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SPECIAL CONSIDERATIONS FOR THE MATHEMATICAL MODELING AND CONTROL OF THE MULTISECTIONAL ASYNCHROOUS MOTOR

In various branches of industry and transport there exists the necessity of the direct realization of the progressive motion of the executive elements of the working machines. For this purpose, it is expedient to apply linear induction motors (LIM), main advantages of these motors are high reliability, simple construction, reduction of the dimensions, mass and cost of the installation as well as the possibility to obtain progressive motion with the unlimited values of acceleration rate and deceleration without any mechanical transmission. However, LIM are characterized by a number of the characteristic features, which must be taken into account in the process of the development and implementation, namely: increased working air gap and, as a result, increased dissipation flows, saturation and magnetic circuit discontinuity, that lead to the emergence of the longitudinal end effects, decrease of efficiency and power factor. Aim of the research is the analysis of the impact of the peculiarities of LIM constructive realization on its static and dynamic characteristics.

Main attention is paid to LIM with the limited length of the inductor or rotor, which can remain in the state when primary and secondary elements interact only partially, i. e., do not have complete overlapping of each other. The base of the specified LIM model is standard model of the rotational induction electric motor of Matlab/Simulink package, using the modified T-shaped equivalent circuits t of LIM, which takes into account transverse and longitudinal edge and end effects as well incomplete overlapping of the inductor.

As a result of research, carried out, it is shown that the incomplete overlapping of the inductor influences both the starting process and steady-state motion of LIM and worsens the transient processes quality, decreases the traction effort and acceleration.

The paper also considers the characteristic features of LIM with multisectional inductor control in starting, steady-state and braking modes.

The results of the performed research enable to formulate the recommendations, regarding the optimization of the construction and improvement of the methods of LIM control.

Key words: *electric motor, linear, induction, inductor, rotor, short, overlapping, incomplete, impact, dynamics, control.*

Introduction

Application of linear induction motors (LIM) enables to simplify the construction, improve the production efficiency of the industrial and transport installations due to obtaining of the tractive effort without the mechanical contact between the moving and stationary parts of the mechanism and usage of the transfer devices.

Principle of functioning of the linear motors with the secondary element in the form of the band corresponds to the rotational induction motor with massive ferromagnetic or hollow nonmagnetic rotor. Windings of LIM inductor have the same connection circuits as the conventional asynchronous motors and are connected to the grid of A. C. three-phase current. The methods of starting and regulation of the rotation speed of the asynchronous motors with short-circuited rotor and LIM and similar.

We will consider several different features of LIM. The inductor of the linear motor has final length in the direction of the running magnetic field, emerging at one end of the inductor core and disappearing at the other end of the inductor core. This feature is characterized as the «disconnection» of the magnetic system of the linear motor, that leads to the emergence of the final effect. This effect, in particular, causes the asymmetry of the currents in the windings of the inductor and creates the pulsing component of the magnetic field of the inductor.

The value of the air working gap in the linear motors, as a rule, is an order greater than in the rotational machines. This leads to the decrease of the efficiency factor and power of LIM. Great value of LIM gaps causes the need to increase the induction in the primary part of the motor that results in its saturation. Due to this reason the induction value in the secondary element turned out to be decreased.

Physical processes, characteristic features of mathematical modeling and LIM control were studied by different authors. The problem of the impact of the final effects of LIM on its state and dynamic characteristics are considered in details in the studies [1 – 4], where the necessity to take into account the impact of magnetic circuit disconnection is proved. In the research [4, 5], ways of compensation the impact of the edge effects of LIM by the constructive means and control methods are considered. At the same time in the considered studies not sufficient attention is paid to the investigation of the impact of the incomplete overlapping phenomenon of the inductor by LIM rotor.

Aim of the research

Aim of the research is the study the electric mechanic properties of LIM with the short rotor and verification of the algorithms of frequency control on the base of using the updated mathematical model.

