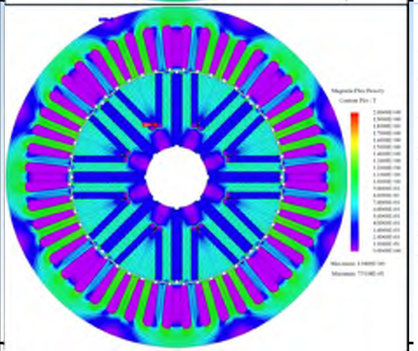
One layer

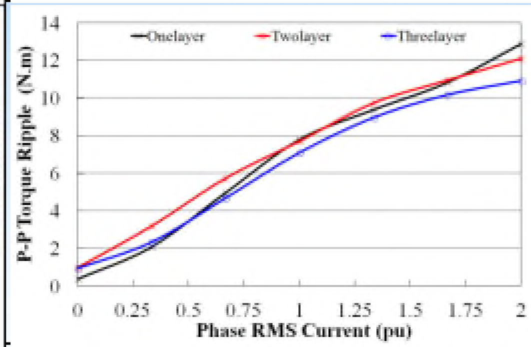




Two and three layers can deliver much higher torque than one layer, two and three layers deliver almost the same torque

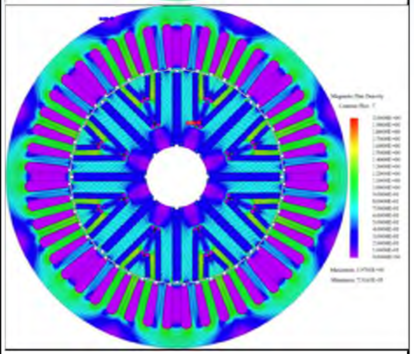
Two Layer

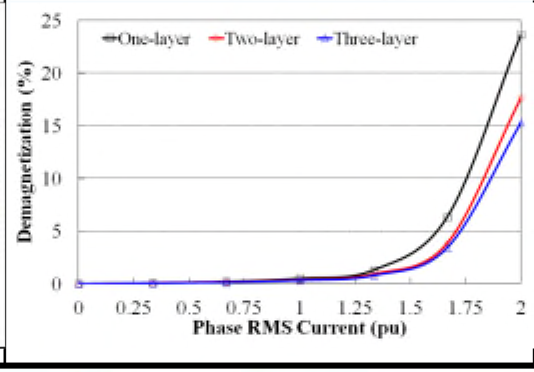




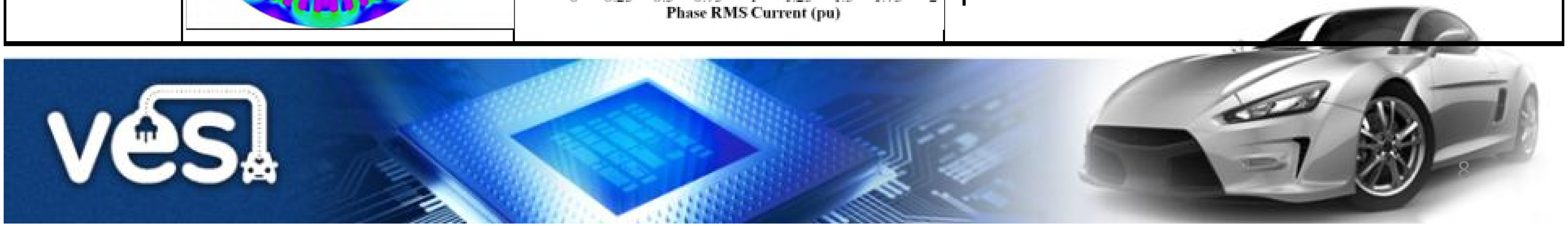
Three machines delver almost same torque ripple

