THE OPTIMAL OPERATIONAL AREA OF THE FRONT LOADER WHILE MATERIAL DEVELOPMENT AND LOADING

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Abstracts: *The operational area of the front loader is an important parameter determining operational conditions for the vehicle. The existence of such a zone is proved. The conditions for its determination are given.*

Key words: *parameters, loaders, optimal value, operational zone, dependency, weight, mass, power, calculation, efficiency.*

I. INTRODUCTION

Bucket front loaders of different sizes and purposes find wide application in road building and maintenance.

Finding the rational technical solutions for the vehicle is an important design task. The biggest concern is the determination of the operational area of the forklift for basic loading and unloading operations.

For the determination of such technical parameters and their selection, which depends on operating conditions, a system of indicators that will provide a reliable and objective assessment needed. The production efficiency of the vehicle is assessed by a number of indicators: productivity, energy consumption, material consumption, etc. The operational time is the most common indicator of the efficiency [6]. The indicator evaluates the loader by a combination of technical and operational parameters and conditions.

II. MAIN CONTENTS

The one of the most important indicators for efficiency is operational time tц [1]. The amount of operational time tц determines the value of other indicators of efficiency (productivity, specific energy consumption and material consumption, operating costs, production costs and a number of commercial, market indicators, etc.). Nowadays during the evaluation of vehicles, the operational cycle time is determined experimentally at the stage of finished product analysis. Loading, material transportation, idling is the main technological operations of the loader (others are considered separately) [5]. It does not take into account the impact of operations on each other, which sometimes can lead to conflicting requirements to the technical parameters of the loader. The tц indicator let to take such a drawbacks into concern.

On the basis of minimizing the mathematical model of the duration of the operational cycle of the loader the selection of loaders and operational areas is proposed to be determined.

For a vehicle with sequential execution of operations, such as loaders, the duration of the operational cycle time is:

$$t_{ц} = \sum_{1}^{n} t_{i} \to \min, \ s, \quad (1)$$

$t_{ц}$ – the amount of time for every operation, s;

n – the amount of operations, completed by one operational cycle.

The execution time of a separate operation is determined by the ratio:

$$t_{oi} = \frac{A_{oi}}{N_{oi}}, \ s, \quad (2)$$

A_{oi} – the mathematical model that determines the work of the resistance forces overcome by the equipment attachment during the execution of a operation, Nm;

N_{oi} – a mathematical model that determines the power that the vehicle implements to perform a work operation, Wt.

The work and the value of the resistance forces depend on the strength and physico-mechanical properties of the soil ($k_{уд.}$, tg ρ, $\gamma_{гр}$, etc), construction of the equipment attachment and the nature of the interaction of the working organ with the soil. The value of the resistance force for digging can be calculated analytically, it is depending on the task [3].

For loaders it is important to establish the optimum values of the main technical and operational parameters, such as weight (mass) m as a main component, energy saturation N/m, engine power N, bucket capacity q, carrying capacity g, minimal operational time $t_{ц}$, maximal possible performance П, depending on the physical and mechanical properties of bulk materials and other production parameters that determine the work of the loader and zone of its operation.

The mathematical model for the duration of the operational cycle of a one-bucket loader is established by analyzing the structural model for the operational cycle. The structural model is represented as the sum of the length of time for performing the basic operations of the loader:

$$t_{ц} = t_{з} + t_{пд} + t_{тр} + t_{в} + t_{х}, \ s, \quad (3)$$

$t_{з}$ – the amount of time for the operation of grabbing the material (scooping up, cutting the soil), s;

$t_{пд}$ – the amount of time for the operation of lifting the working element with the material, s;

$t_{тр}$ – the amount of time for the transportation of material to the place of unloading, s;

$t_в$ – the amount of time for the unloading, s;

t_x – the amount of time for the return of the loader to the starting point,

(idling), s.

The amount of time to implement additional operations, such as: lifting of the bucket, transportation, unloading, positioning, acceleration, braking, etc. is minimal. If necessary, additional operations are accounted for by dimensionless coefficients of influence [2].

