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Modeling of Electro-Hydraulic Power Steering System using Bond Graph Technique

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Abstract: ***A mechanism consists of a number of rigid bodies. The modeling of a mechanism is important for design and control of a system. In mechanics, the formalized procedures for modeling dynamics, like Newton-Euler, Lagrange's Euler and Hamiltonian's method, are mathematically burdensome for large and complex multi-body systems. Moreover, these procedures do not present cause and effect relationship. The bond graph technique is a graphical representation of dynamics. The application of bond graph technique results in a number of advantages. In this paper, an attempt is being done to use bond graph technique for modelling and simulation of Electro-Hydraulic Power steering system. This mechanism is taken to show an important feature of bond graph that it is a modeling tool which can be used for analyzing dynamics in various energy domains. The mechanism being considered is a combination of Electrical, Hydraulic and mechanical systems. The use of bond graph for modeling multi energy domain has rarely been explained.***

Keywords: Modeling, simulation, bond graph and steering system

1. Introduction

Modeling of Electro-Hydraulic Power Steering system provide an effective method for analyzing dynamics characteristics of Electro-Hydraulic Power System (EHPS) and designing high performance steering controllers. Electro-hydraulic power steering system provides the natural, smooth feel of a sophisticated conventional hydraulic power system. Motor power is converted to hydraulic pressure to assist steering. By providing power assist via hydraulic pressure, the system delivers a naturally smooth steering feel. The Electro-Hydraulic Power System (EHPS) improves the fuel economy. In conventional hydraulic steering system, the hydraulic system extracts power from the engine, which lowers the total power output of the vehicle and decreases the fuel mileage of vehicle slightly. In electro-hydraulic power steering system, the power to the hydraulic system is delivered by an electric motor and not by engine directly. Moreover, the electric powered pump operates only when steering assist is needed, this also adds in improving fuel economy. Hydraulic system assist greater reduction ratio than with the gear. EHPS generates fuel efficiency benefits that are almost on a par with those of Electric power steering system, but at a minimum cost. The Electro-hydraulic power steering system consists of the steering wheel, the steering column and steering shaft, Rack and pinion gear, Tie rod, Electric Control Unit (ECU), Torque sensors and Motor and Hydraulic pump assembly. In manual steering system, the input steering angle and torque are transferred to rack and pinion shaft via universal joint. The rotational torque of pinion rod is transformed to propelling power of rack shaft axial force. The rack shaft axial force will be converted to swing motion of tires via tie rod and joints. But in EHPS, the torque sensor and vehicle speed sensor detects the vehicle speed and torque applied by the driver on the steering. These two sensors give this information to the ECU to control the motor of the hydraulic pump, to provide the desired assist steering torque. The purpose of controlling the motor is to improve driver's steering assist by creating appropriate torque. The flexibility of the control allowed by electric motor, offers more precise steering power characteristics.

Krus et al. (1994) developed a pipeline model using the state variables of the pressure and flow rate to simulate the dynamic behaviours in hydraulic pipelines. Zaremba, and Davi (1995) focused on Dynamic analysis and stability of a power assist steering system. Manring et al. (1996) studied the effects and sensitivity of the variation in system parameters, including actuator volume, discharge hose volume, control-gain, and system leakage, on the pump dynamics in modeling and designing a variable-displacement pump. Fitzsimons and Palazzolo (1996) developed a one-degree-of-freedom model of an active hydraulic "mount" to study the effects of servo valve dynamics and fluid compressibility on the hydraulic system. Wu et al. (1998) developed an electro hydraulic steering simulator, which consisted of a dynamic model of steering controller and hardware of main components, including a PWM driver, a solenoid driven E/H steering control valve, and one steering actuating cylinder. This hardware-in-Loop simulator could evaluate the performance of an E/H steering system based on the actual responses of main components corresponding to control signals. Hongchu Qiu,Qin Zhang,John F.Reid and Duqiang Wu in (1999) presents a model and simulation results of an agricultural vehicle electro hydraulic steering system. This model used Ackerman angle and steering actuator displacement to describe the dynamic behaviours in steering rate control. Bingzhao Gao, Kazushi Sanada, Kenichi Furihata (2007) show their interest on yaw rate control of Hydraulic-Power-Steering Heavy Duty Vehicles. Designed controller was tested on the combined simulation model and it was shown that the servo system can get satisfied control performance.

The research in Electric power steering system has also been done in 2009 (Zeng Qun, Huang Juhua, 2009) . In this paper, an optimal control modeling and simulation design is presented for the column assist type EPS system with a brushed motor based on Matlab. L.G. Viana, G. Romero, J.

Maroto and J. Felez (2010) have done their research in hydraulic power assisted steering system. They concluded modeling and simulation by using bond graph technique to make possible the combination of hydraulic and mechanical components.

2. Bond Graph Modeling of Electro-Hydraulic Power Steering System.

In the modeling process of electro-hydraulic steering system, basically it has been considered a combination of inertial, capacitive and resistive elements which work both in mechanical and electrical domains.

