UNIVERSITY OF L'AQUILA

DEPARTMENT OF INDUSTRIAL AND INFORMATION ENGINEERING AND ECONOMICS

ReFreeDrive

Synchronous Reluctance Motor for Traction Applications

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The **Synchronous Reluctance motor** (SynRM) could be a valid alternative for electric and hybrid vehicles due to its simple and rugged construction.

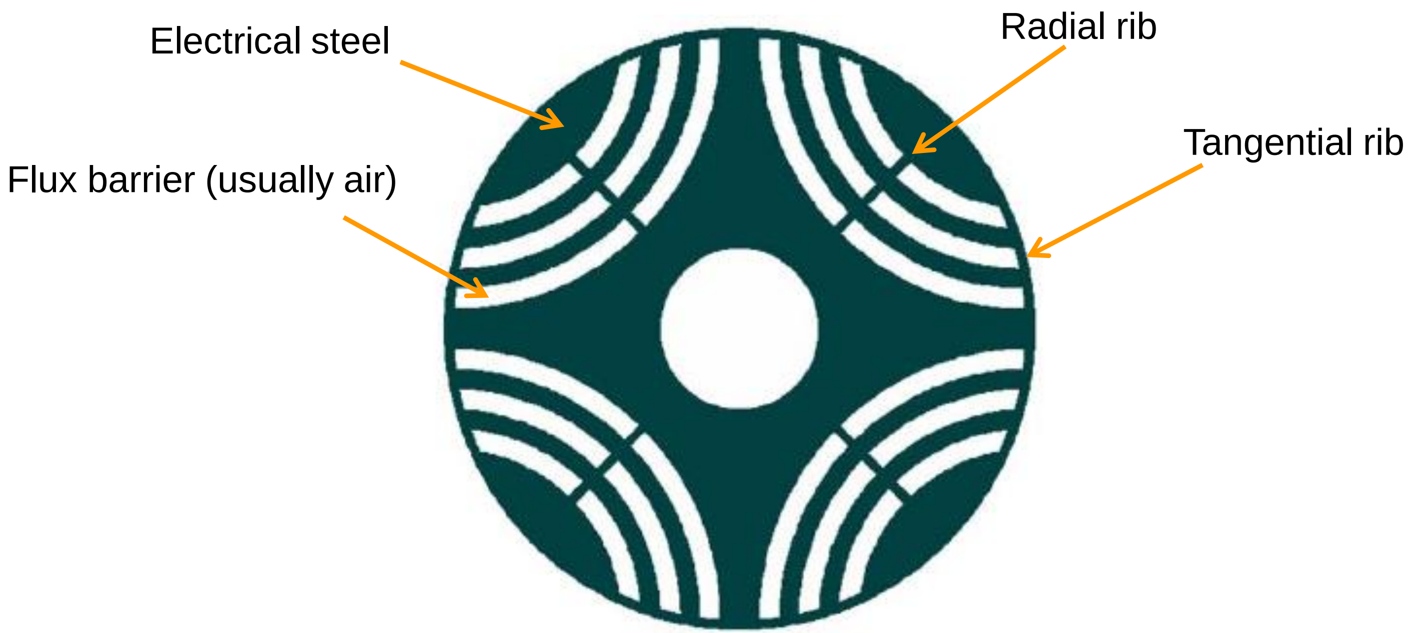
This machine does not have an excitation winding in the rotor core (⟶ no winding, no PM).

The main advantage of the SynRM relies on the absence of rotor copper losses.

⇓

″cold rotor″

Typical cross-section of the Rotor core



Laminated rotors with flux barriers can be manufactured with normal punching tools at low cost.

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The rotor of the SynRM is potentially **less expensive** than both PM and Induction motors due to cancelling cage, winding, and magnets from its structures.

☞ With respect to PM motors, conventional SyRM are known for their lower specific (peak) power and specific (peak) torque, higher noise and lower power factor.

Despite these drawbacks, it is possible to obtain high torque density and high efficiency motors through an **optimized motor design.**

Designers also aim to enhance the specific power of the motor-drives often by increasing their maximum operating speed (→ accurate mechanical analysis).