The mathematical model of the duration of the operational cycle of a one-bucket loader is based on an expression (2). The amount of time for the basic operations, such as grabbing and returning to starting point $t_з$, t_x is determined by the standard mathematical ratios. In order to obtain a general model, more convenient for subsequent analysis are combined mathematical models of a number of terms $t_{пд}$, $t_{тр}$, $t_в$. The mathematical model of the duration of the operational cycle for determining the power parameters of the loader in the abbreviated form is:

$$t_ц = t_з \cdot k_{п.тр/в} + t_х \text{, s.} \quad (4)$$

$k_{п.тр/в}$ – is a dimensionless coefficient that takes into account the time spent on lifting, transporting the bucket and unloading the material.

$$t_ц = \frac{k_{уд.з} \cdot q_п \cdot k_{п.тр/в}}{m_м \cdot g \cdot V_р \cdot \phi_{сц} \cdot k_з} + \frac{m_м \cdot g \cdot l_х \cdot f_х}{N \cdot k_х} \text{, s,} \quad (5)$$

$k_{уд.з}$ – Specific resistance of material gripping by loader bucket (cutting of soil), N/sq.m;

$q_п$ – is a bucket capacity, cbm, $q_п = b_п \cdot h_{ср} \cdot l_к$;

γ – is a volumetric weight of soil in a bucket, N/ cbm;

$m_м$ – is a loader weight, kg;

N – is an engine power, W;

$V_р$ – is an operational speed, mpers;

$b_п$ – is a bucket width, m;

$h_{ср}$ – is a average thickness of detachable chips when striking material (digging), m;

$l_к$ – is a depth of the loader bucket, m;

$l_х$ – is a length of a path from unloading zone to starting point

(idler path), m;

$k_з$, $k_х$ – is a dimensionless coefficients that take into account the fraction of the engine power realized by the vehicle only to grab the load and only to move the loader when performing a blank operation.

$k_{п..тр/в}$ – is a a dimensionless coefficient that takes into account the time required to perform the operation of moving the soil to the zone of unloading, lifting the bucket and unloading the soil from the bucket. The value of the coefficient is determined by the expression:

$$k_{п.тр/в} = 1,2 + \frac{\gamma_{гр} \cdot f_{тр} \cdot l_{тр}}{k_{уд.}}.$$

The first fraction determines the time for performing the basic operations $t_з$, $t_{пд}$, $t_{тр}$ (grabbing, lifting, moving the soil to the zone of unloading, lifting the bucket and unloading the soil from the bucket), the second fraction characterizes the time $t_х$ for the operations of idling the loader.

For the most probable conditions of operation of the loader take the value of the coefficient $k_{п.тр/в}$=1,5…1,7.

The dimensionless coefficients $k_з$ и $k_х$, which taking into account the power consumption of the engine for the grabbing of the load and the movement of the loader when carrying out the idle operation, are determined by expressions:

$$k_з = k_\phi (1 - f_{пр} \pm i) \cdot (1 - \delta_{пр}) \cdot \eta \cdot k_{з.д}$$

$$k_х = k_\phi (1 - f_х \pm i) \cdot (1 - \delta_х) \cdot \eta \cdot k_{з.д},$$

k_φ – is a mass distribution coefficient for driving wheels;

f – is a drag coefficient;

δ – is a skidding ratio;

i – is a bias;

η – is a efficiency of the loader drive;

$k_{з.д}$ – is a engine load factor.

Analysis of the expression for the determination of productivity and cycle time shows that these values depend mainly on the mass of the machine as the main parameter for the traction and coupling characteristics. The minimum time for the operational cycle of the loader and its maximum productivity in certain operating conditions are realized by the optimum value of the mass of the machine and the operational area of the loader.

The optimum value of the mass of the one-bucket loader $m_{опт}$ is determined by expression $\frac{dt_ц}{dm} = 0$.

$$\frac{dt_ц}{dm} = -\frac{k_{уд.з} \cdot q_к \cdot k_{п.тр/в}}{m_м^2 \cdot g \cdot V_р \cdot \phi_{сц} \cdot k_з} + \frac{g \cdot f_х \cdot l_х}{N \cdot k_х} = 0.$$

On the basis of this expression we have:

$$m_{опт} = \left(\frac{k_{уд.з} \cdot q_к \cdot N \cdot k_х \cdot k_{п.тр/в}}{g^2 \cdot V_р \cdot \phi_{сц} \cdot f_х \cdot l_х \cdot k_з} \right)^{1/2}, \text{ kg} \quad (6)$$

The nature of the change in the duration of the operational cycle of the vehicle with the different size of the operational area of the loader is shown at the pic. 1.

The adopted designations are given above.

Minimal time for the operational cycle of the loader $t_{ц.min}$ is determined by substituting the value $m_{опт}$ by the expression (6) in the dependence for determining the cycle time:

$$t_{ц.min} = 2 \cdot \left(\frac{k_{уд.з} \cdot q_к \cdot f_х \cdot l_х \cdot k_{п.тр/в}}{N \cdot V_р \cdot \phi_{сц} \cdot k_з \cdot k_х} \right)^{1/2}, \text{ s} \quad (7)$$

On the basis of expression (1) the optimum size of the operational area of the loader is determined by the $t_{ц.min}$, thus, the value of the given zone will be minimal:

$$l_{х.оп} = \frac{k_{уд.з} \cdot q_k \cdot N \cdot k_х \cdot k_{п.тр./в}}{m_m^2 \cdot g^2 \cdot V_р \cdot \phi_{сц} \cdot f_х \cdot k_з}, \text{ s} \quad (8)$$

Within the loader service zone $l_{х.оп}$, which depends on the parameter N/m loader provides optimal operation with minimum material consumption and maximum productivity. Outside this zone, efficiency can be achieved by increasing the weight of the loader.

