Andrzej RUSEK

STATIC CHARACTERISTICS OF THE SPECIALLY DESIGNED INDUCTION MOTOR FOR A DRIVE SYSTEM FOR POLYMERIZATION REACTOR TAKING INTO CONSIDERATION A LOSS IN LARGE-SIZE SLIDE BEARING MADE OF SINTERED CARBIDES

ABSTRACT *A construction of the specially designed asynchronous induction motor is depicted in the paper. A vertical suspension of the motor using large-size slide bearing made of sintered carbides is described. Operating characteristics are determined on the basis of a system of equations describing steady states of motor operation and additional equations determining increments of slip that results from the load torques of motor caused by friction in lower bearing. The calculations were made for slide bearing considering the assumed curvature of the shape of bearing bushing. The stator current, power consumption, efficiency and power factor as functions of the output torque as well as the stator current and power consumption as functions of the slip were determined. The calculations were made for various assumption concerning the stator parameters and different temperatures of motor operation.*

Keywords: *polymerization reactors, specially designed motors, operating characteristics, slide bearings.*

Andrzej RUSEK, Assoc. prof., Ph.D.
e-mail: rusek@el.pcz.czest.pl

Faculty of Electrical Engineering,
Czestochowa University of Technology

PROCEEDINGS OF ELECTROTECHNICAL INSTITUTE, Issue 253, 2011

1. DESCRIPTION OF CONSTRUCTION OF THE SLIDE BEARING USED IN THE PROTOTYPICAL ASYNCHRONOUS MOTOR SAR-55/1500/09

Polymerization reactors play a fundamental role in the technological line of production of polyethylene. A drive system for polymerization mixer works in two chambers. The operating conditions of the drive system are specific because of necessity of keeping a constant temperature, atmosphere of ethylene and working pressure up to 2800 atm. A motor of the drive system has non-standard dimensions and construction due to the socket fixing in the upper chamber of reactor. The motor is adapted to the vertical work. The drive systems for polymerization reactors often break down due to the extraordinary operating conditions incl. feeding the motor via special electrodes allowing for operation under the pressure up to 2800 atm.

A specially designed motor with pipe body and large-size slide bearing were made in the frame of a government grant as a result of the designing efforts and alternative elaborations. The different curvatures of the large-size slide bearing were considered. The rated parameters of the motor are as follows [1, 2]: P_n = 55 kW, U_{1n} = 380 V, f_n = 50 Hz, M_n = 374 Nm, M_{max} = 842,85 Nm, n_n = 1420 rpm, p_b = 2, I_{1n} = 108 A, J = 1,02 kgm^2, G = 385 kg.

The slide bearing was made as a set of swinging bushing and slide ring having the following basic dimensions [1, 2]: the span of splines incisions 124 mm, the spline width 25 mm, number of splines 6, diameter of swinging foundation 165 mm, internal diameter of the working area 120 mm, external diameter of the working area 190 mm.

Fig. 1. A bottom of the asynchronous motors SAR-55/1500/09 with a cover of the slide bearing set [1, 2]

Fig. 2. The cover of slide bearing set used in the asynchronous motor SAR-55/1500/09; the bearing was made of sintered carbides of type GT-30P-5/6/11/25 [1, 2]

The shapes of bushing curvatures of the large-size slide bearing mounted in the bottom cover of the specially designed asynchronous motor are shown in Figure 3.

