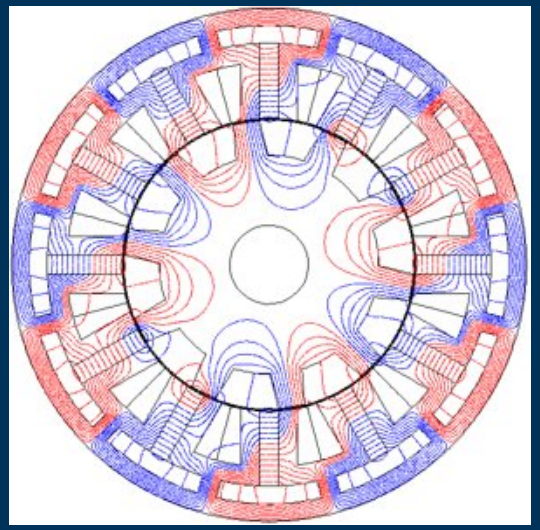
HBM Prenscia Technology Day

Virtual Seminar Series



Novel Permanent Magnet Machines for Electric Vehicles

Presented by Professor ZQ Zhu
Head of Electrical Machines and Drives Research Group
University of Sheffield

Session #2: Electrical Power Testing & Analysis

Novel Permanent Magnet Machines for Electric Vehicles

Abstract

Permanent magnet (PM) machines exhibit high torque density and high efficiency, and are eminently suitable for electric vehicles (EVs). This presentation will start with an introduction of various electrical machine technologies including induction machines (used by Tesla), PM machines (used by Toyota/Nissan/BMW) and synchronous reluctance machines. Their system efficiencies for a typical driving cycle will then be compared. It will continue to overview PM machine topologies for EV applications. Finally, it will highlight the challenges and opportunities for the development of PM machines.

About the presenter, Professor ZQ Zhu

Professor Zhu is a Fellow of the Royal Academy of Engineering, UK, a Fellow of IEEE, USA, and a Fellow of IET, UK, and has been Head of the Electrical Machines and Drives Research Group at University of Sheffield from 2008.His research interests include the design and control of novel high torque/power density and high efficiency permanent magnet machines and drives for applications ranging from electric vehicles through domestic appliances to wind power generation and more electric aircraft. These research activities have been sponsored by the UK/EU government and the global industries based in the UK, Germany, Japan, Denmark, France, and China (e.g. Rolls Royce, Siemens, Valeo, ZF TRW, Jaguar, Midea, CRRC, Toyota, Nissan etc.).

Novel Permanent Magnet Machines for Electric Vehicles

Professor Z. Q. Zhu

FREng, FIEEE, FIET

Head of Electrical Machines and Drives Group

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Sheffield and University of Sheffield

City of Sheffield – a city of innovation

- One of the origins of industrial revolution
- Origin of modern football clubs
- Excellent environment & low living cost

University of Sheffield – engineering matters

- No.1 - UK engineering in terms of R&D income
- 1905 - University of Sheffield
- 1828 - Sheffield School of Medicine
- >29,000 students
- 6 Nobel Prize winners

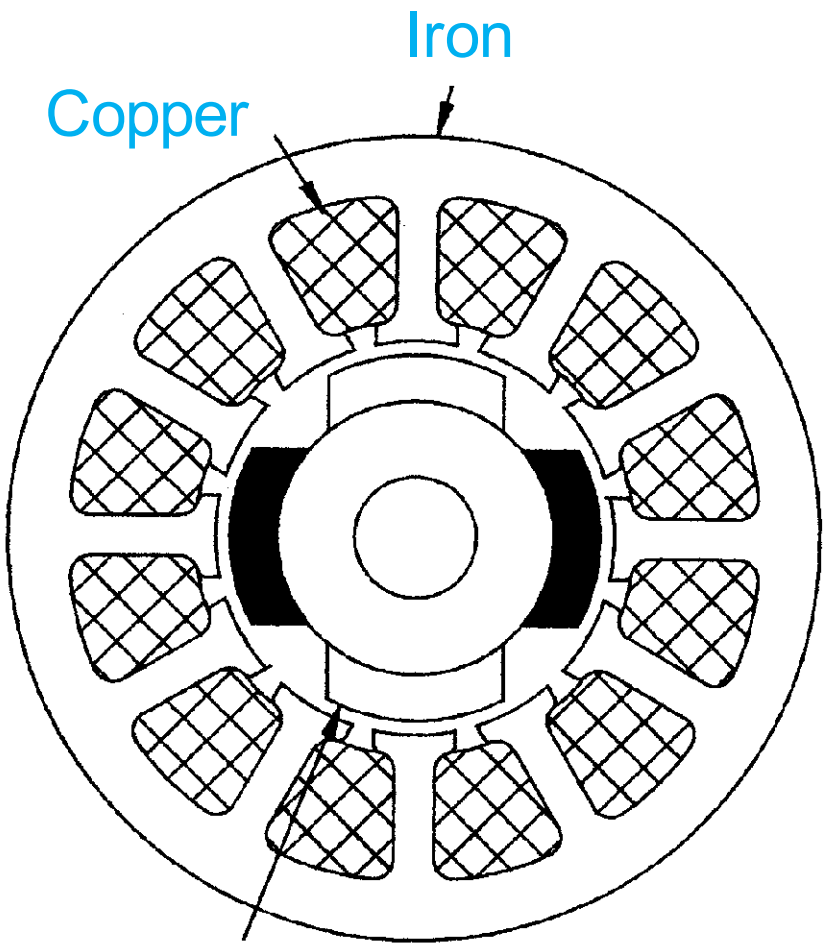
nCode – a Sheffield company

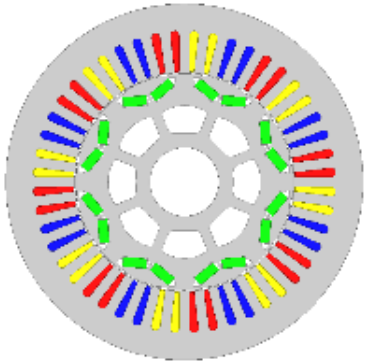
- began in Sheffield in 1982
- bought by HBM in 2008
- became HBM Prenscia in 2016

