COILTECH INTERNATIONAL COIL WINDING EXPO 2019

RARE-EARTH FREE DRIVE UNITS FOR POWERTRAIN ELECTRIFICATION

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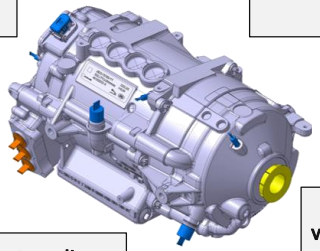
PT-40 Powertrain Electrification | eMachines & Controls

Rare-earth Free Drive Units For Powertrain Electrification
Jaguar I-Pace Permanent Magnet Synchronous Motor

Electric motor overview

Innovative hairpin winding stator

3-phase permanent magnet synchronous motor



High reluctance rotor

Durable and robust rotor mechanical construction

Compact stator assembly within Concentric GB electric drive unit casing

Spiral groove water jacket cooling

Performance

Parameter	Value
Maximum speed	13,000 rpm
Peak torque	348 Nm
Peak power	147 kW
Continuous torque @ 2000 rpm	205 Nm
Continuous power @ 6000 rpm	90 kW
Peak efficiency	>96.5%

Stator

- Distributed hairpin winding
- Durable and robust construction
- Efficiency-optimised conductor profiles
- High copper slot fill
- Highly automated manufacturing
- Compact conductor arrangement

Jaguar I-Pace electric motor: end-of-line stator

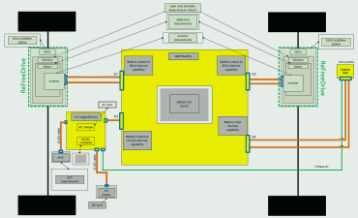
Rotor

- Embedded permanent magnet topology
- High torque and power density
- Enhanced mechanical design for robust high speed operation
- Use of reluctance torque enabling high peak performance density & wide peak efficiency area

Jaguar I-Pace electric motor: rotor assembly

Rare-earth Free Drive Units For Powertrain Electrification From Vehicle To Sub-components

Vehicle Architecture



2WD, 4WD, SUV, Sedan, BEV, PHEV, MHEV, P2, P4, battery voltage, etc..

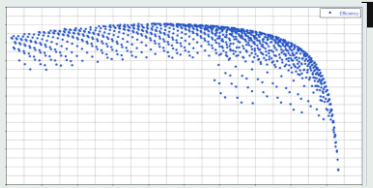
Vehicle targets

- Range
- 0-100 kph time
- 80 – 120 kph time
- Maximum speed
- Off-road pull-away torque
- Repeatable accelerations
- Fail-safe operation
- Cost of ownership, etc..

EDU Component targets

- Efficiency
- Peak torque
- Peak power
- Continuous power
- Stall torque
- Continuous torque
- BEMF or ASC
- Piece cost, etc..

Multi-physics & multi-objective component design optimisation



Virtual assessment of large arrays (>1,000) of powertrain configurations.

Use full design space to trade-off objective functions and define a final topology based on business strategy, customer requirements and performance targets.

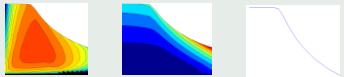
Final EDU topology selection

Converge to solution closest to optimum design within the multi-objective design space

- Package
- Gear ratio
- Cooling
- Motor technology
- Switch technology, etc..

Multiphysics sub-component optimisation

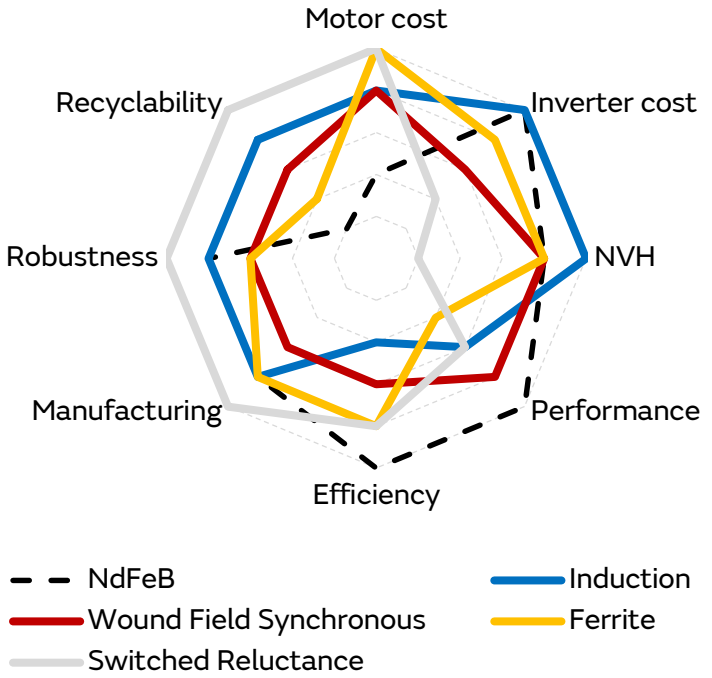
- Electric machine
- Inverter
- Gearbox



Efficiency *Losses* *Peak perf.*

Rare-earth Free Drive Units For Powertrain Electrification
EDU Component Selection: Rare-earth Free Motors