Results of the research

Unlike the conventional rotating induction motor, primary and secondary parts of LIM, obtained by the «unwinding» of the stator and rotor windings in plane may have various length. There exist a great number of the constructive modifications of LIM, for instance, with short inductor and long rotor or vice versa (Fig. 1, a, c, correspondingly), as well as with short inductor and short rotor (Fig. 1, b). For each of these versions, both inductor and rotor can be stationary.

LIM with limited length of the inductor or rotor may remain in the state when primary and secondary elements interact only partially, i. e., they do not have the complete overlapping of each other, as it is shown, for instance, in Fig. 1, b. As a result of the given feature, a number of the inductive resistances of LIM in the process of the displacement of its moving part are not stable and depend on the degree of the mutual overlapping of the primary and secondary elements, this must be taken into account in the process of creating mathematical models and design of the systems of the linear electric drive [6]. It should be noted that for LIM with the long rotor (Fig. 1, a) or long solid inductor (Fig. 1, c), this phenomenon can be neglected, as it occurs only at the initial and final sections of the interaction of the primary and secondary elements.

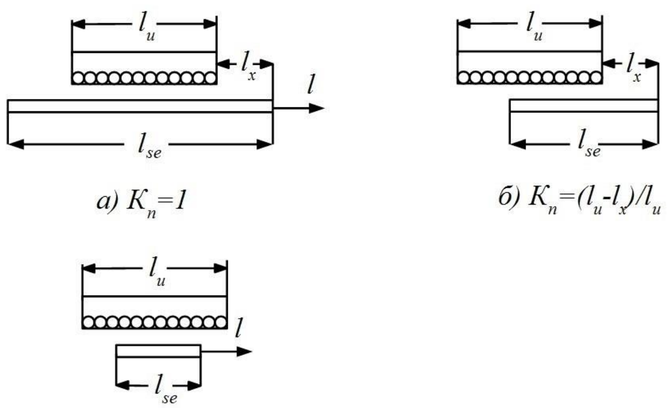

Fig. 1. Variants of the constructive realization of LIM with long and short inductor

Fig. 1 contains the following designations: l_u – is the length of the inductor; l_{se} – is the length of the secondary element; l_x – is the length of the section of the mutual overlapping of the inductor by the secondary element; k_n – is the coefficient, that takes into account the overlapping of the inductor by the secondary element. As it is seen from the Fig. 1, for the LIM with long secondary element (Fig. 1, a) $k_n = 1$, and for the cases of the short secondary element (Fig. 1, b, c) the value of k_n is defined by the relation of the inductor length l_u and the length of the secondary element l_{se}, as well as by their mutual overlapping l_x. Correspondingly, for the variant of the constructive realization in Fig. 1, b $k_n = (l_u - l_x)/l_u$, for the variant in Fig. 1, c $k_n = l_{se}/l_u$.

Assessment of the impact of the incomplete overlapping effect

We will study electrical mechanical processes in LIM with short inductor and rotor in order to assess the impact of the effect of incomplete overlapping.

For the mathematical description of LIM mathematical models on the base of the equivalent circuits (method of E-H four poles, models with the distributed parameters, detailed magnetic equivalent circuits, T-shape equivalent circuits), which enable to build models with different detalization of the separate elements of machine, have found wide application [1 – 3]. Application of T-shape equivalent circuit makes it possible to consider the model of the linear motor as the dynamic one. In this case, the impact of the edge effects is taken into account by means of introduction of the additional resistances in the magnetizing circuit and rotor circuit, values of which are determined on the base of the solution of the equations of electromagnetic field or experimental tests.

That is why, for the investigation of the impact of the above-mentioned characteristics of LIM we will make use of the mathematical model, the base of which is T-shape equivalent circuit, obtained by means of the synthesis of the circuits, which take into account the transversal and longitudinal edge and end effects as well as constructive realization of LIM with long and short secondary element [6]. Let us consider that the windings of the inductors are symmetrical and create in the gap the harmonic wave of magnetomotive force and the components of the electromagnetic fields, caused by the edge effects, do not interact.

