Linear Induction Machines with the Opposite Direction Travelling Magnetic Fields for Induction Heating

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***Abstract* - The features of induction heating installations in a traveling magnetic field are considered. The expediency of using dual-purpose linear induction machines and the prospects of using linear inductors creating opposite direction traveling magnetic fields are shown.**

Keywords - induction heating; traveling magnetic field; combined heating; opposite direction traveling magnetic fields; research results

I. INTRODUCTION

The main directions of improving technology and induction heating device are mechanization and automation of processes, increasing the accuracy of maintaining the regime, increasing the economy of installations. Such tasks are solved when creating flexible automated technological complexes, including in their composition induction heating plants of continuous or periodic action. Automated induction heating lines are characterized by the modular formation of induction heaters, the translational or reciprocating movement of the metal. In view of this, in recent years there has been increasing interest in the use of induction heating installations with traveling or rotating magnetic fields, in which both the thermal and mechanical effects of the magnetic field are useful [1-5].

Works on the application of traveling magnetic fields in induction heating facilities are conducted at the Ural Federal University. For example, the possibilities of creating flexible automated low-temperature induction heating lines for the release of steel sheets and heating of aluminum billets for subsequent pressure treatment are explored. The theoretical and experimental studies performed have revealed the main advantages of installations with a traveling magnetic field, which consist in the following:

1. The specific electromagnetic power transmitted from the inductor to the heated charge increases.
2. There is the possibility of purposeful use of electromagnetic forces to create production lines (heating and moving products in a traveling magnetic field, heating and tensioning of metal bands, etc.). On the contrary, the action of parasitic electromagnetic forces that occur in single-phase installations is eliminated.
3. Electromagnetic power in a heated metal in the case of a traveling magnetic field is distributed more evenly than in the case of a pulsed field, which causes the temperature to equalize.
4. There is an additional possibility of adjusting the heating parameters due to a change in the speed of movement of the heated products.
5. When three-phase inductors are used, the operation of the power supply system is improved by balancing the phases and increasing the power factor of the units.
6. The level of acoustic noise and vibration is reduced.

These advantages of induction heating in a traveling magnetic field are also noted by other researchers [1-5]. At present, the development of induction heating installations in a traveling (rotating) magnetic field is facilitated by the appearance of powerful three-phase sources of increased frequency and the appearance of high-coercivity permanent magnets, enabling the creation of energy-efficient induction heaters with a rotating magnetic field of controlled frequency. New possibilities arise when linear inductors with inadvertently traveling magnetic fields are used in induction heating lines, which besides heating can control the movement of the heated metal and it's positioning in the working zone [6]. This makes it urgent to develop research on induction heating devices based on linear induction machines (LIM) with opposite direction traveling magnetic fields.

II. OBJECT AND RESEARCH RESULTS

In Fig. 1. we show a linear induction machine with an inductor producing opposite direction traveling magnetic fields. The secondary element of such an LIM is an aluminum strip.

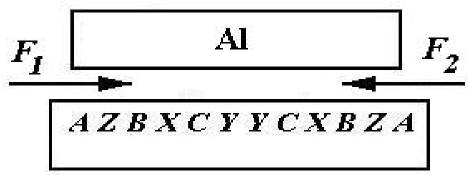

Fig. 1. LIM scheme with opposite direction traveling magnetic fields used for induction heating

The variable phase windings on the left and right sides of the inductor provides the creation of magnetic fields moving in the direction of the center of the coil and creating electromagnetic forces F1 and F2 acting on the aluminum strip (the secondary element of LIM). Controlling the scale of these efforts, it is possible to provide the necessary movement of metal in the working area LIM. When you download aluminum strip, moving from left to right, is selected by the force F1, which provides the movement of the metal above the inductor. When the billet enters the work zone, if the electromagnetic force (F1 = F2) are equal, then it is placed in the center of the inductor and is retained in the work area during heating. At the end of the heating currents in the left and right parts of the winding is adjusted so as to ensure the inequality of electromagnetic forces and unloading of the billet from the core in the desired direction. In the case of F1 > F2 heated billet moves to the right (on production line). If F1 < F2, the billet is unloaded to the left (in the settings package). Operation with movable billet can be performed at reduced voltage, since the power of LIM in mode of induction heating is much more power needed for mechanical movements.

