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Developing a Regulator for Improving the Operation Modes of the Electrical Drive Motor

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Abstract**—**The operation modes of the synchronous motors used in the production processes are greatly conditioned by the accidentally changing technological and power indices. As a result, the electrical drive synchronous motor may appear in irregular operation regimes. Although there are numerous works devoted to the development of the regulator for the synchronous motor operation modes, their application for the motors working in the irregular modes is not expedient. In this work, to estimate the issues concerning the stability of the synchronous electrical drive system, the transfer functions of the electrical drive synchronous motors operating in the synchronous and induction modes have been obtained. For that purpose, a model for investigating the frequency characteristics has been developed in the LabView environment. Frequency characteristics for assessing the transient process of the electrical drive system, operating in the synchronous and induction modes have been obtained, and based on their assessment, a regulator for improving the operation modes of the motor has been proposed. The proposed regulator can be successfully used to prevent the irregular modes of the electrical drive synchronous motor, as well as to estimate the operation state of the drive motor of the mechanism with a changing load.

Keywords**—**Electrical drive system, synchronous motor, regulator, stability, transition process.

I. Introduction

THE operation of the mechanics used in the technological processes of different production enterprises is provided by synchronous electrical drive motors. The operation modes of synchronous electrical drive motors conditioned by technological and energetic indices can periodically change [1]. The analyses have shown that an insignificant change in any technological or energetic index can favour to distortion of the whole technological process [2]-[5]. It is known that the increase of the load moment more than the maximal permissible value leads to the failure of the regular operation of the electrical drive synchronous motor used in the electromechanical system. The change in the technological indices in separate technological processes may occur incidentally. In those processes, the load moment can undergo a change, favouring the occurrence of the irregular operation modes of the electrical drive synchronous motor which can result in the occurrence of failures.

The goal of the present work is to study the frequency characteristics for estimating the issues concerning the stability of the synchronous electrical drive system, and based on this, propose a regulator for improving its operation modes.

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To achieve the mentioned goal:

- the transmission functions of the electrical drive synchronous motors operating in the synchronous and induction modes with an alternating load have been obtained;
- by using the Nyquist criterion, the frequency characteristics have been considered, and by means of them, the issues concerning the system stability have been estimated;
- a regulator for improving the operation modes of the electrical drive synchronous motor working in the synchronous and induction modes has been proposed.

II. The Transfer Functions of the Electrical Drive Synchronous Motor

The equation of the rotor motion of the electrical drive synchronous motor has the following form [6]:

$$T_j \frac{d^2\theta}{dt^2} = M_D - M_{\mathrm{T}} \tag{1}$$

M_D is the electromagnetic moment of the motor; M_{T} - the loading moment of the synchronous motor; θ - the internal angle of the supply voltage vector and the emf vector induced in the stator winding; T_j - the constant of the rotor inertia.

The electromagnetic moment M_D of the synchronous motor can be presented as a sum of the $M_{D.ac}$ induction and $M_{D.c}$ synchronous moments.

By including the $\frac{dM_T}{dt}$ component, characterizing the load change in the differential equation of the rotor motion (1), (1) for the synchronous electrical drive, operating in the induction mode, will take the following form:

$$T_j \frac{d^2\theta}{dt^2} + \frac{2M_k}{s_k}\frac{d\theta}{dt} = M_T + \frac{dM_T}{dt} \tag{2}$$

Taking the following dependence into account:

$$M_{D.as} = -\frac{2M_k}{s_k}\frac{d\theta}{dt} \tag{3}$$

For the electrical drive motor, operating in the synchronous mode, expression (2) will take the following form:

$$T_j \frac{d^2\theta}{dt^2} + \frac{3UE_f}{\omega x_d}\frac{d\theta}{dt} = M_T + \frac{dM_T}{dt} \quad (4)$$

By introducing (2) in the form of Laplace modifications, we obtain [8]:

$$T_1 s^2 \theta(s) + T_2 s\theta(s) = M_T(s) + sM_T(s) \quad (5)$$

where $T_1 = -T_j$, $T_2 = \frac{2M_k}{s_k}$

By presenting (4) in the form of Laplace modifications, we obtain:

$$T_1 s^2 \theta(s) + T_3 s\theta(s) = M_T(s) + sM_T(s) \quad (6)$$

where $T_3 = \frac{3UE_f}{\omega x_d}$

From (5), we obtain the transfer function, characterizing the relation of the loading moment of the synchronous motor and the internal angle θ at operating in the induction mode ($M_D = M_{D.ac}$) [7]:

$$W_a(s) = \frac{1+s}{T_1 s^2 + T_2 s} \quad (7)$$

From (6), we obtain the transfer function, characterizing the relation of the loading moment of the synchronous motor and the internal angle θ at $M_D = M_{D.c}$.

