SIMULATION STUDY OF DUAL MOTOR DRIVE SYSTEM EFFICIENCY

Josef Břoušek[1], Tomáš Petr[2]
[1]Technical University of Liberec, Department of Vehicles and Engines, Liberec, Czech Republic,
josef.brousek@tul.cz
[2]Technical University of Liberec, Department of Vehicles and Engines, Liberec, Czech Republic,
tomas.petr@tul.cz

SIMULACE ÚČINNOSTI POHONU DUAL MOTOR DRIVE SYSTEM

Abstract: *This paper presents a simulation analysis of the overall efficiency of Dual Motor Drive System (DMDS). The simulation was performed in software Ricardo Ignite. The main objective of the analysis was to verify the idea of using two different electric motors connected to the input of a single-speed transmission with mechanical differential. The analysis was performed with the drivetrain considered for a vehicle in C-segment. The results confirmed the expected high values of overall drive efficiency and can be used as a basis for further advanced simulations and electric drives experiments.*

Keywords: *dual motor drive system, efficiency, electric drivetrain, electric vehicle*

1 INTRODUCTION

Due to the continuous tightening of regulated limits on emissions and fuel consumption of vehicles in connection with global warming and limited energy resources in recent years, the attention of vehicle manufacturers, governments and customers is focused on vehicles with alternative propulsion systems as primarily on vehicles with electric and hybrid drives. Research and development are aiming to new concepts of drivetrains and to systems enabling greater availability of known technologies in terms of affordability and reliability of these drivetrains [1]. The main topics for electric vehicles are the topics around electric vehicle range extension on a single charge, high performance and high drive efficiency [2].

Most of the mass-produced common electric vehicles nowadays use only one electric motor with a mechanical single-speed transmission. This solution provides the easiest way how to build sufficient electric drive for a vehicle, for example, VW e-Golf 2017, Hyundai Kona 2018, Nissan Leaf 2019. But as mentioned in the previous paragraph, research and development are further devoted to new possibilities to offer an electric drive with better parameters so that the vehicle is able to fully replace the vehicle with a conventional combustion engine. One way to achieve better parameters is to use a drivetrain with multiple electric motors. Some manufacturers are already starting to offer vehicles with multiple electric motors, especially for vehicles with higher performance, for example, Tesla Model 3 Long Range 2018, Audi e-tron 2019, Mercedes-Benz EQC 2020.

Various work has been done in recent years to increase drive efficiency through the development of new drivetrain arrangements with multiple electric motors. Some authors deal with the arrangement of a drivetrain with one motor for the front axle wheels and the second one for the rear axle wheels [3]. Other authors focus on the efficiency of multi-motor drives connected via planetary gearboxes [4]. The results of these works gradually indicate that the use of a right combination of multiple electric motors can bring improvements in drive efficiency, drive performance, reliability and safety [5]. The authors also mention the lack of literature specifically on the topic of drive efficiency of drives with two electric motors.

Based on our previous analyses and the results of published works by other authors we decided to analyze the drivetrain configuration "Dual Motor Drive System" (DMDS) with one smaller permanent magnet synchronous motor (PMSM) and one larger induction motor (IM). Based on the previously mentioned literature, DMDS could provide increasing drive efficiency by providing high driving dynamics of the vehicle. In contrast to the solutions described in the previous paragraph, DMDS could offer a drivetrain solution with a requirement for very high drive efficiency and mechanical design simplicity that could make this technology more accessible in the current electric vehicle market.

2 SIMULATION METHOD AND PARAMETERS

2.1 SIMULATION SOFTWARE RICARDO IGNITE

For the following simulations in this article, we used simulation software IGNITE by Ricardo. IGNITE is a physical simulation package that allows full modelling and simulation of vehicles. Thanks to its wide range of libraries (Power Train, Standard, ThermoFluid and Modelica), it is possible to simulate conventional vehicles as well as hybrids and electric vehicles [6].

The output of the simulation can be, for example, information about vehicle driving dynamics, engine and motor efficiency, etc. Our used model can be seen in Fig. 1.

