DREEM
E-KICKSCOOTERS

DREEM

Designing use**R** centric **E**-kickscooters & business models for **E**nhancing inter**M**odality

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DELIVERABLE TITLE: **In-Wheel Motor & BMS**

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Contributors	Boris Benedičič, Tomaž Čemažar, Primož Kafol, Gorazd Lampič, Andrej Detela, Raffaele Calabrese
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MAIN COORDINATOR

Name	Federico Galliano
Organization	PUNCH TORINO SPA
Address	Corso Castelfidardo 36, 10129 Torino, Italy
E-mail:	federico.galliano@punchtorino.com

CONSORTIUM PARTNERS

No	Organisation	Country	Acronym
1	Punch Torino	Italy	PUNCH Torino
2	Elaphe Pogonske Technologije Doo	Slovenia	ELAPHE PROPULSION TECHNOLOGIES LTD
3	Domel Elektromotorji in Gospodinjski Aparati D.O.O.	Slovenia	DOMEL D.O.O.
4	Three O'Clock	France	Three o'clock
5	5T SRL	Italy	5T
6	ICLEI European Secretariat GmbH	Germany	ICLEI
7	Bumpair	France	Bumpair
8	Goeteborgs Universitet	Sweden	UGOT
9	Tractebel Engineering	Belgium	Tractebel

ABSTRACT

Goal of the task is to develop a low weight below 2,1 kg and high efficiency over 92% peak 350 W gearless hub motor. For achieving the goal, a three phase transversal flux motor (TFM) is developed, designed and validated using built samples. To build a TFM sample special materials and new manufacturing technologies are used.

Development phase consisted of

- theoretical analysis,
- 3D finite element modeling (FEM),
- 3D computer aided designing (CAD),
- rapid prototyping manufacturing processes and
- sample validation and measurements.

All before mentioned phases are later explained in this deliverable report.

CONTENTS

1 DRIVE SETUP

Developed motor is accompanied with all necessary peripherals. They are described more in detail in below sub sections.

1.1 BMS

Battery pack contains a smart battery management system (BMS) with serial UART interface that communicates with the motor controller. BMS shall manage two different battery pack capacities, composed by a 10 Series 2 parallel battery cells pack.

Table 1: Operating values for both Battery Pack versions are reported in the following tables:

	Range	
	Min	Max
Battery Output Voltage	30V	42V
Charging Voltage	42V	
Charging Current	-	2A
Peak Current	17A	
Continuous Max Current	15A	
Temperature Range	-10°C	+40°C
Storage Temperature Range	-20°C	+50°C

The communication interface with the motor controller adopts half duplex UART (asynchronous serial transceiver) communication mode. Serial communication parameters baud rate is 9600 bps, 8-bit data bit, no calibration bit, 1 bit stop bit.

1.2 MOTOR CONTROLLER

The motor controller is the brushless motor inverter unit, it performs several functions including:

- drive the motor,

- drive the rear light with turn signals,
- communicate with the dashboard via UART serial interface and
- communicate with the battery pack via UART serial interface.

The motor controller shall be capable to:

- drive the motor (350 W – 36 V),
- drive the left and right turn lights,
- drive the rear light,
- drive the brake light,
- provide an auxiliary output connection (5 V – 1 A, will be used to power auxiliary devices),
- provide a charging connector on the case, to recharge the battery from external,
- communicate with the dashboard via UART serial interface and
- communicate with the battery pack via UART serial interface.

1.3 DASHBOARD – MOTOR CONTROLLER COMMUNICATION

The communication between dashboard and motor controller consists of below.

From Dashboard to Motor Controller:

- drive mode,
- turn signals switch status,
- rear light status,
- brake light status,
- wheel diameter,
- throttle status and
- brake lever status.

From Motor Controller to Dashboard:

- controller status,
    - Hall failure status,
    - controller failure status,
    - under-voltage protection status,
    - cruising status,

    - communication failure,
- operating current,
- motor speed,
- battery status,
    - charging status,
    - temperature,
    - voltage,
    - current,
    - full charge capacity,
    - healthy status and
    - number of cycles.

1.4 MOTOR CONTROLLER ELECTRICAL ARCHITECTURE

On below image motor electrical architecture with all peripherals is displayed.

