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MODELICA-BASED MODELING AND SIMULATION OF HYDRAULIC POWER STEERING SYSTEM

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ABSTRACT

To investigate the steering characteristics of the hydraulic power steering system, a Modelica-based modeling approach is proposed. An automobile steering system test bench is set up for parameters identification. System characteristic features such as transmission ratio, stiffness, viscous damping and dry friction are estimated by bench test. The full version of hydraulic power steering system model is established in Dymola platform. For the sake of validating the proposed model, the vehicle steering performances are measured in field experiments which test maneuvers include the parking-lot steering and the lemniscate-shape path following. By driving the model with steering wheel angle signals measured in tests, the simulation results provide estimated performance of the hydraulic power steering system. The comparison between simulation and experiment results demonstrate the feasibility of proposed approach.

Keywords: *Multi-Domain Modeling, Modelica, Hydraulic Power Steering System, Bench Test*

1. INTRODUCTION

Among various subsystems of automobile, the steering system has great influence on vehicle control stability. Therefore, an accurate steering system dynamics model is the key point to predict the vehicle steering performance precisely [1].

For the Hydraulic Power Steering (HPS) or the Electric Power Steering (EPS) involved in the multi-domain modeling of complex system, co-simulation method is commonly used. The co-simulation between the power assisted steering system and vehicle dynamics is established by integrating software from various discipline fields, such as multi-body dynamics and fluid dynamics software. The internal data from different software need to exchange through the software interface, in order to achieve the co-simulation of the entire system. Y.Sun has built the steering system model based on AMESim and ADAMS software. The hydraulic power steering system model is built in AMESim platform, and the multi-body mechanical vehicle model is established in ADAMS/Car environment [2]. Jang has modeled a vehicle multi-body system in ADAMS environment and established an EPS control system in MATLAB/Simulink [3]. Afterwards, a co-simulation between ADAMS and Simulink is performed to evaluate the dynamic responses of the vehicle chassis and the steering system. This co-simulation method result in the complex modeling approach. On the other hand, the exchange of internal data in model through various software interfaces is restricted by the software vendors.

Although these modeling methods could obtain accurate results, but there are following shortcomings. Discrepancies in modeling tools and representation mechanism give rise to the difficulty in data exchanging between models came from different disciplines. As a result, this modeling approach lacks the opening and scalability.

In this paper, Modelica language is used in modeling and simulation of the hydraulic power steering system and the commercial vehicle [4]. The purpose of this paper is to establish a multi-domain simulation model describes the vehicle steering performance. This article is organized as follows. In Section 1, dynamics modeling of hydraulic power steering system is formulated. Section 2 introduces the complete system model built in Dymola platform. The validation of modeling is illustrated in Section 3. Finally, the conclusions are summarized in Section 4.

2. MODELING OF HYDRAULIC POWER STEERING SYSTEM

Modeling and simulation should base on the fully understanding of the system specifications and the

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component physical characteristics. The considered steering system of the commercial vehicle includes the steering wheel and column, hydraulic recirculating ball steering unit, the steering linkage and tires. Figure 1 shows the schematic of a hydraulic power steering system.

