Review and analysis of methods for applying vibration in ploughing

V V Vasilenko¹, S V Vasilenko¹ and N N Achkasova²

¹Voronezh State Agrarian University, 1, Michurina str., Voronezh, 394087, Russia
²Financial University under the Government of the Russian Federation, 49, Lenin-gradsky ave., Moscow, 125993, Russia

E-mail: vladva.vasilenko@yandex.ru

Abstract. The vibration of the working bodies of the plows is forced and spontaneous. Forced vibration requires a drive from an energy source, and spontaneous vibration occurs without a drive if the working bodies are fixed to the frame by means of spring elements. In this case, the oscillation is caused by the variable soil resistance. The vibration mode should be such that the impulse and shock action of the working body allows the tool to be torn off from the treated medium, in which the soil relaxes and decomposes into components capable of mutual displacement. The effectiveness of vibration is to reduce the traction resistance of the plow. When choosing the direction of vibrations, preference should be given to transverse or vertical vibrations, since in the longitudinal direction of vibrations, the vibration speed should be greater than the speed of the plow. Such a mode of oscillation can be provided only with forced oscillations and, therefore, with additional energy consumption. Forced vibrations with a vertical direction may be less intense, but still effective. They can be realized by replacing the support wheel of the plow with a roller in the form of a regular octahedron with an inscribed circle diameter of 0.75 m. Since these vibrations do not coincide with the direction of movement of the plow, the speed of vibration may be less than the speed of movement of the plowing unit; anyway, a positive effect will be achieved.

1. Introduction
The main tillage by the method of moldboard plowing shows the best results in terms of the degree of soil loosening, the turnover of layers and deep embedding of plant residues and weed seeds [1]. Deep burial of weed seeds clears fields without herbicides by about 98% after two years of plowing [2]. Weed suppression is enhanced with a full rotation of the soil layers [3]. For all the usefulness of the moldboard plowing method, it has the disadvantage of increased energy costs. The traction resistance of the plows is greater than that of other tillage implements, and it can be reduced by applying vibrations, as well as by replacing solid moldboards with strip blades. The positive effect of the use of vibration has been noted by many authors. All of them register a decrease in the draft resistance of plows or other tillage implements, if the working bodies are activated by vibrations. The most significant reduction in traction resistance was recorded in Australia when working with vineyards. It was more than 26% at a vibration frequency of 4.86 Hz [4]. If a passive working body such as a bulldozer has a resistance of 100%, then a vibrating body of the same type reduces resistance to 71-93%, depending on the type of soil and its moisture [5]. According to the source [6], the resistance of the vibrating organ
is 0.69-0.93 of the resistance of the passive organ. The authors of the article [7] noticed a decrease in the resistance force of a vibrating organ by 14%. The literature provides information on the search for the optimal vibration intensity. For example, when digging peanuts, good results were obtained with a frequency of 9.0 and 16.7 Hz and an amplitude of 3.2 and 9.6 mm. In this case, the speed of the tractor was 2.4 and 4.8 km/h [8]. Thus, the vibration of the working bodies of the plow can be recognized as an important direction for the further improvement of these tools. To obtain the maximum effect, it is necessary to analyze the methods of vibration excitation, their advantages and disadvantages, and, if possible, calculate the rational vibration modes.