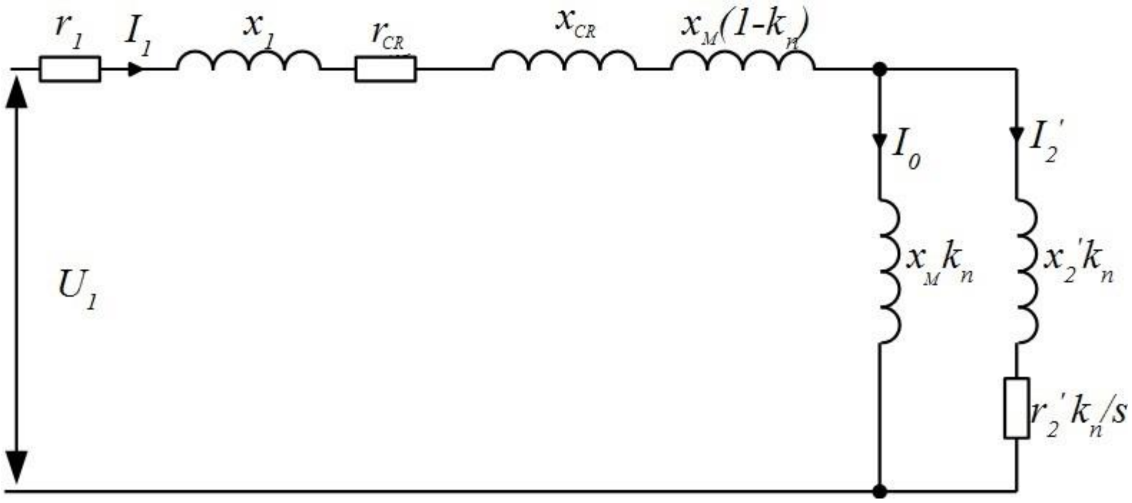

Fig. 2. Modified T-shape equivalent circuit of LIM

Designations of the equivalent circuit: r_1 – is active resistance of the inductor winding, x_1 – is reactive dissipation resistance of the inductor winding; r_{cr}, x_{cr} – are real and imaginary parts of the complex resistance, that takes into account the impact of the longitudinal edge effect; x_M – is reactive resistance of the mutual inductance; x_2' – is secondary reduced reactive resistance; r_2' – is active resistance of the secondary element, calculated with the account of the transversal edge effect; U_1 –is primary phase voltage; I_1 – is current of the inductor winding; I_0 –is magnetizing current; I_2' – is the reduced current of the secondary element; s – is sliding.

For the assessment of the impact of the specific features of LIM with short inductor and rotor (Fig. 1, b) on the static and dynamic characteristic of the electric drive the comparative modeling of the transient processess of the linear induction motor start was performred, taking into consideration and without the account of the variation of the inductor overlapping coefficient in the process of the rotor motion. The results of modeling are shown in Fig. 3 and Fig. 4. Numerical values of LIM parameters are the following: length of the inductor $l_u = 3m$, length of the secondary element $l_{se} = 3m$, number of poles pairs 15, mass of the moving part 720 kg, $r_1 = 0.115Om$, $r_2' = 0.072\text{Om}$, $L_1 = 0.01Gn$, $L_2' = 0.002Gn$, $L_M = 0.002Gn$.

Numbers on the figures indicate the graphs of the transient processess: 1 – without the account of the overlapping coefficient; 2 – with the account of the overlapping coefficient.

Comparative analysis of the transient processes shows that the account of the phenomenon of the incomplete overlapping of LIM inductor by the secondary element results in worsening of the transient process quality. As a result the acceleration decreases and the time of speed up of the linear electricdrive increases. In the given research, taking into consideration the limited length of the LIM inductor, the rotor does not reach the preset speed.

