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# THE RESEARCH MECHANICAL DYNAMIC OF MODEL OF THE ASYNCHRONOUS ENGINE IN SYSTEMS OF CONTINUOUS TRANSPORT

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*Are considered ways of perfection of systems of the asynchronous electric drive with the frequency management, intended for conveyors and mechanisms of moving of cargoes, by development and application of new circuit decisions and algorithms of the management, making possible optimum энергопотребление. The virtual objective model based on preliminary constructed mathematical model and the Model constructed in software package VisSim is offered for use as an element of system of automatic control. It allows to model inclusion, shutdown and a reverser of the asynchronous engine, as well as scalar continuous management of frequency of rotation of a shaft in a range from a minus of 50 % up to plus of 20 % of nominal frequency of rotation of a shaft.* References 7, figures 4, table.
**Key words**: induction motor scalar control, dynamic characteristics, mathematical modeling.

**Introduction.** The most used widely asynchronous electric drives with scalar control to drive the compressors, fans, pumps and other mechanisms - which must be kept at a certain level or the motor rotation speed (effective speed sensor) or of a process parameter for example, the pressure in the pipeline, using an appropriate sensor [1,3,7]. The operating principle of an induction motor scalar control - amplitude and frequency of the supply voltage are changed according to the law $\frac{U}{f^n} = const$, when $n$>=1. It will be look like this relationship in a particular case depends on the requirements imposed load electric drive. As a rule, acts as an independent impact frequency and voltage at a particular frequency is determined by the views of the mechanical characteristics as well as the critical values and starting points. Due to the scalar control it provides a constant overload capacity induction motor, voltage independent of frequency, and still at a fairly low frequencies can occur a significant reduction in torque generated by the motor. The maximum value of scalar control range at which the values of possible implementation of control of the motor rotor speed, torque resistance without loss does not exceed 1:10.

Continuous frequency control rotor speed of an induction motor is very important and urgent task. Frequency regulation is carried out with the use of electronic voltage transducers and the mains frequency in two basic types.

Scalar regulation advantage is ease regulatory organization is quite wide range: in two - three times lower than the nominal frequency and a half - twice the nominal rate. Disadvantage - relatively low accuracy of maintaining the frequency of the desired value, determined by the slope of the working area of natural mechanical stiffness characteristics [6, 7, 8] Note that the use of relatively simple automatic control systems (ACS) management by allowing deviation is essential for one . Two order to increase the accuracy of control of the induction motor speed (BP). Vector control allows you to adjust the rotor speed in a very wide range, from almost zero to a value twice the nominal. At the same time the torque is almost equal to the rated critical.

**Materials and methods of research.** The material for the study are asynchronous electric drive system designed for continuous transport facilities. Such facilities require a sophisticated control system to analyze the condition of the engine, the disturbance coming to him, and simulate the real-time engine to produce a three-phase voltage, phase voltage whose magnitude, frequency and initial phase line voltage network must strictly correspond to the current and desired behavior motor.

We used the methods of structural transformation of automatic control theory, methods of mathematical modeling of nonlinear dynamic systems on digital computers using numerical methods for solving.

Also discussed new systems of frequency control induction motor using the correction and direct torque control blocks. The control system maintains the motor torque at a critical level, i.e. engine as the control object is in an unstable state, and the control system it must have time to keep it unstable state. The main models used mechanical dynamic model proposed below. These models take into account the main, the mechanical inertia of the induction motor, ignoring their relatively small electromagnetic inertia. Scalar AC motor control systems are widely used in those cases where the actuator is relatively low requirements imposed on the range of adjustment of speed and dynamic characteristics of [2,5].