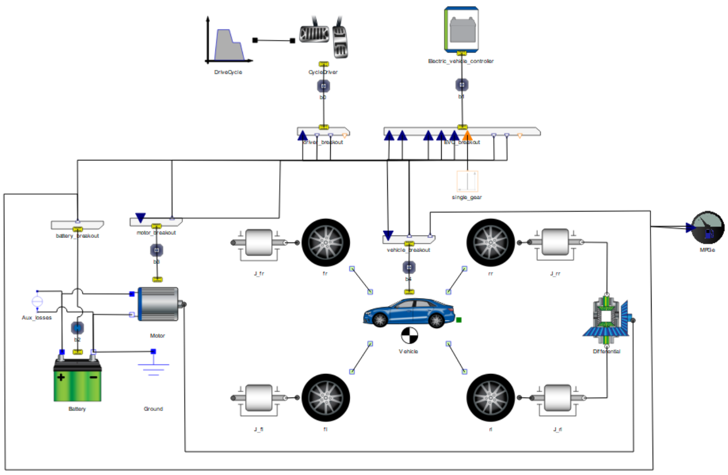

Fig. 1 *Electric drivetrain model in Ricardo Ignite*

A mathematical block "Vehicle" is used to calculate vehicle dynamics. The purpose of this block is to calculate the translational movement of the vehicle (position, speed, acceleration) and a normal load of each axle. The following Fig. 2 shows the vehicle geometry and force relationships to the centre of gravity of the vehicle.

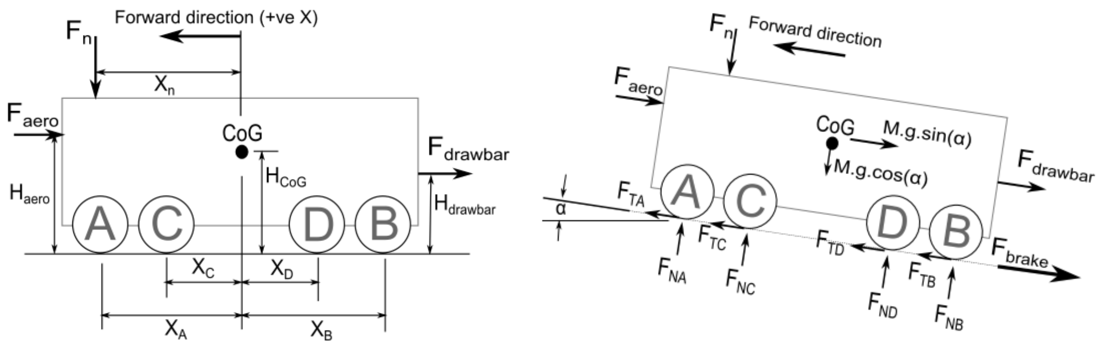

Fig. 2 *Vehicle geometry and force relationships to the centre of gravity of the vehicle* [7]

2.2 DUAL MOTOR DRIVE SYSTEM

At the Department of Vehicles and Engines at TUL, we study drivetrain configuration DMDS. This drivetrain consists of two electric motors and one single-speed transmission with mechanical differential. The main idea is to use mechanical design simplicity of drivetrain while taking advantage of the combination of two electric motors.

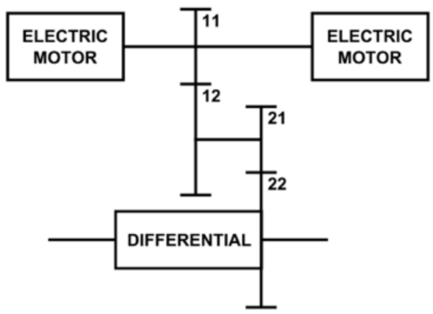

Fig. 3 *Components arrangement of DMDS drivetrain*

DMDS uses two different electric motors connected to the input of single-speed transmission (Fig. 3) to improve drive efficiency and performance parameters of the entire drivetrain. The principle of operation is to maintain the drivetrain in the area of maximum efficiency by means of combined torque control of both motors. This is done by an advanced control algorithm. DMDS thus optimizes the efficiency for most vehicle operating conditions. For example, one small, high efficient motor can be used for smooth low load driving and the assistance, the powerful motor can be used only for the requirement of heavy load, high acceleration or regenerative braking.

2.3 INDUCTION MOTOR AND SYNCHRONOUS PERMANENT MAGNET MOTOR

The most used motors in electric vehicles according to the data published in [8] are nowadays induction motors (IM) (eg. Tesla S) or synchronous permanent magnet motors (PMSM) (eg. Nissan Leaf, Peugeot iOn). Both types of motor can be seen in Fig. 4.

IMs are mainly used because of their low cost, due to the absence of permanent magnets. Furthermore, high reliability and maintenance-free operation are outstanding. In addition, these motors are naturally de-energized in the event of a drive failure, which is very important for safety.

