Rationality of Using Pneumatic Looseners of Vibration Action on Plow Bodies

Serhii Yermakov
*Kamyanets-Podilskyi Instrument
Applied College of Construction,
Architecture and Design*
Kamianets-Podilskyi, Ukraine
dakgps@pdatu.edu.ua

Taras Hutsol
*Department of Agricultural
Engineering*
Odesa State Agrarian University,
Odesa, Ukraine

Oleksandr Hovorov
*Faculty of Engineering and
Technology*
Higher educational institution
«Podillia State University»,
Kamianets-Podilskyi, Ukraine

Pavlo Potapskyi
*Faculty of Energy and Information
Technologies,
Higher educational institution
«Podillia State University»,*
Kamianets-Podilskyi, Ukraine

Serhii Oleksiyko
*Affiliated Unit "Khotyn Vocational
College of Higher Educational
Institution "Podillia State University"*
Khotyn, Ukraine

Abstract— **In modern agriculture, more and more attention is paid to the problems of energy consumption during deep tillage operations. One of the ways to solve this problem is the use of vibrations to facilitate the work of working bodies and reduce the traction resistance of the unit in general. This paper presents one possible implementation of this idea for a plowing unit. The proposed design improvement in this study involves developing a mechanism to induce vibrations in plow bodies. The theoretical basis is the establishment of general laws governing the effect of vibrations on traction resistance. Ensuring vibrations is offered by installing additional pneumatic vibration dampers in the blades on each plough body. This idea is protected by the patent of Ukraine. In order to establish the effect of vibrations on traction resistance, the Goryachkin's rational formula. was adapted in the work. The effect of vibrations in this formula was accounted for by modifying specific parameters based on scientific research on their influence on the coefficient of friction (f_0) and specific traction resistance (K). The theoretical dependence of traction resistance on the speed of movement of the unit for a plough with and without the use of pneumatic looseners is presented in the work. The graphs indicate that the use of oscillating looseners reduces the traction resistance of the plow by 19...23% in the speed range of 0.5...2.5 m/s. The results of these studies are completely correlated with the data from other studies and can be used to clarify and improve methods of calculating vibratory plough.**

Keywords— *plough, pneumatic hammer, pneumatic soil loosener, plough body, traction resistance, coefficient of friction, vibration.*

I. Introduction

As a rule, technological operations related to soil tillage account for up to 40% of total production costs. Therefore, improving soil cultivation technology is a crucial priority.

With the rapid advancement of science and technology, resource conservation must be accompanied by a fundamentally new approach to improving soil tillage quality. In the scientific community, two main approaches to energy resource conservation in soil cultivation have been identified:

- reducing traction resistance;
- developing wide-grip combined machines.

We consider reducing the traction resistance of tillage machines to be the most effective solution, as the development of wide-grip combined machines inevitably leads to increased traction resistance.

A review of scientific studies indicates several possible ways to reduce the traction resistance of tillage machines [1-4]:

- optimizing tool design and reducing weight;
- improving the geometry of working bodies;
- reducing soil friction on working surfaces (e.g., replacing sliding surfaces with rolling surfaces or introducing oscillations in working bodies).

The key challenge in improving tillage machines, including combined models, is reducing traction resistance

without significantly complicating the design. Researchers focus particularly on the use of vibration in soil cultivation, one of the most energy-intensive operations in modern agriculture.

The application of vibration and impulse technology provides a new perspective on energy concentration over time and its more efficient use in soil tillage operations.

II. MATERIALS AND METHODS

This research was conducted as part of the scientific project of the educational and research laboratory "DAK GPS" at Higher Education Institution "Podillia State University" [5-7]. This paper aims to develop a mechanism for generating vibrations in plough bodies and to establish the general theoretical relationship between the oscillatory action of vibratory looseners and the traction resistance of the unit.

The necessity of improving existing technical solutions was substantiated by analyzing the challenges associated with deep soil tillage and the limitations of currently available equipment. The design of a plough body equipped with pneumatic vibratory looseners was based on this analysis, incorporating the best available solutions while identifying and addressing their shortcomings.

The variation in the required traction force with changing ploughing conditions should logically follow from a comprehensive and precise theory that accounts for the complex processes involved in plough operation.

