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Design of Assisted Characteristic Curve for Electric Power Steering System Based on Load Variation

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Abstract: This paper analyzed the influence of changes in load on the assisted characteristic of the EPS system, and a mini-bus as an example, designed its assist characteristic curve under the condition of load change, established the functional relationship that between assist torque and the steering wheel input torque, speed and load, drawn the curved surface diagram showing the relationship between the assist torque, speed and steering wheel input torque under different loads, created a simulation model of the EPS system. Finally, the simulation of the steering lightness of the designed EPS system is carried out by means of MATLAB / Simulink. The simulation results showed that the designed assisting characteristic curve satisfies the EPS characteristics of the vehicle. The design method has a certain engineering significance and practical value.
Keywords: assisted characteristic curve, electric power steering system, load variation

I. INTRODUCTION

The electric power steering system is a kind of electric power steering system which uses the electric motor to provide the assisting torque. It can make use of the control motor to give the different assist torque according to the different conditions of the vehicle driving, which makes the steering of the vehicle flexible and light at low speed, When the car to ensure stable and reliable steering.

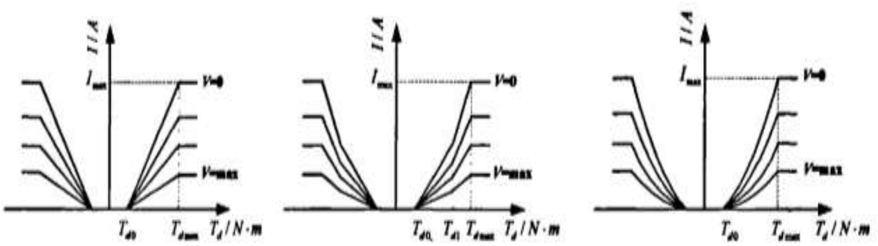
As the EPS system has a simple structure, with the speed of the best torque-assist effect, save energy, protect the environment and many other advantages, there are very broad prospects. Domestic research is mainly focused on the control strategy. Professor Chen Kuiyuan of Tsinghua University EPS on the power control, back to positive control and damping control technology were studied [1]. Some scholars based on the mathematical model of the system, the EPS system to help determine the parameters of the method, the analysis of the ideal power curve [2]. Scholars, such as the national standard through the analysis of EPS characteristics of the typical curve, motor and torque sensors to carry out the power characteristics and vehicle matching design research [3]. Based on the model of electric power steering system, the tire model of automobile puncture was established, and the compensation current of the tire was added to the target current of EPS system [4]. However, none of the above studies consider the effect of load variation on the assist characteristics of the EPS system.

When the car is running, the friction between the tire and the road changes with the load changes, which will lead to unstable steering torque, thus affecting the driver's manual force, resulting in poor road feel. This paper discusses the electric power steering system according to the size of the vehicle load, control the motor to produce different assist torque, making the car at low speed to flexible and lightweight, high-speed steering stability and reliability.

II. DESIGN OF ASSISTING CHARACTERISTIC CURVE

Assist characteristic is the law that the size of the assist torque of the motors with state of automobile motion (steering wheel and the vehicle speed, etc.) changes in the situation [5]. Assist torque of DC motor is proportional to the motor current, so the assisted characteristics of the general use of the motor current and steering wheel torque, the relationship between the speed curve to express[6] .In the assisted characteristics design, the core part is the power curve design.

The assisted characteristic curve of EPS is the function relation between the electric current of the electric motor, the steering wheel input torque, the speed and the front wheel pressure and so on. Under normal circumstances the steering wheel torque and vehicle speed to consider these two parameters to meet the control requirements. The assist characteristic curve determines the controller according to what kind of goal to control the electric current the size, and satisfies the different driving condition under to the assisting torque request. There are three kinds of power characteristic curve of electric power assisted steering system, which are linear, polyline and curve, as shown in Fig. 1[7].



(a) linear type **(b) polyline type** **(c) curve type**

Fig.1 three typical assisted characteristics curve

Among them, the linear-type assisted characteristic curve has the advantages of simple control system and easy to adjust; curve-type assisted characteristic curve is more complex, inconvenient adjustment, but can achieve continuous uniform power; polyline-type assisted characteristic curve between the two.

