Calculation And Simulation Of Slow-Moving Linear Magnetoelectric Drive Of Single-Stage Piston Compressor

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Abstract. The paper proposes an approach to the creation of an energy-efficient slow-moving linear magnetoelectric drive of a long-stroke single-stage piston compressor. The problem of optimal design of the magnetic system of the magnetoelectric motor of reciprocating action satisfying the criterion of the maximum of the developed electromagnetic force while ensuring the minimum mass of the active materials used is solved. A mathematical model for calculating the dynamics of a linear magnetoelectric drive is presented and the results of modeling dynamic starting characteristics are presented.

1. Introduction

Considering that long-stroke piston compressors using a hydraulic type motor have become most common in the industry, to justify the basic design of slow-moving a linear magneto-electric drive (LMED) of long-stroke single-stage piston compressors, we will indicate a number of advantages over hydraulic drives:

– absence of hydraulic subsystem significantly expands the dia-slot of operating conditions, especially for cases of piston compressors at low temperatures;
– feature of LMED is linear dependence of developed force of motor created by armature on current in winding of linear magnetoelectric motor, which makes it possible to simplify control system and make it closed, providing necessary law of armature movement;
– organic fusion of the actuator (engine armature) and the working machine (piston) into a single unit increases reliability of the LMED, simplifies the workability of the assembly and increases repairability.

However, the design and construction of a single-stage piston compressor LMED appears to be a task with a number of features:

– since the electromechanical converter and the working machine are a whole, the design of the drive as a whole must be strictly subject to the requirements of the load;
– variety of forms of design versions of magnetic systems of linear magneto-electric motor, nonuniformity of magnetic flux and complex interaction of physical processes in different drive subsystems make it necessary to use complex mathematical apparatus.

2. Problem statement

Of particular relevance is the task of developing a reciprocating long-run compressor, which produces up to 10 MPa in one piston stage [1, 2]. The solution of the task was made possible by the emergence of high-energy standing magnets having a coercive force of more than 900 kA/m.
Finding optimal LMED magnetic system designs for a slow-moving piston compressor is a difficult creative task and in light of the emerging trend towards the introduction of magnetoelectric machines in various industries requires further consideration [3-6].

Consider the functional diagram of LMED (Fig. 1) and the design of the magnetic system of the linear magnetoelectric motor [7, 8].

![Diagram of LMED](image)

Figure 1. The functional scheme of LMED: PSS – power supply system; EC – electric converter; EMD – electromotive device; A – the actuator; WM – working machine; CD – control device

Control and adjustment device supplies voltage to winding of linear magnetoelectric motor in accordance with specified law of armature motion. For long-stroke LMED, the oscillation frequency does not exceed 3 Hz, which determines the drive type as slow-moving.

The basic methods of measuring the position speed using the incremental position sensor and the principles of creating systems for monitoring the electromechanical complex are given in [3, 4].

Calculation and design of linear magnetoelectric motor for piston compressor drive shall be carried out for initial data given in Table 1.

Table 1. Initial data for calculation of LMED magnetic system

| Parameter                                | Value       |
|------------------------------------------|-------------|
| Diameter Of The Piston, mm               | 20          |
| Design Generated Pressure, MPa           | 10          |
| Linear Current Load, A/m²                | 4 x 10⁴     |
| Average Value of Induction, T            | 0.5         |
| Voltage Frequency, Hz                    | 1-3         |
| Form-factor of a permanent magnet        | 50x50x25    |
| Half Of Armature Stroke, mm              | 100         |
| Coil Number For Two Poles Anchor         | 8           |

3. Construction
The results of calculation of optimal LMED design based on maximum developed force are given in the program window, Fig. 2. [5]. Optimization of parameters of magnetoelectric drive of oscillatory motion is shown below.

Using the results of calculation of optimal magnetic systems LMEP for driving slow-moving single-stage piston compressor allows to determine the basic design of the magnetic system and to perform its solid-state model in the software SolidWorks 2017 (Fig.3).

In order to reduce joule losses, the motor winding is divided into 16 coils, which allow the control device to switch them along the motion of the armature.

4. Modeling

The mathematical model of LMED is represented by equations (1)

\[
\begin{align*}
\frac{di_s}{dt} &= \frac{1}{L_w} (u_s - i_s R_w - c_e \dot{\theta}) \\
\frac{dx}{dt} &= \dot{\theta} \\
\frac{dV}{dt} &= \frac{1}{m} (c_m i_s - F_l)
\end{align*}
\]

where \(i_s\) – current in motor winding; \(L_w, R_w\) – motor winding parameters; \(c_e, c_m\) – constant, determined by numerical calculation of LMED magnetic field; \(\dot{\theta}\) armature movement speed, m/s; \(m\) – armature mass, kg; \(F_l\) – counteractive force of compressed gas, N.

Figure 2. Results of magnetic system parameters calculation

Figure 3. Magnetic system of linear magnetoelectric motor
On this basis, in order to build a mathematical model of individual subsystems of LME and the drive as a whole, we will adopt the following assumptions:

- power supply source and LME control system provides the specified sinusoidal law of current change in the motor winding

\[ i_s = I_m \sin(\omega t) \]  

(2)

- pressure electromagnetic tool developed on LME rod and anti-EMF in the motor winding do not depend on armature travel and are derived from expressions

\[ F_{em}(t) = C_m i_s \, , \quad e(t) = C_e \, \vartheta \, , \]  

(3)

- to take into account the nonlinear properties of the compressed gas medium in the cylinder of the piston compressor in the LME model, we will use the expression for the reaction force of the compressed gas:

\[ F = x_s^{1.4} \cdot 10^{-2} \frac{\pi d^2}{(x_s - x)^{1.4}} \, , \]  

(4)

where \( x_s \) – armature final position, mm; \( d \) – armature diameter, mm; \( x \) – armature current position, mm.

5. Results and Conclusions

The results of calculation of dynamic launch mode of LME are given in Fig. 4.
Figure 4. Results of dynamic characteristics calculation at LMED start-up: a – current in the winding; b – speed and movement of armature; c – developed force and counteraction force; d – power consumption in electromagnetic and electromechanical subsystem

As a result of the carried out studies, the technique of optical-optimal design of the magnetic system of the linear magnetoelectric drive and its software implementation have been developed. Proposed is a const-sleeve of a linear magnetoelectric drive part of a LMED of a ti-hop length-travel single-stage piston compressor, which realizes a given law of motion of an armature and a given electromagnetic force developed.

6. References

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