Maximum loader performance $П_{max}$ is determined from relation $П_{max} = \frac{q_п}{t_{ц.min}}$ and parameter values $t_{ц.min}$.

$$П_{max} = 0,5 \cdot \left(\frac{N \cdot q_п \cdot V_р \cdot \phi_{сц} \cdot k_з \cdot k_х}{k_{уд.з} \cdot f_х \cdot l_х \cdot k_{з.тр}} \right)^{1/2}, \text{ cbm/s} \quad (9)$$

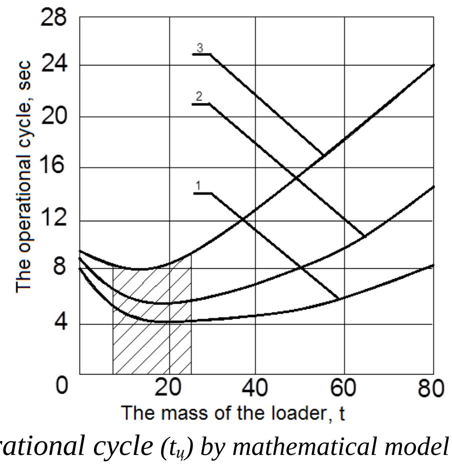

Figure 1. *Changing the operational cycle ($t_ц$) by mathematical model (5) which depends on the mass of the loader (m_m) moving path length (l_x) on the condition that N=170 kW, q_k= 4 cbm, 1 – l_x=5 m; 2 – l_x= 10 m; 3 – l_x=20 m*

Such a performance is gained by the loader in operating conditions with a minimum duration of the operational cycle $t_{ц.min}$.

Expected unit price of a unit of production $C_{уд}$ (rub./cbm) is determined by dividing the price hour $C_{мч}$ (rub./h) on productivity $П_{max}$, cbm /h, calculated from the above expression (9).

The selection of a one-bucket loader is based on the value of two indicators $m_{опт}$ and $(N/m)_{опт}$. From several vehicles a loader with closest to calculated parameters m and (N/m) is selected. With these parameters, as follows from the above, the loader achieves maximum productivity with the minimum specific energy consumption, material consumption and unit price [4].

Power saturation of the loader $N_{эн}$ increases with increasing machine weight m and decreases with increasing strength of the material being dig and bucket capacity. Power saturation $(N/m)_{опт}$ increases with increasing range of idle loader movements.

Engine loader power:

$$N = \frac{m^2 \cdot g^2 \cdot V_р \cdot \phi_{сц} \cdot f_х \cdot l_х \cdot k_з}{k_{уд.з} \cdot q_п \cdot k_х \cdot k_{з.тр}}, \text{ W} \qquad (10)$$

Capacity of the loader bucket:

$$q = \frac{m^2 \cdot g^2 \cdot V_р \cdot \phi_{сц} \cdot f_х \cdot l_х \cdot k_з}{k_{уд.з} \cdot N \cdot k_х \cdot k_{з.тр}}, \text{ cbm} \qquad (11)$$

Optimal operational area with loader mass parameters 10 – 30 ton and the power of 150 - 170 kW by the value of l_x, $l_{тр}$ on the picture 1 shaded within 4 – 10 meters.

III. CONCLUSIONS

The considered dependences allow to predict rational technical parameters of the front loader, as a transport-technological vehicle m, N, l_x and many others. They determine the high efficiency of the vehicle in the relevant operating conditions.

Dependency (8) determines the optimal value of the operational area of the vehicle depending on operating conditions and technical parameters. The loader with certain technical parameters has an optimal (probabilistic) working area for carrying out loading and unloading operations.

An important operational parameter of the loader is the size of the optimum working area (range) of the loader. The influence of magnitude l_x on the parameters of the loader, as a transport-technological system are established theoretically by the expression (8). Based on the dependencies considered, the expected other technical and operational parameters are predicted: the minimum duration of the operational cycle $t_{ц.min}$, optimal weight, power and etc.

Parameters calculated by expressions (1) – (11), provide the shortest operational cycle time in the relevant operating conditions, which is an important indicator of the vehicle.

Outside the optimal operational area, loading operations will be less effective.

The proposed method for calculating optimal parameters can be used to determine the optimum parameters of the loader and the loading and unloading area of loaders.

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