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Achievement of electric energy savings through controlling frequency convertor in the operation process of asynchronous motors in textile enterprises

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Achievement of electric energy savings through controlling frequency convertor in the operation process of asynchronous motors in textile enterprises

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Abstract. In article are brought frequency regulation of the asynchronous electric motor and that reach to energy saving itself. Frequency management is energy saving so regulation of the frequency of the rotation of the asynchronous engine are provided increasing coefficient of efficiency and reduction of the loss to powers. A machine asynchronous is often used today as a power scale ranging with a motor from some Watts to several thousand kW. For power applications exceeding several kW, asynchronous motors run solely on three-phase AC power supplies. Owing to the sensitivity of a process or the critical nature of certain applications, the network may be supported with an Uninterruptible Power Supply.

1. Introduction

Currently, textile enterprises in Uzbekistan are rapidly growing. The textile industry itself is complex and diverse manufacture. One of its largest sector is yarn production. Along with cotton fiber, the production of chemical fibers are developing in Uzbekistan. This will further expand the raw material base of the textile industry of the Republic and increase the range of products. Currently, the electric motors used in the textile enterprise "RUSHAN TEKS" LLC, one of the textile enterprises in Bukhara region, can be operated in several ways. For example, during the operation of electric motor of looms and spinning machines in textile enterprises, current jumping is generated, which is called the starting current or the current in the braked rotor. The starting current magnitude usually is 5-7 times higher than the rated current magnitude has a short-term effect, after acceleration the current magnitude in the electric motor drops to a minimum value. In accordance with existing rules and regulations, various methods of starting are used to reduce the starting current. Alternatively, a number of measures must be taken to stabilize the supply voltage. Some loom capacity control methods of weaving machine are known today.

It is known a loom capacity control method and system. The method involves measuring actual tension value of core threads; measuring actual values of beam roll rotational speed and beam roll engine current; determining required value of beam roll rotational speed by unbalance between actual and predetermined tension values; determining required value of beam roll engine current by unbalance between actual and predetermined beam roll rotational speed values and regulating beam roll rotational speed by unbalance between measured and predetermined beam roll engine current values [1].

However, in this method, in the process of launching of looms, as well as in the process of operation, the disconnection of a large number of threads, as well as the interrupting of electricity, leads to the production of poor quality products and the waste of a lot of time.

We also know the device for regulating shrinkage of the warp at loom [2]. Device has worn warp length pickup 1, ready tissue length transducer 2 and main shaft rotation frequency pickup 3. All units mentioned are connected to unit 4 for calculating rate of motion of the warp and ready tissue. Device also has shrinkage set-point device 5, unit 6 for calculating shrinkage of the warp, digital-to-analog converter 7, unit 8 for controlling rotational frequency of warp beam, actuating engine 9, reducer 10, warp beams tension gauge 11, analog-to-digital converter 15, tension set-point device 13, loom 14. Anchor 16 of the tension gauge is connected kinematically with movable unit 17 of the loom. Warp threads being wound onto warp beams 18, bend about motionless unit 17. Warp beams are collected into droppers 20 and holders 21. Breast beam 22, doffer 15, roller 23 and bar 24 serve as guides for moving tissue [2].

The above mentioned device also has some disadvantages. In the weaving process of the weaving machine there is a lot of thread break during the operation of the weaving machine, as well as during the operation of the start, that is, in the launching process three to four times more electricity is consumed by motor from its current position. The motor is starting with loading, the product that is being produced, that is, as a result of the disconnection of woven threads in some places of the burlap.

Nowadays some manufacturing companies offer the method of controlling looms using a frequency converter [3-8]. However, the control method also requires some research.

2. Materials and methods

In this paper, the authors used an analytical method to analyze the mechanical characteristics of a loom induction motor.

The launching method with a frequency converter in the start-up and controls of looms was tested. It was installed between the circuit breaker and the motor and was controlled by the rotational frequency of the motor. Figure 1 below shows a schematic of the implementation of the tested method.