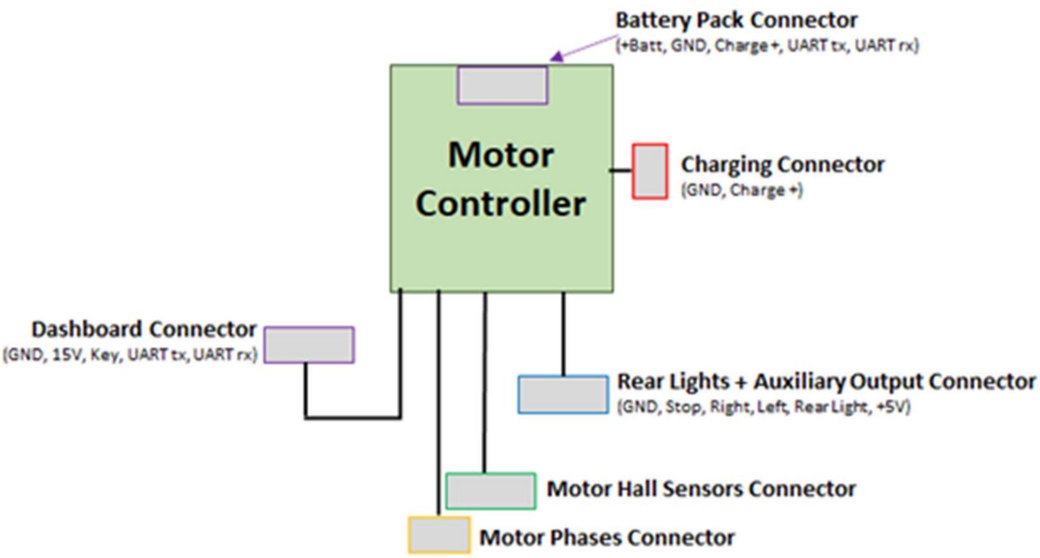

Figure 1: Motor controller electrical architecture.

1.5 MOTOR CONTROLLER OPERATING VALUES

Motor controller that drives the developed motor is described in below table.

Table 2: Motor controller operating values.

	Range	
	Min	Max
Supply voltage	31V	42V
Motor Matching	Brushless DC Motor	
Control Type	Sine Wave	
Motor rated power	350W	
Electronic Brake	Yes	
Rear Light with Turn Signals		12-3W
Auxiliary Output Connection	DC 5V – 500mA	
Throttle	0V	5V
Temperature range	-10°C	+40°C
Storage Temperature range	-20°C	+50°C
Relative Humidity	10%	90%
IP Level	≥54	

2 THEORETICAL ANALYSIS

The concept of TFM motor was firstly analytically validated using equations from electromagnetics. Analytical model of such motor was developed in order to determine optimal dimensions of magnetically active components. The analytical analysis was carried out at Elaphe. It is important to note, that the selection and first optimization of the electromagnetic topology for thus application was selected based on innovation process with careful understanding of specific requirements for this application and characteristics of different technologies that can be used in designing an electric machine. On top of that, specific innovation in the details of the design were invented in order to make it the progress beyond the state of the art. This analysis was initially not done by brute force FEM computer analysis, but by analytical approach, deriving equations of basic physics and design inspired by nature on the white sheet of paper in Nikola Tesla or Leonardo da Vinci style.

Motor is based on ferromagnetic core made from compacted insulated iron powder also named soft magnetic composite (SMC). This material in comparison to tradition electric motor lamination allows magnetic flux to flow in all three dimensions. Usage of such material in TFM motor is necessary due to 3D flux paths. The flux flows in transversal direction, hence the name transversal flux motor.

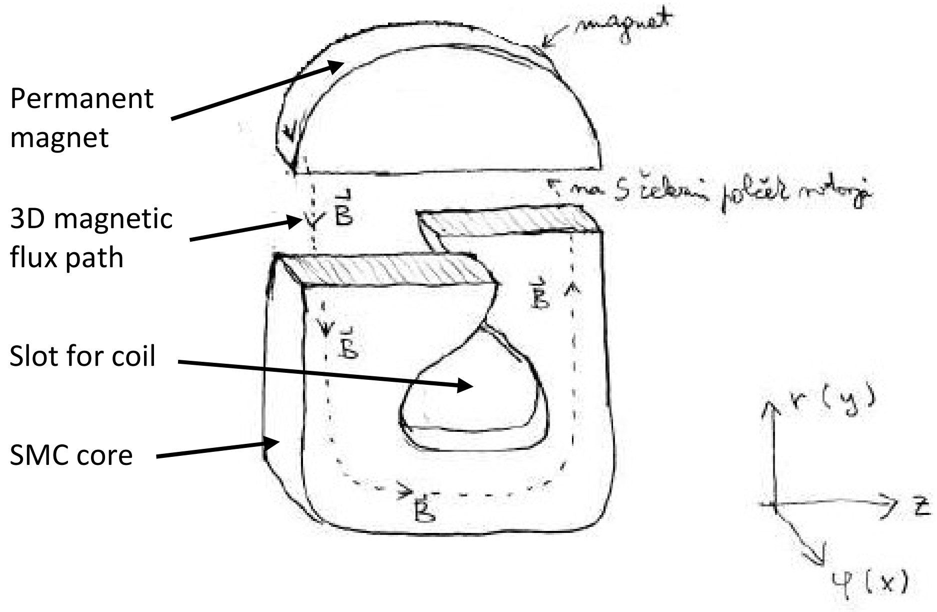

Figure 2: Sketch of one pole for development of TFM analytical model.

3 3D FINITE ELEMENT MODELLING

Resulting optimal geometry from theoretical analysis was than at Domel further analyzed and optimized using 3D FEM electromagnetics software tool. The outcome of optimization was approached after more than 50 different models, each including modifications from previous iteration. Throughout whole optimization manufacturing feasibility of parts was considered. The resulting model from FEM calculations promised efficiency above 90% at nominal working point and a low weight.

