EXPERIMENTAL TESTING OF POWER ASSISTED STEERING

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The paper is focused on the description and creating of the simulation model of the power assisted steering and testing of the functionality and efficiency on the laboratory test rig. The mathematical model is describing the structure of the system and is created from the mathematical models of the subsystems, which compute the dynamic behaviour of the steering wheel, pinion, rotating control valve and of the hydraulic cylinder. The simulation model was realized in the simulation programme MATLAB-Simulink® and was used for the simulation of the testing experiment. The measurements were done on the laboratory test rig, which is controlled by the computer and operated by the swivel pneumatic drive instead of the driver hand. It allows better repeatability of the experiment. The experiments were focused on the evaluation of the efficiency of the hydraulic power assisted steering system.

KEYWORDS

power assisted steering, hydraulic drive, mathematical model, simulation

1 INTRODUCTION

The paper deals with the creating of the mathematical model, simulation and experimental testing of the hydraulic power assisted steering for a passenger car. After the analysis of the structure of the hydraulic power assisted steering system the mathematical models of the subsystems are described. Finally, the whole simulation model built in the simulation programme MATLAB-Simulink® which consists of the mechanical and hydraulic subsystem is introduced and achieved simulation results are presented. The experimental work, simulations, experiments and the measurements on the test rig were focused on the evaluation of the efficiency of the power-assisted system for different driving situations characterized by different load torque. To have the opportunity to steer the steering wheel repeatedly in the same quality, the steering wheel is operated by the pneumatic swivel drive controlled by the proportional valve and digital controller. The presented results were obtained using the computer-controlled experiment and allow to demonstrate the principle and effectiveness of the hydraulic power assisted steering system.

2 MATHEMATICAL MODEL OF HYDRAULIC POWER ASSISTED STEERING

The hydraulic power assisted steering is a system designed to lower the driver's steering effort. The system can be divided in two main subsystems - the hydraulic servo system, which is connected in parallel with the mechanical steering system. The driver is operating using the steering wheel the mechanical subsystem. The steering wheel is connected with the steering rod terminated with the torsion bar. The second end of the torsion bar is connected with the pinion. The main components of the hydraulic drive are the control valve, the hydraulic cylinder and the fixed displacement pump directly driven by the engine supplying the system with compressed oil. The control valve is an open center valve and typically rotating construction. The function of the valve can be described using the Wheatstone bridge with hydraulic resistances, Fig. 1 [Brezina 2014].

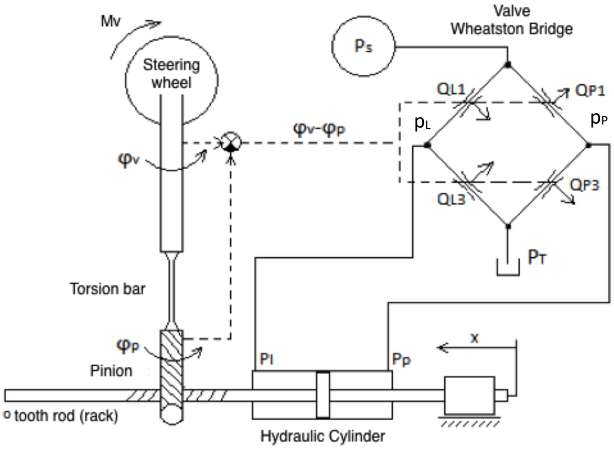

Figure 1. Structure of the hydraulic power assisted steering system

The driver that produces the torque operates the steering wheel [Brezina 2014, Murrenhoff 2008, Noskievic 2011, Roesth 2006]. Due to the stiffness of the torsion bar, the difference between the angle position of the steering wheel and the angle position of the pinion is the variable, which defines the valve displacement. The flows to the hydraulic cylinder chambers depend on the valve displacement and pressure drop on each control edge. Finally, the force produced by the hydraulic cylinder is added to the force produced by the driver on the steering wheel and transmitted using the steering rod, torsion bar and pinion on the piston rod. The sum of these torques, or forces is acting on the wheels.

The mathematical model of the power assisted steering system copies the structure of the system and is created from the equations modelling the mechanical subsystem and equations describing the behavior of the hydraulic subsystem[Noskievič 1999].