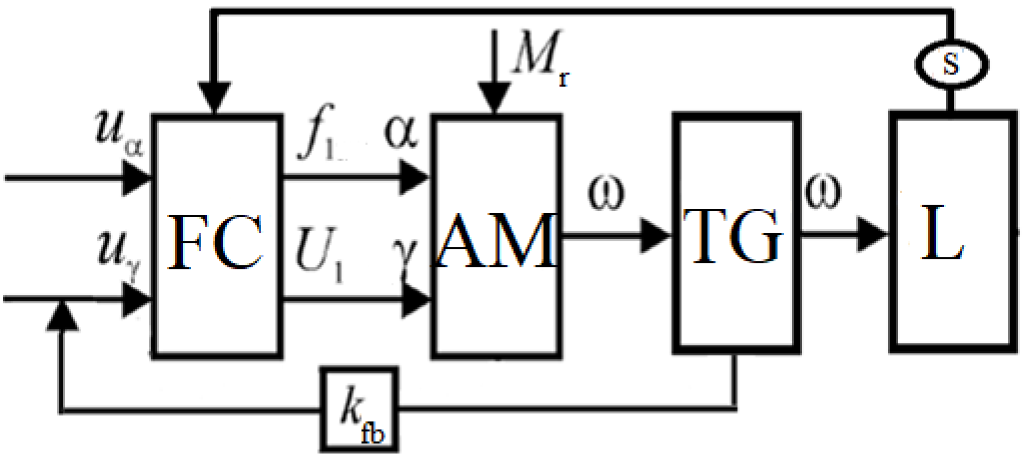

Figure 1. Closed loop functional diagram of frequency control of looms by means of asynchronous motor

Where FC - Frequency converter, AM - Asynchronous motor, TG- Taxogenerator, L – Loom, S-Sensor, k_{fb} - feedback, M_r - Moment of resistance.

One of the most commonly used electric motors in looms is induction motors. The electromagnetic moment of an induction motor is interacting with the rotating field generated by the stator winding of the current component ($I_2 \cos\psi_2$) passing through the conductors of the rotor winding, i.e. with the magnetic flux F_{max} and creates electromagnetic force $F_{em} = B_\delta li$ according to Ampere's law.

The electromagnetic moment generated by this force is determined as follows:

$$M = C_M \cdot F_{max} \cdot I_2 \cdot \cos\psi_2, \qquad (1)$$

where: $C_м = p \cdot m_2 \cdot k_{ch2} \cdot (2)^{-\frac{1}{2}}$ – constant value; F_{max}– maximum value of the magnetic flux.

This formula establishes the relationship between the torque value and the physical events that occur in the motor. It is convenient to use in qualitative analysis of the motor operation in different modes [9-11]. However, the quantities included in this formula (Φ_{max}, I_2 and $\cos\psi_2$) are not directly related to the mains voltage and the operating mode of the machine, and this is much more difficult to determine experimentally [12-15, 16, 17]. Therefore, the simplest determination of the value of the electromagnetic (rotational) torque below can be determined using another formula that allows to take into account the effect of various parameters and operating modes of the machine [18-21]. The equations of induction motors are derived from the generalized machine equations. In steady state, the equilibrium equation of machine voltages is as follows.

$$\left.\begin{aligned}
\dot{U}_{s\alpha} &= R_s \dot{I}_{s\alpha} + j\omega L_s \dot{I}_{s\alpha} + j\omega M \dot{I}_{r\alpha}, \\
\dot{U}_{s\beta} &= R_s \dot{I}_{s\beta} + j\omega L_s \dot{I}_{s\beta} + j\omega M \dot{I}_{r\beta}, \\
-\dot{U}_{r\alpha} &= R_r \dot{I}_{r\alpha} + j\omega L_r \dot{I}_{r\alpha} + j\omega M \dot{I}_{s\alpha} + M \dot{I}_{s\beta}\omega_r + L_r \dot{I}_{r\beta}\omega_r, \\
-\dot{U}_{r\beta} &= R_r \dot{I}_{r\beta} + j\omega L_r \dot{I}_{r\beta} + j\omega M \dot{I}_{s\beta} + M \dot{I}_{s\alpha}\omega_r + L_r \dot{I}_{r\alpha}\omega_r,
\end{aligned}\right\} \qquad (2)$$

