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Development of the Mathematical Model of Thermal Processes in the Controlling Loop of the Hydraulic Power Unit of the Quarry Combine

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ABSTRACT: The paper presents the results of development of a mathematical model of thermal processes in the regulating circuit of a hydrostatic power plant career combine. , in order to develop a multiparameter model of technological loading and the choice of the parameters of the "hydraulic tank-cooler" system of the hydrostatic power unit of a mining machine, depending on the characteristics of its technological loading and the temperature range that is typical for the quarries of Central Asia.

KEYWORDS: quarry combine (harvester), working fluid, hydraulic tank-cooler, thermal processes, hydrostatic power plant, working chamber, thermal equivalent.

I.INTRODUCTION

The mining industry of the Republic of Uzbekistan is one of the leading industries based on a powerful mineral resource base. For a number of important minerals, for example, such as phosphorites in Uzbekistan, according to confirmed reserves and the prospects for their increase, it not only occupies a leading position in the CIS, but also is one of the top ten countries in the world. The main reserves of phosphorites are concentrated in the Jeroy-Sardarinsky deposit of the Central Kyzylkum region of Uzbekistan.

The increase in volumes and nomenclature of extraction of phosphorite ore can be achieved on the basis of the creation of an effective cooling system for the working fluid that provides the temperature adaptation of the hydrostatic transmissions of all mechanisms of a mining machine in the high temperature range which is typical for quarries in Central Asia.

Therefore, in order to develop a multiparameter model of technological loading and the choice of the parameters of the "hydraulic tank-cooler" system of the hydrostatic power unit of a mining machine, depending on the characteristics of its technological loading and the temperature range that is typical for the quarries of Central Asia, we developed a mathematical model of thermal processes in the regulating circuit of a hydrostatic power plant career combine.

II. METHODOLOGY

When the working fluid (WF) passes through the regulating circuit (RC), its temperature rises. The increase in temperature is equal to the difference between the average temperatures of fluid flows passing through the RC. The balance of capacities, for which is expressed by the equation:

$$N_{inp} - N_{out} = E, \tag{1}$$

Where N_{inp}, N_{out} are input and output power of a hydrostatic power plant of a mining combine, respectively, W;
E is the thermal equivalent of the lost power generated by the RC of the hydrostatic power plant of a quarry combine, [3].

It is assumed that the thermal processes occurring during the operation of the RC are adiabatic, and the heat removal to the external medium from the hydro elements of the PK is absent (equal to zero). The assumptions made are correct,

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since they assume heavier circuit conditions than real ones. This in the calculation provides its temperature "reserve" to 6-8% [1].
In turn, the output power of the RC is related to the input known relation:

$$\mathrm{N}_{out} = \mathrm{N}_{inp}\eta\,,\ \mathrm{W}, \tag{2}$$

where: ηisthe overall efficiency of the RC element.
Consequently, the expression (2) taking into account the dependence of the thermal equivalent of the lost hydrostatic power transmission takes the form:

$$N_{out}\left(\frac{1}{\eta}-1\right)=\rho c_1 Q_T \Delta t^0, \tag{3}$$

here: Δt^0 is the temperature difference of WF between the input and output from the hydrostatic power unit of a mining machine, deg;
N_{out} is output power of the hydrostatic power plant of a mining machine, W, equal to

$$N_{out}=(P_h - P_{low})[Q]_H,\ \text{Вт}, \tag{4}$$

where: P_h, P_{low} are pressure in high and low hydrolines of RC of the hydrostatic power plant, respectively, Pa;
$[Q]_n$ is the nominal outlet flow of the WF in the hydrolysis of RK of the power plant of a quarry combine, m^3/s;
From the equation (3), taking into account expression (4) it follows that the temperature difference WF - Δt^0 between the input and output from the hydrostatic power unit of a mining machine is determined by the dependence:

$$\Delta t^o = \frac{P_h - P_{low}}{\rho c_1}\left(\frac{1}{\eta}-1\right)\left(\frac{Q_T}{[Q]_n}\right)^{-1},\ \text{deg}, \tag{5}$$

here: Q_T - the conditioning flow of the WF replenishment of RC, m^3/s
It is known that the effect of changing the share of external leaks in the overall balance of volumetric losses as a result of the wear of the pump (motor) should be taken into account in analyzing the thermal processes in RC [2] of a hydrostatic power plant.
Let us consider in detail the flows of external and internal volumetric leaks during the operation of hydraulic machines of the RC of the hydrostatic power plant.
In accordance with the results obtained in [1, 2], the values of the external volume losses (Q_{yi}) in the operation of hydraulic machines of the PK are determined as follows:
- in the pump

