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COMPARISON OF MECHANICAL PROPERTIES OF ASYNCHRONOUS ELECTRIC MOTORS AT VARIOUS SCHEMES OF PARAMETRIC CONTROL

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ПОРІВНЯННЯ МЕХАНІЧНИХ ХАРАКТЕРИСТИК АСИНХРОННОГО ЕЛЕКТРОДВИГУНА ПРИ РІЗНИХ СХЕМАХ ПАРАМЕТРИЧНОГО УПРАВЛІННЯ

Purpose. To choose general control algorithm for asynchronous motor, to obtain mechanical specifications for different parametric control circuits and compare them.

Methodology. A generalized scheme of parametric control for asynchronous motor and its mathematical description was used for automatic selection of power converter circuits. Based on them, comparative analysis of mechanical characteristics of the motor was performed regarding changes of the parameters of the converter.

Findings. The simulation showed that the type of static mechanical properties of the asynchronous motor depends on the selected power converter circuit, the values of opening angles of the thyristors of stator and rotor switches, control mode and changes of their equivalent resistance value. Calculated mechanical characteristics of the asynchronous motor are supported by experimental results.

Originality. Methods for analytical calculations of mechanical characteristics of the asynchronous motor with various parametric control circuits were proposed.

Practical value. The proposed technique can be used for practical engineering calculations, while the mechanical properties obtained can be applied when designing asynchronous motors with parametric control.

Keywords: *asynchronous motor, generalized circuit, converter, switch, module, thyristors, resistors, characteristics*

Introduction. Construction of electric drives for different technological mechanisms includes calculation of mechanical characteristics of an asynchronous motor (AM). The task of precise calculation of the mechanical characteristics with parametric control over AM presents difficulties associated with the solution of nonlinear differential equations that determine the electric work in the stable and transient modes. With this type of asynchronous motor, the control is reduced to continuous changes of the AM connection scheme; as a result, its work modes represent a sequence of the transient processes, caused by swaps of the switch thyristors. Calculations are also complicated because they should be performed taking into account the asymmetry of the connection scheme of the AM stator and rotor windings, its multiphaseness, mutual influence between the phases and influence of the rotor rotation speed on the nature of electromagnetic phenomena. All this points to the urgency of the problem, which is a practical task and requires solutions via simple engineering methods.

Analysis of the recent research and publications. Most of the calculations of mechanical characteristics are presented via thyristor control over AM [1]. Analytical calculation methods performed for asynchronous-valve cascades or thyristor frequency converters can be partially used for calculation of the AM mechanical characteristics while it is controlled by switches with resistor-thyristor modules (RTM) [2–3]. The main differences are caused both by peculiarities of regulating the current value via controlled valves and by possible schemas of

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the resistors, thyristors, stator and rotor windings connection. Besides, it is known that there occur changes in the AM parameters, such as opening angle of the thyristors, voltage of the stator, EMP of the rotor, currents of the stator and rotor, electromagnetic torque, its slip, and other interrelated dependencies. It is not possible to identify expressions in the form of precise analytical formulas in general even for the most simple power circuits of parametric control. Considering the above difficulties in practice, the calculation of AM mechanical characteristics is performed by close methods featuring very high accuracy. At the same time, these issues require detailed study of starting and braking modes of the AM with different power schemes and the ways of RTM control, separately or simultaneously inserted into the stator and rotor of the AM. The coefficient of efficiency, cos φ, reliability, economy and other indexes of the AM largely depend on the solution of these issues [2–5].

Objective of the article. To obtain a systematic analysis or rational options of AM power circuits, the most convenient way is to use generalized control scheme over AM and its mathematical description, which allows creating a generalized control algorithm and effectively use it while performing research via PC. Moreover, qualitative and quantitative analyses of static mechanical properties are most convenient to carry out using mathematical modeling.

Presentation of the main research and explanation of scientific results. It is widely known that the resulting electromagnetic torque is equal to the algebraic sum of torques from different harmonics. For example, for a generalized scheme of parametric control of S_{13} type the AM torque is determined as follows

$$M = M_1 + M_5 + M_7 + M_{11} \ldots,$$

where indexes near M correspond to the harmonics number.

Calculations and experiments have shown that the impact of higher harmonics on AM electromagnetic torque with parametric control is minor, so for practical purposes, only electromagnetic torque of the first harmonic should be taken into account; this torque is determined by known methods and mathematical expression from the theory of automated asynchronous motor.