PMSM are synchronous motors that use permanent magnets from modern rare earth materials such as Sa-Co, or Nd-Fe-B instead of excitation windings to generate magnetic flux. In addition to significantly simplifying the motor (the motor does not include field windings, rings), the source of excitation current is eliminated. The motor operates at a significantly better efficiency than a comparable IM because it does not remove the magnetizing current from the network. In addition, there is no loss in the rotor in the field winding as in a conventional synchronous motor, or in a rotor cage as in IM. As a result, the motor of the same power has considerably smaller dimensions than a conventional IM and better efficiency [9].

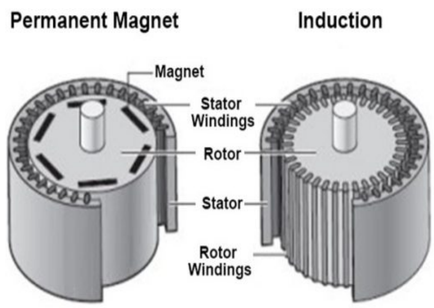

Fig. 4 *Design of induction motor and permanent magnet motor* [10]

2.4 SIMULATION PARAMETERS

We analyzed DMDS installed in the vehicle with VW e-Golf parameters (Tab. 1). We proposed to use electric motors with regard to the requirement of high drive efficiency at low load and city speeds and at the same time with the requirement for achieved high dynamics of the vehicle.

Tab. 1 *Vehicle parameters for simulation*

Parameter	Value	Unit
Vehicle frontal area	2,16	m^2
Aerodynamic drag coefficient	0,25	-
Rolling resistance coefficient	0,015	-

Gear ratio	8,1	-
Wheel moment of inertia	2	kg.m^2
Vehicle mass	1600	kg
Tyre radius	0,31595	m
Air density	1,293	kg/m^3
Transmission efficiency	0,9	-
Battery capacity	35,8	kWh
Nominal battery voltage	400	V
Battery initial state of charge	1	-

For low loads operations, we proposed motor Engiro 205W-04099-ABC. It is water-cooled PMSM with parameters of max. peak torque and power 95 Nm, 24 kW and continuous parameters 42 Nm and 15 kW shown in Fig. 5 [11]. As the assistance motor we proposed induction motor Siemens ELFA 1PV5135-4WS28 with parameters of max. torque and power 360 Nm and 120 kW shown in Fig. 5 [12]. Efficiency maps of both motors can be seen in Fig. 6 and Fig. 7.

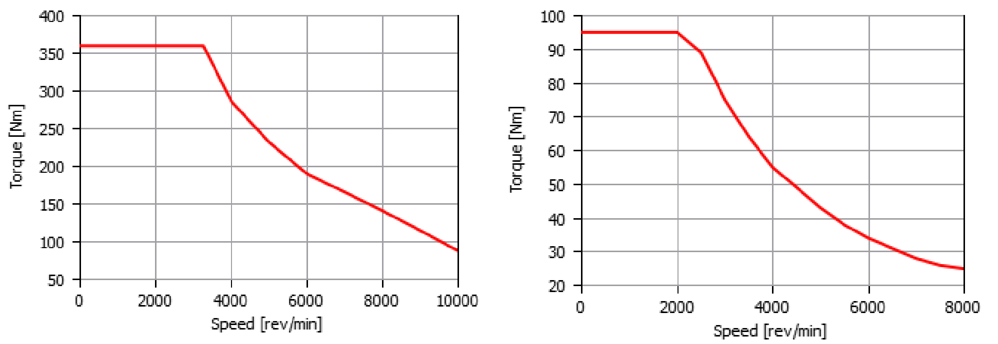

Fig. 5 *Siemens ELFA 1PV5135-4WS28 [12] (left), Engiro 205W-04099-ABC torque characteristics [11] (right)*