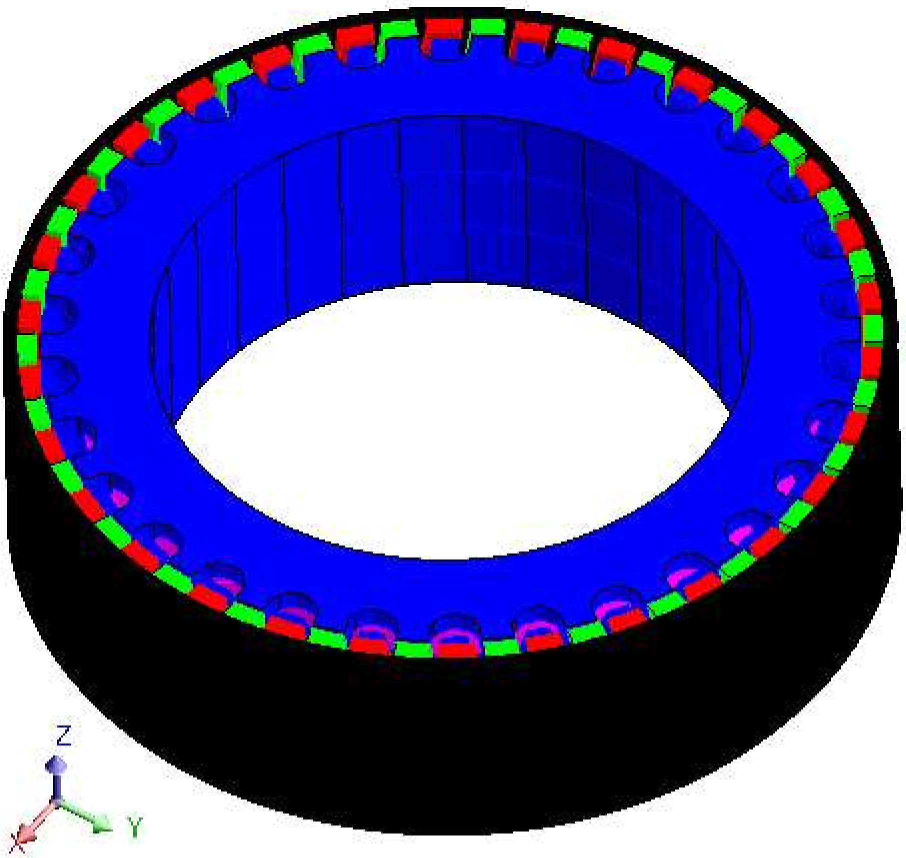

Figure 3: 3D FEM model.

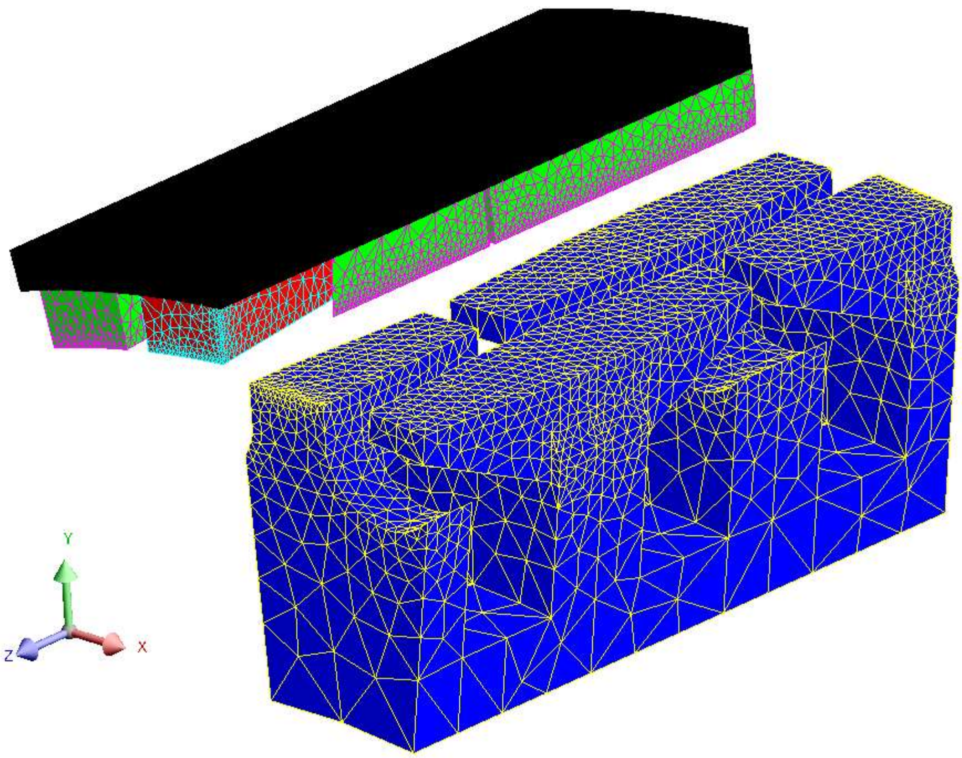

Figure 4: Meshed 3D FEM motor pole-pair model.