$$Q_{ун} = [Q]_n (1-\eta_h)\frac{P_h - P_{low}}{[P]},\quad m^3/s; \tag{6}$$

- in the motor

$$Q_{ум} = k_N [Q]_n (1-\eta_h)\frac{P_h - P_{low}}{[P]},\quad m^3/s; \tag{7}$$

- in the RC

$$Q_{ук} = (1+k_N)[Q]_H (1-\eta_в)\frac{P_B - P_H}{[P]},\quad m^3/s; \tag{8}$$

where: [P] is setting pressure of the safety valve of RC of the hydrostatic power plant, Pa;
k_N - coefficient equal to the ratio of the volume constant of the pump q_H to the volume constant of the hydraulic motor - q_M RC.
With simultaneous operation of several RCs, it is defined as the weighted average value

$$\tilde{k}_N = \sum_{1}^{к} \alpha_0 \psi_{Цi} k_{Ni}, \tag{9}$$

where: k - number of simultaneously activated RC of the hydrostatic power plant, units;
So, in the mode of "excavating the rock layer" k = 3, and in the "turn" mode, k = 2.

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$\psi_{Цi}$ - weight coefficients of the relative duration of activation of the RC during the cycle of operation of a quarry combine.
So, in the mode of "excavating the rock layer" $\psi_{Ц} = K_3$, but in the mode of "turn" $\psi_{Ц} = 1 - K_3$.
α_0 is a coefficient that takes into account the combination of the operation of the working cycle of a mining machine, $\alpha_0 = 1$.
η_{in} is internal volumetric efficiency of hydraulic machines of the RC
As a mathematical model of the thermal processes taking place in the RC, we take the thermal equivalent - E (W) generated in a hydrostatic power unit of a quarry thermal power harvester.
The value of the above-mentioned heat losses, E (W), is the difference in the heat fluxes emerging from the reactor and entering into it from the injection manifold.

$$E = \rho c_1 Q_0 t^0_{об} + \rho c_1 Q_{ук} t^0_{ук} - \rho c_1 Q_T t^0_T, \text{ J/s}, \tag{10}$$

where: Q_0 is the flux of the RG emerging from the WF, m^3/s.
$Qук$ - the flow of external volumetric leakage of WF from RC, m^3/s;
$t^0_{об}$ - temperature of the flow of WF coming from the RC to the system "hydraulic tank-cooler", deg;
$t^0_{ук}$ - temperature of the flow of external volumetric leaks from RC, deg;
t^9_T - the temperature of the conditioned flow of WF entering the RC, deg.

$$Q_T = Q_{ук} + Q_0. \tag{11}$$

Taking into account(11), equation (10) takes the form

$$E = \rho c_1 \left[Q_T \left(t^0_{об} - t^0_T \right) + Q_{ук} \left(t^0_{ук} - t^0_{об} \right) \right], \text{ J/s}. \tag{12}$$

III. EXPERIMENTAL RESULTS

To analyze the thermal processes in the regulating circuit of the hydrostatic power unit of a mining machine, a schematic diagram of the heat flows was compiled, which is shown in Fig. 1.
Next, let us consider in detail the balance of heat flows at the point "H" (Figure 1), which, taking into account the expression (12) after the corresponding algebraic transformations will be:

$$[Q]_H D_H t^0_1 = Q_T t^0_T + [Q]_H D_H t^0_{об} - Q_T t^0_{об}, \tag{13}$$

from where,

$$t^o_{об} - t^o_T = \left(\frac{Q_T}{[Q]_H} \right)^{-1} D_H \left(t^o_{об} - t^o_1 \right), \tag{14}$$

Where, t^0_1 - temperature of heat flow at the entrance to the pump RC, deg.

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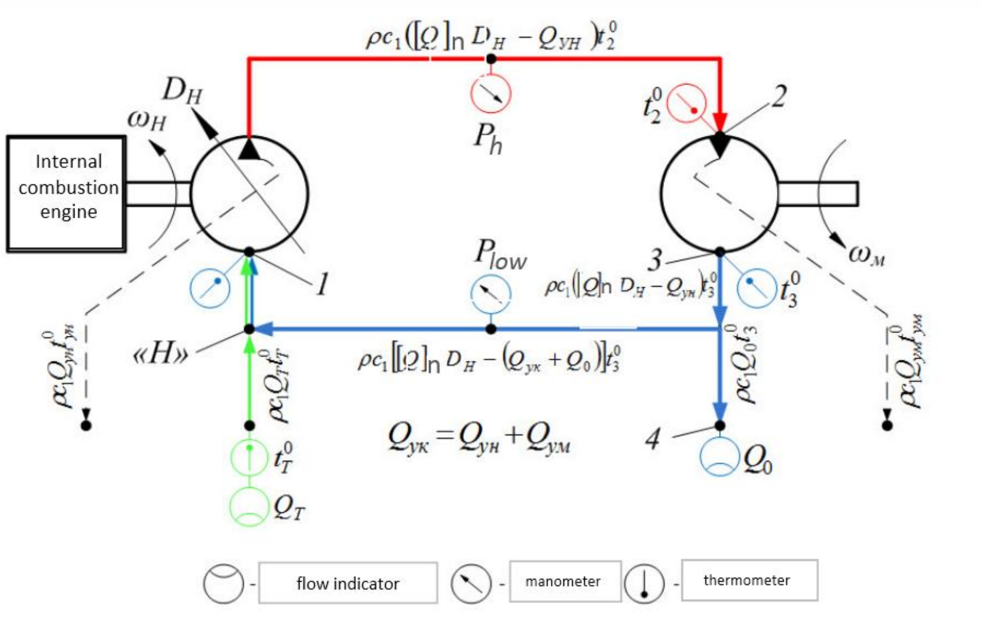

Figure 1. Scheme of heat flow of working fluid in the regulating circuit of a hydrostatic power plant of a quarry combine.

