Modeling and Simulation of BLDC motor in Electric Power Steering

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Abstract—**This paper briefly describes the composition of electric power steering (EPS) system and the development advantages of brushless DC (BLDC) motor. Based on the mathematical model of the BLDC motor and the requirements of the EPS system for assist motor, a control strategy of the BLDC motor used in EPS system is proposed, then a simulation model of control system using in BLDC motor is set up, and its simulation analysis is made. The feasibility, high reliability of the system and the validity of the control method are proved by the fruitful simulation results which serve a design method for a further research of BLDC motor in EPS.**

Index Terms: Electric Power Steering (EPS); Brushless DC (BLDC) motor; simulation analysis; control method

I. INTRODUCTION

Electric power steering (EPS) is an advanced steering system that uses an electric motor to provide steering assist. EPS has many advantages compared with hydraulic power steering system, such as saving energy, protecting environment, and be easy to rectify by changing the design of controller software to adjust the system's characteristic of power assistance in any condition. As a new technology, EPS undoubtedly represents the development direction of steering system in the future.

The power source of EPS is electric motor, which is the major factor affecting the EPS performance. In recent years, the previous brush DC motor used in EPS has been gradually replaced by the brushless DC (BLDC) motor. The BLDC motor is a new type of DC motor which uses the electronic commutation technology instead of mechanical commutation, with operation high efficiency, high starting torque, wide speed range, simple structure, reliable operation, etc. With the advent of high-performance magnetic materials, BLDC motor performance is greatly increased [1]. Its application in the power system will be more widespread, especially in the automotive industry. In practice, in order to shorten design cycles, reduce cost and risk, the BLDC motor system can first use modeling and simulation technology to establish its model. By analyzing the motor speed, torque and other parameters and imposing different control algorithms on the system, a best control strategy can be found. In this way, a lot of actual design time is effectively saved. Finally, in this paper, a simulation model of BLDC motor for EPS control system is built, which based on the mathematical analysis, and the validity of this method has been proved by the simulation result.

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II. COMPOSITION OF ELECTRIC POWER STEERING AND ITS REQUIREMENTS FOR ASSIST MOTOR

A. Composition of Electric Power Steering

The schematic diagram of an EPS system is shown in Fig. 1. The EPS system adopts a so-called column-type EPS system in which the assist motor connected to the steering shaft through spur gears delivers assist torque to the shaft. In this system, EPS is consists of three main components: the signal transducer (including the torque sensor and speed sensor), power steering bodies (motor, clutch, retarding mechanism) and the electronic control unit (ECU).

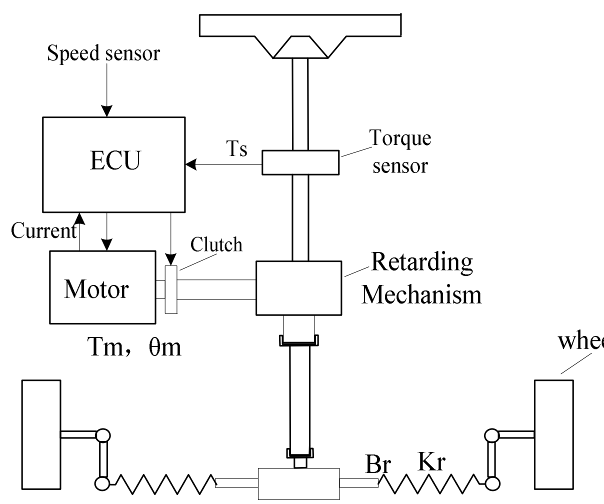

Fig. 1 The schematic diagram of an EPS system

B. Requirements for Assist Motor

In the EPS system, assist motor is a key component of the EPS system. It is also the power source of EPS and its function is in accordance with the instruction output of appropriate auxiliary torque by electronic control unit. Therefore, the motor of EPS has the following requirements [2]:

- Start quickly, good servo performance, low speed with large torque, moment of inertia is small.
- Low noise, good mechanical properties.

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- Easy to control, reliability and high security, convenient maintenance.
- Small size, light weight, as much as possible to save space and reduce weight. In this paper, a 12 V DC vehicle power supply is used.