The static mechanical characteristics with scalar frequency electric control may be calculated using, for example, Kloss formula [6]. When using scalar control systems in the frequency drive is possible to note a few significant drawbacks: in the absence of speed sensor can not be controlled rotational speed due to its dependence on the load; it is impossible to produce a torque control. This problem is solved by installing a torque sensor, but it is irrelevant because of the relatively high cost of installation, often exceeding the cost of the drive. In this case, the torque control process is highly inertial; it is impossible to perform simultaneous control of torque and speed. Recently, we have developed many systems of scalar frequency control induction motor units with frequency correction control laws [4].

Analytical description mechanical dynamic model is very simple and is based on the following equation [2]. The equation of the rotor angular acceleration (rad / s$^2$):

$$\varepsilon = \frac{1}{J}\left(M - M_c\right), \tag{1}$$

where $M$ – electromagnetic torque of the motor; $M_c$ – moment of resistance (braking) load, reduced blood pressure to the shaft. The equation of angular velocity (rad / s (braking) load, reduced blood pressure to the shaft. The equation of angular velocity (rad / s):

$$\omega = \int_0^t \varepsilon(t)dt \ . \tag{2}$$

Modified expression Kloss formula, which takes into account the effect of the voltage $U$ and frequency $f$ of the network, as well as the speed $n$ of the rotor and the critical frequency ncr on electromagnetic torque ($N_m$) of the motor rotation:

$$M = f_1(n, f, U), \tag{3}$$

where $n = \frac{60}{2\pi}$ , $n$ – revolutions per minute (RPM). Let us note that the angular acceleration of the rotor affects the time derivative of the moment of inertia J, but many technical problems this time constant, that allows the use of formula (1) in the above input. The influence of the time derivative of the moment of inertia, reduced to the shaft in a continuous transport mechanisms is shown below. In order not to overload the details set forth in equation (1) it is necessary, that the moment of inertia of the shaft influences the angular acceleration only at the time when the amount of torque and braking torque is not zero. This model takes into account the changes in the dynamics of the torque during the motor acceleration and deceleration. But on the shaft speed can affect and change the moment of inertia in the dynamic equilibrium of the accelerating electromagnetic torque of blood pressure and braking torque on its shaft. Indeed, let the blood pressure drives the conveyor belt or the mill. In this case, the tape or material supplied to the drum, and if the power is uneven, the moment of inertia, the shaft shown AD, will vary.

When adding material by virtue of the law of conservation of momentum (or angular momentum) belt speed or the drum speed will decrease at first, and then the engine as far as possible (the rigidity of the working area – natural mechanical characteristics) will restore the operating frequency. When adding inertia is taken into account the law of conservation of angular momentum:

$$J \cdot \omega = const. \tag{4}$$

Then

$$ln(J \cdot \Omega) = C_1; \qquad ln(J) + ln(\Omega) = C_1; \qquad \frac{d}{dt}\Omega = -\frac{\Omega}{J}\cdot\frac{d}{dt}J. \tag{5}$$

Since transport problems only increase the moment of inertia results in a decrease in rotational speed and moment of inertia reduction does not affect the speed, the acceleration of the shaft to obtain the expression:

$$\varepsilon(t)=\begin{cases}\frac{1}{J}\left[\left(M_{\textit{вм}}-M_m\right)-J\cdot\Omega\right]\ ,\ J>0\\ \frac{1}{J}\left[\left(M_{\textit{вм}}-M_m\right)-J\cdot\Omega\right],\ J\le 0\end{cases}, \tag{6}$$

where $M_{\textit{вм}}$ – rotational moment ( N·m), $M_m$ – braking moment (N·m), $\Omega$ - shaft speed (RPM).

Shaft speed:

$$\Omega=\int_0^t \varepsilon(t)\,dt+\Omega_0 \tag{7}$$

and torque movement

$$M(n,f,U)=\frac{\Delta n_{cr}\,(n_0-n)\,2M\left(\frac{U}{U_{nom}}\right)^2\left(\frac{f}{f_{nom}}\right)^2}{(n_0-n)^2+\Delta n_{cr}}. \tag{8}$$

Formula (8) takes into account the effect of the voltage $U_{nom}$ and frequency $f_{nom}$of the network, as well as the rotational speed $n$ of the rotor and the critical frequency $n_{cr}$ on electromagnetic torque M (Nm) of the motor rotation.

