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Research Article

Mathematical Modeling of Mechanical Characteristics of Transient Processes of Asynchronous Electrical Drives of Weaving Machines in Textile Enterprises

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Abstract

Asynchronous electric motors are widely used in industrial electric drives, including textile enterprises, where their operating efficiency and dynamic characteristics directly affect the energy consumption and productivity of technological equipment. Therefore, accurate mathematical modeling of asynchronous motors is important for analyzing transient operating conditions, determining their electromagnetic and mechanical characteristics, and improving the efficiency of industrial electric drive systems. The purpose of this study is to develop a mathematical model of the 4A100L6U3 squirrel-cage asynchronous electric motor and investigate its dynamic and mechanical characteristics during the starting process. A three-phase asynchronous motor with a rated power of 2.2 kW, supply voltage of 220/380 V, and nominal rotational speed of 950 rpm was selected as the research object. A mathematical model of the motor was developed to describe its electromagnetic and mechanical behavior. Based on the developed model, transient processes occurring during motor starting were simulated and analyzed. The changes in the main electromagnetic and mechanical parameters were investigated, and the mechanical characteristic of the asynchronous electric drive was constructed. Particular attention was given to the starting torque, critical torque, nominal torque, and slip characteristics. The simulation results demonstrate the dynamic behavior of the 4A100L6U3 asynchronous motor during the starting process and provide a basis for evaluating its operating characteristics under industrial conditions. The obtained mechanical characteristic and analyzed torque and slip parameters allow the main operating regimes of the electric drive to be assessed and optimized. The results of the study can be used to improve the energy efficiency and reliability of electric drives in textile enterprises, optimize the operating modes of technological equipment, and improve the control and regulation systems of asynchronous electric motors

Keywords

Asynchronous Electric Motor, Squirrel-Cage Rotor, Electric Drive, Mathematical Modeling, Electromagnetic Torque, Starting Torque, Slip, Transient Process

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1. Introduction

After the Republic of Uzbekistan gained independence, a number of changes took place in the textile industry in our country. In particular, a number of textile and light industry factories were built and put into operation in many regions. Weaving machines in our republic are increasingly being improved. The textile industry itself consists of complex and diverse sectors. One of its largest sectors is yarn and fabric production. Along with cotton fiber, the production of chemical fibers is also developing rapidly in the Republic of Uzbekistan. This allows the textile industry of our independent Republic to further expand the raw material base and increase the range of products produced. As we know, all the mechanisms and details of the weaving machine are driven by electric motors. Spinning machines and weaving machines are mainly used in textile enterprises. In particular, cleaning cotton and producing yarn from cotton using spinning machines are stages of the technological process. At each stage of the technological process, specific technological machines are used, and their main energy consumers are asynchronous motors. 70–75% of the electricity consumed in textile enterprises is consumed by the electric drives of these machines [1-7]. Therefore, the main goal of the study was set to study the possibilities of saving electricity in electric motors. Measures to increase energy efficiency in these enterprises can be divided into 3 groups:

1) improving energy saving measures;
2) increasing the efficiency of energy resources;
3) improving the energy supply system.

2. Methodology

These activities are mainly organized through energy studies at textile enterprises. The main goal of these studies is to identify elements of the power supply system that have energy saving potential and organize rational use of energy [1-5]. If we take spinning machines at textile enterprises, the main consumer of electricity that drives these machines is electric drives (motors), which consume about three quarters of the generated electricity. The main part of these electric motors is asynchronous motors with a short-circuited rotor. Due to the simplicity of their structure, low cost, and reliability in operation, they are widely used in all sectors of the textile industry and the national economy [5, 7].