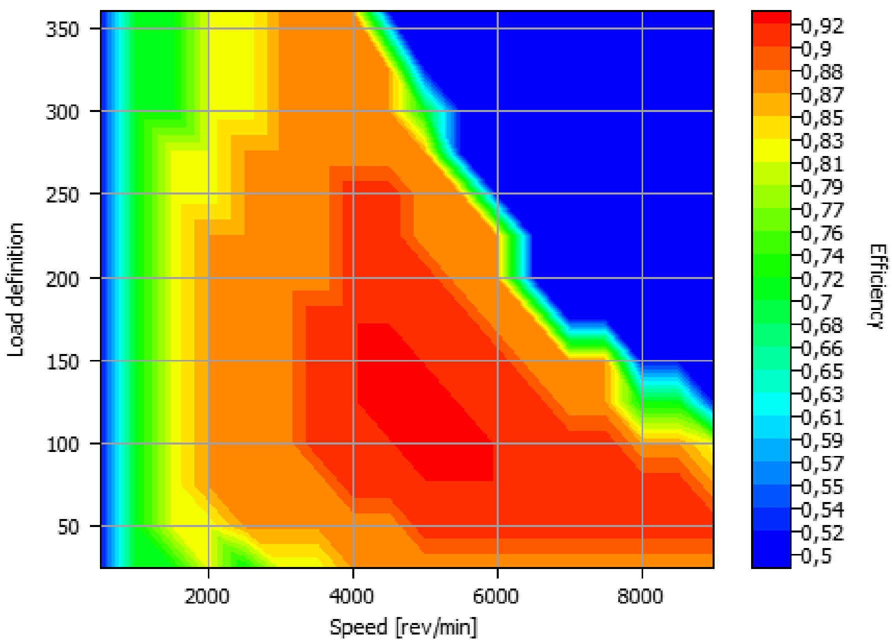

Fig. 6 *Siemens ELFA 1PV5135-4WS28 efficiency map [12]*

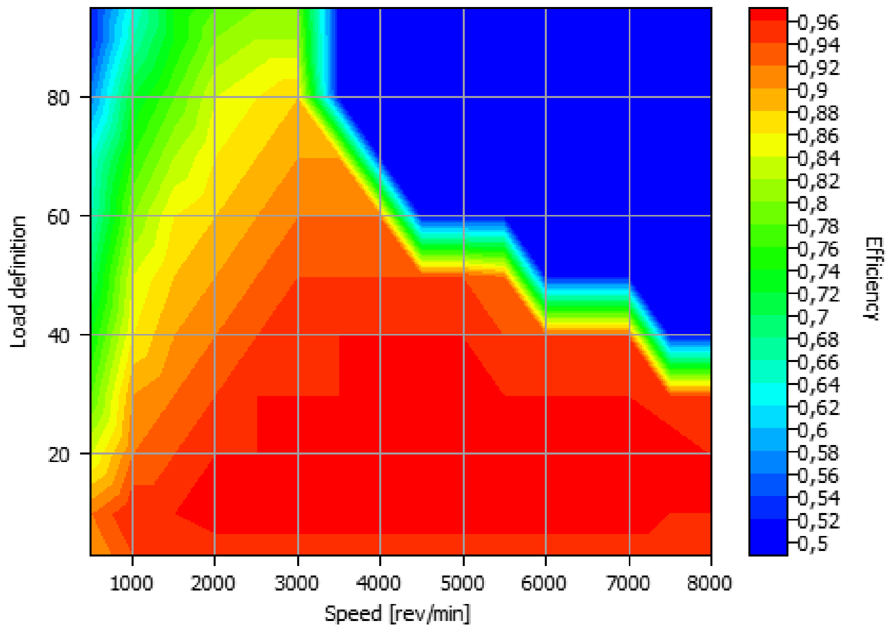

Fig. 7 *Engiro 205W-04099-ABC efficiency map [11]*

We analyzed drive efficiency of proposed DMDS in driving cycle WLTC Class 3 (Fig. 9) and simulated a drive throughout the driving cycle for each individual motor. Then we compared the results of the achieved engine efficiency and selected value of better efficiency. Due to the low power of the PMSM Engiro, we also checked the achieved speed error. And if the speed error was greater than ± 2 km/h compared to the required driving speed, we selected for that moment the efficiency of IM motor Siemens, which had an error less than ± 2 km/h. We did not consider recuperation of regenerative braking energy while driving for the purposes of this simulation.

3 RESULTS

Achieving high dynamics of the vehicle performs the IM motor Siemens, therefore we only tested the acceleration value for this motor. Maximum acceleration results from speed 0 km/h to 100 km/h are shown in Fig. 8. Achieved acceleration time value from speed 0 km/h to 100 km/h was 7,7 s.

