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VIRTUAL MODEL OF ELECTRICALLY ASSISTED POWER STEERING FOR APPLICATION IN DYNAMIC VEHICLE SIMULATOR

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Abstract. *This work aims to develop a generic EPS model, an Electronically Assisted Steering System, using the MatLab/Simulink platform from its mathematical model. EPS uses an electric motor as a source of torque assistance, thus reducing the driver's efforts when steering the steering wheel. For this, control logic is built around of the torque map that is applied by the auxiliary engine in the steering system. The big challenge is to adjust the torque map in the dynamics of the system so that the driver has the feeling of direction. Torque assist varies with vehicle speed and input torque driver, with higher assisted torques for lower speed and lower torque when the vehicle is at high speed, which makes this system non-linear. The expected results based on studies from other bibliographies are a refined model able to realistically simulate EPS, validating the developed mathematical model and proposed control logic.*

Keywords: *EPS model, Control, Simulink, Torque Map, SIMCenter.*

1. INTRODUCTION

According to Gillespie (1992), the steering system is one of the main subsystems for vehicle operation. It has the function of giving drivability and allows the driver directional control of the vehicle. There are some researches regarding the EPS control architecture. Chen et al (2008) proposed a generic base model for advanced two-stage control, first the motor assist torque control and then a steering motion control to satisfy the steering feeling in an environment with disturbance. Chitu et al (2011), presented a Quadratic Linear Regulator (LQR) used as a controller to improve the performance of the Steering Power System (EPS), making optimum and robust control of the system in order to reduce the workload and improve the feeling of direction.

Considering the above context, the proposal of this work is modeling the steering system with the assistance of an electric motor in the steering column, using virtual environments for model creation and simulation for dynamic

analysis. In this sense, MATLAB/Simulink was used to construct the virtual EPS model and the system's operating logic, making use of the VI-CarRealTime advanced steering subsystem to co-simulate the proposed project.

2. METHODOLOGY

The virtual models of automotive subsystems are mostly developed in tables converted to three-dimensional maps that correlate input and output variables. For the construction and execution of this work, the strategy was carried out with the first step being the definition of variables. This is an important step in the study of dynamical systems, therefore, the mathematical model of this system is a fundamental tool to calibrate and approximate it to a real physical system.

Once the mathematical model was defined, the next step was to obtain the transfer functions, which allow expressing the inputs and outputs through mathematical relations. In view of these definitions, it was possible to build the model in the Simulink software, which enables co-simulation with Vi-CaRealTime software. The validation tests to evaluate the steering system were performed as directed by the Fiat CRF.

2.1 Mathematical model of the operation of EPS

The development of this work will have the object of study the rack-and-pinion steering system, electrically assisted, of the type that has the motor assistance coupled in the steering column.

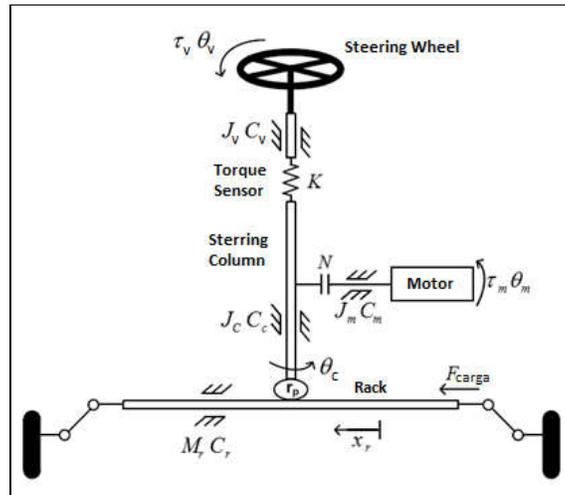


Figure 1 - Dynamic EPS model.

Source: Adapted from Lee, Kim and Kim, 2017.