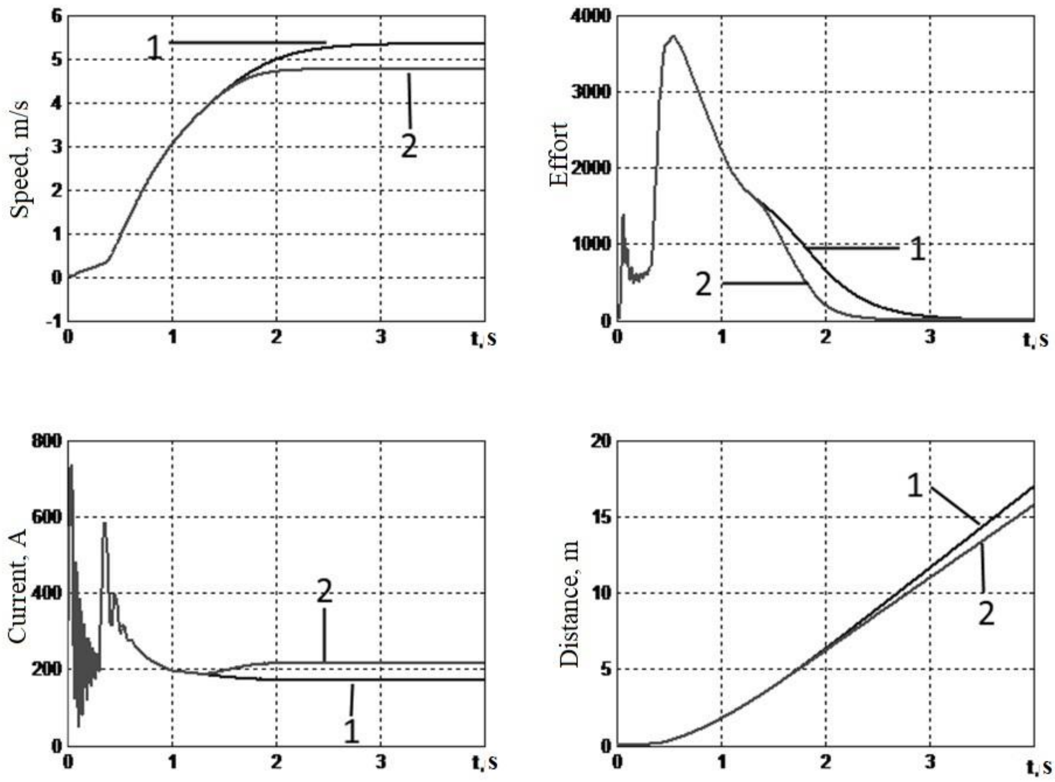

Fig. 3. Dynamic processes of LIM power characteristics variations with and without the account of the overlapping coefficient