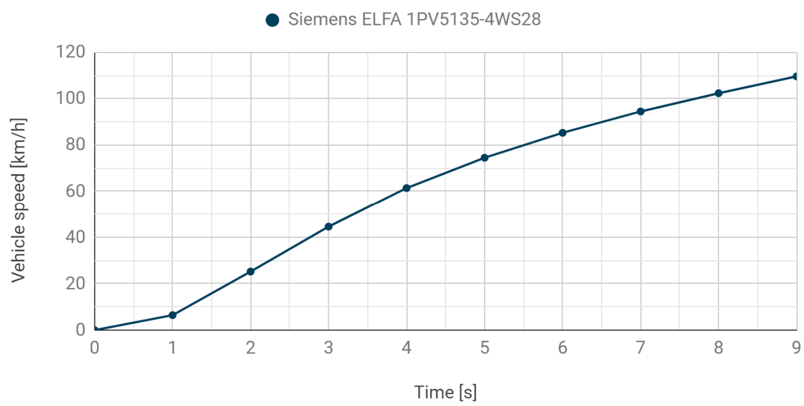

Fig. 8 *Vehicle speed results from speed 0 km/h to 100 km/h with motor Siemens*

Results of DMDS drive efficiency during driving cycle WLTC Class 3. are shown in Fig. 10. Achieved high efficiency of the small PMSM Engiro during low dynamics operation can be seen. On the other hand, during acceleration and high speed often works IM Siemens, which either achieves greater efficiency at these moments or unlike PMSM Engiro met the condition of speed error. DMDS average drive efficiency was 88,4 %. For drivetrain equipped only one IM Siemens ELFA 1PV5135-4WS28 was resulting average drive efficiency 80,2 %.

Fig. 9 *WLTC Class 3 vehicle speed results*

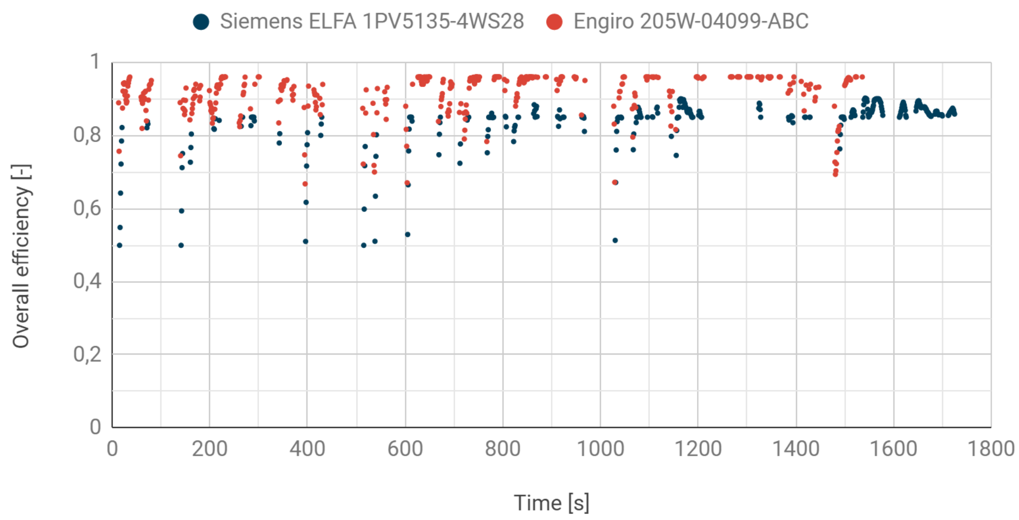

Fig. 10 *Results of DMDS drive efficiency during driving cycle WLTC Class 3*

DISCUSSION

At the beginning of the article, we introduced the idea to use DMDS as a combination of one smaller PMSM and one larger IM connected to the input of single-speed transmission with a mechanical differential in order to achieve high drive efficiency. Results of our simulation study during WLTC Class 3 showed an improvement in overall drive efficiency by 8,2 % compared to a drivetrain with only one IM for a vehicle in C-segment. At the same time, we believe that the achieved acceleration value of 7,7 s from speed 0 km/h to 100 km/h in C-segment is still considered a value for high dynamics vehicles in this segment. This solution made it possible to use only one small highly efficient synchronous motor with rare earth permanent magnets.

Compared to solutions with separate motors to drive the front and rear axle wheels, DMDS offers the possibility to take advantage of improved overall drive efficiency by using a combination of two different suitable motors even for vehicles with only one axle driven. Solution with multi-motor drives connected via planetary gearboxes also brings this option, but it has a much greater design, production and control requirements. Reliability of these systems is also more questionable due to complexity. On the other hand, allows using different gear ratios for each motor and more driving modes due to more possible drive combinations.

Our study provided the initial results of the overall drive efficiency of DMDS and indicate another possibility of drivetrain arrangement with two electric motors. For further development of the DMDS idea would be important to do a sophisticated selection of both motors so that their combination could bring an even greater increase in overall drive efficiency. The next appropriate step should be a detailed selection of a suitable gear ratio for both motors.

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