Design steps

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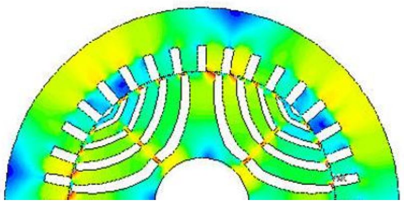

Requirements

↓

Prelim. designs — Sizing procedure by UnivAQ

↓

FEA ←
- Electromagnetic
- Mechanical
- Thermal

↓

Design OPT — Optimization tool by UnivAQ

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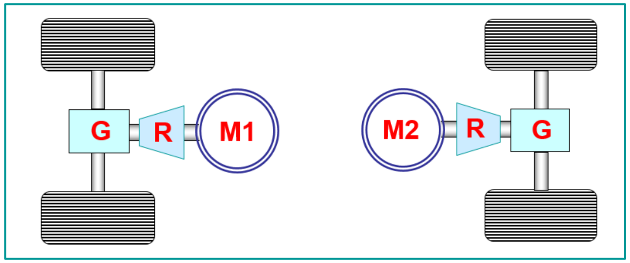
Choice of final design

↓

Prototypes and Test (in progress)

Specifications

Target vehicle: Jaguar XJMY21



Requirement	Unit	Value
Peak Power @ base speed	kW	200
Continuos Power @ max speed	kW	70
Peak efficiency	%	> 96
DC Voltage	V	700
Inverter current	Amax	700
Encoumbrance (ODxL)	mm	250x310
Cooling		Liquid

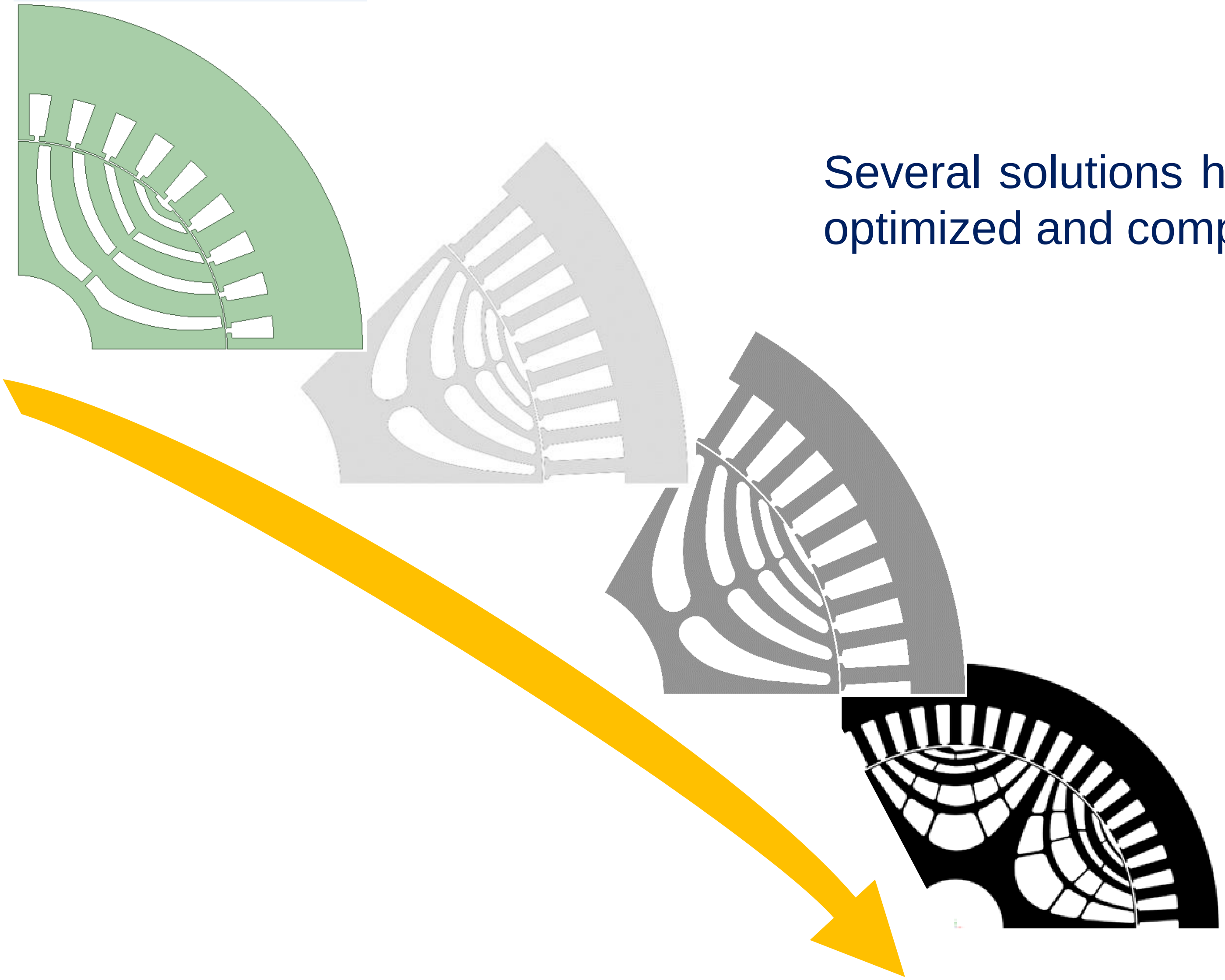
Specifications

Parameter	Unit	Reference Tesla Model S	Goals
Motor		Induction Motor	SynRM
Cooling		Liquid	Liquid
Specific Peak Power (*)	kW/kg	3.3	> 4.3
Specific Peak Torque	Nm/kg	6.32	> 8.2
Maximum speed	krpm	14500	15000 ÷ 18000
Peak efficiency	%	92	> 96
Active parts weight	kg	68	< 47