2. Materials and methods
As an overview of the ways of using vibration in soil cultivation, we will give their classification, analyze the advantages and disadvantages of each method and calculate the possible amplitude and frequency of oscillations of the working bodies of various designs. In agricultural engineering, vibration is mandatory when cleaning and sorting grain mixtures on sieves. For this process, vibration is the most important condition for its functioning. But unlike soil cultivation equipment, grain cleaning plants are stationary machines, they are equipped with an electric drive, and the oscillating working bodies do not have contact with the viscous and sticky processed medium. Therefore, the drive mechanisms of the sieve installations do not differ in variety; they are almost always crank-and-connecting rod and worked out in their design due to the wide practice of their use. As for the vibration of the working bodies of the plow, this is a much more complex problem with a much higher energy consumption, and the existence of many ways to implement this process indicates a continuous search for an optimal design solution. The scientific, technical and patent literature has accumulated so much information about vibration methods that they can be classified into a certain system in order to find analogues of more and more new proposals and compare them with already known technical solutions. All plow vibration methods are divided into two categories - forced and spontaneous vibrations (self-oscillations). If the working body is brought into an oscillating state by some drive mechanism with additional energy consumption, then such vibration is called forced. But if there is no mechanism, and the loosening element of the working body or the entire working body vibrates on its spring-loaded suspension under the action of variable soil resistance, then such vibration is called spontaneous or self-oscillation. Forced vibration can be applied to the entire implement, including its frame, to the working bodies and only to the component parts of the working bodies. It should be borne in mind that the less the mass of the oscillating elements, the higher the oscillation frequency can be realized and the less energy will be required to apply. As far as self-oscillations are concerned, they are not applied to the scale of the entire plow. Only the working bodies or their elements vibrate if they are attached to the frame by springs. Four types of mechanisms are used to drive forced vibration. These include mechanical, electrical, hydraulic and pneumatic devices. Combinations of these are also possible. These mechanisms can be driven by a power take-off shaft, by a support-drive wheel, or by a stand-alone engine. Analysis of literature sources showed that a positive effect on reducing traction resistance appears due to the sliding of overhanging plant residues and adhered soil from the vibrating organ, due to the appearance of leading cracks in the soil, due to mutual movements of soil particles and due to a decrease in force friction. If the vibration is energetic, then small flights of soil particles may appear instead of continuous friction, which also reduces the traction force. The advantage of forced vibration in comparison with self-oscillations is its higher intensity. But all authors point to its significant shortcomings. First of all, forced vibration violates the basic rule of its application: the energy consumption for its drive must be less than the effect obtained from reducing the traction resistance. It turns out that almost always the traction resistance of the tool decreases, and the total energy consumption increases. Another disadvantage of forced vibration is the complexity and cost of the equipment. Taking into ac-
count the fact that forced vibration of the plow working bodies is still used, we will determine the conditions for its use, calculate the modes and compare with the possibilities of spontaneous vibration.

3. The main results of the study
In the scientific literature, there is a concept of vibration speed, which takes into account the frequency and amplitude of sinusoidal oscillations:

\[ V_1 = \omega \cdot A = 2 \cdot \pi \cdot f \cdot A, \]  

where \( V_1 \) is the vibration speed of the working body, m/s; 
\( \omega \) - circular frequency of the crank in the drive mechanism, rad/s; 
\( A \) - vibration amplitude, m; 
\( f \) - vibration frequency, Hz. If the vibrations are excited by the crank mechanism, then this is the number of crank revolutions per second.

Parameter \( V_1 \) shows the maximum vibration speed for sinusoidal oscillations. There is also a concept of the vibration speed averaged over the modulus:

\[ V_p = \frac{2 \cdot \omega \cdot r}{\pi}, \]

where \( r \) is the radius of the crank, with \( r = A, m \).

Oscillations, the direction of which coincides with the direction of movement of the unit, are called longitudinal. In contrast, vibrations can occur in the transverse or vertical directions. Its effectiveness depends on the direction of vibration of the moving tool. Let us consider the case of coincidence of the direction of vibrations with the direction of movement of the plow. The absolute speed of the vibrating implement is the sum of the vibration speed and the speed of the plow:

\[ V = V_1 + V_2, \]  

where \( V \) is the absolute speed, m/s; 
\( V_2 \) - plow speed, m/s.

Parameter \( V_1 \) periodically changes sign from positive to negative, and parameter \( V_2 \) is always positive. If the vibration speed is greater than the speed of movement of the plow, then the plow working body will periodically retreat, stopping any pressure on the soil (Figure 1).

![Figure 1. The movement of the working body forward and backward in the process of longitudinal vibrations](image)

At this moment, the tension in the soil disappears, its relaxation occurs. Soil particles make mutual movements, which increase with the subsequent impact of the working body with an increased speed of its action. The impact process breaks the bonds between soil particles, and therefore the traction resistance of the plow is reduced. But if the vibration speed is less than the speed of the plow, then there is no separation of the working body from the soil, and there is no subsequent impact either. The soil is subjected to pulsating compression without relaxation, so the mutual movement of particles is
hindered. Let's calculate what vibration frequency is required for effective vibrations of the plow working body. Using expressions (1) and (2), you can calculate the extreme values of the absolute speed of the working body:

\[ V = V_2 \pm 2\pi fA . \]

The negative value of the absolute speed occurs at

\[ 2\pi fA \geq V_2 . \] (3)

Inequality (3) characterizes such a mode of oscillation, which makes the impact action of the working body on the soil, and this reduces the traction resistance of the plow. Figure 2 shows a graph of the dependence of the oscillation frequency on the speed of the plow for different values of the amplitude.