Formula (1) for the assisted characteristic function of 3 kinds of assisted characteristic curve [8]:

$$T_a(T_d, v)=K_v(v)\cdot F(T_d) \qquad (1)$$

In the formula, T_a is the assist torque provided by the motor, K_v (v) is the assist coefficient which is changed with the change of the speed, F (T_d) is the function of the assist torque with the input torque of the steering wheel.

Design of assisted characteristics of EPS system

In this paper, a mini-bus as an example (vehicle part of the parameters in Table 1)

Table 1 minibus part of the parameters

Serial number	parameter	unit	Value
1	Curb quality	kg	1150
2	Total mass	Kg	1850
3	Track	mm	1450
4	Full load front axle load	Kg	740
5	Front wheel camber	degree	0◦40'
6	Front axle load	Kg	555
7	Front wheel angle	degree	0
8	Steering system angular transmission ratio		0.88
9	Tire and ground friction coefficient		0.7
10	Steering wheel diameter	mm	380
11	Tire pressure	Pa	240000
12	Wheelbase	mm	2700

Firstly, the maximum resistance moments of the tire under full load and no load condition are calculated. According to formula (2) [9], the maximum resistance moments of the tire are 294 N · m and 191 N · m, respectively.

$$M_R = \frac{f}{3}\sqrt{\frac{G_1^3}{P}} \qquad (2)$$

Where, M_R is standing on an asphalt or concrete pavement steering resistance moment, G1 for the steering axle loads; P for the tire pressure; f is the coefficient of sliding friction between the tire and the ground.

Obviously, the resistance torque under the two load conditions is significantly different, which will lead to steering when the driver's operating power is different, thus affecting the driver's operating comfort. So the size of the assist torque of the EPS system needs to change with the load changes, so that the driver has a better operating comfort. Therefore, this paper presents the following requirements for the load changes under the EPS system assisted characteristics curve.

(1)The size of the assist torque with the speed of change: when the local steering and in very low speed, the tire and the ground resistance torque is larger, the system should provide a larger assist torque; with the increase of speed, the assisting distance should be smaller and smaller, so that the vehicle has good handling stability in high speed steering.

(2) When the steering wheel input torque is very small, the system provides little help from, in order to ensure good road feel; when the steering wheel input torque close to or exceeds the threshold value, the input torque should be kept away from a fixed value, so as not to damage the motor.

(3)The size of the assist torque should change with the load. When the load is large, the EPS system should be able to provide a larger assist torque; when the load is small, the assist torque provided is correspondingly reduced.

Next, set the design parameters.

3.1 Set T_{d0}

T_{d0} is the minimum force on the steering wheel when the motor starts to provide the assist torque. When the steering wheel torque is less than this value, EPS system does not provide assist torque. In general, this value is usually set to 1N · m, so here take T_{d0} = 1N · m.

3.2 Set T_{dmax}

T_{dmax} is the maximum power of the steering wheel when the motor provides maximum assist torque. When the motor current is too large, it may burn the motor, so the provisions of the steering wheel torque is greater than a certain value, the motor provides a constant assist torque. Usually cars T_{dmax} take 5 ~ 8N · m, according to the test and experience to take T_{dmax} = 7N · m.

3.3 Set the assist curve gradient K

From the three curves in Fig. 1, we can see: the straight-type power curve is the simplest, with the control system design simple and convenient, and easy to adjust in the design, so this paper uses linear power curve.

3.4 Set the speed sensor coefficient K_v

In this paper, taking into account the impact of load changes on the assist torque, in the design of assisted characteristic curve to increase a parameter——load m, Its assisted characteristic curve equation can be expressed as follows:

$$T_a(T_d, v, m) = K_v(m, v) \cdot F(T_d) \qquad (3)$$

Where, K_v (m, v) is the speed sensor coefficient that varies with the speed and load.

According to the data in Table 1, this paper selected several load conditions. Based on the ideal value of the input torque of steering system steering wheel at different speeds, and the above formula, we can get the speed sensor coefficient under different load and different speed (as shown in Table 2).

