Research on cooperative control of multiple PMSM systems for electric vehicles

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Abstract: permanent magnet synchronous motor (PMSM) has the characteristics of high efficiency and energy saving, high power factor, simple structure, high speed regulation precision, straight efficiency curve and so on. So it is very important to study the optimal strategy of high performance motor control system.This paper mainly analyzes the principle and vector knowledge of permanent magnet synchronous motor for electric vehicle. Several optimal control strategies are proposed for PMSM.

1. Introduction

Permanent magnet synchronous motor (PMSM) has the advantages of small size, high power factor, fast dynamic response, no excitation current, strict speed synchronization and wide range of speed regulation. It is widely used in various fields of national production. However, in PMSM high-performance speed control system, photoelectric encoder and other sensors are mostly used to detect rotor position or speed, and position or speed detection is used as feedback signal to realize closed-loop control of speed control system. If the precision of speed control system is high, the detection accuracy of corresponding speed and position sensors is high. On the one hand, the existence of the speed sensor hinders the development of the motor in the direction of fast-paced, miniaturization and development. At the same time, its installation also brings the following problems to the system: the installation of the sensor on the motor shaft increases the moment of inertia and improves the overall scale and volume space of the motor; The use of sensors increases the interface circuit and connecting line, increases the system's susceptibility to electromagnetic interference and reduces the reliability; the working conditions of the sensor are fragile and limited by the environment; the sensor and auxiliary circuit increase the cost of the speed control system.

At present, vector control technology and direct torque control technology are widely used in permanent magnet synchronous motor drive system of electric vehicles. The vector control is based on rotor field orientation to decouple the excitation component and torque component of stator current, which makes AC motor control equivalent to DC motor control. Direct torque control technology is based on stator field orientation, which has good dynamic response, simple structure, easy implementation and strong robustness. However, it has the problem of large torque ripple, especially the unreasonable torque ripple caused by switch table failure. In addition, the switching frequency is not constant, which makes the capacity of power devices can not be fully utilized.

2. Construction and mechanical characteristics of permanent magnet synchronous motor(PMSM)

2.1 Structure of permanent magnet synchronous motor

The main components of permanent magnet synchronous motor are stator and rotor, and there is a small air gap between the stator and rotor.The stator has sufficient hardness and toughness, which can reduce the iron consumption produced by the motor during operation.The rotor is equipped with permanent magnet material, and it is made of laminated pressing materials, such as silicon steel sheet, copper guide bar, and aluminum.According to the installation mode of permanent magnet materials on the rotor of the motor, the structure of permanent magnet synchronous motor can be

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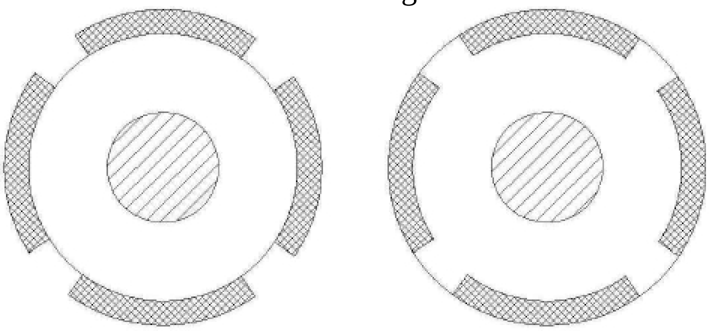
divided into surface type and built-in type.

Figure1 shows two surface structures of the rotor magnetic circuit:

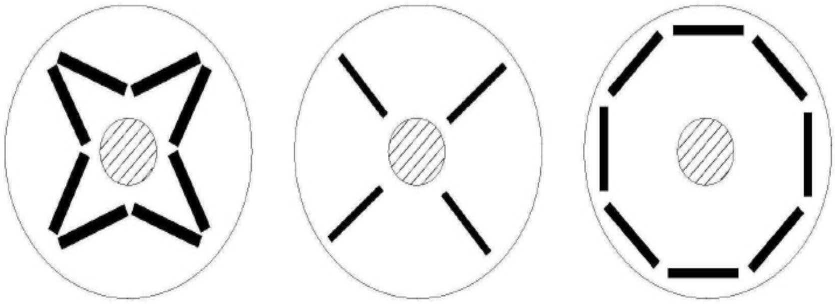


A) B)

