Секція 4. ХОЛОД В ЕНЕРГЕТИЦІ, ПРОМИСЛОВОСТІ ТА НА ТРАНСПОРТІ, ЯК ПЕРЕДУМОВА ПІСЛЯВОЄННОГО ВІДНОВЛЕННЯ КРАЇНИ

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DEVELOPMENT OF A METHODOLOGY FOR CALCULATING THE CHARACTERISTICS OF HERMETIC COMPRESSOR UNITS IN TRANSIENT MODES

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Abstract. Calculation of transient modes of hermetic compressor units of ship systems of microclimate and refrigeration was carried out. The mathematical model of hermetic compressor units in transition operation is described. The method, results of calculation and estimation value of rated slip, maximum and initial starting torque of built-in electric motor are presented.
Keywords: hermetic compressor unit (HCU), the mathematical model, transition operation of HCU.

Introduction. One of the most common types of equipment for microclimate and refrigeration systems on sea and river-going ships is autonomous air conditioners (AC) and monobloc refrigerating machines for provisional storerooms (RMP) with compression refrigeration machine (CRM). The most important element of a CRM is the hermetic compressor unit (HCU), which largely determines the reliability, economy, weight, size and vibration-noise characteristics of the AC and RMP. Therefore, among the areas of science and technology, work on the development and improvement of HCU, which involves a large amount of theoretical and experimental research, is important [5].

Nowadays autonomous air conditioners (AC) are widely used on ships with new principles of propulsion, where to reduce the weight and dimensions of power plant, auxiliary mechanisms and systems it is reasonable to use alternating current at a frequency of 400 Hz. One of the most difficult problems in creation of AC of these ships is development of HCU with electric motor at 400 Hz [5].

One of the tasks of designing hermetic compressor units (HCU) is to determine the main parameters (rated slip, maximum and initial starting torque) of the built-in electric motor, the knowledge of which allows, at the early stages of design of HCU, to set the parameters of mechanical characteristics of the developed electric motor. There are no reliable theoretical methods for solving this problem, and the practical recommendations for open (gland) machines are not applicable to HCU, distinguished by design features and specific operating conditions [1, 2].

Aim. The aim of the work is to develop a methodology for calculating the characteristics of a HCU in transient modes and to determine the parameters (rated slip, maximum and initial starting torque) of the electric motor under development.

Main material. The authors have developed a mathematical model to calculate the transient modes of the HCU depending on the design and operating conditions, to estimate and specify the parameters of the mechanical characteristic of the built-in electric motor.

The mathematical model and calculation of the transient modes of the HCU is based on the following basic assumptions and assumptions: 1. Suction pressure (p_s) and discharge pressure (p_d) are constant, i.e. p_s = const, p_d = const. 2.The thermodynamic system is homogeneous, i.e. the gas pressure is constant at all points in the suction (p_s) and discharge (p_d) side of the HCU cavities at any given time. The simultaneity of changes in refrigerant parameters over the entire volume is maintained.3. The continuity of the medium is respected, i.e. $l/L << 1$ (here l is the free path length of the molecule; L is the characteristic size of the system). 4. The change in potential and kinetic energy of the gas is negligibly small. 5. There is no heat exchange between the gas and the walls of the cylinder. 6. The discharge process ends at an angle of rotation φ = 0° (360°) and the suction process ends at an angle of rotation φ = 180°. 8. The change in the amount of gas in the cylinder occurs: during compression due to leakage through the piston-cylinder gap (hereinafter referred to as leakage), during discharge due to leakage and outflow of gas through the discharge valve, during suction due to leakage and inlet of gas through the suction valve. 9. It is assumed that when pressure equalises in the cylinder and in the suction (discharge) cavity, the suction (discharge) valve opens momentarily.

The model is based on the equation of motion of the machine unit, which, for HCU, can be written with a fair degree of accuracy as [3].

$$M_{\mathrm{D}} - M_R = I_r \frac{d\omega}{d\tau}. \qquad (1)$$

where M_{D} - torque developed by the driving forces (electric motor); M_{R} - torque spent on overcoming useful and harmful resistances of the compressor; I_r - reduced moment of inertia of masses driven in motion; ω - angular velocity; τ - time.

