RESEARCH OF THE PROCESS OF TRANSPORTATION OF THE PRISM OF DRAWING BY DOUBLE-BLADED WORKING EQUIPMENT OF THE BULLDOZER

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Abstract: *During the operation of double-bladed bulldozer the descent of soil from a prism of drawing occurs simultaneously in both directions and much more intensively than at dozer or grader positions which the blade can occupy. According to the laws of dynamics of a variable mass there are reactive forces that can reach significant values but in the calculation of earthmoving machines this factor has not been taken into account so far. The method of calculation of the additional reactive forces resulting from changes in the mass of soil in the prism of drawing in front of the blade of bulldozer is given in this paper. For theoretical analysis of the process of soil transportation in the prism of drawing a calculation scheme of the forces operating on both blades of bulldozer is made.*

***KEYWORDS**: BULLDOZER, BLADE, DIGGING, PRISM OF DRAWING, VARIABLE MASS, RESISTANCE FORCES*

1. Introduction

According to the innovative patent №26478 working equipment of the bulldozer can work in three positions: dozer, grader or double-bladed [1]. Bulldozer is a heavy-weight machine, which has large size and considerable speed. It allows working at the development of solid soils and moving significant masses of loosened soil in the prism of drawing. In the process of collecting the soil into the prism of drawing it not joins only the mass of soil has cut off by cutting elements but at the same time occurs a descent of soil in both directions of the blade when at the dozer position and in the same direction at the grader position of the working equipment. At the double-bladed mode the descent of soil occurs in both directions and much more actively. Thus, the machine collects the large mass of soil into the prism of drawing. According to the equation of Meshchersky I.V. who studied the laws of dynamics of variable mass, there emerge reactive forces, which in case of double-bladed bulldozer can reach significant values [2, 3]. However, in the calculations of earthmoving equipment this factor has not been taken into account so far. Professor Nurakov S. was the first who investigated the influence of reactive forces emerging from the variability of the mass of soil in the buckets of rotary excavators, considering the impact of a speed factor when digging the soil by rotary working equipment without bucket, one of distinguishing feature is the opportunity to develop high speeds of rotation [4, 5].

2. Preconditions and means for resolving the problem

Let's consider the calculation scheme of the double-bladed working equipment of the bulldozer.

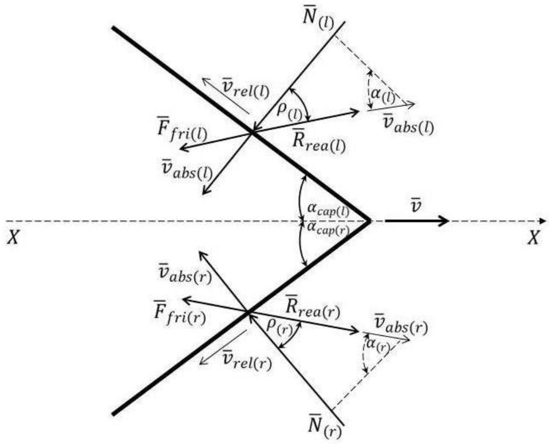

Figure 1. The calculation scheme of forces acting on a prism of drawing at double-bladed position of the bulldozer

The designations, which are adopted on the scheme:

$\bar{N}_{(r,l)}$ – normal forces acting at the right and left blades, *N*;
$\alpha_{cap\,(r,l)}$ – capture angles of the right and left blades, *deg.*;
$\bar{v}$ – speed of movement of the blade, *m/s*;
$\bar{v}_{rel\,(r,l)}$ – relative speeds of movement and soil descent at the right and left blades, *m/s*;
$\bar{v}_{abs\,(r,l)}$ – absolute speeds of movement of the soil at the right and left prisms of drawing, *m/s*;
$\bar{R}_{rea\,(r,l)}$ – reactive forces at the right and left blades from the prism of drawing, *N*;
$\bar{F}_{fri\,(r,l)}$ – friction forces of a prism of drawing at the right and left blades, *N*;
$\rho_{(r,l)}$ – angles of the friction of soil relative to the normal, *deg.*;
$\alpha_{(r,l)}$ – angles between $\bar{R}_{rea\,(r,l)}$ and normals which are equal to $90^{\circ} - \rho_{(r,l)}$, *deg.*

Adopting that the capture angles of the right and left blades are equal, to simplify we will first consider only the right blade, assuming that the left blade is identical to the right one.

We write in a general form the equation of progressive motion of any mass m of soil according to Meshchersky I.V. [2]:

$$(1)\quad m = \frac{d\bar{v}}{dt} = \bar{P} + \frac{dm_1}{dt}(\bar{v}_1 - \bar{v}) - \frac{dm_2}{dt}(\bar{v}_2 - \bar{v}),$$

where m – current value of a variable mass of soil, *kg*;
$\bar{P}$ – main vector of all applied forces, *N*;
$\frac{dm_1}{dt}, \frac{dm_2}{dt}$ – amount of seconds of an attached and detached masses of soil, *kg*;
$\bar{v}_1, \bar{v}_2$ – absolute speeds of attached and detached masses of soil, *m/s*;
$\bar{v}$ – speed of movement of a prism of drawing together with a blade, *m/s*;
t – time, *s*.