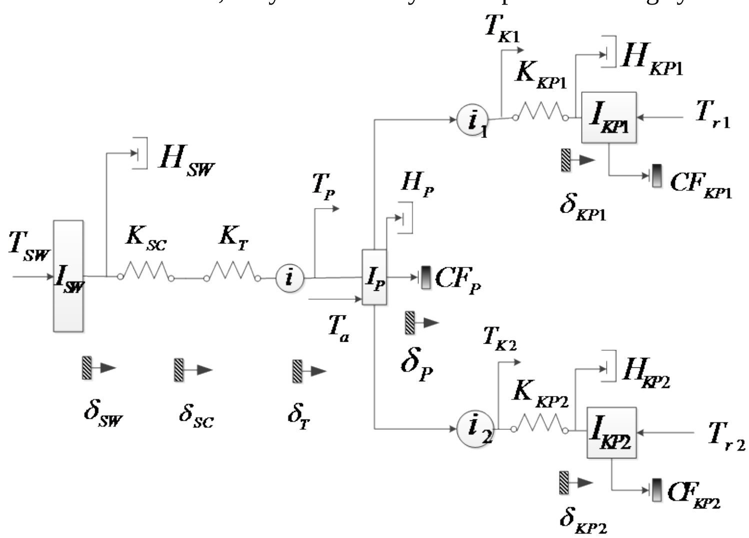

Figure 1 Hydraulic Steering System Model Schematic

As shown in figure 1, the dynamic model uses the basic concept of compliance elements to transmit torque to each successive element in the steering system. The dynamic model of this steering system [5], includes four lumped interia elements. These lumped terms are made up of the interia at the steering wheel I_{SW} ,interia at the left and right wheel assemblies about their respective kingpin axis I_{KP1} (I_{KP2}), and interia of the pitman arm I_P . There are six rotational dynamic degrees of freedom used in this model, which are made up of the angular displacement of the steering wheel δ_{SW} , angular displacement of steering column δ_{SC} ,angular displacement of torsion bar δ_T ,transitional motion of the pitman arm δ_P , and the rotational displacement of the left and right wheel assemblies about each kingpin axis δ_{KP1} (δ_{KP2}).The equations of motion for this system are summarized below in Equations 1 through 8.

$$I_{SW}\cdot\ddot{\delta}_{SW}= T_{SW}-H_{SW}\cdot\dot{\delta}_{SW}-K_{SC}\cdot(\delta_{SW}-\delta_{SC}) \qquad (1)$$

$$I_P\cdot\ddot{\delta}_P=T_P\cdot\eta_F+T_a\cdot\eta_{PS}-H_P\cdot\dot{\delta}_P -\frac{T_{K1}}{i_1}\cdot\eta_B-\frac{T_{K2}}{i_2}\cdot\eta_B-\operatorname{sgn}(\dot{\delta}_P)\cdot CF_P \qquad (2)$$

$$I_{KP1}\cdot\ddot{\delta}_{KP1}=T_{K1}-T_{r1} -H_{KP1}\cdot\delta_{KP1}-\operatorname{sgn}(\dot{\delta}_{KP1})\cdot CF_{KP1} \qquad (3)$$

$$I_{KP2}\cdot\ddot{\delta}_{KP2}=T_{K2}-T_{r2} -H_{KP2}\cdot\delta_{KP2}-\operatorname{sgn}(\dot{\delta}_{KP2})\cdot CF_{KP1} \qquad (4)$$

$$\delta_{SC}=\frac{K_T\cdot i\cdot\delta_P+K_{SC}\cdot\delta_{SW}}{K_T+K_{SC}} \qquad (5)$$

$$T_P=i\cdot K_{SC}\cdot(\delta_{SW}-\delta_{SC}) \qquad (6)$$

$$T_a=\frac{i\cdot p\cdot A\cdot t}{2\pi} \qquad (7)$$

$$T_{Ki}=K_{KPi}\left(\frac{\delta_P}{i_i}-\delta_{KPi}\right)(i=1,2) \qquad (8)$$

The basic premise of this model is to input an angular displacement δ_{SW} with the corresponding angular velocity $\dot{\delta}_{SW}$ into the steering wheel and obtain the required torque T_{SW} back to the driver through the steering system. The dynamic model of the steering system connects into the dynamics of the vehicle body and tire dynamics. Since

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the resisting torque T_{r1} (T_{r2}) in model is determined by tire dynamics, the tire model and the vehicle model are introduced to construct the whole simulation model. The simple linear model developed by Fiala is used to build the tire model [6].The vehicle model adopts the single-track linear model [7]. The parameters of the hydraulic power steering system are given in Table 1.

Table 1 Parameters Of The Power Steering System

Parameter Description	Symbol	Unit	Value
Steering gear angle ratio	i		19.53
Gear ration efficiency in forward transmission	η_F		0.8
Gear ration efficiency in reverse transmission	η_B		0.6
Efficiency of the power steering system	η_{PS}		0.717
Rotational inertia of steering wheel	I_{SW}	$kg \cdot m^2$	0.1883
Rotational inertia of pitman arm	I_P	$kg \cdot m^2$	0.0478
Rotational inertia of left wheel assemblies about respective kingpin axis	I_{KP1}	$kg \cdot m^2$	2.14
Rotational inertia of right wheel assemblies about respective kingpin axis	I_{KP2}	$kg \cdot m^2$	1.68
Rotational stiffness of steering column	K_{SC}	$N.m/rad$	582.9
Rotational stiffness of torsion spring	K_T	$N.m/rad$	219.4
Rotational stiffness of left kingpin	K_{KP1}	$N.m/rad$	83629
Rotational stiffness of right kingpin	K_{KP2}	$N \cdot m/rad$	94909
Viscous damping at steering wheel	H_{SW}	$N \cdot m \cdot s/rad$	0.1
Viscous damping at steering gear	H_P	$N \cdot m \cdot s/rad$	500
Viscous damping at left kingpin	H_{KP1}	$N \cdot m \cdot s/rad$	50
Viscous damping at right kingpin	H_{KP2}	$N \cdot m \cdot s/rad$	50
Screw lead	t	m	0.0115
Hydraulic cylinder piston area	A	m^2	0.005