Equation (1) can only be solved when the motor torque and drag torque are known functions of rotation speed, i.e. $M_{\mathrm{D}} = f_1(\omega)$ and $M_{\mathrm{R}} = f_2(\omega)$. Since the drag torque of a piston HCU is a function of the rotation angle $M_{\mathrm{R}}(\varphi)$ and the driving force torque for an electric motor is a function of the angular velocity $M_{\mathrm{D}}(\omega)$, equation (1) can be solved, for example, numerically.

The result is a system of equations describing the operation of the HCU in starting modes and establishing relationships of the form:

$$M_{\mathrm{D}} = f_1\,(\omega, \omega_0, M_{\mathrm{m}}, s_{\mathrm{s}}, s_{\mathrm{ns}}, a, M_{\mathrm{S}}, \beta_1, \beta_2, \omega_{\mathrm{c}}, U_{\mathrm{ph}}); \qquad (2)$$

$$M_{\mathrm{R}} = f_2\,(\varphi, \Delta\varphi, D_{\mathrm{p}}, S, a_{\mathrm{d}}, I_{\mathrm{red}}, \lambda, \Delta, L, \mu, w_{\mathrm{p}}, j_{\mathrm{p}}, p_{\mathrm{d}}, p_{\mathrm{s}}, p_{\mathrm{f.m}}, M_{\mathrm{f.r}}, p_{\mathrm{beg}}, t_{\mathrm{beg}}, \varphi_{\mathrm{beg}}), \qquad (3)$$

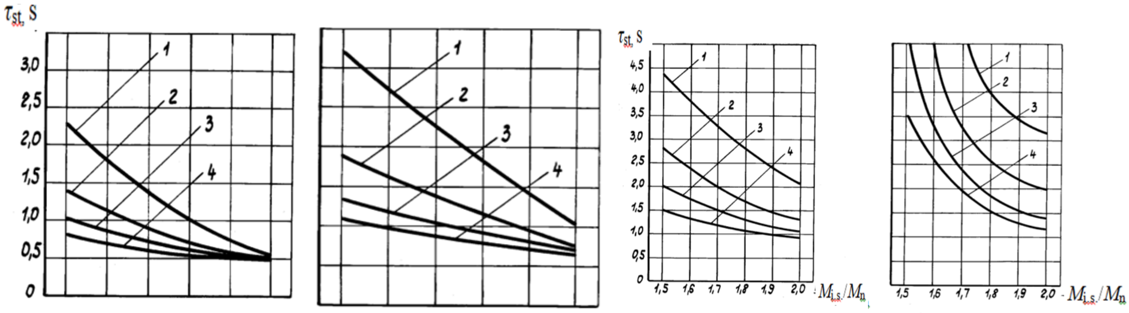
where ω_0 - synchronous angular speed of electric motor; M_{m}, s_{s}, s_{ns} - critical (maximum) moment developed by electric motor and corresponding to it slip, nominal slip; M_{S} - starting moment of electric motor; a, β_1, β_2 - dimensionless parameters of electric motor mechanical characteristic depending on active and reactive resistance of stator and rotor winding phases; ω_{c}, U_{ph} - angular frequency and amplitude value of phase voltage; φ, $\Delta\varphi$ - angle of shaft rotation and angle increment (step of integration); D_{p}, S - diameter and stroke of piston; a_{d} - relative volume of dead space; λ - ratio of piston stroke to the doubled length of connecting rod; I_{red} - reduced moment of inertia; Δ - radial clearance between piston and cylinder; L - piston length to oil wiper groove; μ - coefficient of dynamic viscosity of gas (steam); w_{p}, j_{p} - piston speed and acceleration; p_{d}, p_{s} - discharge and suction pressure; $p_{\mathrm{f.m}}$, $M_{\mathrm{f.r}}$ - average friction pressure of progressively moving parts (piston, connecting rod part) and average friction torque of rotation; p_{beg}, t_{beg}, φ_{beg} - gas pressure and temperature in the cylinder and shaft angle of rotation (piston position) at the beginning of calculation.

In order to verify the adequacy of the model, the results of calculation of transient modes of HCU were compared with the experimental data. The comparison allows us to conclude that this mathematical model accurately reflects the physical essence of the processes that occur during HCU start-up.

