General Method for Design of Rotary – Linear Induction Motor

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Abstract

The paper is devoted to 3-phase rotary – linear induction motor. The authors are concentrated on unconventional solution of rotary – linear induction motor, with main design assumption which was to use for construction standard components (mass produced) of 3-phase induction motor (especially standard complete stator of manufactured induction motor). By this assumption the technology and cost of production are minimized. Basing on the knowledge of the authors the rotary – linear induction motor designed and constructed basing on the elements of manufactured 3-phase induction motor was not considered in the other works.

1 Introduction

Rotary – linear motors have possibility of spiral motion without any complicated transfer mechanical systems of force and torque. Of course, in addition to the spiral trajectory, are possible other trajectories, within the cylinder space. When we supply only one of the modules of the motor – only rotary module, or linear module - the motor can operate only like a rotary motor or linear motor. Thus, the two drives of various types are manufactured in a single drive [2-9].

In the drilling machine, machine tools or mixing machine the more element perform complex motion (rotary - linear). Traditionally in these devices we used motors with one degree of freedom (rotary or linear) connected with mechanical transmission or gear boxes. An alternative solution may it be the motor with two degrees of freedom (rotary – linear motor). Due to the non-typical construction of the rotary – linear induction motor the manufacturing technology is expensive. In design process authors are concentrated on the use of elements of typical manufactured induction motors. This solution enables of lower costs of production non-typical motor by the simplify of manufacturing process.

2 Research object

Rotary – linear induction motor is a construction with two separate stators placed in the one casing (Fig. 1.). Two separate stators cooperate with common tubular rotor (ferromagnetic steel pipe with conductive copper layer). The module which realize linear motion is named L module and adequately module which realize rotary motion is named R module.

The rotary-linear induction motor can be used as direct drive for devices for drilling, milling and mixing or as drive the kinematic pairs of IV class in robots and manipulators.

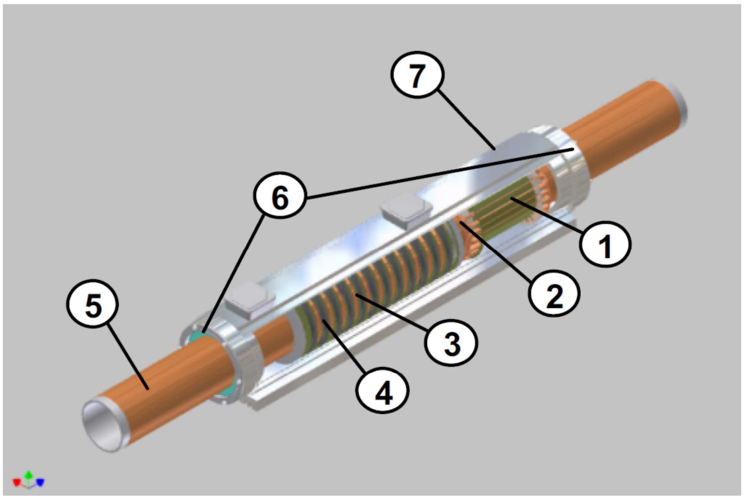

Fig.1. Construction of linear – rotary induction motor: 1 – yoke of stator of rotary module, 2 – winding of rotary module, 3 – yoke of stator of linear module, 4 – winding of linear module, 5 – tubular rotor with conducting cooper layer, 6 – bearings system, 7 – casing

3 Algorithm of design

3.1 Rotary module – module R

In the design of rotary-linear induction motor the main assumption is adoption to fulfill two principles. The basic module (working module) is module R. This module is ready, completely stator (iron core with windings) is taken from series induction cage motor ShR 90X-8M (manufactured by Factory of Electric Motors BESEL). The linear module is additional module (constructed with elements of mentioned motor) for positioning of working tip (tool). Construction of new, original device on an existing design solution does not require the design of stator magnetic circuit of module. It is necessary to design a tubular rotor (thickness of iron and copper layer) and the stator magnetic circuit of module L.