The number of repaired asynchronous motors at all textile enterprises is increasing. Due to the lack of full compliance with the repair technology, it can be observed that the motor operating mode parameters do not correspond to the passport parameters. The decrease in the energy performance of the motor significantly affects the amount of waste in the enterprise [1, 6]. It can be observed that the main shortcomings after repair are associated with incorrect calculation or incorrect winding of the motor winding [16-18]. The work on identifying and eliminating defects in asynchronous motors operated in textile enterprises, calculations for rewinding asynchronous motors in devices, and the operation and control of asynchronous electric drives is focused on the issues of operation and control of asynchronous electric drives. The level of sophistication of technological equipment is often determined by the degree to which electric drives meet technological requirements [8, 10]. This is due to the compactness, environmental safety, reliability, ease of automation, speed and other advantages of electric drives in textile enterprises. The improvement of the technological process is directly related to the improvement of electric drives. Therefore, electric drives are developing rapidly for objective reasons. The main consumer of electricity in textile enterprises is asynchronous motors [5, 7]. Therefore, planned measures to save electricity in asynchronous motors at the scale of textile enterprises can have a significant economic effect [1, 3]. Consistent work is being carried out in our country to modernize the textile industry and widely introduce modern weaving machines into production. The textile industry is one of the important and diversified sectors of the economy, and one of its main directions is the production of various fabrics from cotton fiber. At the same time, along with cotton fiber, the production of chemical fibers is also rapidly developing in Uzbekistan [8-15]. This allows expanding the raw material base for the textile industry of the republic, increasing the range of manufactured products and improving their quality. Weaving machines are divided into continuous and periodic types according to the principle of operation. Textile enterprises mainly use periodic weaving machines. Depending on the method of warp yarn transmission, they are divided into shuttle, rapier, pneumatic, hydraulic and other types of looms. Depending on the width of the fabric, the looms are divided into narrow-width and wide-width types. The structure and technological capabilities of the loom depend on the mechanisms used in it for yarn transmission and warp yarn control, which operate on the basis of eccentric, dobby and jacquard mechanisms [19]. The eccentric mechanism has the simplest design and is widely used in the production of fabrics with a simple weave structure. Achieving high productivity, reducing energy consumption and improving product quality in modern looms largely depends on the operating mode of the asynchronous electric drive. Therefore, mathematical modeling of transient processes and mechanical characteristics of the electric drive is of great scientific and practical importance in ensuring the efficient operation of looms. Looms with a jacquard mechanism are widely used in the production of fabrics with a complex weave structure. Jacquard looms provide high efficiency in weaving fabrics with large flowers and complex patterns. Looms are divided into mechanical and automatic types according to the method of thread feeding. In mechanical looms, when the thread on the shuttle runs out, the loom stops and the shuttle is replaced. In automatic looms, this process is carried out automatically without stopping the loom, which significantly increases production efficiency. In the textile industry, automatic looms such as AT-120, AT-175 and shuttleless looms of the STB type (STB-1-180, STB-1-220, STB-1-250, STB-1-330, STB-2-220 and STB-4-330) are widely used. These machines are characterized by high productivity, reliability and energy efficiency. The weaving machine consists of many mechanisms and gears that provide movement of the working bodies. All the main mechanisms are driven by an electric motor. The rotational motion of the electric motor is transmitted to the working bodies through various gears. Such gears are divided into belt, chain, gear, worm, friction, hydraulic, pneumatic and electric gears. Each type of gear is characterized by the number of gears, useful working coefficient and operating characteristics. The most commonly used electric drives in weaving machines are asynchronous electric motors. In particular, in the textile enterprise of the Bukhara region, three-phase asynchronous electric motors with a squirrel-cage rotor of the types 4A100L6U3, 4A100S4U3, 4A112MA6U3, 4AIRM06U3 and 4AIRM11V6U3 are used in STB weaving machines. The power of these motors is 2.2–4 kW, and the supply voltage is 220/380 V. One of the main characteristics of an asynchronous electric motor is the electromagnetic torque. The electromagnetic torque arises as a result of the interaction of the rotating magnetic field formed in the stator windings and the currents induced in the rotor winding. This torque is the main parameter determining the start-up, acceleration and stable operation of the motor under load. Therefore, mathematical modeling of the transient processes and mechanical characteristics of an asynchronous electric motor is of great importance in increasing the efficiency of weaving machines and reducing energy consumption. ($I_2 \cos\psi_2$) In an asynchronous electric motor, the electromagnetic torque is created as a result of the interaction of the rotating magnetic field created by the stator winding and the currents induced in the rotor winding. Фmax In an asynchronous electric motor, the electromagnetic force is created as a result of the interaction of a current-carrying conductor with a magnetic field according to Ampere's law. This electromagnetic force creates the rotational torque of the rotor and ensures the conversion of electrical energy into mechanical energy. Fem = Bs li is formed.

