OPTIMIZATION OF SOIL DIGGING BY SCOOP OF POWER-SHOVEL WITH ENERGY INTENSITY CRITERION

A. Kruchkov, L. Yevtieieva
National Technical University of Ukraine "Kyiv Polytechnic Institute"
prosp. Peremohy, 37, Kyiv-56, 03056, Ukraine.
E-mail: l2212i@ukr.net

Using the analytical decision of Hamilton-Jacobi equalization and his experimental confirmation, dependence of energy intensity of process of digging of soil by the scoop of power-shovel of EKG type from a number of parameters, determining the process, is set. Optimization of process of digging with the criterion of minimum specific power intensity is executed, that allowed to define optimal digging speeds which provide a minimum of power intensity for all categories of breeds on classification of Dombrovsky-Beljakov.

Key words: power-shovel, scoop, soil, digging, energy intensity, speed of digging, optimization.

PROBLEM STATEMENT. Without regard to the common diminishing of excavation on the careers of Ukraine, loading on one power-shovel did not diminish, and on occasion grew even. Increase of operating variable-stroke of excavation predefined by two reasons:
- by the increase of the productivity of digging (ladling) of mountain breeds by the scoop of power-shovel;
- by the height of coefficient of the use of power-shovel in time.

Possibilities which are determined by the first direction are examined in this article. In the conditions of financial economic crisis for the criterion of estimation of possible productive decisions the natural criterion of efficiency - specific energy intensity of process of digging of array of soil by the scoop of power-shovel is taken.
In this connection, the purpose of work is establishment of conformity to law of forming of energy intensity of process of digging of soil by the scoop of power-shovel as EKG which will allows to set optimal speed of digging and to choose the rational mode of operations of power-shovel on the whole.

EXPERIMENTAL PART AND RESULTS OBTAINED. At research on the results of mathematical design of process of digging of soil of shovel dipper with the use of experimental data for the power-shovel of EKG-5A are used. Applying principle of duality at motion of mass in space [1], equalization of process of digging may be written in form of equalization of Gamilton-Jacoby [2]

$$\frac{\partial D_p}{\partial t} - \frac{e^o_F P_K}{E_s} D_p = T + U,$$  \hspace{1cm} (1)

where $D_p$ – is a mechanical action, which is created by the gear of lift and spent on the process of separation of shaving from an array, its destruction, filling with mountain breed of scoop, on the accumulation of kinetic ($T$) and potential ($U$) constituents of energy, J·c;

$e^o_F$ – specific energy intensity of destruction and filling with mountain breed of scoop, J/m$^3$;

$E_s$ – losses of idling of occasion of lift, J;

$T = \left( m_0 + \frac{\rho}{2} E K_e \right) V_k^2 \frac{1}{2}$ – kinetic energy of motion of bucket arm with shovel dipper and mountain breed, J;

$m_0$ – mass of bucket arm and empty shovel dipper, kg;

$\rho$ – a specific density of soil in a shovel dipper, kg/m$^3$;

$E$ – volume of shovel dipper, m$^3$;

$K_e = K_n/K_p$ – coefficient of exploitation which depends on the coefficient of filling of scoop $K_n$ and coefficient of loosening $K_p$;

$V_k$ – middle speed of digging of soil by a shovel dipper, m$^3$/c;

$U = \left( m_0 + \frac{\rho}{2} E K_e \right) g h_k$ – potential energy of shovel dipper with soil, J;

$P_k$ – productivity of digging, m$^3$/c.

The analytical decision of equalization (1) is known [2] and it may be written taking into account initial conditions for our task as

$$D_p = \left[ \int_0^t (T + U) \exp \left[ - \int_0^t \frac{e^o_F P_K}{E_s} dt \right] dt + C \right] \exp \left[ \int_0^t \frac{e^o_F P_K}{E_s} dt \right] =$$

$$= (T + U) t_k + E_s t_k \exp \left[ \int_0^t \frac{e^o_F P_K}{E_s} dt \right], \text{ J} \cdot \text{c},$$  \hspace{1cm} (2)

where elements in parentheses are: complete energy of the system (gamiltonian), and an exponential function is a dissipative action, expended in destruction of soil and filling scoop of power-shovel by soil.
Taking into account, that the value of specific energy intensity of process of digging is taken as the criterion of efficiency, its expression taking into account time of digging on cycle it may be written as

\[ e_k = \frac{D_p}{t_k^{\frac{1}{2}} E K_e}, \text{ J/m}^3, \] (3)

or after the substitution of corresponding values

\[ e_k = \frac{N_p \eta_{e-m} \exp \left( \frac{K^d e \cdot SV_K}{N^e \eta_{e-m}} \right)}{SV_K} \exp \left( \frac{m_1}{E K_e} + \frac{\rho}{2} \right) \frac{V_k^2}{2} \exp \left( \frac{m_2}{E K_e} + \frac{\rho}{2} \right) g h_k, \text{ J/m}^3, \] (4)

where \( N_p \) – power of gear of lift, W;
\( \eta_{e-m} \) – electromechanical coefficient of efficiency of gear and mechanism of digging, takes into account the losses of idling;
\( S = a \cdot b \) – area of transversal cut of shaving which is taken off taking into account its thickness \( a \) and width \( b \), m\(^2\);
\( V_k \) – speed of digging, m/c.