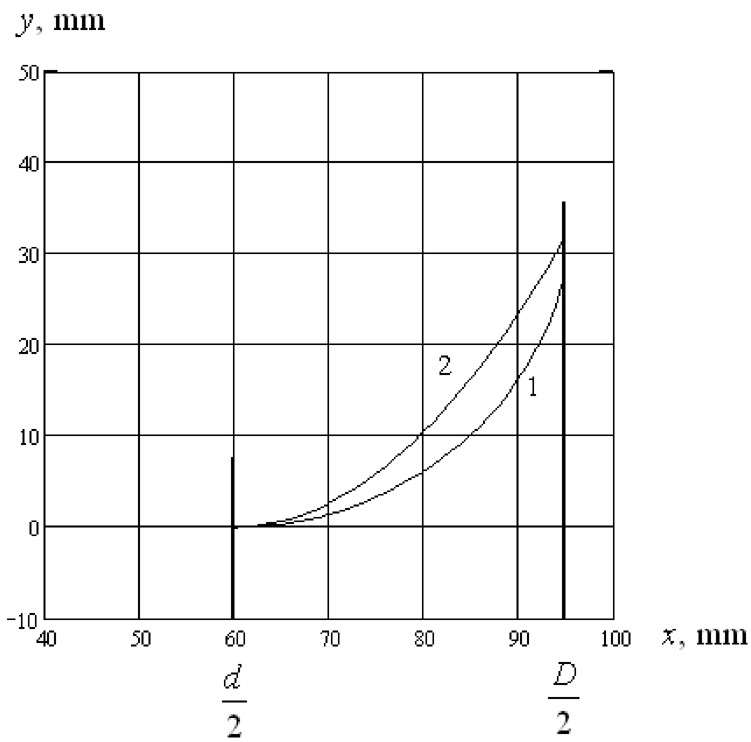

Fig. 3. Curvatures of bushing of large-size slide bearing mounted in the lower cover of the specially designed asynchronous motor SAR-55/1500/09

2. STATIC CHARACTERISTICS OF THE SPECIALLY DESIGNED INDUCTION MOTOR

Static characteristics of the specially designed induction motor are determined on the basis of a system of nonlinear equations describing an equivalent circuit of the motor. The loss in large-size slide bearing and agglutination loss caused by phases of polymerization process occurring in air-gap between stator and rotor are taken into account [4]. The following system of equations describes steady states of the specially designed induction motor. The resistances of equivalent circuit representing the mechanical loss in slide bearing and mechanical loss caused by agglutination of rotor and stator have been taken into account. The mechanical loss in slide bearing comes from rotor weight.

$$\underline{U}_1 - \underline{I}_1\left(R_1 + jX_1\right) - \underline{U}_{10} = 0$$

$$\underline{U}_{10} - \underline{I}_2^{'}\left(R_2^{'} + jX_2^{'}\right) - \underline{U}_{20}^{'} = 0$$

$$\underline{I}_1 - \underline{I}_{\mathrm{Fe}} - \underline{I}_{\mathrm{m}} - \underline{I}_2^{'} = 0$$

$$\underline{I}_2^{'} - \underline{I}_{2\mathrm{zl}}^{'} - \underline{I}_{2\mathrm{tw}}^{'} - \underline{I}_{2\mathrm{tm}}^{'} = 0$$

$$\underline{U}_{10} - \underline{I}_{\mathrm{Fe}} R_{\mathrm{Fe}} = 0\,, \quad \underline{U}_{10} - \underline{I}_{\mathrm{m}} \cdot jX_{\mathrm{m}} = 0$$

$$\underline{U}_{20}^{'} - \underline{I}_{2\mathrm{zl}}^{'} R_{\mathrm{zl}} = 0\,, \underline{U}_{20}^{'} - \underline{I}_{2\mathrm{tw}}^{'} R_{\mathrm{tw}} = 0\,, \quad \underline{U}_{20}^{'} - \underline{I}_{2\mathrm{tm}}^{'} R_{\mathrm{tm}} = 0$$

$$\frac{4\pi}{3p_b} \Delta M_{zl} \left[1 - \left(\Delta s_{zl} + \Delta s_{tw} + \Delta s_{tm}\right)\right] - R_2^{'} \cdot \left|\underline{I}_{2zl}^{'}\right|^{-2} = 0$$

$$\frac{4\pi}{3p_b} \Delta M_{tw} \left[1 - \left(\Delta s_{zl} + \Delta s_{tw} + \Delta s_{tm}\right)\right] - R_2^{'} \cdot \left|\underline{I}_{2tw}^{'}\right|^{-2} = 0$$

$$\frac{4\pi}{3p_b} \Delta M_{tm} \left[1 - \left(\Delta s_{zl} + \Delta s_{tw} + \Delta s_{tm}\right)\right] - R_2^{'} \cdot \left|\underline{I}_{2tm}^{'}\right|^{-2} = 0 \qquad (1)$$

where: U_1, I_1 are feeding voltage and phase current of stator, R_1, X_1 are resistance and leakage reactance of stator phase winding, $R_2^{'}$, $X_2^{'}$ are resistance and leakage reactance of rotor phase winding transformed to the stator winding, X_m is magnetization reactance (reactance of main flux), R_{Fe} is resistance representing the iron loss, R_{zl} is resistance representing the mechanical loss ΔW_{zl} coming from agglutination of rotor, R_{tw} is resistance representing the mechanical loss ΔW_{tw} coming from friction in large-size slide bearing caused by rotor weight, R_{tm} is resistance representing the mechanical loss ΔW_{tm} coming from friction in large-size slide bearing caused by polymerization mixer weight, ΔM_{zl} is increment of load torque coming from agglutination of rotor and stator, ΔM_{tw} is increment of load torque coming from friction in slide bearing caused by rotor weight, ΔW_{tm} is increment of load torque coming from friction in slide bearing caused by mixer weight, Δs_{zl} is increment of slip corresponding with increment ΔM_{zl}, Δs_{tw} is increment of slip corresponding with increment ΔM_{tw}, Δs_{tm} is increment of slip corresponding with increment ΔM_{tm}.