Electrical Machines and Drives Research Group

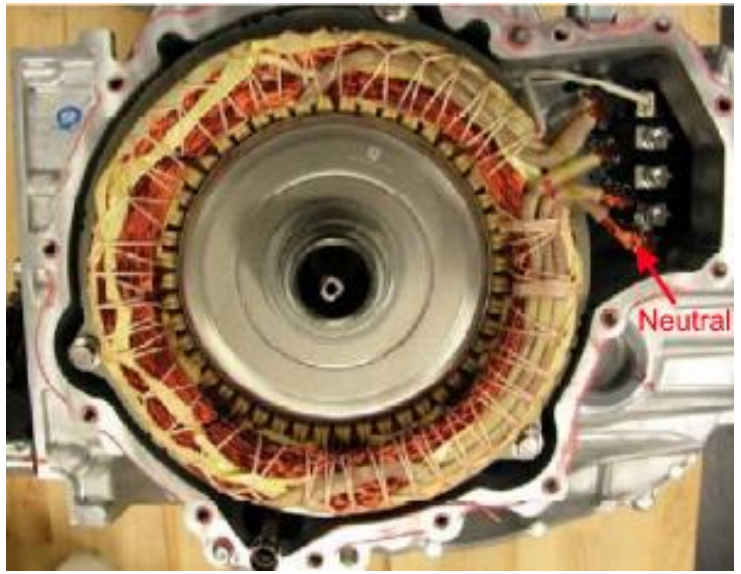
- Headed by Prof. **Z.Q. Zhu**, *Fellow RAEng*, *Fellow IEEE, Fellow IET*
- Global leader in R&D of permanent magnet machines & control systems
- Very strong industrial collaboration, particularly on electric vehicles
- 14 academics (incl. 8 profs) with complimentary skills, 100 PhDs+PGRAs
- **Hosts 6 industry funded research centres & 3 government funded platforms**
    1. The Rolls-Royce University Technology Centre in 'Advanced Electrical Machines' (2003-)
       Director: Prof. Geraint W Jewell
    2. Sheffield Siemens Gamesa Renewable Energy Research Centre (S^2GRE) (2009-).
       Director: Prof. Z.Q. Zhu
    3. Romax Technical Centre (2013-)
       Director: Prof. Kais Atallah
    4. CRRC Electric Drives Technology Centre (2014-)
       Director: Prof. Z.Q. Zhu
    5. Centre for Research into Electrical Energy Storage & Applications (CREESA) (2014-)
       Director: Prof. Dave Stone
    6. Sheffield Midea Electrical Machines and Control Research Centre (2017-)
       Director: Prof. Z.Q. Zhu
    1. EPSRC Prosperity Partnership on Offshore Wind Power (2017-)
       Academic PI: Prof. Z.Q. Zhu
    2. EPSRC Future Electrical Machines Manufacturing Hub (2019-)
       Director: Prof. Geraint W Jewell
    3. Off-shore Renewable Energy Catapult Power Train Research Hub (2019-)
       Director: Prof. Dave Stone

A Permanent Magnet Machine



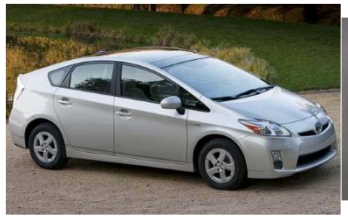


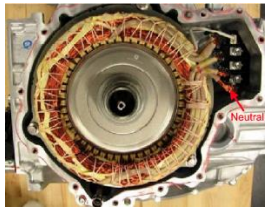
Toyota Prius



1. Permanent magnet + 2. Copper + 3. Iron

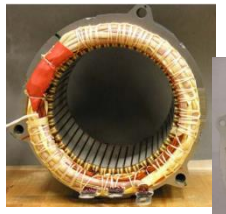
Electrical Machine Technologies in Commercial EVs/HEVs





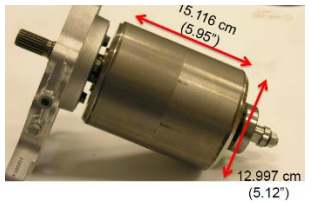
Toyota Prius – IPM (20 years)



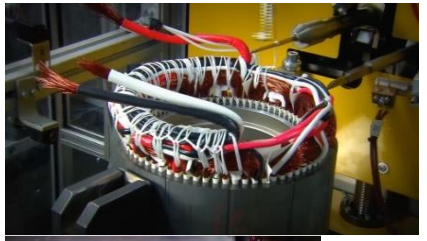



Toyota Lexus & Camry – IPM





Nissan Leaf – IPM (12 years)

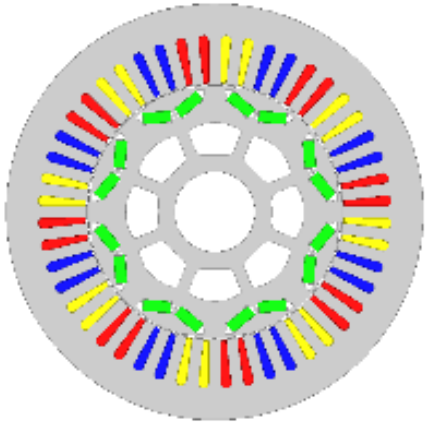

BMW i3 - IPM

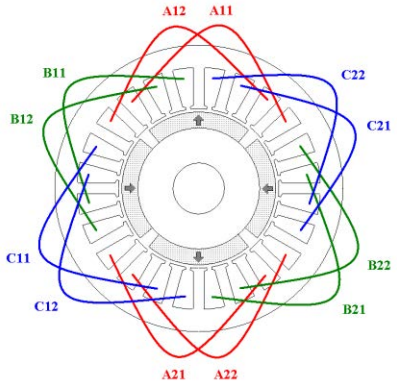

Tesla – IM (Valeo 10 years)

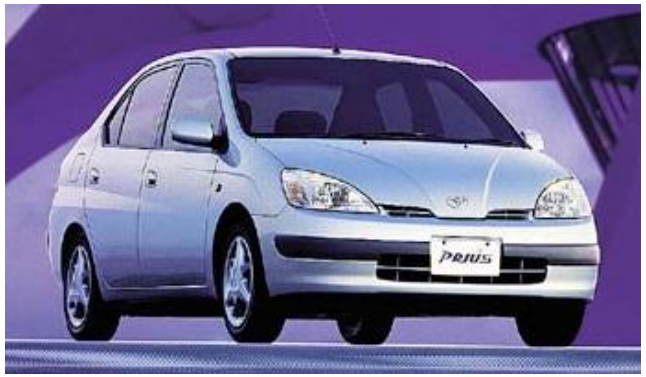
Examples of Stator Winding Topologies for EVs