In accordance with (4.6), the temperature difference in the RC (see Fig. 1) is:

$$t^o_{об} - t^o_1 = \frac{P_h - P_{low}}{\rho c_1}\left(\frac{1}{\eta_к} - 1\right). \qquad (15)$$

Substituting (15) into (14), we get the temperature difference between the heat flow coming from the RC into the "hydraulic tank-cooler" system and the conditioned flow of the WF entering the RC.

$$t^o_{об} - t^o_T = \left(\frac{Q_T}{[Q]_n}\right)^{-1} D_H \frac{P_h - P_{low}}{\rho c_1}\left(\frac{1}{\eta_к} - 1\right). \qquad (16)$$

Using Eq. (6), we determine the temperature difference between the heat flow of external volumetric WF outflows from the RC and the heat flux WF coming from the RC into the "hydraulic tank-cooler" system

$$t^o_{ук} - t^o_{об} = \frac{P_h - P_{low}}{\rho c_1}\left(\frac{1}{\eta_к} - 1\right). \qquad (17)$$

Substituting the results of (4.16) and (4.17) into (4.12), we have:

$$E = \Delta P_к [Q]_n \left[D_H + (1 + k_N)(1 - \eta_в)\frac{\Delta P_к}{[P]}\right]\left(\frac{1}{\eta_к} - 1\right). \quad (18)$$

Further, from equation (4), we find $\Delta P_к$ - pressure drop in the hydrostatic power plant averaged over the cycle of the work of a quarry combine.

$$\Delta P_к = \frac{H_W BWh}{[Q]_n}, \text{ Pa}, \qquad (19)$$

In (18), the relative speed parameter for regulating the volume of the working chambers (pumps) - DH of a hydrostatic power plant of a mining combine, taking into account the previously obtained results, is:

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$$D_H = \frac{1-\eta_в}{1+k_N} + \frac{\omega_{\min}}{\omega_{\max}}, \tag{20}$$

here: $(1-\eta_в)/(1+k_N)$ is the value of the regulation parameter for the volume of the working chambers of the pump (pumps) of the hydrostatic power plant corresponding to the zero flow of the WF in the high-pressure line of the RC;

$\omega_{\min}, \omega_{\max}$ - the minimum and maximum speeds of rotation of the screw-milling organ of a quarry combine, respectively, rad/s.

Substituting the results of (20) into (18) (for a specific value of the pressure drop ($\Delta P_к = \Delta P_{кi}$) in a hydrostatic power plant averaged over a cycle of operation of a mining combine), we have a general expression for the value of the thermal equivalent of the lost power generated by a hydrostatic power unit when mining a rock.

$$E = H_W BW(h)h\left\{\frac{\omega_{\min}}{\omega_{\max}} + (1-\eta_в)\left[(1+k_N)^{-1} + (1+k_N)\xi^{-1}\right]\right\}, \text{ J/s.} \tag{21}$$

Since, the sum of the values of the expression (21) in the curly brackets for a particular model of a mining combine is constant, the dependence (21) finally takes the form:

$$E = \chi H_W BW(h)h \text{ , J/s,} \tag{22}$$

where: χ is a dimensionless factor equal to:

$$\chi = \frac{\omega_{\min}}{\omega_{\max}} + (1-\eta_в)\left[(1+k_N)^{-1} + (1+k_N)\xi^{-1}\right]. \tag{23}$$

IV. CONCLUSION

Analysis of the model of thermal processes (dependence (21)) of the hydrostatic power unit of a mining combine operating in the RC shows that the thermal equivalent of the lost power - E, generated by the RC regardless of the ambient temperature t_0^0 is directly proportional to the product of the energy intensity of the operation of a mining machine for its technical productivity P in the i-th mode.

In this case, the internal volumetric efficiency of the hydraulic pumps RC-- η_{in}, the ratio of the volume constants of the pump - q_H and the hydraulic motor - q_M RC, as well as the ratio of the minimum - ω_{min} and the maximum - ω_{max} of the speeds of rotation of the screw-milling working body of the combine.

The maximum value of the thermal equivalent of the lost power is E_{max}:

$$E_{\max} = \chi H_{W1} BW(h_{\min})h_{\min} \text{ , J/s,} \tag{24}$$

In particular, for the mining machine MTS 250 χ = 0,67.

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