Rare Earth Free e-Drives Featuring Low Cost Manufacturing

ReFreeDrive
Collaborative Project
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Abbreviations

BEV	Battery Electric Vehicle
BOM	Bill of Materials
BOP	Bill of Process
DoA	Document of Activities
HV	High Voltage
EU	European Union
GA	Grant Agreement
IM	Induction Motor
JLR	Jaguar Land Rover
PM	Permanent-Magnet motor
WLTP	Worldwide Harmonized Light Vehicles Test Procedure

1. Executive Summary

This report focuses on the techno-economic evaluation of the 75kW and 200kW ReFreeDrive motors (induction and synchronous reluctance) and power electronics designed, manufactured and tested throughout the project.

The main objectives of this task were, once the optimal design options have been defined, to analyse possible manufacturing avenues and their cost implications and to derive a full assessment of cost of materials and manufacturing costs for the motor and electric drive – based on the weight and choice of materials and related process costs.

- Furthermore, to include assumptions on systems costs including transmission and battery capacity (as systematic approach).
- Then, to combine these cost data with performance data (torque, power, losses, etc.) under the operational considerations such as power or thermal limits.
- Finally, to derive some recommendations for the adoption of the proposed technologies in different vehicle categories and profiles and show their overall market potential as alternatives to current rare-earth Permanent Magnet (PM) motor solutions.

The following approach has been used to derive the final motor should-costs:

- Bill of Material (BOM) definition for the considered motor based on exact materials and assemblies used for prototyping, with associated weights. From a detailed BOM, assembly-level data is summarised into:
    - Stator assembly
    - Rotor assembly
    - Motor passive parts
    - Power electronics (same assumption for all motor variants)
- Bill of Process (BOP) definition for the considered motors based on exact choice of manufacturing technology and assembly assumptions.
- Should-cost derived from the BOM and the BOP for two production volumes to highlight potential savings gained through economies of scales (Figure 1 and Figure 2):
    - 30,000 units per annum
    - 100,000 units per annum

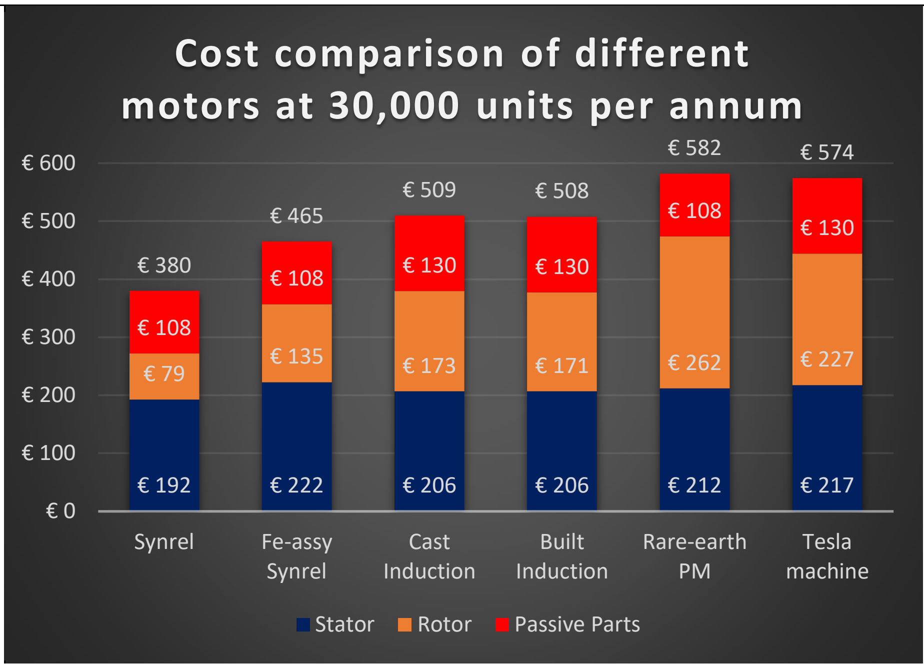

Figure 1. Should-cost summary of ReFreeDrive motors, rare-earth benchmark and Tesla Model S induction motor for 30000 units per annum.