According to Loveykin V.S., Chovniuk Yu.V., and Dyachenko L.A. [8], the formulas for calculating the traction resistance of vibrating ploughs should be refined and improved based on the well-known three-term Goryachkin formula:

$$P = f_0\,G + K\,a\,b + \varepsilon\,a\,b\,\upsilon^2, \quad (1)$$

where P –traction resistance of the tillage implement, H;

f_0 – proportionality factor, which depends on the overall friction coefficient; according to V.P. Goryachkin $f_0 = 0.5$ for stubble, $f_0 = 1.0$ for clover;

G – weight of the machine, N;

K – specific resistance of the plough; $K = 20000$ N/m^2 on the lungs; $K = 30{,}000$ N/m^2 on average; $K = 40000$-50000 N/m^2 on heavy soils;

a, b – width of capture and depth of processing, m;

ε – coefficient, which takes into account the geometric parameters and frictional properties of the working bodies of the soil tillage machine, $\varepsilon = 1500$-2000 N*s^2/m^2;

υ – unit movement speed, m/s.

Goryachkin's rational formula can be seen as an initial attempt to outline key factors before establishing a precise pattern, reflecting the physical relationships between the main parameters of the ploughing process and the overall resistance encountered during operation. However, it does not explicitly account for the influence of various factors on plough traction resistance, including vibration effects, friction forces between field boards and the furrow wall, the vertical component of soil reaction on the plough bodies, resistance forces acting during soil layer separation from the bottom and furrow wall, as well as the thickness of the ploughshare blades.

III. RESULTS AND DISCUSSION

Based on the analysis of existing soil treatment technologies, an improved plough body design is proposed, in which soil loosening precedes its compression and displacement. This is achieved through the use of compressed air from the tractor's pneumatic system, which is an integral part of its design but remains underutilized due to the absence of direct compressed air consumers.

The improved plough body 6 (Fig. 1) includes a rack 7 with a shelf 8 fixed to it with a front part and a field board 10. A soil loosener - a pneumatic hammer 12 (patent of Ukraine №107117) is additionally installed on the ploughshare 9.

Plough bodies 6 with pneumatic hammers 12 are fixed on the frame 5 of the plough and are connected to the air distribution mechanism 11 with the help of flexible pneumatic lines 4, and through the common pneumatic line 3 and the mechanism 2 of the pneumatic control of the level of loosening are connected to the standard pneumatic system 1 of the tractor.

During the movement of the tractor with the plough, with the pneumatic control mechanism 11 turned on, the working bodies of the pneumatic hammers 12 of all bodies 8, making a reciprocating movement along the path of the tractor, will loosen the soil of any categories with vibration shocks, reducing the resistance to its destruction by ploughshares. As a result, the total resistance to the plough unit's movement decreases, reducing the load on the tractor's engine and ensuring stable operation at nominal speed and optimal load conditions.

Initial assessment of the trinomial Goryachkin's allows us to make some assumptions. The first term of the formula expresses the "dead resistance", which is determined when pulling the ploughs in an open furrow, therefore, under the influence of vibrations, this resistance will obviously decrease. The second term expresses the resistance caused by the deformation of the soil layers [9; 10] and depends on the specific resistance K, which will also be affected by the action of vibrations. The third component of the total resistance is related to the provision of kinetic energy to the soil layers particles depending on the speed of the plough [9]. As noted by V.S.Loveykin. for a vibratory plough that works at a traditional speed (v=1.2...1.4 m/s), this third term of the formula is relatively small (~5% of the total traction resistance), so the traction force of the vibratory plough changes slightly with a change in the speed of the vibratory plough [8].
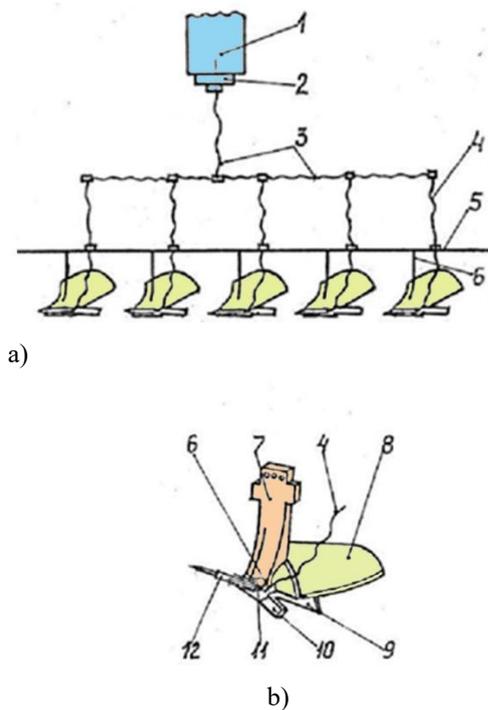
a)

b)

Fig. 1. Scheme of a plough with pneumatic soil looseners: a) general; b) plough body; 1 – tractor pneumatic system; 2 – a mechanism for controlling the degree of loosening of the soil; 3 – common pneumoline; 4 – pneumoline of the plough body; 5 – frame; 6 – plough body; 7 – rack; 8 – shelf; 9 – ploughshare; 10 – field board; 11 – air distribution mechanism; 12 – pneumatic hammer.

