Design of Control Strategies For EPS System

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ABSTRACT.

Electric Power Steering (EPS) system is an advanced steering system that assists steering torque using the electric motor. In this paper studies have been done on the electric power steering system for a front wheel-steered driven four wheels vehicle. First, the principle and structure of EPS are discussed. Then the characteristics of EPS system are analyzed, including the typical power curves which deal the relationship of the assist torque and the steering wheel torque. At last the EPS system's dynamic model and the computerized simulation model have been established in MATLAB/Simulink in terms of three aspects which are the mechanical steering without power system, EPS system and EPS system with PID control. This paper deals with the mathematical model and characteristic curves of EPS System. We have derived the mathematical model of column assisted front wheel steering on the basis of Newton's laws of motion. We designed a controller for our model with the help of assist characteristics curves and PID action. We have carried out simulation on different types of vehicle paths which include circular and moose test path. We chose two different cases of steering and for each case we have carried out simulation by considering the two paths states.

Keywords: EPS, mathematical model, characteristics curves, PID, simulation, circular and moose test path

1. INTRODUCTION

There are four different types of EPS, column, pinion, rack-assisted and a fully steer by wire type. In this paper, the configuration of column-type EPS is shown in Fig. 2(b) is used as an example. It consists of a torque sensor, which senses the driver's movements of the steering wheel as well as the movement of the vehicle; an ECU, which performs torque sensor and vehicle sensor; a motor, which produces turning force according to the output from the ECU; and a reduction gear, which increases the force from the motor and transfers it to the steering mechanism calculations of assisting force based on signals from the (Haobin Jiang, Jingbo Zhao, Haimei Liu, Long Chen 2008)

The aim of the project is to develop a control strategy for electric power steering system to find out steering effort applied by the driver. Model based optimization and control are now accepted by the automotive industry as an effective

approach to innovative design to enhance fuel efficiency and reduced exhaust pollution. There are so many challenges in front of designers while designing the electric power steering system. Some of them are:

To improve motor efficiency using complex algorithms for model-based control. (Chih-Jung, Ho, Shih-Rung. 2008)

Minimizing driver torque and acoustic noise to improve human and machine interface.

Need of fast control loops with minimum cycle time to accurate measurement of key parameters such as torque, motor current, and speed of vehicle (Fan and Yan-ling 2012).

To develop a controller for worst condition.

2. MODEL ASSUMPTION

If all the masses and moment of inertia of various spring and damping element that appear in the system are considered in relation to their interaction with then system will become

complex. Some assumptions are made to simplify the system (Manu Parmar, John Y. Hung 2004).

All mechanical connections are rigid.

All elements behave like a spring mass damper system.

The EPS system is composed of three basic elements: steering column, steering rack, and assist motor.

Neglect the masses of tie-rods and tire.

3. MATHEMATICAL MODEL OF EPS

Stiffness of steering shaft is very important parameter in designing an electric power steering system as it affects returnability considerable. Returnability means ability of the steering wheel to come its center position after completing a turn. When the steering wheel is turned and then released during cornering, it returns to the center position by the torque exerted on the tires by road, which is called as self-aligning torque. This self-aligning torque helps in returnability. Building a mathematical model is very necessary to study the effect of stiffness damping and moment of inertia of steering column and assist motor on driver's torque. A simplified from of EPS as shown in figure 1 is considered to build a mathematical model.

Fig. 1 EPS steering model (Zhang, Yuzhi and Jinhong 2009)

Using newton's laws of motion and with the help of assumption made the equation of EPS can be derived. Consideration the moment of the steering wheel and the viscous damping of input axle, we get,

$$J_c \ddot{\theta}_c + C_c \dot{\theta}_c = T_d + T_{sen} \quad (1)$$

Where, T_d is the driver torque or steering torque working on input wheel, T_{sen} is the anti-torque working on the torsion bar.

$$T_{sen} = K_c \left(\theta_c - \frac{x_r}{R_p} \right) \quad (2)$$

The motor for is a permanent magnetic field DC motor. The relationship among voltage V across it, inductance L , armature resistance R , back electromotive force K_b , motor speed $\frac{d\theta_m}{dt}$, current I and time t is,

$$V_m = LI + RI + K_b \dot{\theta}_m \quad (3)$$

Torque generated by the motor

$$T_m = K_a I \quad (4)$$

Where, K_a is torque co-efficient of motor.