In the laboratory of the Department "Electrical engineering and electrotechnological systems" of the Ural Federal University created several installations LIM, opposite direction traveling magnetic field. Their tests confirmed the ability to control metal movement in the working area of the machine and hold it over the inductor during the heating process.

Characteristics of LIM with a opposite direction traveling magnetic fields in mode of induction heating has not been studied. Therefore, the main attention was paid to the assessment of the distribution of power dissipation along the length of the billet and the temperature distribution. For the study were selected four-pole LIM division of the poles $\tau = 102$ mm, power up to 2000 VA. The machine has single-layer winding embedded in the groove 24. Such winding ensures the creation of pulsating magnetic field (single-phase power supply), and traveling magnetic fields (three-phase power supply). The basic scheme of stacking of the coils of the windings that create different magnetic fields are shown in the table.

TABLE 1 VARIANTS OF SCHEMES OF STRAINING THE COILS OF THE WINDS OF THE INVESTIGATED LIM

1	**The pulsating magnetic field (PF)**	**AAAAAAXXXXXXAAAAAAXXXXXX**
2	**Traveling magnetic field (TMF)**	**AAZZBBXXCCYYAAZZBBXXCCYY**
3	**Opposite direction traveling magnetic field (1c)**	**AAZZBBXXCCYYYYCCXXBBZZAA**
4	**Opposite direction traveling magnetic field (4c)**	**AAZZBBXXCCYYBBZZAAYYCCXX**

The first stage was carried out theoretical studies. LIM calculations for induction heating of the aluminum strip was performed using the mathematical software package ELCUT. During the electromagnetic analysis was to determine the distribution of the electromagnetic forces along the length of the strip obtained by the electromagnetic force and the power dissipation in the various sections of the band. in Fig. 2 shows the distribution of the dissipation along the length of the strip for the winding circuits are shown in the table. 1.

In Fig. 2 that the heating in a pulsing field is characterized by the uneven distribution of power dissipation (curve 1). When heated in a traveling magnetic field power distribution is more uniform (curve 2).

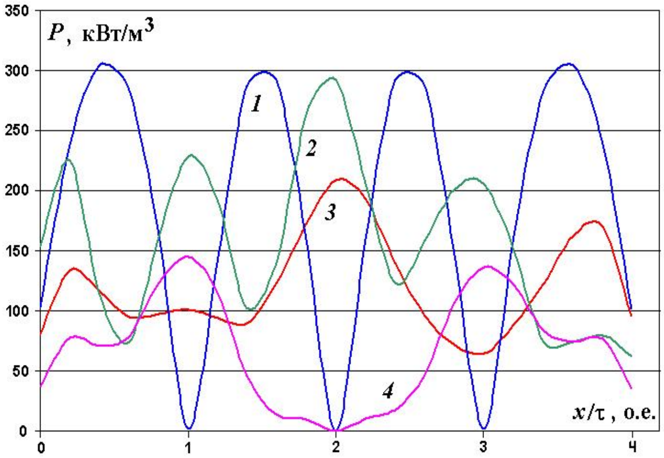

Fig. 2. The power distribution along the length of the aluminum strip

Studies have shown that the distribution of scattered power by heating in the opposite direction traveling magnetic fields depends essentially on the layout of the coil. While LIM-the distortion of the magnetic field is most pronounced in the Central zone of the inductor. Curve 3 in figure 2 corresponds to the symmetrical arrangement of coil windings with the left and right sides of the inductor (option 3 in table 1). The appearance of additional component of the pulsating field increases the power dissipation in the Central part of the inductor and a slight decrease in power at the edges of the strip. The level of power dissipation and irregularity of its distribution along the length of the strip in variants 2 and 3 are comparable. The calculations pending magnetic fields, corresponding to option 4 LIM, indicate the possibility of obtaining an unfavorable outcome. The distortion of the magnetic field in this case leads to a significant reduction in power dissipation in the Central part of the strip (curve 4 in Fig. 2).