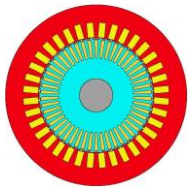
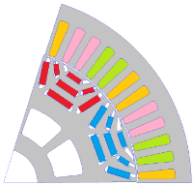
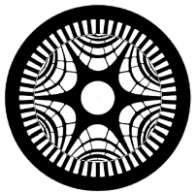
	PM	IM	WS	FM	SR
Performance	++	0	+	-	0
Efficiency	++	-	0	+	+
Motor cost	-	+	+	++	++
Inverter cost	++	++	0	+	-
Robustness	+	+	0	0	++
Overload	0	++	+	-	+
Stall torque	0	++	0	0	0
Manufacturing	+	+	0	+	++
NVH	+	++	+	+	- -
Recyclability	- -	+	0	-	++
Power @ max. speed	+	-	++	-	++

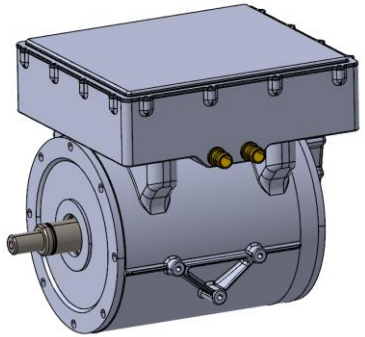


Each traction motor must be tailored to vehicle requirements, customer expectations, architectures, scalability, volumes and even current status of material supply and supplier capability, making each type of motor a potential candidate within a vehicle to benefit a specific purpose

Rare-earth Free Drive Units For Powertrain Electrification
H2020 ReFreeDrive Project: 800V SiC Rare-earth Free EDU

Three rare-earth free motor variants were developed within ReFreeDrive to allow integration within a Jaguar Land Rover high performance vehicle: an induction motor, a ferrite-assisted synchronous reluctance motor and a pure synchronous reluctance motor

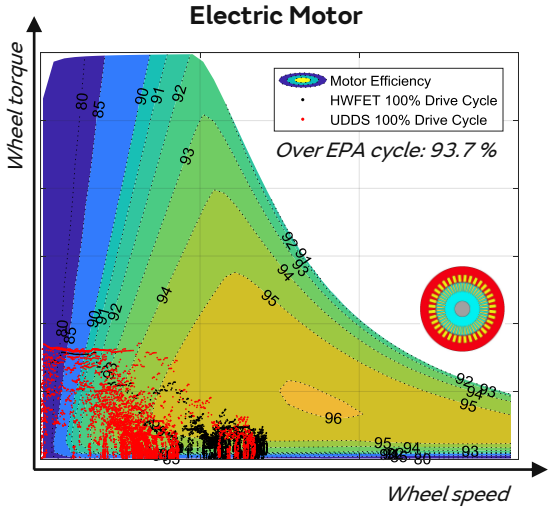
Motor variant	Induction	Ferrite SynRel	Pure SynRel
DC-link voltage	720 V	720 V	720 V
Max. modulation	0.98	0.98	0.98
Max. current	500 Arms	636 Arms	636 Arms
Required inv. kVA	430 kVA	550 kVA	550 kVA
Peak torque	380 Nm	470 Nm	415 Nm
Maximum speed	20,000 rpm	18,000 rpm	18,000 rpm
Gear ratio	13.55	12.19	12.19
Peak overall power	300 kW	250 kW	290 kW
Peak power @nmax	150 kW	90 kW	80 kW
			