Three Layer

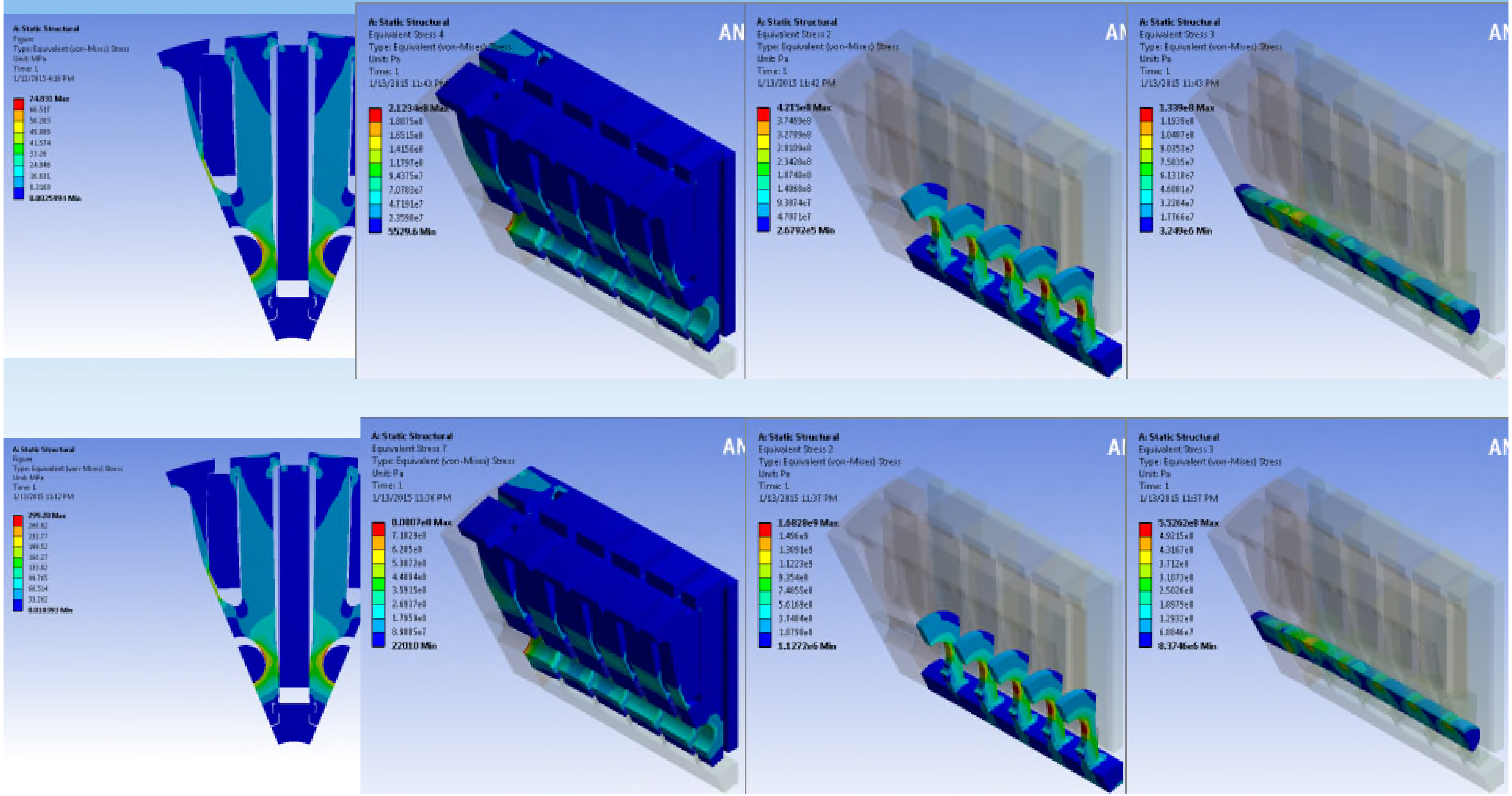




The demagnetization decreases as the magnet layer increases, two layer is chosen for compromise between rotor complexity and performance



