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TRANSPORT DOCTORAL SCHOOL

DOCTORAL THESIS

RESEARCH ON THE INFLUENCE OF THE TRANSMISSION FOR VEHICLE ENERGETIC CONSUMPTION

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Abstract

In order to reduce the CO_2 emission level in accordance with the new CAFE regulations, the transmission represents one of the most important subsystems of modern vehicles, even having the role of a command element for the internal combustion engine.

In the first part of the paper, the imposed requirements for the transmission are being presented, as well as different transmission solutions for reducing the energetic consumption and several modern achievements in this field.

Nowadays, developing a product without simulation is inconceivable. Developing mathematical models which accurately describe physical phenomena or the studied subsystems was made possible through the ever-increasing computing power, so that the projection and optimization decisions could be made in the early design stages, even before creating functional prototypes. The paper analyses the current stage of the modelling and simulation, and presents the available programs in achieving various studies concerning vehicles' energetic consumption.

To simulate the energy performance of propulsion systems, it is recommended to use models that allow the determination of energy consumption in test cycles. It is known from the literature that the test cycles characteristics have a major influence on energy performance. There are several test cycles, but it is generally preferred to use standardized cycles to facilitate the performance comparison. In this paper we use 5 test cycles for the simulations, which differ in terms of duration and average speed: Japanese 10-15 cycle, US 06 cycle, HWFET cycle (Highway Fuel Economy Test Cycle), NEDC cycle (New European Driving Cycle) and WLTC cycle (Worldwide Harmonized Light Vehicles Test Cycle). In order to quantify the fluctuation of vehicle speed in a test cycle, a specific parameter called VSF (Vehicle Speed Fluctuation), which represents the ratio between standard deviation of the vehicle's speed and average vehicle speed, is analyzed. The normal speed distribution and the frequency of different speed values with a multiple of 10 km/h for the test cycles used are also highlighted.

In order to compare the influence of several test cycles on fuel consumption, the parameter $RC_{cb.}$ is used, defined as the ratio between the fuel consumption obtained in test cycle and the fuel consumption for when driving at a constant speed equal to the average speed of each cycle.

The energetic consumption of the vehicle is being influenced by several factors, each corresponding to the propulsion system type: the thermal regime of the engine and the gearbox, the transmission efficiency, the transmission configuration, the electric powertrain architecture, and the hybridization degree. Different specific models of the conventional,

electric and hybrid powertrain systems are being realized for the purpose of highlighting the influence of these factors.

The thermal regime has a major influence on fuel consumption both from the perspective of the internal combustion engine and the gearbox. In order to carry out this study, either curves of variation of engine and gearbox temperatures obtained experimentally for the considered application or for a similar application when running after the studied test cycle, or thermal submodels to calculate the temperature based on internal combustion engine / gearbox parameters and heat fluxes are necessary. In this paper, experimentally determined temperature curves were used for the simulations.

Experimental research has highlighted that the transmission efficiency is dependent on several factors such as: transmitted torque, primary shaft speed, selected gear (or gear ratio), lubricant temperature, the level and quality of the lubricant, the quality of execution and assembly of the transmission components and the constructive features of the transmission. In addition to the transmission efficiency depending on the gear used, simulations were also performed for the transmission efficiency variable with the transmitted torque, the primary shaft speed and the lubricant temperature.

The electric vehicles represents an important option in the process of road transport decarbonization. The limited driving range and high speed performances are obstacles for electric vehicles customer acceptance. While until now the emphasis for the improvement was on battery, power electronics and motor technologies, it becomes obvious that the transmission must be also addressed. The extensively used single-ratio transmission can satisfy the demands of city use, but do not attain other important functional needs that are ensured by conventional and hybrid electric vehicles.

In order to improve the powertrain efficiency and extend the driving range for a given battery capacity and motor size of an electric vehicle, one can adopt a reasonable approach that refers to the use of multi-speed transmission instead of single-ratio reduction transmission.

The multi-speed transmission has the capability to improve acceleration time 0-100 km/h, maximum speed and energy consumption. At the same time, it increases the transmission's gross weight, reduces the transmission efficiency and the manufacturing costs are higher The transmission efficiency is dependent on the gear ratio and the number of gears, so when the number of gears increases the overall transmission efficiency decreases, but the motor is operated at higher efficiency, reducing in this way the energy consumption.

Thus, a model is developed to investigate the influence of the two-speed transmission that equips an electric vehicle on energy consumption compared to the single-speed transmission that equips the same electric vehicle.

A relative parameter by which a comparative study of energy consumption in different test cycles can be performed is the energy consumption ratio ($RC_{en.}$), defined in this paper similarly to the fuel consumption ratio ($RC_{cb.}$).

In order to make a comparison between the energy consumption obtained for a conventional vehicle and an electric vehicle, the equivalent energy consumption was defined based on the value of the lower calorific power for diesel fuel and its density.

Another architecture of the electric propulsion system presented in the relevant literature is the use of two electric motors. For such an architecture, a model was developed in the LMS AMESim simulation environment in order to determine the energy consumption. Three functioning strategies were implemented, for each the energy consumption being determined. Also, a comparison of the obtained energy consumption with the one determined for the reference electric vehicle equipped with a two-speed transmission.

Hybrid vehicles remove the disadvantage of using a single power source unlike electric vehicles. Compared to conventional vehicles equipped with an internal combustion engine, hybrid vehicles ensure low fuel consumption and a lower pollutant emissions level.

Based on how the electric motors and the internal combustion engine are interconnected, there are two basic configurations: parallel hybrid transmissions and series hybrid transmissions. Regardless of the configuration, the fundamental components are the same: the internal combustion engine, the electric motors, the electronic power converters and the electrical energy storage systems. Through a proper connection of the components it is possible to achieve hybrid transmissions capable of behaving both in series and in parallel, either alternately or simultaneously, called mixed hybrid transmissions.

Another classification of hybrid vehicles presented in this paper is based on the hybridization factor (HF), which is the ratio between the power of the electric motor and the total power developed by the internal combustion engine and the electric motor.

To study the influence of the hybridization factor on energy consumption, several simulations are performed for three values: 0.22, 0.32 and 0.42. The simulations are performed considering that the internal combustion engine, the electric motor and the transmission operate at nominal thermal regime. Also, in order to observe the influence of hybridization on energy consumption, the relative fuel economy is determined by considering a vehicle equipped only with a internal combustion engine for which fuel consumption is determined, the other parameters of the vehicle being the same.

After elaborating the models for each propulsion system studied and running them in the program, the correlation between the parameter of variation of the vehicle speed in a test cycle (VSF) and the ratio of fuel consumption ($RC_{cb.}$) or of the energy ($RC_{en.}$) for different propulsion system configurations (conventional, electric, hybrid) is analysed.

For the last part of the paper, with regard to underlining the high level of trust of the models carried out, the obtained results are being analysed for the fuel consumption obtained after simulation and also through experimental investigation obtained on the rolling test bench.