Eunice Project: Eco-design and Validation of In-Wheel Concept for Electric Vehicles

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Short Abstract
Forecasts about close future electrification of transport confirm that the A-B class vehicles with limited range/autonomy are the most appropriate ones to initiate the general deployment of electric vehicles. In-wheel electric motor architecture hold major advantages for the A-B class vehicles, allowing high modularisation of the vehicle architecture, increased interior space and improved driveability.

Nowadays a B-class vehicle does not exist in European market, even though the predicted market for this technology, in a conservative scenario, is 50,000 EV vehicles manufactured in 2015. This is the driver for the EUNICE project: to obtain an efficient in wheel motor concept for B-segment cars at a reasonable cost.

1 Introduction
Even in the actual economic crisis, global demand of light vehicles (A-B class) is expected to grow, and the main objective of this proposal is the development and validation of an in wheel motor assembly prototype based on a McPherson corner suspension topology, in order to address the main technical risks associated with thermal environment under extreme operation, vehicle dynamics, driveability and durability, associated with the motor in wheel configuration. The proposed baseline concept will be based on a fully air cooled-power electronics integrated wheel. The system has been designed so that only two electric motors are needed to provide an acceptable level of vehicle performance. The ease of integration with existing front wheel drive vehicle platform is a key requirement in order to ensure the market penetration of the proposed solution. State of the art electric motors using axial flow topology are being used for the development of the solution. Results of thermo mechanical modelling of the solution will be presented, considering normalized driving cycles but also detailed specifications of extreme cycling conditions provided by OEM during the project, including the hot day-cold day conditions representative of vehicle extreme use. In addition to that, the aspects related to vehicle dynamics, driveability, safety, user acceptance, endurance, will be assessed using “state of the art” analytical tools and procedures.
The chosen concept will be evaluated against OEM specifications. It will necessary to carry out some studies from manufacturing and recycling points of view, in order to ensure the affordability of the solution when in series production. It has to be highlighted that the advantages of the vehicle lay out with electric motors at the wheels in terms of integration, as there is plenty of space for different elements such as battery, accessories and even small range extender concepts. The benefits of this lay out can be seen in the Figure 2:

Figure 2: Preliminary vehicle lay out with electric motors at the wheels in terms of integration.

2 Main Targets of the EUNICE solution:

The integration of electric motors into the wheel requires of high power density in order to provide the required torque and hence appropriated driveability. Based on the preliminary analysis activities at the beginning of the project (thermo mechanical, electric/electronic, vehicle dynamics characteristics) the main targets are:
TARGET 1: Competitive performance versus representative B class internal combustion engine vehicle 26kW nominal power, 62kW peak power (15 seconds).

The solution presented aims to suit perfectly the performance required by a conventional ICE B class vehicle. The modularity that can be achieved by the in wheel powertrain solution, could be easily integrated in other future platforms, not covering only the B class but also C class or different goods delivery vehicles, thus representing a clear advantage for the OEMs, by dramatically reducing the total development costs for the launching of new vehicle platforms and/or models. It is important to highlight that motor in wheel allows significant flexibility not only in the front axle but also at the rear, which is one of the preferred lays out for new electric vehicles.

TARGET 2: Increased total unsprung mass of the front axle vehicle over B class representative vehicle <45%.

B class suspension dynamic behaviour performance is critical, because ride comfort and quality are concepts of increasing importance for B class cars. An increased unsprung weight below 40% will be a very challenging target in terms of manufacturing, and will help to avoid side effects in suspension dynamic performance related with high unsprung mass [1,2,3]. Comfortable ride suspension system would have a dominant frequency between 1 and 3 Hz, and the increased sprung mass of the B class EV, comparing with the conventional ICE B class vehicle, will help and allow to maintain the suspension dynamic range within the human comfortable perceived frequency range (1-3Hz).

Two critical issues are being considered within the project in order to meet the targets:

- Thermal behaviour and management. In order to evaluate the thermal behaviour of the system, it is necessary to carry out a detailed thermal analysis of the solution, which will take into account the following aspects:
  - Detailed heat sources of the components that comprise the integrated solution.
  - Ventilation flow pattern, using all the flows from the vehicle front and wheel well.
  - Description of the motor in wheel solution physical properties, specially the heat transfer coefficients of all surfaces as well as the masses and thermal characteristics of the different components.

- Driving dynamics assessment. In order to maintain the same comfort performances as in the B class segment vehicles in the market, with a driveability equivalent to existing vehicles. For this purpose, the integration of components is critical to maintain the module weight as low as possible.

Main design solutions of the EUNICE solution are summarized in the Figure 3:
The power electronics module will be attached in a separated casing attached to motor casings, but using mechanical connections that will avoid heating to be transmitted while maintaining structural integrity under harsh vibration environment. The IGBT module will be attached to the air cooled cool plate, which will feature a fin arrangement to efficiently evacuate the losses, which could reach 1.5kW “peak power” design case. The e-motor will feature internal recirculation of gearbox oil at the yoke area, removing heat from the motor and gearbox that will be taken to the coolest portions of the casing. Internal air cooling will be implemented by additional features in the rotor of the electrical machine. Additional ducting and forced cooling concepts will be explored, as well as the by-pass of cool air from the air conditioning circuit, which might be necessary for extreme conditions in order to ensure that an appropriated temperature difference is available. It has to be highlighted that the features to be implemented in the baseline are dependant of the combination of driving cycles with extreme temperature conditions.

Concerning the supply chain of the solution is summarized as follows:

- Tier 1: Magneti Marelli Suspension Systems (integrates all the components into the front axle).
- Tier 1.5: GKN EVO eDrive Systems Ltd (supplies the electric drive featuring e-motor and gearbox with housing).
- Tier 2: Infineon Technologies AG (power electronics components).
- Tier 2: Hayes Lemmerz, S.r.l. (Wheel assembly).

### 3 EUNICE in wheel solution specifications

Within this project, the quarter car corner based on electric motor in-wheel topology will target a nominal power of 26kW per wheel (62kW peak for 15 seconds) and oriented to B class vehicles, following the market trends and evolution for the next 5 years, which indicates that this B-class will increase gradually its market penetration annually.
The expected performance of the EUNICE solution is represented in the table and pictures in Figure 4, for a PININFARINA modified FIAT PUNTO 1.4 T-Jet car, which is an excellent representative of a good-seller B-class car in Europe and worldwide. In blue the performance of the Internal Combustion Engine FIAT PUNTO model, 16v and 120 CV. In green the same model equipped with two front EUNICE project in-wheel motors.

![Figure 4: Estimated performance of the solution on the FIAT PUNTO platform, comparison with the internal combustion engine 1.4 16v model performances, and preliminary EUNICE solution design.](image)

The winning solution anticipated is an “in-wheel motor” solution, based on standard McPherson suspension type, which is the most widespread suspension type in the B-C class cars. This concept will be conveniently re-engineered and eco-designed to reduce its weight while achieving good performances, designed with the critical issues related to the motor in wheel configuration as key drivers, integrated with the other e-corner components and adapted to the new extra functionalities.

To provide a final power-train solution based on the in-wheel motor topology, that could be ready for a short-term commercialization by the partners of the consortium, or to be sold to third companies, all the critical technical aspects (thermal, vehicle dynamics, safety, reliability) will be considered inside the project. All the design phases are covered for all the components and functionalities required by the complete system: the electrical motor operation, the cooling system and its integration with the vehicle thermal management strategy, the integration into a suspension system, the electric motor control and the power electronics.

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**References**


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