Developed algorithm used the "Transformation of structure" method [1]. The "Transformation of structure" method basing on the changes of electromagnetic circuit of 3-phase induction motor, which resulted is the transformation of the structure of rotor of cage motor (the rotor slots and aluminum bars are replaced by tubular rotor with copper conductive layer – Fig. 2). The specificity of the method allows observing changes curves: torque versus slip curve $T_e = f(s)$ and stator current versus slip curve $I_s = f(s)$ (by the adopted simplifying assumptions).

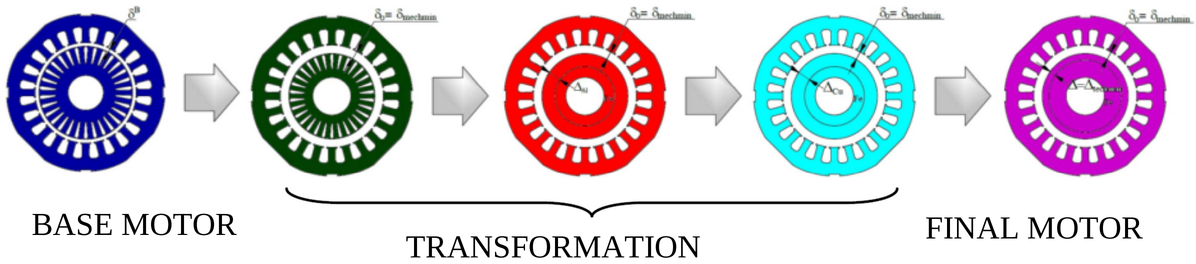

Fig.2. Idea of „Transformation of structure” induction cage motor to rotary module of linear – rotary induction motor

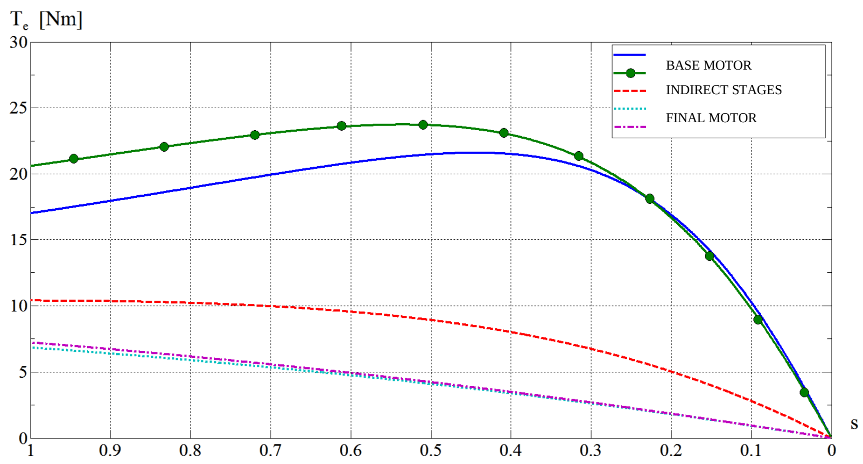

Fig.3. „Transformation of structure” – electromagnetic torque versus slip curve $T_e = f(s)$ for adequately stages of transformation