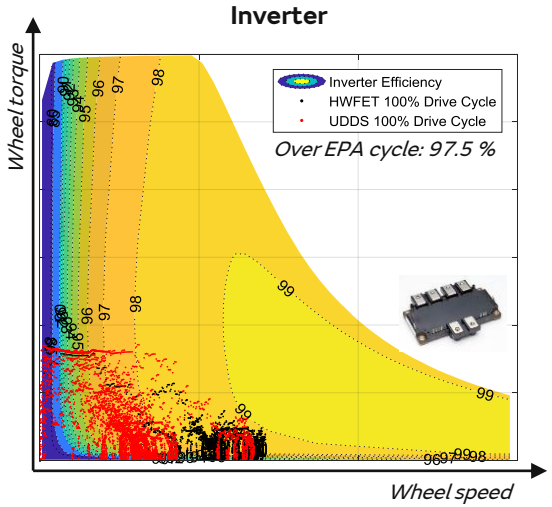


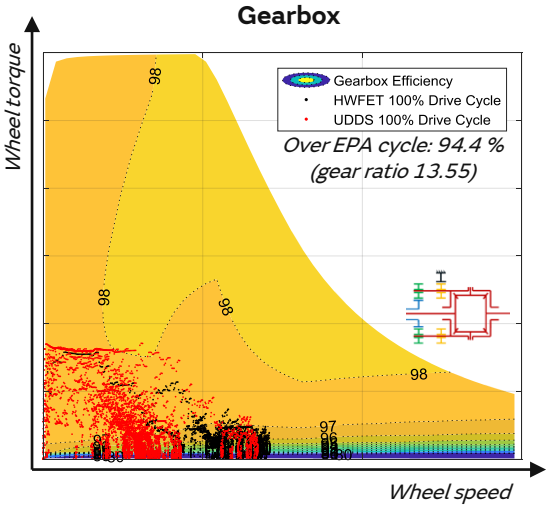
Motor and inverter of the high performance EDU

Mitsubishi FMF800DX-24A SiC module

Rare-earth Free Drive Units For Powertrain Electrification
ReFreeDrive: Induction Motor EDU Efficiency Breakdown



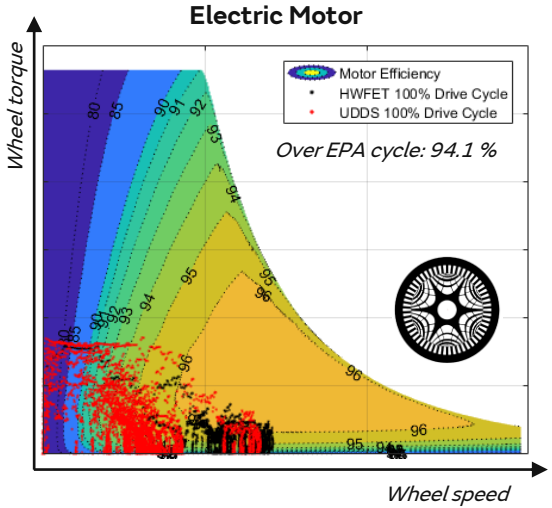


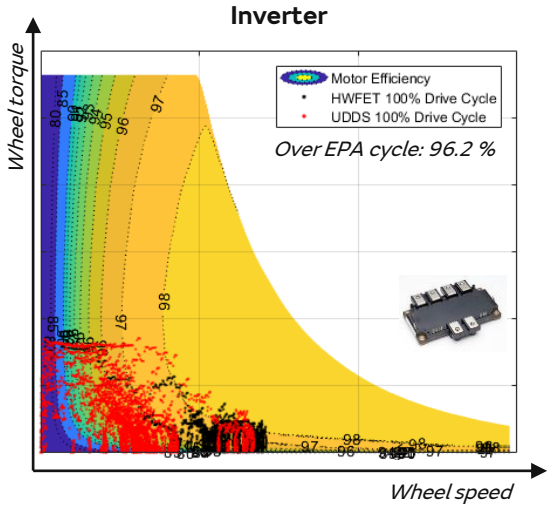


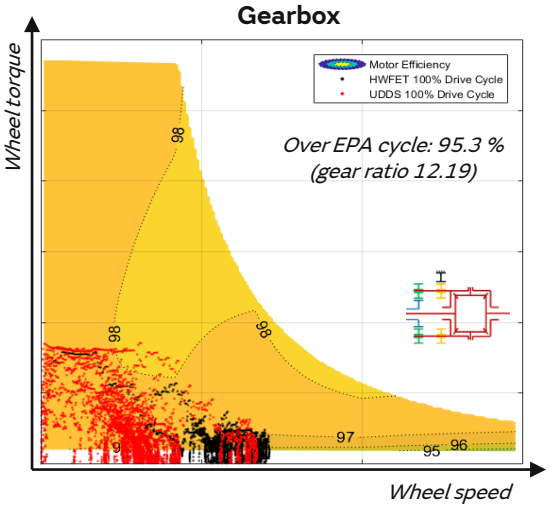
- Overall EPA EDU efficiency: 86.2 %
- Total EDU energy loss consumption over cycle: 36.17 Wh/km
- Maximum machine speed 20,000 rpm
- Best overall efficiency at highway cruising speeds and beyond