$$W_c(s) = \frac{1+s}{T_1 s^2 + T_3 s} \quad (8)$$

Obtaining the transfer functions of the electrical drive synchronous motors, operating in the synchronous and induction modes with a changing load, the frequency characteristics of the system have been considered, and the issues concerning the stability have been estimated [8], [9].

III. Estimating the Stability of the Drive Motor, Operating in the Synchronous Mode, and Introducing the Regulator

The frequency characteristics of the system, operating in the synchronous mode and the estimation of the system stability have been carried out for three different values of the supply voltage.

- in case of the nominal supply voltage ($T_3 = 1684$),
- in case of supply voltage higher than the nominal ($T_3 = 28299$),
- in case of supply voltage lower than the nominal ($T_3 = 10780$).

For the considered cases, the transmission functions will take the following form:

- in case of the nominal supply voltage

$$W_c(s) = \frac{s+1}{2300s^2 + 1684s}$$

- in case of supply voltage higher than the nominal

$$W_c(s) = \frac{s+1}{2300s^2 + 28299s}$$

- in case of supply voltage lower than the nominal

$$W_c(s) = \frac{s+1}{2300s^2 + 10780s}$$

In Fig. 1, the Nyquist plot of the open system in case of the nominal supply voltage and the frequency characteristic of the closed system are introduced for the data T1 and T3, respectively.

In Fig. 2, the model for investigating the frequency characteristics in the LabView environment is introduced.

In Table I, the data obtained in the result of studying the characteristic parameters of the transient processes of the electrical drive motor, operating in the synchronous mode at different values of the supply voltage are introduced.

At different values of the supply voltage, the analysis of the characteristic parameters obtained for transition processes shows that, to improve the operation of the system, it is necessary to introduce a regulator. As a result of investigations carried out, a Proportional-Integral (PI) regulator has been designed.

TABLE I
THE VALUES OF THE CHARACTERISTIC PARAMETERS OF THE TRANSIENT PROCESS OF THE ELECTRICAL DRIVE MOTOR, OPERATING IN THE SYNCHRONOUS MODE

Characteristic parameters of the transient process	Electrical drive motor, operating in the synchronous mode		
	In case of the nominal supply voltage	In case of supply voltage higher than the nominal	In case of supply voltage lower than the nominal
The growing time, sec	37 000	62200	23700
Superregulation, %	0	0	0
Stabilization time, sec	65 900	111000	42200

TABLE II
THE CHARACTERISTIC PARAMETER VALUES OF THE TRANSIENT PROCESS OF THE ELECTRICAL DRIVE MOTOR, OPERATING IN THE SYNCHRONOUS MODE AT INTRODUCING THE PI REGULATOR

Characteristic parameters of the transient process	Electrical drive motor, operating in the synchronous mode		
	In case of the nominal supply voltage	In case of supply voltage higher than the nominal	In case of supply voltage lower than the nominal
The growing time, sec.	0.188	0.123	0.267
Superregulation, %	17.4	15.2	19.6
Stabilization time, sec	1.71	1.28	2.0

