Frantisek Brumercik – Michal Lukac – Jacek Caban *

UNCONVENTIONAL POWERTRAIN SIMULATION

This article presents an unconventional principle of the vehicle power flow transmission, different from the commonly used powertrains. Presented powertrain consists of a combined hydro-mechanical transmission with hydrostatic units and torque converter in parallel lines with mechanical components providing the continuous gear ratio change.

Keywords: *Vehicle, powertrain, CVT, simulation.*

1. Introduction

Most of the commonly used commercial vehicles have regular manual transmission, which works with the step ratio change via the so called range and split transmission gear groups. The tendency is to make the work of the driver less complicated by the automated manual gearboxes (Volvo I-Shift and I-Shift Dual Clutch, Scania Opticruise, etc.), increasing the efficiency and driving comfort [1].

The common structure of the drivetrain with an automatic transmission is the power transmission line built in the sequence of the engine - torque converter - automated step gearbox driven by the electromechanical elements - transaxle.

2. System and model structure

The presented transmission contains mechanical parts (gears, shafts, one-way clutches), the hydrostatic units and a complex hydrodynamic torque converter (Fig. 1). It was developed for vehicles with the maximum total engine power of 100 kW [2].

One of the hydrostatic unit is regulated via the proportional-derivative (PD) control system, which controls the angle of the unit regulation plate inclination (β). The power flow is divided into mechanical, hydrostatic and hydrodynamic line during the continuous ratio change – the gearbox works as a continuously variable transmission (CVT).

After the kinematic and dynamic analysis of the transmission structure was done, the mathematical block model was built. It is based on the Matlab/Simulink environment. The model is assembled from partial subsystems represented via calculation blocks [3 and 4]. Mechanical, hydrostatic and hydrodynamic

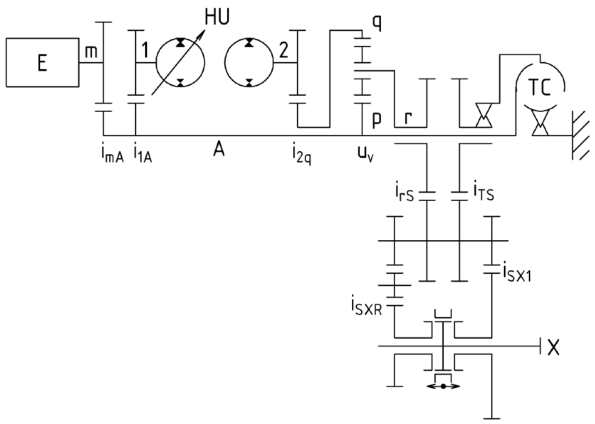

Fig. 1. Kinematic structure of the transmission: A – input shaft, X – output shaft; E – engine, HU – hydrostatic unit, TC – torque converter (Source: authors)

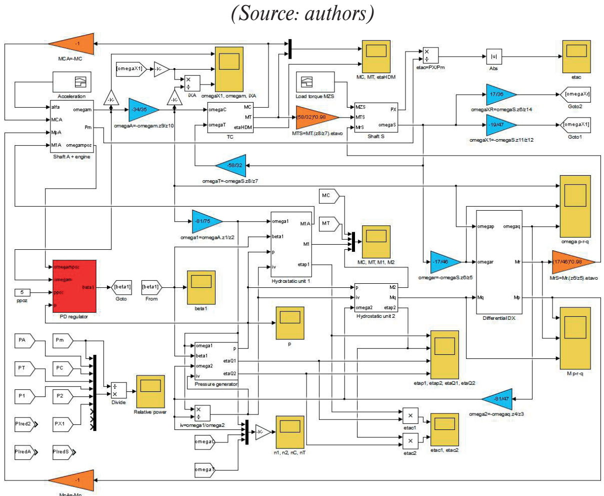

Fig. 2. Block structure of the mathematical transmission model (Source: authors)

* [1]Frantisek Brumercik, [1]Michal Lukac, [2]Jacek Caban
[1]Mechanical Engineering Faculty, University of Zilina, Slovakia
[2]University of Life Science in Lublin, Faculty of Production Engineering, Poland
E-mail: brumercikf@fstroj.uniza.sk

power flow line as well as the electronic control system has its own subsystem block, which is connected to other parts of the model. The diagram of the mathematical block model of the transmission system is shown in Fig. 2.

