

## **Is multispeed gear train a competitive solution for C-segment EV powertrain?**

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### **Abstract**

We propose a comparative analysis between two electrical powertrains for C-segment EV traction requirement: a single speed ( 8:1) and a two-speed automatic shifting transmission (1<sup>st</sup> gear: 16, 2<sup>nd</sup> gear: 8) trains, using rare-earth-free interior permanent magnet (IPM) machines. Efficiency maps, energy consumption for Artemis driving cycle as well as weight of the two proposed trains are looked at. Apart from its apparent complexity and potentially additional cost, it is found that the two-speed automatic transmission shifting power train is competitive regarding the electrical machine active material amount and, more importantly, the overall driving cycle efficiency.

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*Keywords: electric vehicle, gear train, electrical machines, rare-earth-free, efficiency*

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## **1 Introduction**

When designing the electrical machine for a geared powertrain, the size/weight and performance of the machine depend strongly on the gear ratio and the number of gears. Thus a particular attention has to be given to the choice of an appropriate gear ratio or, when a multispeed gearbox is adopted, to the choice of the number of gears and their ratios. The impact of this choice on the powertrain initial cost and overall efficiency over a vehicle driving cycle efficiency is currently an effervescent research subject [1]. Aside from the machine cost and efficiency, another design constraint is the constant power operating region. Indeed, a high constant power operating zone restricts the feasible machine topologies, especially when low grade permanent magnets are used [2] or, in a larger extent, when the machine has no field excitation source.

## **2 Machine design**

The starting point is the transient torque/speed characteristic of a C-segment EV traction. The vehicle traction requirements and constraints considered are summarized in table 1. The first solution considered is a single gear power train with a commonly adopted gear ratio of 8:1. As shown in Fig. 1, the selected and optimally designed machine is a V-shape flux focussing 12-pole/72-slot IPM using Y40 (0.43T @ 20°C)

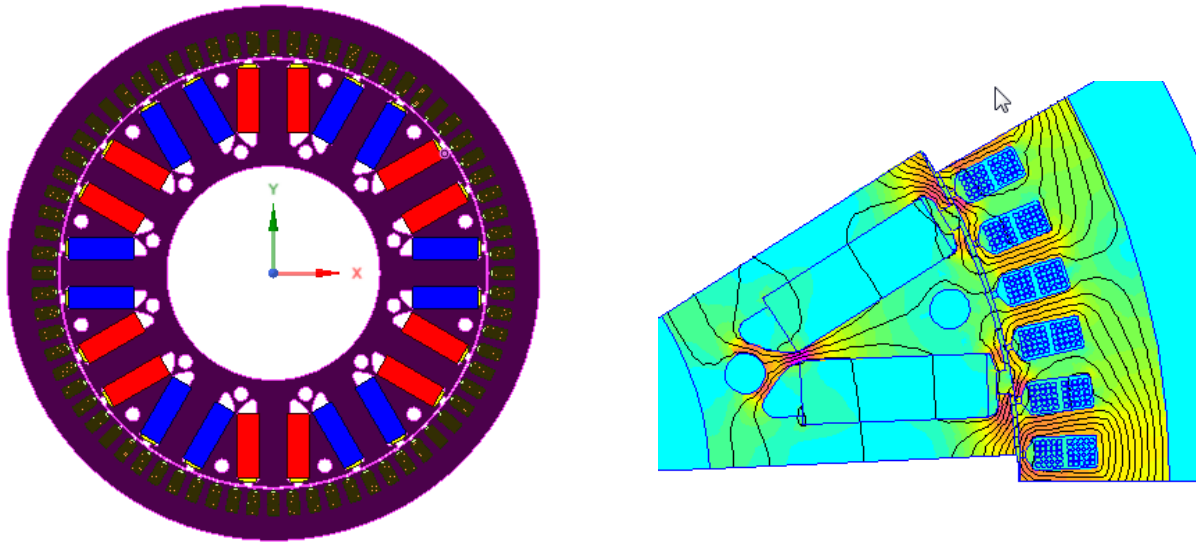


Figure 1 2D view of the adopted machine

ferrite magnets, having 260mm external diameter and 110 active axial length. The maximum current density is fixed to 20 Arms/mm<sup>2</sup> to comply with the possibility of adopting air cooling. The machine torque-speed characteristics and efficiency maps calculation are explained in [2]. The next step of this work consists to only adjust the active axial length of the initial machine so as not to alter the power converter rating (270 V<sub>dc</sub> and 400A<sub>peak</sub>) but only to develop half the maximum torque required by the 8:1 single gear machine.