To analyze the force working on the mechanism for the motor, an equation can be obtain as follows,

$$J_m \ddot{\theta}_m + C_m \dot{\theta}_m = T_m - T_a \quad (5)$$

Where T_a is assist torque and it is given by,

$$T_a = K_m \left(\theta_m - G \frac{x_r}{R_p} \right) \quad (6)$$

Where, G is motor gear ratio. When a vehicle steers, steering resistance is primarily influenced by the friction created by the tire and the surface of ground and various and other friction, it is given by,

$$F_{TR} = K_r x_r + F_d \quad (7)$$

Where F_d is the random signal from the road and it is proportional to rack displacement.

Combining equation (1) to (7) we get

$$J_c \ddot{\theta}_c + C_c \dot{\theta}_c + K_c \theta_c = T_d + K_c \frac{x_r}{R_p} \quad (8)$$

$$J_m \ddot{\theta}_m + C_m \dot{\theta}_m + K_m \theta_m = T_m + K_m \left(G \frac{x_r}{R_p} \right) \quad (9)$$

$$\begin{aligned} M_r \ddot{x}_r + C_r \dot{x}_r + K_r x_r &= \frac{K_r}{R_p} \left(\theta_c - \frac{x_r}{R_p} \right) \\ &+ G \frac{K_m}{R_p} \left(\theta_m - G \frac{x_r}{R_p} \right) + F_d \end{aligned} \quad (10)$$

This is a simple mathematical model of electric power steering. In (8), (9) and (10), J_c , C_c , K_c , T_d are steering column and steering wheel

rotational moment of inertia, viscous damping coefficient of steering column, torsion bar stiffness, driver torque respectively, of steering column, J_m , C_m , K_m , θ_m , T_m , are motor rotational moment of inertia, viscous damping coefficient of motor shaft, motor shaft stiffness, motor rotation angle, motor torque respectively, of motor is gear ratio, T_d is driver torque, T_a is assist torque, and L is Motor induction, I is motor current, V_m is motor terminal voltage, R is Armature resistance, V is Armature resistance.

Figure 2 shows the torque flow of the steering system. The driver's torque (T_d) actuates the motor which sends the assist torque to displace the rack. Output y is the actual torque acting on the rack to displace it which should be identical to driver torque.

Fig 2: Torque flow of EPAS

(Prasanth babu kandula 2006)

4. ASSIST CHARACTERISTIC CURVES:

The major object of EPS system is to provide a proper amount of assist torque by the electric motor to reduce the effort of the driver when the vehicle is cornering. For generating a suitable torque output from the motor to assist the driver, assist characteristic curves are needed. According to assist curves, the core controller of the EPS system receives signals from the torque sensor and vehicle speed sensor and calculates a suitable amount of assist gain to output to motor controller. Therefore, the motor can provide a proper torque to assist the driver to turn the steering wheel figure 3 (Hu, Yeh and Ho 2008).

Fig.3 Assist characteristic curves of EPS

(Hu,Yeh and Ho 2008)

Fig.4 Assist characteristic curves of EPS

(Hu, Yeh and Ho 2008)

The power-assisted characteristic of EPS has three typical kinds of characteristic curves; the straight line type, the broken line type, and the curve type. Each characteristic curves can be divided into three areas; the no power assisted area, the changing area of power-assisted and the fixed area. In comparison to the three kinds of power-assisted characteristic curves, the straight-line characteristic curve is the simplest, which is convenient to design and adjust the control system easily. The curvilinear power-assisted characteristic curve is so complicated.

The target motor current which is determined by the assist characteristic based on the input of torque sensor and vehicle speed sensor. The relationship of the real-time vehicle speed is derived from vehicle speed sensor and the steering wheel torque is expressed by the following function $I_T = f(V, T_S)$. By using the Lookup Table (2-D) block in MATLAB/Simulink, the assist characteristic can be realized as shown in Figure 4 (Tsung-Hsien Hu, Chih-Jung Yeh, Shih-Rung Ho 2008)

5. SIMULATION RESULTS:

Simulations were performed in Matlab /Simulink in order to evaluate assist characteristic of EPS and torque sensor responses. The simulations were carried out for the vehicle following a particular path. Two type of path were considered i.e. (1) circular path and (2) moose test path. Also simulations were carried to observe, how assist is vary with load of the vehicle. PID controller is used with different values of K_p, K_i, K_d . The controller takes signals from torque and speed sensor. According to the signal input, controller decides how much torque is required, according to that it sends the current signal to the assist motor as shown in figure 5 (Guobiao Shi, Rongwei Shen, Yi Lin 2007).