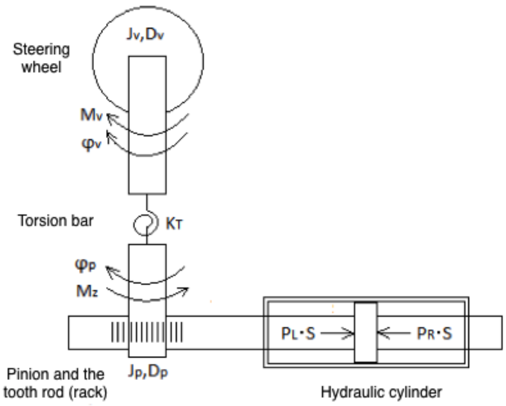

Figure 2. Structure of the power assisted steering system – mechanical subsystem

The mechanical subsystem is described using two motion equations. The first described the steering wheel characterized by the mass with inertia J_v doing the rotational motion.

$$J_v\ddot{\varphi}_v + B_v\dot{\varphi}_v + K_T(\varphi_v - \varphi_p) + M_{fv} = M_v \quad (1)$$

The connection between the steering wheel and the pinion is realized by the torsion bar modeled by the torsion spring with the torsion stiffness K_T. $J_v$is the inertia of the steering wheel and steering rod, B_v is the viscous friction coefficient of the steering wheel, M_v is the torque produced by the driver's action on the steering wheel, M_{fv} is the friction torque of the steering wheel. If the friction is very low, the friction torque can be neglected, and the motion equation becomes the form

$$J_v\ddot{\varphi}_v + B_v\dot{\varphi}_v + K_T\left(\varphi_v - \varphi_p\right) = M_v \qquad (2)$$

The stiffness of the torsion bar can be calculated using the formulas

$$K_T = \frac{G.J}{l},\ G = \frac{E}{2(1+\mu)} \ ,\ J = \frac{\pi\, d^4}{32} \qquad (3)$$

where G is the shear modulus, J is the quadratic torque of the cross-section area of the torsion bar, l is the length of the torsion bar, E is the Young modulus in pulling, μ is the Poisson number of the steel, d is the diameter of the torsion bar.

The second motion equation is describing the behaviour of the pinion and has the form

$$J_p\ddot{\varphi}_p + B_p\dot{\varphi}_v + K_T\left(\varphi_v - \varphi_p\right) - p_P S\cdot r_p + p_L S\cdot r_p + M_z = 0 \qquad (4)$$

where J_p is the inertia of the pinion and rack, B_p is the damping coefficient of the pinion, M_z is the external load torque. The friction torque of the pinion is neglected.

The hydraulic circuit of the power steering assisted system is shown in Fig. 1.The flows Q_{L1}, Q_{L3}, Q_{P1}, Q_{P3} through the hydraulic resistances in the Wheatstone bridge are given by the formulas

$$Q_{L1} = \alpha\cdot S_L(\varphi)\sqrt{\frac{2}{\varrho}}\sqrt{|p_s - p_L|}\cdot \mathrm{sgn}(p_s - p_L) \qquad (5)$$

$$Q_{L3} = \alpha\cdot S_P(\varphi)\sqrt{\frac{2}{\varrho}}\sqrt{|p_L - p_T|}\cdot \mathrm{sgn}(p_L - p_T) \qquad (6)$$

$$Q_{P1} = \alpha\cdot S_P(\varphi)\sqrt{\frac{2}{\varrho}}\sqrt{|p_s - p_P|}\cdot \mathrm{sgn}(p_s - p_P) \qquad (7)$$

$$Q_{P3} = \alpha\cdot S_L(\varphi)\sqrt{\frac{2}{\varrho}}\sqrt{|p_P - p_T|}\cdot \mathrm{sgn}(p_P - p_T) \qquad (8)$$