Note, that the change of moment of inertia reduced to the shaft and is accompanied in practice the moment of resistance change (deceleration) on the shaft motor which compensates by changing torque. In the simulation, it is the moment of resistance change was taken into account. The above-described scalar control system was investigated on a virtual object model based on the above formulas built in VisSim. In the circuit model used asynchronous motor 4A250S4У3 within the parameters given in the table. The complete circuit model for the study of scalar proposed system is shown in fig. 1. In the model studied trigger modes with rated torque, load shedding and impingement. Fig. 1 shows plots of transients in the drive in the start mode with nominal torque up to 50 Hz.

| Type of engine | $P_n$, kilowatt | $n_n$, RPM | $\eta_n$, % | cos $\varphi_n$ | $M_{max}/M_n$ | $M_p/M_n$ | $M_{min}/M_n$ | $I_p/I_n$ |
|---|---|---|---|---|---|---|---|---|
| 4A80B4У3 | 1,5 | 1415 | 77 | 0,83 | 2,2 | 2 | 1,6 | 5 |

The total control of the model presented in fig. 1 with continuous control variables: fc, Hz and Uc,V. The model in fig. 2 is considered with braking bearings. The moment of inertia of the shaft significantly manifested at portions start, reverse and stop the induction motor, and when the load increases. Mechanical dynamic model of asynchronous motor control starting torque, with a discrete (On - Off - Reverse) and continuous (frequency and supply voltage) control, and taking into account the effect of rate of change of the moment of inertia of the shaft speed and torque in motor tasks (increase the moment of inertia decreases engine speed, and a decrease in the moment of inertia does not affect it).

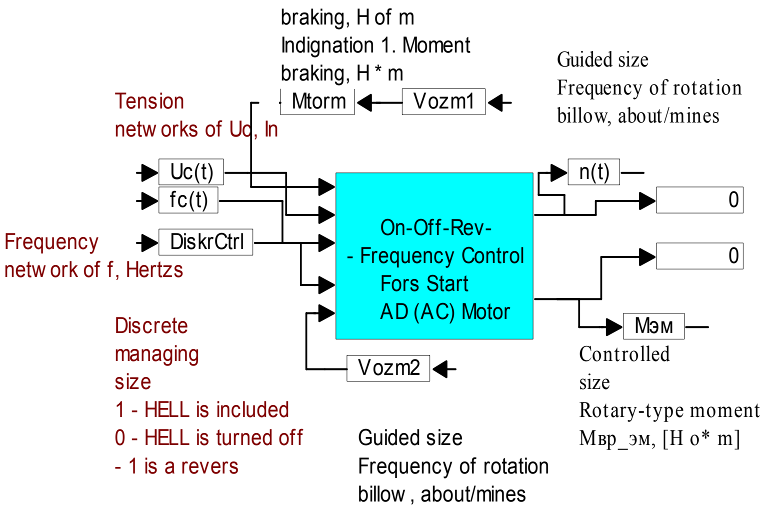


Fig. 1

One solution is to build a system with block correction voltage generating issuing corrective-incoming signal as a function of the estimated parameter – the tangent of the angle between current and electromotive force of the stator is determined from the measured instantaneous stator phase current values and setpoints stator phase voltages [6].

The functional diagram of the system scalar control frequency electric drive with a block on the basis of an asynchronous motor with squirrel-cage rotor correction is shown in fig. 3. Typical scheme of frequency scalar control frequency converter, formed on the basis of the voltage inverter, complemented by blocks 10-13 correction vector control law on the fig. 4.

Functional diagram of the asynchronous motor with a scalar control system is shown in fig. 4. Asynchronous motor control system works as follows.