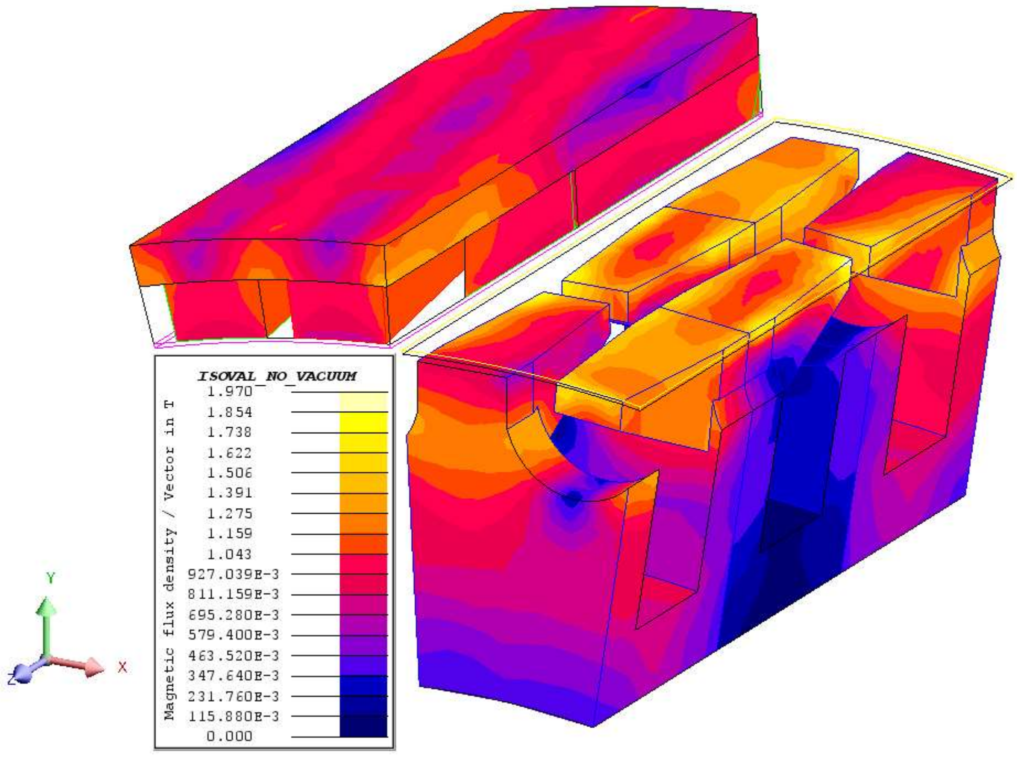

Figure 5: Solved 3D FEM motor pole-pair model.

4 3D COMPUTER AIDED DESIGN

With promising results from 3D FEM, an innovative mechanical housing model was built around electromagnetic structure in order to transfer torque developed in the electromagnetic structure. The main goal at motor housing design was to develop a innovative lightweight and reliable housing. In this development phase the connectivity of the motor and scooter was also considered.

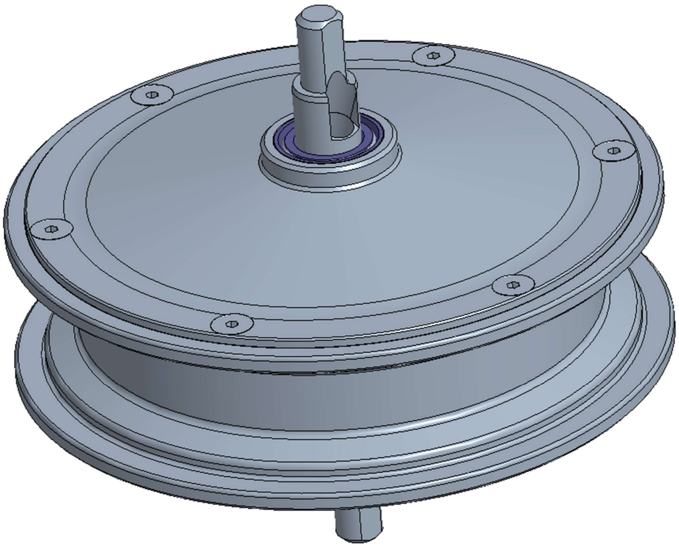

Figure 6: Motor assembly top.