Distributed winding

- Reluctance torque
- Long end winding



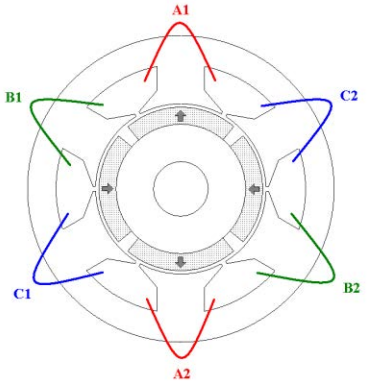




Toyota

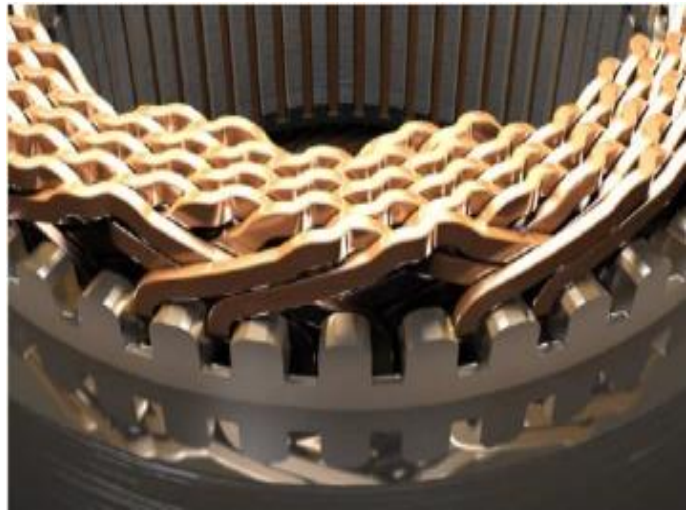
Tooth coil winding

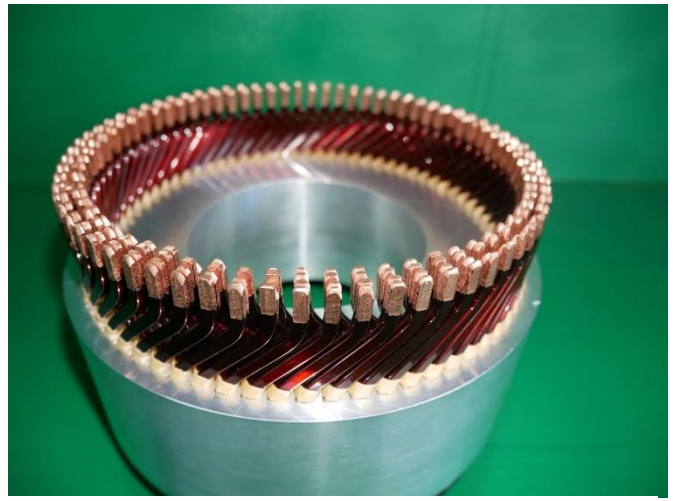
- Modular, automation
- Short end winding