V(Km/h) / K_v / M(Kg)	0	20	30	40	60	80
1255(no-load)	3.08	1.37	0.64	0.58	0.49	0.33
1462(half-load)	3.92	2.04	1.21	1.14	0.71	0.42
1750(full load)	4.89	2.67	1.93	1.76	0.97	0.55

Table 2 the speed sensor coefficient under different load and different speed

Since the load change is continuous, the speed sensor coefficient based on the load and speed should be a continuously varying surface. In order to show the relationship between the speed sensor coefficient and load and speed, the three-dimensional surface of the vehicle speed sensor coefficient about load and speed is fitted according to the selected parameters and the data in Table 2. Fig. 2 shows the fitted surface. At last, the equation of the speed sensor coefficient is:

$$K_v = (-1.1 \cdot 10^{-5} \cdot V^3 + 0.002V^2 - 0.15V + 4.9) \cdot 0.00057M \qquad (4)$$

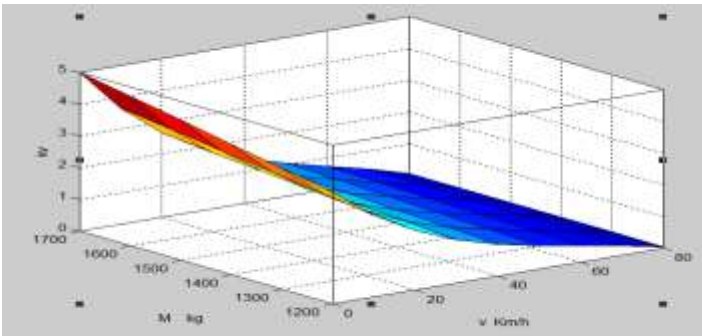
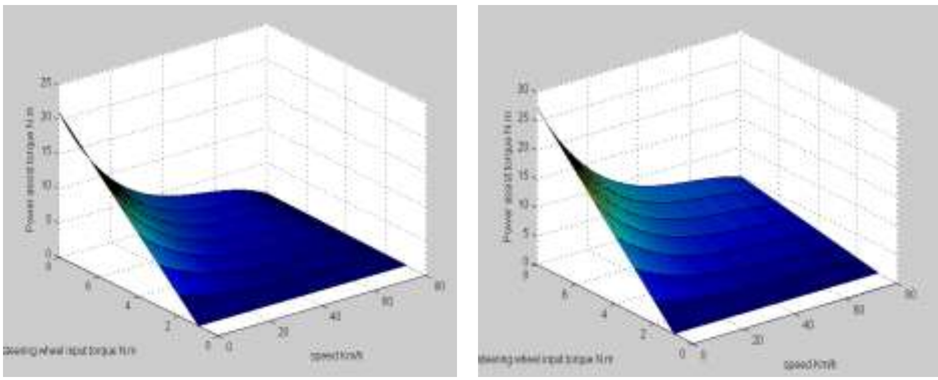


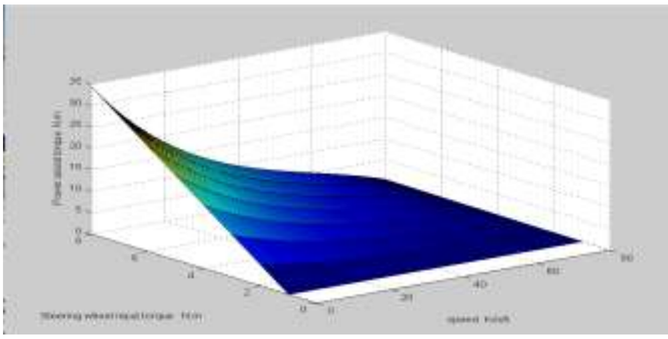
Fig. 2 fitting surface curve of speed sensor coefficient based on load variation

It can be seen from Fig. 2 that the speed sensor coefficient increases with the load at the same speed, and the speed sensor coefficient decreases with the increase of the speed under the same load.

In order to more intuitively reflect the different assist torque provided by EPS system under different loads, three typical load conditions are adopted: no-load, half-load and full load. Then, according to the curve of the speed sensor coefficient in Fig. 2 and the formula (3), the three-dimensional diagrams of the relationship between assist torque and speed and steering wheel input torque are drawn in this paper (as shown in Fig. 4).