To evaluate the starting characteristics of the HCU, a graph is calculated and plotted showing the dependence of the starting time τ_{st} on the multiplicity of the initial starting torque $M_{i.s.}/M_v$ of the built-in electric motor at different piston-cylinder clearances 2Δ, rated and undervoltage of the supply network. The calculation is carried out for several maximum (critical) torque values of the built-in electric motor in order to select a rational variant.

On fig. 1 shows such dependences for the compressor unit KHGV-14 (two-cylinder, cylinder diameter 50 mm, stroke 24 mm, speed 66,7 s^{-1} at frequency 400 Hz) at a multiple of maximum moment of the built in electric motor, equal to 2,5. Starts were calculated at temperatures t_0 = 10 ºC, t_c = 55 ºC. A position of pistons before start-up was chosen taking into account the most probable range of angles at stopping of HCU [4]. The start-up was considered successful if its time did not exceed 5 s.

It can be seen from the graphs that the start-up time is virtually independent of the value of 2Δ when the motor torque is significantly higher than the motor resistance torque (Fig. 1, a, multiplicity of starting torque 2) at nominal mains voltage. As the torque decreases (with decreasing electrical voltage and $M_{i.s.}/M_v$) the start-up time depends significantly on the value of 2Δ, which is confirmed experimentally. It can be seen from Fig. 1, that with a minimum gap of 12 micron and a voltage of 10% below the nominal voltage (normally a greater voltage drop is not observed on courts) the KHGV-14,0 starts up with a multiple of $M_{i.s.}/M_n$ = 1,5 (Fig. 1, c). When the voltage drops to $0{,}85U_n$, the required multiplicity $M_{i.s.}/M_n$ should be increased to 1,9 ... 2.



a ***b*** ***c*** ***d***

Fig.1. Dependence of start-up time τ_{st} of compressor unit KHGV-14 on multiplicity of initial starting torque ($M_{i.s.}/M_n$) of the built-in electric motor (multiplicity of maximum torque equals 2,5):

a - nominal supply voltage $U = U_н$; ***b*** - U = $0{,}95U_н$; ***c*** - U = $0{,}9U_н$; ***d*** - U = $0{,}85U_н$;

1 - diameter gap 2Δ = 12 micron; 2 - 16 micron; 3 - 20 micron; 4 - 25 micron

Conclusions. The parameters of the built-in electric motor (rated slip, maximum and starting torque) determine the volumetric and energy performance, temperature level and durability of the hermetic compressor. Therefore, when designing the latter, due consideration should be given to the choice of electric motor.

The developed mathematical model of transient modes of one- and two-cylinder HCU allows to calculate and estimate parameters of mechanical characteristics of designed electric motors from operating conditions and design features of HCU. The calculated starting characteristics for HCU with 400 Hz power supply are presented.

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ELECTRICAL LOSSES OF HERMETIC COMPRESSOR UNITS FOR MARINE AIR CONDITIONING

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Abstract. Special studies have been carried out that evaluate the electrical losses of hermetic compressor units for marine air conditioning. Experiments were carried out in a certain sequence. The electrical losses of the hermetic compressor units (HCU) were estimated from the efficiency of the built-in electric motors of the high-speed compressors. It has been experimentally established that the efficiency of built-in electric motors of the high-speed (shaft rotation frequency 50 rps and more) HCU of ship air conditioning equipment, operating in the power range of 0,7 ... 1,2 nominal, practically coincide with the test results of these electric motors under uniform electromagnetic load, brake, in contrast to the built-in HCU motors of the same performance, but with a shaft rotation of 25 rps, in which the efficiency is reduced.
Keywords: hermetic compressor unit (HCU), experiment, electrical losses, efficiency, electric motors, shaft rotation frequency.

Introduction. The main characteristics of the hermetic compressor unit (HCU) largely depend on the built-in electric motor. In turn, the indicators of the built-in electric motor significantly depend on the characteristics HCU, with which it has a common shaft, housing and casing. Majority HCU – these are one- and two-cylinder machines, characterized by a significant uneven change in load (opposing moment). At HCU with shaft rotation frequency 25 rps this causes a large ripple in the built-in motor torque, which leads to a decrease in its efficiency and therefore worsens energy performance HCU.