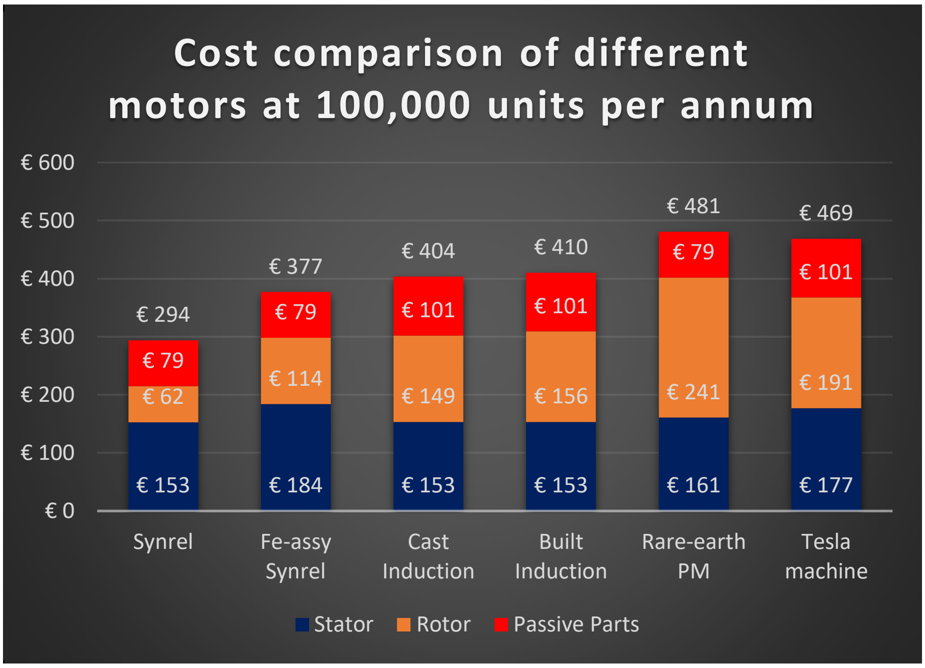

Figure 2. Should-cost summary of ReFreeDrive motors, rare-earth benchmark and Tesla Model S induction motor for 100000 units per annum.

All the machines designed within the ReFreeDrive project are cheaper than the benchmark Tesla Model S induction motor and enable a significant cost saving compared to the rare-earth benchmark, which is based on a rare-earth motor of similar specification and size as the ReFreeDrive machines.

As the gearbox and the battery pack are not part of the ReFreeDrive project, in this present exercise analysis we have added those two key elements as "simulated assumptions" based on internal Jaguar-Land Rover (JLR) data. An internal battery cost is used to quantify the potential cost savings through different cycle energy-consumption of the motors and to derive a representative overall powertrain cost.

Then these cost summaries have been combined with performance metrics (both simulated design performance as well as measured performance data from previous tasks of the project) of the different ReFreeDrive motors to create a comprehensive overview of the benefits of each key technology as a traction machine used within automotive applications (Figure 3).

The weight targets are achieved for all motor variants, same as are the peak torque density targets and the peak power density targets in Nm/L and kW/L.

The energy consumption of the motors over the Worldwide Harmonized Light Vehicles Test Procedure (WLTP3) cycle is used to derive the required increase in battery capacity i.e. in battery cost in order to achieve the same range as the most efficient motor, which in this case is the Rare-earth PM motor (not part of the ReFreeDrive project).

It was obvious that our ReFreeDrive motor alternatives will never surpass the rare-earth PM motor total driving efficiency for a given powertrain configuration (assumed same gearbox and battery size).