Table 1: Traction requirements and constraints

Requirement	Target
Top speed	12000 rpm
Peak output power	60 kW for 20sec
Oprating dc bus voltage	200 – 400V, 270 nominal
Maximum current	400 A
Maximum outer diameter	260 mm

The torque/speed characteristics and the efficiency maps of these two machines are shown in figs. 2 and 3, respectively. It can already be observed on the efficiency maps that the second machine has a wider high efficiency area and, as can be expected, this will have an influence on the overall driving cycle efficiency. Table 2 gives the machine active material mass of the two machines and their associated gearboxes. The exercise of selecting the optimal gear train for each drive is not an obvious one as we haven't done any detailed mechanical calculations so far. This is the reason why the choice was dictated by commercially available products: Getrag two speed gearbox for electric vehicles [3], and a transverse single-speed electric drive transmission from BorgWarner [4]. These two gearboxes have comparable maximum transferable power and the two-speed Getrag one includes the dual clutch and the control unit in the mass count. When looking at the total weight (in table 2) of the two drive solutions we can see that is not the determining criterion dictating the choice as there is almost no difference between the two solutions. The cost analysis is difficult to perform with accuracy at this stage. In the next section we will look at the energy consumption of the two drives when they are used to in a C-segment vehicle.

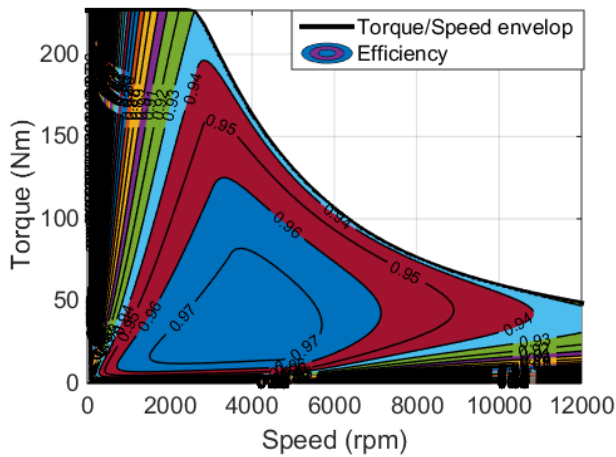


Figure 2: Single gear (8:1) machine torque/speed characteristic

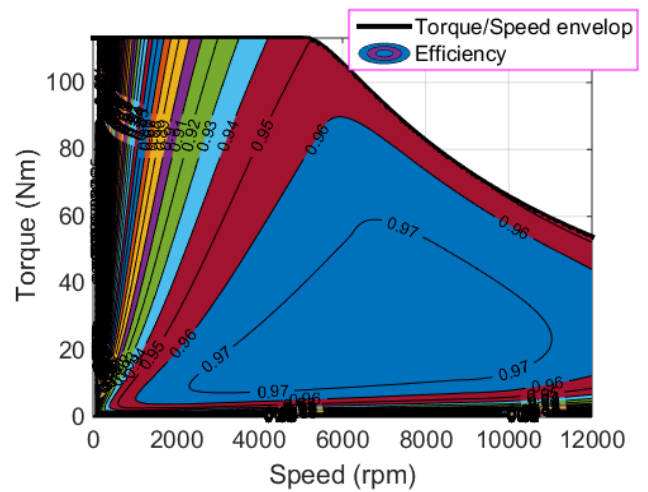


Figure 3: two-speed automatic shifting transmission machine torque/speed characteristic

