Comparison of dynamic characteristics of the ideal field oriented control model and its based on act (automated control theory) real analogue

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Abstract. This article is dedicated to the accuracy of modeling the dynamic characteristics of a field oriented control model. The field oriented control model is based on automatic control theory and using the parameters of a real electric motor. As a result of the simulation, several dynamic characteristics were obtained. The comparison of these characteristics with the dynamic characteristics of the assembled system of field oriented control of a real electric motor is carried out. It is concluded that the operation of the field oriented control model with a certain error corresponds to the operation of the field oriented control system of a synchronous electric motor.

1. Introduction

The method of controlling an AC electric motor, called "vector control", appeared in the late 70s - early 80s of the last century. In a broad sense, all methods of controlling an AC motor using vector mathematics to describe the processes occurring in the motor can be called vector control. We can also give another, narrower definition of the method: vector control is the control of torque, speed or position, based on equations of engine dynamics and an interconnected change in the instantaneous phase and amplitude of the current, or stator voltage, at which the instantaneous magnitude and spatial position of the magnetic change according to the required law fields in the engine.

In this scientific work, vector control of a synchronous motor is considered. The pursued goal is to study the principles of vector control of this type of engine and the possibility of using engines with vector control in production, as well as to identify the most practical vector control engine for this purpose.

2. The common idea of building of velocity control system

The motor speed can be controlled by changing its moment, and the motor moment can be changed by controlling the stator current vector. Regulation is carried out in a coordinate system that rotates synchronously with the state vectors of the engine. This system, as a rule, is associated with a vector \( \psi_R \) - the flow of the rotor. The axes of this two-phase coordinate system are called \( d \) and \( q \), moreover, the rotor stream is oriented by the \( d \) axis of this system.

The vector current regulator consists of two scalar regulators \( d \) and \( q \) projections of the vector and uses the real stator current vector measured and transformed into the system as feedback. The current regulator in the same system forms a stator voltage vector, which is characterized by two
components: \( U_{Sd} \) and \( U_{Sq} \). Then, using coordinate transformations, the stator voltage vector is transferred to a fixed coordinate system associated with the stator, where it is then realized. The implementation of the stator voltage vector is carried out using pulse-width modulation (PWM).

To synthesize a control system, it is necessary to determine the relationship between the moment and projections of the stator current vector on the axis \( dq \) of the system rotating synchronously with the rotor flow. To carry out coordinate transformations, it is necessary to know the current rotation angle of the system \( dq \) (rotation angle \( \psi_R \)). This angle must be measured or calculated.

3. Vector control of a permanent magnet synchronous machine

Figure 1 shows the structure of vector control of a synchronous electric motor.

![Figure 1. Structure of a vector control system for synchronous motor speed.](image)

- \( C\omega \) – speed calculator;
- \( SC \) – PI or PID-speed controller, issuing a torque reference signal based on a speed error;
- \( TL \) – torque limiter;
- \( CI_q \) – stator current q-component calculator;
- \( CuC_d \) – P or PI controller of the current of the d-component, generating a signal for setting the voltage along the d axis, based on the current error;
- \( CuC_q \) – P or PI current regulator of the q-component, generating a signal for setting the voltage along the q axis, based on the current error;
- \( CLCU \) – cross-link compensation unit;
- \( CC1 \) – coordinate converter, which transfers the stator current from a three-phase stationary coordinate system to a two-phase, and then to a rotating system \( dq \);  
- \( CC2 \) – coordinate converter, translating the stator voltage vector from a rotating system \( dq \) to a fixed coordinate system;
- \( PWM \) – a power PWM converter implements the stator voltage vector.

If we neglect the magnetic losses, in a fixed coordinate system \( \alpha\beta \), the equatorial equations of the stator of a synchronous motor are as follows:

\[
\begin{align*}
U_{Sa} &= \frac{d\psi_{Sa}}{dt} + I_{Sa}R_S; \\
U_{S\beta} &= \frac{d\psi_{S\beta}}{dt} + I_{S\beta}R_S.
\end{align*}
\]

In a rotating coordinate system \( dq \):
\[
U_{sd} = \frac{d\psi_{sd}}{dt} + I_{sd}R_S - \omega\psi_{sq}; \\
U_{sq} = \frac{d\psi_{sq}}{dt} + I_{sq}R_S + \omega\psi_{sd}.
\] (2)

4. Modelling of permanent magnet synchronous machine’s field oriented control and its comparison with its based on act real analogue

A model of vector control of a synchronous motor was made. The model is shown in figure 2.

![Vector control model of synchronous motor.](image)

Figure 2. Vector control model of synchronous motor.

The parameters of a real engine were loaded into this model. As a result, a vector engine control model with real parameters based on ACT was obtained. The simulation results are shown in figure 3, figure 4 and figure 5.

![PWM signal on each of the three phases in the motor windings.](image)

Figure 3. PWM signal on each of the three phases in the motor windings.
In order to verify the results obtained in practice, a field oriented control system was assembled (figure 6).
Changing the PWM signal at the phases of the electric motor, the law of changing the torque on the shaft in idle mode, as well as changing the speed of rotation of the motor shaft in the ACT-based vector control model are correspond to the results of measuring the corresponding dynamic characteristics in the assembled real vector control system.

At the moment, further development of a more advanced ACT model is ongoing, with the aim of increasing the accuracy of modeling and better matching the simulation results with the data obtained as a result of an experiment with vector control of a real electric motor.

References
[1] Anuchin A S 2015 Electric drive control systems (Moscow: MPEI Publishing House) chapter 5 pp 308-327
[2] Merzougu M S and Naceri F 2008 Comparison of Field-Oriented Control and Direct Torque Control for Permanent Magnet Synchronous Motor (PMSM) International Science Index International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering 2
[3] Karasev A V and Smirnov V M Mathematical model of direct torque control of an asynchronous drive (Saransk: State Educational Institution of Higher Professional Learning “Mordovian State University named after N. P. Ogareva”)
[4] Dadenkov D A, Soloedky E M and Shachkov A M 2014 Modeling a vector control system of an induction motor in the package Matlab / Simulink Bulletin of PNIPU. Electrical Engineering, Information Technology, Control Systems (Perm: Perm National Research Polytechnic University)
[5] Yu N and Kalachev Y N Vector regulation (practice notes) ETF Supply and technical support 72
[6] Anosov V N, Diab A A and Kotin D A 2017 Vector control of asynchronous electric drives based on predictive models: a training manual “Doe” electronic library system ISBN 978-5-7782-3285-3 175 p