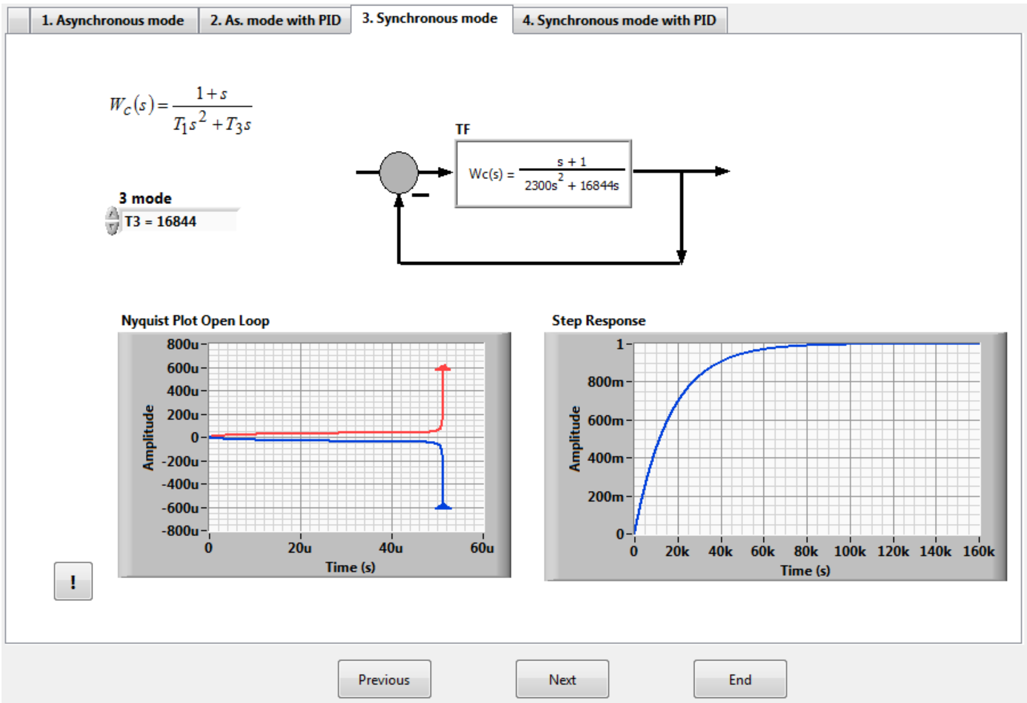

Fig. 1 The front panel of the interface, estimating the frequency characteristics of the electrical drive synchronous motor, operating in the synchronous mode and the system stability

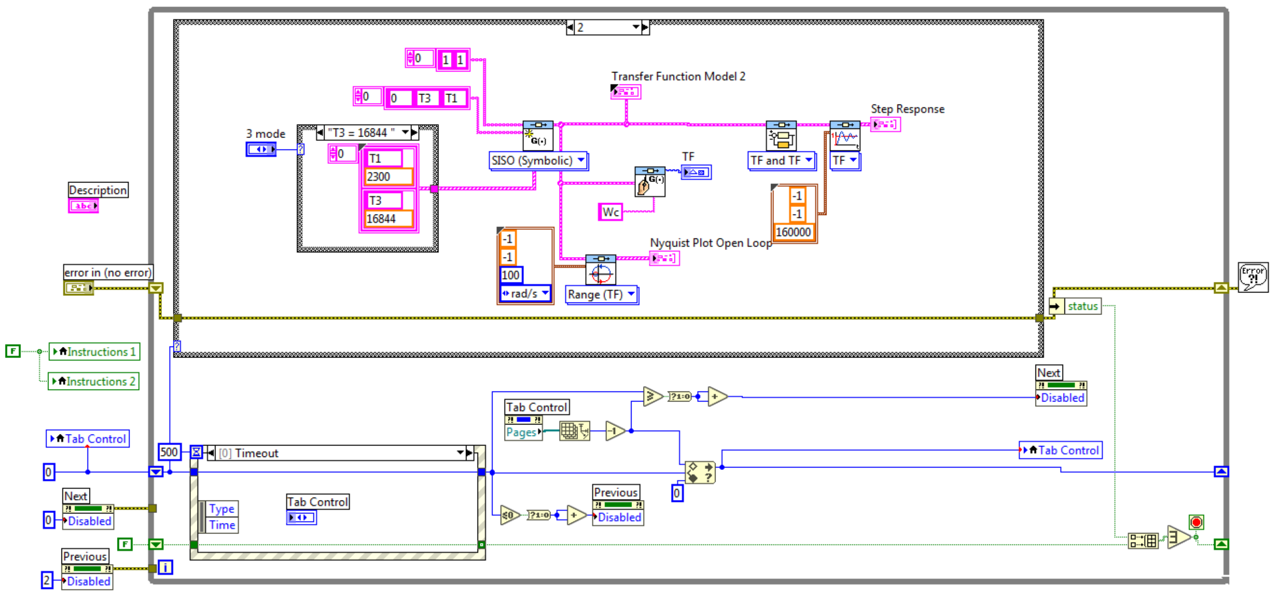

Fig. 2 The model of investigating the stability indices and the frequency characteristics of the electrical drive synchronous motor, operating in the synchronous mode

In Figs. 3 and 4, the Nyquist plot of the open system, the frequency characteristic and the model of their investigation for the motor, operating in the synchronous mode are presented.