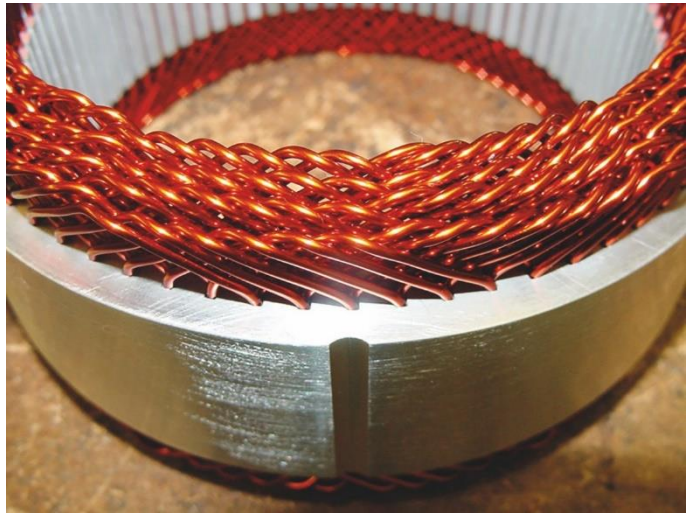


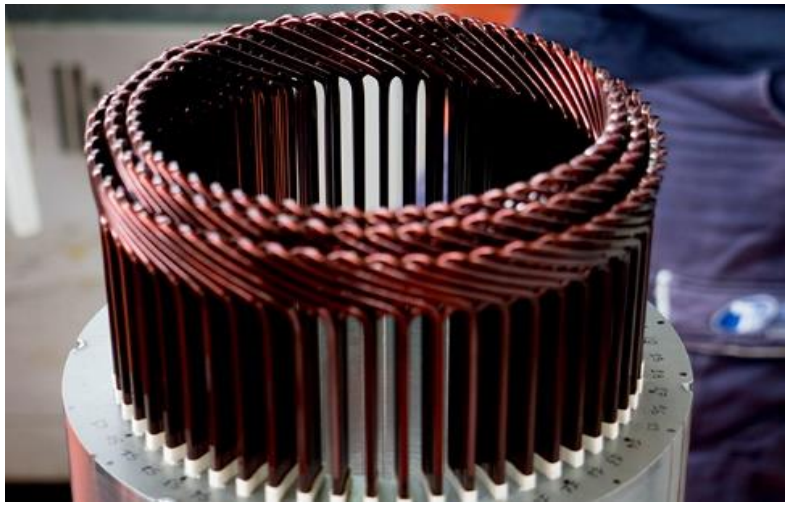
Honda

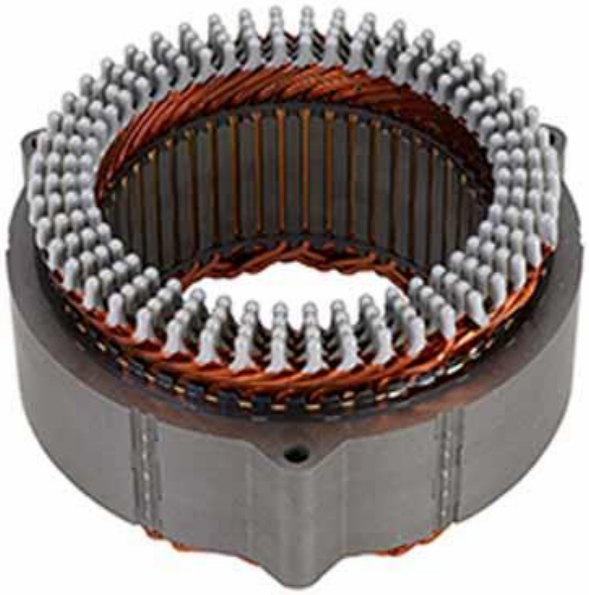
Hairpin Winding Technique





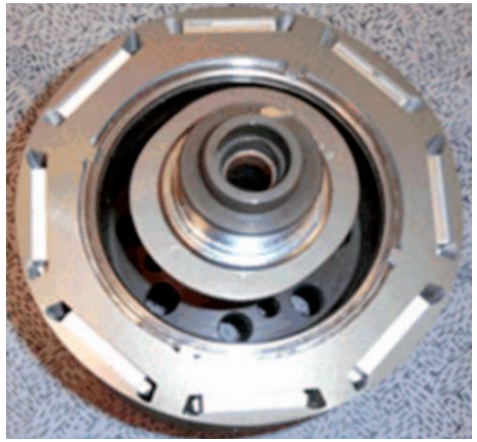




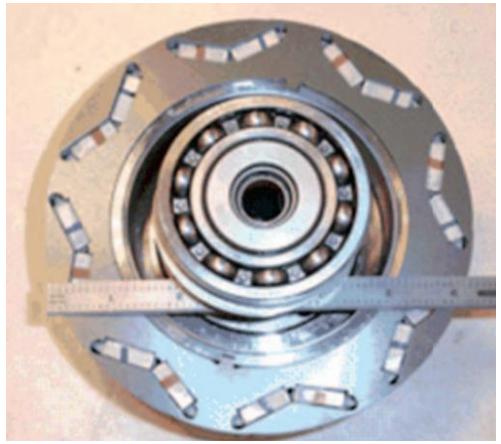


Source: www

Development of Rotor Topologies in Toyota HEVs



Prius03

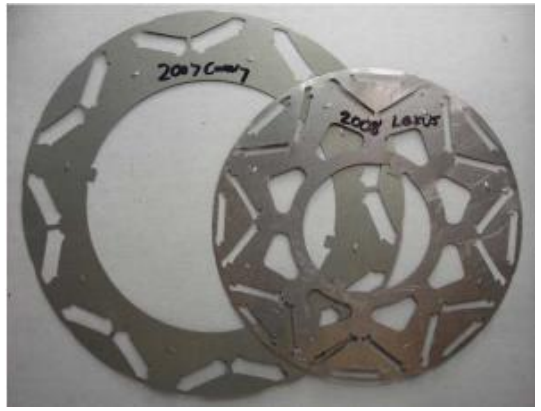


Prius04

Prius10

Prius17

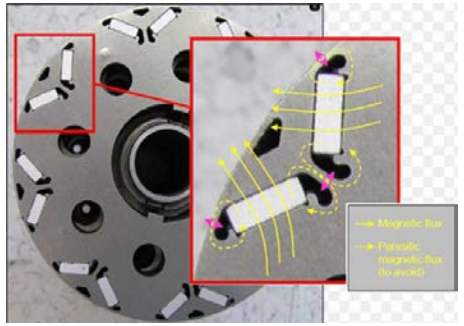
Various Rotor Topologies in Commercial EVs/HEVs



Toyota (V, ~Δ, V+)

Nissan (Δ)

Ford (V-)

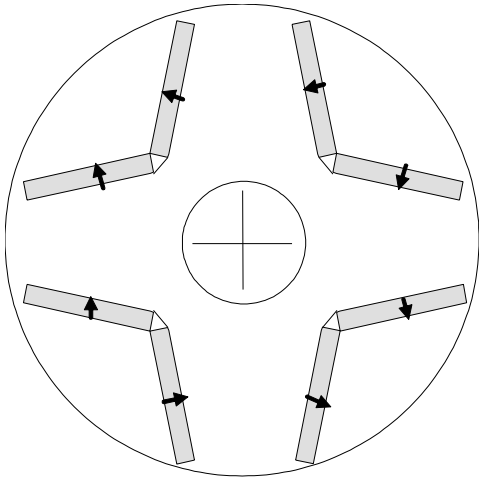


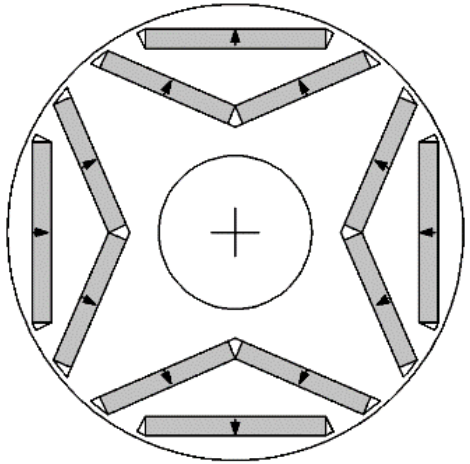
GM (2V)

BMW (2I)

