

# Method of defining rational parameters for excavator buckets vibrating devices in order to reduce soil adhesion

S A Zenkov

Bratsk State University, 40, Makarenko St., Bratsk, 665709, Russia

E-mail: [mf@brstu.ru](mailto:mf@brstu.ru)

**Abstract.** The article describes the method of defining rational parameters for excavator buckets vibrating devices in order to reduce soil adhesion under various operating conditions. The method includes limits formation, calculating geometric parameters of curved mold concentrator for excavator buckets with magnetostriction vibration exciters; calculating parameters of acoustic influence equipment; calculating power demand of equipment, defining adhesive forces of soil to buckets with given values of external factors; defining equipment operation mode (turn-on frequency, exposure time). Suggested method enables one to define required parameters of vibrating equipment to excavator buckets during the design phase.

## 1. Introduction

The field experience of operating earthmoving machines shows that when working with wet ground (especially under subzero temperature) soil freezing and adhesion to working tools substantially reduces performance of machines.

Performance decrease is caused by reduction of bucket useful capacity because of incomplete unloading, increase of cutting (digging) drag force resulted by wet ground adhesion to working tool, growth of ram drag of a bucket, longer machine downtime for working tools cleaning. Moreover, energy losses increase because of more friction forces and overall quality of work falls down. Friction force when digging and grading equals to 30...70 % of overall digging resistance, and performance drops by 1.2...2 times and more [1-10].

## 2. Formulation of the problem and method of solution

The influence of vibration (magnetostriction vibration exciter) on soil adhesion is investigated [3,10]. Magnetostriction vibration exciters generate acoustic and thermal energy in the wall of a bucket, eliminating soil freezing to the bucket. Vibrothermal exposure causes technological effect which involves widening humidity ranges for effective application and reducing friction forces. Destruction of adhesive links requires less vibrator driving force when being heated up. Vibration helps to boost heating of contact layer, thus reducing thermal energy losses.

The method of calculating geometric parameters of the magnetostriction vibration exciter and the curved mold concentrator includes: limits formation, calculating geometric parameters of curved mold concentrator for excavator buckets with magnetostriction vibration exciters; calculating parameters of acoustic influence equipment; calculating power demand of equipment, defining adhesive forces of soil to buckets with given values of external factors; defining the equipment operation mode (turn-on frequency, exposure time).



Solving a problem of selecting geometric parameters of curved mold concentrators and magnetostriction vibration exciters is carried out with consideration of the following limits [3]:

1. To provide stable longitudinal resonance of the vibration exciter the ratio between cross-section  $H_0$  and length of the grip should be 1:20 or more.
2. The concentrator should have an axis plane.
3. The concentrator axis in a free state is an arc of a circle with radius  $r_0$  and is centered around the axis plane.
4. Thickness “ $H$ ” in the axis plane (figure 1) is significantly less than curve ( $H = 0,2r_0$ ).
5. Cross-section is shifted by deformation only within the axis plane.
6. Concentrator length should be resonant. Half-wavelength concentrator has the smallest dimensions.

The theoretical model of selecting geometric parameters of curved mold concentrators is based on differential equations of longitudinal and shear waves propagation in a curved bar [4]. To determine resonant length of a curved exponential concentrator, figure 1 was considered. The system of equations describing elastic waves propagation consists of longitudinal and shear elastic vibrations equations [4].

After transforming of longitudinal and shear elastic vibrations equations one gets a new equation system which is needed to solve to get all the required concentrator parameters [4]:

$$\frac{d^2 \varepsilon(S)}{dS^2} + \frac{d \ln \Omega(S)}{dS} \cdot \frac{d \varepsilon(S)}{dS} + (K^2 - \frac{1}{r_0^2}) \varepsilon(S) = 0 \quad (1)$$

$$\eta(S) = \frac{1}{r_0(K^2 - \frac{1}{r_0^2})} \cdot \frac{d \varepsilon(S)}{dS} \quad (2)$$

where  $\varepsilon(S)$  - cross-section shift along concentrator axis caused by vibration;

$\eta(S)$  - cross-section shift normally to concentrator axis;

$\Omega(S)$  - concentrator cross-section area;

$S$  – current cross-section coordinates;  $dS$  – concentrator length element;  $r_0$  - curve radius of concentrator (axis);  $K = \frac{\omega}{V}$  where  $\omega = 2\pi \cdot f$  - vibration circular frequency (1/c);  $f$  - frequency (Hz);

$V = \sqrt{\frac{E}{\rho}}$  - velocity of longitudinal wave propagation inside concentrator material;

$E$  - Young's modulus;  $\rho$  - concentrator material density.