3. Simulation procedure

The simulation of described transmission is based on a system response to a load set, which represents the vehicle driving resistance forces or torques. The minimum and maximum resistance torques were calculated according to the kinematic structure without the consideration of power losses along the transmission power flow line [5].

After the simulation of the system response to the constant minimal and maximal loads, the step load change was simulated to test the quality of the control system. The real load changes in the traffic are not so steep, so the robustness of the PD regulator subsystem is tested properly. The load step change is shown in Fig. 3.

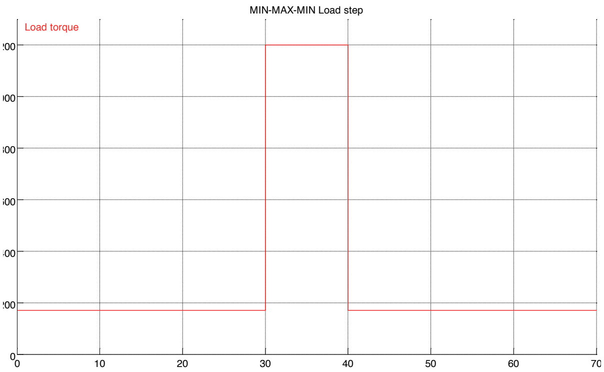

Fig. 3. Load step change diagram (Source: authors)

The initial conditions of the simulation progress were the engine idle running and the acceleration – pedal put on 100% by the minimal load applied. In the interval from 0 to 30 sec. the system variables are changed according to the initial conditions at the start of the simulation.

After 30 seconds, during which the gearbox output shaft X reached stabilised speed value, the load steps to maximum. This fact causes significant drop of the output shaft speed. This is the moment, when the observation of the system behaviour starts to be interesting [5 and 6].

The achievement of the steady state as a response to the load step in the 30-th and 40-th sec. is monitored and refers to the quality of the PD control system changing the β_1 parameter of the regulated hydrostatic unit. The results of this particular simulation are shown in Figs. 4 to 7.

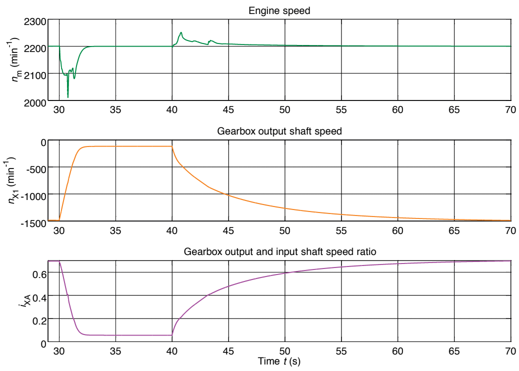

Fig. 4. Time development of the speed of the engine crank shaft (m), output gearbox shaft (X) and the gearbox output to input shaft speed ratio (i_{XA}) (Source: authors)

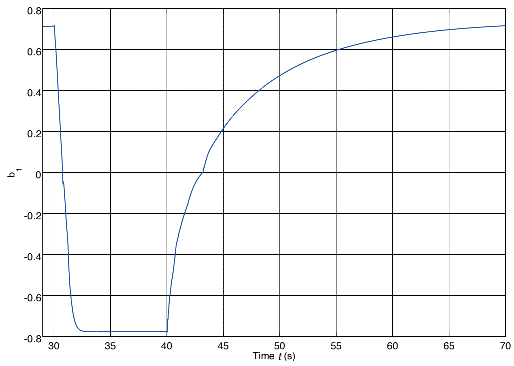

Fig. 5. Change of the hydrostatic unit regulation plate (β_1) (Source: authors)