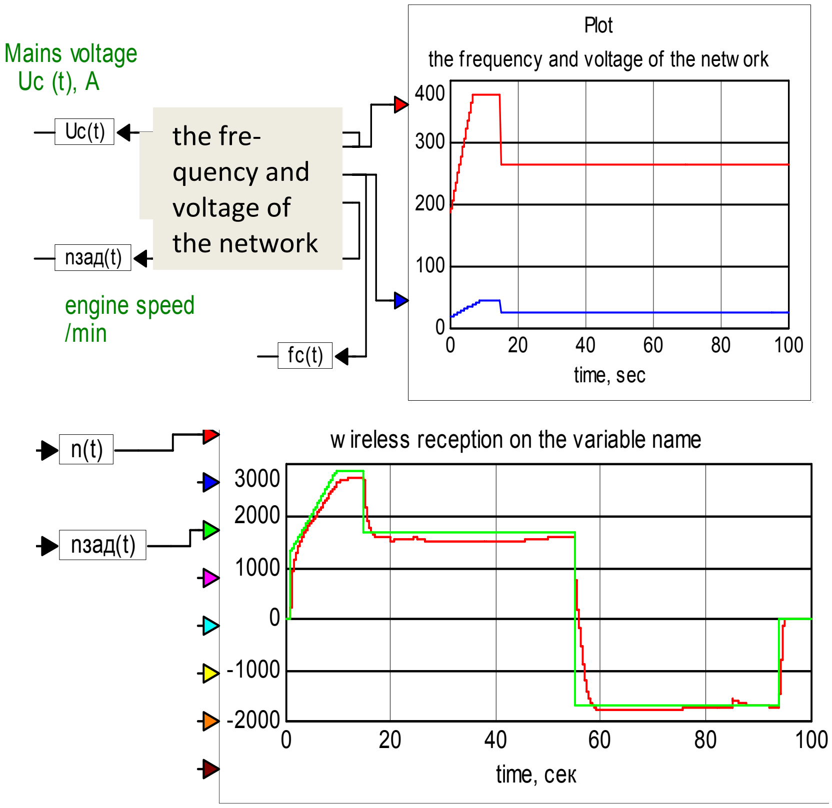


Fig. 2

Inverter 1, two power outputs of which are connected through current sensors 2 and 3 with two stator windings of the induction motor 4, voltage feeds the stator windings of the induction motor pulse-modulated voltage ripple of power. The duration of the voltage pulses is determined by controlling pulsations coming from the output of the PWM control unit performing PWM modulation and voltage regulation. Formation of the sinusoidal phase reference signals on the block 5 is made block 6 forming the harmonic signal instantaneous voltage setting values generate signals $U^*_{1A}, U^*_{1B}, U^*_{1C}$. Block of task of management signals 7, the control signal setting unit generates the reference signal to the frequency $\omega_1$ *, arriving at the frequency input unit 6, and the amplitude of the reference signal voltage $U_1$* entering through the adder 8 to the input unit 6 the amplitude.