Where $\dot{U}_{s\alpha}$, $\dot{U}_{s\beta}$, $\dot{U}_{r\alpha}$, $\dot{U}_{r\beta}$ - voltages in the stator and rotor windings along the axes α and β accordingly; ω_r - angular speed of the rotor; $\dot{I}_{s\alpha}$, $\dot{I}_{s\beta}$, $\dot{I}_{r\alpha}$, $\dot{I}_{r\beta}$ -currents in the stator and rotor windings along the axes α and β accordingly; R_s, R_r - active resistances of stator and rotor windings; L_s, L_r - scattering inductance of stator and rotor windings; M - mutual inductance; j - moment of inertia.

For short-circuited induction motors $\dot{U}_{r\alpha} = 0$; $\dot{U}_{r\beta} = 0$;

$$j\omega L_s = j\omega M + j\omega l_{s\sigma};$$

$$j\omega L_r = j\omega M + j\omega l_{r\sigma};$$

$$x_0 = \omega M;$$

$$x_s = \omega l_{s\sigma};$$

Taking into account $x_r = \omega l_{r\sigma}$ and relative speeds $v = \omega_r \cdot (\omega_s)^{-1}$ equation of equilibrium of asynchronous machine voltages has the following form.

$$\left.\begin{aligned}
\dot{U}_{s\alpha} &= R_s\dot{I}_{s\alpha} + jx_s\dot{I}_{s\alpha} + jx_0\dot{I}_{s\alpha} + jx_0\dot{I}_{s\alpha},\\
\dot{U}_{s\beta} &= R_s\dot{I}_{s\beta} + jx_s\dot{I}_{s\beta} + jx_0\dot{I}_{s\beta} + jx_0\dot{I}_{s\beta},\\
0 &= -R_r\dot{I}_{ra} - jx_r\dot{I}_{r\alpha} - jx_0\dot{I}_{ra} - jx_0\dot{I}_{s\alpha} + x_0\dot{I}_{r\beta}v + (x_r + x_0)\dot{I}_{r\beta}v,\\
0 &= -R_r\dot{I}_{r\beta} - jx_r\dot{I}_{r\beta} - jx_0\dot{I}_{r\beta} - jx_0\dot{I}_{s\beta} + x_0\dot{I}_{r\alpha}v + (x_r + x_0)\dot{I}_{r\alpha}v.
\end{aligned}\right\} \tag{3}$$

Taking into account, $\dot{I}_{s\beta} = j\dot{I}_{s\alpha}$, $\dot{I}_{r\beta} = j\dot{I}_{r\alpha}$ and after the intermediate changes we have the following equations.

$$\left.\begin{aligned}
\dot{U}_s &= R_s\dot{I}_s + jx_s\dot{I}_s + jx_0\dot{I}_0,\\
0 &= -R_r\dot{I}_r - jx_r(l-v)\dot{I}_r - jx_0(l-v)\dot{I}_r - jx_0(l-v)\dot{I}_s,\\
\dot{I}_0 &= \dot{I}_s + \dot{I}_r.
\end{aligned}\right\} \tag{4}$$

By bringing the rotor winding to the stator winding and taking into account the slip:

$$S = (\omega_c \pm \omega_r) \cdot \omega_c^{-1} = 1 \pm v, \tag{5}$$

After the replacements $\dot{E}_0 = -j\dot{I}_0 z_0$ and $\dot{E}_s = \dot{E}_r = \dot{E}_0$ we have the following equation for asynchronous machine:

$$\begin{aligned}
\dot{U}_s &= -\dot{E} + \dot{I}_s z_s,\\
0 &= \dot{E}_0 - \dot{I}'_r z_r - \dot{I}'_r R'_r(1-s)/s,
\end{aligned} \tag{6}$$

$$\dot{I}_0 = \dot{I}_s + \dot{I}'_r, \tag{7}$$

The equation (1.3) for the stator winding can be written as follows.

$$\left.\begin{aligned}
U_{s\alpha} &= d\Psi_{s\alpha}/dt - w_s\Psi_{s\beta} + R_sI_{s\alpha}\\
U_{s\beta} &= d\Psi_{s\beta}/dt - w_s\Psi_{s\alpha} + R_sI_{s\beta}
\end{aligned}\right\} \tag{8}$$

