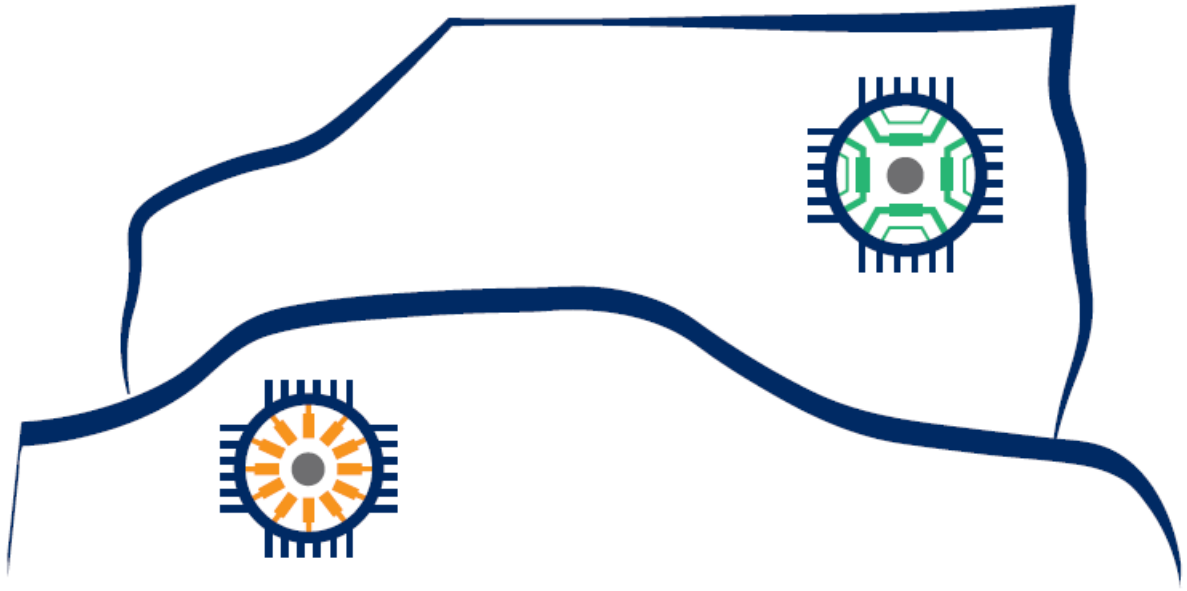


ReFreeDrive

Driving the future of electromobility through innovative rare-earth free motor technologies

Javier Romo, Fundación CIDAUT

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

ReFreeDrive Project Overview

General Figures

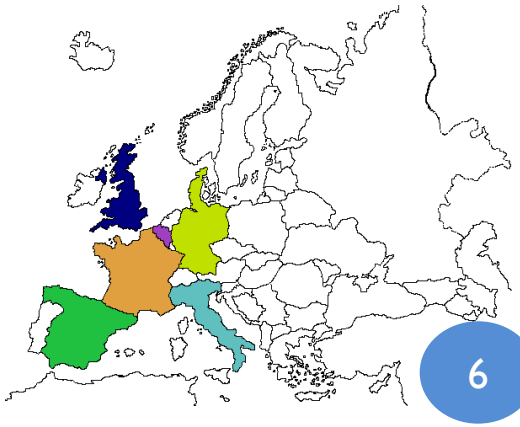
Title: Rare earth free e-Drives featuring low cost manufacturing

Grant Agreement No: 770143

Topic: GV-04-2017

Project Total Costs: 5,999,131.25€

Total EU Contribution: 5,999,131.25€



3 UNITED KINGDOM
European Copper Institute
Motor Design Limited
Jaguar Land Rover

1 BELGIUM
Aurubis

1 FRANCE
IFP Energies Nouvelles

6 ITALY
Universitá degli studi dell'Aquila
Centro Sviluppo Materiali
Tecnomatic
Mavel
R13 Technology
Privé

1 GERMANY
MetallGiesserei
Breuckman

1 SPAIN
Fundación Cidaut

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

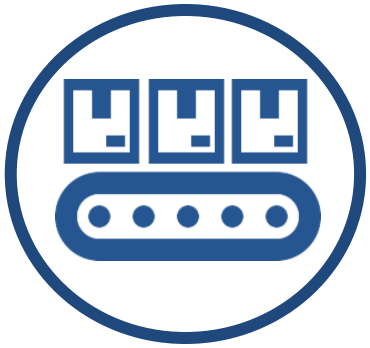
ReFreeDrive Project Overview

Project Objectives

- The main aim of this project is to develop **rare earth-free traction technologies**