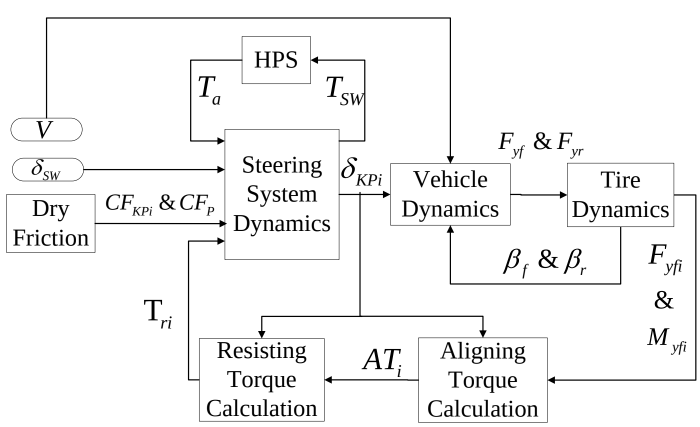

Figure 2 The Whole Simulation Model Of The Steering System

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3. IMPLEMENTATION OF STEERING SYSTEM MODELING IN DYMOLA

Based on the dynamic analysis of the steering system, the whole simulation model is constructed by integrating the steering system model, vehicle model, tire model, dry friction model and the torque calculation model according to their interactional relations in Dymola platform [8]. Fig.2 shows the whole simulation model of the steering system.

The eq.1-8 mentioned above are programmed in Modelica language. Fig.3 shows the high level modeling diagram in Dymola. It is consistent with the physical system as shown in Fig.2. Each icon represents a physical component. Composition line represents physical connection. Differential algebraic equations govern physical behavior of the component.

The input variables in this model include the vehicle speed V and the steering wheel angle δ_{SW}. It can be used for the evaluation of vehicle steering dynamic performance, such as lateral acceleration, yaw rate and steering wheel torque. Comparison between experimental results and simulation results of proposed model verify the accuracy and efficiency of the proposed model.

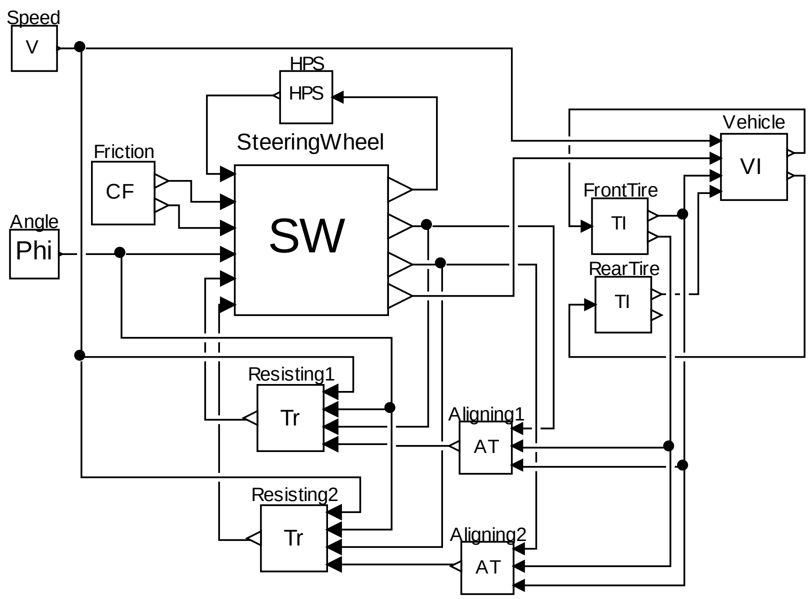

Figure 3 Diagram Of Hydraulic Steering System In Dymola Platform.

4. MODEL VALIDATION WITH EXPERIMENT

4.1 Bench test

To acquire more accuracy parameters in model, an automobile steering system test bench is set up. The bench is equipped to gather the following signals: steering-wheel angle, steering-wheel torque, left and right front-wheel angle and load. The transmission ratio, stiffness, vicious damping and dry friction characteristic features of steering system are derived from bench test by appropriate post-processing. The parameters of the simulation model are predefined by the characteristic features in Table 1.