For the rotor winding:

$$\left.\begin{aligned}
0 &= \mathrm{d}\Psi_{r\alpha}/\mathrm{d}t - (w - w_s)\Psi_{r\beta} + R_rI_{r\alpha}\\
0 &= \mathrm{d}\Psi_{r\beta}/\mathrm{d}t - (w - w_s)\Psi_{r\alpha} + R_rI_{r\beta}
\end{aligned}\right\} \tag{9}$$

Rotor motion equation

$$\frac{\mathrm{d}w_\mathrm{r}}{\mathrm{d}t} = \frac{P}{j}\left(M_{em} - M_r\right) \tag{10}$$

Electromagnetic moment of induction motor

$$M_\mathrm{em} = \frac{m_1 \cdot U^2_{1nom}}{\omega_{1nom}} \cdot \gamma^2 \cdot \left([a\cdot(\alpha)]^2 \cdot \frac{\beta}{r_2} + [b\cdot(\alpha)]^2 \cdot \frac{r_2}{\beta} + 2\cdot r_1 \cdot \alpha\right)^{-1} \tag{11}$$

where $\alpha = \omega_1 \cdot (\omega_{1nom})^{-1} = f_1 \cdot (f_{1nom})^{-1}$ - relative frequency of the stator;
$\beta = \omega_2 \cdot (\omega_{1nom})^{-1} = (\omega_1 - \omega) \cdot \omega_{1nom}{}^{-1} = f_2 \cdot (f_{1nom})^{-1}$ - relative frequency of the rotor;
$\gamma = U_1 \cdot U_{1nom}{}^{-1}$ - relative voltage of the stator;
$\mu = м \cdot м_{nom}{}^{-1}$ - relative moment; $a = r_1 \cdot r_2{}^{-1}$.

Bringing to the Kloss's formula

$$M_{em} = (2 \cdot M_к \cdot (1 + q \cdot \beta_к)) \cdot (\frac{\beta}{\beta_к} + \frac{\beta_к}{\beta} + 2 \cdot q \cdot \beta_к)^{-1} \quad (12)$$

where $q = (r_1 \cdot X^2{}_m) \cdot (r_2 \cdot \alpha \cdot Z_1{}^2)^{-1}$; $\beta_к = r_2 \cdot (Z_2 \cdot (\alpha)) \cdot (Z_1(\alpha) \cdot X_2)^{-1}$ - absolute critical slip. Critical moment

$$M_c(\alpha, \gamma) = m_1 \cdot U^2{}_{1nom} \cdot (\omega_{1nom})^{-1} \cdot \gamma^2 \cdot q \cdot \beta_c \cdot (2 \cdot r_1 \cdot \alpha \cdot (1 + q \cdot \beta_c))^{-1} \quad (13)$$

Law of asynchronous motor control (MP Kostenko's law)

$$\gamma = \alpha \cdot (\mu)^{1/2} \quad , \quad U \cdot (U_{nom})^{-1} = f \cdot (f_{nom})^{-1} \cdot \left(\frac{M}{M_{nom}} \right)^{1/2} \quad (14)$$

In the Fig. 2 below the natural characteristic (continuous line) and U/f = constant law based frequency controlled (intermittent line) mechanical characteristic of a 4A100L6U3 type short-circuited rotor induction motor which has following specifications 2.2 kW, 220/380 V and a rotational speed 950 rpm are shown.

