Electromagnetic fields, characteristics and practical structures of linear induction machines with a short operating body

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***Abstract*—This report is devoted to the creation and investigation of unconventional electric machines-linear induction motors. The computations were made on the basis of electromagnetic field theory for specific calculating models of linear induction motors with solid, limited length working body which moves in relation to an inductor.**

***Keywords—department activity; linear induction machines structures; electromagnetic fields calculating models and assumptions; differential equations; machines' integral characteristics and practical application*.**

I. INTRODUCTION

For more than 40 years the Department of Electrical Engineering and Electro-mechanics of the PNIPU has been engaged in research and development of unconventional electric machines and drives, in particular induction machines with open magnetic circuits.

There were created linear flat, tubular, front, saddle, segment, disk and arch-stator motors for devices of high technologies and transport systems in different branches of industry.

Some of the motors developed have been successfully tested by the customers and introduced into production manufacture with unique applications.

Great attention is paid to the Linear Induction Motors (LIM) applied in systems of traveling or alternating movement, and also for the gearless devices with rotary motion of an operating body.

It is well known that the elaboration of a successful theory of LIMs for such systems and devices is extremely complicated as it is conditioned by the influence of edge effects, appearing in LIMs and also by the great variety of the motors constructive executions.

Among LIMs two general types of structures are often recognized: a) with a Long Operating Body (LIMLOB) and b) with a Short Operating Body (LIMSOB). The theory of the LIMLOBs is covered rather adequately [1, 2], but the LIMSOBs at the moment are not properly being studied.

II. DESCRIPTION OF THE LIMSOB CALCULATING MODEL

These days there are a considerable amount of calculating models and types of LIMLOBs, but none of them are to a necessary degree meet the requirements, which take place in the LIMSOBs.

In such motors, the mode of operations varies periodically from the maximum load (working body is in the area of a motor's inductor) to no-load operation (working body has left the area of a motor's inductor). Thus, the calculating model of the LIMSOBs should simultaneously meet both the conditions: of no-load operation, and of a maximum power demand.

This model is described in the report and it correctly takes into account a composite character of the magnetic field distribution in active and edge areas of the inductor.

The magnetic field in the gap of LIMs inductors and outside it, has a complex character and it is difficult to calculate it. But there is no need to calculate it at every point of the spatial field distribution. Proper allowance must be made only for the zones inside and outside of the inductor where the operating body is located.

It is expedient to introduce some unusual assumptions, which without distorting basic physical processes taking place in the motors that would ensure considerable simplification of mathematical expressions.

1) Let us accept that the motors breadth is quite wide, i.e. let us assume that in the initial stage of the analysis the electromagnetic field does not depend on the width. The limited width of LIMs (a transverse edge effect [3]) and the phenomena caused by irregularity of the field distribution within a thickness of the working body (a thick edge effect) might be taken into account on theoretical grounds of a quasi-three-dimensional method of LIM electromagnetic calculations [2].

2) The occurrence of inductors slots was considered in the computation with the help of Carter's coefficient by the relevant increasing of the air gap.

3) The inner surfaces of inductors are covered by the infinitely thin layers of current, which line density is in the certain conformity with the actual non-symmetrical current load of a primary winding.

4) Only the basic harmonic of the current load is considered.

5) The magnetic permeability of the inductor's yoke directed toward vertical Z-axis (across of the yoke) is

accepted as $\mu_z=\infty$, and along of the yoke X-axes is accepted as $\mu_x=\mu_s$.

The permeability of an air gap is accepted as $\mu_z=\mu_0$, and $\mu_x=0$.

6) Let us assume that at the entrance and exit inductors' zones magnetic flux extends through the infinitely long shunting cores' sections. Its height is equal to the height of the inductors' cores and magnetic permeability of these entrance and exit sections along the X-axes direction accepted as μ_x' and μ''.

The assumptions 1-4 are conventional in the theory of LIMLOBs and are justified in details in [1].

The unusual assumptions 5 and 6 for the first time were used in PNIPU to study longitudinal edge effect of LIM without working body (when the motor is idling) and for LIMLOB with symmetric system of phases' currents [2].

The value of permeability $\mu_s\neq0$ along the yoke of inductors made feasible to create a convenient way of accounting the inductors' steel saturation.

Assumption 6 makes possible to depict the complex structure of the field distribution outside inductors in the form of equivalent rectangles. This has been proved in [2, 3] and in other publications of the PNIPU collaborators.

III. THE LIMLOBs COMPUTATION AND INVESTIGATION

The physical processes in the LIMSOBs are much more complicated than in the LIMLOBs. The principal feature of the LIMSOBs is the electromagnetic phases' asymmetry originating not only from the inductor interruption, but also due to a change of an operating body's position relative to the inductor. The currents and phases' powers of the LIMSOB inductor windings are greatly different (unbalanced). Therefore, the LIMSOBs should be considered as an asymmetrical multi-phase system using special methods of calculation, for example, the method of symmetric components.

This method must be connected to the solution of the task of the LIMSOBs electromagnetic field distribution at the change of the body's position and velocity relative to the length's limited inductor (a very complicated and interesting problem in the theory of such linear induction machines).

In line with this statement in the report on the base of calculating model outlined above, the differential equations of the LIMSOB's electromagnetic field are obtained, and their solutions have been accepted allowing taking into account electromagnetic phase's asymmetry at the entrance of a body into and egress from the inductor.

The electromagnetic power of every winding of an inductor's phase is determined as a result of interaction of a resulting field with the current of the relevant phase. For this it is also necessary to take into account the electromagnetic powers stipulated by the currents in compensation elements of a winding.

The tractive electromagnetic force, acting on the winding, and on a core of the LIMSOBs inductor; the efficiency and a power factor of the motors have also been defined.

One of the objects of laboratory experimental research was a flat linear induction motor with one-sided inductor installed above a laminated ferro-magnetic slab (passive core). Such a motor is an analog of a bilateral LIM dissected along the working body plane into half. The motor's inductor was fed from the actual mains of a three-phase current with a practically symmetric system of linear voltages (380V). Cooper plates of 0.5 mm and 5 mm width were used as short working bodies.

The value of an electromagnetic goodness-factor of a motor (specific Reynolds's number for LIM) was varied by using different plates within a wide range: 0,97-12,3 and its values covers practically the whole of the spectrum of Reynolds's numbers which are available for low-speed linear induction motors for electric traction in many transport systems and industrial equipment.

The LIMSOBs modifications have been used in the special linear drives for transport systems of products movement in remote requirement of protective hermetically sealed chambers.

The transmission of an electric traction on the bogies of a transport system is effected by means, both of a running and stationary electromagnetic fields that is able to raise essentially reliability and safety of transport systems work to improve environmental protection and staff working conditions.

Experimental research and computations showed that the theoretical methods are being devised in the PNIPU to provide acceptable accuracy of calculations in engineering practice.

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