α is the losses coefficient, ρ is the oil density, p_s is the system pressure, p_T is the tank pressure and p_R and p_L are the pressures in the cylinder chambers.S_L, S_P are the cross section areas of the openings of the control valve, which depend on the difference between the angular position of the steering wheel and pinion $S_p(\varphi)$ a $S_L(\varphi)$ and are given by the functions

$$S_P = f_1\left(\varphi_v - \varphi_p\right) \qquad (9)$$

$$S_L = f_2\left(\varphi_v - \varphi_p\right) \qquad (10)$$

Two equations describing the hydraulic capacity in the left and right chamber of the hydraulic cylinder allows to compute the pressures p_L and p_P as follows

$$\dot{p}_L = \frac{K}{S\left(L/_2 - x\right)}\left(Q_{L1} - Q_{L3} + S\dot{x} + Q_{SP}\right) \qquad (11)$$

$$\dot{p}_P = \frac{K}{S\left(L/_2 - x\right)}\left(Q_{R1} - Q_{R3} - S\dot{x} - Q_{SP}\right) \qquad (12)$$

where K is the bulk modulus, S is the cross-section area of the piston, L is the stroke of the hydraulic cylinder, x is the actual position of the piston, Q_{SP} is the leakage flow.

The introduced mathematical model of the power assisted steering system represented by the equations (1) ÷ (12) was programmed in MATLAB-Simulink®. Different steering situations were simulated using the created simulation model. The simulation model of the whole system is shown in Fig. 3, [Březina 2014].

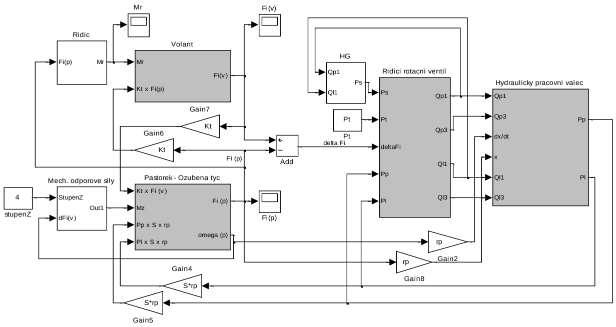

Figure 3. The simulation model of the power assisted steering system.

3 TEST RIG AND EXPERIMENTAL TESTING OF THE POWER ASSISTED STEERING SYSTEM

The test rig of the power assisted steering system shown in Fig. 4 was built in the laboratory[Březina 2014].

Figure 4. Laboratory test rig of the power assisted steering system

The steering wheel is operated by the swivel pneumatic drive. To achieve better repeatability of the experiment the steering wheel is operated by the swivel pneumatic drive instead of the driver hand. The angular position of the shaft of the pneumatic drive is controlled using the proportional pneumatic valve and the digital control system SPC200. The piston rod of the hydraulic cylinder is connected using the force transducer with the mechanism producing the friction force, which models the forces acting on the front wheel in the car during various driving manoeuvres. It is possible to tune the magnitude of the produced force using the screw. Important variables are measured and the values transmitted in the computer for the next evaluation.

The experimental testing was focused on the evaluation of the efficiency of the power assisted steering system by driving the car. The driver's maneuvers in the moose test as a good comparable and repeatable driver's action has been chosen, Fig. 5. The test simulates the situation, when an animal – for example a moose, or a child is rushing out onto the road and the driver is trying to avoid it [Brabec 2011, Brezina 2014, Noskievic 2011] and can be described as follows. The driver is driving the car in the right line and changes the line to the left line and back. Typically, the test is repeated with increased speed.

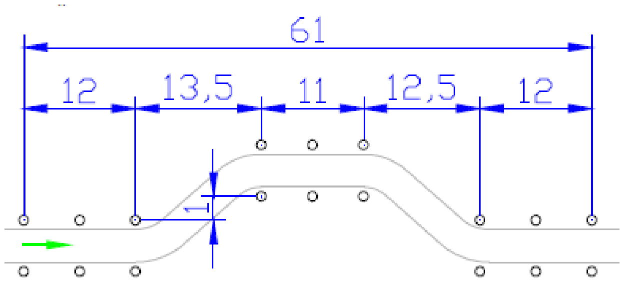

Figure 5. The standardized parameters (m) of the trajectory by the moose test [Roesth 2006]

The course of the piston position of the power assisted steering system during the moose test at the speed of 60 km/h is shown in Fig. 6, [Brabec 2011]. The course of the angular position of the steering wheel has the similar shape due to the fixed connection between the piston rod and steering wheel. For that reason, the similar profile was defined for the desired value of the position angle of the pneumatic drive, which operates the steering wheel of the test rig instead of the driver.