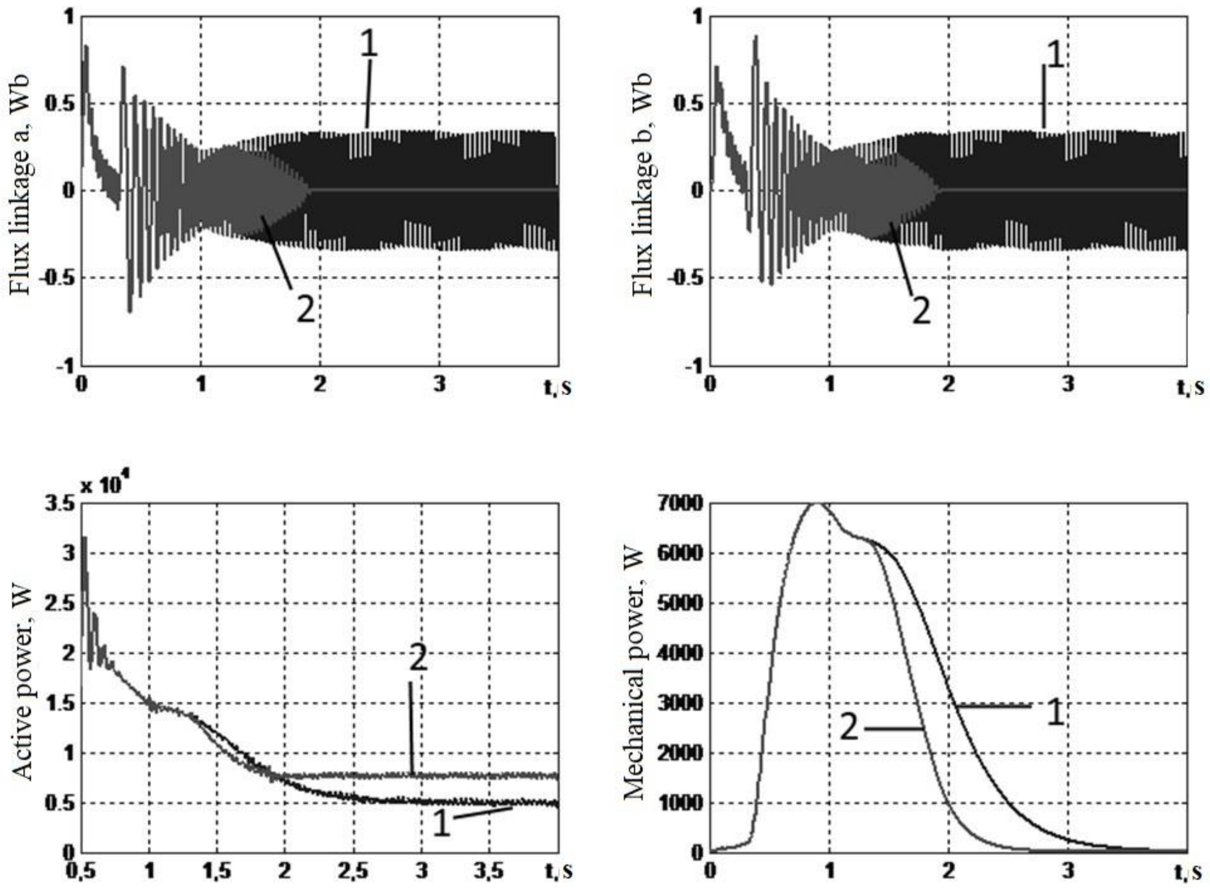

Fig. 4. Dynamic processes of LIM energy characteristics variations with and without the account of the overlapping coefficient

The obtained results can be spead to LIM with long inductor where, for saving electric energy, the inductor winding is realized sectionally. Sections of the inductor of such LIM are connected to the grid in parallel only in case of their direct interaction with the rotor, and others, non-active sections are disconnected.

The example of practical application of LIM with long sectional inductor are the systems of high speed ground transport, systems for launching the aircrafts from aircraft carriers, ropeless elevators for the high-rise buildings and elevating-transport machines with the linear drive. The important advantage of such LIM is the lack of moving current supply. This advantage may be important, for instance, for high speed ground transport on the magnetic cushion, which moves at a speed of up to 500 km/hr, or in the elevating installations with the linear drive.

Characteristic features of multisectional LIM control

In case of the independent supply of the sections, the length of which is comparable with the length of the secondary element, the same effects of the incomplete overlapping of the inductor by the rotor as those which were considered for LIM with short inductor and rotor (Fig. 1, b) appear.

Scheme of the electric drive with the multisectional LIM is shown in Fig. 5.