LOWER COSTS

INDUSTRIAL FEASIBILITY



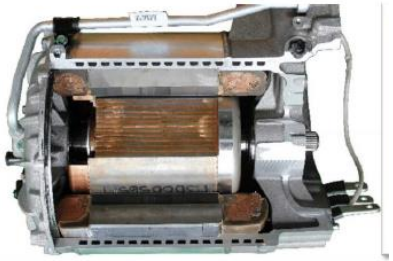
MASS PRODUCTION

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

ReFreeDrive Project Overview

Target figures

Benchmark Tesla S60



INCREASE SPECIFIC TORQUE BY 30%

REDUCE MOTOR ENERGY LOSSES BY 50%

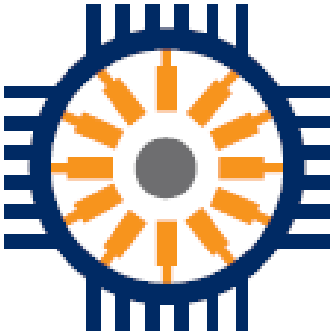
15% COST REDUCTION AGAINST SIMILAR SOLUTIONS

INCREASE POWER DENSITY IN POWER ELECTRONICS BY 50%

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

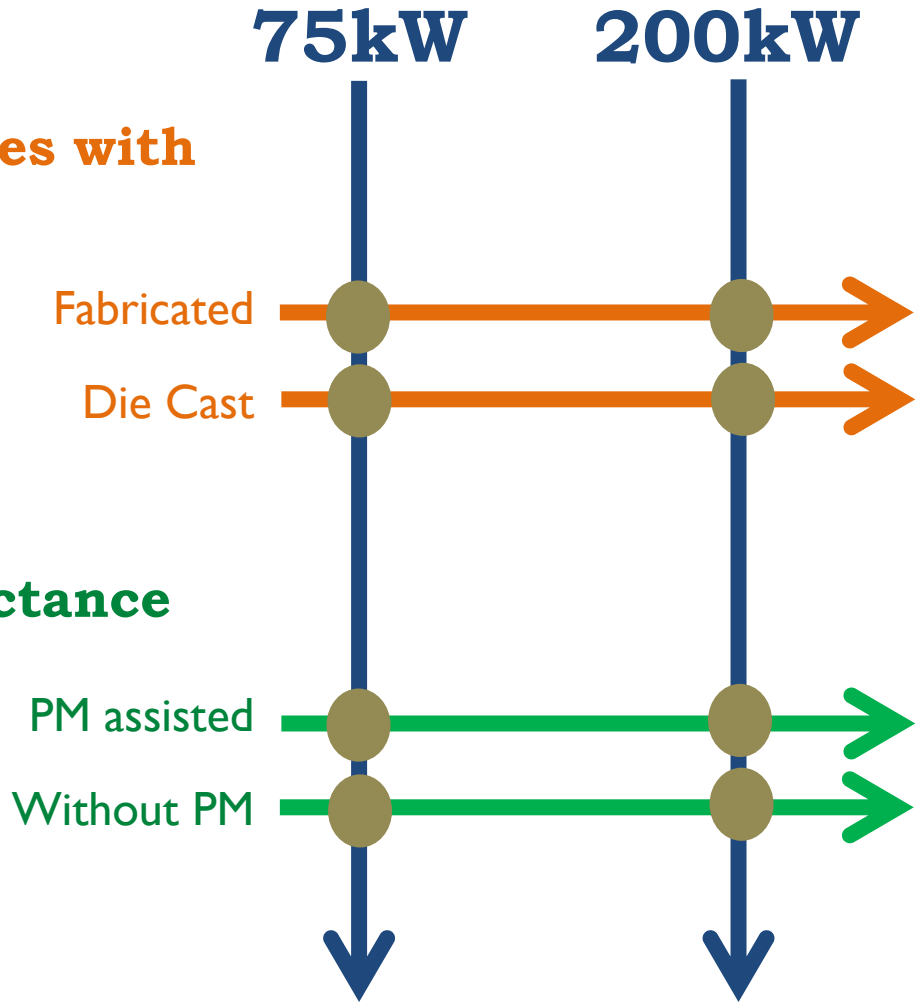
ReFreeDrive Project Overview

Project Technologies



Induction machines with copper rotor

Synchronous reluctance machines



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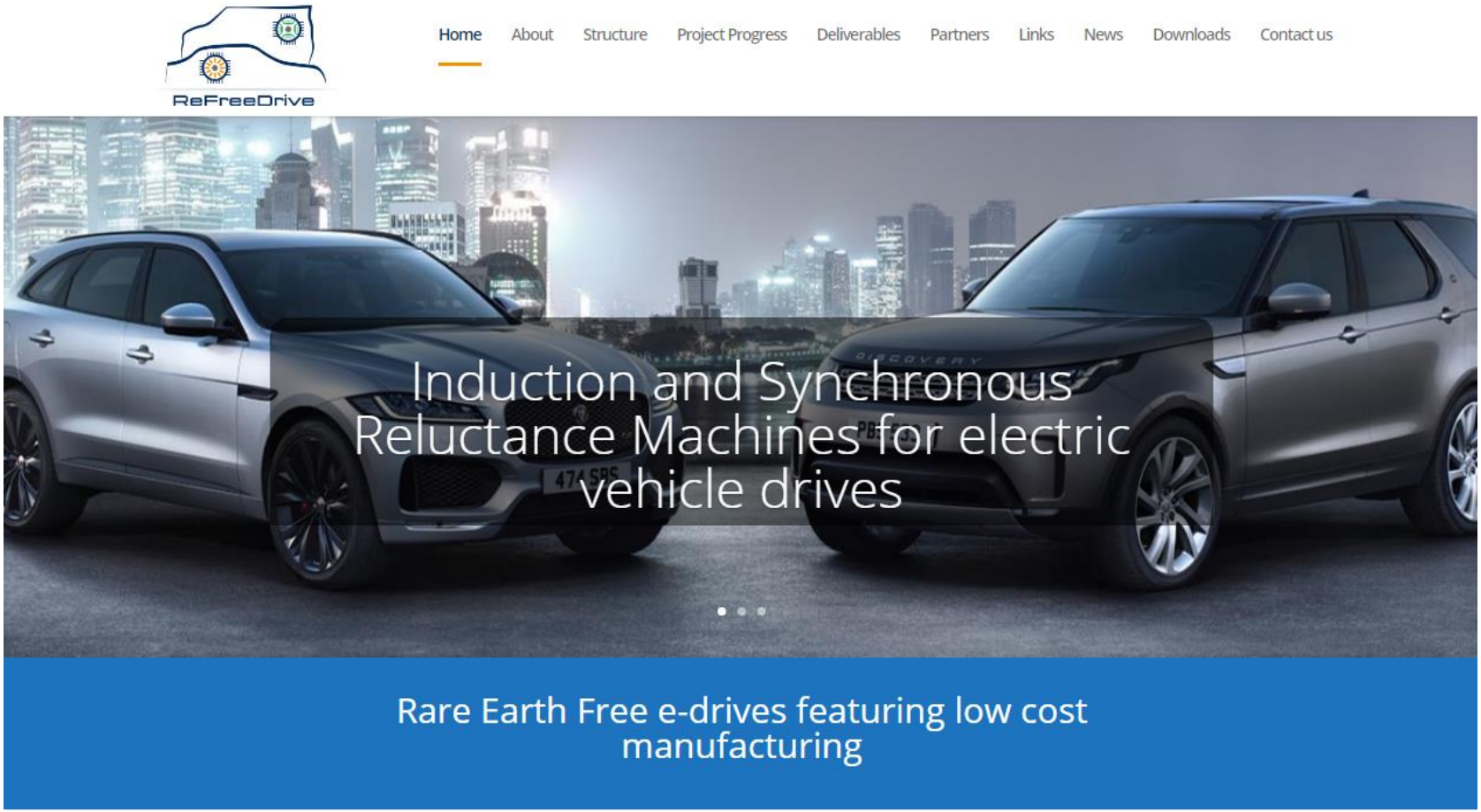
ReFreeDrive Project Overview