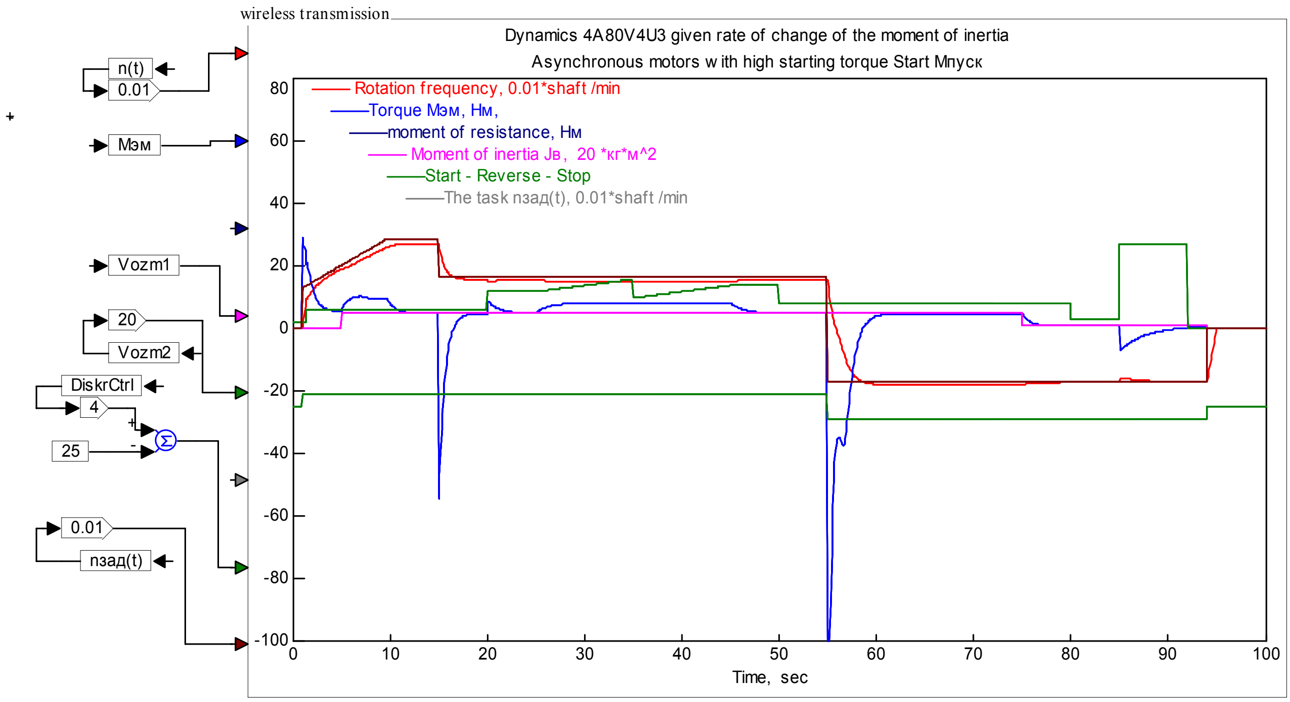


Fig. 3

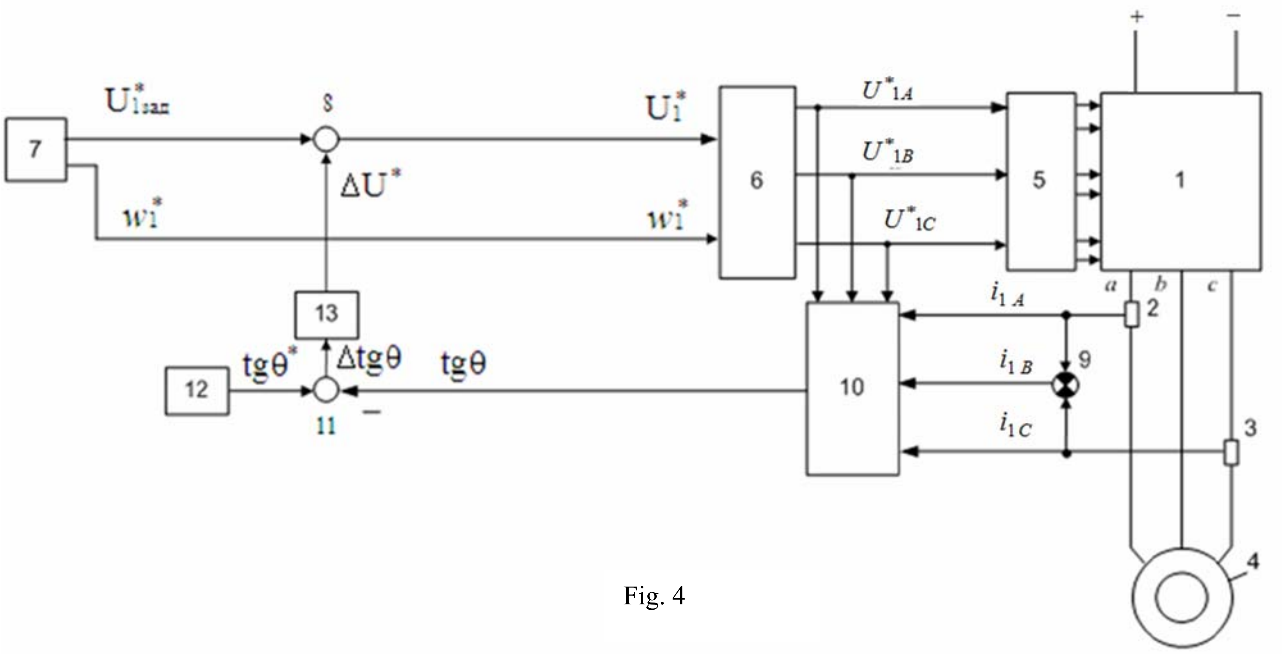


Fig. 4

Blocks the correction vector control law are 10,11,12, 13, and input adder 9 for phase rotor currents. At starting of engine and adjusting of his frequency of rotation block of task of management signals 7 will realize the change of signals of task under the law of frequency management programed in this bloc $U^*_1 = f(\omega^*_1)$. Reference signals are generated in accordance with equations (9)

$$\begin{cases} U^*_{1A} = U_1^* \cdot sin\left(\omega_1^* \cdot t\right); \\ U^*_{1B} = U_1^* \cdot sin\left(\omega_1^* \cdot t - \left(2\pi/3\right)\right); \\ U^*_{1C} = U_1^* \cdot sin\left(\omega_1^* \cdot t + \left(2\pi/3\right)\right), \end{cases} \quad (9)$$

where $U_1^*$ − generalized stress vector unit $\bar{U}_1^*$.

If there is a change in load on the motor shaft or the speed control is performed, then to provide a minimal stator current value for a given value of the static torque on the shaft of the engine is necessary to change the amplitude of the voltage $U_1$ * so that the angle between stator current and magnetizing current $\varphi_0$ (Fig. 4) was close to $45^0$, for a given condition angle θ * between the stator current vector and the stator will strive to $45^0$, then tgθ * = 1. Based on the vector diagram can determine the tangent of the angle between the current vector and the stator electromotive force. As a result of the research, it was found that the corrective signal is scalar voltage $\Delta U$ can be formed as an integral function of the previously determined signal Δ tgθ:

$$\Delta U = \int_0^{t_{end}} \alpha U_{1n} \cdot \Delta tg\theta \cdot dt \ , \quad (10)$$