Figure 1 Two surface structures of the rotor magnetic circuit

A) Protrusion B) Insertion

Three built-in structural forms of the rotor magnetic circuit are shown in Figure 2-2:



A) B) C)

Figure 2 Three different forms of the magnetic circuit structure of the built-in rotor

A) Mixed B) Radial C) Tangential

2.2 Mechanical characteristics of permanent magnet synchronous motor

As the motor efficiency has a very important significance and influence on the economy of automobiles, the equal-efficiency characteristic curve of permanent magnet synchronous motor has become an important basis for automobile design and control.The characteristic of PMSM is that its maximum torque and maximum power change with the change of rotating speed, and the basis is that there is no equipower part. Therefore, PMSM can achieve the optimal benefit when running at a flat speed and low torque.

3. Principle and magnetic field analysis of permanent magnet synchronous motor

3.1 Principle of permanent magnet synchronous motor

When the motor is not in operation, thethree-phasesymmetrical voltage is powered by the stator three-phas windings, so that the voltage acts on the rotor windings on the relative rotor to stimulate the polyphase symmetrical current, and then the rotor rotating magnetic field appears. The stator and rotor rotating magnetic field of the same rotation speed, the joint action of the torque, speed up the rotor.

When the motor'srevolving speed n is different from the revolving speed of the stator rotating magnetic field n_1, there will be magnetic field cutting, and the induction electromotive force will be generated in the rotor winding. Its frequency f is,

$$f = \frac{p\Delta_n}{60} = \frac{p(n_1 - n)}{60}$$

Therefore, the magnetomotive force of the rotor and stator is the same, namely, the synchronous speed n_1.

3.2 Relationship between permanent magnet synchronous motor and magnetic field

When the permanent magnet synchronous motor runs normally, there are two magnetic fields: no-load magnetic field and armature reactive magnetic field.

In the no-load magnetic field, the PMSM runs at the same speed. In addition, the armature current is relatively small, so it can be known that the motor has permanent magnets inside.When the rotor is running at the synchronous speed, a rotating magnetic field will be generated in the PMSM, and the amplitude of air gap density can be obtained as follows:

$$B_{\delta 1} = \frac{4}{\pi} B_{\delta} \sin \frac{a_i \pi}{2}$$

The air gap flux is:

$$\Phi_{\delta 0} = B_{\delta} a_i \tau_1 L_{ef}$$

In the armature reaction magnetic field, the variation of the air gap magnetic field is more complicated than that of the no-load magnetic field, so only the fundamental wave component is considered. Armature reaction plays a role of demagnetization and alternating magnetism in the PSMS, and it will also have some changes in space. Among them, the direction of current is opposite to that of the electromotive force of the armature winding. When the main magnetic is stressed, there will be an electromagnetic torque.The magnetomotive force of the armature reaction is;

$$F_{a(\psi=0)} = F_{aq}$$

4. Mathematical model of PMSM

The mathematical model theory of PMSM is conducted in d-q coordinate system. The variables such as voltage, current and flux are decoupled to obtain the decomposed variables. There are two electromagnetic torques of PMSM: one is permanent magnet torque, and the other is reluctance torque. The electromagnetic torque control is a kind of current control between d and q axes.

The stator of PMSM is a three-phase winding, and there are the following requirements in mathematical modeling:

a) Induction electromotive force will be generated in the armature winding of the stator, and it is a sine wave, so is the rotor in the air gap space.

b) The amortisseur windingof the rotor can be ignored.

c) The magnetic circuit of the stator is linear, and the inductance parameters remain unchanged.

d) Iron core eddy current loss and hysteresis loss can be ignored.

As the mathematical model in the a-b-c coordinate system is a nonlinear variable system, the flux linkage equation of the synchronous motor in the three-phase stationary coordinate system is as follows:

$$\begin{bmatrix} \psi_A \\ \psi_B \\ \psi_C \end{bmatrix} = \begin{bmatrix} L_{AA} & M_{AB} & M_{AC} \\ M_{BA} & L_{BB} & M_{BC} \\ M_{CA} & M_{CB} & L_{CC} \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \begin{bmatrix} \psi_{fA} \\ \psi_{fB} \\ \psi_{fC} \end{bmatrix}$$

Where

Ψ_A, Ψ_B, and Ψ_C arethe flux linkages of the three-phase winding;