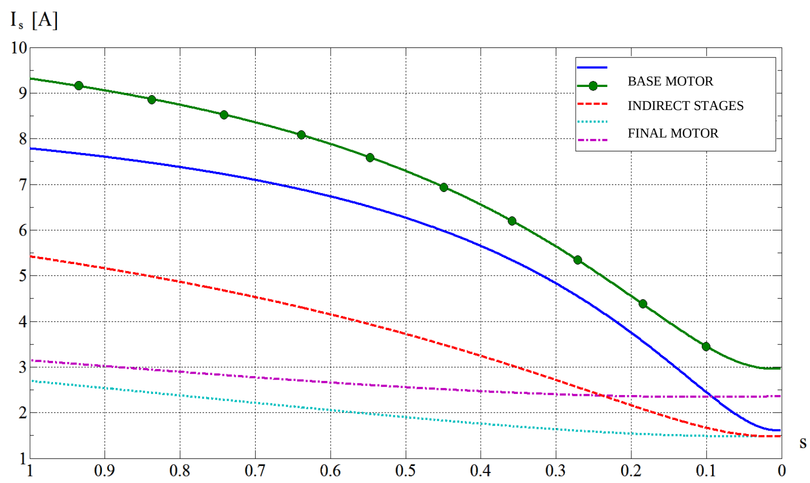

Fig.4. „Transformation of structure” – stator current versus slip curve $I_s = f(s)$ for adequately stages of transformation

3.2 Linear module – module L

In the next step the dimension of magnetic circuit of linear module are determined [1]. Determination of dimensions of magnetic circuit includes:

- Determination of thickness of ferromagnetic layer Δ_{Fe}.
- Determination of width of the stator tooth,
- Determination of width of the solid ring - the width of the stator groove,
- Determination of the number of turns and winding wire diameter.

To reduce the cost of produced of sheet metal, the dimensions adopted for the module L equal to the relevant selected dimensions of the module R: inner diameter of stator yoke of the module L – d_{ys} = 113 mm, outer diameter of the stator module L - d_{es} = 135 mm, inner diameter of the stator module L - d_{is} = 86 mm. Other dimensions of magnetic circuit: stator tooth width module L -, the width of the stator groove module L - were established on the basis of the adopted maximum values of saturation in the yoke of the rotor, yoke of the stator and stator tooth (Fig .5.).

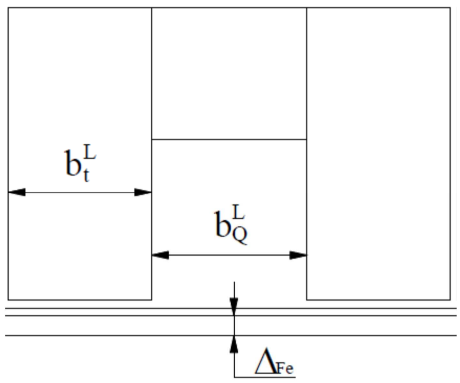

Fig. 5. Dimension of slots and teeth of stator – module L

Basing on the analytical calculation and the values of saturation in mentioned zones the dimension of magnetic circuit are calculated. In order to verify the dimensions of module L the analysis of the electromagnetic field distribution was used. In a study using FEMM (Finite Element Method Magnetics) was determined distributions of the magnetic field - based on the preset boundary conditions. The analysis was conducted for the case of axially symmetric, the nonlinear magnetization characteristics of ferromagnetic elements and 134 000 mesh elements. The results of calculation are shown in Figure 8.

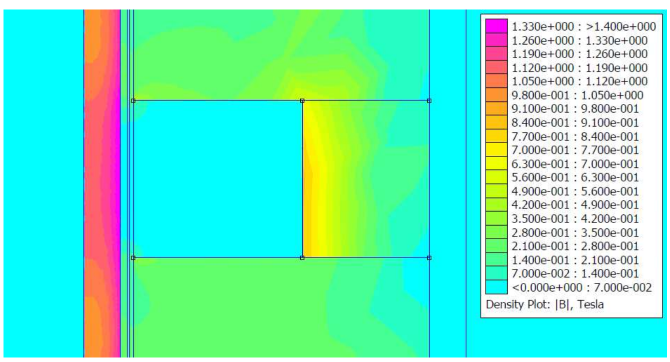

Fig. 5. Electromagnetic field distribution for selected parts of module L

The results of the analysis of the magnetic field distribution have confirmed the analytical calculations for the magnetic circuit dimensions for the module L of rotary - linear induction motor. Basing on the dimension and winding data the curves for module L: electromagnetic force versus slip curve F^L_e=f(s) and stator current versus slip curve I^L_e=f(s) are calculated (Fig. 6 and Fig. 7).

