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# Calculation of a Device to Reduce the Load on the Working Body of a Dump Type Bulldozer

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**ABSTRACT**: The article considers the design of a bulldozer blade with a vibration exciter. The system of automatic control of the operation mode of the dynamic action blade is presented, which will reduce the efforts that need to be applied to the working body for soil development. Based on the analysis of the uneven load distribution on the cutting edge of the blade blade, mutual correlation functions and dispersion of cutting resistance forces were found in individual sections of the blade blade of dynamic action, which made it possible to draw up a scheme for automating the operating mode of each vibration exciter of the blade of dynamic action, depending on the effect of the ground cutting resistance force on each individual dynamic element. The proposed technical solution makes it possible to reduce the efforts that must be applied to the working body for soil development, reducing the energy intensity of soil development with inclusions.

**KEYWORDS**: dynamic element, vibration exciter, dispersion, ground cutting resistance force, nomogram, amplifier, divider, dynamic load.

## I. INTRODUCTION

Depending on the power and design of the basic machine, bulldozers can work on different soils: from swampy and sandy to collapsible or loosened rocks and ores. It is known that heavy loads act on the bulldozer dump, especially when developing soils with inclusions. These loads are transferred to the base machine, which is accompanied by premature activation of parts of the base machine that are not involved in the destruction of the soil.

To solve the above problem, a design of a dump is proposed that can work in soils with rocky inclusions, while at the same time we get the opportunity to reduce the effort that needs to be applied to the soil and the bulldozer will have high productivity**.** The purpose of the article**.** Based on the analysis of the forces acting on the blade during the development of the soil, to justify:
- the dispersion of the forces of resistance to cutting soil in certain areas of the cutting edge of the blade blade of dynamic action, when working in soils with inclusions;
- correlation of resistance forces in different parts of the knife;
and develop:
- an automatic control system for the operation of the dynamic action blade, which will reduce the efforts that need to be applied to the working body for soil development.

## II. MATERIAL AND METHODS

Until now, the cutting resistance force has been considered as the only force applied at the center of the cutting edge of a knife or tooth. However, with a large cutting edge, width, in particular for dump type machines, this approach is too simplistic.

The known dependencies [1, 2] describe quite fully the random force of resistance to cutting on each individual section of the knife. However, in order to characterize the loaded state of the knife as a whole, when calculating the strength of a bulldozer blade or when creating loads on a stand during testing of dumps, it is necessary to know the normalized mutual correlation functions $r_{pipj}\,(\tau)$ for resistance forces at different sections of the knife or the corresponding normalized mutual spectral densities $r_{pipj}(\omega)$. The cutting resistance forces in individual sections of the knife are statistically independent and, consequently, the functions $r_{pipj}\ (\tau)$ and $r_{pipj}(\omega)$ are identically zero [3]. This simplest hypothesis, however, does not agree with the physical essence of the cutting process of cohesive soils, and some conclusions from it contradict experimental data.

When choosing the most appropriate form for the $r_{pipj}\ (\tau)$ functions, the following considerations were taken into account:
1) functions: $r_{pipj}\ (\tau)$ should have the same character of change as the normalized correlation function $\rho_{p1}(\tau)$, but smaller ordinates, therefore the correlation between the individual values of the resistance forces in different sections of the knife will obviously be weaker than in the same section;
2) it can be expected that at τ = 0, the correlation between the forces $p_i$ and $pj$ is not negative and decreases rapidly as the distance between the considered knife sections increases.
In accordance with these considerations, the formula is proposed to describe the normalized mutual correlation functions $r_{pipj}(\tau)$:

$$r_{pipj}(\tau) = e^{-\beta|i-j|}\rho_{p1}(\tau). \quad (1)$$

where $\rho_{p1}(\tau)$ is the normalized correlation function of the cutting resistance force for a particular section of the knife; $\beta$ is an empirical coefficient depending on the properties of the soil and the length of the sections.

If we put $|i-j| = K$, the formula (1) can be represented as:

$$r_{pipj+K}(\tau) = e^{-\beta K}\rho_{p1}(\tau). \quad (2)$$

The coefficient $\beta$ can be found experimentally using the relationship between the variances of the total cutting resistance force and the resistance force on a separate section of the knife.