4WD with 0/100 F/R torque distribution

Rare-earth Free Drive Units For Powertrain Electrification
ReFreeDrive: Pure SynRel EDU Efficiency Breakdown



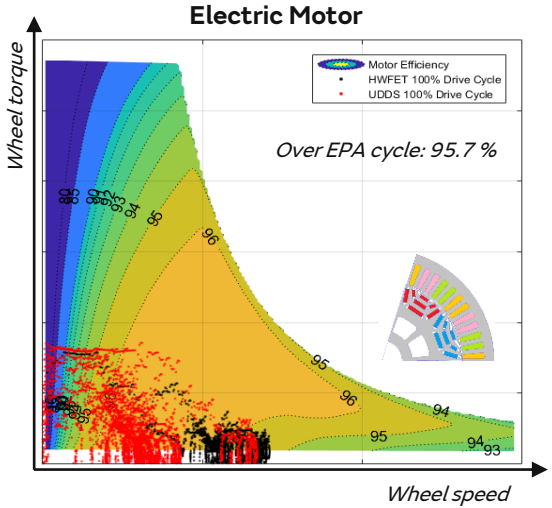


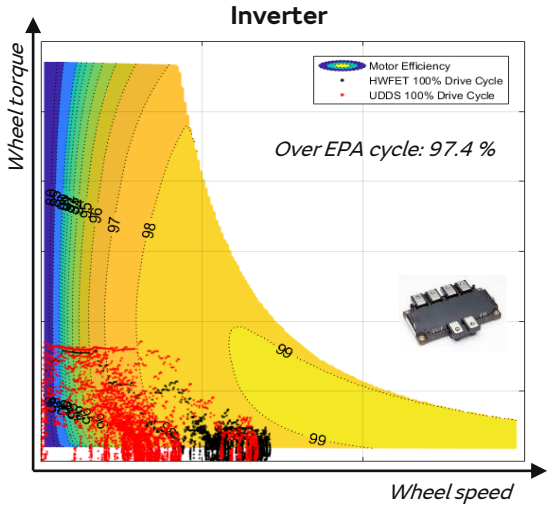


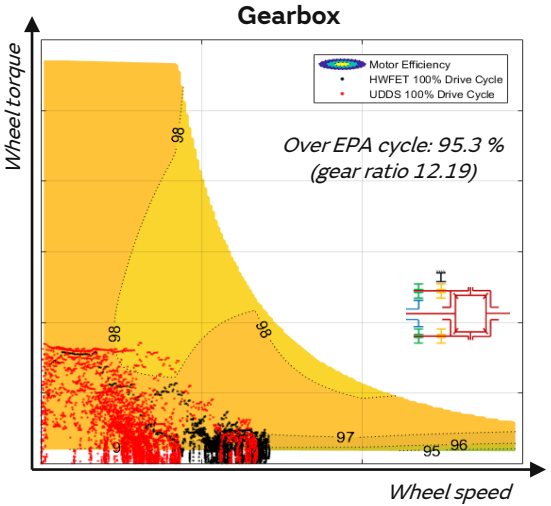
- Overall EPA EDU efficiency: 85.8 %
- Total EDU energy loss consumption over cycle: 37.77 Wh/km
- Maximum machine speed 18,000 rpm
- Best overall efficiency around HWFET drive cycle operating points

4WD with 0/100 F/R torque distribution

Rare-earth Free Drive Units For Powertrain Electrification
ReFreeDrive: Ferrite-assisted SynRel EDU Efficiency Breakdown