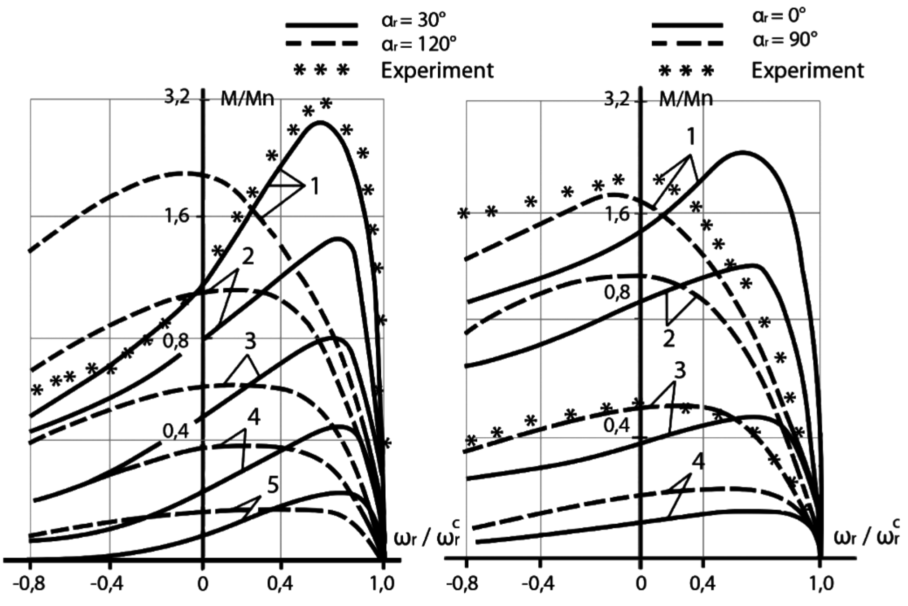
AM mechanical characteristics with parametric control in the stator and rotor circuits, as previously noted, can be calculated by PC using SXEP routines [5]. When performing calculations into SXEP, the following groups of initial data are entered which include:

- network voltage U_A, U_B, U_C for each A, B, C phase, which powers stator windings, frequency of power network f_m and phase shifting of the power phases φ_A, φ_B, φ_C;
- circuit parameters of the stator and rotor: r_A, r_B, r_C, r_a, r_b, r_{c1}, L_A, L_B, L_C, L_a, L_b, L_c, M_{12}, M_{21}, p, M_2, $I_{\partial B}$;
- current scale for the stator and rotor, electromagnetic torque, rotary rotations, consumed power, etc.;
- sign of mode – PR (rotary rotations ω_r = var or ω_r = = const);
- criteria of reaching a sustainable mode – KP and required precision of calculation E;
- nominal step of integration – H, minimal step – H_1, which is equal to 10^{-6} c, the number of points per one period (commonly it equals 20);
- nonzero initial conditions and features selected to calculate the power switch circuits that establish limits and intermediate values of the RTM resistances.

Verification of the sustainable integration mode is performed after a given number of periods of the power network (the so-called macro step). Prior to the next macro step, two previous steps are compared according to one of the selected criteria. If $KP = 1$ the average values of variables are compared, at $KP = 2$ instantaneous values are considered, at $KP = 3$ the average frequency of the rotor rotation. If the achieved value of the power satisfies E specified value, then a sign of the end of the calculation is established. When $PR = 0$, there is a nonconstant rotation frequency mode ω_r = var, calculation is performed and the instant values of variables are displayed. When $PR > 0$ ω_r = const mode is set, an average electromagnetic torque, rms currents, consumed power and losses in the stator and rotor circuit are calculated. Then a new value of velocity is set up and so on, until the entire set ω_r is not processed.

The simulation showed that the type of static mechanical properties of AM depends on the selected power circuit, values of opening angles α_S and α_r, SK and RK valves control method of switches and equivalent resistance values of the RTM. Changes of these factors can provide a different form of mechanical characteristic of the asynchronous motor. It is enough to compare the characteristics shown in Fig. 1, obtained on a PC from generalized scheme of the parametric control over AM and marking of the scheme of $S_{12}Z_0r_{32}$ type and all other circuits.