https://www.refreedrive.eu



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

ReFreeDrive Project Overview

https://www.linkedin.com/company/electric-drivetrain-innovation-cluster/

Contact us

Alicia Rodríguez
Coordinator
alirod@cidaut.es

Javier Romo
Technical Manager
javrom@cidaut.es

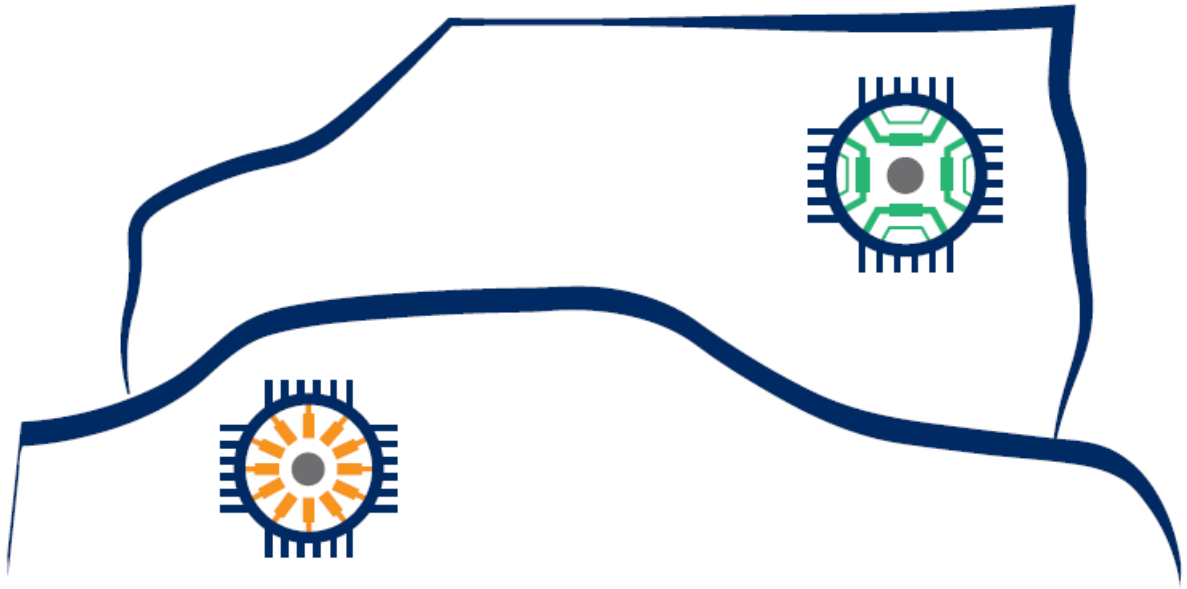
Fernando Nuño
Communication Manager
fernando.nuno@copperalliance.es

Fundación cidaut
Investigación y Desarrollo en Transporte y Energía

Fundación cidaut
Investigación y Desarrollo en Transporte y Energía

Cu European Copper Institute
Copper Alliance

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143



ReFreeDrive

Induction motors

Mircea Popescu, Motor Design LTD

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

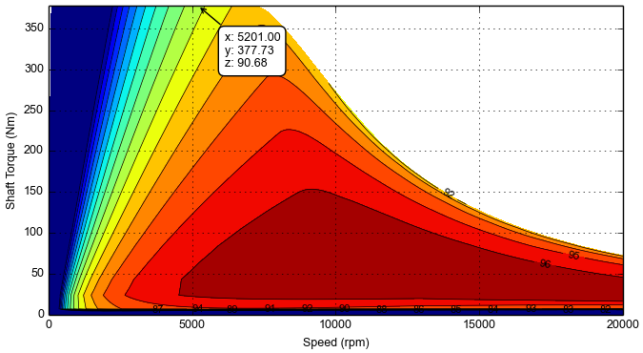
ReFreeDrive Project Overview

Induction Motors

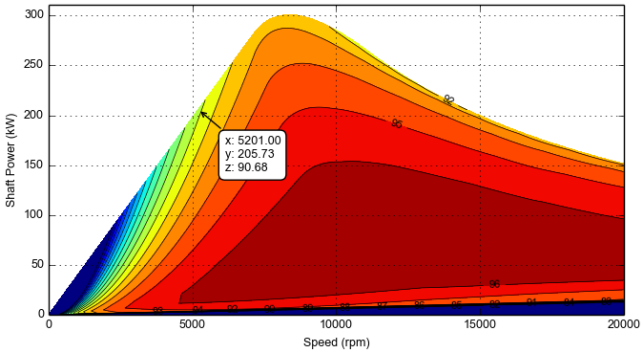
Electromagnetic Design

- Machine topology:
  - 4-pole, 36-slot, 50-bar
- Geometry:
  - OD = 190mm
  - L = 161mm
- Materials
  - M235-35A steel (rotor & stator)
  - CuAg0.04 (fabricated rotor cage)
  - Cu-ETP (die-casted rotor cage)
- Stator winding:
  - Turns / Phase = 12
  - Packing factor (%) = 73
- Power supply:
  - DC Voltage = 350V/720V
  - Current = 350Arms/500Arms

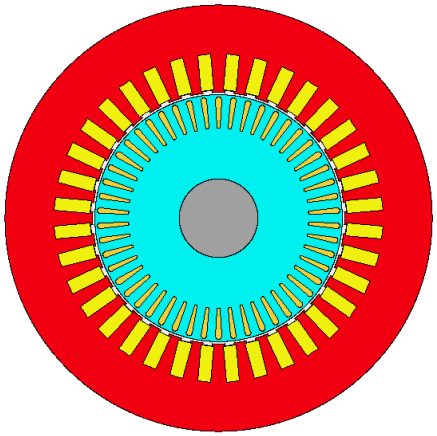
Torque-Efficiency Map



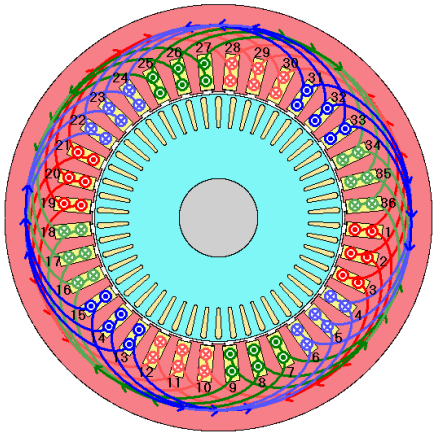
Power-Efficiency Map



Radial Geometry



Winding pattern



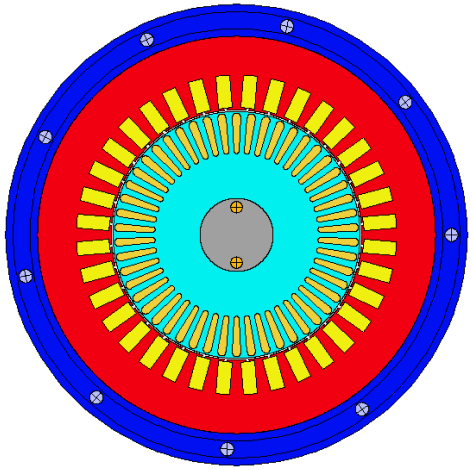
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