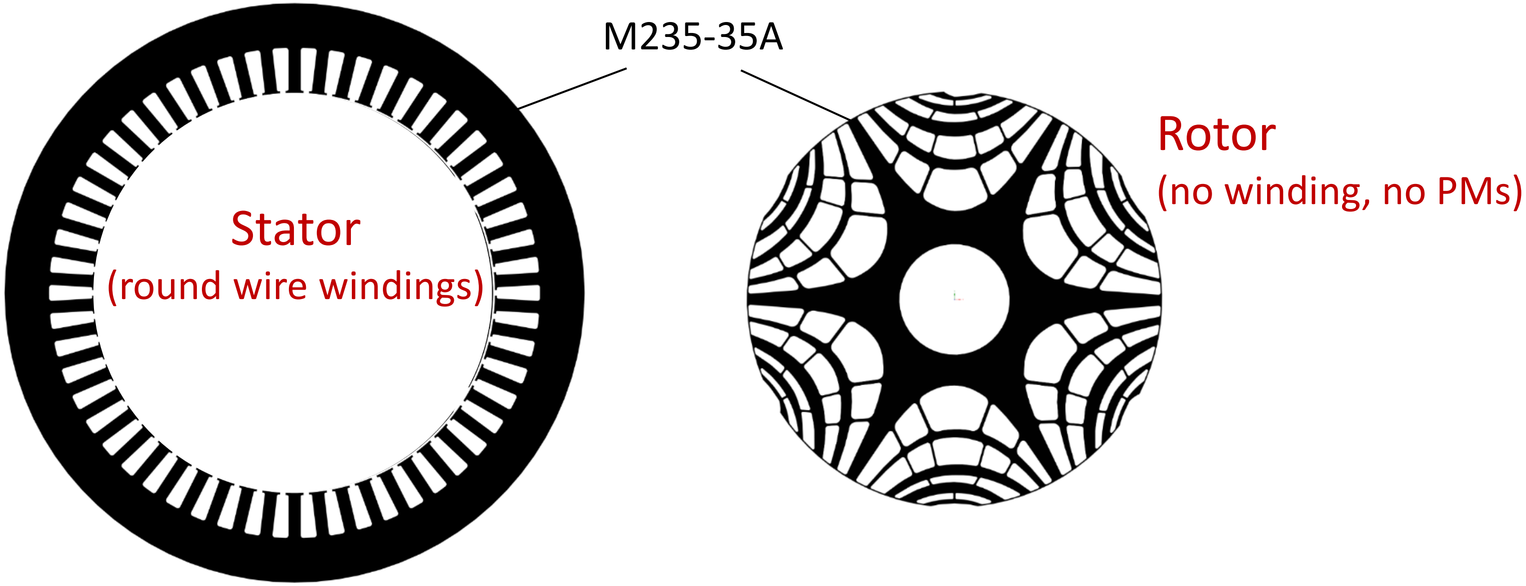
(*) active parts only

Designs evolution

Several solutions have been optimized and compared.



The final design - **200 kW** - (6-pole, 54-slots, OD=220mm; L=200 mm)



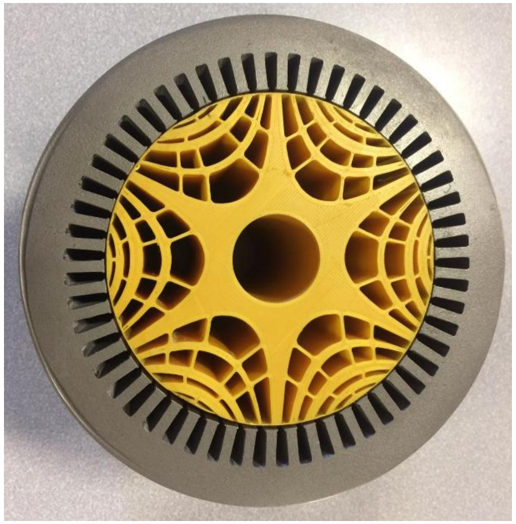
The rotor presents "asymmetric shape" with **"**multiple ribs**"** that connect the segments to each other axially and transversally

⟹ **accurate Electromagnetic + Mechanical optimization**

These connections maintain enough mechanical integrity in the rotor structure when rotational forces are applied at high speed (→ 18000 rpm).