The AM mechanical characteristics are not only obtained by calculations on the PC, but are also proved experimentally. The graphs show calculated characteristics as solid and stroke-dotted lines, and experimental characteristics are marked with asterisks. To obtain the AM mechanical characteristics, electric motors of two MTF 411-8 and MTF 211-6 types were used that function in a move mode with parametric control. On the graphs, electromagnetic torque M is expressed in parts of nominal torque Mn of the electric motor, and the actual value ω_r in parts of the synchronous frequency ω_r^c of rotor rotation. In the stator circuit a switch of S_{12} type is used, but other types such as S_{13}, S_{22} can be applied. Type of the mechanical characteristics has no significant changes. A switch of Z_0r_{32} type is used for the AM rotor. The same mechanical characteristics are valid for other types of switches that comprised into the rotor circuit, for example, Z_KR_{32} type. The calculated characteristics (Fig. 1, *a*) for the asynchronous motor of MTF 411-8 type are identified in the process of changes of the thyristor's opening angles α_S of the stator switch with values of 60°, 70°, 80°, 90° and 110° and two values of the angle αr of the rotor switch that equals 30° and 120°. The same characteristics are calculated for the asynchronous motor of MTF 211-6 type with α_S of the stator switch with values of φ°, 60°, 80°, 110° and two values of the angle α_r of the rotor switch that equals 0° and 90° (Fig. 1, *b*). Ex-



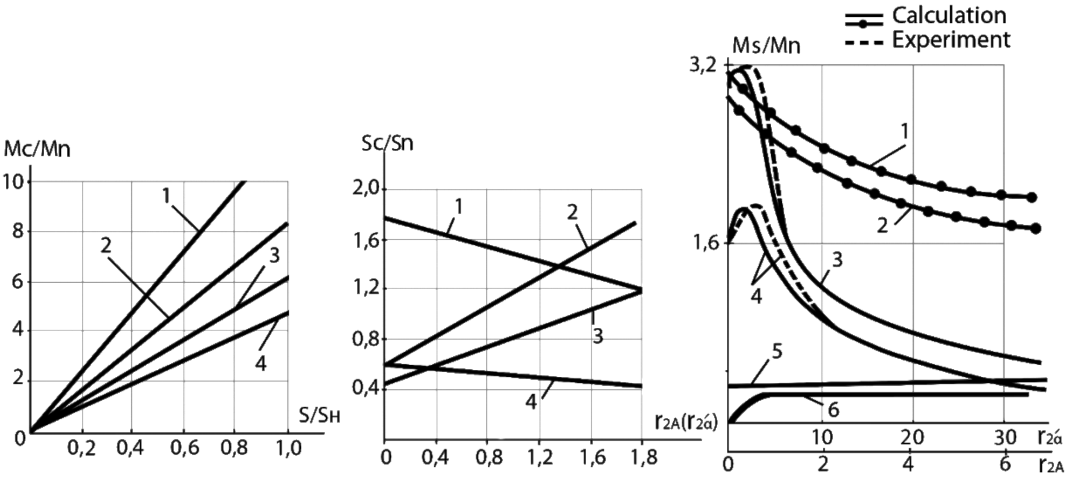
a *b*

Fig. 1. AM mechanical characteristics with phase control via the RTM thyristors, scheme of S12Z0r32 type:

a – MTF411-8;1–5 respectively $\alpha_S = 60°, 70°, 80°, 90°, 110°$; *b – MTF211-6; 1–4 respectively* $\alpha_S = \varphi°, 60°, 80°, 110°$; *M and Mn are electromagnetic and nominal torques of the asynchronous motor respectively;* α_r *and* α_S *are opening angles of thyristors of the switch of the rotor and stator respectively;* ω_r *and* ω_r^c *are actual values of the velocity and asynchronous rotation frequency of the rotor respectively*

perimental characteristics for the asynchronous motor of MTF 411-8 type are obtained with the thyristor's opening angles $\alpha_S = 60°$ and $\alpha_r = 30°$, and for the asynchronous motor of MTF 211-6 type with $\alpha_S = \varphi°$ and $\alpha_r = 90°$.