4.2 Road Test

In order to validate the model of hydraulic power steering system, two types of maneuvers are performed at various driving condition. One is parking-lot maneuvering in no-load condition to validate the effect of assist steering. The other is lemniscate-shape path following in full-load condition to evaluate the steering handiness of the test vehicle. The steering wheel torque and angle signals are gathered and pretreated by the data acquisition board (DAQ).The test results can be real-time displayed on the notebook.

The simulation model is driven by the angular displacement of the steering wheel measured in field tests. The steering wheel angle (SWA) measured in vehicle field test is fitted into a curve as the input of the simulation model. Therefore, the

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simulated steering wheel angle is coincident with SWA in Fig.4. After model calculation, the simulated steering wheel torque and the measured steering wheel torque (SWT) have good coincidence in time domain. Because of the variability of the driver inputs, these maneuvers differ from one run to the next. Therefore, four times experiments are performed and the results have very good consistency as shown in the indicator diagram Fig.5. From Fig.4-5, we can see the predictions of the simulation model agree well with the experimental results.

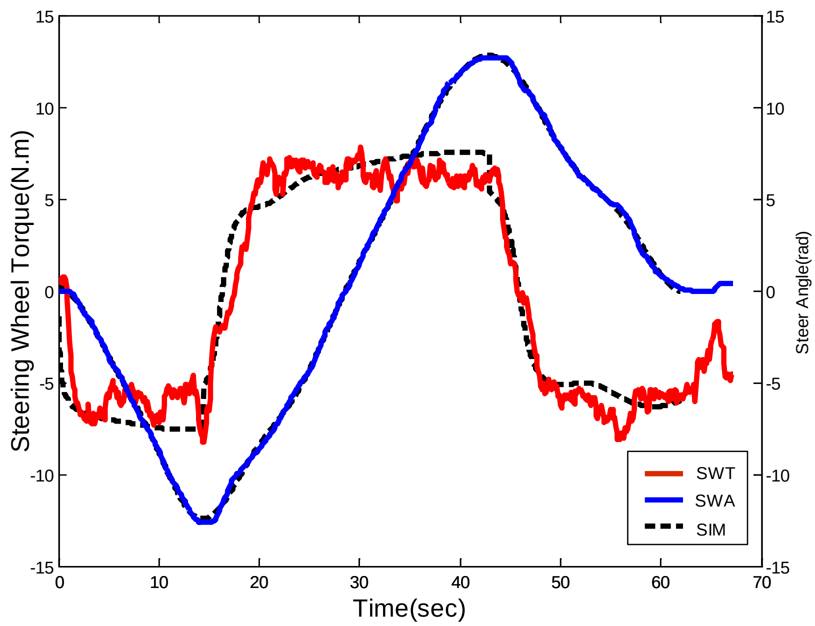

Figure 4 Steering Wheel Torque And Angle At Parking-Lot Maneuver

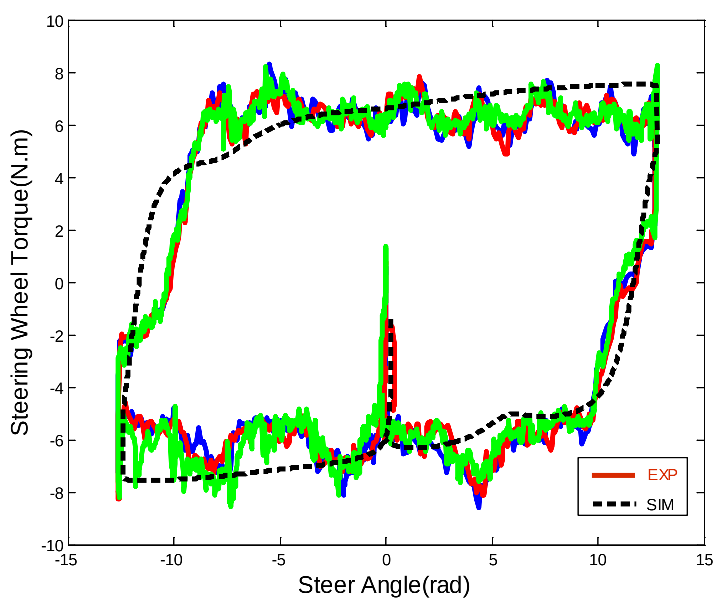

Figure 5 Steering Wheel Torque Vs. Angle At Parking-Lot Maneuver

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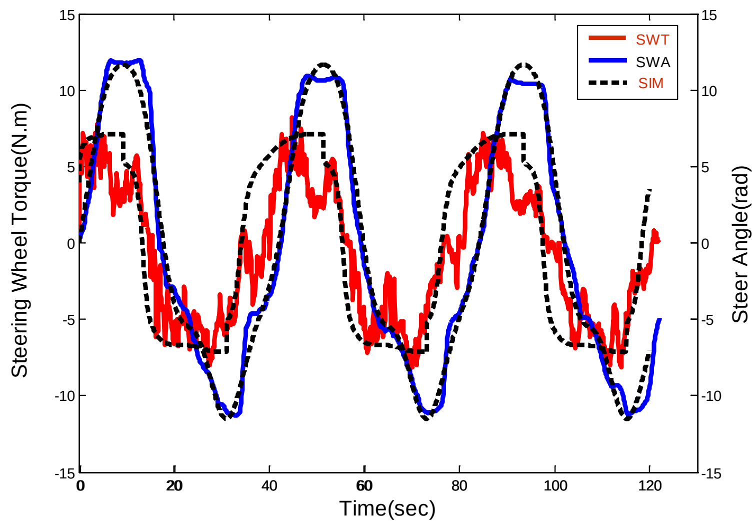

Figure 6 Steering Wheel Torque And Angle For Driving On A Lemniscate-Shape Path

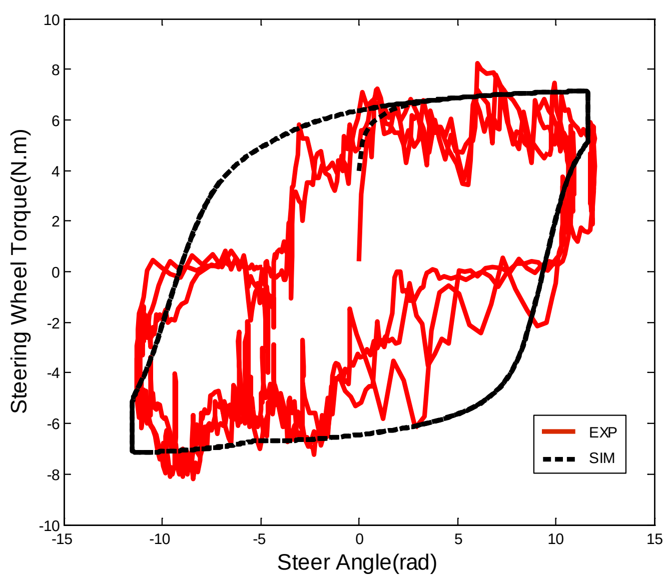

Figure 7 Steering Wheel Torque Vs. Angle For Driving On A Lemniscate-Shape Path

