Development and research of the electric drive generalized computer model with pulse-phase regulation of angular speed

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Abstract. The article presents the developed generalized computer model of the electric drive with pulse-phase regulation of the angular speed. The model was created on the basis of a pulse frequency-phase detector (PFPD) model with additional functionality, that give a possibility to investigate the most effective ways to control this electric drive, from the point of view of dynamic indicators improving of regulation quality. On the basis of the known methods of phasing and synchronization, the model of precision electric drive was validated. The test showed that the work of the model meets theoretical expectations.

1. Introduction

Electric drives with phase synchronization (EDPS) and synchronous-in-phase electric drives (SiPED), based on the phase-locked loop (PLL) principle, are widely used in the survey-search and scanning systems construction and devices, in technical vision systems of modern robotic complexes, installations of phototelegraphic and video recording equipment, tape and recording devices, copiers, multi-color printing machines.

The widespread use of electric drives based on the PLL principle is primarily due to high accuracy in a wide range of angular speed control (angle control accuracy is achieved in the order of arc seconds units; in the region of high rotation frequencies, in the region of high rotational frequencies — in the order of 0.001% in the range of angular speed variation 100: 1 or more) [1].

The phase-locked loop principle is implemented by using a pulsed frequency signal generated by a quartz oscillator as a master signal \( f_{\text{ref}} \); as a feedback signal – a frequency signal \( f_{\text{fb}} \) generated at the output of a pulse frequency rotation sensor (PFS), and as a comparing element - a logical comparison device (LCD), implemented on the basis of a pulse frequency-phase discriminator (PFPD).

Functional diagram of a synchronous-in-phase electric drive using the PLL principle is shown in Figure 1: FMB – frequency master block, CD – correction device, PC – power converter, EM – electric motor, PFS - pulse frequency rotation sensor, PS – position sensor, PMB – phase mismatch block, RB – regulation block, LCD – logical comparison device, PR – phasing regulator.

In LCD saturation modes \( \gamma = \pm 0.5 \) the maximum acceleration of the electric drive \( \varepsilon_m \) is ensured, which corresponds to the value of the angular error in the proportional operation mode \( \Delta \alpha = \pm \varphi_0 / 2 \), \( \Delta \varphi = \pm 0.5 \), where \( \varphi_0 = \pm 2\pi / z \) – angular distance between PFS marks, \( z \) – amount of PFS marks. The current limit of the EM is usually set to the appropriate control signal at the CD output in the PFPD saturation modes \( \gamma = \pm 0.5 \).
2. Theoretical basis

To reduce overshoot and improve the performance of EDPS and SSED, various ways of controlling the electric drive are used. There are ways to improve the dynamics of the drive. It’s synchronization methods (internal control loop) and phasing methods (external control loop).

The most widely used methods of SiPED regulating, based on the sequential docking algorithm in time of two processes: synchronization and phasing (phasing occurs after synchronization), due to their implementation simplicity, which does not require a large number of measuring elements. Thanks to the development of measuring devices of the coordinates of the electric drive, implementing indirect numerical methods for determining the angle error, the error in angular speed and acceleration, recently control methods based on prephasing were added to them (carried out before synchronization at a given angular speed).

Figure 2 shows the classification of the drive synchronizing ways. Figure 3 - classification of synchronous-in-phase electric drive phasing methods.

![Figure 1. Synchronous-in-phase electric drive functional scheme](image)

![Figure 2. Classification of the drive synchronizing ways](image)
Figure 3. Classification of synchronous-in-phase electric drive phasing methods

From the point of view of improving the dynamic indicators of the SiPED regulation quality, for implementing the most effective methods of controlling the electric drive as LCD, it is necessary to use PFPD with additional functionality: indication of PFPD operation mode, moments of one frequency’s two pulses passage between another frequency’s two pulses (moments of the angle mismatch change by $\phi(0)$) and possibility of PFPD forced setting in the desired operation mode.

Classification of options for the PFPD additional features use in the EDPS and SSED control systems [1] is shown in Fig. 4.

Figure 4. Classification of options for the pulse frequency-phase discriminator with enhanced functionality use

3. Formulation of the problem
An effective method for studying EDPS and SiPED is the imitational computer simulation method [2]. This method allows to obtain fairly accurate results with significant time and money savings. Features of SiPED computer simulation are determined by the presence in the EDPS model of multi-valued
static nonlinearity, which is part of the PFPD mathematical model. To create computer models, one of the most suitable software packages is Matlab and its application - Simulink.

During forming the EDPS computer model, two PFPD models can be used:
- with the representation of PFPD in the multi-valued static nonlinearity with linearization form of PWM in the high rotation speeds region;
- with the PFPD presentation as a logical structure, taking into account the pulse nature of the signals’ compared frequencies [3].

The second approach allows for more accurate modeling in the low speeds area. The first one provides greater speed with similar accuracy, but only in the high angular speed area of the electric drive. To create PFPD computer model, the of a pulse frequency-phase discriminator full model is taken as a basis (Fig. 5). At the same time, there is no model of a nonlinear element that would allow to model the known EDPS controlling methods, since there is no indication of the nonlinear element state, (moments of the angular mismatch change by $\phi_0$) and a convenient way to force it into the required mode in the existing models.

The aim of the work is to develop a generalized computer model of the electric drive, built on the basis of the PLL principle, using the PFPD model (multi-valued static nonlinearity with linearized PWM), which allows to simulate known methods of the electric drive controlling.

4. Experimental and Results
Figure 6 shows the nonlinear element (PFPD) model developed in Simulink of the Matlab software package with additional functionality: indication of the nonlinear element operation mode, moments of angular mismatch change by $\phi_0$ and the possibility of the PFPD forcing to the required mode.

The algorithm of the created PFPD computer model program part (M-function) is shown in Figure 7.
To test the developed PFPD model, a time-optimal method simulation of synchronous-in-phase electric drive regulation was carried out using the model shown in Figure 8. In this regulation method, the PFPD forced setting in speed-up modes with maximum acceleration, deceleration with maximum acceleration and in proportional operation mode is used.

As a result of modeling, phase portraits on Fig. 9 and Fig. 10 (magnified scale of Fig. 9 in the synchronization area), time diagrams of the angular mismatch (Fig. 11) and indication of the angular mismatch change moments by $\phi$ (Fig. 12) were obtained, which corresponds to the passage of one frequency’s two pulses between two pulses of another frequency.

In Figure 12, the black-filled area is the set (several thousand) of pulses appearing at the 2/2 and 0/2 outputs of the PFPD block when the angle error varies by $\phi_0$.

5. Conclusion
The developed generalized computer model of the electric drive with pulse-phase regulation of the angular speed, created on the PFPD model basis with additional functionality, gives a possibility to investigate the most efficient electric drive control methods, from the point of view of improving the dynamic quality indicators of SiPED control and EDPS regulation.
Figure 7. Algorithm of PFPD M-function program.
Figure 8. The generalized model of synchronous-in-phase electric drive

Figure 9. Phasing portrait
Figure 10. Phase synchronization portrait

Figure 11. The angular mismatch timing diagram.

Figure 12. The timing diagram of the moments indication of the angular mismatch change at an angle by $\phi_0$
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