Výzkum teplotních režimů lineárního indukčního motoru

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Research of Thermal Regimes of Linear Induction Motor

Abstract – **The paper presents a simplified mathematical model of linear induction motor to study its thermal regimes. The model takes into account the heat removal from the active zone due to the movement of the secondary element. The estimation of influence of motor speed on the temperature of its design elements is also verified.**

Keywords – Linear Induction Motor, Vehicle, Heating, Numerical Modelling, Dynamic Modelling, Equivalent Thermal Circuit, Design Elements.

I. INTRODUCTION

Employees of Donetsk National Technical University (Ukraine), Ural State Technical University (now Ural Federal University), as well as Pervomaisk Electromechanical Plant (Pervomaisk, Lugansk region, Ukraine) have developed a traction electric drive for the Mezhdurechensky mining and processing integrated works «Kemerovougol». Multi-motor electric drive of conveyor train (CT) is a set of three-motor modules, distributed throughout the movement line of the CT, depending on its profile (the angle of ascent). Each module consists of three motors installed in the inter-rail space of the track structure, three mobile control and compensation devices and one packaged transformer substation. The general view of a linear induction motor (LIM) is given in Figure I [1–3]. Inductors are located on the roadbed, and secondary elements are located below the bottoms of moving wagons. Rated motor data are: voltage 660 V, current 780 A, frequency 50 Hz, active power 150 kW, velocity 11 m/s. The starting current of the motor is 1070 A, the maximum traction force is 18.5 kN.

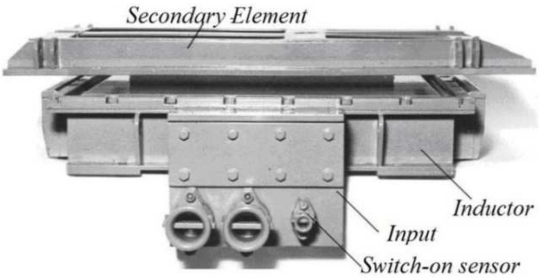

Figure I. General view of traction LIM

In this paper the authors consider the simulation of thermal processes in the operating modes by detailed equivalent thermal circuit method. Similar problems were successfully solved in [4–6] using the above mentioned method. The presented results published in this collection of scientific papers do not reflect the complete research work.

The results of study of thermal processes in the LIM will be completely presented in subsequent work.

II. PERFORMANCE CALCULATIONS

The LIM's equivalent thermal circuit (ETC) with a stationary secondary element (model 1), which is shown in Figure II (K switches are open, i.e. SE does not go beyond the active zone of the inductor and is represented by one thermal mass M2 in this zone), is similar to the known ETC of common rotating electric machines [5, 6]. It should be noted that in the circuit under consideration (see Figure II) the figure of the inductor is viewed from above and corresponds to the variant of the motor location on a moving train. This feature is not principal in terms of consideration of the processes in the electric drive.

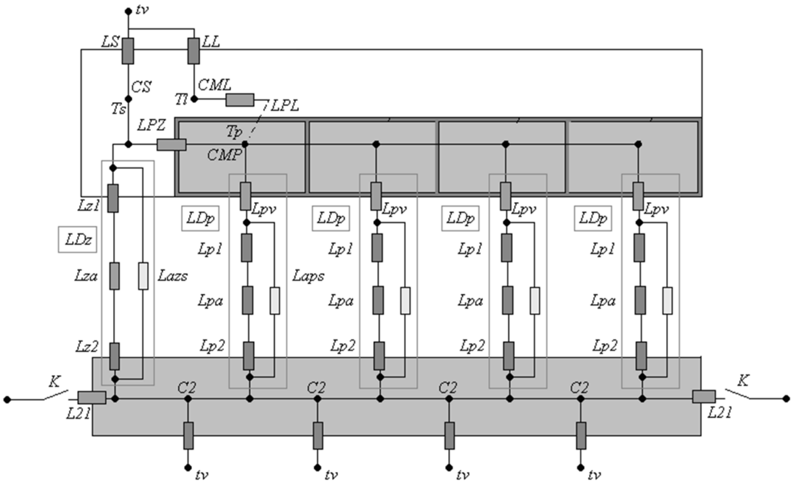

Figure II. Detailed thermal equivalent circuit of the LIM

Copper thermal masses of the slot parts of the winding, its end-windings and the inductor core are interconnected by thermal conductivities of heat transfer: *LS* – core-air; *LL* – end-windings - air; *Lz*1 – surface of the teeth - air; *Lz*2 – surface of the SE, overlapped by teeth - air; *Lp*2 – surface of the SE, overlapped by slots-air taking into account the thermal resistance of the electrical insulation of the coils; *LK*2 – SE − air; thermal conductivity: *LPZ* – slot copper – electrical insulation – core (teeth); *LPL* – slot copper - end-windings copper; *Lza* – air gap under the teeth; *Lpa* – air gap under the slot; *L*2*l*, *L*2*r* – active part of the SE-protruding left and right passive parts of the SE; radiations: *Lazs* – external surfaces of teeth-SE; *Laps* – external surfaces of coils in slots-SE. If the heat transfer of the active part of the SE to its left and right passive parts (model 2) is taken into account, the same ETC (Fig. 4) will be obtained, but with the closed switches.