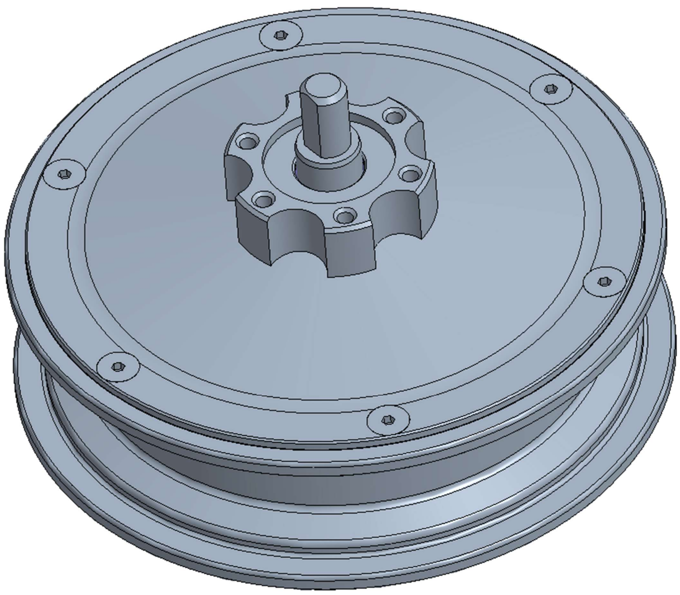

Figure 7: Motor assembly bottom.

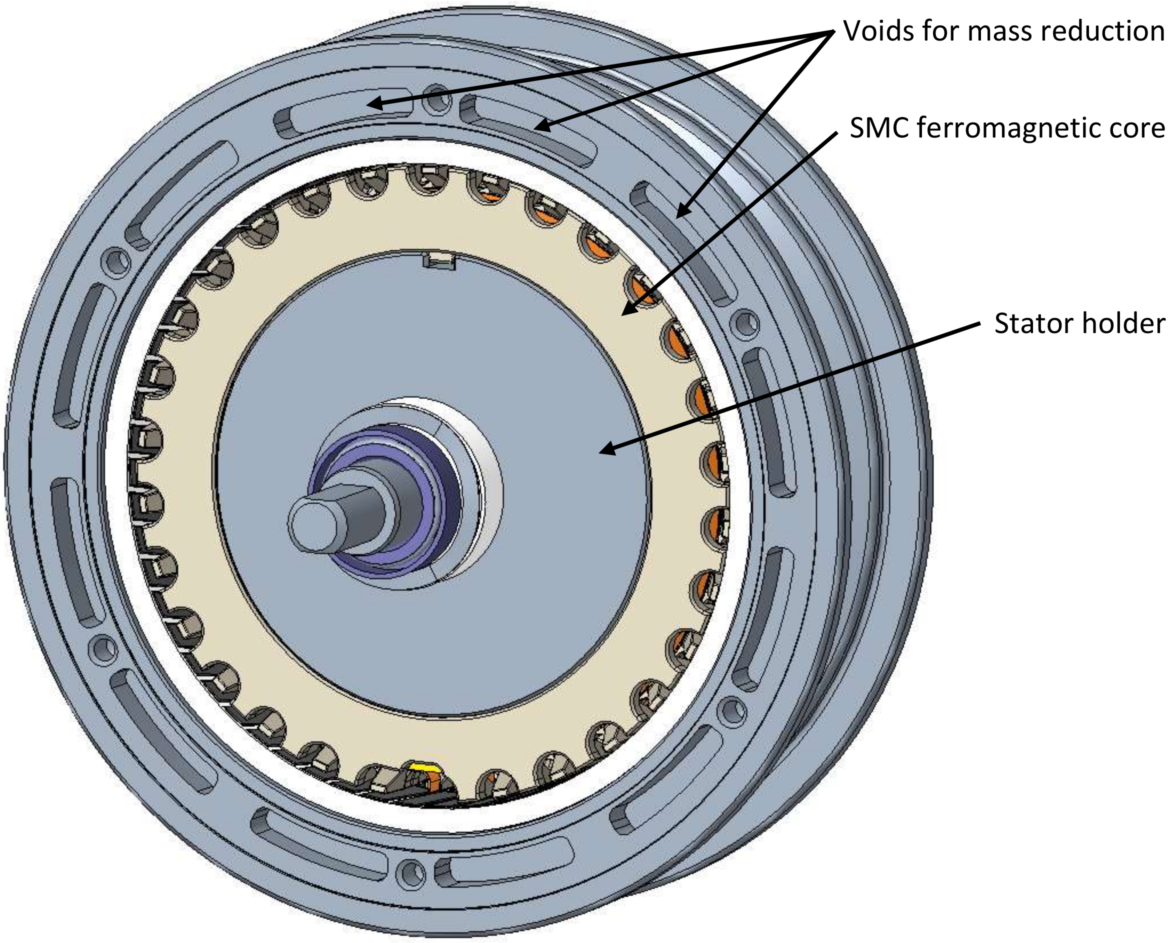

Figure 8: Motor assembly without cover.