Ignoring the mechanical loss coming from agglutination of rotor and stator, i.e. $\underline{I}'_{2\mathrm{zl}} = 0$, $\Delta M_{\mathrm{zl}} = 0$, $\Delta s_{\mathrm{zl}} = 0$, the system of equations (1) is transformed to the form (2).

$$\underline{U}_1 - \underline{I}_1\left(R_1 + jX_1\right) - \underline{U}_{10} = 0$$

$$\underline{U}_{10} - \underline{I}_2^{'}\left(R_2^{'} + jX_2^{'}\right) - \underline{U}_{20}^{'} = 0$$

$$\underline{I}_1 - \underline{I}_{\mathrm{Fe}} - \underline{I}_{\mathrm{m}} - \underline{I}_2^{'} = 0$$

$$\underline{I}_2^{'} - \underline{I}_{2\mathrm{tw}}^{'} - \underline{I}_{2\mathrm{tm}}^{'} = 0$$

$$\underline{U}_{10} - \underline{I}_{\mathrm{Fe}} R_{\mathrm{Fe}} = 0\,,\ \underline{U}_{10} - \underline{I}_{\mathrm{m}} \cdot jX_{\mathrm{m}} = 0$$

$$\underline{U}_{20}^{'} - \underline{I}_{2\mathrm{tw}}^{'} R_{\mathrm{tw}} = 0\,,\ \underline{U}_{20}^{'} - \underline{I}_{2\mathrm{tm}}^{'} R_{\mathrm{tm}} = 0$$

$$\frac{4\pi}{3p_b} \Delta M_{tw}\left[1 - \left(\Delta s_{zl} + \Delta s_{tw} + \Delta s_{tm}\right)\right] - R_2^{'} \cdot \left|\underline{I}_{2tw}^{'}\right|^{-2} = 0$$

$$\frac{4\pi}{3p_b} \Delta M_{tm}\left[1 - \left(\Delta s_{zl} + \Delta s_{tw} + \Delta s_{tm}\right)\right] - R_2^{'} \cdot \left|\underline{I}_{2tm}^{'}\right|^{-2} = 0 \tag{2}$$

The increment of load torque (3) of asynchronous motor coming from friction in slide bearing caused by rotor weight is expressed on the basis of [1, 3]

$$\Delta M_{\mathrm{tw}} = M_{\mathrm{t}}^{*} \mu_{\mathrm{ks}} \frac{B\left(\omega_{\mathrm{rm}}\right)}{\left(1 - \frac{d}{D}\right)} G_{\mathrm{w}} \tag{3}$$

where: M_{t}^{*} is relative value of friction torque in slide bearing with respect to the flat slide bearing with the same size limits, external and internal, respectively, d is internal diameter of slide bearing, D is external diameter of slide bearing, μ_{ks} is initial sliding friction factor, $B\left(\omega_{\mathrm{rm}}\right)$ is polynomial determining the relative change of sliding friction factor as a function of linear velocity of sliding areas considering dependency derived experimentally for sintered carbide GT-30P-5/6/11/25, G_{w} is weight of asynchronous motor rotor.

Considering the constructional data of prototype of induction motor SAR-55/1500/09, the increment of load torque coming from sliding friction in bearing caused by rotor weight is given by (4) on the basis of [3] and dependency (3).

$$\Delta M_{\mathrm{tw}} = 0{,}0181 M_{\mathrm{t}}^{*} G_{\mathrm{w}} \tag{4}$$

The increment of load torque ΔM_{tm} coming from sliding friction caused by variable weight of mixers of different types in reactor chamber is given by dependency (5) analogous to (4).

$$\Delta M_{\mathrm{tm}} = M_{\mathrm{t}}^{*} \mu_{\mathrm{ks}} \frac{B\left(\omega_{\mathrm{rm}}\right)}{\left(1 - \frac{d}{D}\right)} G_{mi} \tag{5}$$

where: G_{mi} is weight of i-th mixer.

