DEVELOPMENT OF THE LUENBERGER OBSERVER FOR THE AUTOMATED ELECTRIC DRIVE OF HERMETIC COMPRESSOR

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Abstract: The basic requirements for control systems of automated electric drives of hermetic compressors of small refrigeration units are determined. The analysis of the existing sensorless control systems of three-phase AC drives is carried out. The topology of the adaptive Luenberger observer is proposed, which allows real-time evaluation of the current value of the rotational speed and torque on the shaft of the hermetic compressor motor. Based on the linearized model of a three-phase asynchronous motor, the Luenberger observer is synthesized by the modal method with the distribution of the roots of the characteristic polynomial in the standard linear Bessel form. Expressions are obtained for calculating the coefficients of the Luenberger matrix and the geometric mean root of the characteristic polynomial of the observer. To ensure the necessary accuracy of identifying the coordinates of the state of an automated electric drive of a hermetic compressor, an observer structure is proposed based on a complete mathematical model of a three-phase asynchronous motor made in a fixed coordinate system. Using simulation tools, the work of the designed Luenberger observer is studied on the example of a modernized three-phase asynchronous motor of a hermetic compressor of a domestic refrigerator. For this example, the coefficients of the Luenberger matrix and the geometric mean root of the characteristic polynomial of the observer are calculated. The effectiveness of the proposed method for identifying the rotational speed and moment of resistance of a compressor electric motor by an adaptive observer based on the calculation of the electromagnetic torque of the motor from measured sensors of phase voltages and currents is confirmed. The error of the observer under investigation does not exceed 0.5 % in rotation frequency and 10 % in respect to the moment of resistance. The resulting structure of the adaptive Luenberger observer allows to build closed-loop control systems for automated electric drives of the hermetic compressor of a small refrigeration unit.

Keywords: Luenberger observer, automated electric drive, frequency converter, hermetic compressor, small refrigeration unit.

1. Introduction

Opportunities for improving the energy and mass-dimensional characteristics of hermetic compressors of small refrigeration units (SRU) can be obtained by automated control of the motor speed of the compressor [1, 2]. However, refrigeration manufacturers face the difficult task of developing an electric drive control system in the absence of the technical possibility of installing a motor speed sensor in a hermetic compressor. In addition, since SRUs operate with a variable heat load [2], it is necessary to ensure that the magnitude of the disturbing action is determined in real time – the moment of resistance on the compressor shaft.

In practice, in three-phase automated electric drives (AED), the most widely used are special algorithms for identifying state coordinates: adaptive systems with a master model [3], state observers [4–6], Kalman filters [7, 8], etc. Analysis of works [4, 8] allows to conclude that the most efficient and simple to implement are algorithms based on full-order adaptive Luenberger observers, which are discussed further.

When using state observers, a mathematical model of a three-phase asynchronous motor (TAM) is introduced into the control system, which evaluates the current value of the rotor speed $\hat{\Omega}$. In [4, 5], for this purpose, equations are used that describe only electromagnetic processes in the TAM. This approach allows to simply determine the value of the rotor speed, while the problem of effectively identifying the moment of resistance of the compressor remains unresolved.

The aim of research is development of a mathematical model of the observer coordinates of the AED of a hermetic compressor, which allows in real time to estimate the motor speed and the moment of resistance on the shaft.

To achieve the aim it is necessary to solve the following tasks:

– to synthesize the structure of the observer coordinates, allowing in real time to estimate the frequency of motor rotation and the moment of resistance on the shaft;

– by means of simulation modeling to conduct a study of the accuracy of the obtained observer of coordinates.

2. Methods

The synthesis of the Luenberger observer and the determination of its parameters will be carried out by a modal method with the distribution of the roots of the characteristic polynomial according to the standard linear Bessel form [6]. The starting point of the calculation is the canonical form of writing the differential equations of the TAM linearized mathematical model:

$$\frac{d}{dt}M = -\frac{1}{T_2}M - \frac{z_p \cdot h_i}{T_2}\Omega + \frac{h_i}{T_2}\omega_1;$$

$$\frac{d}{dt}\Omega = \frac{1}{J}M - \frac{1}{J}M_c. \qquad (1)$$

It is assumed that the control system is a direct measurement of the TAM electromagnetic moment M. Then the output matrix $\mathbf{C} = [1 \;\; 0]$, and the vector of the output (measured) variables:

$$\mathbf{Y} = \mathbf{CX} = [1 \;\; 0] \cdot \begin{bmatrix} M \\ \Omega \end{bmatrix} = M.$$

The observer for estimating the vector of state coordinates is built on the basis of a TAM mathematical model o by supplementing it with a "stabilizing additive" $\mathbf{L}(\mathbf{Y} - \hat{\mathbf{Y}})$ [3, 5]

$$\frac{d}{dt}\hat{M} = -\frac{1}{T_2}\hat{M} - \frac{z_p \cdot h_i}{T_2}\hat{\Omega} + \frac{h_i}{T_2}\omega_1 + L_1\left(M - \hat{M}\right);$$

$$\frac{d}{dt}\hat{\Omega} = \frac{1}{J}\hat{M} + L_2\left(M - \hat{M}\right). \qquad (2)$$