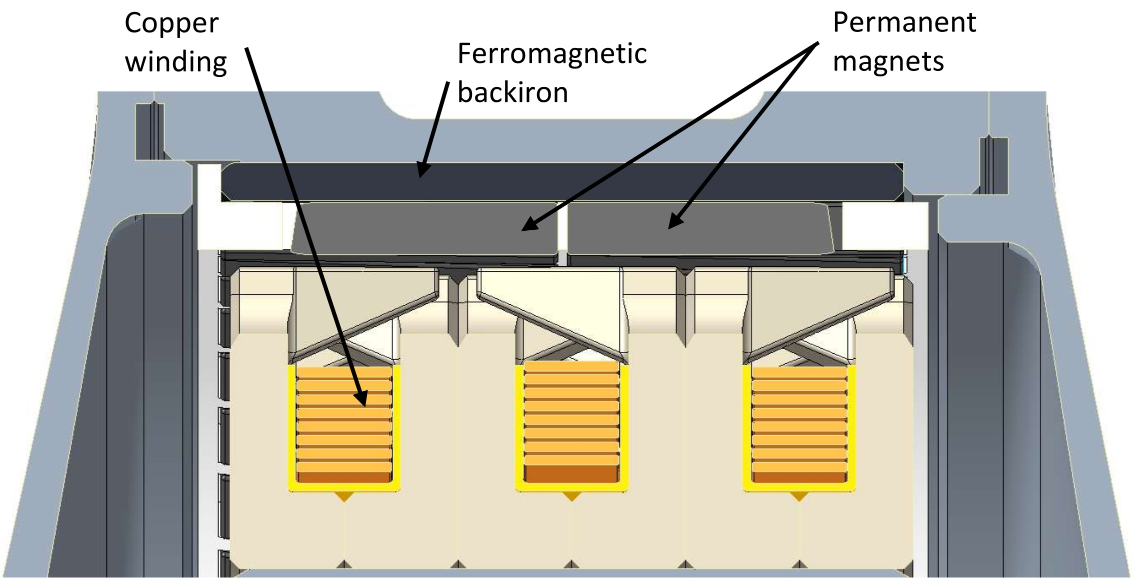

Figure 9: Motor assembly cross section.

5 PROTOTYPING MANUFACTURING PROCESS

Manufacturing of samples was carried out using rapid prototyping processes such as CNC machining, 3D printing and laser cutting. All assembly parts manufacturing excluding standard parts and magnets were produced in company Domel. The later assembly of the motor was also done in Domel. The final weight of optimized magnetically active parts was 1,4 kg and total drive weight without tyre was 2,7 kg.

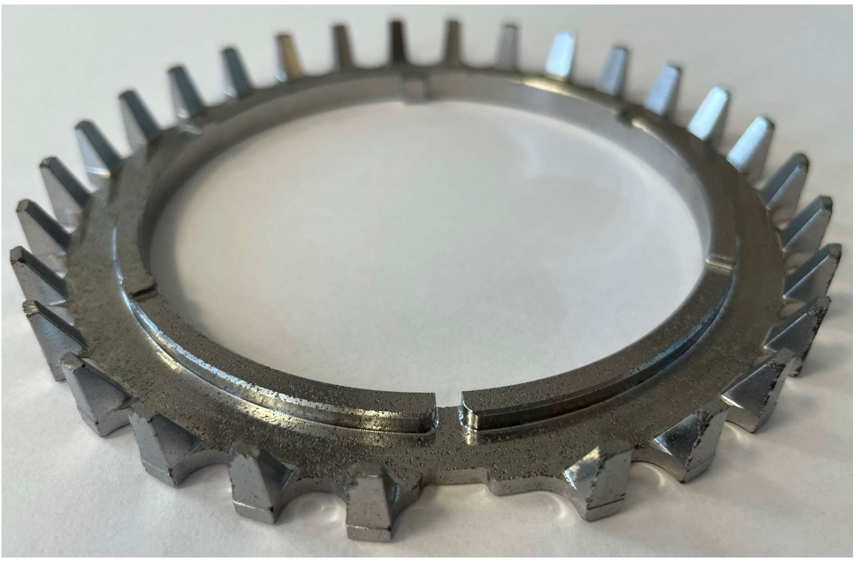

Figure 10: Machined motor phase halve.

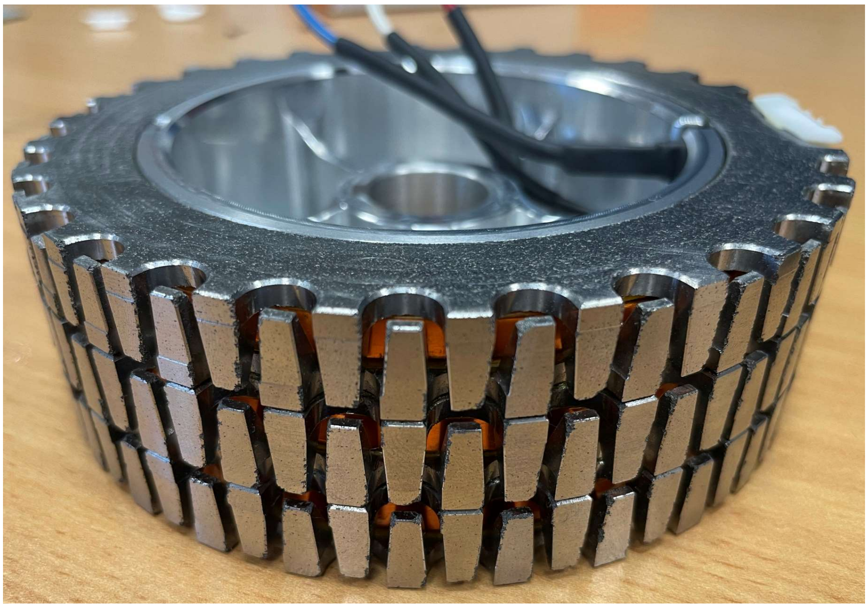

Figure 11: Assembled SMC stator stack.