where $t_{end}$ – end time of the drive; $U_{1n}$ – nominal phase voltage of the stator; α – normalizing factor, which in the electric study on computer model adopted 0,01 <α <0,1. As a result of the research it found that the system voltage correction reduces the stator current of up to 6% lower in relation to the nominal values of the static moment, that provides improved energy performance, however, the correction unit does not provide stabilization of the engine torque in the starting mode, and does not affect the nature of the transients at the start of the drive.

**Conclusions.** The model is valid for engines operating in vehicles as a drive device (conveyor, drum mills, etc.). If the moment of inertia changes with no loss of the rotating (moving) mass, then the change in torque as the upward and downward will be accompanied by a corresponding inverse change in the rotational speed, and in the equation (3) the acceleration will be determined by the upper equality both in the positive, and at negative rates of change of torque. Therefore, in the model of fig. 3 will need to remove the stopper from the bottom of the derivative of the total torque. The influence of rate of change of the moment of inertia, reduced to the shaft to determine the changes arising from this torque. Changes in the moment of inertia relatively little effect on the speed of the shaft. When hard scalar control speed value approximately, but with good accuracy is given by the frequency $f_c(t)$ network. $f_c(t) = (0,6 – 1,2)\ f_{nom}$. The model is designed for use as part of an automatic control system. It allows you to simulate the start, stop and reverse the induction motor, and the ongoing management of the inner shaft speed in the range from minus 50% to + 20% of the rated shaft speed.


