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H-RAM: Hybrid Rear Axle Module An innovative hybrid differential for P3 and P4 applications

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Summary

H-RAM is an innovative electrified rear differential concept for P3 and P4 applications aiming to improve the electric functionalities in a hybrid powertrain. This paper will provide an overview of H-RAM concept, show the benefits of a highly integrated design and demonstrate the advantages versus other hybrid powertrains in terms of performances and modularity.

Keywords: BEV (battery electric vehicle), PHEV (plug in hybrid electric vehicle), efficiency, emissions, vehicle performance.

1 Introduction

The legislation limits for pollutants emissions are strongly pushing OEMs to electrification of their vehicle fleet. Even high performance car manufacturers are taking on the challenge of using electrification - a trend also observed for premium and exotic vehicles. This electrification job is seen from some manufacturers as an opportunity to increase the vehicle performances while moving to more “green” powertrains. It means that the installation of electric power on the vehicle should certainly not affect the performances of the vehicle models with only an internal combustion engine, but increase the performances while cutting the pollutants emissions during driving. As such it is no easy task, since the hybrid system (battery, inverter, and electric motor) affects strongly the overall vehicle weight and thus its driving dynamics as well as system cost. On top of this most manufacturers look for synergies between hybrid and standard versions in order to minimize cost and investments of the overall vehicle platform. All the arguments above weigh even stronger focussing on high performance cars due to the challenges posed by low to medium production volumes. Because of this, modularity of the specific subsystems plays a key role during the concept selection.

2 The concept

The Dana Graziano E-drive development started with these considerations together with the experience gained during transmissions production and internal development programs, like the OGeco transmission, a development inspired by an idea of designing a robust and efficient transmission including electrical drive.

Analysing different hybrid architecture, the multispeed P3 configuration was selected as the best solution to maximize the performances benefit of the additional electric power in combination with a high efficiency mechanical layout, which is beneficial especially in EV and Hybrid mode. In order to maximize the system efficiency and reduce the overall weight and mechanical complexity versus AT's and DCT's, the P3 hybrid module was integrated in an automated manual style transmission.

During the OGeco development, the efficiency advantages of the P3 architecture versus a comparable P2 was measured on HiL test rig.

Experimental results showed up to 8% of energy saving of the P3 architecture versus the comparable P2 one during WLTC driving cycle run in EV mode.

Following these earlier activities, Dana Graziano has developed and patented a P3 hybrid powertrain concept in form of a compact Hybrid Axle Module.

The subassemblies are represented here in *Figure 1*. It firstly comprises of an input module before the bevel gear set driven by the internal combustion engine before finally driving the differential.

Whereby the output from the conventional gearbox of the combustion engine is connected to the input flange of the Dana Graziano hybrid rear axle module through the prop shaft.

The motion is transferred via a cylindrical gear set, providing an additional gear ratio offering flexibility regarding powertrain adaptation and packaging before finally driving the differential via the bevel gear set. Hybrid functionality for this fully integrated system is provided by the second power source into the differential, an electric motor with a hollow rotor shaft allowing the drive shaft to pass torque from the differential through the E-Motor to the wheel. Also known as a concentrically or in-line configuration.