Fig. 1 shows that precise accuracy of calculated and experimental characteristics is achieved. Latest characteristics proved the admissibility of using the asynchronous motor with parametric control for practical engineering calculations and design. According to the results of research, with reduction of opening angle α_S of the stator switch (α_r = const) critical slip S_K decreases and the critical torque M_K of the AM increases. At the same time with angle α_r (α_s = const) increasing, the critical torque decreases and the critical slip of the AM increases. Adjustment of the thyristors opening angle causes changes of the equivalent resistance of the RTM – r_{2A}, r'_{2A}, that causes change of the critical torque *MC* and critical slip *SC*. As an example, in Fig. 2, *a, b* dependencies are shown respectively: $M_C = f(r_{2A}, r'_{2A}, S)$ and $S_C =$



a *b* *c*

Fig. 2. Dependencies of equivalent resistance of the RTM on:

a – critical torque;1–4 respectively $r_{2A} = r'_{2A} = 0$; $r_{2A} = r_A$, $r'_{2a} = 0$; $r_{2A} = 0$, $r'_{2a} = 2r'_a$; $r_{2A} = r_A$, $r'_{2a} = 2\,r'_a$; *b – slip; 1–4 respectively* $r'_{2a} = 2r'_a$; $r_{2A} = 0$; $r_{2A} = r_A$; $r'_{2a} = 0$; *c – inrush torque; 1–6 respectively* $r'_{2a} = r'_a$; $r'_{2a} = 0$; $r_{2A} = 0$; $r_{2A} = r_A$; $r'_{2a} = 30\,r'_a$; $r_{2A} = 20\,rA$; M_s, M_n *and* M_C *are values of the starting, nominal and critical torques of the AM respectively;* r_{2A} *and* r'_{2a} *are equivalent resistance values;* S_C *and* S_n *are critical and nominal slips of the AM respectively*

$= f(r_{2A}, r'_{2A})$. In these graphs values of the critical torque M_C and critical slip S_C are indicated, respectively, in parts of the nominal moment M_n and nominal slip S_N. As it follows from the charts, the highest value of the critical torque is achieved with $r_{2A} = r'_a = 0$, and the lowest – at $r_{2A} = r_A$, $r'_{2A} = 2\ r'_a$. Increase in the value of the equivalent resistance in the rotor circuit r'_a results in increasing slip, while increasing r'_{2a} reduces the value of the AM slip. To ensure smooth acceleration of the AM the RK's αr, angle should be adjusted, as a result, equivalent resistance of the RTM and the ratio between the active and inductive resistances will change. It is possible to achieve an increase in the starting torque M_n while reducing inrush currents simultaneously.

Inrush torque *Mi* of the AM depends on the value of the RTM equivalent resistance in the rotor circuit r'_{2a}, and in the stator circuit (Fig. 2, *c*). With huge increase in $r'_{2a} \geqslant 50\ r'_a$ the starting torque rapidly decreases. Decrease in the resistance $r_{2A} \leqslant 0$ noticeably increases the starting torque. That is why the values of the resistors which is comprised into the RTM must be selected to provide necessary starting torque of the AM with minimal losses in the stator and rotor circuits.

RTM presence in the rotor circuit allows the AM with the pulse adjustment of valves in schemes of $Z_L R_{32}$ and $Z_L R_{33}$, type to expand the range of regulation of the rotary rotation and to get artificial characteristics, which are quite close to the natural mechanical characteristics. To confirm this, it is necessary to point out the characteristics that are shown in Fig. 3 with the thyristor's opening angles α_S and α_r being equal to zero and porosity $\gamma = I$. Increase in the porosity γ provides tougher mechanical characteristics. At the same time the critical torque is growing and the critical slip is decreasing.

The decreasing starting torque of the AM suggests the possibility of providing modes with adjustable current in the rotor circuits and required electrical losses in the AM by changing porosity γ.

Conclusions. Analysis of the AM mechanical characteristics allows making a conclusion about appropriate variation range of α_S and α_r angles in the process of regulation; that allows forming the required mechanical characteristics. Theoretically, for the stator and rotor switch schemes, the change of angles α_S and α_r is in range $j \leq \alpha_S \leq 180°$ and $0° \leq \alpha_r \leq 180°$, respectively. However, with large thyristor opening angles ($\alpha_S \geq 115°$) the electromagnetic torque of the AM on the regulated characteristics cannot be greater than 3–5 % from their values on the real characteristic. Further increase in the angle α_S makes no sense in practice, because the lowest value of the torque of the AM idle for most drives makes up to 10 % of the nominal torque. Thus, the required range of angles α_S changes as follows: $j \leq \alpha_S \leq 115°$. At the same time, the range of variation of the angle α_r should be maximized and is: $0° \leq \alpha_r \leq 180°$.