(a) no-load **(b) half-load**



(c) full load

Fig. 3 the diagram between assist torque and speed, steering wheel input torque under different loads

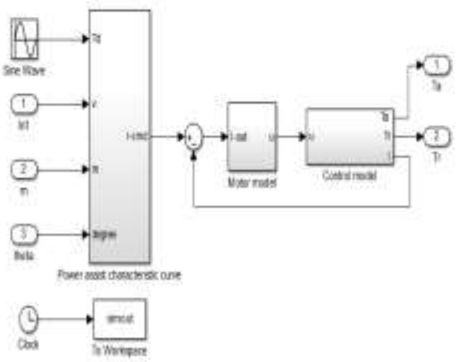
As can be seen in Fig. 3, in these three conditions, the lower speed EPS system can provide greater power; the higher the speed EPS system can provide less power; which meet the Steering flexibility of low-speed driving and high-speed steering stability requirements.

When the vehicle speed is 0, the assist torque is 34N·m at full load; the assist torque is 27N·m at half load; the assist torque is 21N·m at no-load; which satisfies design requirement that EPS systems provide different assist torque under the different load.

4 System Simulation Analysis

The steering performance of the automobile is mainly evaluated from the aspects of steering easiness, returnability and handling stability, and the steering easiness of automobile is the main goal of EPS system. Therefore, this paper analyzes and evaluates the steering easiness of the EPS system.

A EPS system model is established in Matlab/Simulink, as shown in Fig. 4.



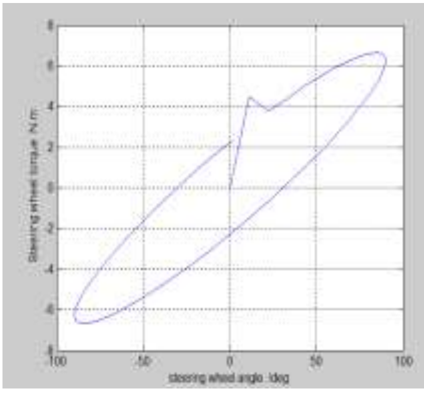
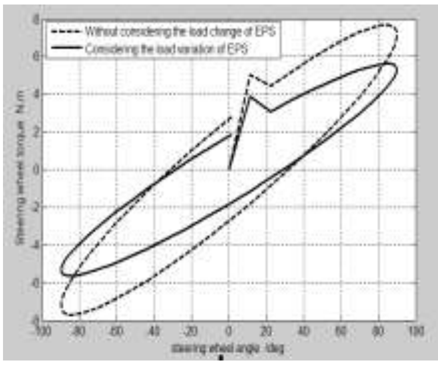
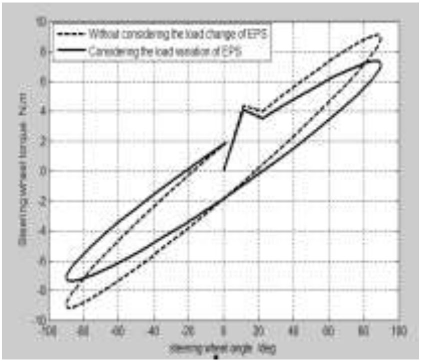


Fig. 4 control model of EPS system **Fig.5** steering wheel torque diagram

The sinusoidal signal is used as the angle input of the steering wheel. Fig. 5 shows the torque diagram of the steering system when the EPS system does not consider the change of the load. Where, the motor helps the driver to overcome part of the steering resistance, and the steering wheel of the maximum torque is 6.6N·m, which proves the design of the simulation model is correct.

Fig.6 shows the result of the simulation test of the steering easiness under half load and full load condition. The dashed line in Fig. 6 is the steering wheel force required for EPS systems that do not take into account the load changes; the solid line is the steering force required for the EPS system taking into account the load changes. By comparing the curves in Fig. 6, we can draw the following conclusions: EPS systems that do not take into account load changes are significantly less stressed at lower loads, which can cause the steering system to turn too lightly under small loads. Considering the load changes of the EPS system in the larger load can provide greater assist torque, and in the smaller load can provide less assist torque. It can adjust the size of the assist torque according to the change of the load to meet the assist torque demand of the steering system under different loads so as to improve the operation comfort and feel of the driver in steering.





(a) Half-load case simulation test chart **(b)** Full-load condition simulation test chart

Fig.6 results of different simulation of steering easiness test

V. CONCLUSION

The EPS system designed in this paper can adjust the boosting size according to the change of the load, which satisfies the design requirement of the EPS power-assisting characteristic based on the load variation, enhances the boosting performance of the EPS system under high load and improves the driver's operating comfort and driving feel.

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