INCREASING TRACTION AND ENERGY INDICATORS BY SIMULATION OF OPERATION MODES AND ELECTROMAGNETIC CIRCUITS OF A LINEAR ASYNCHRONOUS MOTOR

***R.Yunusov** - "Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University*

Abstract

The quality of operation of a modern electric drive is largely determined by the correct choice of the electric motor used, which in turn ensures long-term reliable operation of the electric drive and high efficiency of technological and production processes in industry, transport, agro-industrial complex, construction and other areas. Linear asynchronous electric motors drive the working bodies of the mechanisms directly and quite fully fulfill their drive characteristics, allow eliminating mechanical converters and increase performance. This solves the problem of maximum articulation, splicing of a source of mechanical energy - an electric motor and an executive technological mechanism. The most rational ways to improve the traction and energy performance of linear asynchronous motors is the optimal choice of the inductor winding and the design of the secondary element. The given mathematical model of varying complexity of electrical and magnetic circuits allows you to calculate the electromagnetic parameters of the electric motor. The characteristic curves of the magnetic field in the air gap in numerical and physical experiments show the acceptable compatibility.

***Keywords:** electric motor, model, equivalent circuit, calculation, winding, inductor, experiment, working mode.*

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Introduction. The electric drive is the main type of drive in the production enterprises of the agro-industrial complex. So, about 60-75% of the electricity consumed by the enterprise falls on the electric drive. It has become widespread, as it has a number of advantages over hydraulic, pneumatic and other types of drive: flexible and reliable power supply system; simple and convenient automated control, high efficiency [1, 2].

Linear induction motors (LAM) are a rapidly developing class of special electrical machines, characterized by an extraordinary variety of design schemes and their designs. This is due to the fundamental possibility in many cases to directly combine a linear drive with a working body that performs rectilinear or reciprocating motion in a variety of devices (more than 50% of all electric motors are used to obtain rectilinear motion) [3, 4].

Linear induction motors (LIM) are electrical machines with magnetic circuit asymmetry caused by an open magnetic circuit. The asymmetry of the magnetic circuit leads to the asymmetry of the currents and magnetic fluxes of the inductor and the secondary element, to a decrease in traction and efficiency. Improving the traction and energy performance of the LIM can be achieved by changing the configuration of the magnetic circuit and using various schemes for connecting the inductor winding and the way it is powered [5-7].

Methods. Electromagnetic calculations were carried out on the basis of electrical and magnetic equivalent circuits [8-10]. On Figure 1 presents a computational mathematical model that allows you to analyze various ways to power the inductor winding. For power supply, alternating current (AC) sources with the number of phases varying within m = 1, 2, 3, …, n, symmetrical and asymmetrical systems of linear voltages, direct current (DC) sources for obtaining the dynamic braking mode, as well as both AC and DC sources can be used. currents to obtain a creeping speed mode (combined mode) [9-12]. By connecting the coils (Figure 1) in an appropriate way, it is possible to study the ring and drum windings with parallel and series connections of the branches, as well as special asymmetric winding circuits that improve the LIM performance [13-15].

For each winding coil, an equation can be written based on the second Kirchhoff law; in the matrix form of the entire winding, it will take the form [13]:

$$\left[U_*\right]=\left|K_{\varphi}^{s}\right|\cdot\left[\Phi_*\right]+\left|K_{ABC}\right|\cdot\left|I_{*\varphi}^{s}\right|, \qquad (1)$$

where $\left|I_{*\varphi}^{s}\right|$, $\left[U_*\right]$, $\left[\Phi_*\right]$ – are the vectors of the phase current, line voltage and flux in p.u.; $\left|K_{\varphi}^{s}\right|$, $\left|K_{ABC}\right|$ – are coefficient matrices.

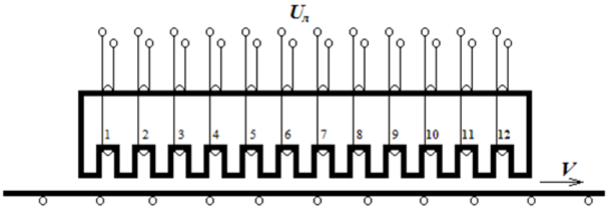
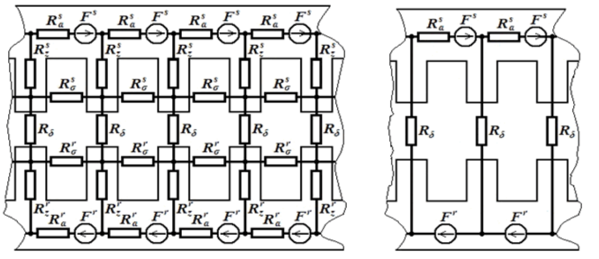


Figure 1. Calculation model of the LIM with an annular winding of the inductor and a smooth surface of the secondary element.

The LIM magnetic equivalent circuit (Figure 2,a) makes it possible to take into account the saturation of individual sections of the magnetic circuit, the non-uniformity of the air gap, the discreteness of the distribution of the current load of the primary winding, and a number of other design features. If we do not take into account the saturation of individual sections of the magnetic circuit, then the magnetic equivalent circuit can be simplified (Figure 2,b). Applying the second Kirchhoff law for magnetic circuits (Figure 2,b), we obtain an equation that in matrix form has the form [13]:

$$\left[I_*\right]+\left|I_*^{s}\right|=\left|K_R\right|\cdot\left[\Phi_*\right], \qquad (2)$$

where $\left[I_*\right]$, $\left|I_*^{s}\right|$ – are the vectors of currents in the slot of the secondary element and the inductor in r.u.; $\left|K_R\right|$ – is the matrix of coefficients.



a b

Figure 2. Mathematical model, taking into account the different saturation of the sections of the magnetic circuit for the analysis of ways to connect the inductor windings: a – full account of the saturation of the sections of the magnetic

circuit; b – a simplified model for taking into account the saturation of sections of the magnetic circuit.