1) **Electric Motor** - The voltage U applied to the electrical motor which convert voltage signal into mechanical approach to the rotation of the shaft which is connected to hydraulic system. the motor resistance R_a and the motor inductance L_2 are considered in this model. K_b is considered as motor torque constant, the assist motor moment of inertia is I_7, the motor resistance coefficient is R_6 and the compliance of the motor is K_9.
2) **Steering System** – The mechanical steering system can be divided into
   - The steering wheel which is inertial components represents the moment of inertia of the steering wheel.
   - Steering column mechanics is considered on rotated pieces of inertia components, damping components and capacitive components.
   - Rack and pinion gear of the bond graph model should be considered as speed of transformation and its main function is to assist the wheel direction. It depends upon torque of the steering shaft in both clockwise and anticlockwise direction.
   - Tie rod is a part of steering system which transform the movement of steering column to wheels. During the turning of the steering wheel, the wheels connected to the tie-rod is also turn respectively. It is considered as flexibility factor, damping coefficient as its control the movement of wheels.
   - Wheels. The wheels are connected to the tie-rod.The bond graph model of the wheel also consider as inertial components and damping elements.
3) **Hydraulic Part** – This model has pressure line which is represented by the elements R_{12} and K_{14} that are the radial stiffness. When the steering system is turned to right direction under this condition the valves R_{16} and R_{27} are opened. while R_{18} and R_{30} stay closed. When the steering system is turned to left direction then under this condition the valves R_{18} and R_{30} are opened. while R_{16} and R_{27} stay closed. The rotary valve is represented by four resistances(R_{18}, R_{16}, R_{27} and R_{30}) that are the right and left and also represent in and out passes of the rotary valves and for each resistance pair there is a compliance pair (K_{26} and K_{23}) which are referred to compressibility at the respective hydraulic chamber of the valve. The transformer TFPs represents cross-sectional area of the hydraulic piston section into the rack components, which convert hydraulic pressure in longitudinal force which is delivered to the rack component mechanism.
4) **Rack Pinion mechanism and Tie-Rod** – The mass of the rack is M_{45}, the resistance of the rack is B_r, the compliance of the rack is considered negligible, the compliance of the tie rod is K_{48}, the resistance of tie rod is R_{49}, the inertia of the tire is J_{53} and the resistance offered by tire on the road is R_{52}, which is equal to the aligning torque. Translation motion of tie rod is converted into rotational motion of the tire, the length ratio of steering arm is G_t. Bond graph of the EHPS system has been shown in fig. 1.1.

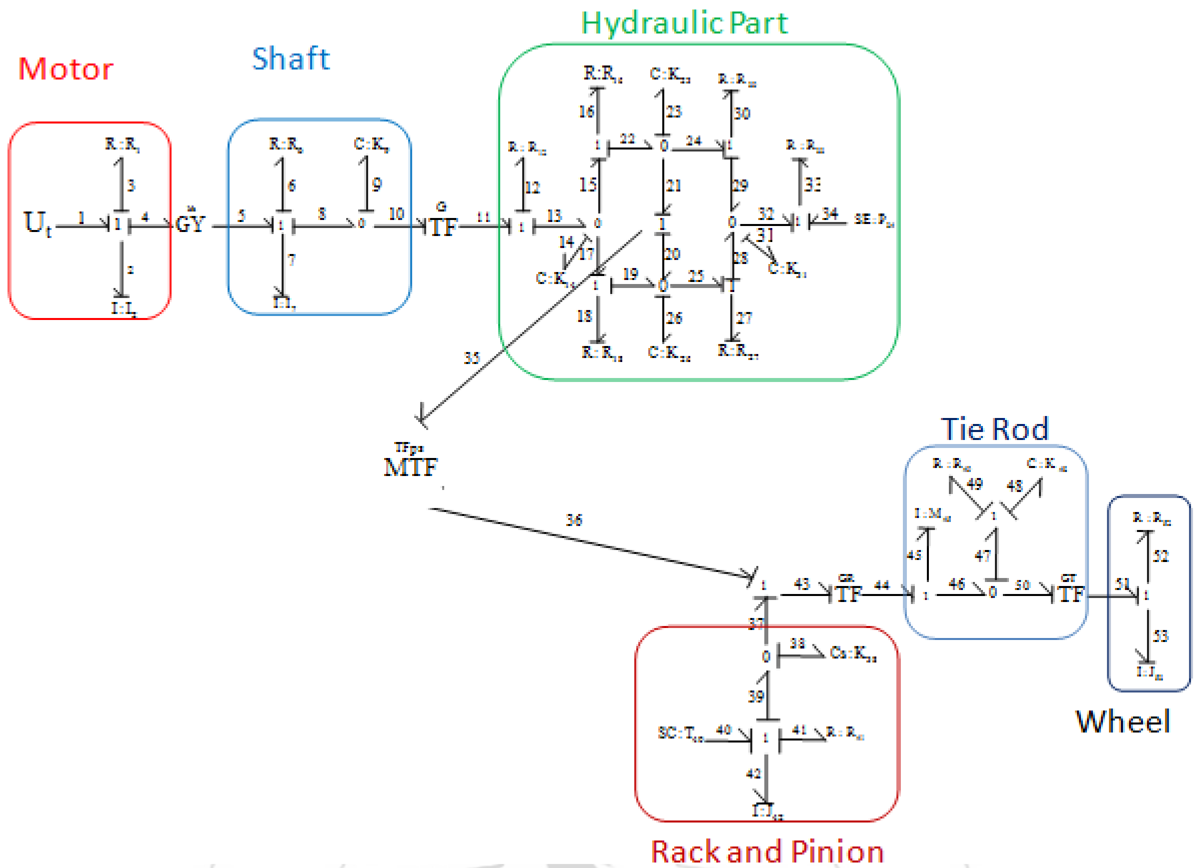

Figure 1.1: Bond Graph Model of Electro-Hydraulic Power steering System

3. Conclusion and Future work

In this work, EHPS system, being a combination of various systems such as electric, hydraulic and Mechanical, has been modelled using multiband graph technique. Stiffness and damping parameters are considered on various joints. Further simulation of this system will be done using MATLAB. Analysis of various kinematic quantities will be performed.

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