Popular PM Rotor Topologies for Commercial EVs/HEVs

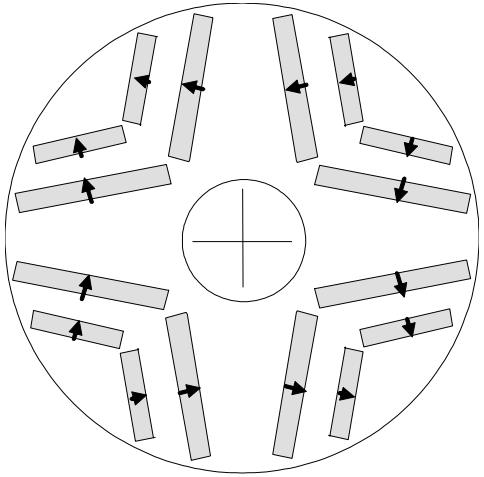
Toyota

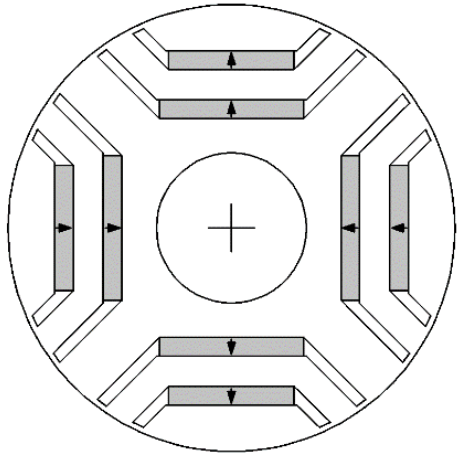




Nissan

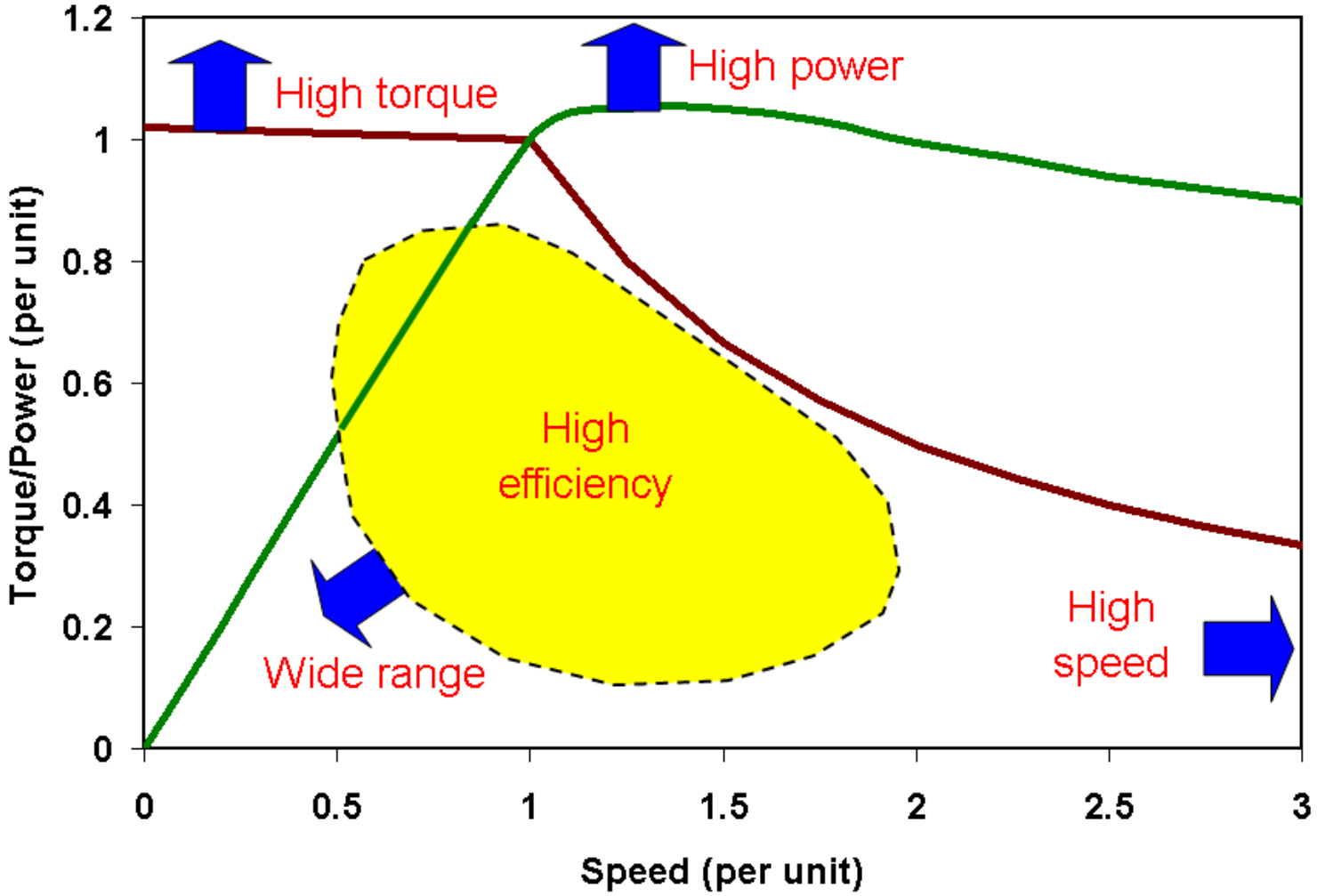
GM





BMW

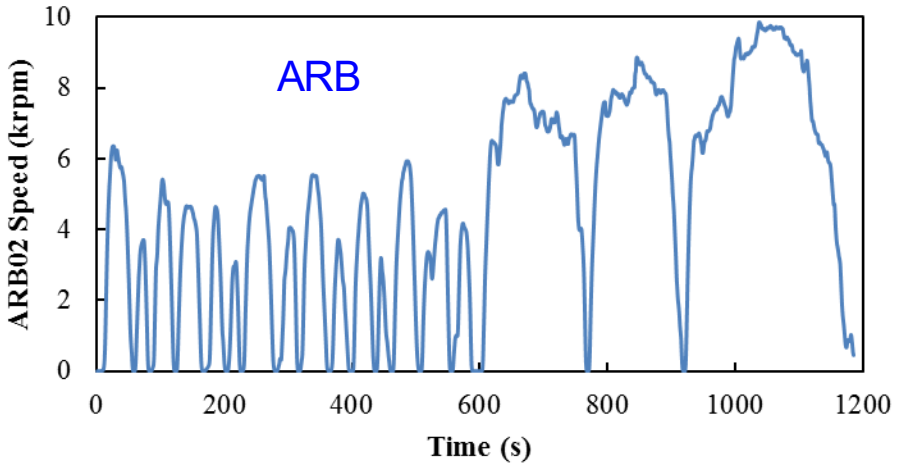
Requirements for Electrical Machines in EVs/HEVs

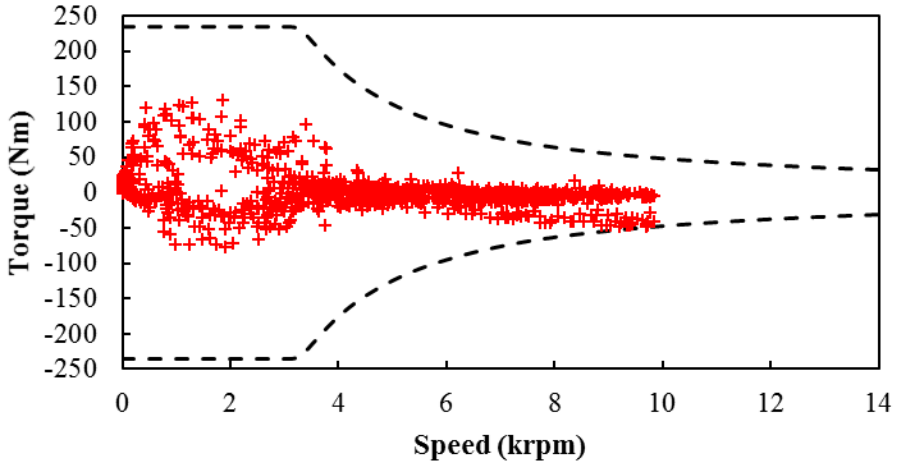


Why Permanent Magnet Machines?