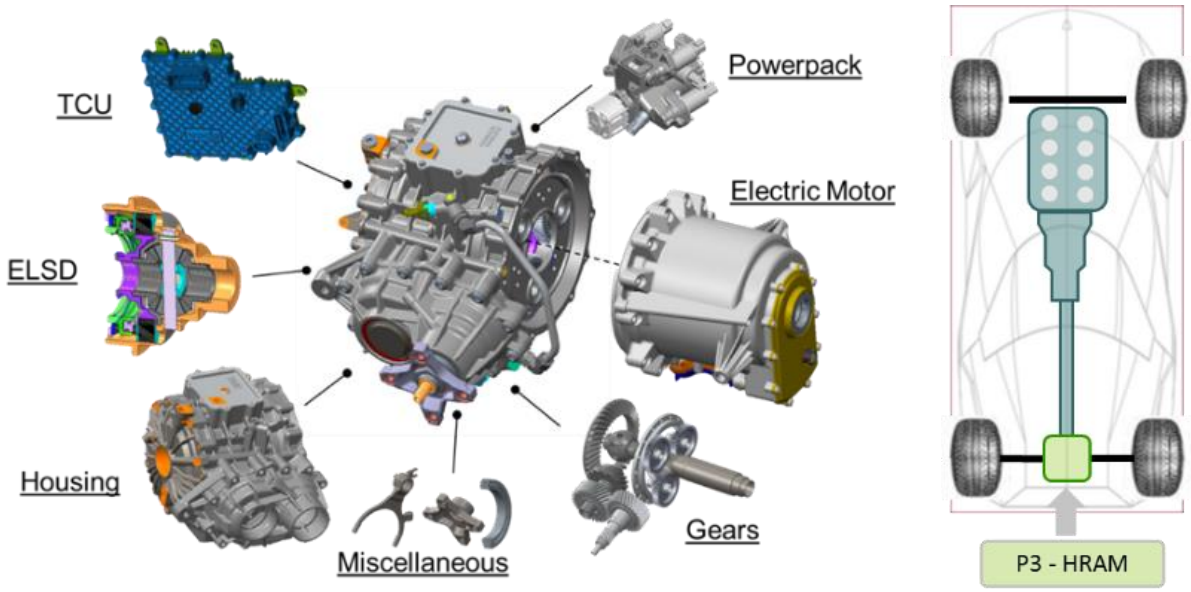

Figure 1 - Two speed Hybrid Rear Axle Module and subcomponents

Removing the mechanical link between the prop shaft and the final drive, the system can be re-configured as a stand-alone electric axle, suitable for both front and rear wheel drive application as a so called P4 axle. This modularity makes the technology suitable for P3 hybrid, P4 through the road hybrid or BEV architectures.

The arrangement forms the basis for the “Hybrid Rear Axle Module” and optionally can be equipped with the Dana Graziano electrical limited slip differential (eLSD), a mechanical LSD or a traditional open differential (standard option) within the same package envelope.

Using the eLSD (*Figure 2*) combines the differential functionality with performance enhancing traction control, for increased driving experience in pure electric and hybrid mode without compromise.

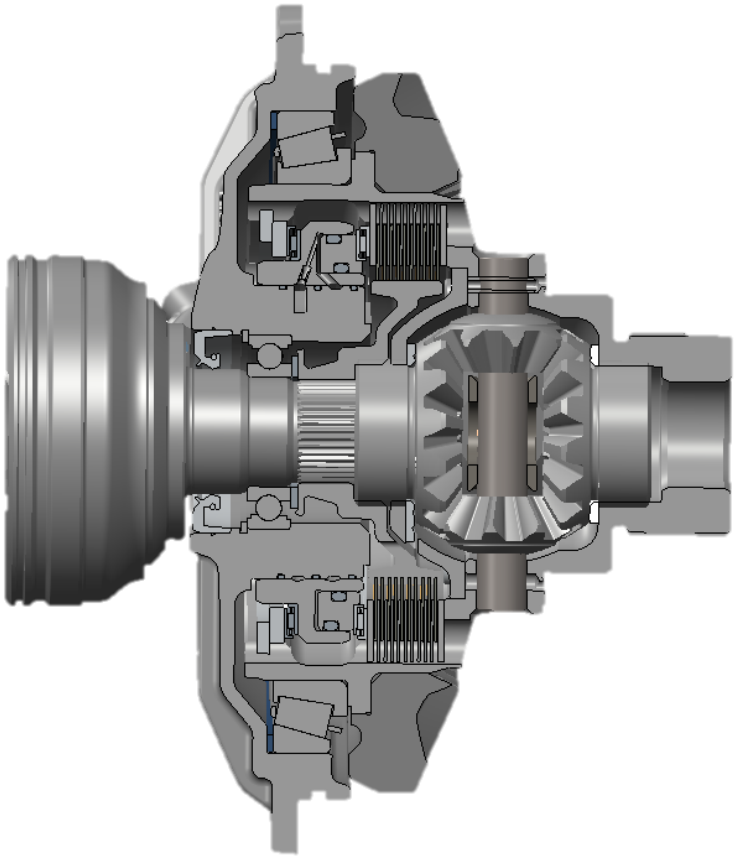

Figure 2 - The electrical limited slip differential (eLSD) by Dana Graziano

The rear axle is capable of 2500 Nm locking torque and is suitable for all sport car applications, being actuated in less than 100 ms both in closing and opening manoeuvres.