The elements of the matrix L are determined by equating the characteristic polynomial of the observer to the normalized polynomial [7]:

$$L_1 = A_1 \cdot \Omega' - \frac{1}{T_2},$$

$$L_2 = \frac{1 - (\Omega')^2 \cdot T_2 \cdot J}{z_p \cdot h_i \cdot J}, \qquad (3)$$

where Ω’ – the geometric mean root, the value of which is chosen from the condition of providing the required speed of the observer $\Omega' = (5...10)\cdot\omega_{1n}$; A_1 – the form factor, according to the accepted standard linear Bessel form, equal to 1.73.

To ensure the greatest accuracy of the observer, it is desirable to implement it on the basis of a TAM complete mathematical model, performed in a fixed coordinate system [9]. For this equation, the observer (3) should be converted to the form:

$$T_2\frac{d}{dt}\hat{M}+\hat{M}=h_i\cdot\left[\omega_1 - z_p\cdot\hat{\Omega}+\frac{T_2\cdot L_1}{h_i}\cdot\left(M-\hat{M}\right)\right];$$

$$J\frac{d}{dt}\hat{\Omega}=\hat{M}+J\cdot L_2\left(M-\hat{M}\right). \qquad (7)$$

The transformed equations correspond to the block diagram presented in **Fig. 1.**

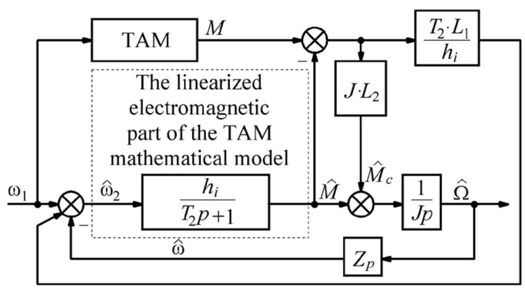

Fig. 1. Block diagram of the linearized Luenberger observer

Analysis of equations (7) and the scheme in **Fig. 1** allows to conclude that the “stabilizing additive” $J\cdot L_2\left(M-\hat{M}\right)$ is in fact an estimated value of the moment of TAM resistance $\hat{M}_r$.

3. Results

Research of the obtained scheme of the Luenberger observer is carried out using the data of the modernized TAM taken from [10]. Since the nominal frequency of the modernized TAM is f_{1n}=100 Hz, the value of the geometric mean root characterizing the response of the Luenberger observer is assumed to be Ω’=6280 s^{-1}. This value corresponds to the coefficients of the Luenberger matrix: L_1=15958 and L_2=–8110.

As a result of simulation modeling of the Luenberger observer together with the TAM of the SRU hermetic compressor with the nominal frequency reference signal and nominal compressor load, the average value of which is 0.3 N·m, graphs of the rotation speed Ω and the resistance moment M_r of the TAM under investigation are obtained, as well as estimates $\hat{\Omega}$ and $\hat{M}_r$ the output of the observer (**Fig. 2**).

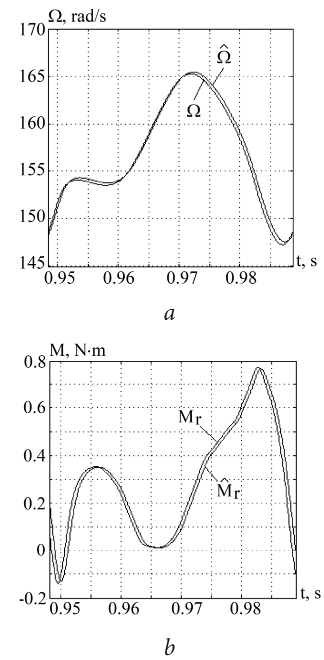

Fig. 2. Changing the coordinates of the TAM state and their assessment: *a* – rotational speed; *b* – resistance moment

4. Discussion

From **Fig. 2** it can be seen that the estimated coordinates of the state of the compressor electric drive are rather close to their real values, and the observer’s error does not exceed 0.5 % in rotation frequency and 10 % in respect to the resistance moment. The increased value of the error in estimating the resistance moment of the investigated TAM compared to the estimated rotation frequency is explained by the presence of a second “stabilizing” additive $T_2\cdot L_1/h_i\cdot\left(M-\hat{M}\right)$ besides $J\cdot L_2\left(M-\hat{M}\right)$.

The resulting structure of the Luenberger observer allows to build AED control systems of the hermetic compressor closed in an observer.

In order to improve the accuracy of the estimation of the moment of resistance, it is possible to further improve the proposed structure of the Luenberger observer on the basis of observers of reduced order.

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