Thus, to assess the influence of vibrations on plough operation, it is first of all important to trace their influence on the f0 and K indicators and on the total traction resistance. These indicators are established mainly by research and their results are described in many works.

Various researchers have proven that vibrations are an effective way to reduce traction when the volume of disturbed soil increases. In particular, X. Dong et al. [11] proved that at the vibration frequency of 6.7 and 8.3 Hz, the required traction force of the soil loosener was stable and significantly reduced, which can improve the soil loosening efficiency and reduce the harmful vibration on the tractor. Odey Simon and others. [12] estimated the traction resistance of a vibrating deep loosener and a non-vibrating operation at a depth of 0.35 m for a vibrating deep loosener to be 6.9% - 17% less than for a non-vibrating one. Xirui's experiments also confirmed that the deep loosener using oscillating equipment requires 16-28% less traction resistance compared to traditional ones [13].

Bulgakov V.M., Sviren M.O. and others. experimentally established that when using vibrations in plough, the friction of the soil sliding along the ploughshare and the shelf is significantly reduced, which is the main component in the overall amount of traction resistance [14; 15]. The sticking of working organs also decreases. On light and medium soils, the traction resistance is reduced by 20–30%, and on particularly heavy soils by more than 50% (at optimal vibration modes).

Many researchers have noted that excessive tillage depth not only increases energy consumption and reduces earthmoving efficiency but also accelerates wear and damage to machinery under harsh conditions. This problem can be solved by bionics and vibration techniques [16-18]. Research in a field experiment with deep tillage by Yang M. [19] showed that the soil resistance gradually decreased with increasing vibration frequency. The use of vibrations of the working bodies allowed not only to reduce the resistance, but also to reduce the total energy consumption: the rate of reduction of the resistance reached 14.2–21.2%, and the total energy consumption was reduced by 11.2–16.5%. According to Vasylenko V.V., under the influence of vibration, the soil friction coefficient changes from f = 0.61 (without vibration) to f = 0.50 (with vibration of the friction surface). According to their conclusions, vibration can reduce the coefficient of friction by 18% [20]. Loveykin V.S. etc. note that due to vibrations, this indicator decreases to f = 0.3 for stubble (from 0.5 in Goryachkin V.P.) and to f = 0.5...0.54 for clover (1.0 in Goryachkin V.P.), that is, by 40–45% [8].

Based on the given data for modeling the traction resistance of the plough according to the Goryachkin's formula we will use f0 =0.5 without vibrations and f0 =0.3 with vibrations (stubble), and specific resistance K =50000 N/m2 and K =40000 N/m2 with vibrations (loamy soils), respectively. Other components of the Goryachkin's formula we will accept as permanent. G=1100N, b=5*0.35=1.75 m, (five-furrow plough); ε=1500 N*s2/m2.

The graph of the dependence of the traction resistance on the movement speed v will be repeated three times at the processing depth a = 0.25; 0.30; 0.35 m. The range of the variable υ is assumed to be 0.5–2.5 m/s.

As a result, we will get a graph (Fig. 2), which clearly shows the positive influence of vibrations on the total traction resistance of the plough.
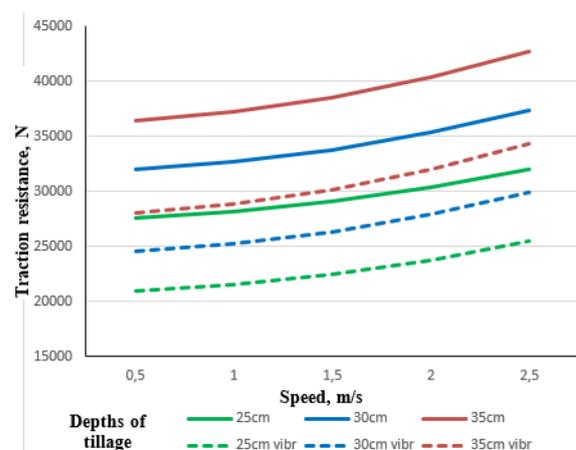

Fig. 2. Dependence of the traction resistance on the speed of movement at different depths of tillage: ▬▬▬▬ theoretical curves without vibrations; ▬ ▬ ▬ theoretical curves with a vibration exciter.