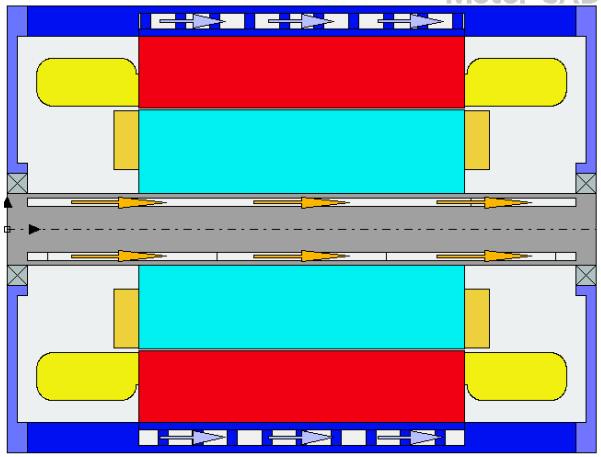
ReFreeDrive Project Overview

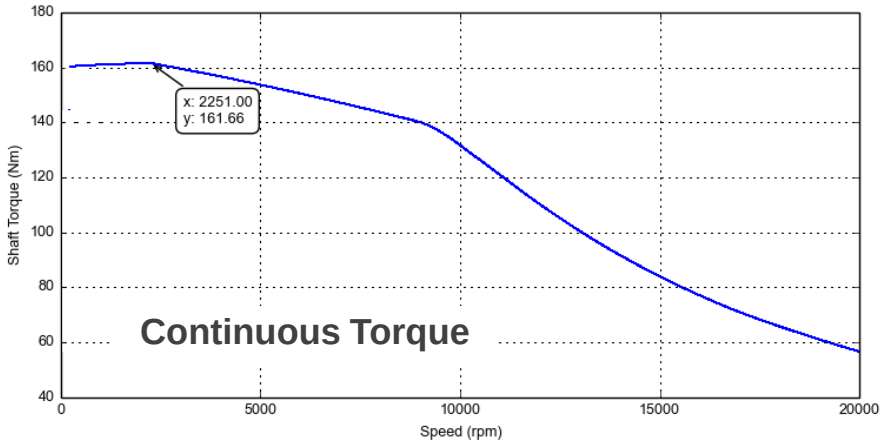
Induction Motors

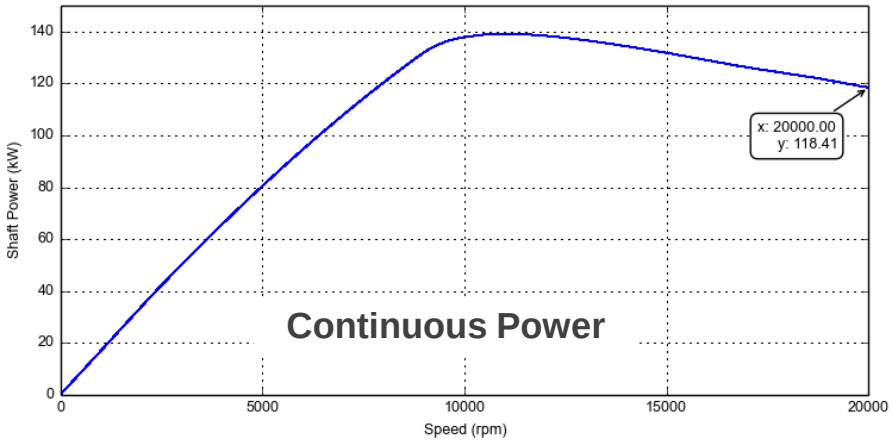
Thermal Design

- Series Cooling system:
- Stator jacket
- Rotor groove
- EWG 50/50
- Flow rate 10 l/min









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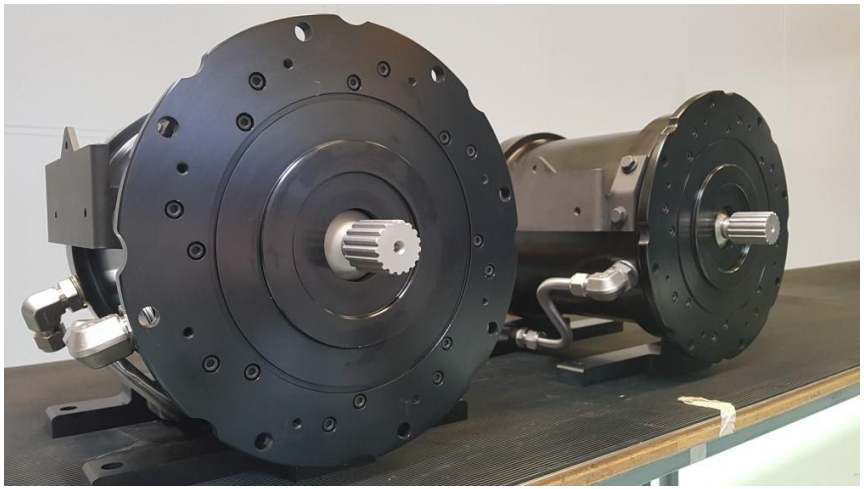
ReFreeDrive Project Overview

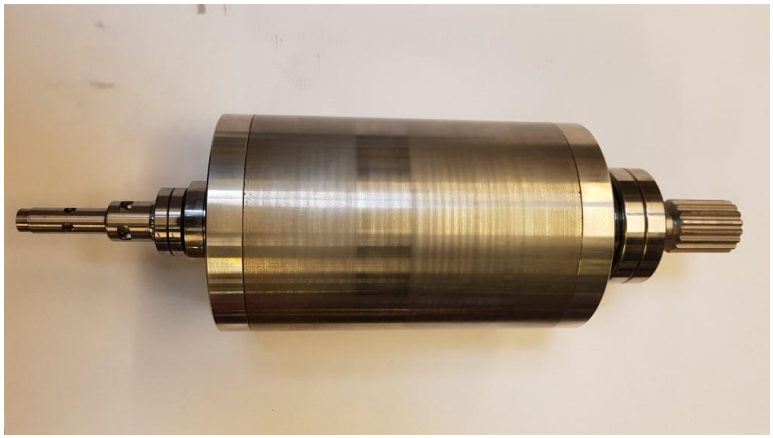
Induction Motors

Prototype



Assembled Motors

Rotor Assembly



Stator Assembly

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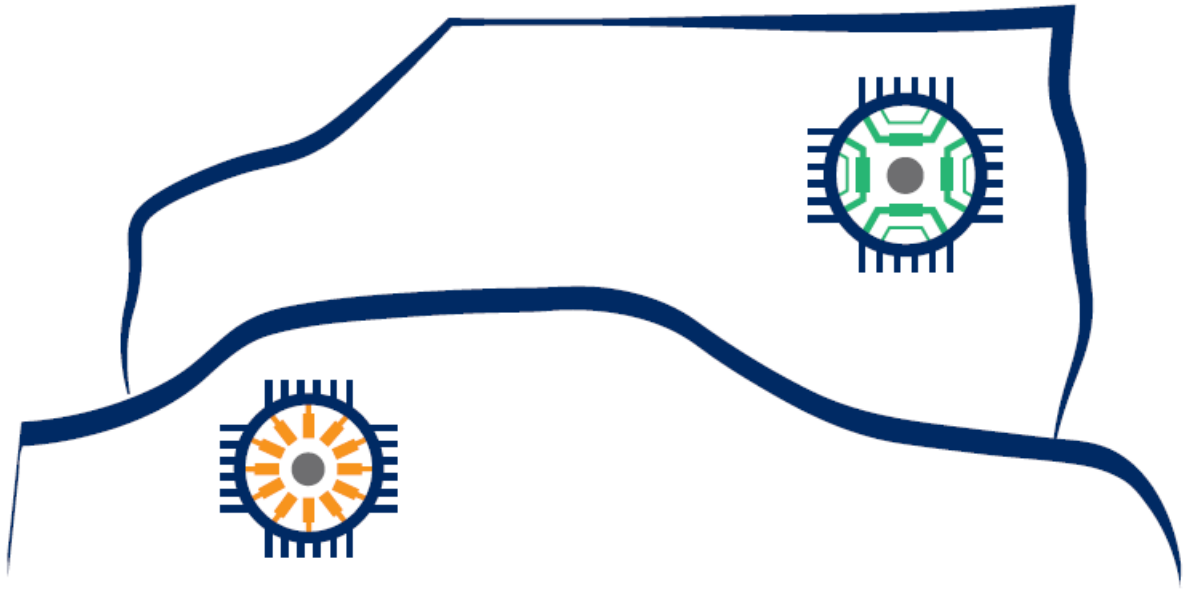