Considering the constructional data of prototype of induction motor SAR-55/1500/09, the increment of load torque coming from sliding friction in bearing caused by mixer weight is given by dependency (6) analogous to the dependency (5).

$$\Delta M_{\mathrm{tm}} = 0{,}0181 M_{\mathrm{t}}^{*} G_{\mathrm{mi}} \tag{6}$$

Considering the additional mechanical loss in slide bearing on the basis of [3] the efficiency of prototype of induction motor SAR-55/1500/09 is given as follows

$$\eta = \frac{4\pi f_1 \left(\Delta M_{tm} + \Delta M_{tw} + \Delta M_{zl}\right)}{3 p_b \cdot \left|\underline{U}_1\right| \left|\underline{I}_1\right| \cos\varphi} (1 - s) \tag{7}$$

where: p_b is number of pole pairs, f_1 is frequency of supply voltage.

The temperature is a meaningful parameter of the working cycle of polymerization chamber. The temperature limit of given cycle is not allowed to be exceeded. Therefore, the operating characteristics were determined for the following conditions: temperature of motor operation 15°C and 80°C, omission or consideration of resistance and leakage reactance of stator winding, weight of mixer G_{mi} = 1000 ÷ 8000 N.

Dependencies $I_1 = I(s)$, $P_1 = P(s)$, $I_1 = I(M_{uz})$, $P_1 = P(M_{uz})$, $n = n(M_{uz})$, $\eta = \eta(M_{uz})$, $\cos\varphi = f(M_{uz})$ are shown in Figure 4 to 10, respectively.