Calculation of specific dynamic resistance of soil to digging \( K_F^d \), is conducted taking into account the prescribed in paper [3] normality, that resistance of mountain breed to digging of power-shovel scoop grows nonlinear with the increase of speed of digging and is described by a cube polynomial in the real range of change of speed

\[ K_F^d = K_F^c + K_1 V_K^1 + K_2 V_K^2 + K_3 V_K^3, \text{ MPa}. \] (5)

Coefficients \( K_1, K_2, K_3 \) for all categories of mountain breeds on the classification of Dombrovsky-Beljakov [4; 5] are resulted in a table 1.

<table>
<thead>
<tr>
<th>Category of breed</th>
<th>( K_1 )</th>
<th>( K_2 )</th>
<th>( K_3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>II max</td>
<td>0,0123</td>
<td>0,0005</td>
<td>0,0002</td>
</tr>
<tr>
<td>II mid</td>
<td>0,0108</td>
<td>0,0003</td>
<td>0,0002</td>
</tr>
<tr>
<td>II min</td>
<td>0,0093</td>
<td>-0,0005</td>
<td>0,0002</td>
</tr>
<tr>
<td>III max</td>
<td>0,0162</td>
<td>0,0023</td>
<td>0,0001</td>
</tr>
<tr>
<td>III mid</td>
<td>0,0182</td>
<td>-0,0006</td>
<td>0,0002</td>
</tr>
<tr>
<td>III min</td>
<td>0,0206</td>
<td>-0,0025</td>
<td>0,0003</td>
</tr>
<tr>
<td>IV max</td>
<td>0,0324</td>
<td>-0,0003</td>
<td>0,0002</td>
</tr>
<tr>
<td>IV mid</td>
<td>0,0265</td>
<td>-0,0002</td>
<td>0,0002</td>
</tr>
<tr>
<td>IV min</td>
<td>0,0206</td>
<td>-0,0001</td>
<td>0,0001</td>
</tr>
<tr>
<td>V max</td>
<td>0,0367</td>
<td>-0,0007</td>
<td>0,0003</td>
</tr>
<tr>
<td>V mid</td>
<td>0,0315</td>
<td>-0,0005</td>
<td>0,0002</td>
</tr>
<tr>
<td>V min</td>
<td>0,0263</td>
<td>-0,0002</td>
<td>0,0002</td>
</tr>
<tr>
<td>VI max</td>
<td>0,054</td>
<td>0,0005</td>
<td>0,0001</td>
</tr>
<tr>
<td>VI mid</td>
<td>0,037</td>
<td>0,0017</td>
<td>0,0001</td>
</tr>
<tr>
<td>VI min</td>
<td>0,0201</td>
<td>0,0028</td>
<td>0,00001</td>
</tr>
</tbody>
</table>
Results of calculation of specific energy intensity of digging for the power-shovel EKG-5A on expression (4) considering (5), are presented at Fig. 1. Calculation confirms evidently the presence of minimum value of $e_k$ for all six categories of breeds, which are provided by the optimal values of speed of digging $V_k^o$ (Fig. 1, table 2) for shovel EKG-5A.

![Figure 1 – Extreme dependence $e_k = f(V_k)$ for six categories of mountain breeds](image)

Table 2 – Optimal parameters of process of digging for the power-shovel EKG-5A

<table>
<thead>
<tr>
<th>Category of soil</th>
<th>$e_k^{\text{min}}$, MJ/ m³</th>
<th>$V_k^o$, m/c</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0,6006</td>
<td>1,41</td>
</tr>
<tr>
<td>2</td>
<td>0,7145</td>
<td>1,26</td>
</tr>
<tr>
<td>3</td>
<td>0,9461</td>
<td>0,96</td>
</tr>
<tr>
<td>4</td>
<td>1,249</td>
<td>0,78</td>
</tr>
<tr>
<td>5</td>
<td>1,623</td>
<td>0,67</td>
</tr>
<tr>
<td>6</td>
<td>2,658</td>
<td>0,45</td>
</tr>
</tbody>
</table>

The analysis of dependence $e_k = f(V_k)$ (Fig. 1) shows that for the first and second categories of breeds there are shallow minimums, that considerably simplify a management of power-shovel at regime, close to optimal. For the 3...6 categories the reliable optimal regime of digging may be supported only under automatic control of digging process.

CONCLUSIONS.

1. Possibility of management of excavation productivity by the change of speed of digging and thickness of soil shaving leads to the change of energy intensity of process of digging.

2. It was experimentally set, that there are minimum values of specific energy intensity of digging process for all categories of breeds, noticeable especially for 4 .. 6 categories of mountain breeds.

3. The mathematical model of process of digging, confirmed by experiment, allowed to specify the optimal values of speeds of digging and corresponding to them energy capacities for all categories of breeds on classification of Dombrovsky-Beljakov, that it is necessary to take into account as at hand so at automatic optimal control of digging a process.
REFERENCES


4. Dombrovsky, N.G. (1969), Ekskavatory, Mashinostroyeniye, Moscow, USSR.


ОПТИМИЗАЦИЯ ПРОЦЕССА КОПАНИЯ ГРУНТА КОВШОМ ЭКСКАВАТОРА ПО КРИТЕРИЮ ЭНЕРГОЕМКОСТИ

А. И. Крючков, Л. И. Евтеева

Национальный технический университет Украины «КПИ»

Ключевые слова: экскаватор, ковш, грунт, копание, энергоемкость, скорость копания, оптимизация.

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