ReFreeDrive

Pure SynRel motors

Giuseppe Fabri, University of L'Aquila

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

ReFreeDrive Project Overview

Pure SynRel motors

Motor Design

- Pros:
  - Simple stator (close to IM)
  - cost effective rotor solution,
  - no magnets no copper in the rotor
  - No cooling issues in the rotor
  - High Efficiency
- Cons:
  - Very challenging design for high speed
  - Poor power factor
  - Torque ripple
- Machine topology:
  - 6-pole, 54- stator slot
  - Round wire windings
- Geometry:
  - OD = 220mm
  - L = 200mm
- Materials
  - M235-35A steel (rotor & stator)
- Power supply:
  - DC Voltage = 350V/720V
  - Current = 350Arms/635Arms

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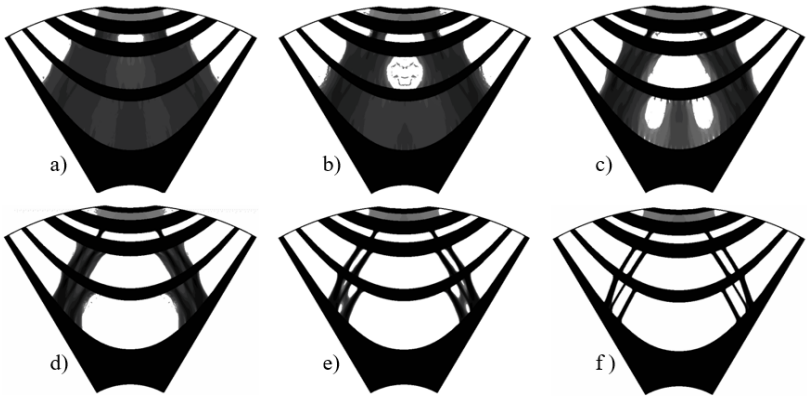
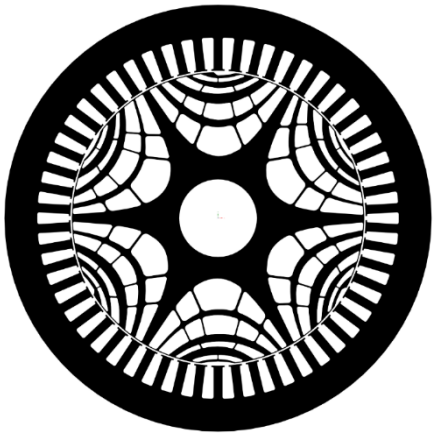
Rotor design aided by topology optimization



A. Credo, G. Fabri, M. Villani and M. Popescu, "Adopting the topology optimization in the design of high-speed synchronous reluctance motors for electric vehicles," ***IEEE Transactions on Industry Applications***

www.refreedrive.eu



Optimized for:

- low torque ripple,
- acceptable power factor
- High efficiency
- High speed

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ReFreeDrive Project Overview

Pure SynRel motors

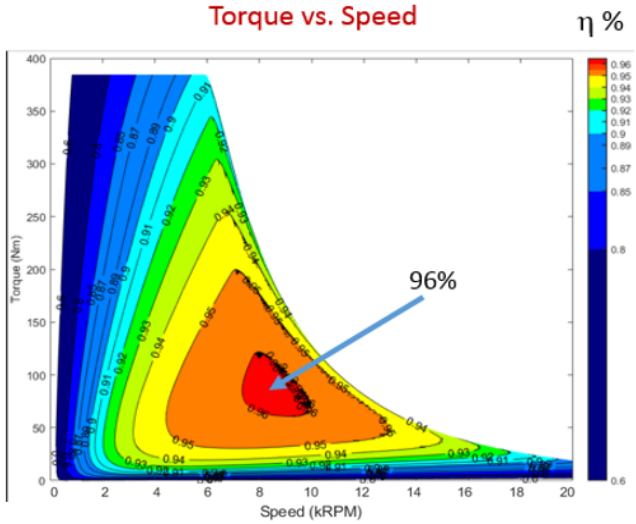
Performance

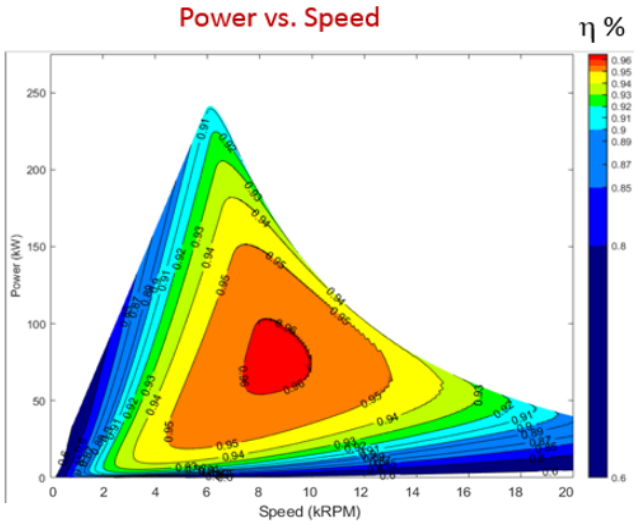
The design matches the challenging requirements

- Very wide speed range;
- High peak efficiency, good efficiency at low speed;
- Acceptable power factor;
- Interesting EV motor technology for less demanding application.

And the research continues…

Parameter	unit	Tesla Model S	RFD Goals	SynRel design
Motor type		Induction Motor		SynRM
Cooling		Liquid		Liquid
Specific Peak Power (*)	kW/kg	3.3	> 4.3	5.3
Specific Peak Torque	Nm/kg	6.32	> 8.2	8.4
Maximum speed	krpm	14500	15000 ÷ 18000	18000
Peak efficiency	%	92	> 96	96
Active parts weight	kg	68	< 47	46
Motor dimensions (+): Total Length	mm	225	< 310	310





* active parts only
\+ housing included
\# efficiency maps include mechanical losses