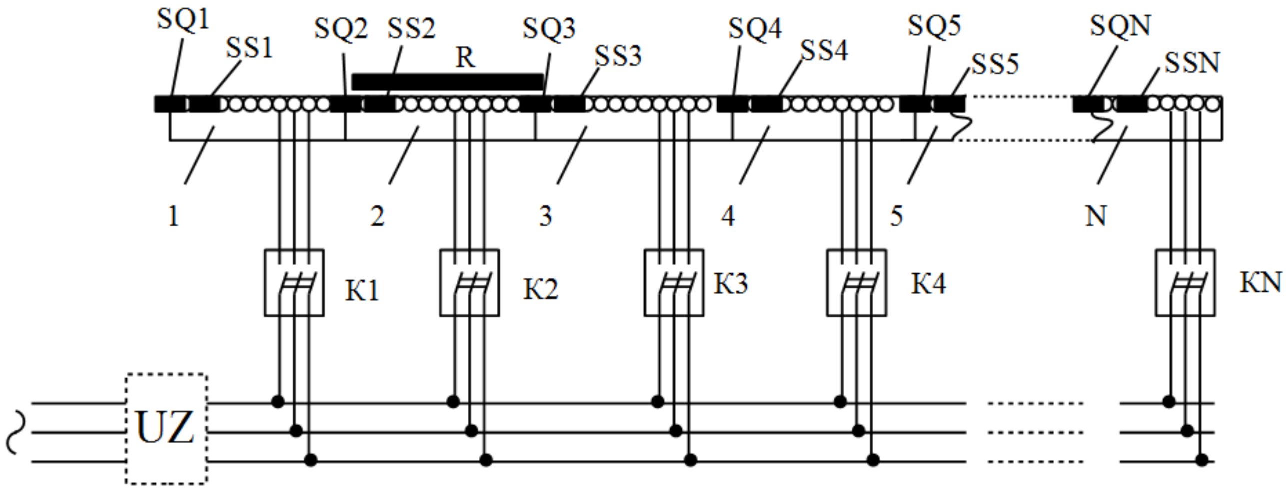

Fig. 5. Control scheme of the multisectional LIM

Fig. 5 contains the denotations: 1 … N – are the sections of the inductor; K1 … KN – are switches (contact or contactless); R – is the rotor (secondary element); SS1 … SSN, SQ1 … SQN – are sensors, located at the beginning and end or each section of the inductor and used for the determination of the location and direction of the rotor motion; UZ –is the convertor (is used if there exists the need of the smooth start or speed regulation of LIM).

Connection and disconnection of the inductor sections is performed by the switches, which are controlled by the commands of the location sensors. When the rotor approaches the next section of the inductor the location sensor, situated at the beginning of the section functions and connects the corresponding switch, which sends the supply to the active section. Simultaneously the sensor disconnects the supply of the previous section of the inductor.

Due to the regulation of the location or the operation time of the location sensors the switching of the LIM inductor sections may occur synchronously or with the delay, regarding the moving rotor. The latter mode can be used for the regulation of the acceleration and speed of LIM. To perform the mode of electric braking separate sections of the inductor can be connected to the source of supply with the inverse order of phase alternation.

The results of the research, carried out, prove the necessity to take into account the incomplete overlapping of LIM inductor by the secondary element and development of measures, aimed at the compensation of the impact of this phenomenon. Such measures can be directed at the improvement of LIM construction and methods of its control.

Conclusions

1. Mathematical model of LIM on the base of the modified T-shape equivalent circuit enables to assess the impact of overlapping coefficient of the inductor change on static and dynamic characteristics of LIM, carry out investigations of static and dynamic modes of the linear electric drive.
2. Comparative analysis of the transient processes at the start up of the linear motor, carried out with the account and without the account of the overlapping coefficient shows that the phenomenon of the incomplete overlapping of the inductor influences both the process of the start up and steady-state motion of LIM and leads to the worsening of the transient processes quality, reduction of the traction effort and acceleration.
3. Results of the research provide the possibility to determine the characteristic features of control of LIM with long sectional inductor, formulate recommendations regarding the optimization of its construction and methods of control.

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