Final Rotor Stress Analysis



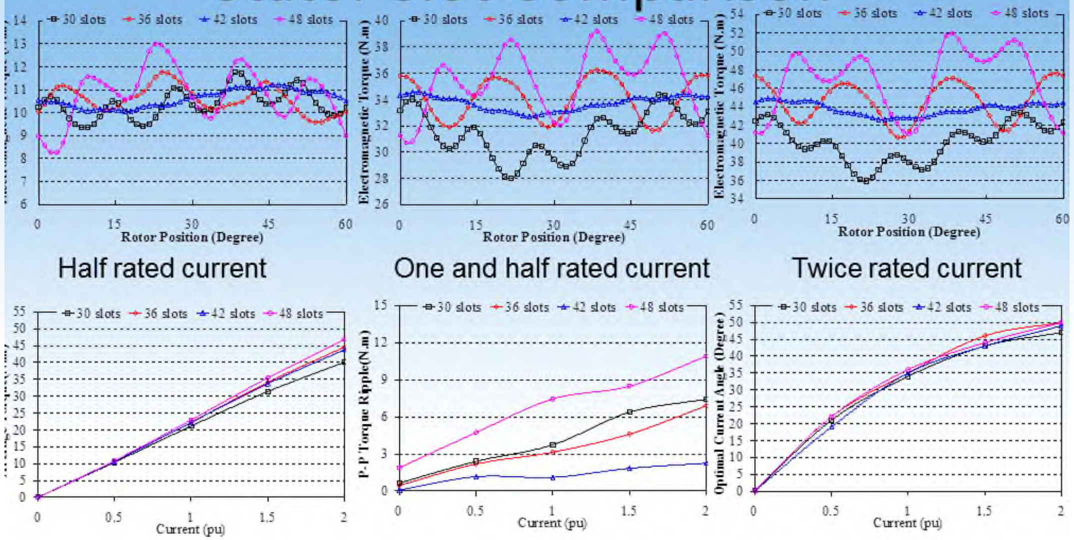
Stator Design

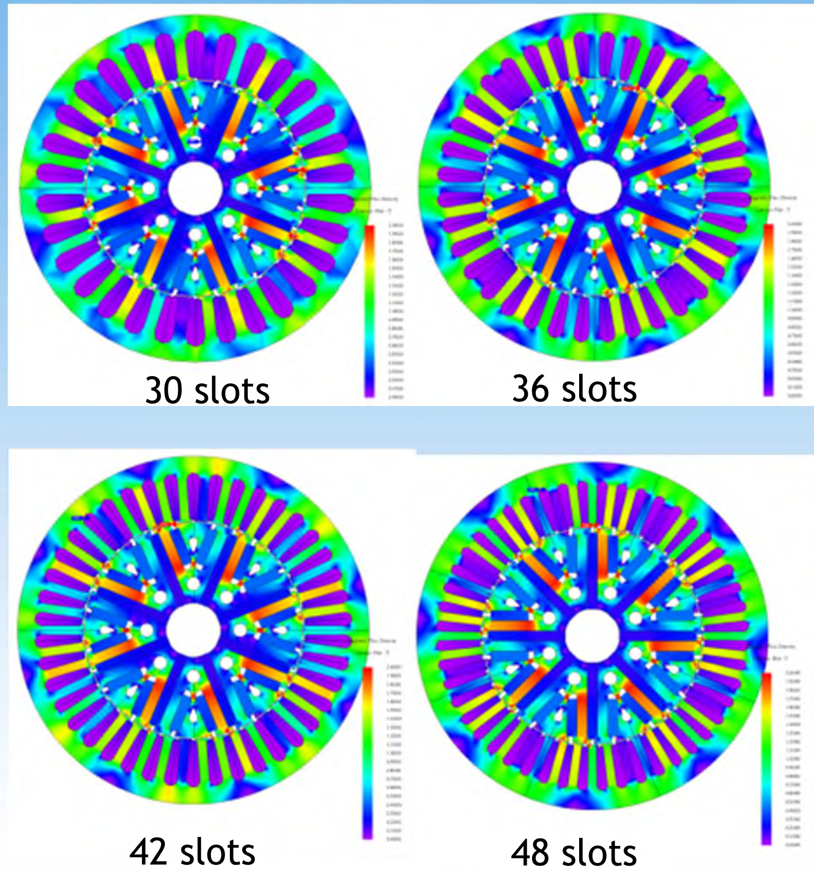
Principal design problem: Maximize electromagnetic performance and minimize demagnetization risk.

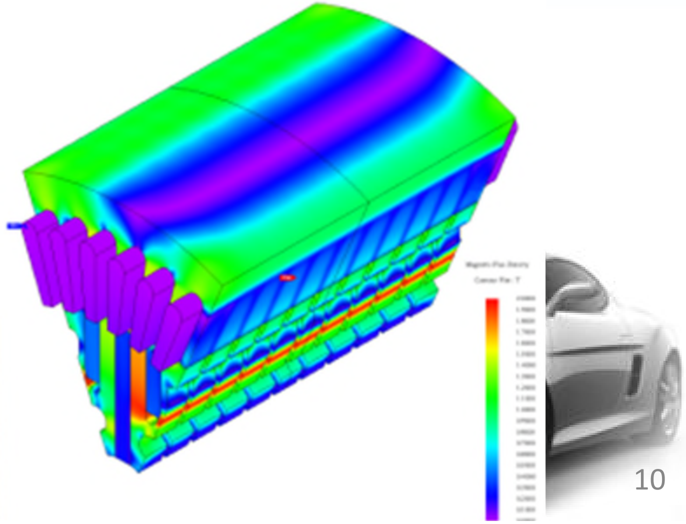
APPROACH USED:

•Stator slot shape and size are optimized to minimize the copper resistive loss.