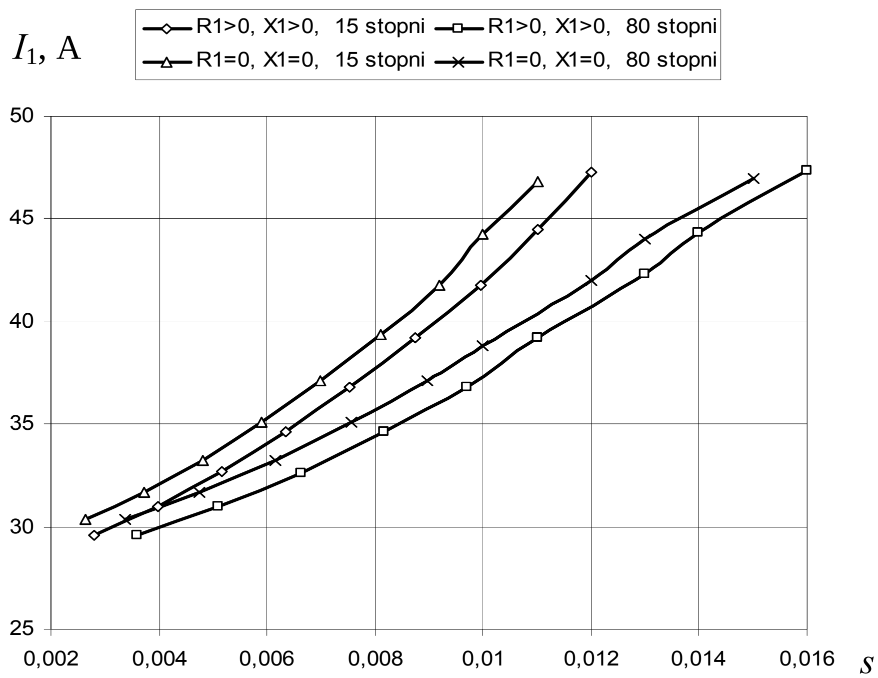

Fig. 4. Stator phase current versus slip of motor SAR-55/1500/09

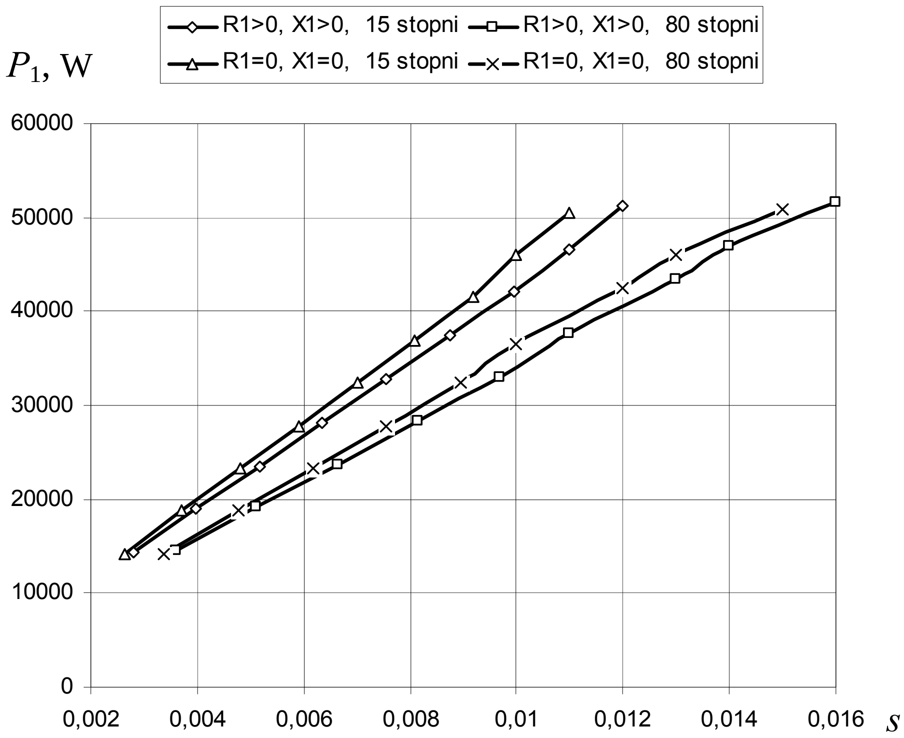

Fig. 5. Active power running from the grid versus slip of motor SAR-55/1500/09

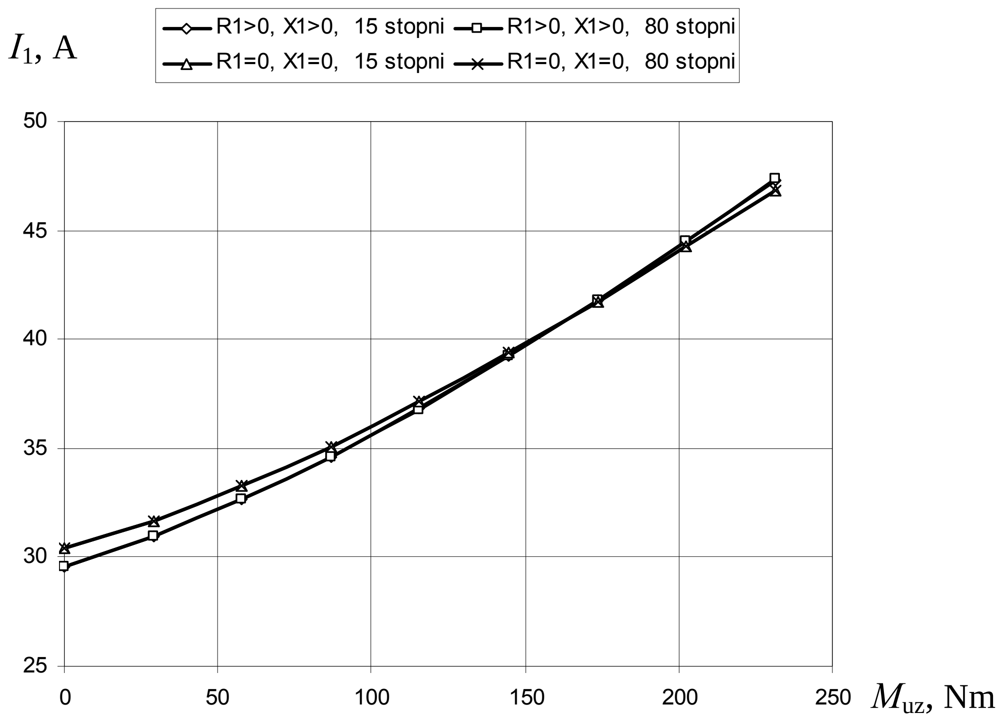

Fig. 6. Stator phase current versus output torque on the shaft of motor applied in the drive system for polymerization reactor