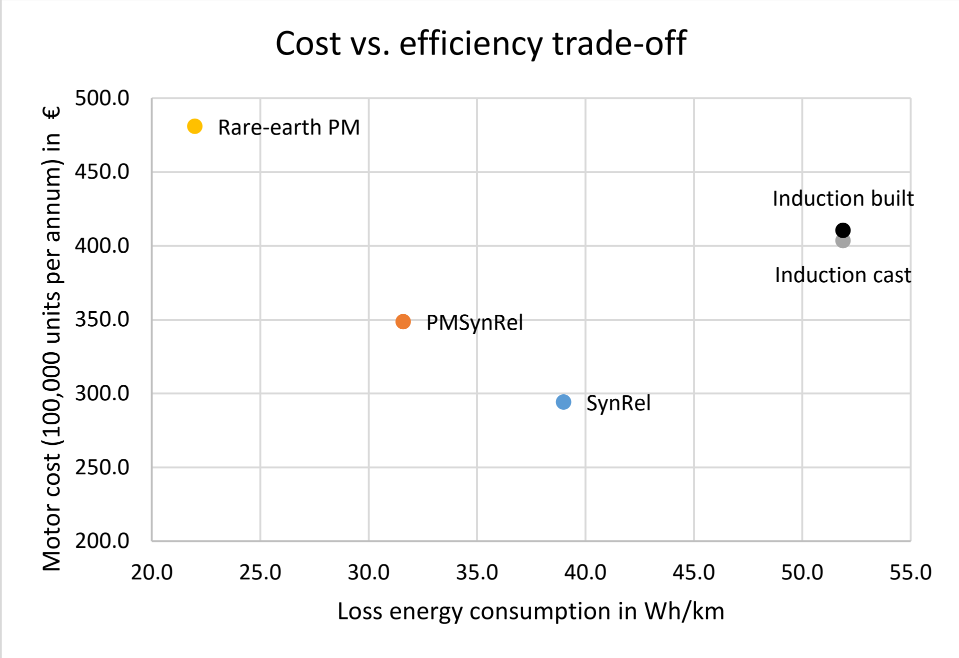

Figure 3. Cost vs efficiency trade-off for different motor technologies.

However, the cost advantage of our motors compared to rare-earth PM motor can become a relevant criterion of choice for future automotive use cases. As the battery price is expected to decrease in some years, the cheaper motor solutions as developed in our ReFreeDrive project (induction motor and synchronous reluctance motor) will become more viable economically, when the efficiency lost by switching to a cheaper motor technology can be offset through a higher battery capacity.

Given the massive uptake of Battery Electric Vehicles (BEV) production beyond 2025, and the expected demand for rare-earth based PMs also in other end-uses beside E-mobility, we see a huge potential for series application of the ReFreeDrive drivetrain proposals with their adequate performance, whenever ultimate power density can be traded-off for other goals as cost reduction, local supply guarantee and ease of recyclability.

There was only a small deviation - a laguna - in the content compared to the Document of Activities (DoA), as we could not use any real measured performance data for the variant of “induction motor with fabricated rotor”. Given the logistic problems due to Covid-19 and other issues at the sub-contracted supplier in the UK, the fabricated Induction Motor (IM) could not be produced, assembled and shipped to the testing facility in time to allow any testing during the official course of the already extended project lifetime. This was a clear knock-on effect from WP6 and WP7 (more details on the respective reasons see deliverables of WP6 & WP7. This caused also a small delay of 2 weeks in final submission of this delivery, as the real test results of the “induction motor with die-cast rotor” were affected by a wrongly calibrated software control, and hence our last hope – until virtually last minute- was to wait to fix software issues and test again the IM with the second variant of the "fabricated rotor" to prove targets on the bench.

Nevertheless, we then could use a combination of simulated design performance and real test performance to provide an overview on both motor topologies here.

Furthermore, as a surplus to the Grant Agreement (GA), we added a comparison in some aspects to the rare-earth PM motors, which indicates relevant directions to potential users of our ReFreeDrive solutions for possible substitution scenarios in future automotive applications.

These additional comparisons provide relevant information to assess the potential contribution of our ReFreeDrive alternatives in the context of the European Union (EU) Commission's Green Deal and particularly within its new Circular Economy Action Plan.