By means of the model introduced in Fig. 4, the data obtained in the result of investigating the characteristic parameters of the transition process of the electrical drive motor, operating in the synchronous mode at introducing the PI regulator have been estimated for different values of supply voltage (Table II).

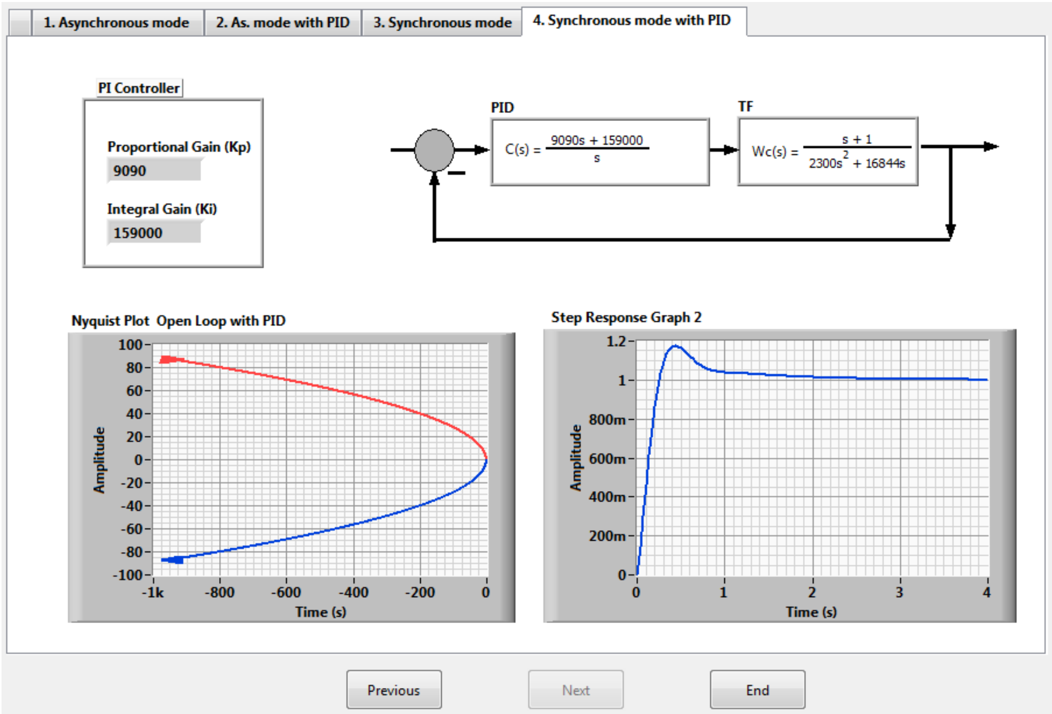

Fig. 3 The frontal interface panel of the Nyquist plot and frequency characteristic of the electrical drive motor open system, operating in the synchronous mode at introducing the PI regulator