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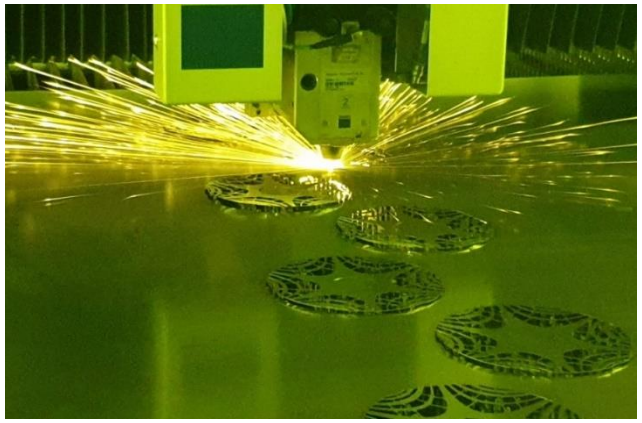
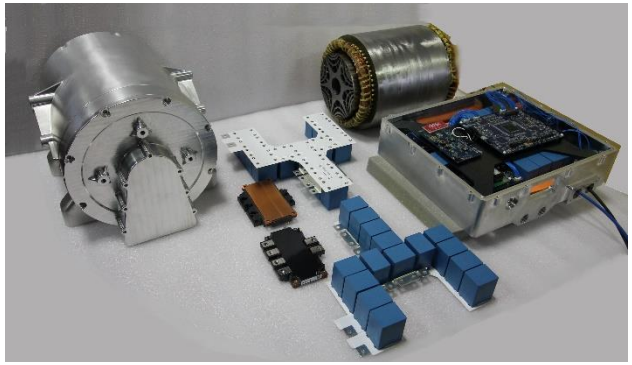
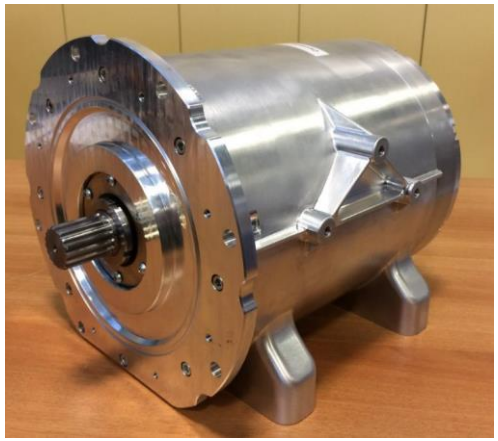
ReFreeDrive Project Overview

Pure SynRel motors

Prototyping







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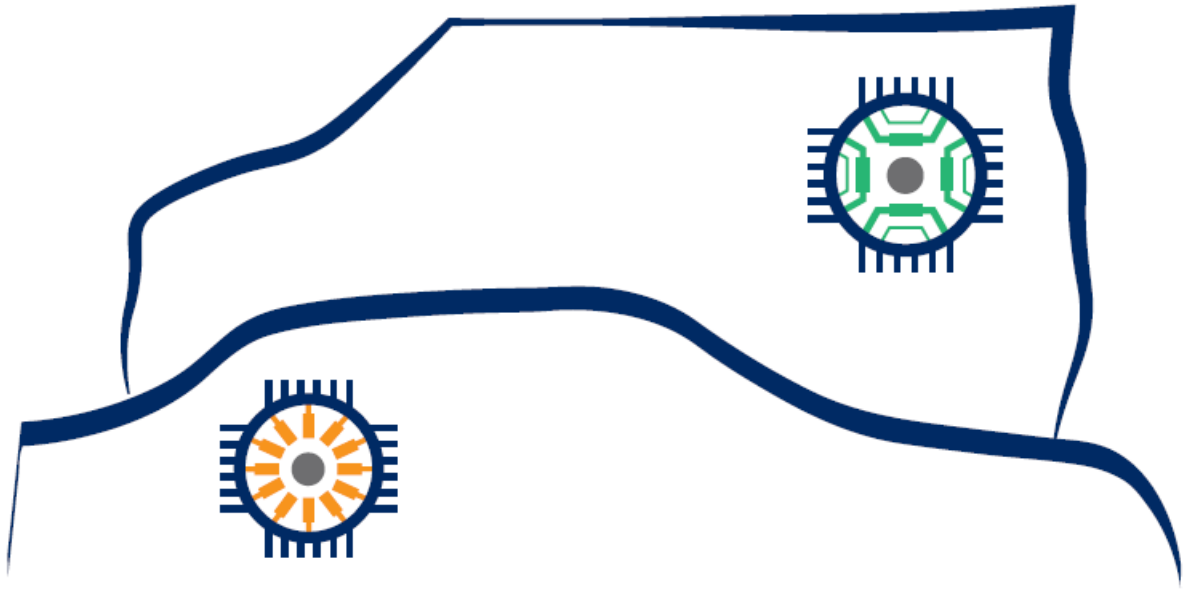


ReFreeDrive

PMa SynRel motors

Adrien Gilson, IFP Energies Nouvelles

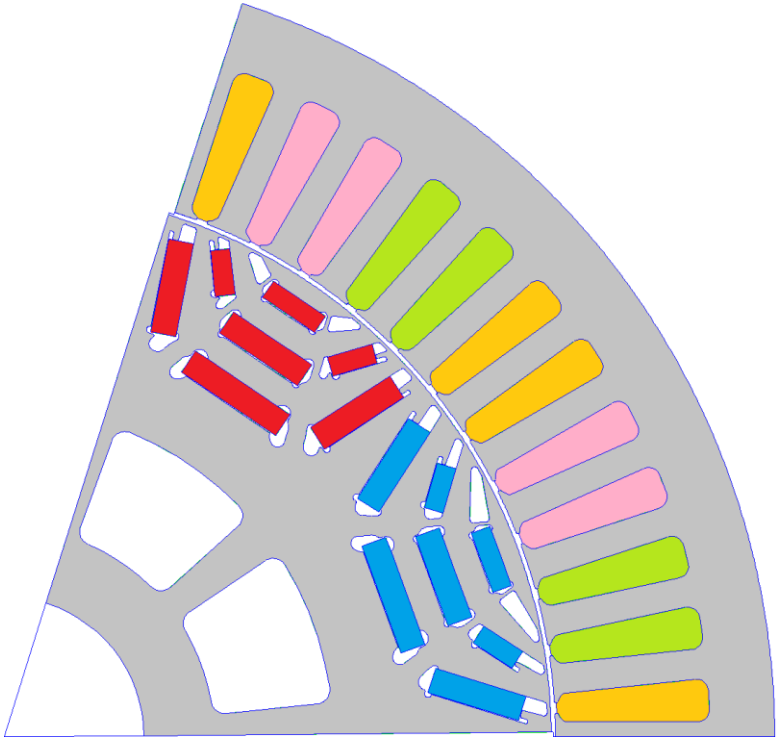
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

Design of 75 kW and 200 kW PMaSynRel Motor using rare earth free ferrites

Stator and rotor design

- Machaon rotor design
- 5 pole pairs
- SPP = 2
- 7 ferrite magnets per pole
- AG = 0.6 mm

Designation	Material
Lamination	M235-35A
Magnet	Ferrite
Copper wire	G2 H class



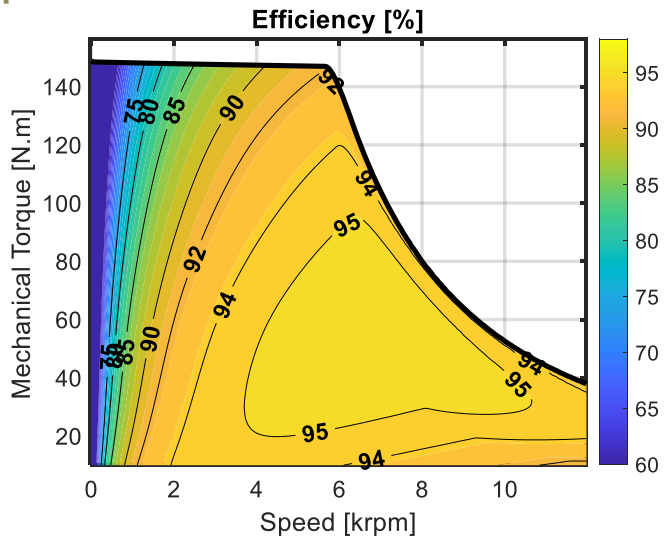
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