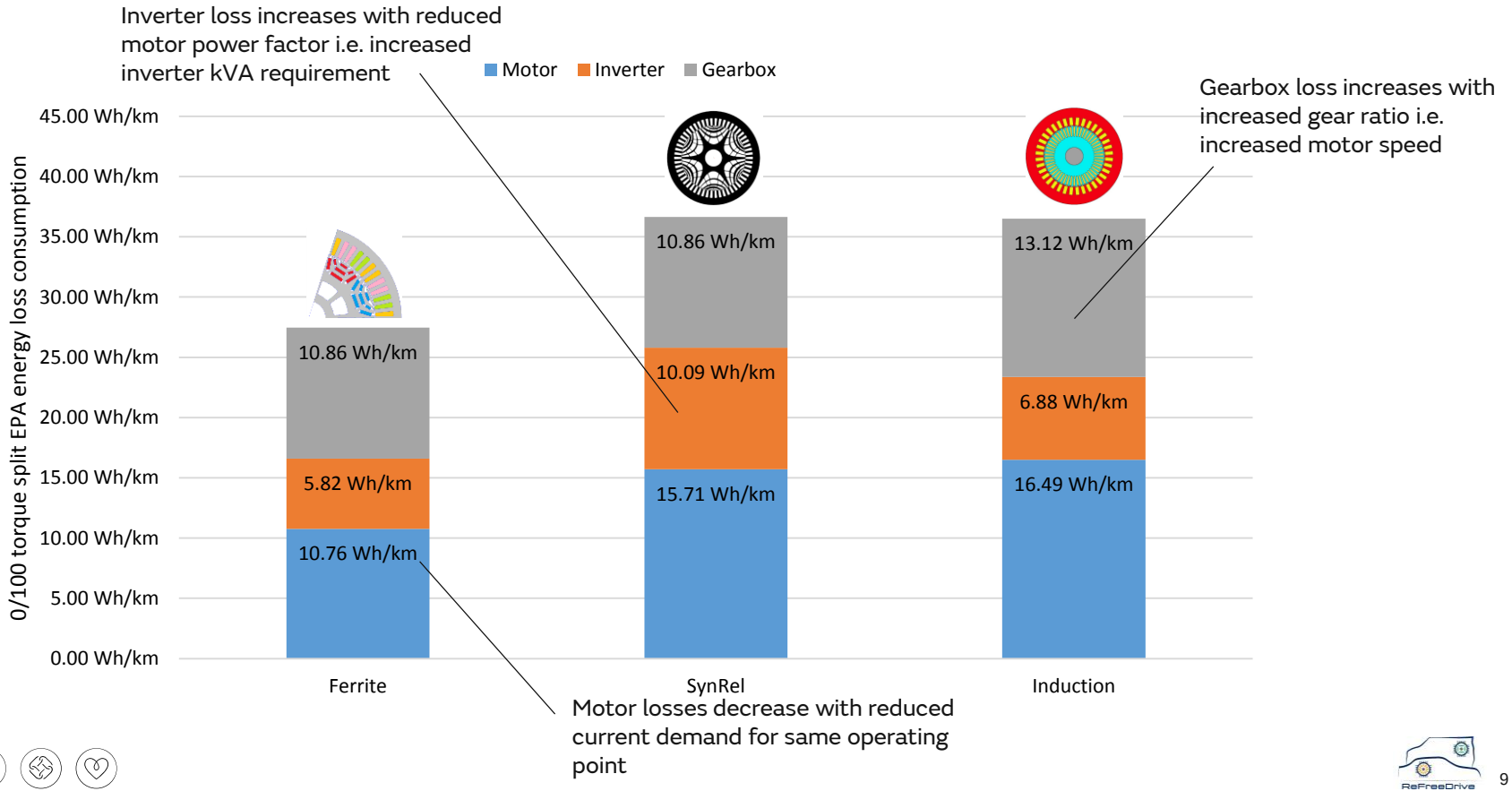




- Overall EPA EDU efficiency: 88.9 %
- Total EDU energy loss consumption over cycle: 27.45 Wh/km
- Maximum machine speed 18,000 rpm
- Good efficiency over UDDS compared to other motor technologies induction and pure SynRel

4WD with 0/100 F/R torque distribution

Rare-earth Free Drive Units For Powertrain Electrification
Energy Loss Consumption Summary of ReFreeDrive EDUs



Rare-earth Free Drive Units For Powertrain Electrification Conclusion

- Permanent magnet assisted synchronous reluctance drive units still remain first choice when solely range and performance density are the primary design drivers
- However, a number of different factors will contribute to a technology mix including motors without rare-earth materials within the powertrain in the future:
    - Volatility of Neodymium and Dysprosium prices
    - Secured supply of materials used in rare-earth free motors
    - Specific customer requirements such as excellent off-road capability (induction motor drives inherently deliver higher stall torque as the inverter operates in AC even at 0 speed) or ultra low-cost
- Motor efficiency not only main contributor to powertrain efficiency: higher motor efficiency may come at a trade-off of inverter or gearbox efficiency. Optimisation must be run at system level and not at component level.
- H2020 ReFreeDrive project has proven suitability of rare-earth free motors for high performance, high voltage powertrains.