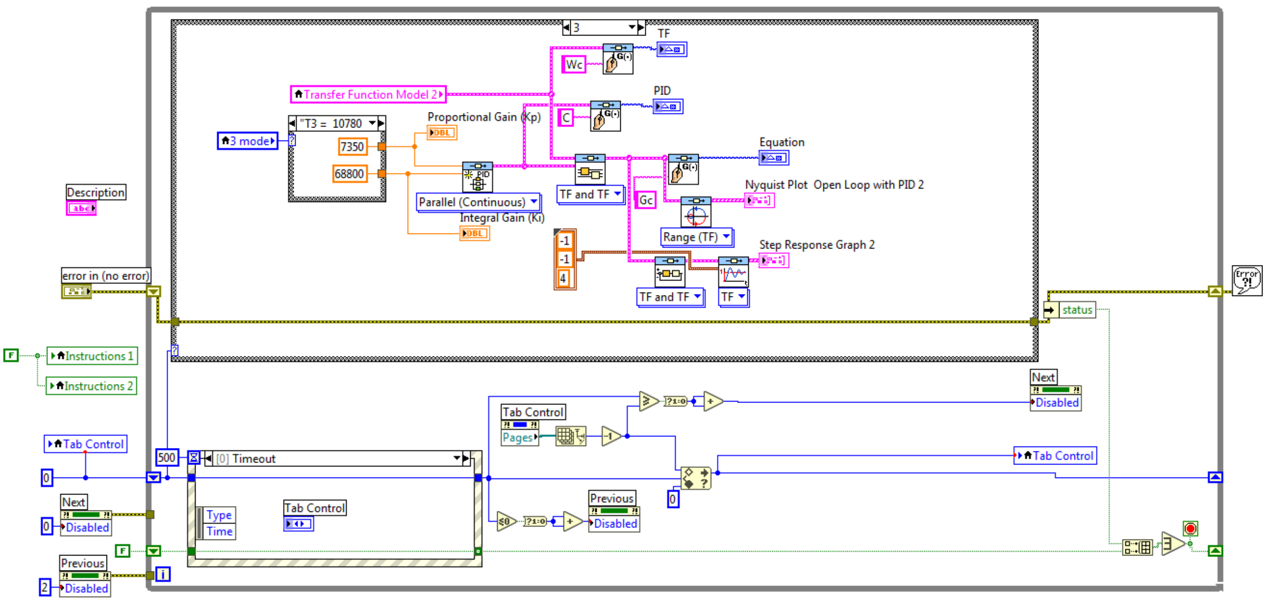

Fig. 4 A model for investigating the frequency characteristics of the closed system of the electrical drive motor, operating in the synchronous mode in case of introducing the PI regulators

The comparative analysis of the characteristic parameters of the transient processes presented in Table I and II shows that as a result of introducing the regulator, the operation modes of the system improve, regardless of the supply voltage value.

IV. Estimation of the Stability of the Drive Motor, Operating in the Induction Mode, and Introduction of a Regulator

The electrical drive synchronous motor of technological processes may appear in a short-term induction mode. Short-term induction modes can be [10]: maintenance - to ensure the regular operation of the electrical drive system; or emergency - occurring when the motor gets out of synchronism conditioned by the impact of different factors, for which the changes in the supply voltage and load (when it exceeds the maximum permissible limit) can serve as a source.

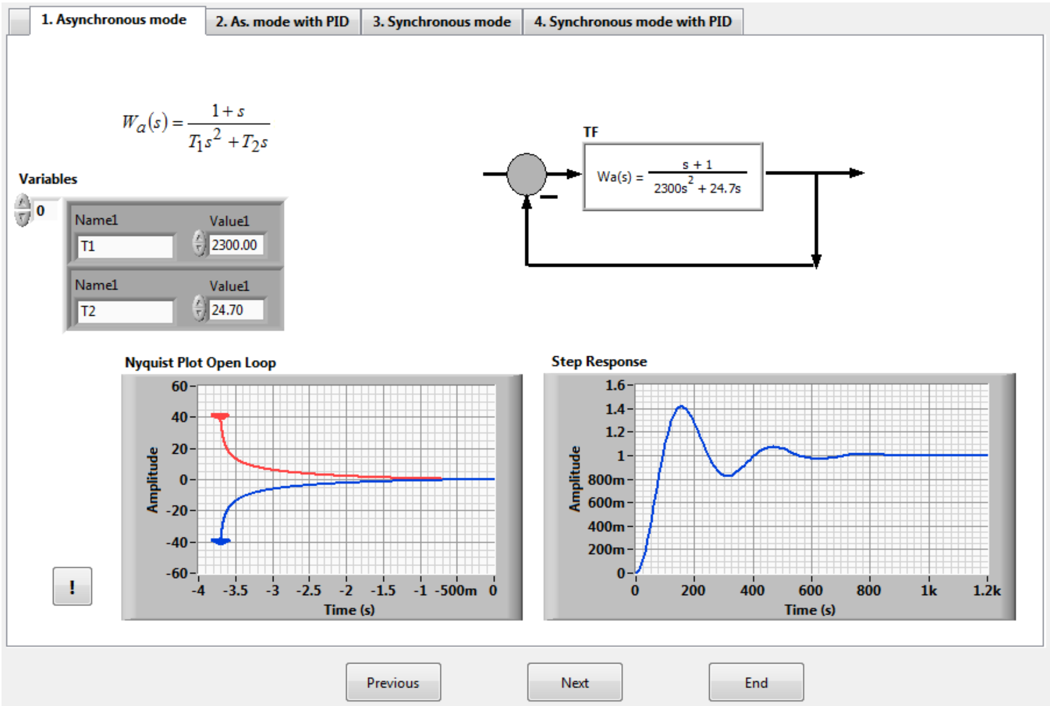

Fig. 5 The frontal interface panel for investigating the Nyquist plot and frequency characteristics of the system without a regulator at the operation of the motor in the induction mode

