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A COMPUTATIONAL MODEL OF POWERTRAIN COMPONENTS IN SIMULINK

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Abstract: *The article deals with the development of a computational model of an engine, a transmission and a clutch. These parts of the powertrain were created using blocks from the libraries of the Simulink software while the input parameters for individual components were set on the basis of constructional CAD documentation of the vehicle. The creation of the computational model is described and some of the results of the Simulink simulations are presented. Furthermore, examples of the simulations of gear ratio change and cranktrain torsional vibration analysis are shown at the end of this article.*

Keywords: Diesel Engine, Torsion Model, Transmission, Clutch, Computational Model, Simulink.

1. Introduction

In order to accelerate the development and lower the expenses of prototype realization, advanced computational models of a vehicle's powertrain are used with rising frequency. As a result, the problems often associated with the first prototype running can be significantly reduced. Nowadays, software developers offer many different forms of development support for computational models, including some well-equipped libraries which make the creation of various model parts easier.

This article deals with the creation of computational models of parts included in a heavy commercial vehicle's powertrain. The following chapters describe the creation of engine computational models and transmission computational models meant to represent the 8-cylinder diesel engine and the accompanying transmission in the vehicle. The aim was to develop computational models which are able to simulate the relevant part of a powertrain with a sufficient level of detail, including torsional vibrations. The models assembled have a modular structure and will be gradually enhanced by models of powertrain additional substructures, which will allow real-time simulations of the complex model and the development of mechatronical systems for this vehicle.

The model was assembled using the Simulink software environment, which can serve for the creation of own computational models and simulation calculations, including real-time simulations. In the article there are described two examples computations which simulate a cranktrain torsional vibrations and the process of gear ratio change.

2. Fundamental Input Parameters for Computational Model Creation

The input parameter for a computational engine model is the course of indicated pressure inside a cylinder. From this pressure, the engine torque can be calculated (Kožoušek, 1983). Therefore, a script to create a 3D matrix of the engine torque depicted in Fig. 1a was written in the Matlab software. The dimensions of the matrix are 13x720x2 and it is composed of two 2D matrices which represent the maximum and minimum fuel supply. 13 rows of the 2D matrix contain engine torque curves during one working cycle which corresponds to the engine speed range from 800 rpm to 2 000 rpm. Consequently, the resulting engine torque value is determined by the crank angle, engine speed and fuel supply.

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In order to allow the computational engine model to perform also a torsional vibrations analysis, it was devised as a dynamic torsional system. The motion equations obtained according to the Lagrangian method are written as

$$M\ddot{\varphi} + K\dot{\varphi} + C\varphi = T(t) \tag{1}$$

where the vector of generalised coordinates φ contains angular displacements of system elements, M is the mass matrix, C is the stiffness matrix, K is the damping matrix and $T(t)$ is the vector of excitation engine torques. The input parameters of the computational engine model are the values of the moments of inertia, torsional stiffness values and damping coefficient values. The kinetic energy of the reciprocating masses depends on the crank angle. For the calculation of the mass matrix is used the mean value, so the mass matrix elements are constant. The damping coefficient values were set according to the measurement results on a similar powertrain. The calculation of the eigenfrequencies is carried out as an eigenvalue problem according to the literature (Píštěk & Štětina, 1993).