Preliminary prototype - **200 kW** (by 3D Printer)

to verify the overall dimension and the feasibility of the stator winding



(This prototypes is in → UnivAQ stand 9-E08 - Hall 9)

Performance

Parameter	Unit	200 kW		
		Reference Tesla Model S	Goals	New design
Motor		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
Outer Diameter	mm	254	< 250	250

(*) active parts only
(+) housing included

Performance of the SynRM

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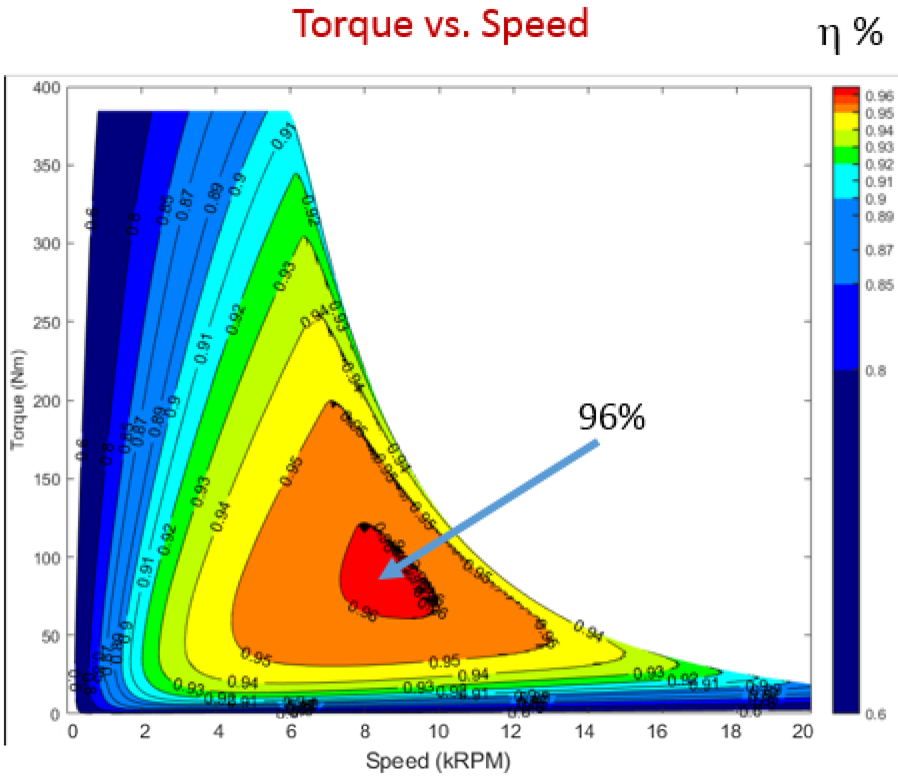
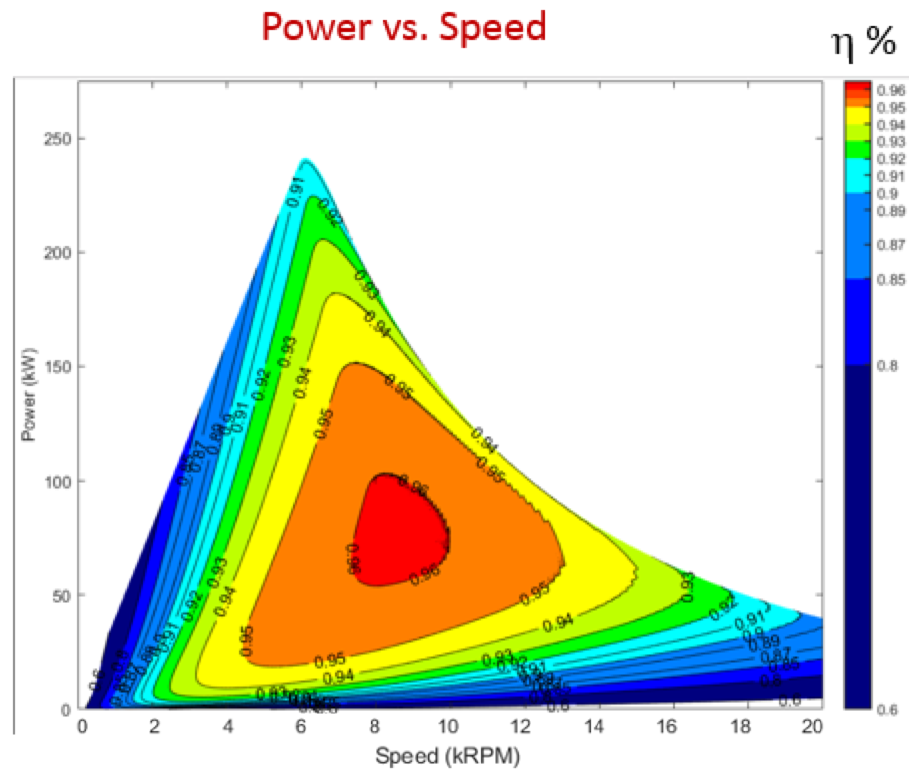
Hp: Tcu = 160°C; VDC = 700 V