Now we design both parts of the vector equation (1) on the axis directed by the speed v of progressive motion of the working equipment, and we will get the scalar equation:

$$(2)\quad m\frac{dv}{dt} = P_{tan} - \sum F_{fri} + \frac{dm_1}{dt}(v_1 - v) - \frac{dm_2}{dt}(v_2 - v),$$

where P_{tan} – tangential traction force, which is parallel to the direction of movement of the blade, *N*;
$\sum F_{fri}$ – projection of the sum of resistance forces on a blade from the friction of a prism of drawing on the massif, which in general view consists of three components, *N*.

$$(3)\quad \sum F_{fri} = F_{fri\,1} + F_{fri\,2} + F_{fri\,3},$$

where $F_{fri\,1}, F_{fri\,2}, F_{fri\,3}$ – components of the resistance to the digging from friction of the right and left prisms of drawing and the blade on the massif, *N*.

In the formula (2) the third and fourth components are the reactive forces, which caused by the process of changing of the transported mass during the collection and movement of the prism of drawing.

Currently these components have not been taken into account in the engineering calculations when the factor of speed at best is considered by means of a coefficient whose value is determined experimentally in certain specific circumstances. However, in case of substantial speeds and collected masses of soil, these reactive components can reach significant values and ignoring them can lead to notable deviations from the actual loadings and therefore can introduce essential errors in calculations what will be reflected in reliability of the machines.

Now for simplification we consider the reaction forces of resistance R_{rea} separately from attached and detached masses on a prism of drawing:

(4) $R_{rea\,(r)} = \frac{dm_1}{dt}(v_1 - v) - \frac{dm_2}{dt}(v_2 - v)$

or

(5) $R_{rea\,(r)} = \frac{dm_1}{dt}v_{1x} - \frac{dm_2}{dt}v_{2x}$,

where $v_{1x} = v_1 - v$ – projection of the relative speed of attached soil to a trajectory of movement of the blade (x-axis), *m/s*;

$v_{2x} = v_2 - v$ – projection of the relative speed of detached soil to a trajectory of movement of the blade (x-axis), *m/s*.

Considering the expression (5) we write the basic differential equation of motion of the blade (1) as follows:

(6) $m\frac{dv}{dt} = P - \sum F_{fri} + R_{rea}$

Hence, according to the diagram (Figure 1) for the right blade when it is set at capture angle $\alpha_{cap\,(r)}$ and taking into account the fact that there is a continuous side descent of soil along the blade with a relative speed $v_{rel\,(r)}$, the formula (5) can be written as follows:

(7) $R_{rea\,(r)} = \frac{dm_1}{dt}v + \frac{dm_2}{dt}v_{rel}\,cos\alpha_{cap\,(r)}$

Due to the fact that in front of the blade soil is not collected but moves aside, then

(8) $\frac{dm_1}{dt} = \frac{dm_2}{dt}$

We write dm_1 as follows:

(9) $dm_1 = F_{sec} \times \gamma \times dt$,

where F_{sec} – the area of cross section of sliced shavings, m^2;

γ – volume density of soil in the massif, kg/m^3.

Then,

(10) $\frac{dm_1}{dt} = F_{sec} \times \gamma \times v$

Therefore, the expression for the reactive resistance from variability of mass of soil in a prism of drawing will be written in the following form:

(11) $R_{rea\,(r)} = -F_{sec} \times \gamma_r \times v\,(v - v_{rel}\,cos\alpha_{cap\,(r)})$

From here for the double-bladed working equipment of the bulldozer the total reactive component in a general equation will be equal to the sum of forces at the right and left blades:

(12) $\sum R_{rea} = 2(-F_{sec} \times \gamma_r \times v\,(v - v_{rel}\,cos\beta)$

Now we turn to the determination of the relative speed v_{rel} (Figure 1). At steady motion the friction force F_{fri} and the reaction force R_{rea} are balanced, and therefore the absolute speed v_{abs} also will be directed at an angle ρ to the norms.

Then from a triangle of speeds we can obtain an expression:

(13) $v_{rel} = \frac{cos\,(\alpha_{cap\,(r)}+\rho)\times v}{cos\rho}$

After substituting the values of v_{rel} in a formula (11), we obtain:

(14) $R_{rea\,(r)} = -F_{sec\,(r)} \times v^2 \times \gamma \left[1 - \frac{cos\,(\alpha_{cap\,(r)}+\rho)\times cos\,\alpha_{cap\,(r)}}{cos\rho}\right]$

Hence, the total reactance at the working equipment of the bulldozer can be determined using the following dependency:

(15) $\sum R_{rea} = -2F_{sec\,(r)} \times v^2 \times \gamma \left[1 - \frac{cos\,(\alpha_{cap\,(r)}+\rho)\times cos\,\alpha_{cap\,(r)}}{cos\rho}\right]$

3. Conclusion

Thus, the side descent of soil from both blades causes additional reactance to the digging depending from the speed and mass of soil in front of the blades. Calculations derived from the inferential dependencies show us that the additional reactance for double-bladed bulldozer can reach significant values up to 20-25% from the total resistance to the digging, which must be taken into account for engineering calculations.

4. Literature

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