Due to the chosen approach the electric motor size can be selected according to the performance requirements and the available vehicle package. The electric motor is connected through a planetary gear set module directly to the differential housing, bypassing the bevel set, for the maximum efficiency. In addition two gear ratios allow for a wide speed range.

The planetary gear set module is a compound epicyclical two-stage transmission. This architecture allows high reduction ratios between the electric machine (max speed up to 18000rpm) and the wheels in a compact package. Furthermore it allows the possibility to have two selectable transmission ratios (for a higher torque-speed envelope and better efficiency) to the wheels. In *Figure 3* a view of the planetary gear set is presented.

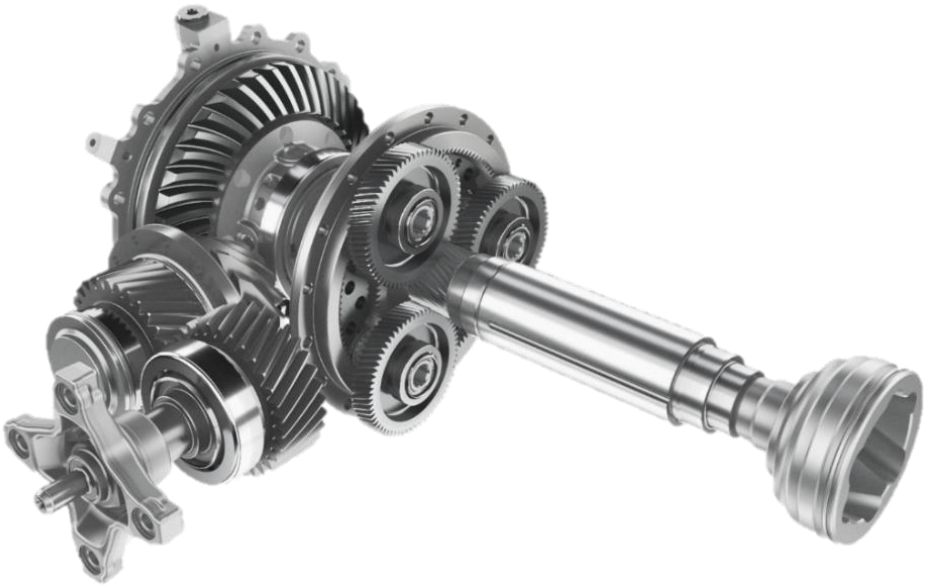

Figure 3 - Internals of 2 speed planetary set

The shifting system is based on a dog-clutch, hydraulically actuating a sleeve from neutral position into gear. The speed synchronization is ensured by the electric motor enabling an overall shifting time of less than 100ms. A typical manoeuvre is shown in *Figure 4*. Shift time examples are: < 70ms for Neutral to first gear shifts and < 95ms for first to second gear shift. Thanks to the hybrid system specification, the gear shifting is programed for vehicle speed above 150km/h, making it possible to drive the WLTC without shifts.