L_{AA}, L_{BB}, and L_{CC} arethe self-induction of each phase winding;

M_{AB}, M_{BA}, and M_{CA} are the mutual inductance of each phase winding;

Ψ_{fA}, Ψ_{fB}, and Ψ_{fC} arethe permanent magnet flux linkage per pole of three-phase winding linkage;

The voltage equation in coordinates A, B and C is:

$$\begin{bmatrix} U_A \\ U_B \\ U_C \end{bmatrix} = R \begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix} + P \begin{bmatrix} \psi_A \\ \psi_B \\ \psi_C \end{bmatrix}$$

Where U_A, U_B, and U_C are the phase voltages of the three-phase winding;

I_A, I_B, and I_C are the phase currents of the three-phase winding;

P is the differential operator.

5. Vector analysis of PMSM

Germany is the first country which put forward the vector control theory, and then the European and American countries also began to pay attention to this theory. The idea of vector control is applied to the basic parameters such as voltage, current and flux as the reference, and then the current in the flux is vectored to obtain the excitation part and torque part, and later, the relevant part of the flux is affected by the armature current to maintain the inherent dynamic state.

5.1 Principle of vector coordinate transformation

It is known form the theory of AC motor that there is a synchronous velocity between the stator and rotor air gap, and the coordinate transformation rule of the vector is that the power or amplitude are the same before and after transformation. Two space vector diagrams of PMSM can be obtained by changing the vector coordinates:

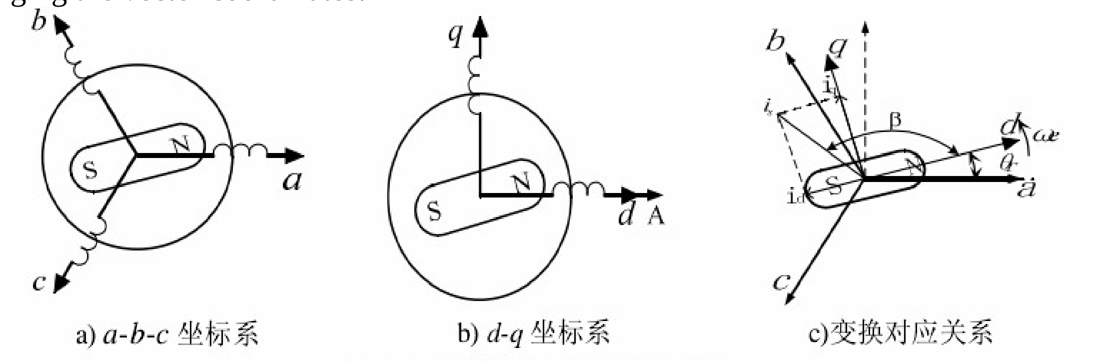


Figure 3 Space vector diagram of PMSM

In the a-b-c coordinate system of 120° spatial difference degree in Figure a), the direction is the direction of axis a.Axis d is recombined with axis A, and axis d is 90° behind axis q, and the d-q coordinate system rotates at the same speed with the rotor. It can be expressed by Clarke transformation as follows:

5.2 Sine pulse width adjustment

The theory of sinusoidal pulse width modulation (SPWM) is to take sinusoidal wave as a control signal and triangular wave as a carrier wave, and obtain SPWM waveform through vector modulation. The simplest method to realize SPWM waveform is equivalent area method, which mainly uses formulas to calculate the width of pulse. Another method is to calculate the pulse width time from the intersection point of sinusoidal regulating wave and triangular wave to obtain the SPWM waveform.

According to the figureAnother method is regular sampling method. The principle is to obtain SPWM waveform by sampling triangular wave with voltage.

The SPWM waveform obtained by this method is more accurate and has less error than the SPWM obtained by the previous two methods

6. Conclusion

At present, there are still many improvements in the development of electric vehicles. We can design some energy storage during special operation to make electric vehicles have more efficient operation mode. Because of the short sampling period, the vector control has less current harmonics and less torque ripple. Due to the hysteresis control current, the switching frequency is not constant. Although sine wave pulse width modulation can be used to realize vector control by controlling voltage to obtain constant switching frequency, two PI regulators need to be added, which increases the complexity of the system and the difficulty of parameter tuning. The realization of vector control needs continuous rotor position information, which requires the installation of rotor position sensor, which increases the installation and maintenance cost of the system and affects the reliability of the system.

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