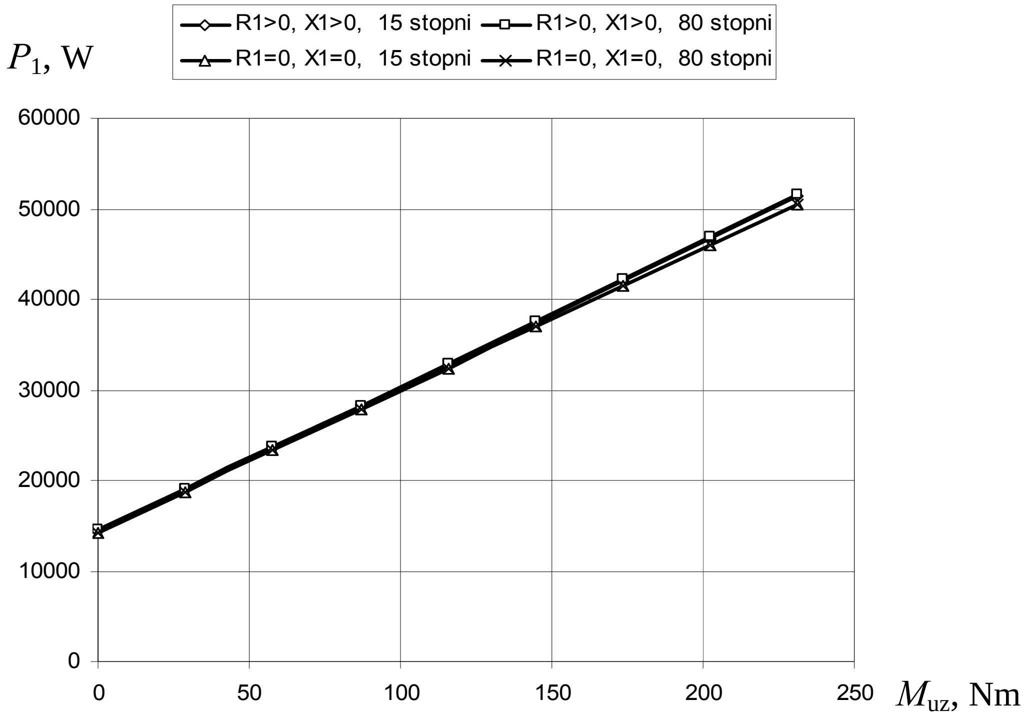

Fig. 7. Active power running from the grid versus output torque on the shaft of motor applied in the drive system for polymerization reactor

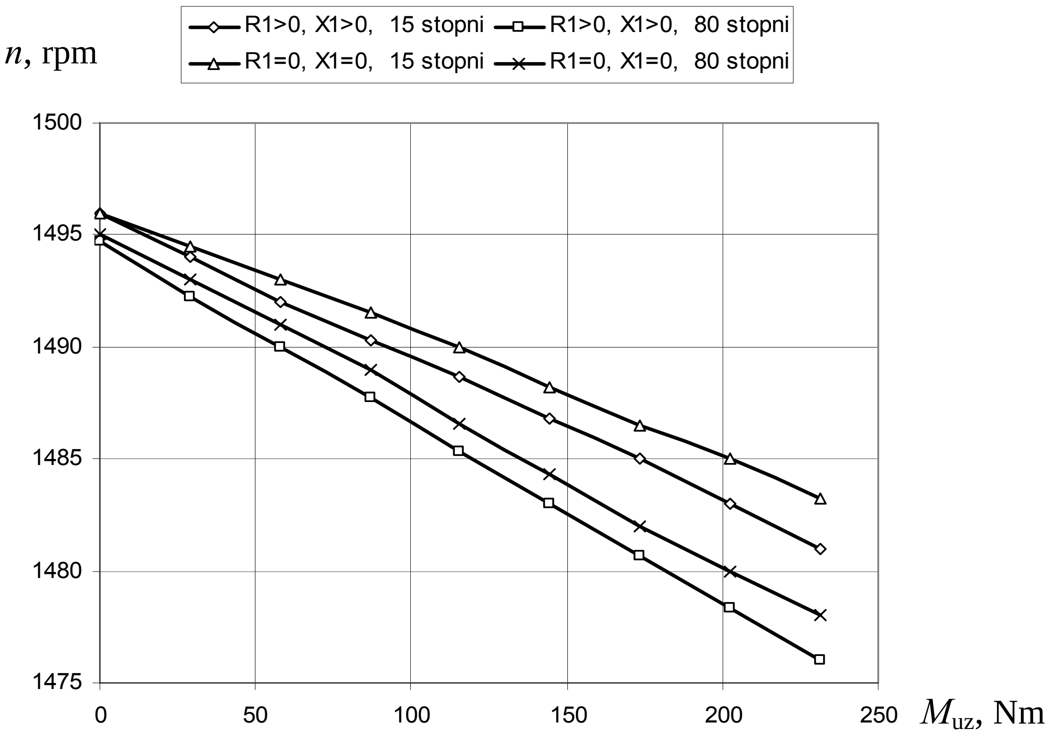

Fig. 8. Rotational speed of motor versus output torque on the shaft of motor applied in the drive system for polymerization reactor