According to the known properties of stationary random processes [4, 5], the correlation function of the total cutting resistance force:

$$K_p(\tau) = \sum_{i=1}^{n} K_{pi}(\tau) + 2\sum_{i<j} R_{pipj}\ (\tau) \quad (3)$$

where $K_{pi}(\tau)$ is the correlation function of force on the *i*-th region of the knife; $R_{pipj}(\tau)$ is the mutual correlation function of forces on the *i*-th *j*-th sections of the knife.

The right-hand side of formula (3) can be expressed in terms of normalized correlation functions of forces:

$$K_p(\tau) = \sum_{i=1}^{n} D_{pi}\rho_{pi}(\tau) + 2\sum_{i<j} \sqrt{D_{pi}}D_{pj}r_{pipj}\ (\tau) \quad (4)$$

where $D_{pi}$, $D_{pj}$ are the dispersions of the cutting resistance forces on the *i*-th and *j*-th sections of the knife; n is the total number of sections.

Considering that in this case the statistical characteristics of the forces in individual sections of the knife are the same, and taking into account expression (2), we obtain:

$$K_p(\tau) = D_{p1}\left[n\rho_{pi}(\tau) + 2\sum_{K=1}^{n-1}(n-K)r_K(\tau)\right] \quad (5)$$

or

$$K_p(\tau) = D_{p1}\rho_{p1}(\tau)\left[n + 2\sum_{K=1}^{n-1}(n-K)e^{-\beta K}\right] \quad (6)$$

For τ = 0, formula (6) gives an expression for the variance of the total force:

$$D_p = D_{p1}\left[n + 2\sum_{K=1}^{n-1}(n-K)e^{-\beta K}\right] \quad (7)$$

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If the number of sections $n$ into which the cutting edge of the knife is divided is large enough (at least 5), it is more convenient to replace the sums included in formulas (6) and (7) with integrals. In this case, formula (7) will take the form:

$$K_p(\tau) = D_{p1}\left[n + 2\int_{0.5}^{n-0.5}(n-K)e^{-\beta K}dK\right] =$$

$$D_{p1}\left[n + \frac{2}{\beta}\left(n - 0.5 - \frac{1}{\beta}\right)e^{-0.5\beta} + \frac{2}{\beta}\left(\frac{1}{\beta} - 0.5\right)e^{-(n-0.5)\beta}\right] \qquad (8)$$

It is easy to see that for $\beta\to\infty$ (the absence of a statistical relationship between individual forces), the expression in square brackets goes to $n$, and for $\beta\to 0$ (absolutely rigid relationship) it is directed to $n^2$. If $n = 1$, the specified expression is also equal to one.

In real conditions, $n\beta \gg 1$ (the correlation between the forces of resistance to cutting on individual completely attenuates within the overall width of the knife).

Therefore, instead of formula (8) we get:

$$D_p = D_{p1}\left[n + \frac{2}{\beta}\left(n - 0.5 - \frac{1}{\beta}\right)e^{-0.5\beta}\right] \qquad (9)$$

The equalities (8) and (9) establish the relationship between the values 〖$D_p/D_{p1}$, $n$ and $\beta$, can be used to determine the parameter $\beta$ by a known value of the number of sites and the ratio of variances $D_p/D_{p1}$.For this purpose, a nomogram is constructed based on formula (9), shown in Fig.1.

A rational method for determining the parameter $\beta$ is as follows:
1) the number of sections n is assigned into which the cutting edge of the knife is divided;
2) experimentally determine the dispersion of the cutting resistance force for the knife as a whole $D_p$ and for one section $D_{p1}$ at a given cutting depth;
3) using the nomogram in Fig.1. we find the value of the parameter $\beta$.

The dynamic action blade is presented in the form of a supporting frame, which is divided into sections, with a separate dynamic element installed in each section, which, thanks to a vibration exciter, performs vertical, reciprocating motion in the frame along the groove (Fig.2).