		Peak Power 5 sec.	Continuous Power S1
Phase current	Amax	700	171
Phase voltage	Vmax	416	416
Speed	**rpm**	**6000**	**18000**
Average_Torque	Nm	387	28
Output Power	**kW**	**243**	**53**
Joule losses	W	22344	1333
Iron losses	W	1021	1524
Power factor		0.61	0.56
Torque ripple (*)	%	14.9	25

(*) no skewed rotor

Efficiency Maps

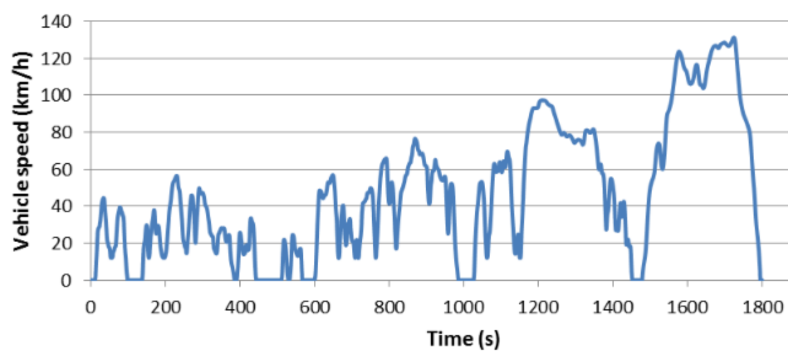


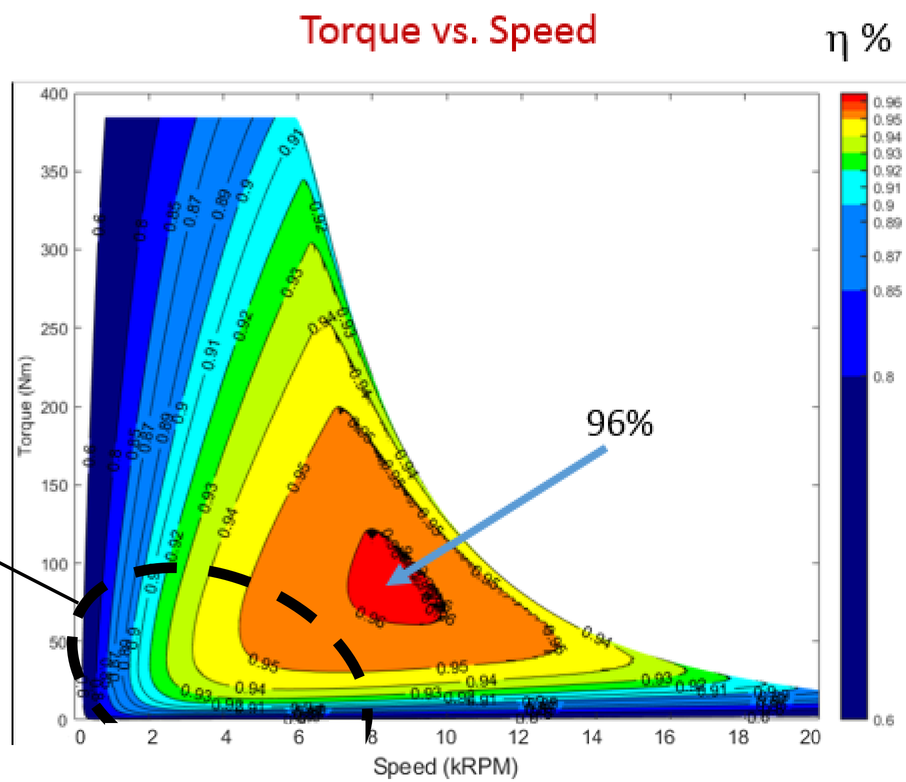


The efficiency includes the ”mechanical losses”.