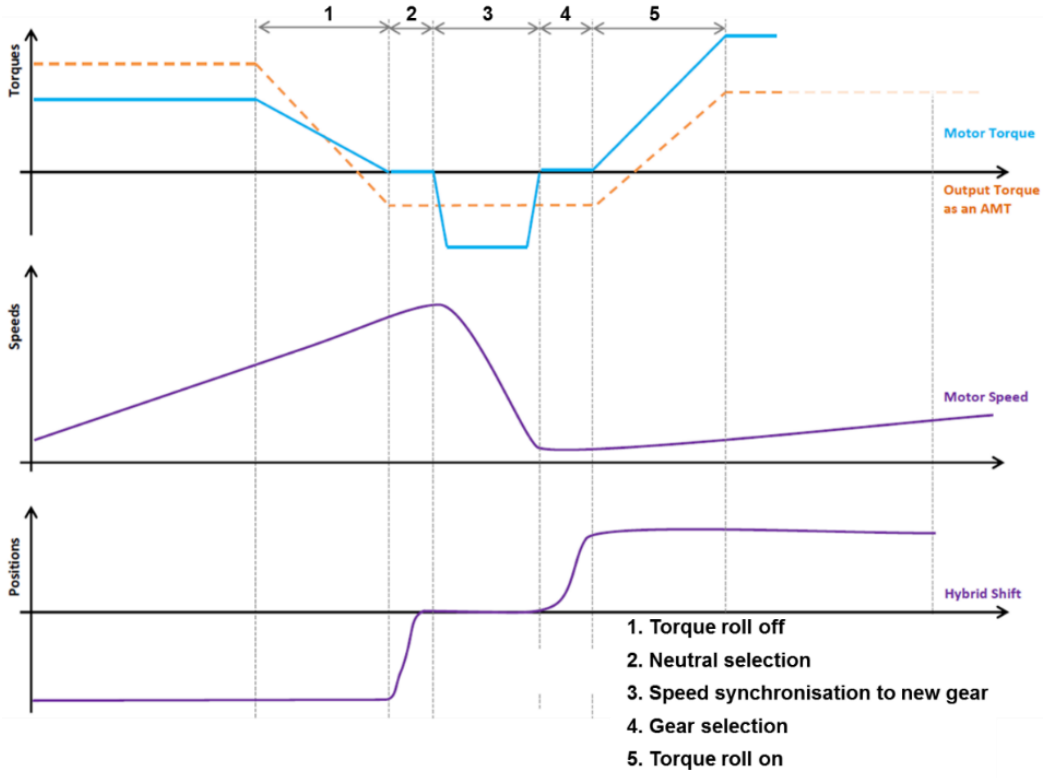

Figure 4 – Shifting example

The concept´s peculiarity is its compactness that allows OEMs to package a complete hybrid system within the sub frame of the rear axle, without modification of the standard powertrain (ICE, gearbox and prop-shaft). It enables all the advantages of a P3 hybrid configuration, such as the higher efficiency from the electric machine to the wheels and the capability of a very strong eBoost at low speeds when in high gear. For this purpose the graph in *Figure 5* shows how a P3 hybrid configuration, being independent from the ICE gearbox ratio, allows an important advantage in the eBoost torque at low speed with regards to a P2 system.

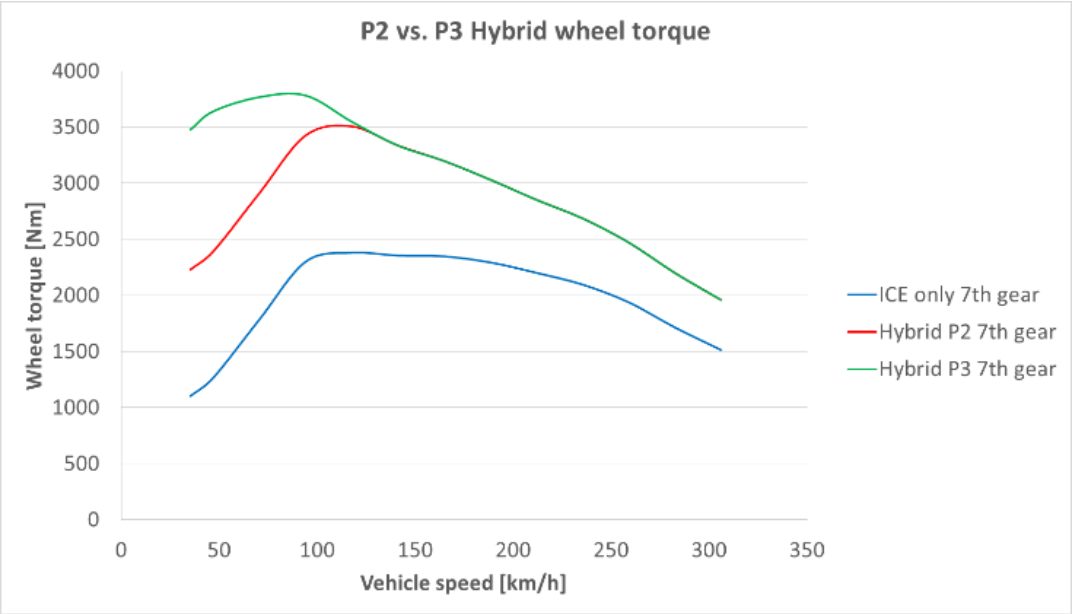

Figure 5 - P2 vs. P3 hybrid wheel torque in high gear

From a driveability point of view the advantage of the e-Boost effect is useful to have and is an important torque assist directly to the wheels in case of acceleration request without the need of downshifting on the ICE gearbox side. It can then provide immediate boost in case of kick down manoeuvre when the downshift is needed.

