Research of heat mode of linear permanent magnet motor for Long –Way one stage piston compressor

A A Tatevosyan
Omsk State Technical University, 11, Mira ave., Omsk, 644050, Russia

Abstract. The paper discusses one of the design stages of an electrical complex of a linear motor of a low-speed long-stroke piston compressor based on a permanent magnet synchronous motor (SMPM). The article concerns with studying the thermal regime of the magnetic system. The temperature regime up to 80 \(^\circ\)C is the limitation for the use of permanent magnets of the N40 series based on the NdFeB alloy, consequently the problem of determining the amount of heat released by the winding is urgent. To study the thermal regime, a prototype of a linear permanent magnet motor was developed and tested with a long-term current flow of 5 A. The efficiency of using a sectioned winding divided into eight coils especially when the coils switched in two pairs is shown.

1. Introduction

Permanent magnet (PM) motors are rapidly replacing the dominant induction motors in industrial applications including pumps, fans, and compressors. Compared to induction motors, PM has higher efficiency.

Considering that long-stroke piston compressors using a hydraulic motor are widespread in industry and to justify the use of the basic design of a linear permanent magnet motor (LPMM) of low-speed long-stroke single-stage piston compressors, we will indicate a number of advantages over hydraulic drives:

- the absence of a hydraulic subsystem significantly expands the range of operating conditions, this is especially true for cases where piston compressors are used at low temperatures;
- a feature of the LPMM is the linear dependence of the developed force of the motor created by the armature on the current in the winding of the linear magnetoelectric motor. It allows to simplify the control system and make it closed, providing the law of armature motion implementation;
- an interacting of the actuator (motor inductor) and the working machine (piston) increases the reliability of the LPMM, simplifies the manufacturability of assembly and increases maintainability.

At the same time, the design and creation of the LPMM of a single-stage reciprocating compressor seems to be a task that has a number of features [1-4]:

- due to the fact that the electromechanical converter and the working machine are coordinated, the design of the drive must be strictly subordinated to the load requirements;
- the variety of design forms of the LPMM magnetic systems, fluctuations in the magnetic flux and the complex interconnection of physical processes occurring in various drive subsystems necessitate the use of a complex mathematical apparatus.

Of particular relevance is the task of developing a long-stroke piston compressor, which creates pressure up to 10 MPa in one piston stage [5, 6]. The solution to this problem became possible with the arrival of high-energy permanent magnets with a coercive force of more than 900 kA / m.
The search for optimal designs of LPMM magnetic systems for a low-speed piston compressor is a complex creative task that requires further consideration.

2. Problem Statement

Of particular interest is the problem of thermal calculation of a linear magnetoelectric motor (LPMM) as part of a piston compressor drive. Heat losses in the LPMM windings reduce the efficiency, affect negatively to the permanent magnets N40 of the inductor (demagnetization temperature 800 C), and also accelerate the wearing process of the insulation. In this regard, the study of the thermal regime is a key task in the development and design of LPMM. To carry out an experiment we use a prototype LPMM model, containing eight coils and 48 permanent magnets of a prismatic shape 50x50x25. Winding parameters: active resistance of one coil is 4 Ohm, inductance is 100 mH, and the inductance of a coil installed in the magnetic system with a located inductor increases to 206 mH. Fig. 1 shows the appearance of the LPMM [7].

Simulation modeling of the thermal regime is performed in the ELCUT 6.0 software as a related task of calculating the electromagnetic and thermal fields.

3. Theory

Calculation of two-dimensional stationary magnetic fields of the Finite Elements Method is performed with using the differential equation of heat conduction [8,9], that has the following form in Cartesian system.

\[
\frac{\partial}{\partial x}\left(r_x \frac{\partial T}{\partial x}\right) + \frac{1}{r} \frac{\partial T}{\partial x} + \frac{\partial}{\partial y}\left(\lambda_y \frac{\partial T}{\partial y}\right) = q, \quad (1)
\]

under given boundary conditions

\[
\lambda_x \frac{\partial T}{\partial x} e_x + \lambda_y \frac{\partial T}{\partial y} e_y - \alpha (T - T_{oc}) = 0, \quad (2)
\]
where \( \lambda_x \), \( \lambda_y \) – thermal conductivity at the current point of the computational domain in the direction of coordinates \( x \) and \( y \); \( T(x, y) \) – temperature distribution function; \( q \) – bulk density of heating sources; \( e_x \), \( e_y \) – directing cosines of the heat-transfer surface normal with reference to the coordinate axes; \( \alpha \) – heat transfer coefficient by convection into the environment; \( T_{\infty} \) – ambient temperature.

4. The Experimental Research

Winding connection diagram consists of two groups of four coils. Coils in a group are connected in series. The groups are connected in series in opposite directions. The winding direction in the two groups is different.

- + output of the source is connected to the coil start terminal 1.
- - output the source is connected to the coil end terminal 8.

Cooling of the windings is natural.

The temperature was measured by two independent instruments: a mercury thermometer and an M890C instrument. The induction was measured with a TPU device.

Ambient temperature is 27 °C.

At the beginning of the experiment: the current in the motor winding is maintained at 5 A; the voltage applied to the winding is 149.3 V; the power delivered by the source is 780 W.

At the end of the experiment: current in the winding is under 5 A; voltage supplied to the winding is 183 V; the power supplied by the source is 930 W.

An average value of induction in the winding area \( B \) is 44 mT.

The result is shown in Fig. 2.

![Figure 2](image)

**Figure 2.** Experimental study of the temperature in the inductor zone at constant current in the winding 5 A

Thus, it is advisable to apply an operation mode when only four coils in series are used. The operating diagram and connection circuit of LPMM coils are given in Fig. 3.
Figure 3. Timing diagram of operation (a) and connection coils diagram (b).

Fig. 4 shows the experimental static characteristics of the electromagnetic force for various combinations of the operation of the armature coils, obtained on the developed prototype LPMM.

Figure 4. Static characteristics of a LPMM with a different number of series-connected armature coils (1 – 4 coils, 2 – 6 coils, 3 – 8 coils): a – electromagnetic force, b – power consumed by the LPMM.

5. Conclusion

The research carried out in the article results in the possibility of applying the method of designing a LPMM, implemented in the form of software. The conducted study of the thermal regime indicates the advisability of using a sectioned winding and sequential switching of the coils. This approach leads to an increase in attractive effort and reduces electrical and heat losses, which in turn increases the efficiency of the LPMM.

6. References

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