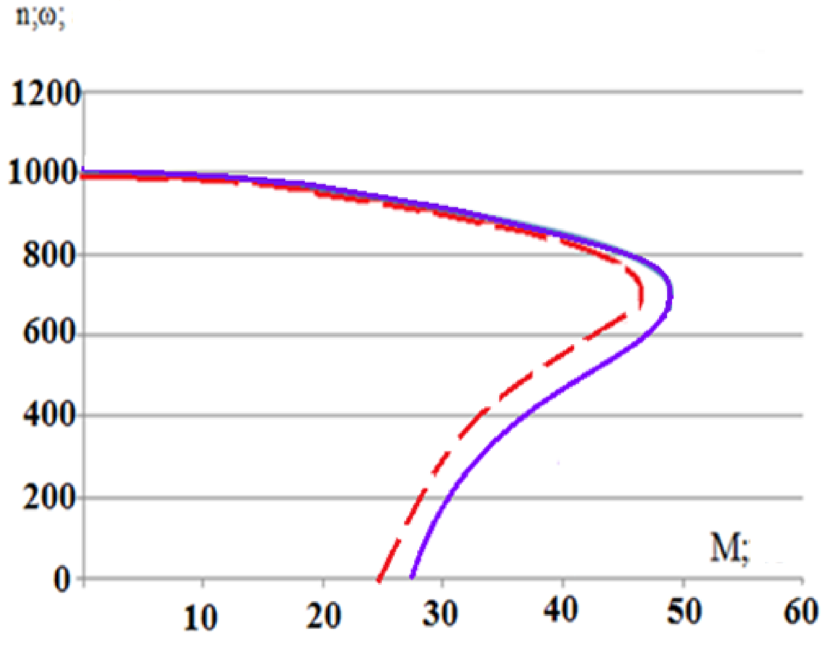

Figure 2. Mechanical characteristics of 4A100L6U3 type short-circuited rotor induction motor: natural (continuous line) and frequency-controlled mode (intermittent line)

From Fig. 2 it can be seen that the mechanical characteristics of the induction motor with the frequency control mode are very close to the natural mechanical characteristic.

3. Discussions

The following defects were prevented during the control of the loom using a frequency converter:

- The yarns do not break, in result some non-woven areas are woven as well.
- Prevents the rope threads from hanging without being wrapped around the body threads, i.e. ensures that they are kept at the same tension (same speed).
- As a result of hanging the ropes without wrapping them with twine, the breaking of the winding in short sections, so the appearance of several lines in the fabric, the breakage of the threads (same tension, so the same speed is ensured) and the production of quality fabric is achieved.

We divide the modes of smooth start of electric motors on looms into the following three groups:

- normal mode start time is limited from 10 seconds to 20 seconds, the value of starting currents is 3.5x I_{nom};

- the heavy mode is characterized by slightly larger inertial moment loads. Starting currents are limited to 4.5x I_{nom}, and acceleration time is 30 seconds [22] ;

- very heavy mode implies the presence of very high moments of inertia. The starting currents can reach 5.5x I_{nom}, and the acceleration time can be significantly increased from 30 seconds [22].

4. Conclusions

According to research investigation we can make following conclusions:

1. Starting torque regulators control only one phase (single-phase control) of a three-phase induction motor. While such a control method can control smooth start, it cannot provide a decrease in starting currents. In fact, when controlling the starting torque, the current in the motor windings is equal to the current in the direct start. However, unlike the direct-start method, such current flows in the coils for a long time, so the electric motor can overheat. These types of devices cannot be used in drives where the starting currents need to be reduced. They do not ensure the start-up of high inertial mechanisms (risk of motor overheating), as well as the series start-up (braking) of the electric drive.

2. Voltage control without feedback signal. This can only work using a program developed by the user. Due to the lack of feedback from the electric motor, it is not possible to change the motor rotation frequency depending on the changing load. In other cases, such devices meet all the requirements for smooth starting devices, capable of controlling all phases of the electric motor. This type of smooth start device is common. The motor starting circuit is determined by giving the initial value of the starting voltage and determining the time it takes to start. Many devices of this type can also be used to limit the starting current, for which it is necessary to reduce the starting voltage. These devices can also be used to control the speed of the loom electric motor and to make the drive stop slowly and slowly. Two-phase regulators can reduce the voltage across the three-phase motor, but the current will be unbalanced.

3. Voltage control with feedback signal is a modern method to control this type of device. In such devices, it is possible to control the voltage, taking into account the current value of the current, taking into account the values entered by the user. The obtained data can also be used in the operation of various protection devices (phase imbalance, overload, etc.). The method of smooth start of induction motors significantly reduces energy consumption.

The results of the study show that the mechanical characteristics of the motor taken by the frequency control method differ by 4.8% from the natural characteristics.

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