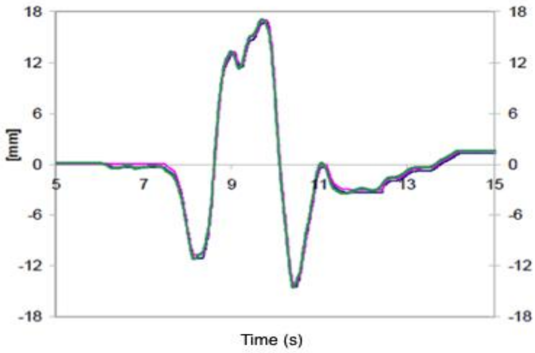

Figure 6.Piston rod position during the moose test.

The course of the steering wheel position during the moose test is shown in Fig. 7.

The moose test was repeated on the test rig for different magnitude of the friction force. Using the measured variables, the torque produced by the pneumatic drive, the torqueproduced by the hydraulic cylinder and acting on the pinion and finally the load torque on the pinion were evaluated. The results of the measurements on the test rig are summarized in Fig. 8 and Fig. 9, [Brezina 2014].

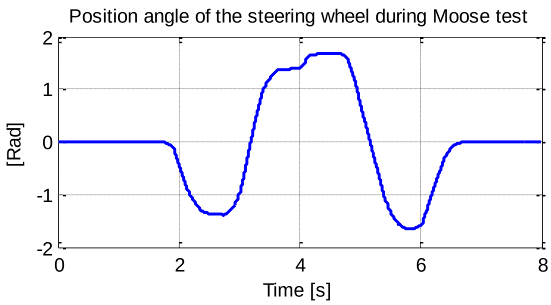

Figure 7. Position angle of the steering wheel during the moose test.

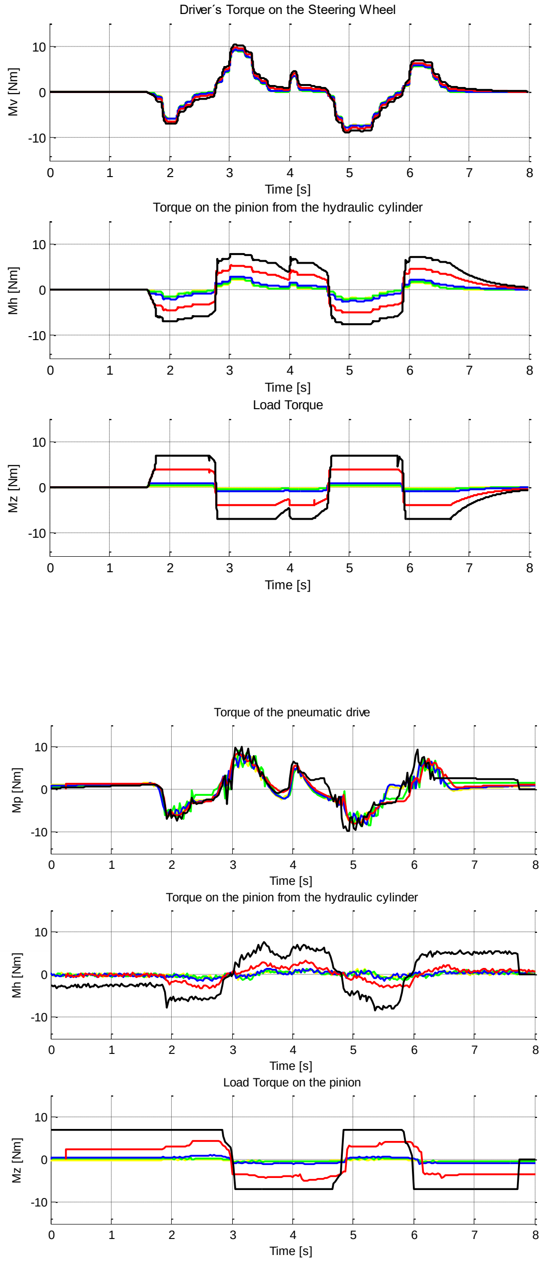

Figure 8. Torque of the pneumatic drive (upper plot), torque on the pinion from the hydraulic cylinder (middle plot) and load torque (down plot) for different load (different colours), experimentally on the test rig obtained values (upper graph) and values obtained using the simulation experiments (down graph).