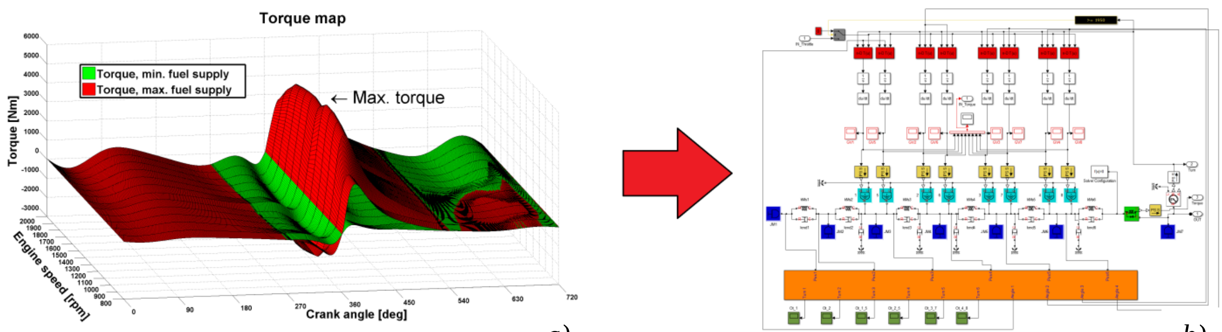
The computational model of a clutch which transfers the engine torque can be assembled in two ways, both described in (Budynas & Nisbett, 2006). One follows the even clutch wear assumption, while the other uses the assumption of even pressure distribution on the clutch friction lining. In this computational model, the even wear assumption was adopted. The transmission of a heavy commercial vehicle is composed of several parts. The first one is a gearbox, where normal and reduction gears are changed. The second one is the main gearbox used for the selection of 5 forward gear ratios and 1 reverse gear ratio. The main gearbox is followed by an auxiliary gearbox with 2 further gear ratios which further enhance the gear ratio range. The driver can therefore choose from 7 forward gear ratios. The first 5 are selected in the main gearbox and the additional 6th and 7th are selected as a combination of main and auxiliary gearboxes‘ ratios. The input parameters are the individual gear ratio values, moments of inertia of rotating components, torsional stiffness of the shafts and values describing synchronizers, as they are also included in the computational transmission model. To define the torque transfer through the synchronizer, the same two assumptions applicable for the clutch can be used. For the computational model, the even wear assumption was used in this case as well. The model also describes the forces transferred by the spring through the ball contained in the synchronizer to increase the accuracy of the simulation. The equations for the synchronizer calculations are described in details in (Budynas & Nisbett, 2006).

3. Computational Models

Individual computational models were assembled from the basic blocks included in Simulink software libraries. The user guide and tutorials for modelling in Simulink were gathered from (Dabney & Harman, 2004; Grepl, 2007). The computational models of the powertrain contain many modules, only some of which will be mentioned here, namely the engine and transmission subsystems models.

3.1. Computational model of the engine

The structure of the computational engine model is presented in Fig. 1b. Fundamental parts of the model are blocks which describe the parameters of rotational parts and torsional springs and a torque generator.



a) *b)*

Fig. 1: Input values and computational model of the engine.

Using these blocks, a torsional system is assembled as a dynamic model of a real engine. The 3D matrices defined in Chapter 2 are connected to the mentioned blocks generating the torque in the torsional system. This torsional model enables to determine the rotational speeds of parts during the simulation. Therefore the speed sensor is placed at the engine output and the value serves as an input to the 3D matrix. The orange submodel in Fig. 1b reports the exact crank angle value which is the second input to the 3D matrix. The last input is the accelerator pedal position which is controlled by the user. Using these inputs, the torque on each crank throw can be calculated. Individual 3D matrices are also shifted according to the ignition sequence of the engine cylinders.

3.2. Computational model of the transmission

The computational transmission model is composed of blocks similar to those used in the engine model. It contains blocks representing rotational parts, synchronizers, gears and other elements which serve to control the selection of individual gear ratios. On the other hand, this model does not contain torsional springs as the loaded shaft length depends on various gear ratios; therefore, the torsional stiffness is not constant. However, these torsional stiffnesses as well as gear couplings are by orders of magnitude higher than the other shafts in the powertrain.

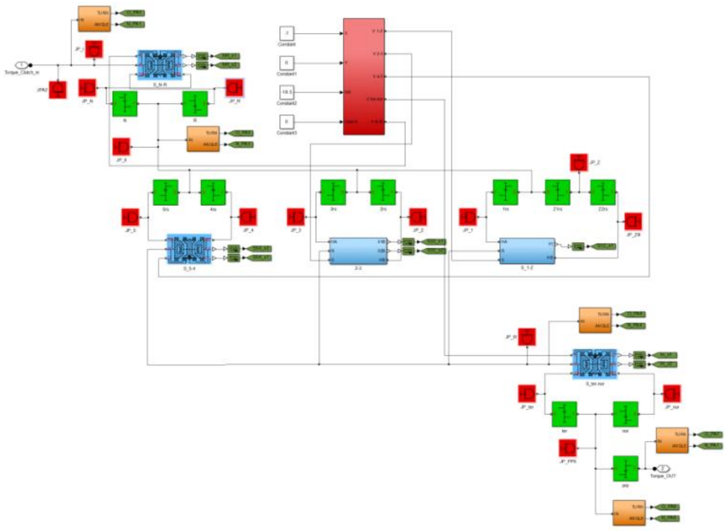


Fig. 2: Computational model of the transmission.