The stator stack was potted with epoxy resin due to brittleness of the SMC material.

Figure 12: Potted stator stack.

Figure 13: Motor housing assembly.

6 SAMPLE VALIDATION AND MEASUREMENTS

Assembled samples were measured in testing laboratories at Domel. With measurements we managed to confirm that motor is capable of operating with high efficiency of 90% at nominal operating point. The motor also performs with high efficiency values above 85% through wide range of output torque. Heating tests also confirmed that the motor is capable to permanently operate with output power of 430 W.

The measuring setup consisted of hysteresis brake, torque sensor and sample motor. All equipment was coupled together using clutches.

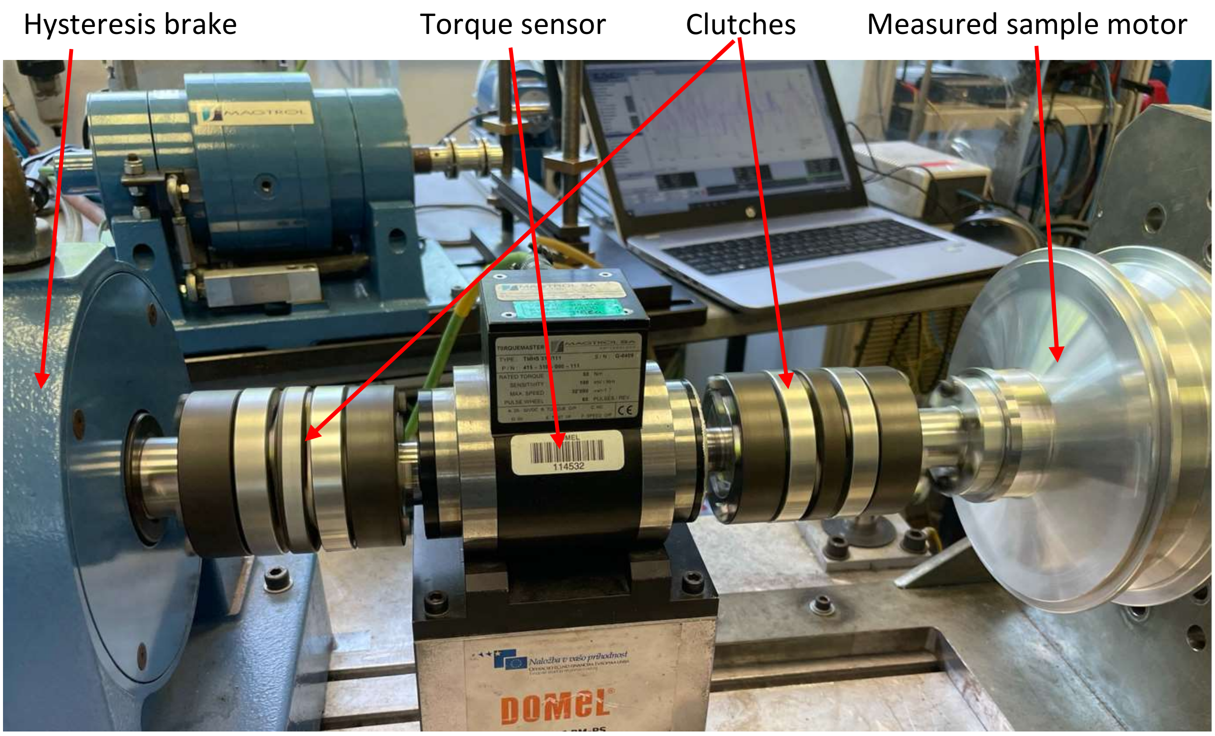

Figure 14: Motor characteristics measurement setup.