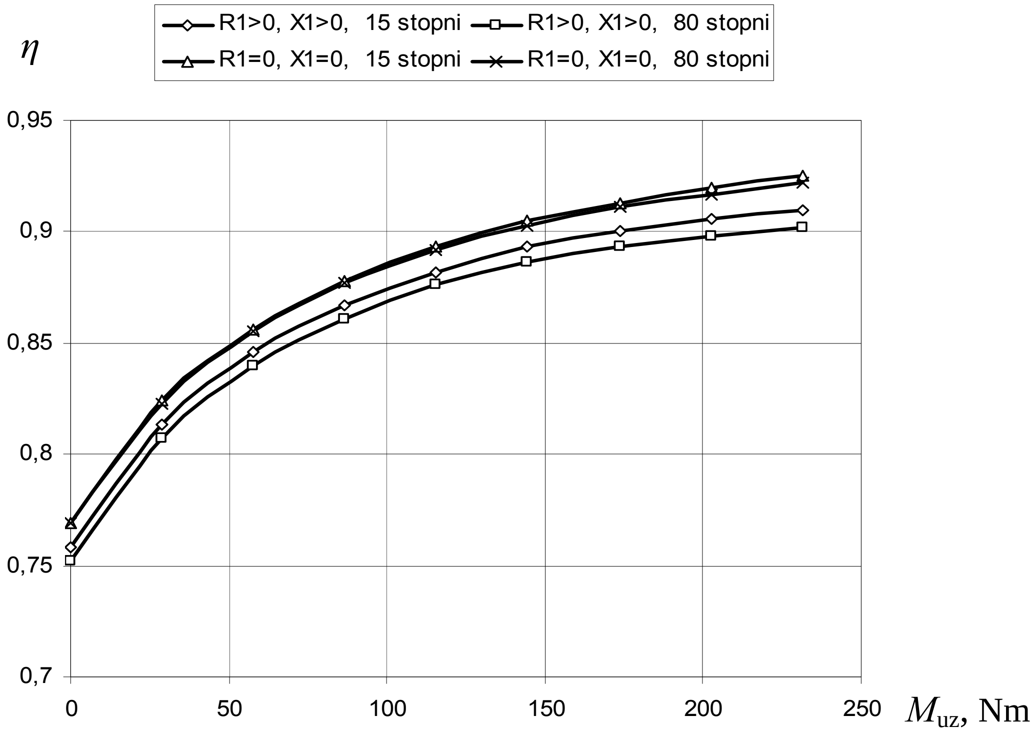

Fig. 9. Efficiency versus output torque on the shaft of motor applied in the drive system for polymerization reactor

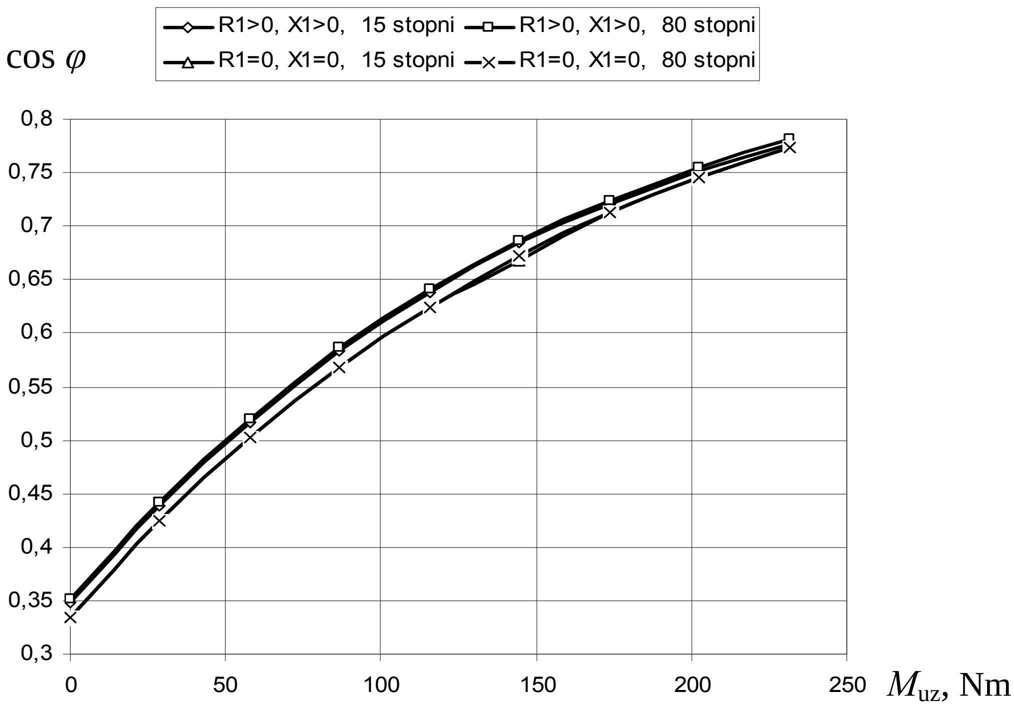

Fig. 10. Power factor versus output torque on the shaft of motor applied in the drive system for polymerization reactor