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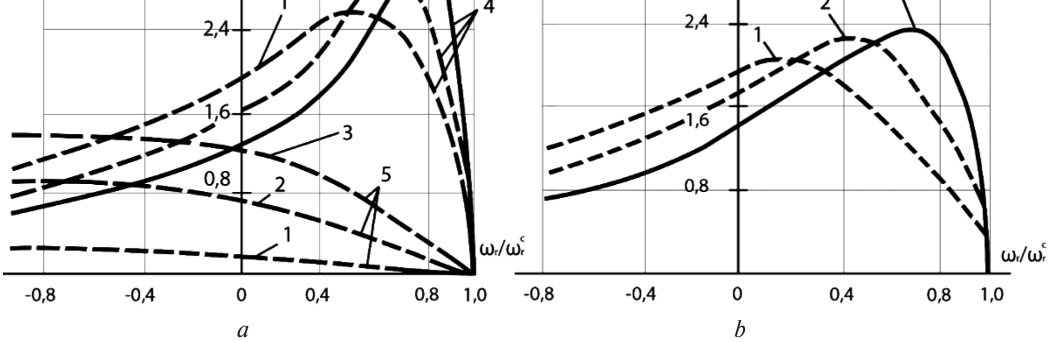

a *b*

Fig. 3. Mechanical characteristics of the AM scheme type:

a – $Z_L\ r_{32}$; 1–5 respectively $\gamma = 0$; $\gamma = 0{,}5$; $\gamma = 1$; $\alpha_r = 0°$; $\alpha_r = 120°$; b – $Z_L\ r_{33}$; 1–3 respectively $\gamma = 0$; $\gamma = 0{,}5$; $\gamma = 1$; M is the value of the electromagnetic torque; α_r, α_S, ω_r, ω_r^c and M_n see Fig. 1; γ is porosity

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Мета. Обрати загальний алгоритм управління асинхронним електродвигуном, отримати механічні характеристики для різних схем параметричного управління та виконати їх порівняння.

Методика. Використана узагальнена схема параметричного управління асинхронним електродвигуном та її математичний опис для автоматизованого вибору силових схем перетворювачів. На їх основі виконано порівняний аналіз механічних характеристик електродвигуна при зміні параметрів перетворювача.

Результати. У результаті моделювання встановлено, що вид статичних механічних характеристик асинхронного електродвигуна залежить від обраної силової схеми перетворювача, величин кутів відкривання тиристорів статорного й роторного комутаторів, способу управління ними та зміни в них еквівалентної величини опорів. Розрахункові механічні характеристики асинхронного електродвигуна підтверджені результатами експериментальних досліджень.

Наукова новизна. Запропонована методика для аналітичних розрахунків механічних характеристик електродвигуна при різних параметричних схемах управління.

Практична значимість. Запропонована методика може бути використана для практичних інженерних розрахунків, а отримані механічні характеристики – при проектуванні електроприводів з параметричним управлінням.

Ключові слова: *асинхронний електродвигун, узагальнена схема, перетворювач, комутатор, модуль, тиристори, резистори, характеристики*

Цель. Выбрать общий алгоритм управления асинхронным электродвигателем, получить механические характеристики для различных схем параметрического управления и выполнить их сравнение.

Методика. Использована обобщенная схема параметрического управления асинхронным электродвигателем и ее математическое описание для автоматизированного выбора силовых схем преобразователей. На их основе выполнен сравнительный анализ механических характеристик электродвигателя при изменении параметров преобразователя.

Результаты. При моделировании установлено, что вид статических механических характеристик асинхронного электродвигателя зависит от выбранной силовой схемы преобразователя, величин углов открывания тиристоров статорного и роторного коммутаторов, способа управления ими и изменения в них эквивалентной величины сопротивлений. Расчетные механические характеристики асинхронного электродвигателя подтверждены результатами экспериментальных исследований.

Научная новизна. Предложена методика для аналитических расчетов механических характеристик электродвигателей при разных параметрических схемах управления.

Практическая значимость. Предложенная методика может быть использована для практических инженерных расчетов, а полученные механические характеристики – при проектировании электроприводов с параметрическим управлением.

Ключевые слова: *асинхронный электродвигатель, обобщенная схема, преобразователь, коммутатор, модуль, тиристоры, резисторы, характеристики*

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