### 3 Driving cycle energy consumption

Based on the efficiency maps already calculated, driving cycle simulations can be performed once an optimal control strategy (minimum copper loss in this paper) is chosen. We used Artemis cycle as it is the most representative of European driving behaviour. The urban, road and motorway operating points as well as the required and designed machines transient (18 s) torque/speed characteristics are given in figs. 4 and 5

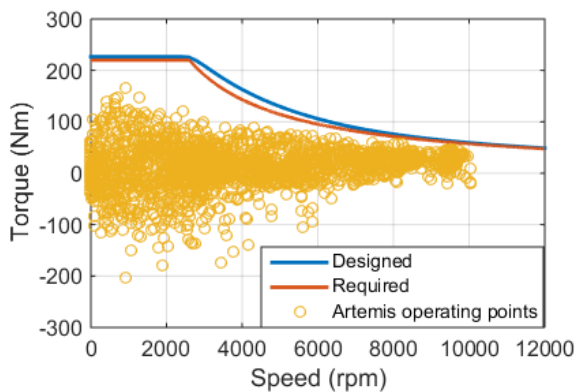


Figure 2: Artemis operating point for the case of single gear (8:1) drive train

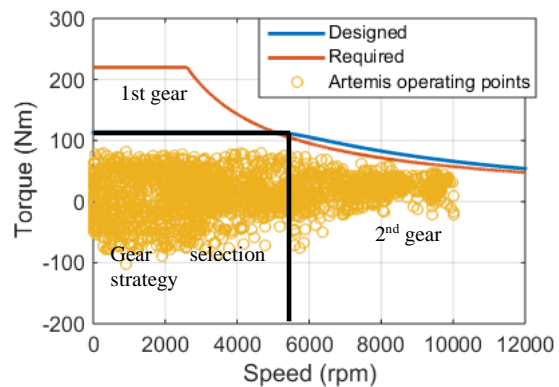


Figure 3: Artemis operating point for the case of two-speed automatic transmission drive train

Table 3 summarizes the overall energy consumption of the two drive trains. A 6.3% gain in energy consumption is achieved with the two-speed automatic transmission drive train over the entire Artemis cycle. Note that the gearbox efficiency is not considered here and that no gear selection strategy was adopted in the enclosed area on fig. 5. For this purpose the reader is invited to read [5] and [6] for further insight into the potential benefit of such a control strategy. Another point to highlight is the dynamic performance of the 2-speed drivetrain thanks to a wider constant torque region resulting in a better acceleration capability.

Table 3: Energy consumption (kWh) in 1 Artemis driving cycle

	Urban	Road	Motorway
Single gear drive	0.80	2.24	5.51
Automatic transmission drive	0.75	2.07	5.3

## 4 Conclusion

We proposed a comparative analysis between two power trains for C-segment EV traction requirements. We have shown that using a two-speed automatic transmission power train allows to down size the machine and save energy (though without considering the gearbox efficiency), and to reduce the machine constant power operating region. With this alleviated constraint other machine technologies become feasible in view to comply with the traction specifications; this is notably the case of magnet-less machines.

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**Tahar Hamiti** was born in Larbàa Nath Irathen, Algeria, in 1979. He received the Ingénieur d'Etat degree in automatic control systems from the University of Tizi-Ouzou, Algeria, and the PhD degree in electrical engineering from the University of Lorraine, France. From 2010 to 2015, he was a Research Fellow and subsequently a Lecturer within the Power Electronics, Machines and Control Group, The University of Nottingham, UK. In 2015 Dr Hamiti joined VEDECOM, a French institute for energy transition to work on novel electrical machines for electric and hybrid vehicles. His research interests include modeling, design, and control of electrical machines for transportation applications and power generation.



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**Dominique Lhotellier** spent nearly 20 years on innovative solutions in power electronics and e-motors for affordable more electric cars, at RENAULT. He is now in charge of Electrification projects at VEDECOM, a new French institute for more electric cars."