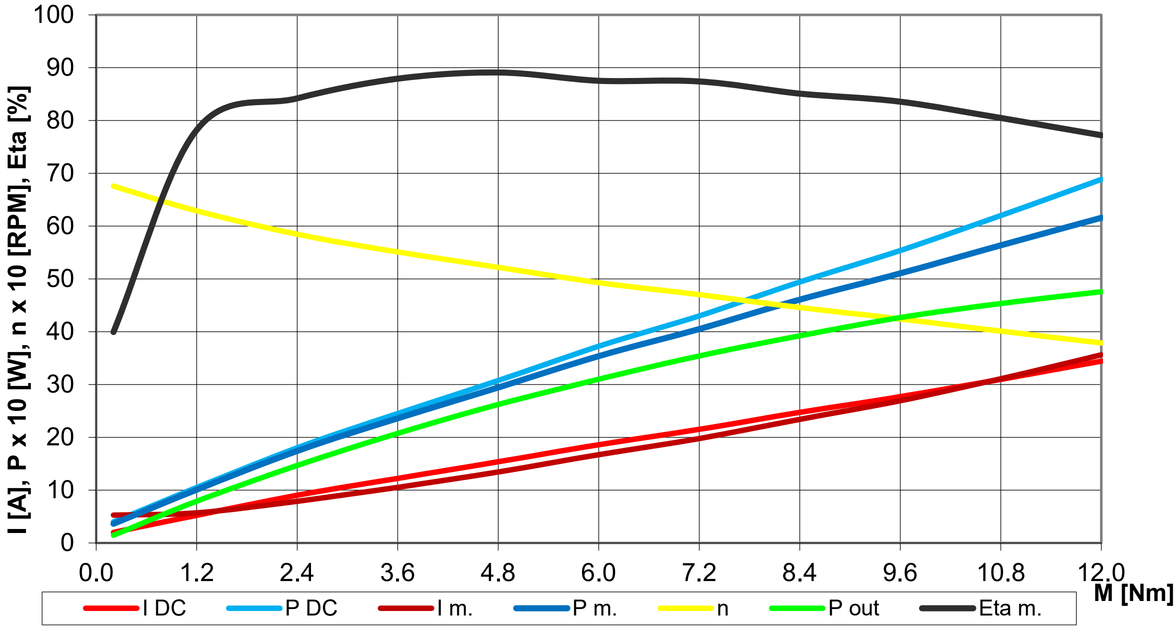

Figure 15: Motor performance graph.

To perform heating tests a thermocouple was placed on winding. Figure below displays motor heating test graph. Motor was from start operating at 12 Nm, 375 rpm, 470 W for 13 minutes and than at 10 Nm 10 Nm, 410 rpm, 430 W. As can be seen from the graph below the motor is capable of continuously operating with 430 W of output power.

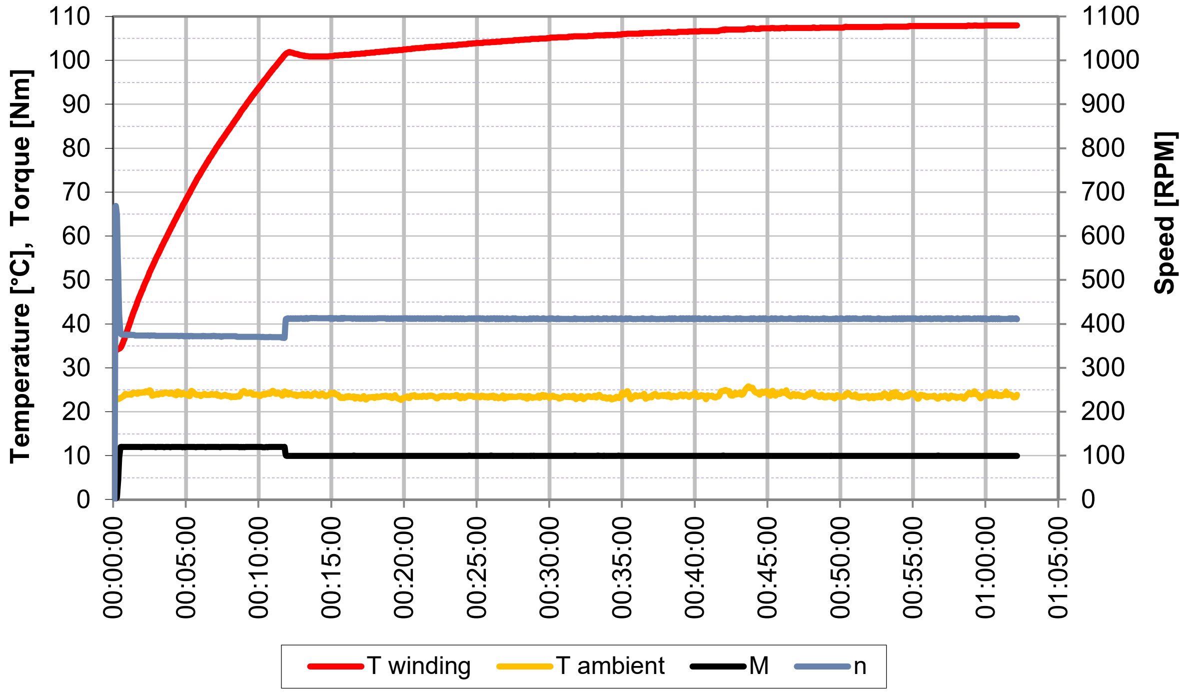

Figure 16: Motor heating test graph.

7 CONCLUSION

Within the given timeline the team managed to develop, manufacture, test and validate a lightweight high efficiency sample motor. Developed sample TFM motor is able to meet all requirements set up in the beginning of the project. The developed motor not only achieves all goals but also outperforms some of them. For example, motor was able to operate with 430 W continuously instead of the goal 350 W. This means that the motor can be declared for higher output power or it can be scaled down to achieve 350 W and with this even further lower the motor weight.

PARTNERS

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