The thermal mathematical model of the motor is a system of differential equations (1) written for the temperatures of the allocated thermal masses (nodes) in accordance with nodal potential method [5]

$$\frac{\mathrm{d}T_i}{\mathrm{d}t} = A \cdot T_{i-1} - B \cdot T_i + C \cdot T_{i+1} + D + q'_{\mathrm{v}i} . \qquad (1)$$

The coefficients of the system of equations are

$$A = \frac{a}{t_{\mathrm{z}}^2} + \frac{\upsilon}{t_{\mathrm{z}}}; \qquad B = \frac{2a}{t_{\mathrm{z}}^2} + \frac{a}{c_{\mathrm{p}} \cdot d \cdot \Delta} + \frac{\upsilon}{t_{\mathrm{z}}}; \qquad C = \frac{a}{t_{\mathrm{z}}^2}; \qquad D = \frac{\alpha}{c_{\mathrm{p}} \cdot d \cdot \Delta} T_{\mathrm{c}};$$

where $a = \frac{\lambda}{c_{\mathrm{p}} d}$ is the heat diffusivity of the SE's strip; q_{v} is the specific heat dissipation power; c_{p} is the specific heat capacitance of the strip material; d is the density of the strip material; υ is the velocity of the strip; T_i is the average temperature of the ith section, whose height is equal to t_{z}, thickness is equal to Δ and length is equal to L_{t}.

III. PERFORMANCE CALCULATIONS

In this part of the paper the results obtained by means of the detailed thermal equivalent circuit are presented. Analysing the temperature distribution graph in time (Figure III), it can be concluded that the maximum temperature of the linear motor is achieved in the windings of the inductor, so that it is worth considering the possibility of overheating the inductor windings. It should be noted that the winding of this motor is able to withstand heating up to about 200 °C. Such high temperatures of the coil winding of the inductor are achieved due to the presence of thermal insulation and cooling industrial oil.

The distribution of the temperature of the inductor elements along its length at the beginning, middle and end of the heating time interval $t_k = 500$ s, when the train moves at the nominal velocity and the active part of the motor are distributed to 4 sections, is shown in Figure IV. It can be seen that the temperatures of different sections (from the 1st one to the 4th one) of each selected element of the construction vary in time equally.

It should be noted that the temperatures of the inductor and SE elements in the active zone are significantly reduced due to the "outflow" of heat into the protruding parts of the active zone and the moving parts of the SE. This feature fundamentally distinguishes the LIM from a common rotating motor, reducing the thermal loads of the machine in the active zone.

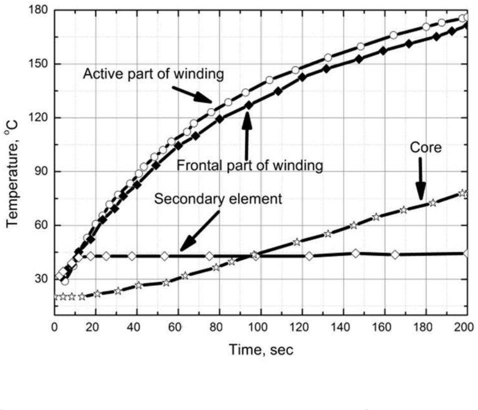

Figure III. Dependence of temperature on the time of different parts of LIM

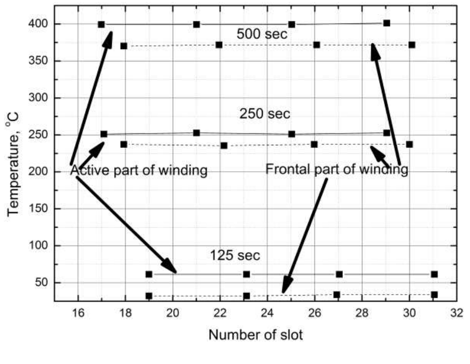

Figure IV. Distribution of temperatures of the inductor elements along its length at the beginning, middle and end of the interval of operation t_{k} at the velocity of the SE equal to 10.6 m/s (slip is equal to 0.2)

The heating curves of SE elements when the train moves at a velocity equal to 0.005 m/s, are shown in Fig. 5. The section numbers are counted from the section at the input edge of the inductor: 0- in front of the input edge, 1–4 - in the area of the inductor, more than 4 - outside the output edge of the inductor (Figure V). It should be borne in mind that on the section with some number, in the course of time, new less heated sections of the moving SE appear, replacing the former ones.

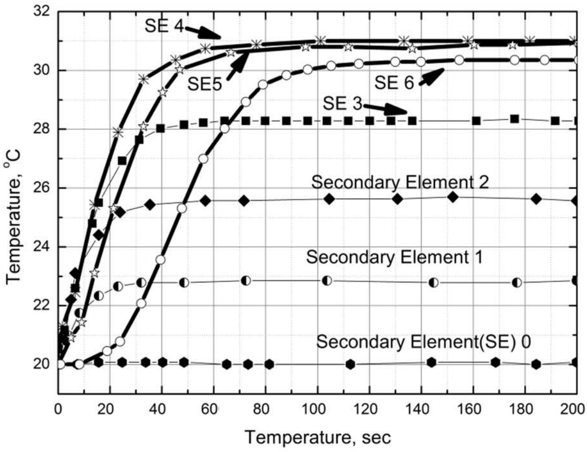

Figure V. Heating curves of SE at the velocity equal to 0.005 m/s

IV. CONCLUSION

The results of the carried out studies show that application of detailed electrical, magnetic and thermal equivalent circuits allows calculating a detailed condition of the distribution of electric, magnetic and thermal characteristics of the motor (taking into account the heat transfer from active zone during the motion of the secondary element) by the computers with modest computational capabilities, and at a low time (about several minutes). These features of the proposed method for calculating the characteristics of LIM are especially necessary at the design stage of transport systems with linear electric drives.

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