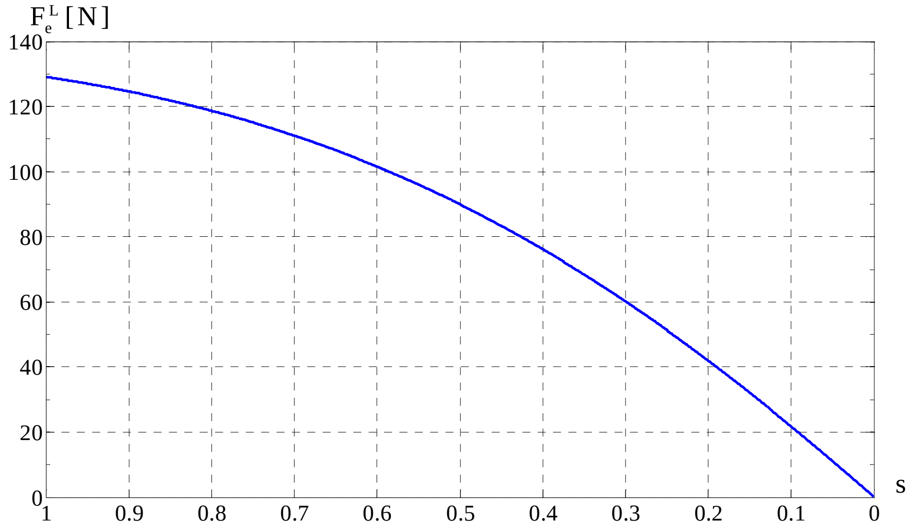

Fig. 6. Electromagnetic force versus slip curve F^L_e=f(s) – module L

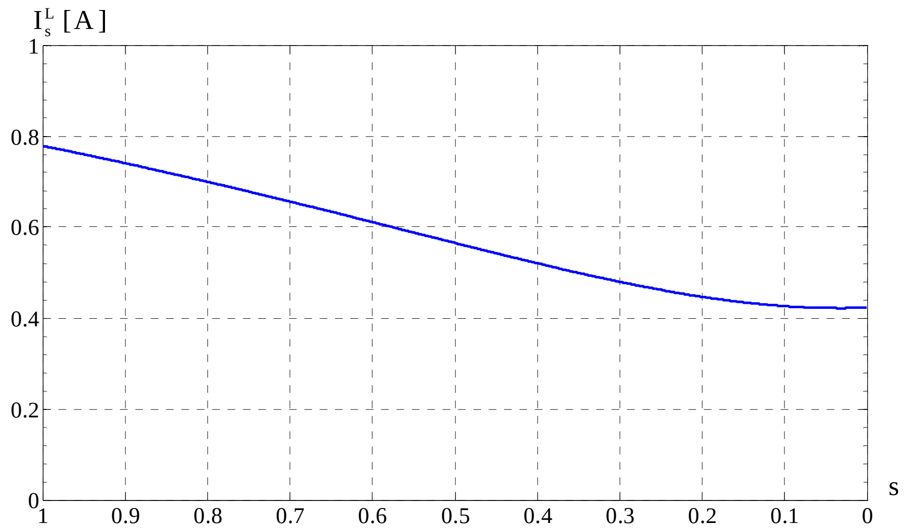

Fig. 7. Stator current versus slip curve I^L_e=f(s) – module L

4 Conclusion

Due to the fact that the linear motors - rotary drives belong to the category of special (unconventional machines), they will most often designed and constructed for specific processes (for use in specific devices) for a clearly defined tasks of driving. The requirements relating to the drive of linear and rotary motion must always be clearly and strictly defined in the design assumptions. Developed algorithm based on the mass-produced motors allows to design of rotary – linear induction motor at a lower cost of production.

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