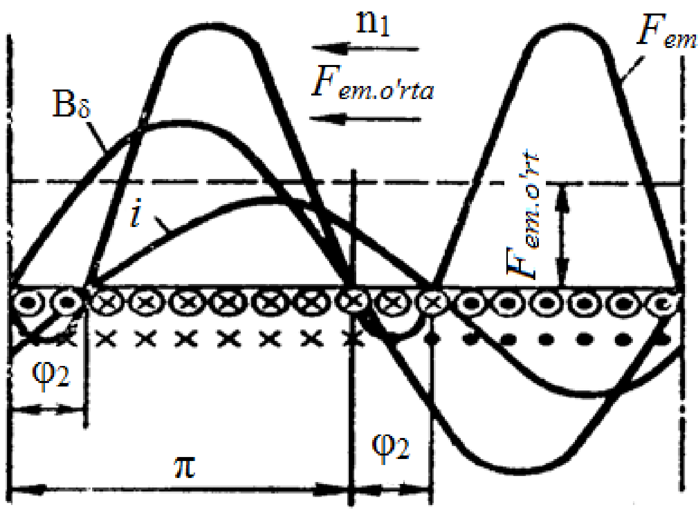

Figure 1. *Distribution of magnetic induction (Bδ) in the air gap of an asynchronous electric machine, rotor teeth (i) and electromagnetic force (Fэм) distribution characteristics.*

The electromagnetic torque resulting from this electromagnetic force is determined by the following expression:

$$M = C_{\mathrm{M}} \cdot F_{\max} \cdot I_2 \cdot \cos\psi_2 \tag{1}$$

where:

$C_M = p*m_2*k_{ch2}/\sqrt{2}$– constant value:

$F_{\max}$– maximum value of the magnetic flux.

Formula (1) can be used not only for asynchronous machines, but also for all types of electric machines. This formula expresses the relationship between the physical processes occurring in the motor and the torque. Using this expression, it is possible to qualitatively analyze the state of the motor in various operating modes. However, since the quantities Фmax, I_2 and $\cos\psi_2$ in this formula are not directly related to the power source and the operating mode of the electric machine, their practical determination is difficult. Therefore, a simplified expression of the electromagnetic (torque) torque is considered below, which allows taking into account the influence of the design parameters of the machine and operating conditions. The electromagnetic force method is used to determine the electromagnetic torque. Based on the relationship between the electromagnetic power (Pэм) and the mechanical power (Pмех) from the energy diagram, the electromagnetic torque is determined as follows:

$$P_{em} = \mathrm{M} \cdot \omega_1;\ P_{\mathrm{mex}} = \mathrm{M} \cdot \omega \quad (2)$$

where:

$$\omega_1 = (2 \cdot \pi \cdot n_1/60) \cdot (\mathrm{p/p}) = (2 \cdot \pi/\mathrm{p}) \cdot (\mathrm{p} \cdot n_1/60) = 2 \cdot \pi \cdot f/\mathrm{p}$$

And $\omega = 2 \cdot \pi \cdot n/60$ Taking into account the angle of displacement of the rotating magnetic field and the angle of rotation of the rotor, the electromagnetic torque according to expression (2) is determined as follows:

$$M = P_{em}/\omega_1 \quad (3)$$

Therefore, the electromagnetic torque of an asynchronous motor is directly proportional to the generated electromagnetic force. To determine the angle of rotation (displacement) based on the energy diagram, the following expression is used:

$$\mathrm{P'}_{e2} = P_{em} - P_{mex} \quad (4)$$

$$\text{or } \mathrm{P}'_{e2} = M \cdot \omega_1 - M \cdot \omega = M \cdot (\omega_1 - \omega) \quad (5)$$

1- The right side of equation (5) (ω_1/ω_1)We multiply the right side of the formula by the following ratio:

$$\mathrm{P}'_{e2} = M \cdot \omega_1 \cdot S \quad (6)$$

the following formula:

$$M = \mathrm{P}'_{e2}/(\omega_1 \cdot S) = m_1 \cdot (\mathrm{I'}_2)^2 \cdot \mathrm{r'}_2/(\omega_1 \cdot S) \quad (7)$$