From Newton's Laws it was possible to model the dynamic system of EPS. As shown in Figure 1, the dynamics of the system can be modeled by a grouping of four masses: the steering wheel, the steering column, the engine and the rack. In order to equate the system, the stiffness constants, the damping coefficients and the moments of inertia of each mass grouping were considered. In this way we have equations (1) to (8) that describe the dynamics of the steering system and its parameters presented in Table 1.

$$J_v \ddot{\theta}_v + C_v \dot{\theta}_v + K(\theta_v - \theta_c) = \tau_v \quad (1)$$

$$J_c \ddot{\theta}_c + C_c \dot{\theta}_c + K(\theta_c - \theta_p) = \tau_{engr} - \tau_{pinhão} \quad (2)$$

$$J_m \ddot{\theta}_m + C_m \dot{\theta}_m = \tau_m - \tau_{engr}/N \quad (3)$$

$$M_r \ddot{x}_r + C_r \dot{x}_r = \tau_{pinhão}/r_p - F_{carga} \quad (4)$$

$$x_r = r_p \theta_c \quad (5)$$

$$\theta_m = N\theta_c \quad (6)$$

$$\tau_a = N\tau_m \quad (7)$$

$$\tau_l = r_p F_{carga} \quad (8)$$

The differential equations (1), (2) and (3) result from Newton's second law modeling applied to the steering wheel, steering column and EPS motor respectively. Equation (4) represents the dynamics of the rack. The displacement of the rack is given by equation (5). The product of the motor transmission ratio by the steering column angle results in the engine rotation angle of the EPS, according to equation (6). The assistance torque applied to the column is expressed by equation (7). The parameters used are defined in Table 1.

Table 1 - Parameters of the equations.

| Symbols | Description | Value | Units |
|-----------------|--|----------|-------------------|
| I_v | Moment of inertia of the flywheel | 0,040 | Kg.m ² |
| I_c | Moment of inertia of the column | | |
| I_m | Moment of inertia of the engine | | |
| M_r | Rack Mass | 2,420 | kg |
| θ_v | Steering wheel angle | | |
| θ_c | Angle of the column | | |
| θ_m | Engine angle | | |
| C_v | Coefficient of damping the flywheel | | |
| C_c | Coefficient of column damping | | |
| C_m | Motor damping coefficient | | |
| C_r | Rack Density Coefficient | | |
| K | Torsional stiffness of the spine | 30,70 | N.m/° |
| τ_p | Driver Torque | | |
| τ_{engr} | Gear Torque | | |
| τ_m | Engine torque | | |
| $\tau_{pinhão}$ | Pinion Torque | | |
| F_{carga} | Load from the tire / track contact in the rack | | |
| N | Gear ratio | 20,5:1 | mm |
| r_p | Pinion Radius | 8,9423 | mm |
| τ_a | Torque of assistance | | |
| τ_l | Load Torque | | |
| x_r | Rack displacement | 144 ±1,5 | mm |

2.2 Transfer Functions and Block Diagram of the EPS

According to Nise (2015), a dynamic system represented by differential equations is difficult to model as a block diagram. For this, the bases of the Laplace transform are established to allow the representation of the inputs, outputs and the system as separate entities, being able to study them in the frequency domain. Thus, the Laplace transform is defined as:

$$\mathcal{L}[f(t)] = F(s) = \int_0^{\infty} f(t)e^{-st} dt \quad (9)$$

From the differential equations that govern the dynamic system of the EPS it was possible to obtain the functions of transfer of the system through the Laplace transforms. The construction of the model was done using Matlab / Simulink software. The steering wheel transfer function, $V(s)$ and of the assembly, motor, rack and steering column, $G(s)$, were obtained by applying Laplace in equations (1) and (2) respectively.

$$V(s) = \theta_v(s) [J_v s^2 + C_v s + K] = \tau_v(s) - K\theta_c(s) \quad (10)$$

$$G(s) = \theta_c(s) [J_{equi} s^2 + C_{equi} s] = \tau_a - \tau_l - K[\theta_c(s) - \theta_v(s)] \quad (11)$$

In this way, the block diagram and the signal flow for the dynamics of the EPS as shown in Figure 2 were constructed.

