Rare Earth Free e-Drives Featuring Low Cost Manufacturing

ReFreeDrive

Collaborative Project
Grant Agreement Number 770143

Start date of the project: 1st October 2017, Duration: 36 months

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

Deliverable no.: D3.4

Title of the deliverable: CR-IM Full Design Report (Including CAD) for Inner and Outer Rotor Designs

Contractual Date of Delivery:	**30 June 2019**
Actual Date of Delivery:	**30 June 2019**
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Work package contributing to the deliverable	**WP3**
Nature:	**Confidential**
Version:	**1.2**

Abbreviations

BC: Boundary Conditions

CR-IM: Copper Rotor - Induction Motor

EDT: Electric Drives Technologies

GA: Grant Agreement

IM: Induction Motor

IR: Inner Rotor

KPI: Key Performance Indicator

NVH: Noise, Vibration and Harshness

OD: Outer Diameter

OR: Outer Rotor

WP: Work Package

Executive Summary

The present report covers the final, full design summary for Copper Rotor Induction Motors (CR-IM) with Inner Rotor (IR) for traction systems in Electric Drives Technologies (EDT). This is one of the technical solutions investigated by ReFreeDrive project.

The overall objectives of the entire Work Package 3 (WP3) are according to the ReFreeDrive Grant Agreement (GA):

- To identify the key factors in copper alloy cage rotor Induction Motor (IM) design that lead to an increase in power/torque density and lower cost.
- To select the materials –copper alloy electrical steels laminations- for IM high speed applications eliminating rare earth materials content and lowering costs.
- To achieve an electro-magnetic design of an IM with internal rotor fulfilling the requirements specified in WP2.
- To achieve the electro-magnetic design of an IM with Outer Rotor (OR) fulfilling the requirements specified in WP2. A comparison of different stator-rotor configurations will be done for evaluating the best trade-off between performance and cost.
- To design the cooling system and analyse the selected IM inner and outer rotor topologies based
- To ensure the mechanical design of the selected topologies (i.e., mechanical strength to centrifugal forces, etc.) and investigate the Noise, Vibration and Harshness (NVH)
- One of the alternative technical solutions, CR-IM with outer rotor for traction systems in EDT, was determined to have lower technological potential, as described in detail within deliverable 3.2. Accordingly, this solution is discarded for further thermal analysis or NVH and not included in this deliverable.

The objective of this deliverable is to report the work done in Task 3.4.

The degree of fulfilment required by the GA has been achieved. The deviation on content is related to the exclusion of CR-IM outer rotor from thermal analysis due to the technical limitations of the solution. No deviation on time has occurred in the degree of fulfilment. There are no impacts on the overall project implementation.

In WP3, inner and outer rotor induction motors configurations with cage built using die-casted or fabricated rotor technologies are proposed. When IR topology is used in combination with high rotational speed, i.e. $\geq$ 20000rpm, the torque density and the specific power are increased. Similarly, an OR topology can be used at lower rotational speed, i.e. $\leq$ 18000rpm, the increase in torque density and specific power is guaranteed due to the inherent higher diameter in the motor airgap.

Task 3.4 (*IM Mechanical Design of a Selected Inner or Outer Rotor Topology*) aims at looking at NVH response, as other mechanical aspects like modal analysis and mechanical stress are

reported in Task 3.3. Only inner rotor topology is analysed, as results from Task 3.2 showed that this solution is clearly superior to the outer rotor topology for traction systems in EDT.

The objectives of Task 3.4 are:

- Task 3.4.1 Noise, vibration and harshness analysis
- Task 3.4.2 Final CAD drawings for prototyping stage (WP6)
- Task 3.4.3 Summary of final design

This report is divided in three main sections.

- Section 1 (*Noise, Vibration and Harshness Analysis*), the estimated noise at one operating point are briefly discussed.
- Section 2 (*CAD Drawings Set for Manufacturing*) describes the list of draft drawings needed for manufacturing.
- Section 3 (*Summary of final design*) contains a short description of final CR-IM inner rotor topology that is going to be prototyped.

The final design IR IM topology respects all the selected Key Performance Indicators (KPI) values given in Table ES 1.

Table ES 1 summarizes the KPI values for the high power range application (200kW). The specified specific torque and specific power targets are peak values and relate to active weight, including housing.

Table ES 2 summarizes the main volume Boundary Conditions (BC). All quantities include the housing.

The low power range motor is scaled from the high power motor to fit the targetted vehicle requirements. The dimensions will remain the same, only the power supply levels will change (method used by TESLA motors).

Table ES 1 - KPI values

KPI	Unit	Reference (TESLA 60S)	ReFreeDrive Goals	Comment
Specific power	kW/kg	3.31	> 4.3	Peak value, active parts only
Specific torque	Nm/kg	6.32	> 8.2	Peak value, active parts only
Efficiency	%	92%	96%	Peak value

Table ES 2 – Main Volume, Weight and Speed BC values

Bondary Conditions (BC)	Unit	Value
Machine total length	mm	310
Machine total OD*	mm	250
Maximum speed	rpm	20,000
Active weight	kg	< 44.6

*OD: Outer Diameter