Efficiency Maps and WLTP_Class3 driving-cycle

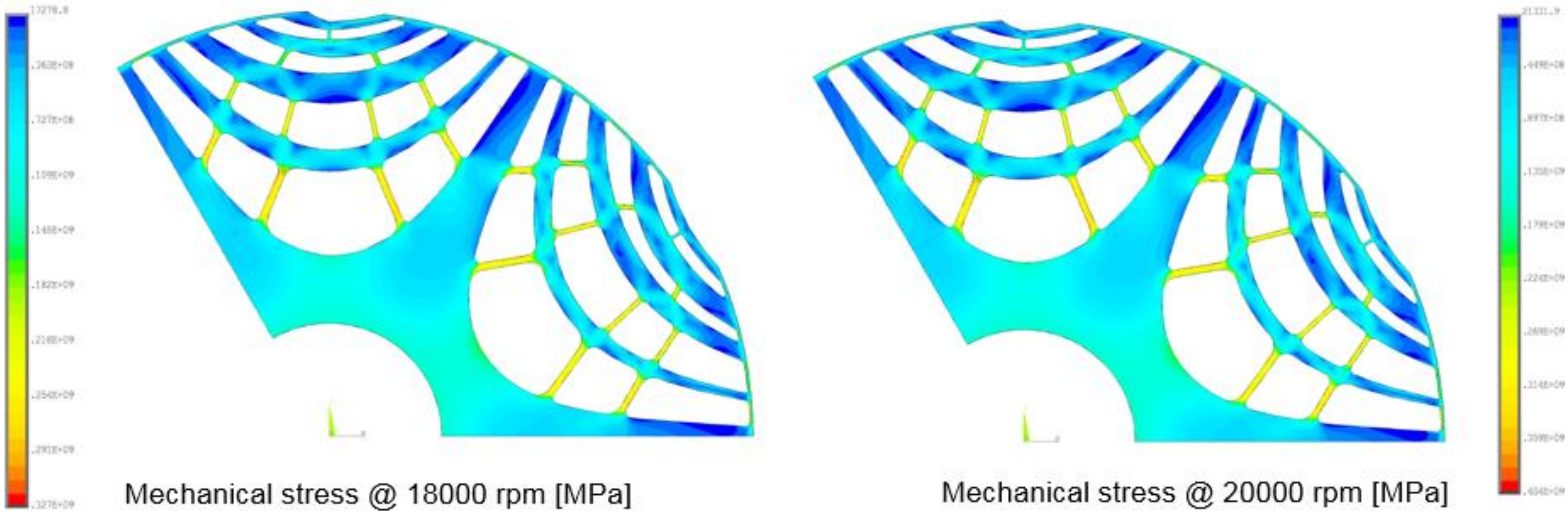
WLTP_Class3





Operating range

Mechanical analysis @ high speed



Mechanical stress @ 18000 rpm [MPa]

Mechanical stress @ 20000 rpm [MPa]

The design satisfies the mechanical limits of the chosen electrical steel.

Paper presented at: International Electric Machines & Drives Conference

May 12-15, 2019 • Westin San Diego • San Diego, CA

3D CFD Thermal analysis @ Continuous Power (53 kW, 18000 rpm)

- Housing Water Jacket with 4 parallel channels
- Flow rate = 10 l/min (EGW 50/50), Inlet temp. 75°C

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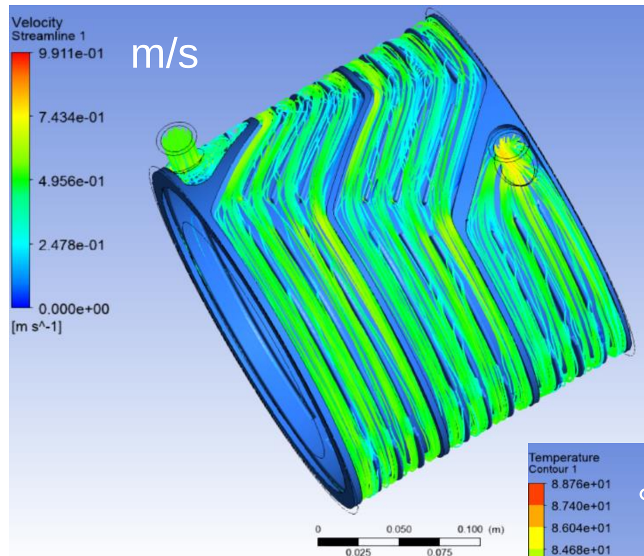
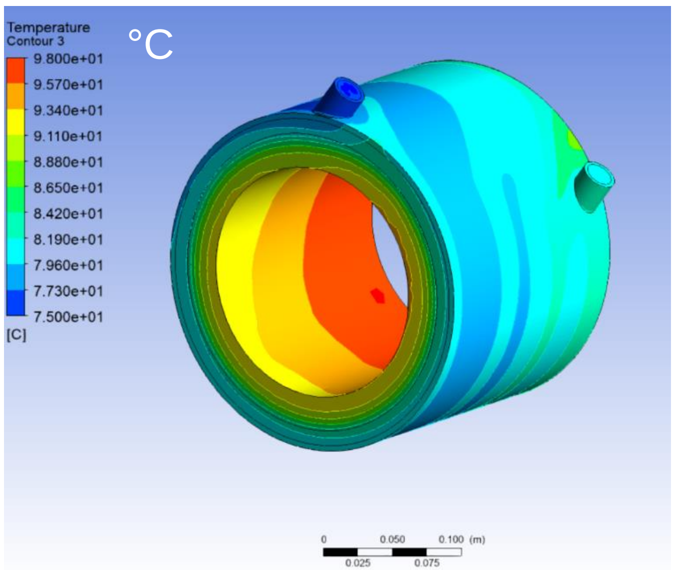
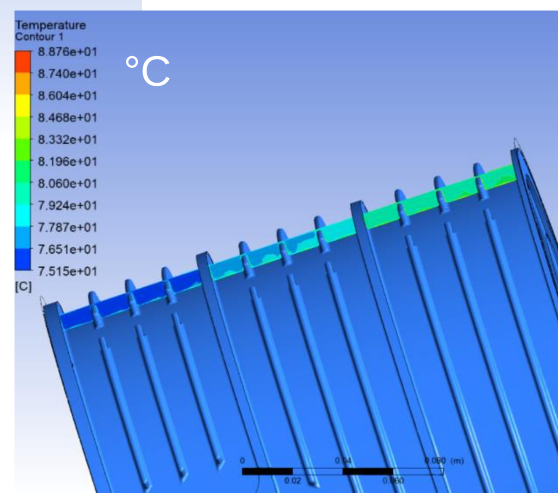
Fluid velocity