1. *Aliev I.I.* Handbook of Electrical and electrical equipment. 3-e izd., ispr. – M.: Vysshaja shkola, 2002.– 255p. (Rus.).
2. *German-Galkin S.G.* Computer modeling of semiconductor systems in MATLAB 6.0: uchebnoe posobie: KORONA print, 2001.– 320 p. (Rus.).
3. *Klyuchev V.I.* Theory of electric drive. - M.: Yenergoatomizdat, 1985.– 560 p. (Rus.).
4. *Kovach K.P.* Transients in AC machines / K.P. Kovach, I. Rac. – M.; L.: Gosyenergoizdat, 1963. – 744 p. (Rus.).
5. *Pjatibratov G.Ja.* The mathematical description and simulation of compensation systems gravity asynchronous variable frequency drives / G.Ja. Pjatibratov, D.V. Baryl'nik, O.A. Kravchenko; YUzh.-Ros. gos. tehn.un-t. – Novocherkassk, 2006. – 150 s. – Dep. v VINITI 19.07.06, № 971-V2006. (Rus.).
6. *Fedosov B.T.* Equations of state of dynamic objects with delay.– Rudnyi, RII, 2010. – 34 p. (Rus.).
7. *SHreiner R.T.* Mathematical modeling of AC drives with solid-state frequency converters / R.T. SHreiner. – Ekaterinburg: URO RAN, 2000. − 654 p. (Rus.).
8. *Verdonck Walter, Swevers Jan*. Improving the Dynamic Accuracy of Industrial Robots by Trajectory Pre-Compensation. // Proceedings. 2002 IEEE International Conference on Robotics and Automation. 2002.


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**Исследование механодинамической модели асинхронного двигателя в системах непрерывного транспорта**

*Рассмотрены способы совершенствования систем асинхронного электропривода с частотным управлением, предназначенных для конвейеров и механизмов перемещения грузов, путём разработки и применения новых схемных решений и алгоритмов управления, позволяющих осуществлять оптимальное энергопотребление. Предложена виртуальная объектная модель, основанная на предварительно построенной математической модели и построенная в VisSim. Модель предназначена для использования в качестве элемента системы автоматического регулирования. Она позволяет моделировать включение, выключение и реверс асинхронного двигателя, а также скалярное непрерывное управление частотой вращения вала в диапазоне от -50% до +20% номинальной частоты вращения вала.* Библ. 8, рис. 4, таблица.
**Ключевые слова:** асинхронный двигатель, скалярное управление, динамические характеристики, математическое моделирование.

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**Дослідження механодинамічної моделі асинхронного двигуна в системах безперервного транспорту**

*Наведено способи вдосконалення систем асинхронного електроприводу з частотним керуванням, призначених для конвеєрів і механізмів переміщення вантажів, шляхом розробки і застосування нових схемних рішень і алгоритмів керування, що дають змогу здійснювати оптимальне енергоспоживання. Запропоновано віртуальну об'єктну модель, засновану на попередньо побудованій математичній моделі, і побудовано в VisSim. Модель призначена для використання в якості елемента системи автоматичного регулювання. Вона дозволяє моделювати ввімкнення, вимкнення і реверс асинхронного двигуна, а також скалярне безперервне управління частотою обертання вала в діапазоні від -50% до +20% номінальної частоти обертання вала.* Бібл. 8, рис. 4, таблиця.
**Ключові слова:** асинхронний двигун, скалярне управління, динамічні характеристики, математичне моделювання.

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