Modelling the movement of a cultivating shovel in the ground

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Abstract. The paper presents the results of the calculation of the forces acting on the cultivating shovel when moving in the ground. For research, the finite element method implemented in the ANSYS program was used. The tasks of constructing a grid model of the ground were solved, the horizontal component of the force of the impact of the ground when moving at different speeds was determined.

1. Introduction
For trenching, various devices with cultivating shovels (CSs) are used. In the proposed design, as a working body, a flexible tubular element is used, at the end of which a CS is attached.

The change in pressure in the inner cavity of the rack causes the cross-sections to deform and the free end with the cultivating shovel moves. In the process of cultivating the soil, the working body is influenced by the resistance forces of the soil of a variable nature, which causes rack vibrations. The flow of working fluid into the cavity of the rack under variable pressure leads to oscillatory movements of a CS with a certain amplitude and frequency, which depend on the parameters of the supplied pressure. Calculation of vibration parameters of flexible tubular springs is given in [1-5].

2. Formulation of the problem
To ensure trouble-free operation of the cultivator, it is necessary to solve the following problems:

1. Building a grid model of the CS movement in the ground.
2. Determination of the horizontal component of the force R of the soil impact on the shovel, depending on the speed of movement.

3. Theory
To simulate the movement of a CS in the soil, we assume the following - the treated soil will be considered as a continuous medium. The movement of an object in a continuous medium can be equivalently replaced by “flowing around” a body at rest with a continuous medium at the same speed; this approach will allow the use of ANSYS Fluent.
To determine the relationship between the horizontal component $R$ and the velocity $V$ of the cultivating shovel (CS), we use the dependence:

$$R = C_x F \frac{\rho V^2}{2}$$

(1)

here $F$ is the mid-sectional area — the largest cross-sectional area; $\rho$ is the density of the continuous medium (of the soil under consideration), $V$ is the CS velocity in the soil, $C_x$ is a dimensionless coefficient characterized by the geometric component and the rate of flowing around with the continuous medium (i.e., it is a function of velocity).

So, $C_x$ and the horizontal component $R$ directly depends on the design of the CS, in this paper, we consider the influence of the most primitive design below but evaluate the influence of the grid model and the size of its elements, as well as models of the behaviour of a continuous medium.

4. Experiment results

The CS is made of steel, geometric characteristics: length - 500 mm, height - 200 mm, width - 400 mm. Hydrodynamic calculation was carried out in toolbox - fluent.
All hydrodynamic problems require an iterative approach to solving, we consider the change in the value of the drag coefficient $C_x$ depending on iterations and on the velocity of flowing around with a continuous medium for various models of continuous medium behavior.

![Graph of $C_x$ value vs. Number of iterations](image)

**Figure 3.** Results of the evaluation of the influence of the number of iterations

The calculation results showed that to obtain reliable results, iterations may be limited to 300. The distribution of velocities in the simulated volume is shown in Figure 4, and the effect of the movement velocity on the resistance force is shown in Figure 6.

![Graph showing the effect of flow velocity](image)

**Figure 4.** Results of the evaluation of the effect of flow velocity
Figure 5. Velocity distribution in the simulated volume

Figure 6. The influence of the movement velocity of the cultivating shovel on the resistance

5. Conclusions
The proposed methodology for determining the resistance of soil to the CS movement allows one to calculate the permissible velocity of its movement with a fixed geometric dimension of the element to which it is attached. More accurate modelling of the design of the CS will refine the value of the movement velocity.

References
[1] Pirogov S P 2009 Manometric tubular springs (St. Petersburg: Nedra) 276
[2] Pirogov S P, Cherentsov D A and Chuba A Yu 2015 Fluctuations of manometric tubular springs (Tyumen: TSOGU) 95
[3] Pirogov S P, Cherentsov D A and Chuba A Yu 2018 Tubular spring mechanisms (Tyumen: IUT) 78
[4] Pirogov S P and Chuba A Yu 2017 Application of manometric tubular springs in agricultural machines Agro-food policy in Russia 9 (69) 82-8
[5] Andreeva L E 1962 Elastic elements of devices (Moscow: Mashgiz) 456
[6] Akselrad E L 1976 Flexible shells (Moscow: Nauka) 376
[7] Cherentsov D A 2014 Determination of generalized resistance forces in second-order Lagrange equations describing the oscillations of manometric springs in the presence of viscous friction forces Natural and technical sciences 4 (72) 12-5
[8] Cherentsov D A, Chuba A Yu and Pirogov S P 2013 Model of oscillations of a manometric tubular spring in a viscous fluid In the collection: Problems of the functioning of transport systems Materials of the All-Russian Scientific and Practical Conference of Students, Graduate Students and Young Scientists, dedicated to the 50th anniversary of the founding of the Tyumen Industrial Institute 373-7
[9] Cherentsov D A, Pirogov S P and Dorofeev S M 2014 A mathematical model of a manometric spring in a viscous medium Bulletin of the Tyumen State University. Physical and mathematical modelling. Oil, gas, energy 7 234-41
[10] Cherentsov D A, Pirogov S P, Dorofeev S M and Cherentsova S A 2017 Study of damped oscillations of manometric springs with a rigid tip News of higher educational institutions. Oil and gas 1 116-20
[11] Pirogov S P 2016 Foundations of the Design of Vibration-Resistant Measurement Techniques. Volume 59, Issue 8, November, 845–9.
[12] Pirogov S P 2018 Oscillations of manometric tubular springs with rigid end S P Pirogov, D A Cherentsov, S M Dorofeev and Y S Ryabova IOP Conf. Series: Materials Science and Engineering 357 012030 doi:10.1088/1757-899X/357/1/012030
[13] S P Pirogov, A Y Chuba and D A Cherentsov 2018 Effect of section shape on frequencies of natural oscillations of tubular springs IOP Conf. Series: Materials Science and Engineering 357 012032 doi:10.1088/1757-899X/357/1/012032
[14] Pirogov S P and Cherentsov D A 2016 Theoretical foundations of the design of vibration-resistant manometers Measurement Techniques 59 8 845-9
[15] Pirogov S P, Cherentsov D A and Gulyaev B A 2016 Prospects of applying vibration-resistant pressure gauges in the oil and gas industry IOP Conference Series: Materials Science and Engineering "International Scientific-Practical Conference of Students, Graduate Students and Young Scientists "Transport and Storage of Hydrocarbons."" C 012013