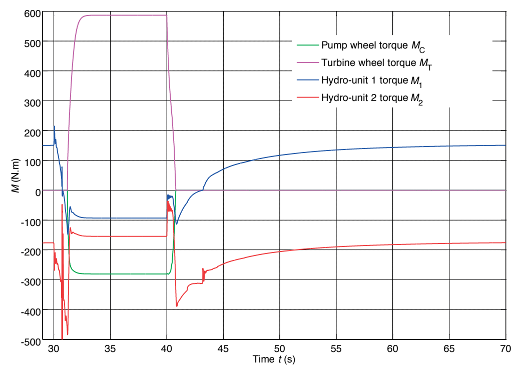

Fig. 6. Time development of the torque on the hydrostatic and hydrodynamic transmission parts (Source: authors)

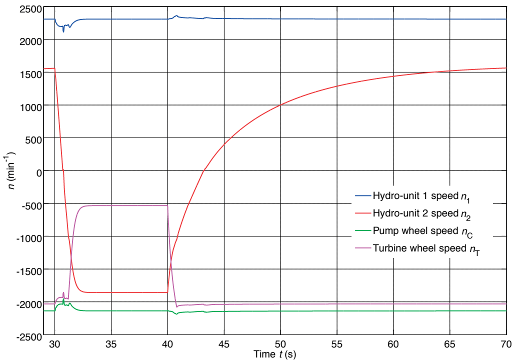

Fig. 7. Diagram of the speed of the hydrostatic and hydrodynamic transmission parts
(Source: authors)

4. Simulation evaluation

The simulation of the step changes of the load torque allows to check the behaviour of the simulated PD regulation and to consider the change fluency of the observed values according to sudden load changes. These changes cannot happen as fast in the real transport operation, but the step load changes provide a view about the functionality of the hydrostatic control unit and thus the whole gearbox by extreme load cases.

By the change of the minimal value of 412 N.m to maximum of 2909 N.m, the notable drop of the engine and output shaft speed is visible (Fig. 4). The torque converter starts to operate at about 30-th sec. of the simulation process. The engine speed is after about 3 sec. back to the initial value of 2200 min^{-1} (Fig. 4). The hydrostatic unit regulation plate inclination changes fluently, without interferences by the extreme load change. The control system adapts the gearbox operation according to the desired engine speed and the pressure in the low-pressure pipe of the hydrostatic power flow line (Fig. 5).

When the load value changes back to minimal value of 412 N.m after about 10 sec. maximum load applied, the transmission output shaft speed starts to rise and the engine crank shaft is released. The PD regulation put the regulation plate inclination and also the engine speed to the value at the start of the step change at 30-th sec. of the simulation (Fig. 4).

The global efficiency of the power transmission by the minimal load in the stable state is above 0.8. This value is, with regard to the usage of hydrostatic and hydrodynamic elements without any ratio step controllers (automated friction brakes, clutches), quite satisfactory. The collaboration between the engine and the gearbox is permanently controlled via the PD controller of the regulated hydrostatic unit.

By the maximum load of 2909 N.m applied, the torque converter is operating during the whole period of step change. Thus, the global efficiency drops, but that is the consequence of the converter characteristics by the torque multiplication. The hydrostatic power flow line works in the range of power circulation, which is also negative considering the power transmission efficiency value. The torque demand by this working steady state is so high that the multiplication factor is much more important than the efficiency drop.

The torque and speed of the other particular transmission parts are shown in Figs. 6 and 7. The simulation results show that the PD controller can regulate the value of the regulating plate inclination according to the desired engine speed values in the wide range of load cases [7 and 8].

5. Conclusion

The article presents simulation results of an unconventional vehicle transmission, which can be used in commercial vehicles and mobile working machines. The kinematic structure and the dynamic behaviour of the system is extracted into the mathematical model [9]. Thus, the simulation of number of load cases can be done and the control system can be tested without the need of a number of prototypes to be built. The model provides also the possibility of all subsystem properties editing. This allows to shorten the development time and to cut the costs in the area of R & D process significantly [10].

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