III. MATHEMATICAL MODEL OF PERMANENT MAGNET BLDC MOTOR

Modeling the entire system is the key to motor model-building. In order to simplify the model and analysis, the following assumptions are made [3]:

- Ignore the magnetic circuit saturation, excluding the eddy current and hysteretic loss.
- Ignore alveolar effect, winding evenly distributed, three-phase stator windings are symmetrical and concentrated.
- Not consider the armature reaction, air-gap magnetic field distribution is similar to trapezoidal wave.

Fig. 2 shows the circuit topology of a three-phase inverter for the brushless motor. Based on the above-mentioned assumptions, the equivalent circuit of BLDC motor is shown in Fig. 3.

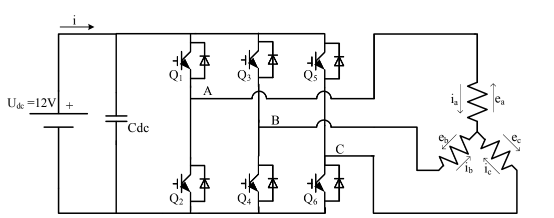

Fig. 2 Circuit topology of a three-phase inverter for BLDC motor

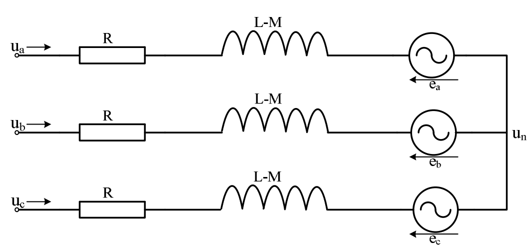

Fig. 3 The equivalent circuit of BLDC motor

Based on the above-mentioned equivalent circuit, the voltage equation of the employed BLDC motor can be expressed as (1):

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} p \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} + \begin{bmatrix} u_n \\ u_n \\ u_n \end{bmatrix} \quad (1)$$

Where $u_n = \frac{1}{3}\left(\sum_{i=a}^{c} u_i - \sum_{i=a}^{c} e_i\right)$

The equation of BLDC motor electromagnetic torque can be written as (2) and its motion equation can be depicted by (3)

$$T_e = \frac{1}{\omega}(e_a i_a + e_b i_b + e_c i_c) \quad (2)$$

$$\dot{\omega} = \frac{T_e - T_L - B\omega}{J} \quad (3)$$

IV. THE ESTABLISHMENT OF SIMULATION MODEL AND SIMULATION RESULTS

For the BLDC motor of EPS, current control strategy is adopted. This control strategy only needs wheel torque signal and vehicle speed signal. Depending on these two signals and pre-established assistant torque curves, the required current is acquired (expressed as i_{ref}). The control scheme of the system is shown in Fig. 4 [2].

In this paper, one outer speed loop and one inner current loop as the double-loop control system is introduced, shown in Fig. 5. In the double-loop control system, a discrete PID controller is adopted in the speed loop and a hysteretic current controller is adopted in the current loop on the principle of hysteretic current track PWM inverter.

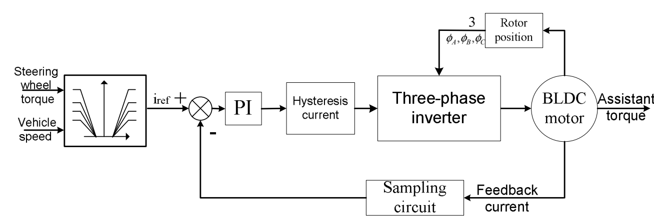

Fig. 4 The control scheme of BLDC motor system in EPS

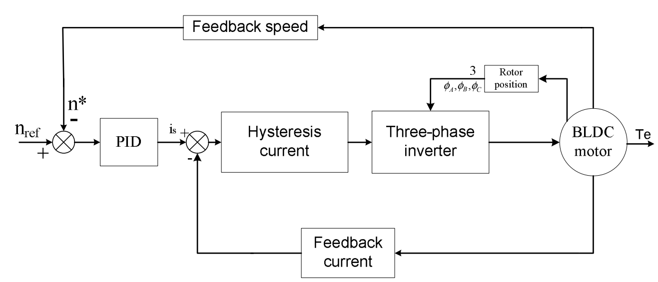

Fig. 5 The double-loop control diagram of BLDC motor

With the help of Matlab/Simulink, the simulation model (as shown in Fig. 6 [4]) can be set up to verify the control strategies. The subsystem blocks of BLDC motor, IGBT inverter, reference current and speed controller are created respectively based on their own characteristics.