Differential equations of wave propagation in exponential concentrator serve as a general equation of fluctuations for some other curved concentrators as well (stepwise, wedge-shaped, crescent).

The concentrator area changes exponentially:

$$\Omega = \Omega_0 e^{BS} \quad (3)$$

where  $\Omega_0$  - concentrator cross-section area when  $S = 0$

Having differentiated equation (3):

$$B = \frac{d \ln \Omega}{dS}$$

Solution of equation (1) with respect to resonant length is given by:

$$l_{0\varepsilon} = \sqrt{\frac{\pi^2 + \frac{1}{4} \ln\left(\frac{Hl_{0\varepsilon}}{H_0}\right)^2}{K^2 - \frac{1}{r_0^2}}}. \quad (4)$$

where  $H_0$  - initial height of concentrator cross-section;

$Hl_{0\varepsilon}$  - concentrator cross-section height when  $S = l_{0\varepsilon}$ .

Coordinate of longitudinal fluctuations node is defined by:

$$x_0 = \frac{1}{\beta} \arctg \frac{\beta}{\alpha}. \quad (5)$$

Coordinate of maximum shear fluctuations is defined by:

$$l_{0\eta} = \frac{\pi}{\beta} - x_0. \quad (6)$$

Constant and coefficients:

$$\alpha = -\frac{\beta}{2}; \quad \beta = \sqrt{K^2 \frac{1}{r_0^2} - \frac{B^2}{4}}; \quad B = \frac{\ln Hl_{0\varepsilon} / H_0}{l_{0\varepsilon}}. \quad (7)$$

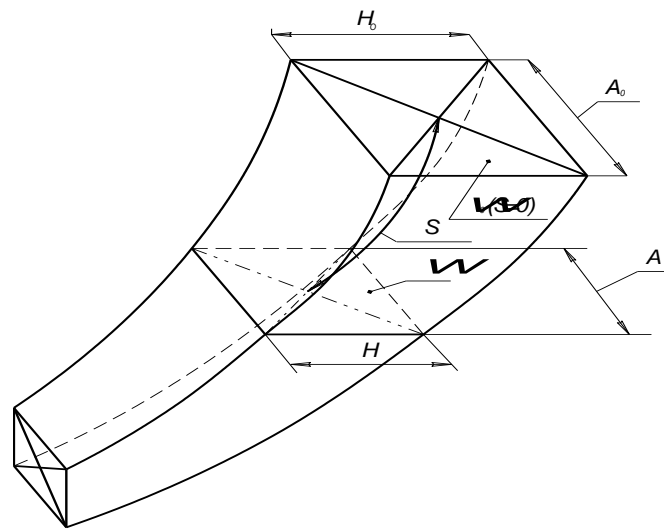
Formula for longitudinal fluctuations amplitude of concentrator at the resonant length is given by:

$$\varepsilon_{l_{0\varepsilon}} = \varepsilon_{Vibr} \cdot e^{-\frac{B}{2} l_{0\varepsilon}} \left( \cos \beta l_{0\varepsilon} + \frac{B}{2\beta} \cdot \sin \beta \cdot l_{0\varepsilon} \right). \quad (8)$$

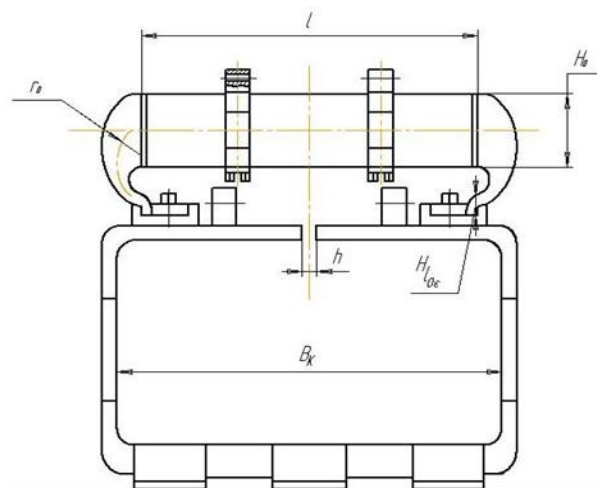
Formula for shear fluctuations amplitude is given by:

$$\varepsilon_{l_{0\varepsilon}} = \frac{\varepsilon_{Vibr} \cdot e^{-\frac{B}{2} l_{0\varepsilon}} \left( \cos \beta l_{0\varepsilon} + \frac{B}{2\beta} \cdot \sin \beta \cdot l_{0\varepsilon} \right)}{\eta \left[ \frac{2\pi f}{V} - \frac{1}{r_0^2} \right] \cdot 4\beta}. \quad (9)$$

where  $\varepsilon_{Vibr}$  - shift on the tip of vibration exciter:



**Figure 1.** Computational scheme for defining geometric parameters of exponential concentrator.



**Figure 2.** Computational scheme for defining rational values of geometric parameters for excavator buckets vibrating devices.

$$\varepsilon_{vibr} = \lambda \frac{V}{2f}. \quad (10)$$

where  $\lambda_S$  - magnetostriction constant of the material.

The computational scheme for defining parameters of acoustic vibrating equipment for a front shovel excavator is presented in figure 2. The equipment is mounted on the back wall of a bucket. Calculation is organized as follows:

Let us consider the major excavator parameter – bucket capacity  $q$ . In this case, the bucket width is given by [3]:

$$B_K = 1.2\sqrt[3]{q} . \quad (11)$$

Vibration exciter length is taken as:

$$l = 0.8B_K$$

On the other hand, vibration exciter length  $l$  equals to [6]:

$$l = n \frac{\lambda}{2} = n \frac{V}{2f} . \quad (12)$$

where  $n$  - harmonic number;

$V$  - propagation rate of longitudinal wave inside the material;

$f$  - vibration frequency;

(12) helps to define frequency of vibration exciter:

$$f = n \frac{V}{2l} = n \frac{\sqrt{\frac{E}{\rho}}}{2l} . \quad (13)$$

Initial height of shear concentrator with consideration of the limits is taken as:

$$H_0 = 0.05l$$

Curve radius of concentrator (axis):  $r_0 = 0.5H$

Calculating resonant length of concentrator according to formula (4):

$$l_{0\varepsilon} = \sqrt{\frac{\pi^2 + \frac{1}{4} \left( \ln \frac{Hl_{0\varepsilon}}{H_0} \right)}{4\pi^2 f \frac{\rho}{E} - \frac{1}{r_0^2}}}$$

Defining longitudinal amplitude of the concentrator at the resonant length using the formula (8) considering (10)

$$\varepsilon_{l_{0\varepsilon}} = \lambda_S \frac{V}{2F} e^{-\frac{B}{2l_{0\varepsilon}}} \left( \cos \beta \cdot l_{0\varepsilon} + \frac{B}{2\beta} \sin \beta \cdot l_{0\varepsilon} \right) . \quad (14)$$

Defining amplitude of shear vibrations using the formula (9) considering (10)

$$\eta = \lambda_S \cdot \frac{e^{-\frac{B}{2l_{0\varepsilon}}} (B^2 + 4\beta^2) \sin \beta \cdot l_{0\varepsilon}}{r_0 \left[ \frac{2\pi f}{V} - \frac{1}{r_0^2} \right] \cdot 4\beta} . \quad (15)$$

Setting the gap width for back wall based on requirement of misfit of its parts:

$$h \geq 2\varepsilon l_{0\varepsilon} . \quad (16)$$

The rest bucket parameters are calculated using the distinguished method [3].

Total electric power consumed by magnetostriction vibration exciter is derived from the formula [3]:

$$P_E = P_{ER} + P_M + P_\alpha . \quad (17)$$

where  $P_E$  - electrical losses power;

$P_\alpha$  - acoustic power of vibration exciter;

$P_M$  - mechanical losses power.

Mechanical losses power is given by:

$$P_{ER} = \frac{U_m^2}{50fl} \operatorname{tg} \delta . \quad (18)$$

where  $U_m$  - vibration exciter driving voltage;

$\operatorname{tg} \delta$  - magnetic loss tangent;

$l$  - electrical inductance.