Therefore, the electromagnetic torque of an asynchronous motor is directly proportional to the electric power in the rotor winding. If G is defined as a quantity related to the rotor, then the value of $\mathrm{I'}_2$(7), $\omega_1 = (2 \cdot \pi \cdot f_1)/\mathrm{p}$ we accept the general form of the expression for determining the electromagnetic torque of an asynchronous electric machine as follows

$$M = (m_1 \cdot p \cdot U_1^2 \cdot r'_2)/\{2 \cdot \pi \cdot f_1 \cdot S) \cdot [(r_1 + r'_2/S)^2 + (x_2 + x'_2)^2]\} \quad (8)$$

In formula (8), when determining the torque M in the replacement scheme for asynchronous motors with a power of P>10 kW, it is assumed that $c_1 \approx 1$ It is necessary to increase the accuracy in calculating the electromagnetic torque, therefore, the complex number c_1 in formula (8) is expressed as follows

$$M = (m_1 \cdot p \cdot U_1^2 \cdot r'_2)/\{2 \cdot \pi \cdot f_1 \cdot S) \cdot [(r_1 + c_1 \cdot r'_2/S)^2 + (x_1 + c_1 \cdot x'_2)^2]\} \quad (9)$$

Where $c_1 \approx 1{,}02 \div 1{,}05$, in expressions $P \leq 10\text{kW}$ (8) and (9), all quantities except the slip S are considered constant and change depending on the change in the load torque. One of the main characteristics of a three-phase squirrel-cage asynchronous motors is its mechanical characteristic. Based on certain limits of this characteristic, it is possible to determine the operating mode of an asynchronous motor. The steady-state form of the mechanical characteristic is usually determined using the Kloss formula:

$$M = 2 \cdot M_{\text{кр}}/(S/S_{\text{кр}} + S_{\text{кр}}/S) \quad (10)$$

where

M - Electromagnetic torque of the induction motor;

$M_{\text{кр}}$ - Critical torque of the induction motor;

S - slip;

$S_{\text{кр}}$ - slip value corresponding to the maximum (critical) electromagnetic torque of the induction motor.

The mechanical characteristics of induction motors can also be calculated using values from catalogs or reference books. In this case, the torque value is calculated for 4 points and the mechanical characteristic of the induction motor is constructed (Figure 2).

$$n = n_0 = 60 \cdot f/p,\ \mathrm{M{=}0}$$

where f is the actual frequency;

p is the number of poles.

2 Dashed line - nominal operating mode of the induction motor

$$n = n_0,\ M = M_{\text{н}} = 9550 \cdot P_{\text{н}}/n_{\text{н}},$$

where Pн is the nominal power of the induction motor, kW;

3 - critical point mode, in this case $n = n_{\text{кр}},\ M = M_{\text{кр}} = \lambda \cdot M_{\text{н}}$;

4 - starting mode, $n = 0,\ M = M_{\text{п.т}} = \beta \cdot M_{\text{н}}$.

Figure 2 shows the mechanical characteristics of a 4A100L6У3 squirrel-cage induction motor used in weaving looms. The rated power of the motor is 2.2 kW, the voltage is 220/380 V, and the rotation speed is 950 rpm.

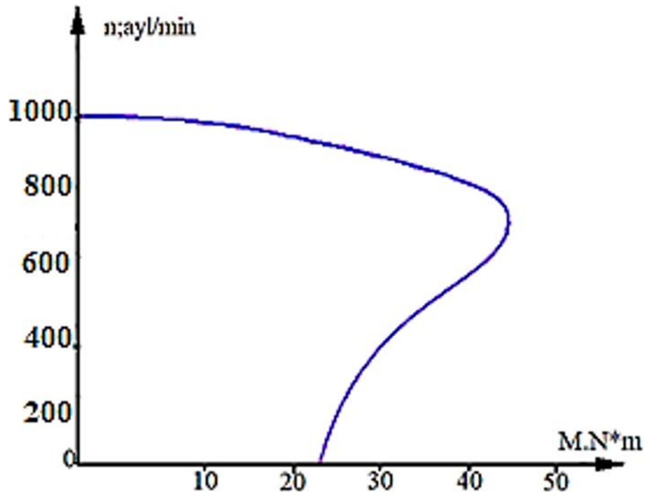

Figure 2. Mechanical characteristics of a 4A100L6U3 squirrel-cage induction motor.