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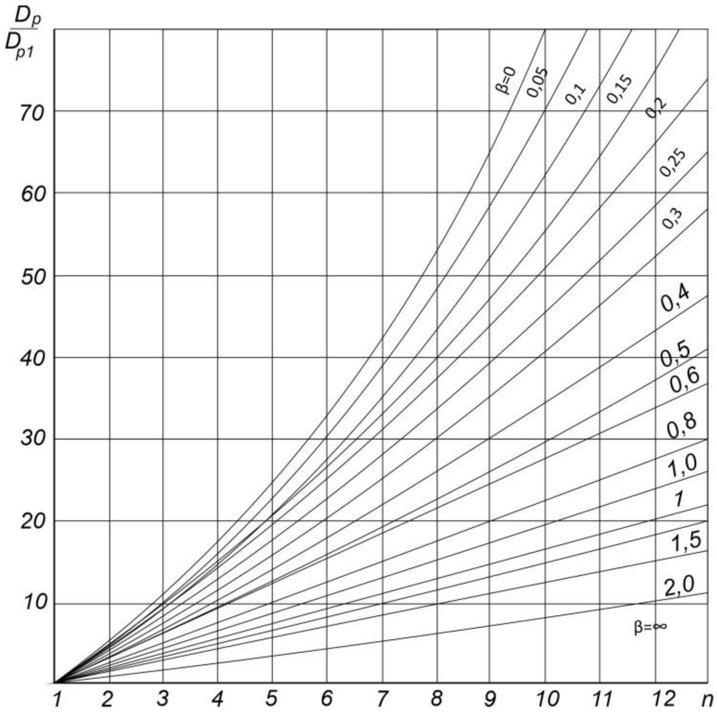


**Figure 1. Nomogram for determining the $\beta$ parameter.**

When exposed to external loads on the working body of the dump type, the number of vibration exciters on the dump may not coincide with the number of loaded sections n into which the cutting edge of the knife was divided. In this case, the $\beta$ parameter will change and take on some new value $\beta' \neq \beta$.

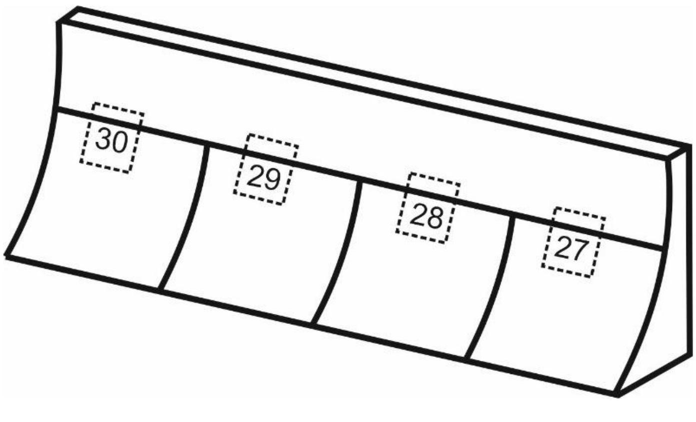


**Figure 2. Bulldozer blade with four vibration exciters.**

Let's say, for example, the number of plots n needs to be reduced by m times (m is an integer), in other words, you need to combine every m plots into one. In this case, the value $\beta'$ can be found as follows:
1) using formula (7) for $m = n$, calculate the variance $D'_{p1}$ for the new site and find the ratio $D_p/D'_{p1}$;
2) using the nomogram in Fig.1. taking $n' = n/m$ as $n$ and $D_p/D'_{p1}$ as 〚$D_p/D'_{p1}$, we determine the value $\beta'$ as the new value of the parameter $\beta$.
The scheme of automatic regulation of the mode of operation of vibration exciters (Fig.3).
The number of sensors determined by the expression:

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$$K=2n-1 \qquad (10)$$

Sensors 1, 2, 3, 4, 5, 6 and 7 are connected to the hydraulic pump block along the channels, and the first two hydraulic pumps 8 and 9 form a group with a gain factor of 1, the next two hydraulic pumps 10 and 11 form a group with a gain factor of 2, etc., and the last hydraulic pump has a gain factor *n* equal to the number of dynamic elements of the blade. The amplifier block is connected by *K* channels to the divider block, and the first two dividers 15 and 16 each have one output, while the first of them (position 15) is connected to the first adder (position 22), and the second (position 16) is connected to the last (*n*-th) adder (position 25). The next two dividers 17 and 18 have two outputs, each of which, at the first divider – position 17, is connected to the first two adders (positions 22 and 23), and at the second – to the last two (positions 24 and 25), etc., and the last divider 21 has *n* outputs and is connected to each of the adders is 22, 23, 24 and 25.

The output of each adder is connected to a power amplifier 26, the output of which is switched with the inputs of *n* vibration exciters 27, 28, 29 and 30. The determination of the switching of hydraulic pumps and adders, the gain and separation coefficients for each channel (pump) are shown in Table.1.