The equation of the electrical state of the secondary element with ideal side tires, written in matrix form, has the form [13]:

$$[K_I^r]\cdot[I_*]=[K_\varphi^r]\cdot[\Phi_*], \tag{3}$$

where $[K_I^r]$, $[K_\varphi^r]$ – is the matrix of coefficients.

Solving together the equation (1) - (3), we obtain the matrix equation in the final form [10-12]:

$$\left\{[K_\varphi^r]\cdot[R]^{-1}[K_I]+[K_{ABC}]\right\}\cdot[I_{*\varphi}^s]=[U_*], \tag{4}$$

where $[R]=[K_I^r]\cdot[K_R]+[K_\varphi^r]$; $[K_I]=[K_I^r]\cdot[K_{pr}]$ – is the transformation matrix of the phase current $[I_{*\varphi}^s]$ vector of the inductor $[I_*^s]$, the current vector in the slot, i.e. $[I_*^s]=[K_{pr}]\cdot[I_{*\varphi}^s]$.

Traction and energy indicators are determined by known formulas [16, 17]. Based on the above methodology for calculating the LIM parameters, a computer program was developed.

To test the theoretical provisions, an experimental model of an arc-stator induction motor (AIM) was created, on which studies of the field distribution in the gap and yoke of the inductor, ways to improve the traction and energy performance of the engine were carried out. The studies were carried out for various AIM operation modes: motor, brake (regenerative and dynamic), combined.

Two inductors were made: with drum and ring windings. Both inductors are made from the stator of an A02-81-6 asynchronous motor; for this, 1/3 of the stator wire magnet with the number of teeth z = 24 is cut out.

The drum-wound inductor has the following parameters: p = 2; q = 2; a = 2; Wk = 70. The presence of two parallel winding branches makes it possible to study the AIM parameters with serial and parallel connections of the branches and the combined operation mode of the AIM with parallel connection of the branches by simultaneously applying a three-phase voltage system to the winding terminals and to the zero points of the stars – voltage from a direct current source.

The inductor with an annular winding has 24 coils (Wk = 70), the ends of which are brought to the panel (in addition, there are additional taps), which makes it possible to reduce the number of coil turns. This design of the winding allows you to explore not only symmetrical winding circuits with series and parallel connection of branches, but also their more complex options, which can improve the AIM performance in various operating modes.

Results. Structurally, the experimental model is made as follows: a DIM with a squirrel-cage rotor (δ = 3 mm) and a direct current generator of the MP-22 type, which serves as a load, are installed on a welded frame; digital tachometer connected to the shaft, allows you to measure the speed of rotation; a set of measuring instruments and a control panel are located on the stand. To measure the field, measuring coils are used, which are wound around each tooth, to measure the field in the gap and around the yoke – to measure the field in the yoke. The ends of the measuring instruments and a control panel are located on the stand. To measure the field, measuring coils are used, which are wound around each tooth, to measure the field in the gap and around the yoke – to measure the field in the yoke. The ends of the measuring coils are brought to the panel and connected in turn to the voltmeter. Comparison of the calculated (curve 1) and experimental (curve 2) characteristics (Figure 3) gives good agreement between the results.

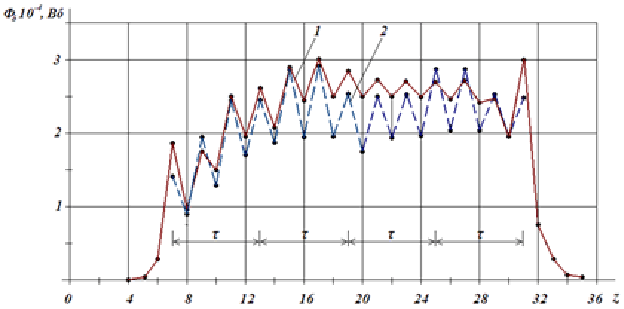


Figure 3. Calculated (1) and experimental (2) magnetic field envelopes in the LIM air gap.

Conclusion. Thus, the proposed method for calculating the characteristics of the LIM takes into account the discreteness of the distribution of the current load of the primary winding, the scheme of its connection and power supply, the difference in the parameters of its sections, the non-uniformity of the air gap and, in the general case, the heterogeneity of the saturation of the sections of the magnetic circuit, the influence of the leakage inductance of the rod and the parameters of the side tires of the secondary body.

The experimental model makes it possible to conduct extensive studies of the influence on the LIM performance of various methods of connecting the inductor winding and give practical recommendations. So, for example, when a winding is powered from a source with a symmetrical system of linear voltages, uneven current loading of phases and parallel branches can lead to winding overheating, which must be taken into account when designing.

In the studied range of parameters, the characteristics of the LIM slightly depend on the method of connecting the phase sections of the primary winding, but the presence of parallel branches contributes to the creation of special schemes of combined inductor windings to obtain two-current power supply modes and effective dynamic braking.

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