Research on control strategy of the vehicle electric power steering system based on brushless DC motor

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Abstract: The structure and working principle of steering column-power type electricpower steering (EPS) system were introduced. The control strategy and assist characteristics of EPS system were designed based on brushless DC motor. Torque control strategy of power steering motor was designed based on the research of brushless DC motor structure and control method. Power steering tests were completed in the EPS system test bench. The test results showed that the designed control strategy is effective and can get a good assist characteristics.

Introduction

Electric power steering system(EPS) is a new type of automobile power steering system which has many advantages such as saving energy, environment protection and assist characteristic , etc. The research about EPS system is mainly focused on the selection of the booster motor, the optimization design of controller and control strategies[1,2].

Structural Composition and Working Principle

The structure of the steering column-power type electric power steering system is shown in Fig.1. It consists of speed sensor, torque sensor of steering wheel, angle sensor of steering wheel, current sensor of motor, electronic control unit, brushless DC motor and steering rack.

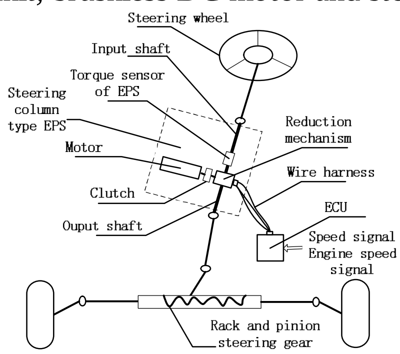


Fig.1. The structure of electric power steering system

When the driver operates the steering wheel , the sensors detect a variety of signals such as steering torque signal, vehicle speed signal, engine speed signal processing and other types of signals and send it to the ECU. Based on the respective signals sending to the ECU in which the working conditions of vehicle can be determined ,power-assisted was controlled through the torque signals, road feeling was controlled by the speed signal, then power-assisted motor output the torque of the working conditions, the reduction mechanism reduce speed and increase torque,then amplified the torque again on a rack and pinion steering gear to achieve the power-assisted steering role. When the torque of steering wheel amplifies, the motor increases torque to ensure the portability of steering .At higher speeds, the torque is reduced in order to obtain a better road feel [3,4].

EPS system control strategy and assist characteristic design

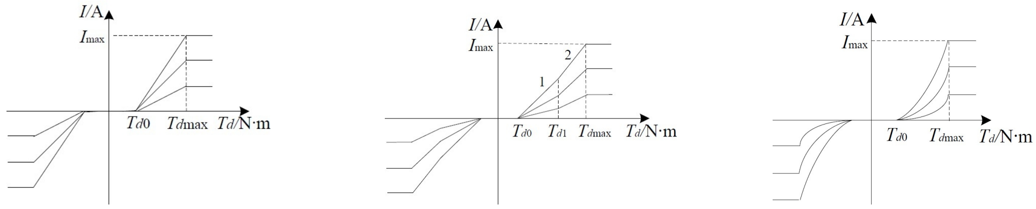
System overall control strategy

The EPS system is based on the traditional mechanical steering system and increased of the electronic control system. Electronic control unit of EPS system is based on the power of the motor torque. Therefore, the control strategy of EPS system can be divided into two layers [5], the upper layer is decision-making control, the lower layer is execution control. The operation mode of EPS system can be divided into the assist control mode, the damping control mode and return-to-center control mode.This paper studied on assist control mode.

The basic assist characteristic selection

The assist characteristic refers to the relationship between motor current changing and movement condition of the car(steering wheel torque and speed).

The commonly used three kinds of basic assist characteristics are liner type, broken line type and curve type is shown in Fig.2. Because of the changing between motor current and steering wheel torque is linear,so linear type of assist characteristics is simple and easy to control, which is used commonly[6].



(a) Linear type (b) Broken line type (c) Curve type

Fig.2. The simulation stytem of assist characteristic

Matching between the assist characteristic and the vehicle

The selection of assist characteristics should be matched with the vehicle. Speed coefficient Td0, Tdmax and Imax is set according to the vehicle performance parameters for linear assist characteristic curve,

Td0: When the steering torque is less than Td0, booster motor does not provide assistance to prevent the frequent moves of motor. Td0 should be appropriate, otherwise it will make steering too hard or too sensitive . In this paper, Td0 = 1N • m.

Tdmax: According to national standards, the maximum tangential force of steering wheel should not exceed 50N . The diameter of steering wheel is 350mm, the maximum torque of the steering wheel can be calculated by the following formula:

$$T_{d\max} = F_{d\max} R_d \qquad (1)$$

Fdmax : the steering wheel maximum tangential force, N, Rd :steering radius, m.

Calculation :Tdmax = 8.75 N • m, due to different physical drivers, in this paper Tdmax = 8 N • m.

Imax: The motor torque coefficient is constant, the maximum assist motor current depends on the maximum steering torque when the vehicle is static; Empirical formula of resistance.

$$T_{r\max} = \frac{f}{3}\sqrt{\frac{G_1^3}{p}} \qquad (2)$$

Trmax: the steering resistance torque, N • m , f : the sliding friction coefficient of the tire and the road surface, generally take 0.7 , G : the front axle load, N, P : tire pressure, Pa.