Fig. 5 Simulink control block for EPS

5.1: With EPS and without EPS

In case of EPS driver torque is less than 15 N-m while in case of without EPS it is more than 15 N-m. This shows that driver needs to apply more torque in case of without EPS. Figure 5.8 show simulation results for circular path with steering wheel angle 1 rad. EPS case we take gear ratio is $G=20$, $K_p = 8, K_i = .1, K_d = .1$, spring constant $K_s = 80$ and without EPS case we take gear ratio $G= 0, K_p = 0, K_i = 0, K_d = 0$, spring constant $K_s = 1120$ and spring damper is 10.

Fig. 6 Circular path

In case of EPS driver torque is less than 10 N-m while in case of without EPS it is more than 13 N-m. This shows that driver needs to apply more torque in case of without EPS. For this case we take gear ratio is 20, $K_p = 4, K_i = 1, K_d = 1$ and spring constant, $K_s = 80$ and without EPS case we take gear ratio $G= 0, K_p = 0, K_i = 0, K_d = 0$, spring constant $K_s = 1120$ and spring damper is 1.

Fig. 7 Moose test path

5.2 Driver torque at different road stiffness

The fig.8 plot driver torque (N-m) and time(s) and in this case vehicle enters a circle first and then follows a circular path with a constant steering wheel angle. When road stiffness change the torque apply by driver also change. If road stiffness increase the torque by driver also increase.

Fig. 8 Circular path

The fig.9 plot driver torque (N-m) and time(s) and in Moose test is used to test how much a certain vehicle acts when avoiding a certain danger e.g. goat, dog and cow. It is also called as elk test .this test is performed on dry road surface. In this test traffic cones are set up in S-shape to simulated obstacle, the road and its edges, with presence of person at each available place in vehicle and weight in trunk to achieve maximum load. When

road stiffness change the torque apply by driver also change. If road stiffness increase the torque by driver also increase.

Fig. 9 Moose test path

5.3 Angle Theta1 and Theta2 at different road stiffness

From Fig. 10, it shows that the current of the motor's armature and the driver's input torque nearly superposed, validating the mathematical model and control strategy. In this paper, EPS model is set up, and the simulation results of mechanical steering without power system, EPS system and the EPS system with PID control are compared. At last, the actual current of the motor following the target current precisely shows that the designed assistance characteristic works effectively.

The next simulation, Fig. 11 shows the comparison of the steering wheel input force (the blue line) and the electron motor output force (the pink line) when vehicle speed is 30km/h.

Fig. 12 Time responses of three types of steering In the result of simulation, as shown in Fig. 12, the steering wheel is unit step input. Without power assist, the driver must provide the whole torque required for steering. However, with power assist, the amount of driver's torque is significantly reduced based on the reference steering torque from torque map. Fig.11 also shows that PID control used in EPS control strategy works well.

6. CONCLUSION AND FUTURE WORK

In this paper we have studied the electric power steering system for a front wheel- steered, rear-wheel driven four wheeled vehicles. We have derived the mathematical model of column assisted front wheel steering on the basis of Newton's law of motion. We designed a controller for our model with the help of assist characteristics curves and PID controller. We have carried out simulation for different types of vehicle path which include circular and moose test path. We choose two different cases of steering and for each case we have carried out simulation by considering the two paths states above. The simulation result shows that the introducing of a feedback to EPS is an effective way to improve the vehicle performance. EPS with torque control play a significant role in portability when the vehicle turning at low speed and cornering. We can say that our controller can provide good steering efforts. Though the EPS is very useful and efficient, it needs complex algorithms to design, torque sensors used in EPS are very expensive, and this increases the cast of practical

implementation. It is also shown that the steering torque can follow the reference steering torque determined from a torque map reasonably well, independent of load torques which tend to vary depending on the driving conditions. It is a challenge in front of designers to design a simple and low cost EPS for practical application.

Future work may include the following,

Conducting the experiments on test bench and actual vehicle to find out controller performances.

This may include some modifications in controller depending on vehicle instrumentation and feedback available.

Improving the considered model by including the effort of lateral slip on steering rack.

In the future, hardware implementation of the PID controlled EPS is expected to be completed.

We also plan to test this control system by conducting real-world road test.

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