- Most widely used for EVs, e.g. Toyota, Nissan, BMW, (and even Tesla) etc.
- High torque/power density
- High efficiency, particularly at most frequently operated low speed/low torque operation region

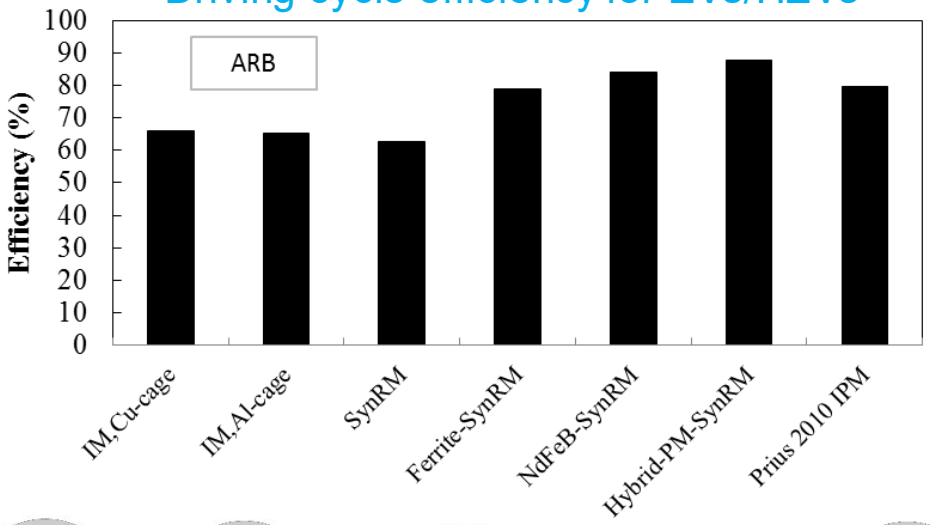
Driving Cycle Efficiency of Electrical Machines

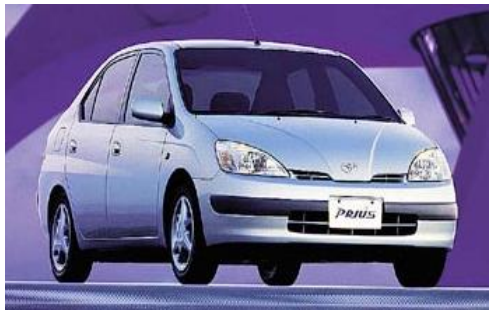


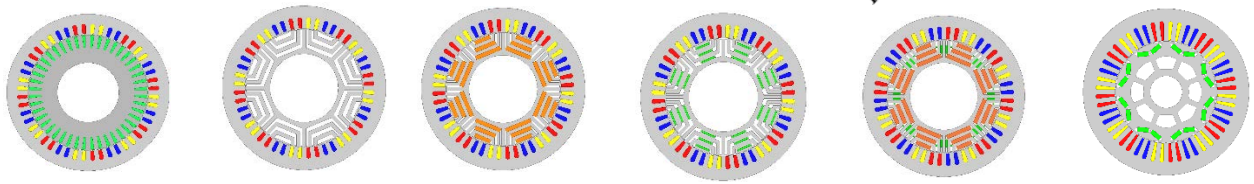


- Efficiency used to be only at a working point
- Not enough even for a region
- Need to match with load operation (driving cycle)