![Figure 2](image_url)  
1 – \(A=0.002\) m; 2 – \(A=0.003\) m; 3 – \(A=0.004\) m; 4 – \(A=0.006\) m; 5 – \(A=0.012\) m

**Figure 2.** Dependence of the frequency of forced vibrations on the speed of the plow at different amplitudes

It turned out that with forced longitudinal vibrations of the working body with an amplitude from 0.004 to 0.005 m and a plow speed from 1.5 to 2.5 m/s, the frequency should be in the range from 50 to 100 Hz. Such a vibration mode cannot be spontaneous, and a drive from a power source is required. The easiest way to solve this problem is to apply the vertical vibrations of the entire plow equipped with a non-circular support wheel. This eliminates the need for a special drive mechanism. It is enough to equip the plow with a regular polygon instead of a round wheel. The size of the polygon and the number of its edges determine the vibration amplitude, and the plow speed also affects the vibration frequency. A preliminary analysis of the shape and size of the reference polygon showed that an octahedron with an inscribed circle diameter of 0.75 m is a rational option. In order to prevent the adhesion of soil to the supporting surface of the polyhedron, this surface is made of separate rods E, A, B, F, and so on, rigidly fixed between two side plates at the level of the inscribed circle (Figure 3).
Figure 3. Fragment of an octagonal non-circular support wheel in the view from the side

Removable pins M, C, N and so on are inserted at the vertices of the octahedron. When plowing with vibration, the plow periodically rests on removable pins and rises by an amount equal to the difference between the distances OA and OC. If you remove all of the removable pins, the support roller will roll on the permanently attached pins and there will be no vibration. Geometric analysis shows that when vibration is on, the plow frame will periodically rise to a height of 0.023 m, that is, the vibration amplitude is $A = 0.0115$ m. The vibration frequency depends on the plow speed:

$$ f = \frac{z \cdot V}{\pi D}, $$

where $f$ is the oscillation frequency, Hz;
$V$ – plow speed, m/s;
$z$ – number of faces of the support roller;
$D$ is the diameter of the inscribed circle, m.

The vibration frequency calculated by expression (4) will be 5.1-10.2 Hz at a plow speed of 1.5-3.0 m/s. Vibration occurs in the vertical direction; therefore, even with such a very non-intensive mode, the impact action of the working body on the soil will be observed. And this will lead to a decrease in the draft resistance of the plow.

4. Conclusion
To reduce the resistance force of the working body during soil cultivation, its impulse and shock effect should allow separation from the treated medium, at which the soil relaxes and decomposes into constituent elements capable of mutual displacement. The longitudinal direction of vibrations, when it coincides with the direction of movement of the plowing unit, can be effective in reducing the force of traction resistance only when forced vibration driven by an energy source is applied, since the vibration speed must be greater than the speed of the plow. With longitudinal vibrations, the vibration frequency must be at least 50 Hz. With transverse or vertical vibrations of the plow working bodies, their periodic separation from the soil and the subsequent shock impact occur at lower values of the amplitude and frequency. Vertical vibrations can be obtained by simply replacing the plow support wheel...
with an octagonal roller. With an inscribed circle diameter of 0.75 m, the vibration amplitude is 0.0115 m, and the frequency is in the range of 5.1-10.2 Hz, depending on the speed of the plow.

References

[1] Goul T M, Kjell M, Hugh R et al 2015 Method, timing and duration of bare fallow for the control of Cirsium arvense and other creeping perennials *Crop protection* 77 31-37

[2] De Vore J D, Norsworthy J K, Brye K R 2013 Influence of Deep Tillage, a Rye Cover Crop, and Various Soybean Production Systems on Palmer Amaranth Emergence in Soybean *Weed technology* 27-2 263-270

[3] Vasilenko V V, Afonichev D N, Vasilenko S V et al 2018 Increase of rotation angle of soil layers during plow operation *MEACS 2017 IOP Publishing IOP Conf. Series: Materials Science and Engineering* 327 042114

[4] Shahgoli G, Saunders Ch, Desbiolles J et al 2006 An investigation into the performance of vibratory tillage using straight and bent leg tines *Soil management for sustainability* 38 21

[5] Szabo B, Barnes F, Sture S et al 1998 Effectiveness of vibrating bulldozer and plow blades on draft force reduction *Transactions of the ASAE* 41-2 283-290

[6] Niyamapa T, Salokhe V M 2000 Soil disturbance and force mechanics of vibrating tillage tool *Journal of terramechanics* 37-3 151-166

[7] Zhang X, Wang Ch, Chen Zh et al 2016 Design and experiment of a bionic vibratory subsoiler for banana fields in southern China *International journal of agricultural and biological Engineering* 9-6 75-83

[8] Dawelbeit M I, Wright M E 1999 Design and testing of a vibratory peanut digger *Applied engineering in agriculture* 15-5 389-392

[9] Vasilenko V V, Vasilenko S V and Muhin A A 2013 RF Pat. No. 2478270 *Mounted vibrating plow* (Voronezh. VSAU).