3. CONCLUSIONS

On the basis of the abovegiven analysis and dependencies between main parameters of asynchronous motor and output torque or slip the following conclusions may be formulated:

- system of equations (2) allow determining the operating characteristics of the specially designed asynchronous motor including a possibility of modelling with the consideration of an influence of friction in large-size slide bearing in the wide range and polymerization seizure of motor rotor as well;
- dependency (7) determining efficiency of motor versus slip may be particularized by introducing the additional mechanical loss coming from friction in slide bearing; it allows determining precisely the efficiency of motor at the initial stage of designing efforts;
- the operating characteristics of the prototype of the specially designed asynchronous motor applied in the drive system for polymerization reactor were presented in the paper; the characteristics allow determining a brief foredesign regarding the performance of the main drive system for polymerization reactor what was presented and applied i.a. as a result of the government grant no. 6 T10 2003C/06105.

LITERATURE

1. Government grant no. 6 T10 2003C/06105: Opracowanie i wykonanie silnika indukcyjnego specjalnego wykonania z przetwornicą częstotliwości o zmodyfikowanym układzie sterowania do uruchomienia produkcji głównych układów napędowych reaktorów polimeryzacji. Część I – Opis badań, Czestochowa University of Technology, Faculty of Electrical Engineering, 2005 (unpublished study).
2. Government grant no. 6 T10 2003C/06105: Opracowanie i wykonanie silnika indukcyjnego specjalnego wykonania z przetwornicą częstotliwości o zmodyfikowanym układzie sterowania do uruchomienia produkcji głównych układów napędowych reaktorów polimeryzacji. Część II – Wyniki badań i dokumentacja, Czestochowa University of Technology, Faculty of Electrical Engineering, 2005 (unpublished study).
3. Research work BZ-3-302/3/2003: Opracowanie modelu matematycznego i analiza obliczeniowa napędu głównego reaktora polimeryzacji, Czestochowa University of Technology, Faculty of Electrical Engineering, 2003 (unpublished study).

4. Rusek A.: Schemat zastępczy indukcyjnego silnika asynchronicznego specjalnego wykonania do pracy w układzie napędowym reaktora polimeryzacji z uwzględnieniem straty mocy w wielkogabarytowym łożysku ślizgowym z węglików spiekanych, XLVI International Symposium on Electrical Machines SME'2011, Szczecin, czerwiec 2011.

Manuscript submitted 29.11.2011

CHARAKTERYSTYKI STATYCZNE SILNIKA INDUKCYJNEGO SPECJALNEGO WYKONANIA DO PRACY W UKŁADZIE NAPĘDOWYM REAKTORA POLIMERYZACJI Z UWZGLĘDNIENIEM STRAT MOCY W WIELKOGABARYTOWYM ŁOŻYSKU ŚLIZGOWYM Z WĘGLIKÓW SPIEKANYCH

Andrzej RUSEK

STRESZCZENIE *W artykule przedstawiono opis konstrukcji indukcyjnego silnika asynchronicznego specjalnego wykonania z podaniem opisu pionowego zawieszenia silnika z wykorzystaniem wielkogabarytowego łożyska ślizgowego z węglików spiekanych. W oparciu o układ równań opisujących stany ustalone pracy silnika oraz dodatkowe równania określające przyrosty poślizgów wynikające z momentów obciążenia silnika wynikających z tarcia w łożysku ślizgowym wyznaczono eksploatacyjne charakterystyki statyczne silnika. Obliczenia wykonano dla łożyska ślizgowego dla przyjętej krzywizny kształtu panewki łożyska ślizgowego, określając zależności prądu stojana, mocy pobieranej z sieci, sprawności i współczynnika mocy od wartości momentu użytecznego oraz wartości prądu stojana i mocy pobieranej z sieci od poślizgu. Obliczenia wykonano dla różnych założeń w odniesieniu parametrów stojana oraz dla różnych temperatur pracy silnika, przyjmując zmienne wartości ciężaru mieszadła w układzie napędowym reaktora polimeryzacji.*