Design of 75 kW and 200 kW PMaSynRel Motor using rare earth free ferrites

Simulated electromagnetics performances

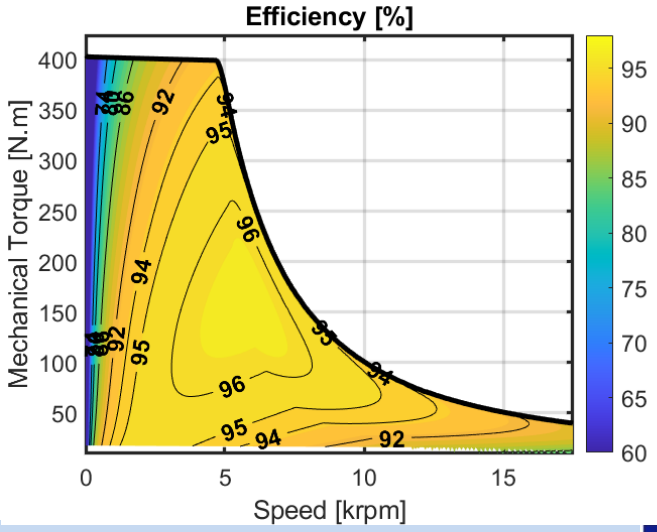
75 kW

- Max torque = 148 N.m
- Peak Power = 88 kW (350 V_{DC})
- Maximum efficiency = 95 %
- Weight = 19 kg (Active Part)



200 kW

- Max torque = 405 N.m
- Peak Power = 206 kW (750 V_{DC})
- Maximum efficiency = 96 %
- Weight = 46.1 kg (Active Part)



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

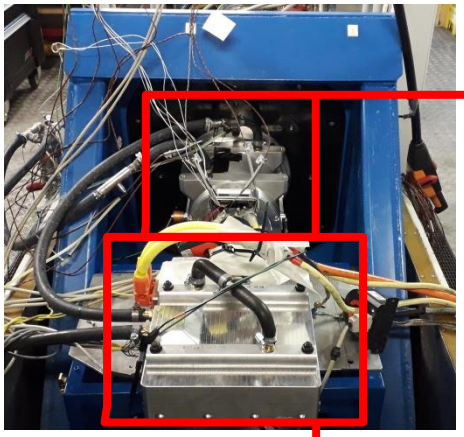
Motor Testing

PMa SynRel – 75 kW motor

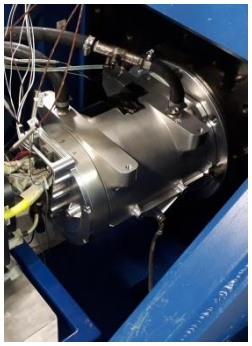
IFPEN Test Bench

Up to:

- 126 kW
- 390 Nm
- 19000 rpm

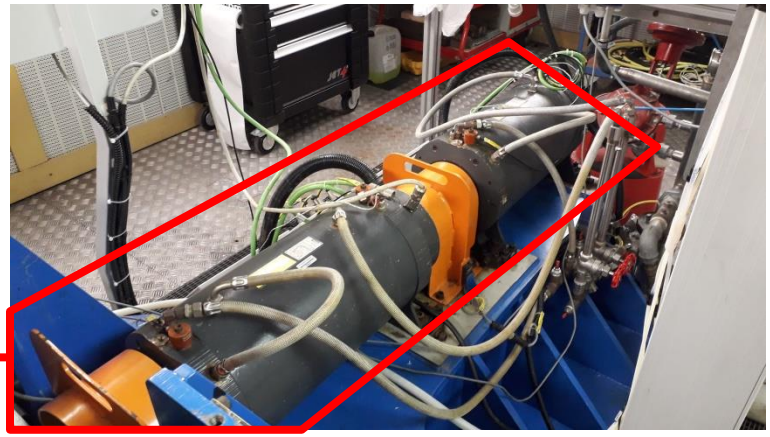


ReFreeDrive
PMa SynRel 75 kW



SiC Inverter

Load Machines

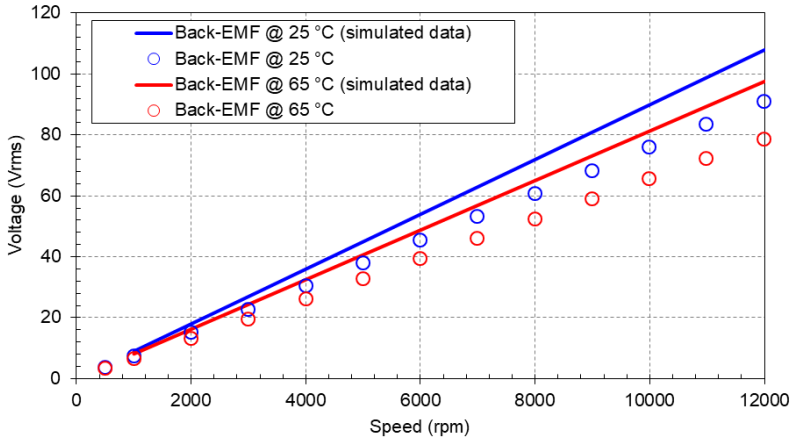


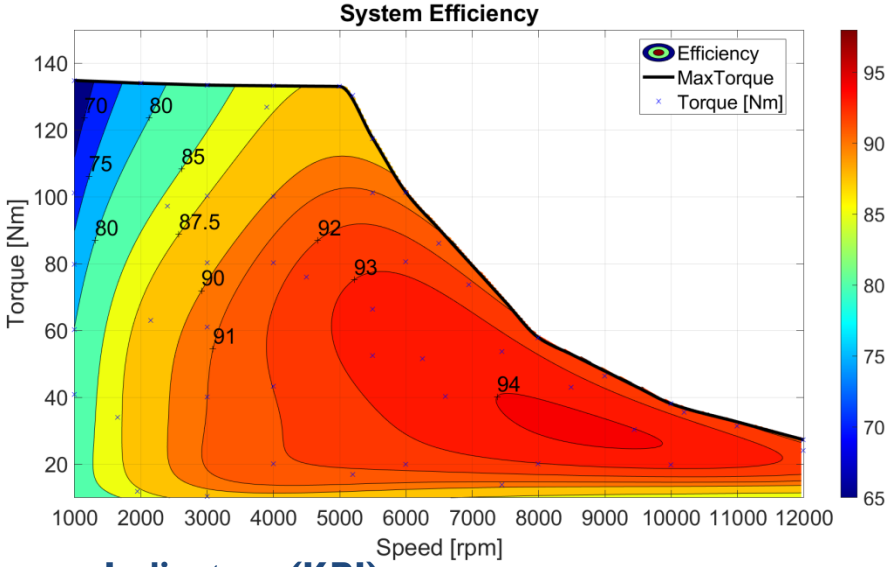
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