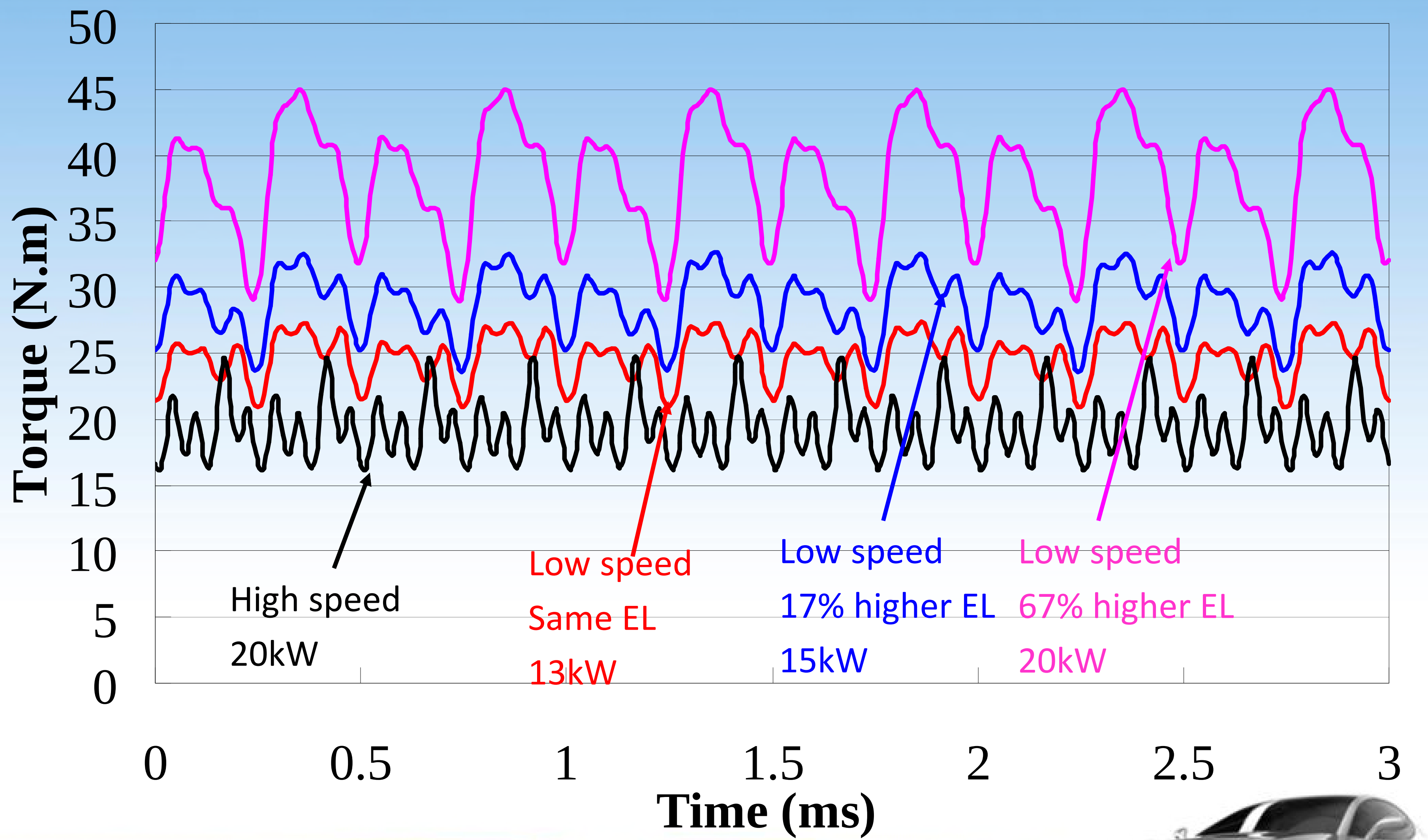
Stator Slot Comparison







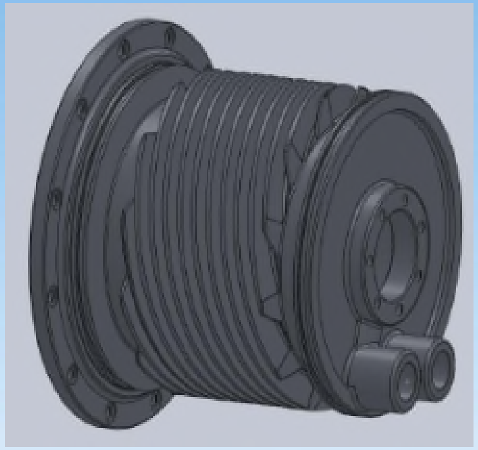
Torque performance prediction



Comparison

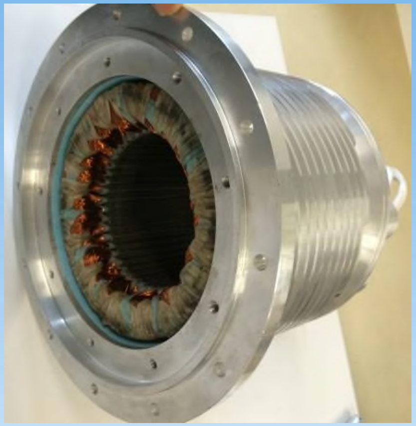
Machine Type	High Speed	Low Speed_1	Low Speed_2	Low Speed 3
Power	20kW	13kW	15kW	20kW
Coil Turns	3	5	5	4
Current (RMS)	114.5A	68.7A	80.6A	143A
Resistance	15.2mOhm	42.3mOhm	42.3mOhm	27.1mOhm
Copper Loss	600W	600W	824W	1600W
Core loss	361.5W	223.5W	262W	317W
Electromagnetic Efficiency	95.40%	94.10%	93.30%	91.30%

Stator Design (contd)



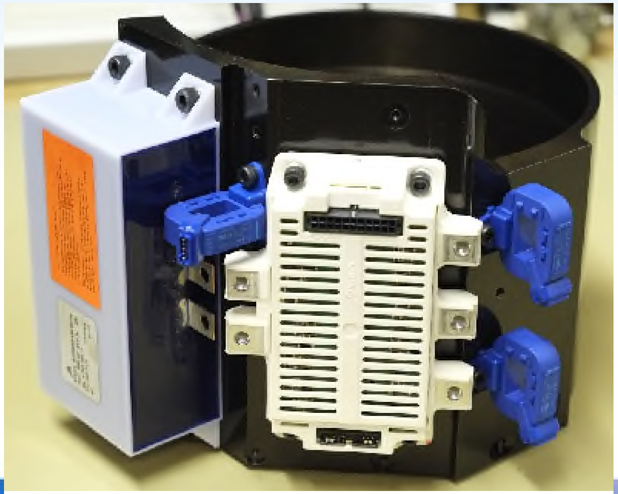
Helical cooling fins on motor body maximise heat transfer.