The block diagram shows the inputs and outputs of each block of the system. The load on the rack is the source of system excitation, coming from the tire/track contact. From this load it is possible to calculate the assist torque on the steering column, thus estimating the effort on the steering wheel sensed by the driver.

The variables of steering angle, rack load and speed are external and come from the complete vehicle model built in Vi-CarRealTime software. The proposed virtual model is fed by these variables, which in turn returns to the vehicle model the displacement of the rack, in order to calculate the steering angle of the wheels.

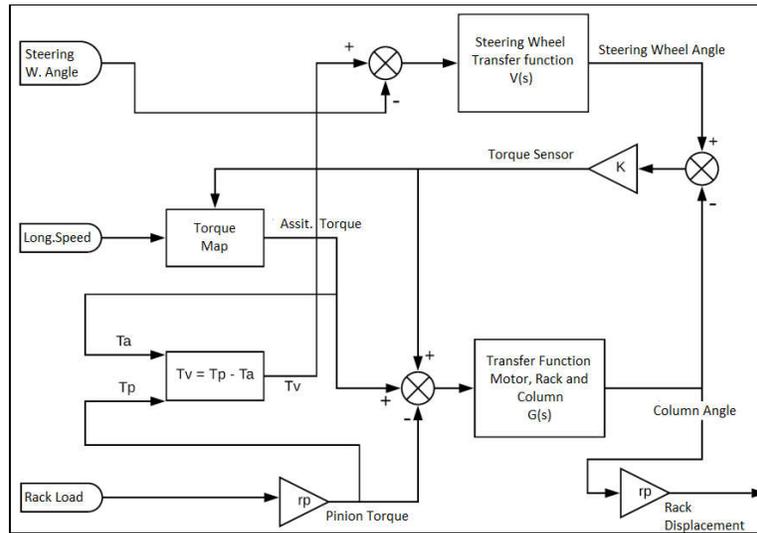


Figure 2 - Block diagram of the EPS dynamic model.

3. RESULTS

Considering the methodology performed, some results will be presented and analyzed in this section, to evaluate the dynamic behavior of the virtual model of the EPS, proposed by this work. The results are the analysis and interpretation of the functioning of the developed virtual model.

3.1 Virtual Model on Simulink

From the mathematical equations proposed for the dynamics of the system, it was possible to obtain the virtual model of the electric steering system, built in the Simulink interface. The developed model was elaborated based on the block diagram shown in Figure 2 of the previous section.

The angle of the steering wheel, the load on the rack and the longitudinal speed of the vehicle are given inputs to the steering system plant. The load on the rack comes from the tire/track contact. The forces generated from this contact, act through the mechanisms of connection of the steering system to the steering wheel, functioning as a return of the interactions between the track and the vehicle for the driver. The outputs are respectively the torque measured by the sensor and the angular variation, θ_c , of the steering column, as shown in Figure 3

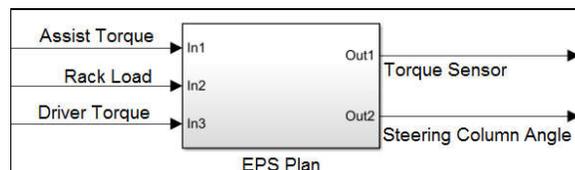


Figure 1 – EPS Model on Simulink

It is shown in Figure 4 the controller scheme where, the torque measured by the sensor along with the longitudinal velocity are input data for the same controller, which will make a comparison of these inputs with the torque map. After this procedure, the controller will associate the input values to determine the assist torque that will be used as input data for the system plant.