Housing Temperature

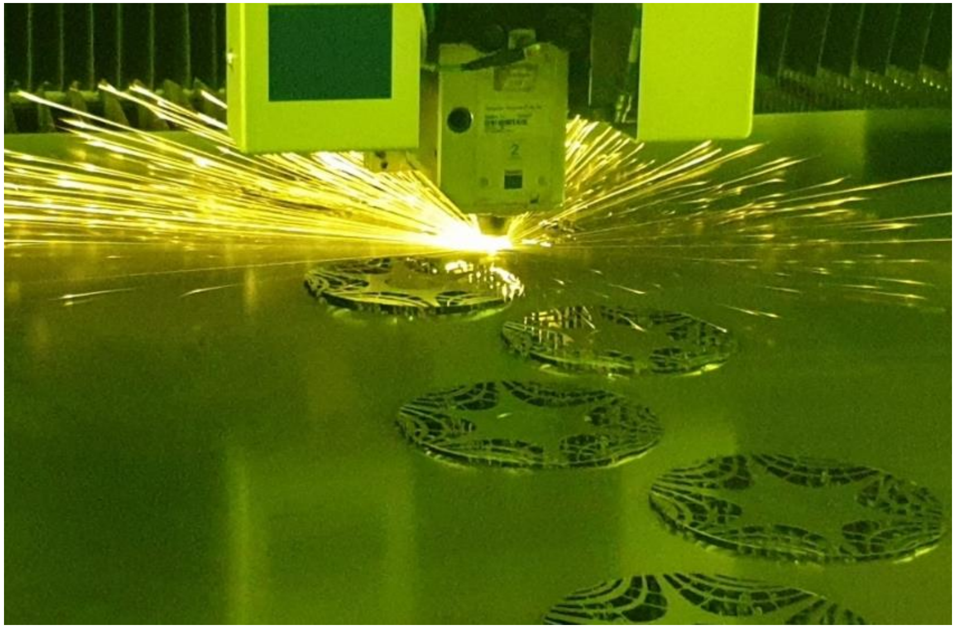


Fluid Temperature

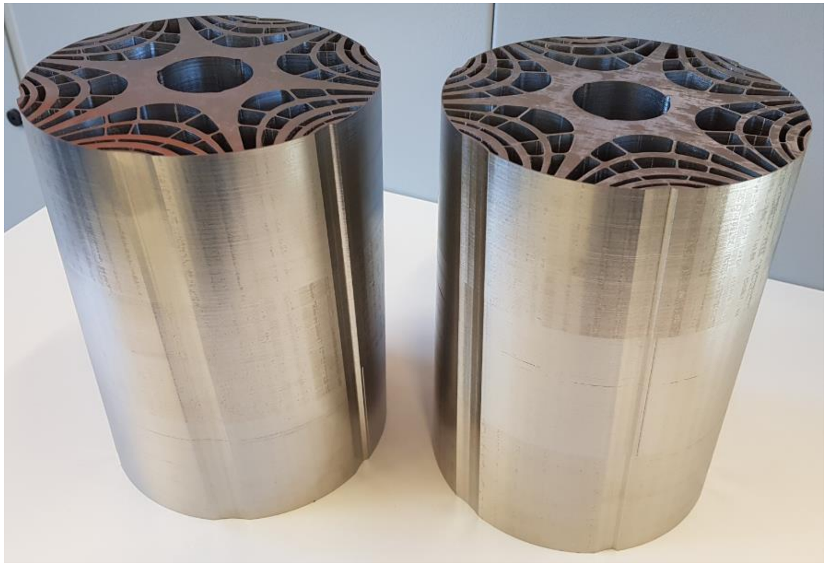


The 3D Fluent analysis at continuous power has pointed out a steady-state outlet fluid temperature of 82°C.
The winding hotspot temperature is about 170°C.