The maximum output torque of the motor can be calculated by the following formula (applied to the column assist-type):

$$T_{m\max} > \frac{T_{r\max} - T_{d\max} g_r h_r g_t}{g_m h_m g_r h_r g_t} \qquad (3)$$

Tmmax: the maximum output torque of brushless DC motor, N • m, gm: the transmission ratio of motor reduction mechanism; ηm: the transmission efficiency of motor and the reduction mechanism , gr: the ratio of rack and pinion steering gear, mm / rad , ηr : Forward transmission efficiency of rack and pinion steering gear, gt : the transmission ratio (from the steering tie rod to the steering wheel swizzle), rad / mm.

Maximum assist current of motor can be calculated by the following formula:

$$I_{\max} = \frac{T_{mmax}}{K_i} \quad (4)$$

Ki : Torque coefficient of brushless DC motor.In this paper, Imax = 30A.

Design of torque control strategy for brushless DC motor

The control of assist motor torque has three methods. Respectively is the motor armature voltage control, steering wheel torque direct control and motor armature current control. So this paper uses motor armature current control method which is also called PWM wave technology,is easy to implement and has high control precision. Combine the traditional PID with modern control theory .Fuzzy PID controller was designed for closed-loop current control, so that the system gets higher control precision. The core of fuzzy PID controller was fuzzy controller. Design of fuzzy PID controller shown in Fig.3, By fuzzy controller parameter tuning, the total of PID parameters satisfy the following formula:

$$K_p = K_{p0} + \Delta K_p \quad (5)$$

$$K_i = K_{i0} + \Delta K_i \quad (6)$$

$$K_d = K_{d0} + \Delta K_d \quad (7)$$

Kp0: initial ratio of PID regulator,Ki0: differential coefficient of PID regulator,Kd0: integral coefficients of PID regulator. Fuzzy PID controller via real-time adjustment of the three PID parameters to improve the dynamic performance of the EPS system.

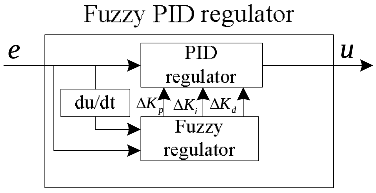


Fig.3. The Fuzzy PID controller structure

Result Analysis

In order to verify the validity of the control strategy, the controller is tested on the electric assist steering test bench . The input-output torque characteristic curve is shown in Fig.4. The characteristic speed of the selection was 0km / h, 20km / h, 40km / h, 60km / h and 80km / h, the maximum input torque of steering wheel was set to 12N • m, Servo motor rotated input shaft in uniform speed. The figure shows that at the set input torque, with the input torque increases, the output torque meet the linear increases within 1 ~ 8 N • m . At the same input torque, with the increased of vehicle speed, the output torque decreased gradually; System torque Hysteresis can be seen from the return line,but the curve is highly symmetry and with little smooth fluctuations ,which is helpful to obtain better assist.

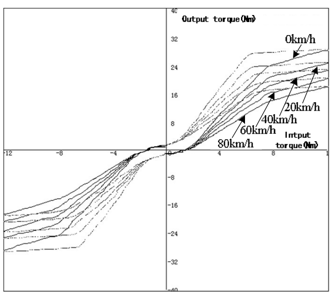


Fig.4. Input-output torque characteristic curve

The characteristic test of input torque and motor current is shown in Fig.5. Maximum torque of steering wheel was 12N • m, the rotational speed was 3r/min. The figure shows, when the torque value of steering wheel was less than 1N • m, the motor did not provide assistance; When the torque of steering wheel exceeded 1N • m and kept increasing, the motor assist torque was increased gradually; When the steering wheel torque exceeds 8N • m, the motor assist torque remained constant. For the control of road feel, the assist torque was reduced when the speed increased so that the driver could get a good road feeling. The overall results show that the control strategy designed in this paper was effective, the assist characteristic line was smooth, the motor torque ripple was small, which meets the requirements of the basic assist demand.

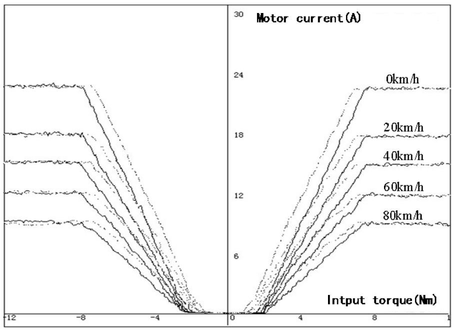


Fig.5.Current characteristic curve

Conclusion

This paper studied the EPS system based on the brushless DC motor, the overall control strategy and the power characteristics of the system were designed. Match the speed parameter with these three kinds of steering wheel torque : The three-phase full bridge driving circuit is designed; Combining the traditional PID control with the fuzzy control theory, the fuzzy PID controller was designed to improve the performance of dynamic control and robust performance of the system. The results show that the control strategy was effective, the motor torque ripple was small, the dynamic response was fast, and a good assist characteristic was achieved.

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