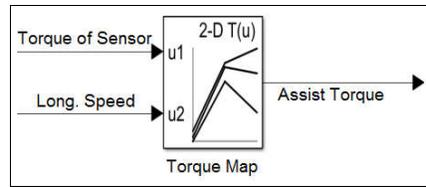


Figure 2 – Scheme of the controller

The more detailed schematic of the complete dynamic model of EPS constructed in Simulink is shown in Figure 5. In this scheme, the model construction and the main system input signals are shown.

The steering wheel angle, as input by the driver, the steering wheel will pass through transfer function, generating a steering wheel angle θ_p . From the signal flow, the product of the torsion bar stiffness by the angular variation between the steering system column and the steering wheel, will be exactly the torque read by the torque sensor. This torque sensor signal along with the longitudinal speed of the vehicle are reference data for calculating the assist torque that is applied to the EPS column. The assist torque added to the driver torque must overcome the torque generated on the pinion from the load on the rack.

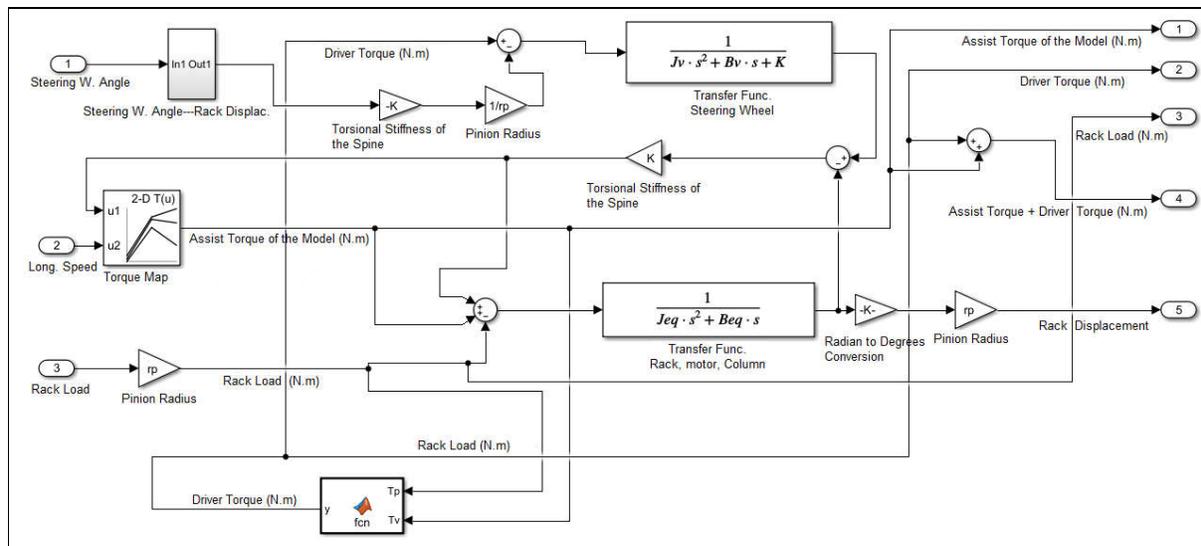


Figure 5 – Detailed Scheme of the EPS from Simulink

4. CONCLUSIONS

In the present work a virtual model of electric direction was created for application in a vehicle dynamics simulator of 9 degrees of freedom. Such a steering model was constructed so that it was possible to simulate in laboratory environment the actual behavior of an electric steering system.

The elaborated model had its architecture designed in the MatLab/Simulink program interface. This program allows to integrate, in a process of cossimulation, the computational models of automotive subsystems with Vi-CarRealTime software, in which the complete vehicle models are built. In this sense, it is possible to affirm that it was successful in the construction of the computational model of the steering system and its integration, with the program used for the elaboration of numerical models of vehicles. It was observed that the structure of the proposed model allows a simple and efficient change of torque maps and also of the physical properties of the system, such as moments of inertia, torsion bar stiffness and damping coefficients, besides allowing the implementation of controllers and algorithms for specific maneuvers.

5. ACKNOWLEDGEMENTS

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