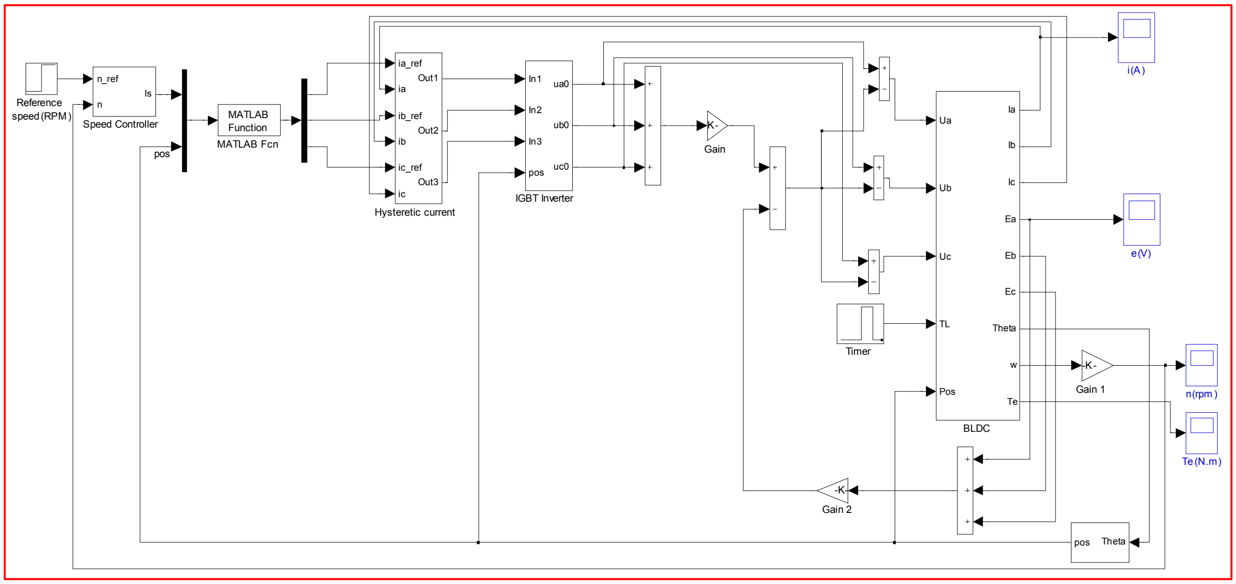

Fig. 6 The simulation model of BLDC motor

The BLDC motor parameters used in the simulation are shown in TABLE I.

TABLE I. NOMENCLATURES

Symbol	Description	Value	Unit
n_e	Rated speed	1000	r/min
R	Stator phase winding resistance	0.1	Ω
L	Self-inductance of stator winding	1	mH
M	Mutual inductance	0.5	mH
J	Motor inertia	0.002	kg. m^2
n_p	Number of pole pairs of the motor	1	-
U	Supply voltage by the battery	12	V
K_e	Back-EMF coefficient	0.025	V/(rad.s^{-1})
B	Viscous damping coefficient	0.0002	N.m/(rad.s^{-1})
T	Simulation time	0.5	s
T_L	Sudden load	0.5	N.m

According to the motor parameters mentioned above, the simulation experiments of control system are conducted. Waiting until the system enters its steady-state, the sudden load is increased from 0.1N·m to 0.6N·m at 0.25s and returned to the previous at 0.4s and the simulation waveforms have been shown in Fig. 7~10. Fig. 7 and Fig. 8 respectively show the simulation waveforms of the torque and the phase A current. In the start-up stage, the system maintain a constant torque, which does not result in greater torque and phase current impact as shown in Fig. 7 and Fig. 8. The Fig. 7 indicates that with the sudden increase of the load, the torque has a greater pulse, which is mainly caused by the current commutation and frequent switching of the current hysteretic controller.