The calculated power dissipation obtained using the electromagnetic analysis were used in subsequent thermal calculations. In this case, during heating determines the temperature distribution along the length of the aluminum strip and evaluated by the uneven heating of different parts of the strip. in Fig. 3 shows the time variation of the relative deviation of the temperature of various parts of the strip from its average value. The relative deviation of the temperature □□ determined by the formula:

$$\delta\theta = \frac{\theta_{max} - \theta_{min}}{\theta_{aver}},$$

where θ_{max} and θ_{min} - are the maximum and minimum temperatures for the strip length, θ_{aver} - is the average temperature.

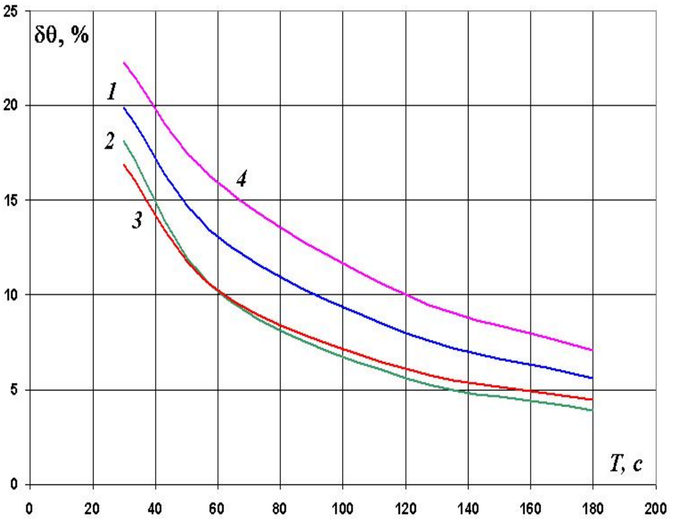

Fig. 3. The change in temperature along the length of the aluminum strip by heating in various magnetic fields (numbers in the graphs correspond to the parameters in table 1)

The non-uniform temperature distribution along the length of the strip corresponds to the calculations obtained in calculating the power dissipation. The strip heating in the working magnetic field (curve 2) and heating in the opposing magnetic field in variant 3 of the table. 1 (curve 3) is characterized by a smaller temperature change from the mean value than heating in a pulsed field (curve 1). When the heating length increases, the temperature along the strip length is equalized by heat transfer processes. However, when using a pulsed magnetic field after three minutes of warm-up, the temperature remains high (about 6.5%).

It can be noted that the option of heating in opposite direction traveling magnetic fields by the scheme of coils 4 (table. 1) is characterized by the largest temperature deviations along the length of the strip (curve 4 in Fig. 3).

CONCLUSION

In order to obtain high quality of billets by organizing the required distribution of temperature field in the billet volume a traveling wave heating system is offered. The studie of induction heating devices in a traveling magnetic field allow us to draw a number of conclusions:

- demonstrated the possibility of creating two-purpose LIM, combining the functions of moving and heating metal products and blanks;

- shows the possibility of using in induction heating devices in a traveling magnetic field linear inductors with opposite direction traveling magnetic fields;

- it is confirmed that induction heating devices in a moving magnetic field provide a more even distribution of the power dissipated and the temperature of the heated band than the setting of the pulsating field;

- when using induction heating LIM with a counter-so field, you must carefully approach the choice of the scheme of laying the turns on the inductor.

In general, the results of the studies confirmed the advantages of induction heating in a moving magnetic field and the need to develop studies on the characteristics of linear induction machines with counter magnetic fields.

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