Stator lamination with windings

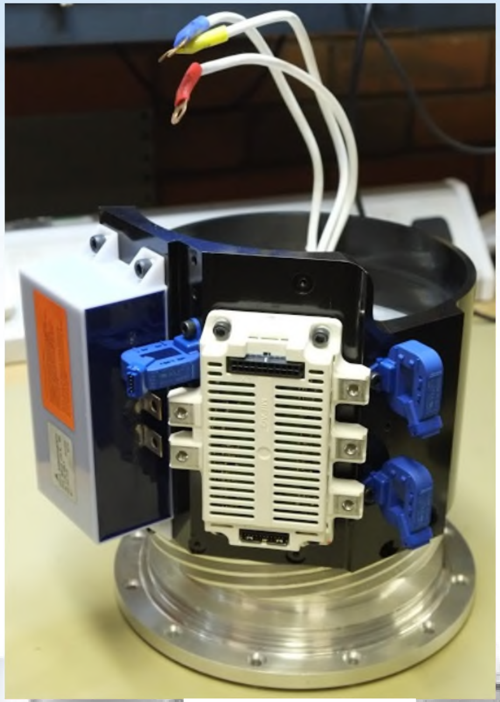


Partially assembled stator

Aluminium casing



Drive component Mounted on Aluminium Casing



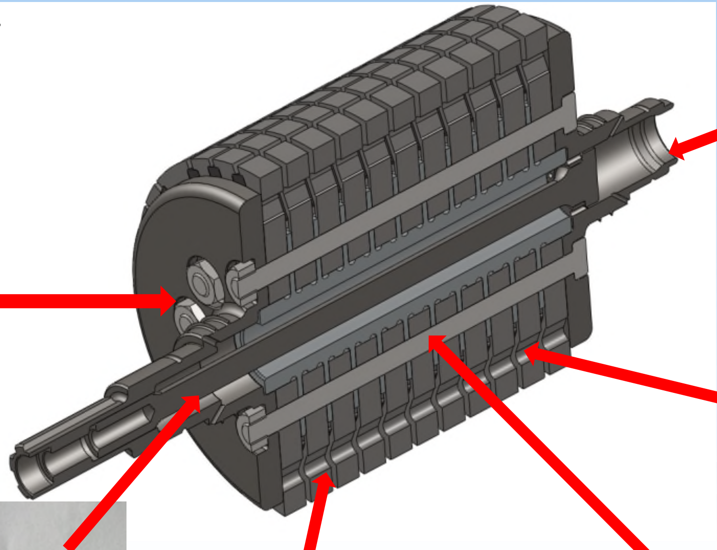
Stator

Rotor Assembly (high speed)

- High-strength, **pin-supports** used to **reduce stress** in the lamination steel.
- Optimal rotor has **eight poles and is 95.4mm diameter.**
- Employ Nippon Steel 0.35mm lamination 35H250 with 420MPa tensile strength to minimize rotor core loss.

Rotor right cover

Rotor left cover



Pin holders

Rotor shaft tie pin

Lamination with pin holders

Lamination support pins

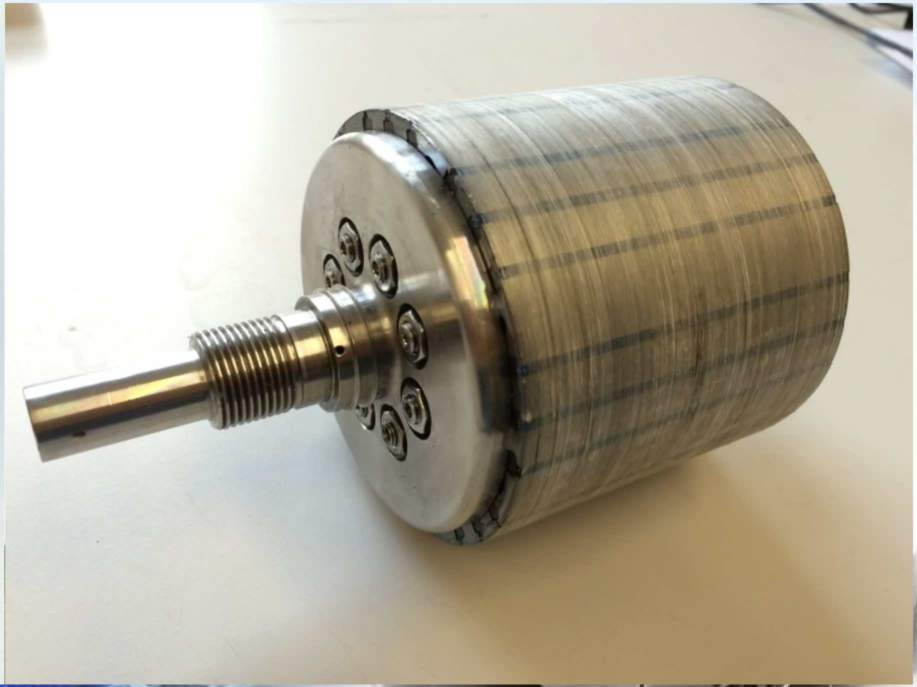
Rotor Assembly Issues

- Communications issues with sub-contactor
- Incorrect tolerances leading to lamination jam and magnets broken