The graph depicting the dependence of traction resistance on speed at different tillage depths for traditional and vibratory ploughs generally aligns in shape and values with similar graphs presented by other researchers. [9; 10; 20; 21]. In all these sources, the graphs of the dependence of traction resistance on speed are increasing and slightly concave, as in our case.

Analyzing the graphs for the effectiveness of vibrations, it can be noted that the use of vibrations reduces the theoretically calculated traction resistance of the plough in the range of speeds of 0.5–2.5 m/s by 19–23%. Moreover, at lower speeds, the influence of vibrations is more important: a reduction in traction resistance by 22-23% at a speed of 0.5 m/s and by 19-20% at 2.5 m/s.

If we compare these numbers with the data provided by other scientists, we will have a decrease in traction resistance due to the action of vibration according to data from Simon O. is 17%, Xirui - 16–18%, Bulgakov V.M., Sviren M.O. – 20-30% [14], Yang M. - 14.2–21.2% [19], Vasylenko V.V., Afonychev – 18% [20]. These values correlate well with the obtained theoretical curves.

IV. Conclusions

The application of the proposed plough body with a pneumatic soil loosener in plough units is both promising and environmentally friendly. Reducing overall movement resistance will increase the unit's speed and, consequently, its productivity. Optimizing the diesel engine's speed and load modes will enhance its operational efficiency and economic performance. Additionally, utilizing compressed air from the tractor's pneumatic system to power the pneumatic hammers will stabilize its load.

As a result, fluctuations and maximum deviations in soil resistance will decrease, improving the reliability and durability of both the plough bodies and the plough as a whole. Furthermore, working conditions will improve by eliminating the need to modify the plough for heavy soils, such as removing the rear body.

A comparison of theoretical results indicates a significant reduction in traction resistance for tillage implements equipped with vibrating working bodies compared to conventional ones. The developed model of tillage tool operation allows for the assessment of vibration looseners' effectiveness in reducing traction resistance. This conclusion is supported by graphs that align with similar findings in other studies.

Implementing vibrating working bodies in tillage tools will help minimize agricultural machinery operating costs. The use of vibrations reduces the theoretically calculated traction resistance of the plough within the speed range of 0.5–2.5 m/s by 19–23%. Moreover, at lower speeds, the influence of vibrations is more pronounced: reducing traction resistance by 22–23% at 0.5 m/s and by 19–20% at 2.5 m/s.

The results obtained in the work can further serve to clarify and improve existing engineering methods for calculating the main characteristics and parameters of vibratory ploughs, both at the stages of their design / construction, and in real operation modes.

References

[1] V. P. Horjachkyn, Sobranie sochinenij v 3-x tomax, 1965, vol. 1, 720 p.; vol. 2, 459 p.; vol. 3, 512 p.

[2] V. V. Adamchuk, H. L. Baranov, and O. S. Baranovs'kyi, Suchasni tendencii rozvytku sil'skogospodars'koi tekhniky, Kyiv: Ahrarna nauka, 2004, 396 p.

[3] B. Szabo, F. Barnes, and S. Sture, "Effectiveness of vibrating bulldozer and plow blades on draft force reduction," Transactions of the ASAE, vol. 41, no. 2, pp. 283–290, 1998.

[4] M. Korchak, "Problems of field contamination when growing energy corn as monoculture," E3S Web of Conferences, vol. 154, 2020, Art. no. 01009. https://doi.org/10.1051/e3sconf/202015401009

[5] S. Yermakov, T. Hutsol, V. Devin, S. Oleksiyko, and P. Potapskyi, "The effectiveness of cognitive digressions in classes of general technical disciplines in institutions of higher education of agro-technical direction," Engineering for Rural Development, Jelgava, May 25–27, 2022, pp. 460–465. https://doi.org/10.22616/ERDev.2022.21.TF154

[6] V. Devin, S. Yermakov, O. Gorbovy, V. Pidlisnyj, and A. Semenov, "Research on Working Bodies of Hammer Crushers Employing the Finite Element Method," Vide. Tehnologija. Resursi - Environment. Technologies. Resources, vol. 3, Rezekne, Latvia, 2023, pp. 65–68. https://doi.org/10.17770/etr2023vol3.7197

[7] S. Yermakov, T. Hutsol, I. Garasymchuk, P. Fedirko, and V. Dubik, "Study of the unloading and selection process of energy willow cuttings for the creation of a planting machine," Environment. Technologies. Resources, vol. 3, Rezekne, Latvia, 2023, pp. 271–275. https://doi.org/10.17770/etr2023vol3.7199

[8] V. S. Loviekin, Yu. V. Chovniuk, and L. A. Dyachenko, "Dynamičnyj analiz tjahovoho oporu vybropluhiv," Vibratsii v tekhnitsi ta tekhnolohiiakh, no. 3(67), pp. 112–115, 2012.