Driving cycle efficiency for EVs/HEVs





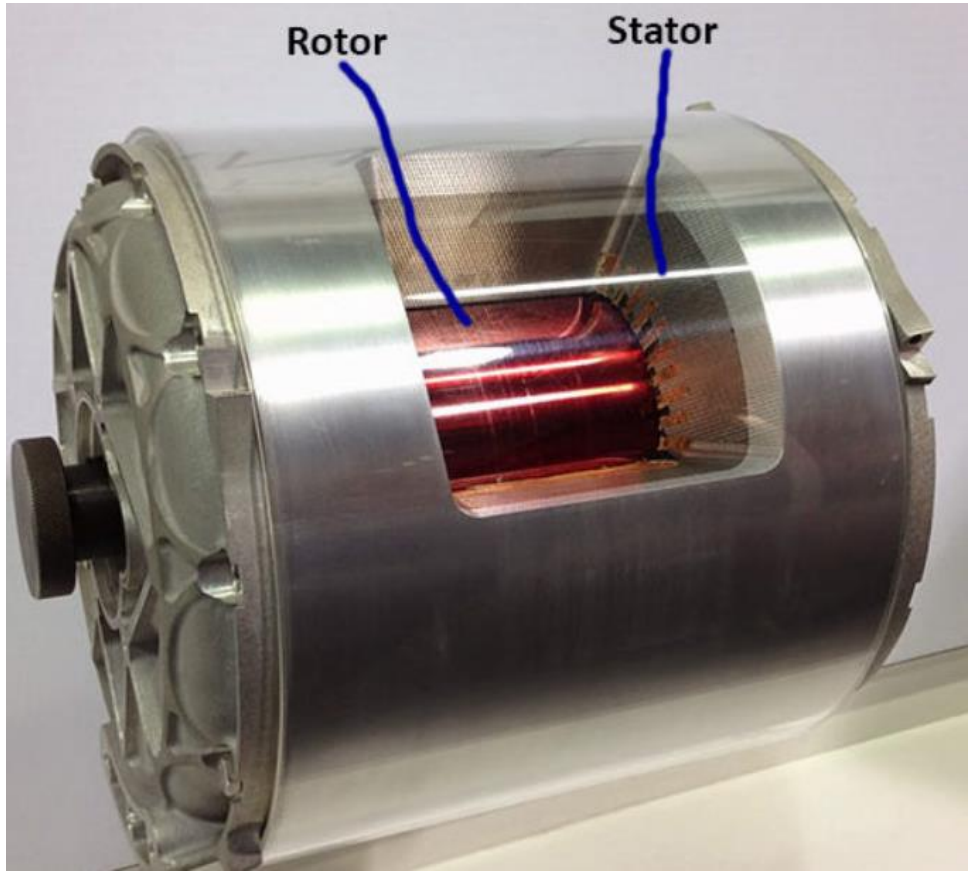


Permanent Magnet Machines

Tesla

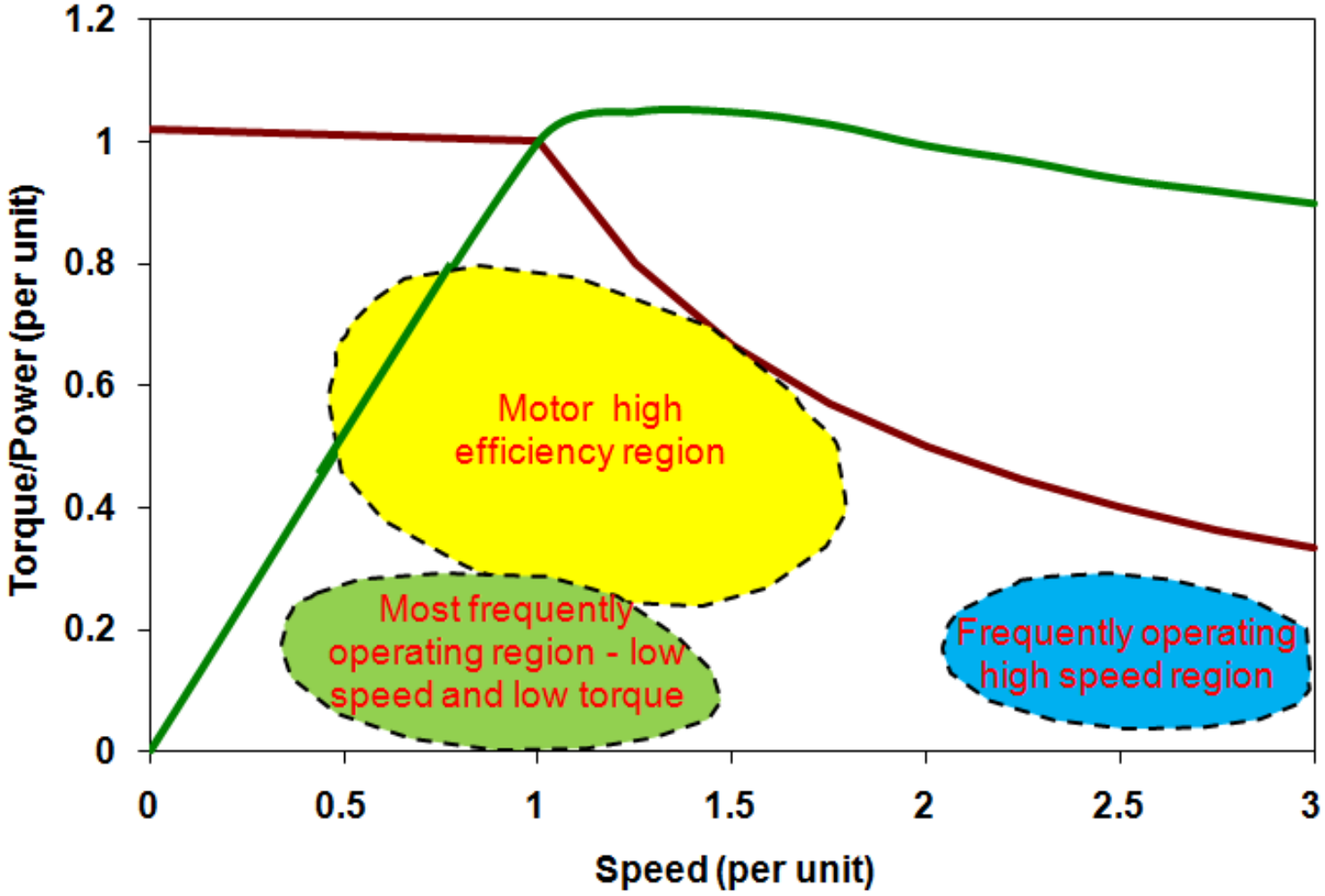
Dual Electrical Machines

Tesla

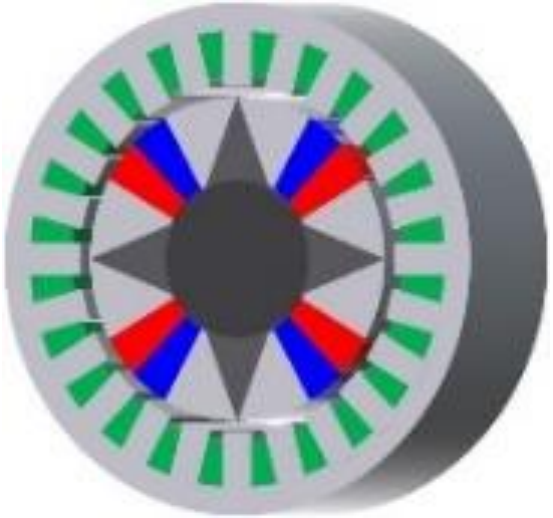


Induction machine + Permanent magnet machine

Mis-Matched Machine High Efficiency & EV Driving Cycles



Memory Permanent Magnet Machines



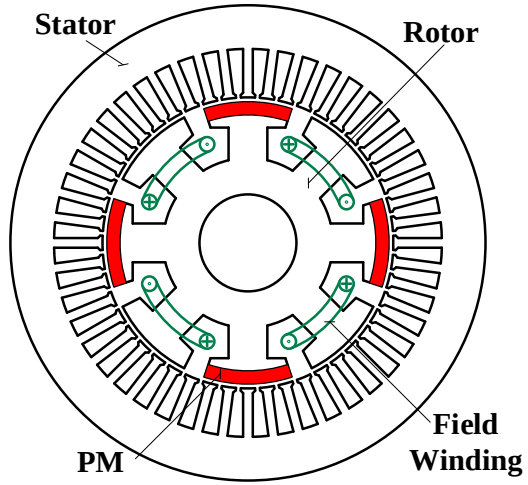
- Hybrid PMs, one with high coecivity (CPM) and another one with low coecivity (VPM)
- Online magnetisation/ demagnetisation of low coecivity PMs (VPM) by a short current pulse
- Enhanced low speed torque
- Extended operating speed range
- Enhances low/high speed operating efficiency

Developed memory PM machines

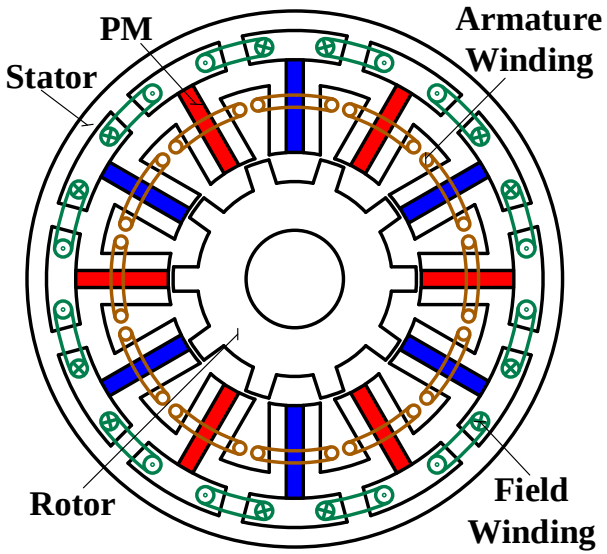
- 2018 IEEE IAS Transactions Paper Award