- Better communications with sub-contractor
- Tolerances less critical
- Successful rotor assembly

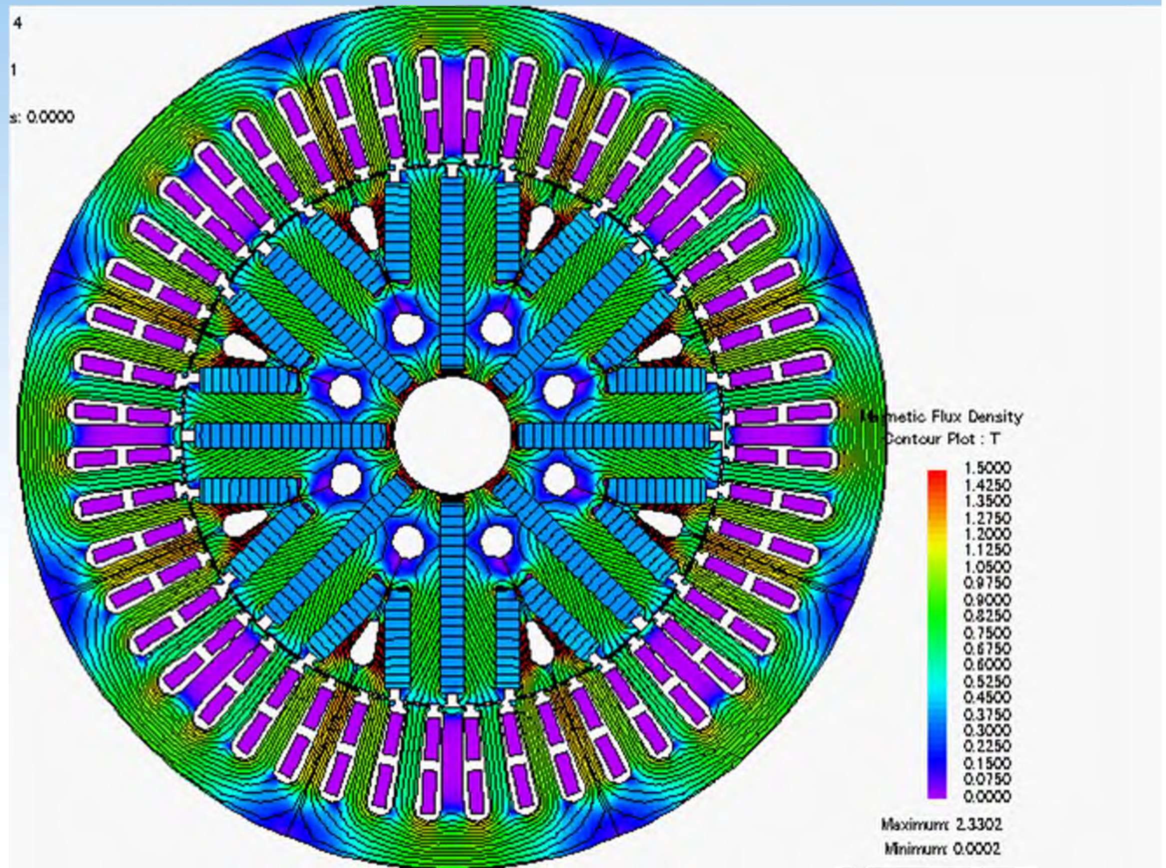
High speed

Low speed



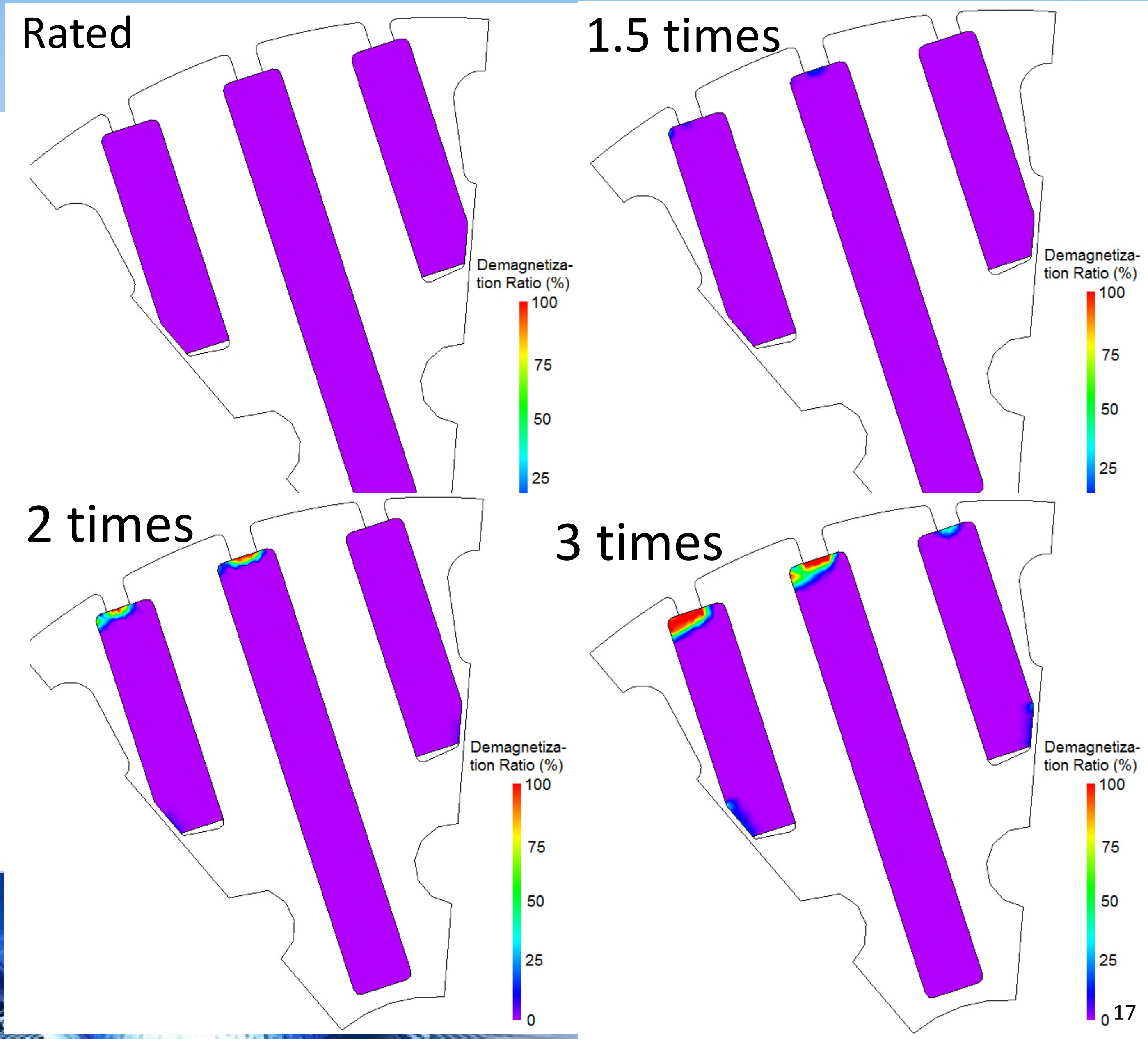
Dynamic Demagnetization Analysis