Other interesting features are electric and hybrid drive, therefore CO2 emissions reduction and KERS, useful for recovering kinetic energy, especially when a charge sustaining strategy is implemented.

The first P3-Hybrid module (*Figure 6)* has been developed, built, tested and shipped in a period of only 10 months, and has been successfully installed in vehicles, enabling development and system application activities.

Figure 6 - Compact external package

3 Actuation

The Dana Graziano Hybrid Rear Axle Module is equipped with a hydraulic power pack in order to deliver all the actuation needed for the functionality and high power density of this unit. With the scope to provide a compact package, Dana Graziano's R&D department developed a simple and elegant system that can operate without the accumulator while still maintaining high actuation time performances.

The power pack is composed by a BLDC motor driving a gear pump which feeds the high pressure line. The nature of BLDCs allows the use of the pump motor in a 100% duty cycle, this means with the proper choice of the line pressure valve, when an actuation is needed there is no need to wait for the acceleration of the electric motor which is already spinning. Thanks to this arrangement the dynamic response of the hydraulics is excellent. A pressure regulating valve is then able to control the pressure in the eLSD piston chamber that is related to the requested locking torque from the VCU.

4 Optional functions

The Hybrid module can facilitate a park brake mechanism if required. Dana Graziano developed and tested a patented park brake solution suitable for the P3 / P4-hybrid module. This mechanism is integral and can be linked to the hydraulic control unit for actuation.

Depending on the vehicle specifications and application strategy a thermal management for the hybrid module may be desirable. Therefor an oil to water heat exchanger could be fit to the hybrid module and connected downstream to the coolant circuit of the electric motor, without the need of a separate connection to the vehicle coolant circuit.

5 Summary

Dana Graziano with his new Hybrid Rear Axle Module offers as a Tier 1 supplier a step forward on the path to electrification, with a compact package and full hybrid functionalities. An efficient drive train, capable of P3 hybrid functionalities and equipped with high performance active differential, makes the system perfectly suitable for OEMs who want to accept the heat of hybridization without compromises on performances.

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Authors

Roberto Gay is Head of Product Development EMEAR at Dana Graziano(Turin). He graduates at Turin Polytechnic in 1994 as Aeronautic Engineer and joined Dana Graziano in 1995 as manufacturing engineering responsible for the design of assembly lines and EOL test rig for high performance automotive transmission. In 2003 moved to product development as design responsible for AWD and EV product line, than as Head of Automotive Transmission Design and, since March 2016, in the current position.

Carlo Cavallino graduated mechanical engineering at Politecnico of Turin. He joined Dana Graziano (Turin) in 2005 as project engineer for 4WD application and high performance DCT Transmission. He had the responsibility of the advance engineering for three year and nowadays he lead the "powertrain systems development" team. Focus of the team is the design and development of powertrain systems for hybrid and EV application.

Sergio De Santis is a Project Engineer at Dana Graziano (Turin). He graduated at high school in 1998 and had a master of mechanical designer after the diploma. Joined Dana Graziano in 2002 covering a role of designer specialized on 4WD system; starting from 2011 worked on DCT transmission and high performance applications. Nowadays he is covering a role of Project Engineer on P3 and P4 Electric Axles for high performance cars.

Peter Riemer, Senior Project Engineer and Sales at Dana Incorporated, starting in 2017 in Germany. In his current position he is supporting the hybrid and electric transmission business with customers, following his previous experience in driveline business development for automotive transmission, AMT & DCT actuation development and CVT transmission testing. He graduated in 1995 at the Fachhochschule für Technik und Wirtschaft in Berlin as a Dipl. Ing. (FH) for vehicle engineering.