Prototype manufacturing



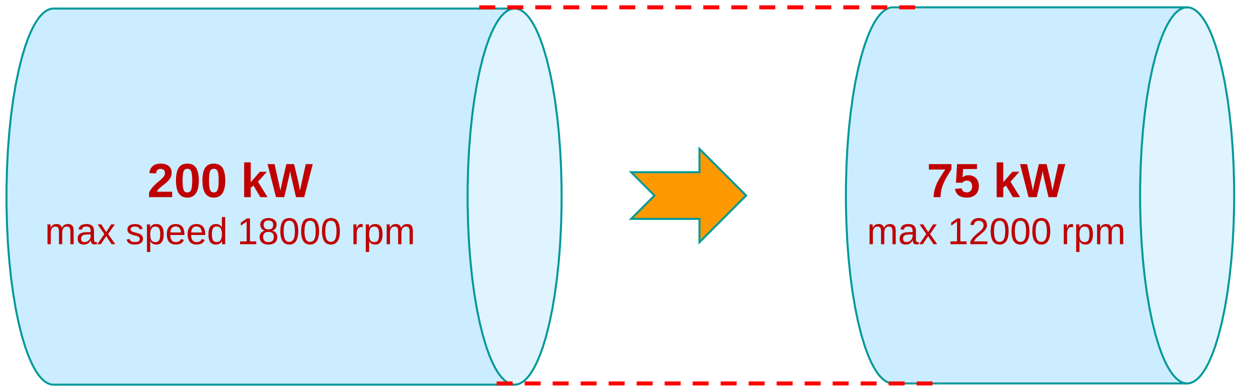
Laser cut of electrical steel



Skewed rotor cores

Low Power SynRM - **75 kW**

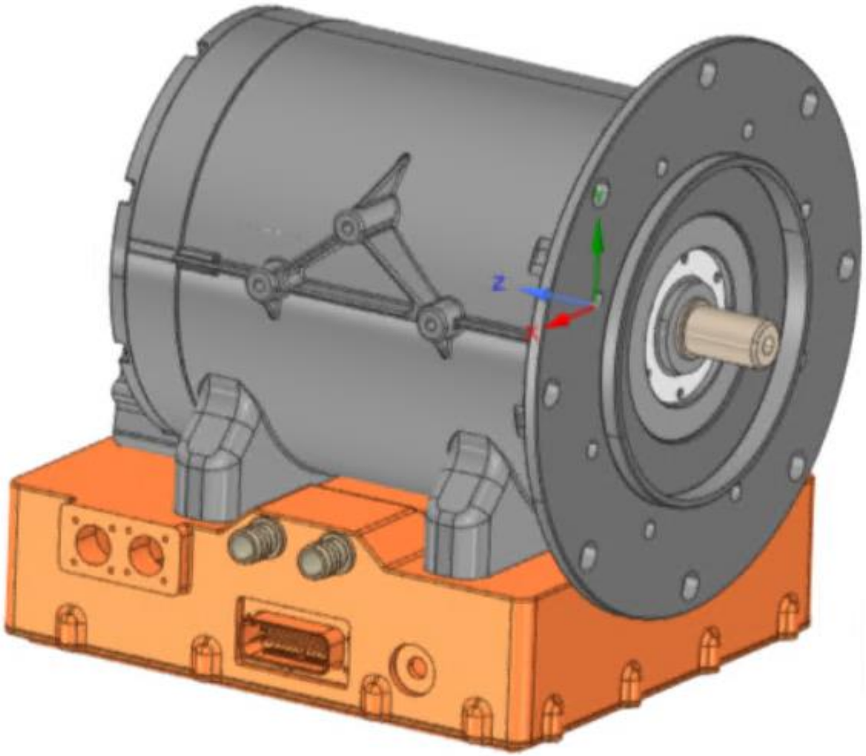
The lower power machine (75 kW) has been **scaled** from the 200 kW design by only changing the stator winding and stack length (→ same housing).



This scaled version will be integrated on a vehicle powertrain for performance testing.

Integration Motor+Drive

Liquid Cooled



Conclusions

The innovative proposed SynRM fully satisfies the requirements and appears to be a good solution for automotive applications.

The mechanical FE analysis has pointed out no critical stress at high speed, with a reasonable deformation with respect to the airgap dimension. The results confirm that the rotor structure is able to withstand mechanical stress at high speeds.

From the 200 kW design, the lower power machine (75 kW) has been scaled by only changing the stator winding and stack length.

Since the 75 kW motor has a lower operating speed than the 200 KW motor, its design satisfies as well the mechanical limits.

The 75 and 200 kW SynRMs are currently being prototyped and will be tested next year.

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