- Irreversible de-magnetisation will occurs if flux density in PM is below knee point threshold value.
- Simulation results allow virtually complete mitigation of de-magnetisation



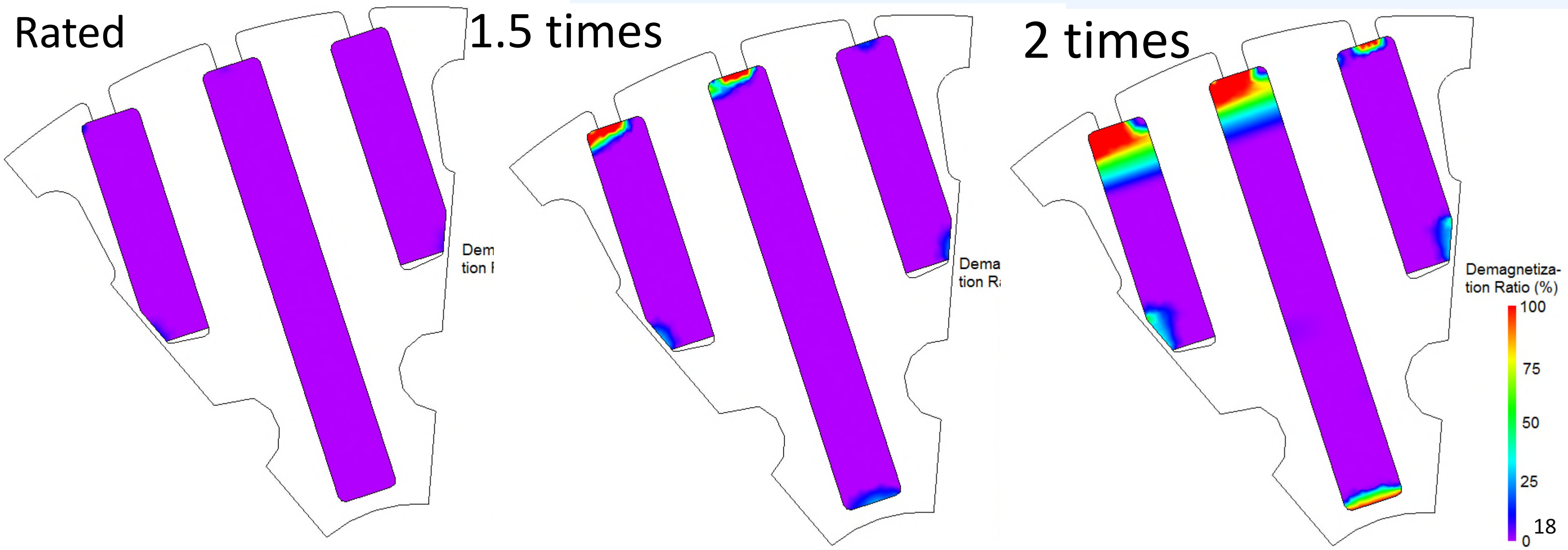
Demagnetization under different loading conditions