Motor Testing

PMa SynRel – 75 kW motor

- Most of the **target performances were achieved** according to our key performance indicator
- However, mainly due to **weaker magnets than anticipated** the peak torque and power are lower than expected. Investigation in progress.
- **The efficiency of the system (motor + inverter) on the driving cycle is 90 %.**





Motor Key Performance Indicators (KPI)

Parameter	Unit	RFD goal (min)	Achieved	RFD goal (max)
Specific peak power	kW/kg	3.1	3.64	-
Specific peak torque	Nm/kg	5.0	6.97	-
Active parts weight	kg	-	19.5	24
Peak efficiency	%	96	96.3	-

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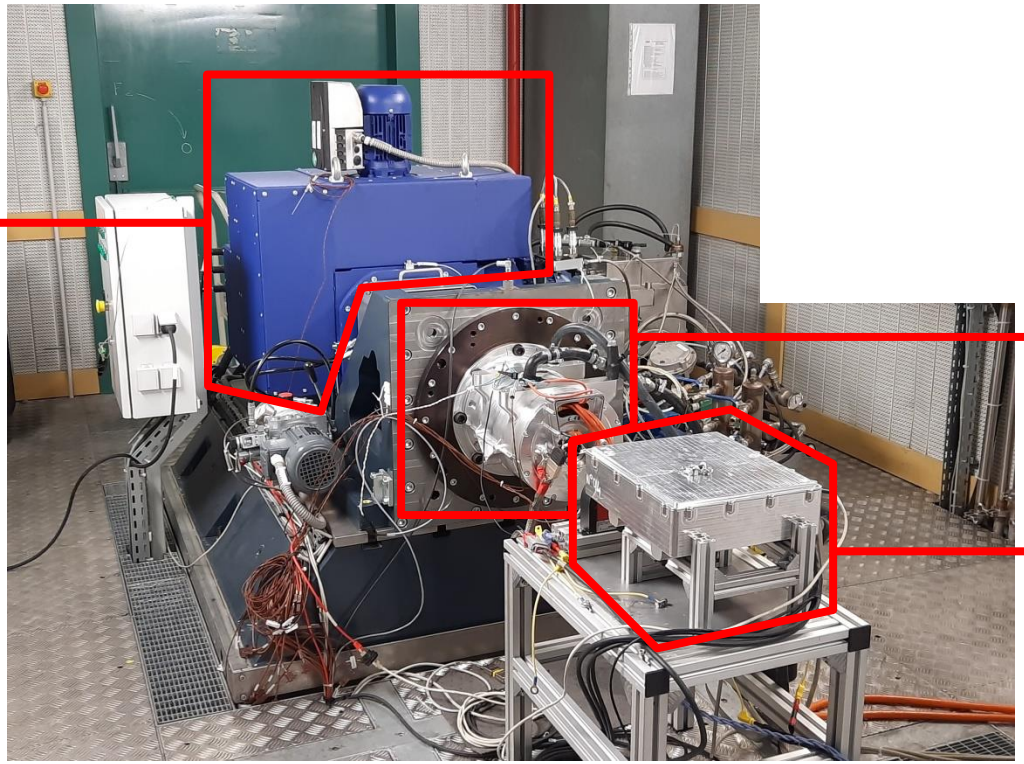
Motor Testing

PMa SynRel – 200 kW motor



IFPEN Test Bench

Up to:

- 250 kW
- 500 Nm
- 20000 rpm

- Tests on the ReFreeDrive PMa SynRel 200 kW motor are close to completion at IFPEN
- We are expecting to have lower magnet performances than expected (identical to 75kW)
- **The measured motor peak efficiency is 96.3 %**

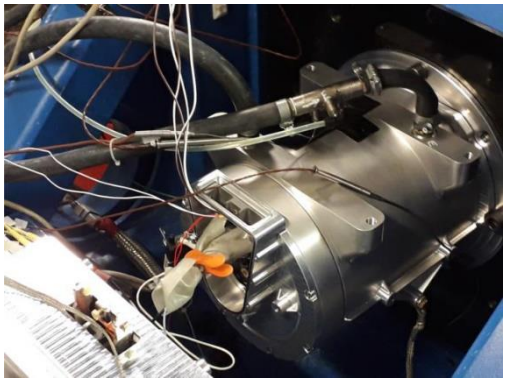
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

ReFreeDrive Project Overview

Next steps

December 2020 | March 2021

Motor & Integrated powertrain testing	In-vehicle integration



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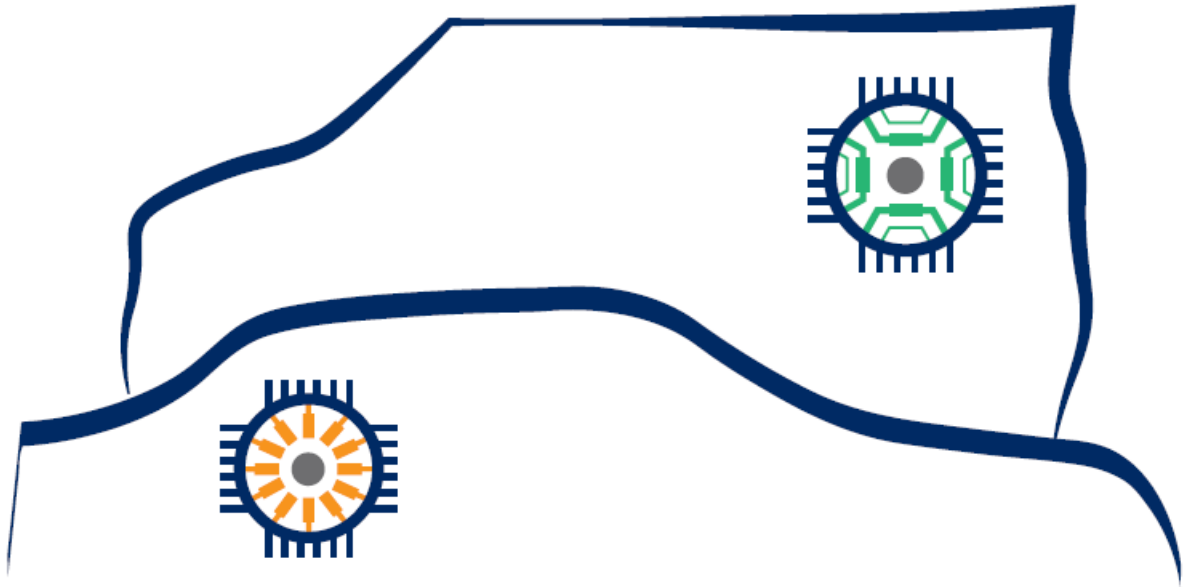

ReFreeDrive

Thank you for your attention!

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