4. Examples of Computational Simulations

Computational models were used to perform braking simulations of the engine with and without the transmission connected to a virtual dynamometer. In the following subchapters the results of engine torsional vibrations simulation and gear change simulation are presented.

4.1. Torsional vibrations simulation

The simulation was carried out with fixed throttle position. The engine speed settled at 1 487 rpm and the torque at the engine output was being monitored and subsequently processed by the Fourier Transform with Hann window according to (Zaplatílek & Doňar, 2006). The results are the harmonic components of the resulting engine torque measured after the flywheel.

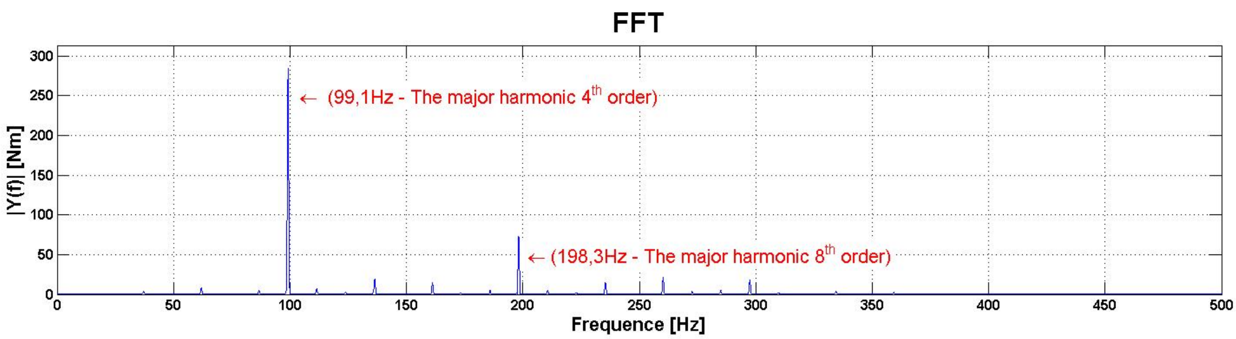


Fig. 3: FFT analysis of engine torque at 1 487 rpm.

4.2. Gear change simulation

In order to conduct the gear change simulation, engine and transmission computational model were joined together and controlled by additional algorithm, which simulates gradual rise of engine speed followed by a clutch pedal depression, engine speed drop and gear change. The clutch pedal is then let loose and the engine speed rises again. This is repeated until the highest gear is selected. Resulting engine speed curves and transmission output speed curves are given in Fig. 4.

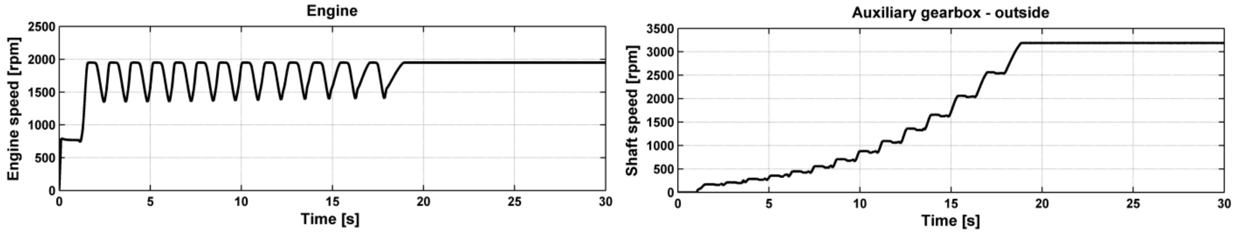


Fig. 4: Speed curves of individual driveline parts.

5. Conclusions

The computational models of an engine, a transmission and a clutch were assembled using the blocks from the libraries of Simulink software. The aim was to create computational models able to represent real parts of a vehicle powertrain of known construction parameters with sufficient accuracy.

In the second chapter, the description of input parameter preparation is given, while the third chapter presents the main subsystems of computational models and their assembly in the Simulink environment. The final chapter then describes selected simulations of an engine and a gear change. The results prove that the behaviour of these models is correct.

The described computational models will be enhanced by further modules in the future, which will allow the simulation of the whole powertrain of a commercial vehicle. This complex computational model will then be used for the development of mechatronical systems aimed at commercial vehicles' powertrains and undercarriages. It will also be possible to run the simulations in real-time. Some of these have already been run using the real-time testing hardware supplied by National Instruments.

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