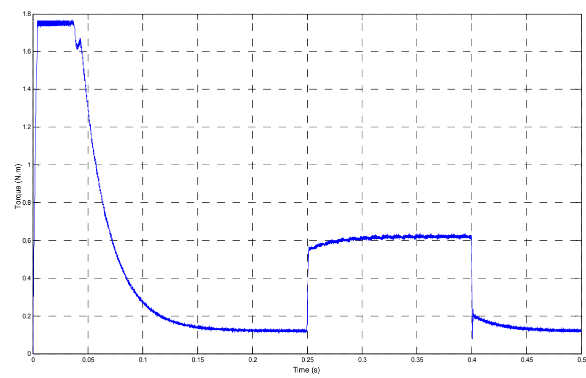

Fig. 7 The torque response waveform

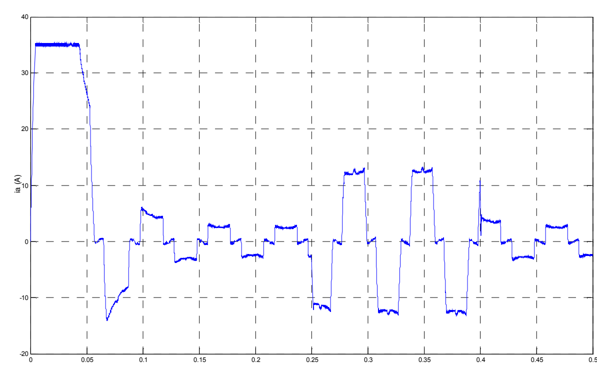

Fig. 8 The phase A current waveform

The role of the reference current in amplitude limiting is very effective as shown in Fig. 8. Fig. 9 shows the phase A back-EMF simulation waveform. Fig. 10 shows the speed simulation waveform which shows the system has quick and smooth response in the reference speed n=1000 r/min. Whether the time at 0.25s or 0.4s, when the load suddenly increases or reduced, the speed response reached steady-state is fast.

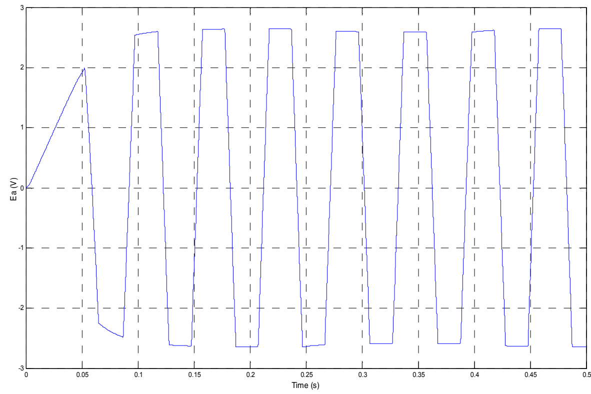

Fig. 9 The phase A back-EMF waveform

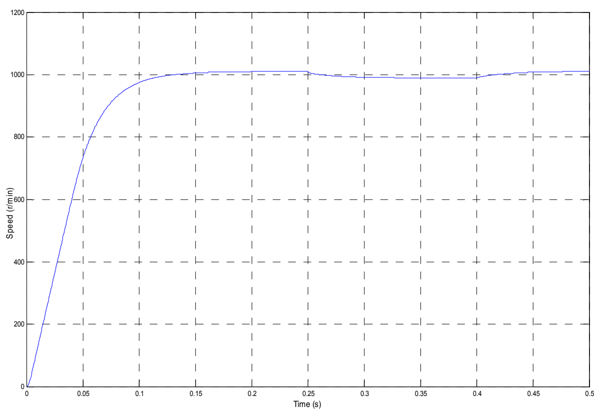

Fig. 10 The speed response waveform

V. CONCLUSIONS

In this paper, a feasible simulation model of the BLDC motor is established in Matlab/Simulink on the basis of the motor performance of the requirements in the column–type EPS system and the electromagnetic equations of BLDC motor. The fruitful simulation results show that the proposed control strategy of the BLDC motor is valid. Based on the study above, according to the specific characteristics of EPS, changing the part of the functional modules or control strategies is convenient, so a more precise current control strategy of BLDC motor for EPS will be further researched.

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