Lemniscate-shape path is always used to evaluate the steering handiness of the vehicle. In this vehicle test, the minimum radius of the lemniscate-shape curve is 9 m. Therefore, the polar coordinates equation of locus is defined as $L = 27 \cdot \sqrt{\cos(2\psi)}$. In this case, vehicle moves at a constant speed 10 km/h. Fig.6-7 show the comparison between simulation and experimental results.

As shown in Fig.6, the simulation results coincide well with SWA and SWT. In Fig.7, we can see that the average friction torque of the simulation results is a little greater than the experimental results. This is due to the linear tire model used in the simulation model.

5. CONCLUSIONS

This paper presents a modeling and simulation method to investigate the steering characteristics of the hydraulic power steering system on the commercial vehicle. Modelica language is used to present the complete system architecture. The full version of hydraulic steering system model is developed in Dymola platform. The characteristic features of the steering system model such as the

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transmission ratio, viscous damping, stiffness, dry friction are measured through a series of bench test. In order to validate the model of hydraulic power steering system, two types of maneuvers are performed at various driving condition.

As shown in Fig.4-7, we can see the simulation results reflect the actual performance of the hydraulic power steering system. It proves the rationality of the simulation model. This comparison between simulation and experiment results demonstrate the feasibility of proposed approach.

This simulation method has a good interactive interface, and can quickly achieve the purpose of modeling and simulation. Meanwhile, the established model can be used in further optimization and analysis of the steering system.

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