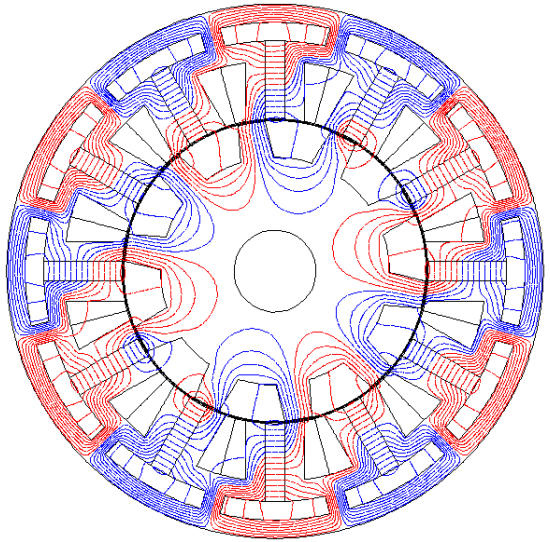
Hybrid-excited Machines

- **Two excitation sources, i.e. PMs and DC field windings**
- **Similar advantages as memory machines**
- **Potential advantages:**
  - More flexible control parameters for flux-weakening operation, $I_d + I_f$
  - Enhanced peak torque at low speed
  - Easier flux weakening at high speed
  - Wider operating speed range
  - Extended high efficiency operation region
  - Significantly reduced risk of uncontrolled generator voltage
- **Potential issues**
  - Complicated machine structure and control strategy
  - Reduced torque and efficiency

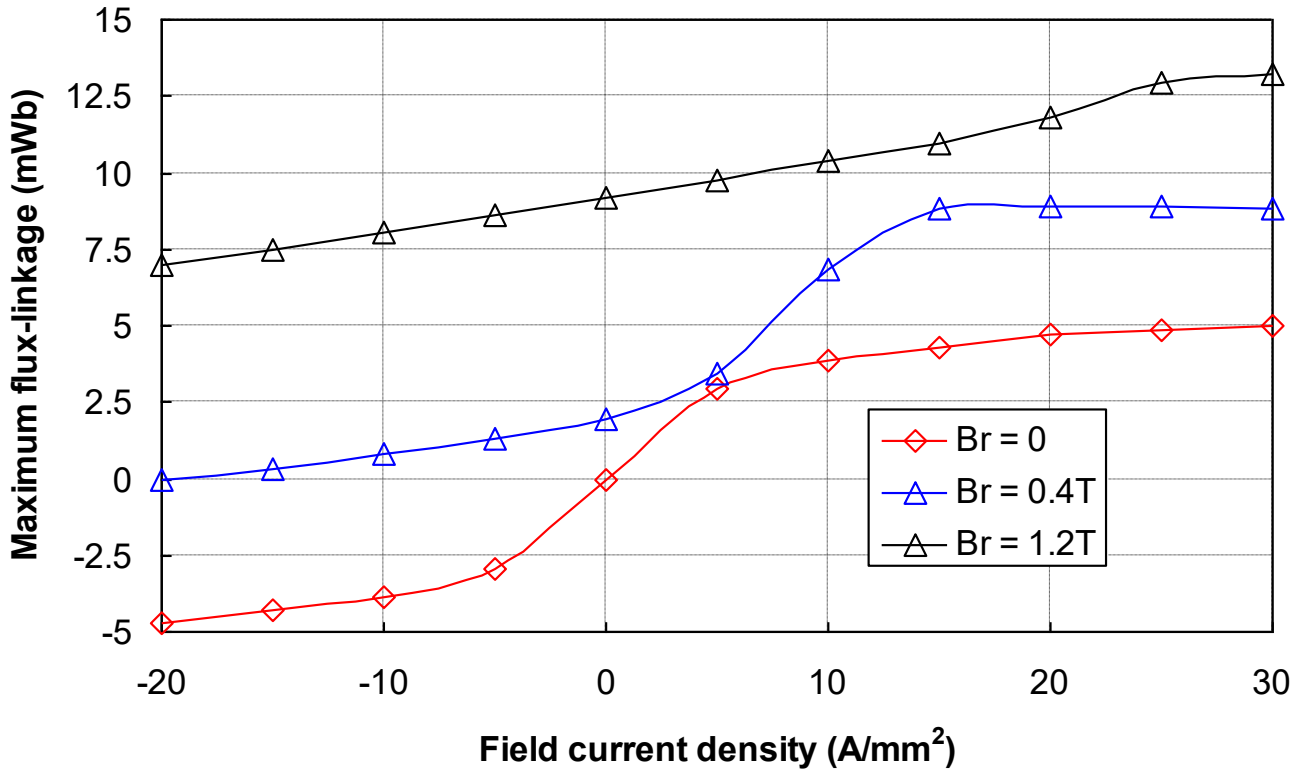


Hybrid-excited Machines





Hybrid excitation based on flux-switching PMM (parallel HE)



Summary and Challenges

- Permanent magnet (PM) machines prevailing in EVs
- PM machines exhibit high torque and high efficiency
- Numerous PM machines being developed
- Many challenges still exist for improving system efficiency and fault tolerance, as well as using less rare-earth magnet material

Q&A

HBK
HOTTINGER BRÜEL & KJÆR

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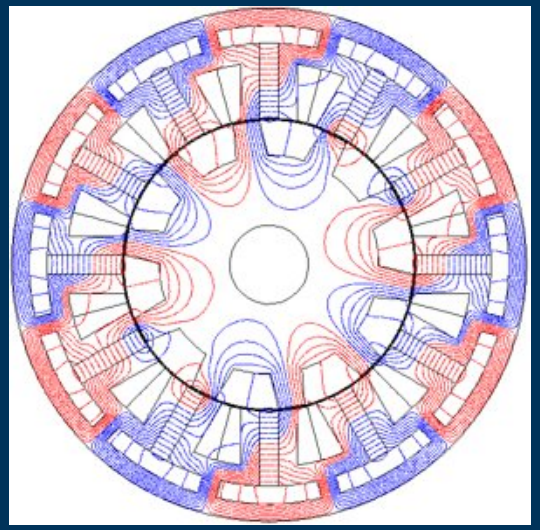

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