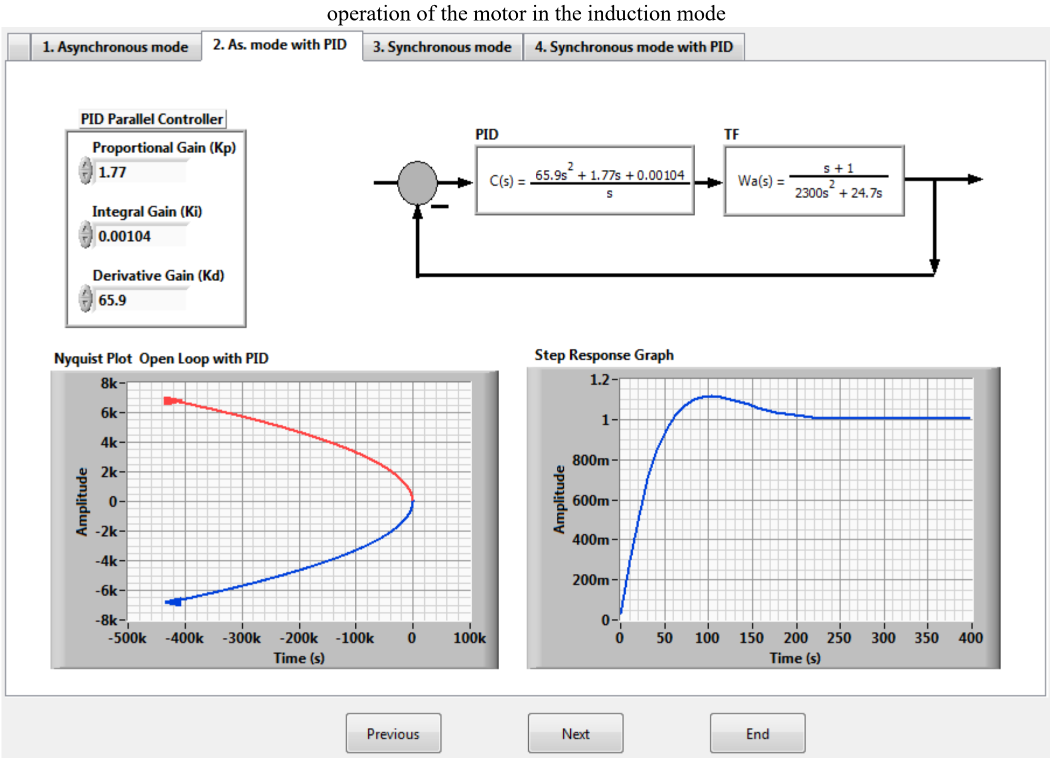

Fig. 6 The frontal interface panel for investigating the Nyquist plot and frequency characteristics of the system with a PID regulator at the operation of the motor in the induction mode

Based on the above mentioned, to avoid the occurrence of the electrical drive synchronous motor in an irregular operation mode, the possibility of regulating the characteristics of the synchronous motor, operating in the induction mode has been considered.

Based on the transmission function characterizing the relation of the loading moment of the synchronous motor at operating in the induction mode and the inner angle θ (7), the time characteristic of the system has been obtained in case of the data $T_1 = 2300$ and $T_2 = 24,7$ respectively.

Figs. 5 and 6 introduce the Nyquist plots and frequency characteristics of the system at the operation of the motor in the induction mode before the introduction of the regulator and after the introduction of the Proportional-Integral-Derivative (PID) regulator respectively.

By means of the model for investigating the time characteristics of the synchronous motor in the induction operation mode, the characteristic parameters of the systems' transient processes have been estimated without a regulator and with a PID regulator (Table III).

TABLE III
THE CHARACTERISTIC PARAMETERS OF THE TRANSIENT PROCESSES OF THE SYNCHRONOUS MOTOR, OPERATING IN THE INDUCTION MODE

Characteristic parameters of the transient process	A system operating in the induction mode without a regulator	A system operating in the induction mode with a PID regulator
The growing time, sec.	61.7	43.6
Superregulation, %	41.0	11.6
Stabilization time, sec	669	199

V. CONCLUSION

A regulator for improving the operation of the electrical drive synchronous motors has been proposed which gives an opportunity, regardless of the motor's operating mode, to reduce manyfold the stabilization time of the system.

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