The contribution to the comfort of the driver when steering the car can be demonstrated using the bar graph in Fig. 10, where the driver's torque is depicted by blue colour, the green bar shows the contribution of the power assisted steering system, and the orange colour is used for the load torque. The results are shown for five different magnitudes of the load torque. The upper graph summarized the experimental results, and the simulation results are shown in the lower graph.

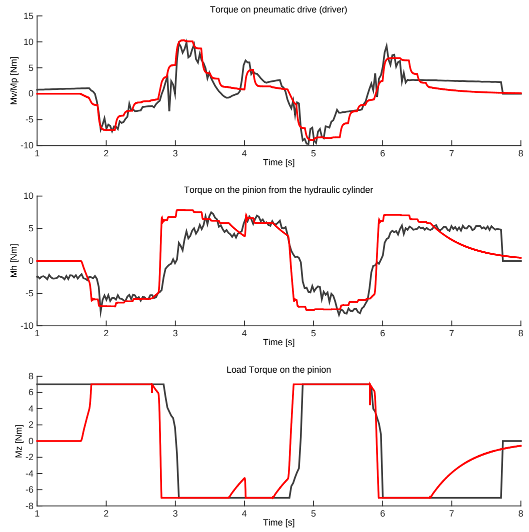

Figure 9. Comparison of the torques obtained experimentally on the test rig (black line) and using simulation (red line).

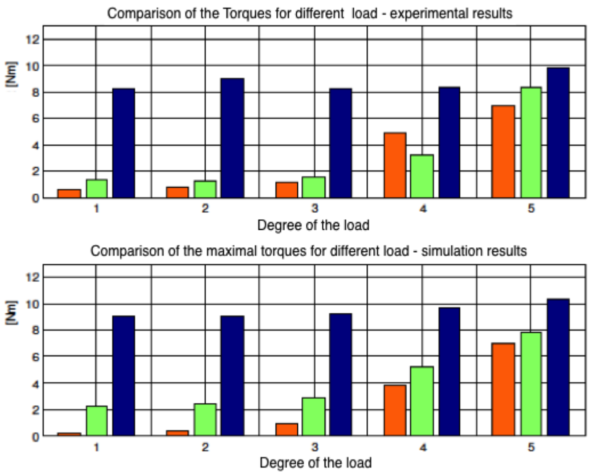

Figure 10. Comparison of the activity of the power assisted steering system for different loads. Experimental data – upper graph, simulation results – lower graph. Orange – maximum load torque, green power assisted steering system contribution, blue maximum driver's torque.

The simulation and also the measurement results demonstrate the increasing contribution of the hydraulic cylinder in dependence on the increased load torque. The driver's torque is practically the same. This is the effect of the hydraulic power assisted steering system. Higher load will result in increased contribution of the power assisted steering system, while the driver's effort stays practically constant.

4 CONCLUSIONS

The paper presents the experiments realized with the simulation model in MATLAB-Simulink® and experimental test rig of the power steering system for a passenger car.The presented test rig was realized in the laboratory and allows demonstrating the function of the power assisted steering system, to measure the important variables determining the state of the system and evaluating the efficiency of the system. To achieve repeatedly the same results of the experiments, the steering wheel is operated by the pneumatic drive controlled by the proportional valve and digital control system.

The experimental testing was done for the driver's manoeuvre in the moose test. The driver's action was simulated, and also experimentally realized on the test rig. The simulation and the experimental results are shown in plots, and the contribution of the power assisted steering system was evaluated for five various loads. The outputs of the experimental work evaluate and quantify the contribution of the power assisted steering system to the comfort of the driver by driving the car.

The results are summarized in the bar graphs separately for the experiments on the test rig and for the simulation results. It allows also the evaluation of the good quality of the simulation model. The evaluation of the effect of the power assisted steering system on the driver's activity can be used for the comparison of the different steering systems used in cars. The test rig is a part of the laboratory of mechatronic systems and allows students and researchers experimenting with the real system to study the principles of the power assisted steering, to make measurements and design some improvements.

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