"As can be seen from Figure 2, the nominal torque of the induction motor is $M_н$=22 Н · м ,, the starting torque is $M_{и.т}$=44 Н · *м*, and the critical torque of the induction motor is $M_{кр}$=44 Н · м, $M_{кр}$=48,4 Nm.

3. Conclusion and Recommendations

In this research work, the issues of mathematical modeling of the mechanical characteristics of transient processes occurring in asynchronous electric drives of weaving machines used in textile enterprises were considered. A 4A100L6U3 squirrel-cage induction motor used in weaving machines of a textile enterprise was selected. Based on the mathematical model of the asynchronous electric drive, a system of equations was formed that allows determining the electromagnetic torque, rotational speed, slip coefficient and mechanical characteristics of the motor. Using the developed model, transient processes of the motor during start-up, load change and steady-state operation were analyzed. As a result of the research, the main mechanical indicators of the asynchronous motor were - The values of starting torque, nominal torque, critical torque and critical slip were determined and a mechanical description was built. The results obtained allow assessing the dynamic state of an asynchronous electric drive, optimizing its operating modes and increasing the reliability of technological processes. The use of the mathematical modeling method is an effective tool for increasing the energy efficiency of electric drives used in textile enterprises, reducing electricity consumption and improving control systems. The developed model can be used in the future to study asynchronous motors of various powers and modern frequency-controlled electric drives. In general, mathematical modeling of the mechanical characteristics of transient processes in asynchronous electric drives of weaving machines of textile enterprises allows for a deep study of their dynamic characteristics, selection of optimal operating modes and increase production efficiency.

Abbreviations

$P_н$ Nominal Power of the Induction Motor
M Electromagnetic Torque of the Induction Motor
$M_{кр}$ Critical Torque of the Induction Motor

Author Contributions

Pirmatov Nurali: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Validation, Writing – original draft, Writing – review & editing

Panoev Abdullo: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Methodology, Resources, Software, Validation, Writing – original draft, Writing – review & editing

Karimova Noila: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Methodology, Resources, Software, Validation, Writing – original draft, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

Pirmatov Nurali is a professor in the Department of Electrical Machines and Drives Engineering at Tashkent State Technical University named after Islam Karimov (TSTU), Tashkent, Uzbekistan. He received his engineering, PhD, and DSc degrees in electrical machines and electrical engineering from Tashkent Polytechnic Institute, Tashkent, Tomsk Polytechnic Institute, Russia, and Tashkent State Technical University named after Islam Karimov, Tashkent in 1983, 1991, and 2006, respectively. Since 2010, he has been a professor at TSTU, Tashkent, Uzbekistan. Currently, he is the head of the research group studying AC electric machines. His research interests include transient processes in synchronous generators with longitudinal-transverse excitation, design of synchronous machines with longitudinal-transverse excitation, energy saving in electric drives and AC electric machines, electric drives, and renewable energy.

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Karimova Noila Since 2026, she has been studying for a doctorate at Bukhara State Technical University in the specialty "Electrical Engineering. Power Plants, Systems. Electrotechnical Complexes and Devices". She is currently conducting scientific research on the topic of mathematical modeling of transient processes of asynchronous electric drives used in textile enterprises.

Research Field

Pirmatov Nurali: Mathematical Modeling of Heat & Mass Transfer, Raw Cotton Primary Processing & Drying Dynamics, Numerical Methods (Galerkin Method, Differential Equations), and Textile Machinery Optimization.

Panoev Abdullo: Raw Cotton Primary Processing, Heat and Mass Transfer Dynamics, Mathematical Modeling of Thermal Processes, and Textile Industry Equipment Optimization.

Karimova Noila: Agricultural Machinery & Equipment, Raw Cotton Primary Processing, Heat-Mass Transfer Dynamics, and Mathematical Modeling of Drying Processes.