- Negligible demagnetiza-tion of 0.73% at 2 times rated current;
- 3.2% at 3 times rated current.



Demagnetization at low environmental temperature -60°C

- Completely safe at rated loading;
- Demagnetization of 2.3% at 1.5 times current;
- Demagnetization of 12% at 2 times current.

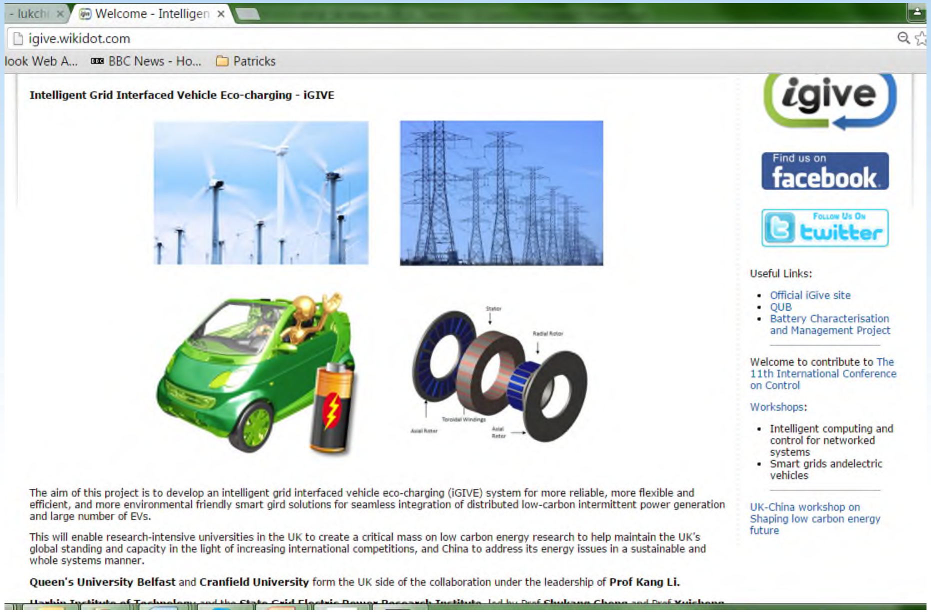


Conclusion

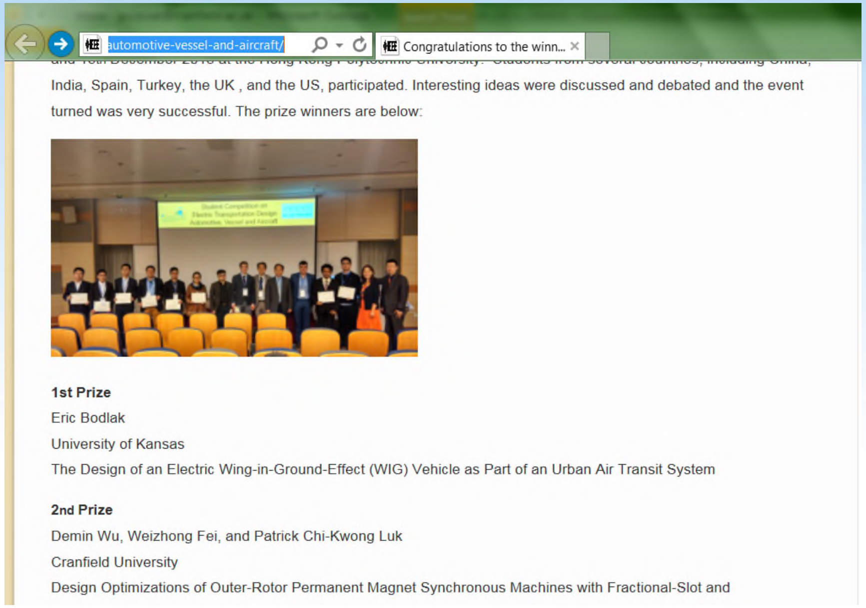
- Demo 1 has very good anti-demagnetization ability even under overloading conditions
- At extremely low environmental temperature, demagnetization can be completely avoided by monitoring current with control program (our integrated drive concept being developed)
- A compelling and viable alternative to existing EV drives

VESI – related Successes

- iGIVE EPSRC-funded Program



- Two Paper Awards ($1600) at the IEEE Transport Electrification Community (TEC) 2015 conference



- 11 publications, including 3 IEEE Trans papers