The number of sections of the blade *n*, which are affected by the load, is set (Fig. 2), while it is known that the cutting resistance in individual sections of the blade is statistically independent and the correlation between the individual values of the resistance forces in different sections of the blade will be weaker than in the same section. In addition, the correlation between individual sections of the dump decreases linearly with increasing distance between them.

Sensors are installed on the vibration exciter, and their number depends on the number of sections of the blade load and is determined by the expression:

$$K=2n-1$$

where *K* is the number of sensors; *n* is the basis of the loaded sections of the dump.

**Table 1**

**Characteristics of the circuit elements**

| Group number | Number of hydraulic pumps | Channel number (hydraulic pump) | The coefficient of effort | Separation coefficient | Number of separation outputs | Number of adders |
|---|---|---|---|---|---|---|
| 1 | 2 | 1.2 | 1 | 1 | 1 | 1,n |
| 2 | 2 | 3,4 | 2 | 1/2 | 2 | 1,2,n -1,n |
| 3 | 2 | 5,6 | 3 | 1/3 | 3 | 1,2,3,n-2,n-1,n |
| . | . | … | … | … | … | … |
| . | . | … | … | … | … | … |
| . | . | … | … | … | … | … |
| n-2 | 2 | K-4, K-3 | n-2 | 1/(n-2) | n-2 | 1,2,3, …,n -2,3,4,5,…n-1,n |
| n-1 | 2 | K-2, K-1 | n-1 | 1/(n-1) | n-1 | 1,2,3, …,n -1,2,3,4,5,… n-1,n |
| n | 1 | K | n | 1/n | n | 1,2,3,…,n-1,n |

With an increase in the number of loaded sections n, a smoother decrease in the cross-correlation coefficient can be obtained.

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Let's consider the operation of the circuit with the number of blade sections *n*=4 (Fig.3), while it is necessary to have sensors:

$$K=2n-1=2\cdot 4-1=7$$

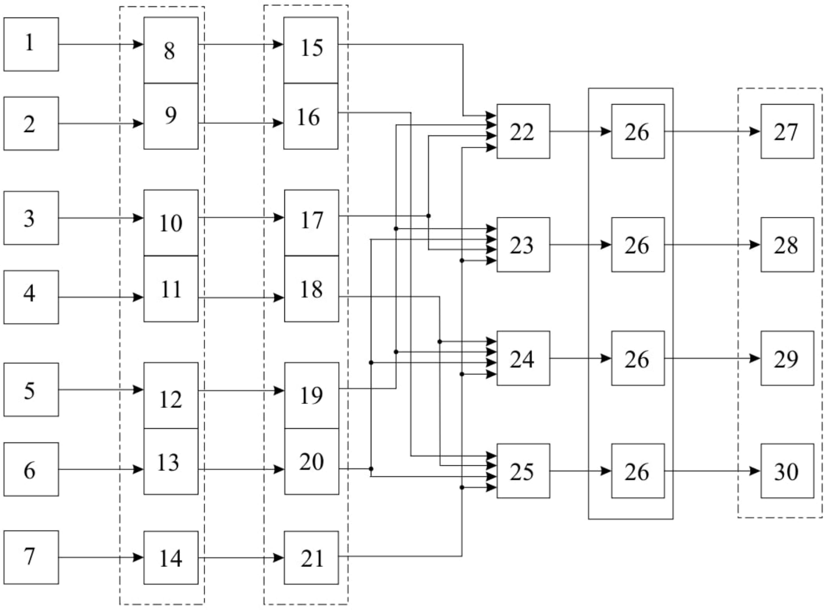


**Figure 3. Schematic diagram of the automatic control of the vibration exciters operation mode.**

Sensors 1, 2, 3, 4, 5, 6 and 7 transmit signals with the same characteristics, which are supplied to hydraulic pumps, which increase the flow of liquid to the hydraulic control unit. The signals from sensors 1 and 2 are transmitted to hydraulic pumps 8 and 9 having a flow gain factor of 1, and through hydraulic valves 15 and 16, two streams flow respectively to adders 22 and 25, where they are summed. The signals from sensors 3 and 4 are transmitted to hydraulic pumps 10 and 11 having a flow gain factor of two, and are divided each in hydraulic valves 17 and 18 into two identical streams that flow to different adders – from the hydraulic distributor 17 to the adder 22 and 23, and from the hydraulic distributor 18 to the adders 24 and 25. Signals from sensors 5 and 6 transmitted to hydraulic pumps 12 and 13 having a flow gain factor of three are divided in hydraulic valves 19 and 20 each into three identical streams, which also flow to different adders, from the hydraulic distributor 19 to the adders 22, 23, 24, and from the hydraulic distributor 20 to the adders 23, 24, 25. The signal from the sensor 7 is transmitted to the hydraulic pump 14, which has a gain factor of four, then divided in the hydraulic distributor 21 into 4 identical streams going to all four adders-22, 23, 24 and 25. The signals from the outputs of the adders are sent to the power amplifier unit 26, which has the same gain coefficients for all *n= 4* channels, which is needed to control the vibration exciters 27, 28, 29 and 30 installed on separate dynamic elements of the bulldozer blade. The coefficient of mutual correlation between the sections with vibration exciters 27 and 28 is 0.75, since there is no mutual connection between the first and sixth sensors. The coefficient of mutual correlation between the sections with vibration exciters 27 and 28 decreases to 0.5, since there is no connection at two levels (between the first and sixth, third and fourth channels). The coefficient of mutual correlation between the sites with vibration exciters 27 and 30 is reduced to 0.25, since there is no connection at three levels already. Thus, the correlation between individual sections of the dump decreases with linear dependence as the distance between the considered sections of the load program increases.

According to the results of the research, the design of the dynamic action blade was developed. The dynamic action blade is made in the form of a load-bearing frame 1 (Fig.4), in the front part of which several dynamic elements 2 are installed, with the possibility of movement in the frame 1 along the guide grooves 3. moreover, on the front part of the dynamic elements 2, the frontal plates are attached to the front part of the load-bearing frame 1, to the dynamic elements 2 4. Cutting knives 5 are attached to the bottom of the dynamic elements 2. A striker 6, a vibration exciter 7 is attached to the upper part of the dynamic elements 2 [6], while the body of the vibration exciter 7 is rigidly mounted in the supporting

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frame 1, and the striker 6 is made in the form of a spherical hinge with the possibility of free rotation in the dynamic element 2.

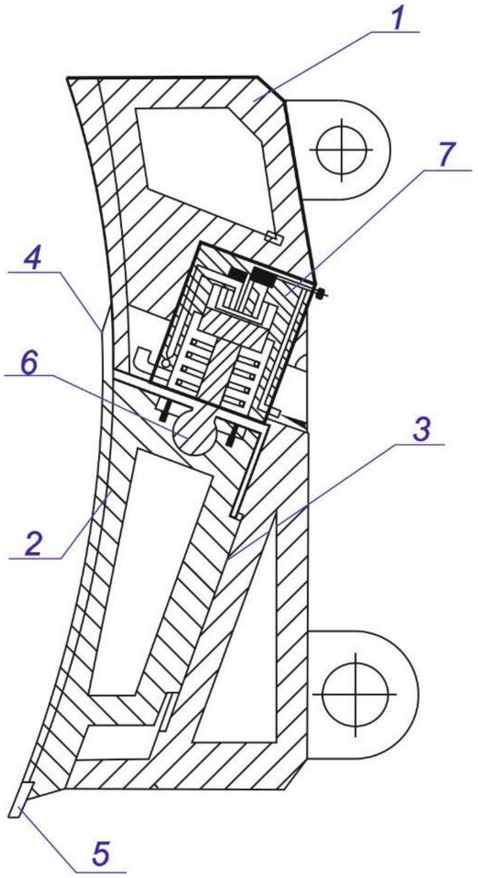


Figure 4. the blade of dynamic action.

## III. CONCLUSION

Based on the analysis of the uneven distribution of the load on the cutting edge of the blade, mutual correlation functions and dispersion of cutting resistance forces in individual sections of the blade of dynamic action are found.

Having analyzed the process of cutting soil with a dynamic action blade and each of its dynamic elements, a scheme for automating the operation mode of a dynamic action blade is proposed, which allows automatically adjusting the operation mode of each vibration exciter, depending on the effect of the resistance force to cutting soil on each individual section of the blade. The proposed technical solution makes it possible to reduce the efforts that must be applied to the working body for soil development, reducing the energy intensity of soil development with inclusions.

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