Maximum acoustic power transferred to the load is defined using:

$$P_\alpha = \pi \left( \frac{\lambda_s}{2} \right)_{\sigma_0=0} \cdot \sigma \cdot S \cdot l \cdot f . \quad (19)$$

where  $\lambda_s$  - saturation magnetostriction;

$l$  - vibration exciter length;

$S$  – cross-section area;

$\sigma_0$  - maximum stress, which equals to fatigue limit of magnetostrictive material.

Mechanical losses power is given by:

$$P_M = \frac{P_\alpha}{\eta_{M\alpha}} . \quad (20)$$

where  $\eta_{M\alpha}$  - mechanical efficiency,  $\eta_{M\alpha} = 0.7$  [3].

### 3. Results and Discussion

Calculating adhesion amount with the given external factors values is executed using regression models.

Depending on operating conditions of the excavator, adhesion amount is based on:

- regression equation [1] when the temperature is negative (up to  $+30^\circ \text{C}$ );

- regression equation [2] when the temperature is negative ( $-35^\circ \text{C}$  and above):

$$\begin{aligned} \tau = & -648.92 + 66770250D + 10.95P + 19.96W + 1.34T + 7.79t \\ & - 6.52 \cdot 10^6 D^2 - 0.01P^2 - 0.09W^2 - 0.042T^2 - 0.10t^2 - 409.5D \cdot P \\ & - 718WD + 484.5DT + 182.5Pt + 0.09WP - 0.36WT + 0.13Wt - 0.11tT; \end{aligned} \quad (21)$$

where  $t$  - shearing stress;  $D$  - effective size of soil particle;  $P$  - pressure of soil to bucket surface;  $W$  - ground moisture content;  $T$  - air temperature;  $t$  - soil and bucket contact time.

The amount of time, after which acoustic exposure equipment should be turned on, is derived from (21), where shear stress is given values defined with acoustic exposure on ( $10 < t < 20$  kPa).

Shear stress value under acoustic exposure is defined by [3]:

$$\tau = 22.87 - 13.27A - 2.11 \cdot 10^{-4} F - 0.21t + 81.25A^2 - 5.65 \cdot 10^{-4} AF - 0.56At \quad (22)$$

where  $A$  - vibration exciter fluctuation amplitude;  $F$  - fluctuation frequency;  $t$  - exposure time.

Formula (22) is used to calculate acoustic exposure time (when  $10 < \tau < 20$  kPa).

$$t = \frac{(22.87 - \tau - 13.27A - 2.11 \cdot 10^{-4} F + 81.25A^2 - 5.65 \cdot 10^{-4} F + 9.07 \cdot 10^{-4} AF)}{(0.21 + 0.56A)} \quad (23)$$

where  $A$  and  $F$  when  $A = \varepsilon_{l_{0\varepsilon}}$  и  $F = f$  are defined by (13) and (14).

#### 4. Conclusion

The suggested method enables one to define required parameters of vibrating equipment to excavator buckets during the design phase. Application of the equipment described reduces soil adhesion to excavator buckets by a factor of 2 [8].

#### References

- [1] Zadneprovsky R P 1992 *Working bodies earthwork and reclamation machines and equipment for soil and high humidity materials* (Moscow: Mashinostroenie) 176
- [2] Zenkov S A, Balahonov N A and Ignatyev K A *Vestnik* 2014 *MGSU* **2** 98-104
- [3] Zenkov S A and Kurmashev E V 2009 *The journal Nauchno-tekhnicheskie vedomosti SPbGPU* **89-2** 90-94
- [4] Buturovich I and Han Duc Kim 1969 Calculation curved concentrators *Trudy LPI* **309** 169
- [5] Rajaram G and Erbach D C 1999 *Journal of Terramechanics* **36** 39-49
- [6] Sharma V K, Drew L O, Nelson L 1977 *Transactions of the ASAE* **20** 46-51
- [7] Tong J 1993 *Study on reducing adhesion and resistance of soil to soil engaging components of machinery for land locomotion by bionics*. A Ph.D. Dissertation, Jilin University of Technology, Changchun, China (in Chinese)
- [8] Tong J, Ren L, Yan J, Ma Y and Chen B 1999 *Int. Agricultural Eng. J.* **8** 1-22
- [9] Wang X L, Ito N, Kito K and Garcia P P 1998 *J. of Terramech.* **35** 87-101
- [10] Zenkov S A 2009 *Systems Methods Technologies* **1** 59-64