[9] D. H. Vojtiuk, Sil's'kogospodars'ki mashyny: osnovy teorii ta rozrakhunku, Sumy: VTD Universytets'ka knyha, 2008, 543 p.

[10] P. M. Zajika, Teoriia sil's'kogospodars'kykh mashyn. T. 1 (4.1). Mashyny ta znariad'dia dlia obrobky hruntu, Kharkiv: Oko, 444 p.

[11] X. Dong, H. Zheng, C. Su, Y. Li, J. Song, and J. Wang, "Test and analysis of vibration characteristics of vibration subsoiler," INMATEH. Agricultural Engineering, vol. 68, no. 3, pp. 906–917, 2022. https://doi.org/10.35633/inmateh-68-90

[12] Patent 1197117 Ukraine, Korpus pluha z pnevmatychnym rozpushyvachem hruntu, 2016, Biul. № 10, p. 5.

[13] S. Yermakov, A. Rud, and M. Vusatyi, "The distribution of cash expenses for the creation of bioenergy willow plantations in Ukraine," Vide. Tehnologija. Resursi - Environment. Technologies. Resources, vol. 1, Rezekne, Latvia, 2023, pp. 74–80. https://doi.org/10.17770/etr2023vol1.7191

[14] V. M. Bulgakov, M. O. Sviren', and R. V. Kisil'ov, "Doslidzhennia vybraziinykh protsesiv pry osnovnomu obrobci hruntu," Naukovyi visnyk Tavriiskoho derzhavnoho ahrotekhnolohichnoho universytetu, vol. 5, no. 1, pp. 3–13, 2015.

[15] V. M. Bulgakov, M. O. Sviren', I. P. Palamarchuk, et al., Vybraziini mashyny sil's'kogospodars'koho vyrobnytstva: Monohrafiia, Kirovohrad: KOD, 2012, 512 p.

[16] J. Sun, Y. Wang, Y. Ma, J. Tong, and Z. Zhang, "DEM simulation of bionic subsoilers (tillage depth > 40 cm) with drag reduction and lower soil disturbance characteristics," Advances in Engineering Software, vol. 119, pp. 30–37, 2018. https://doi.org/10.1016/j.advengsoft.2018.02.001

[17] X. Ma, S. Wang, and H. Wang, "Vibration soil crushing mechanism of self-excited vibration subsoiler in coastal area," Journal of Coastal Research, vol. 103, pp. 426–430, 2020. https://doi.org/10.2112/SI103-087.1

[18] J. Li, X. Jiang, Y. Ma, J. Tong, and B. Hu, "Bionic design of a potato digging shovel with drag reduction based on the discrete

element method (DEM) in clay soil," Applied Sciences, vol. 10, 7096, 2020. https://doi.org/10.3390/app10207096

[19] M. Yang, X. Sun, X. Deng, Z. Lu, and T. Wang, "Extrapolation of tractor traction resistance load spectrum and compilation of loading spectrum based on optimal threshold selection using a genetic algorithm," Agriculture, vol. 13, no. 6, 1133, 2023. https://doi.org/10.3390/agriculture13061133

[20] V. V. Vasilenko and S. V. Vasilenko, "Effect of vibration on resistance force of plough," Advances in Engineering Research, vol. 151, pp. 779–783, 2018.

[21] D. H. Vojtiuk, Sil's'kogospodars'ki mashyny. Osnovy teorii ta rozrakhunku, Kyiv: Vyshcha osvita, 2005, 464 p.

[22] A. Tryhuba, T. Hutsol, I. Tryhuba, et al., "Risk assessment of investments in projects of production of raw materials for bioethanol," Processes, vol. 9, no. 1, 12, 2021. https://doi.org/10.3390/pr9010012

[23] I. V. Holovach, I. P. Palamarchuk, and M. O. Sviren', "Minimal'no dopustyma chastota kolyvan' vibraziynogo vykopuyuchogo robochoho orhanu," Vibratsii v tekhnitsi ta tekhnolohiiakh, no. 4(68), pp. 35–41, 2012.

[24] M. Korchak, S. Yermakov, T. Hutsol, L. Burko, and W. Tulej, "Features of weediness of the field by root residues of corn," Vide. Tehnologija. Resursi - Environment, Technology, Resources, vol. 1, pp. 122–126, 2021. https://doi.org/10.17770/etr2021vol1.6541