Mathematical modeling of the stress state of the tubular stand of the cultivator

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Abstract. The paper presents the results of the calculation of stresses and strains of the cultivator stand structure with a flexible tubular element under loading with internal pressure and external force. For research, we used the finite element method, implemented in the program "ANSYS". The tasks of building a grid model of a tubular element were solved, the displacements of the free end and stresses under the action of internal pressure were determined, and the maximum allowable pressure value was found. The horizontal component of the impact force of the soil on the cultivator, at which buckling occurs, is determined, and the influence of the section shape on the characteristics of the cultivator stand is investigated.

Keywords: stress, strain, buckling, tubular element

1. Introduction

Currently, flexible tubular elements (manometric tubular springs) are used not only as sensitive elements of pressure gauges (manometers) but also are widely used as power elements of various mechanisms (brakes, manipulators, agricultural machines) \cite{1}, \cite{2}.

The design of the working bodies of tillage and seeding machines must comply with optimal agrotechnical requirements and minimize energy costs. It is possible to achieve by creating machines with controlled working bodies that are able to precisely meet agrotechnical requirements and respond in a timely manner to changing external conditions.

Thus, in the design of the cultivator \cite{3}, \cite{4}, a flexible tubular element is proposed to be used as a working body.
Figure 1. The working body of the cultivator.

The design of the working body of the cultivator (Fig. 1.) includes: a chisel point 1 mounted on the C-shaped stand 2. The stand is made of a flexible tubular element with a nozzle 3, which allows you to change pressure in the cavity inside the element. A bracket 5 is designed to mount the stand 2 to the frame 4.

The change in pressure in the internal cavity of the stand causes the cross-sections to deform and the free end with the chisel point 1 moves. In the process of tillage, the working body of the cultivator is influenced by the resistance forces of the soil of variable nature, which causes stand oscillations. The flow of the working fluid through the nozzle 3 into the cavity of the stand 2 under variable pressure leads to oscillatory movements of the chisel point with a certain amplitude and frequency that depend on the parameters of the supplied pressure.

A review of the designs of elastic tubular elements (manometric springs) is given in [5]. The work [6] studies the oscillatory motion of noncircular tubes, the parameters of attenuating tube oscillations in a viscous medium are studied in [7], and the influence of a rigid tip is considered in [8].

2. Problem statement

The use of a flexible tubular element in the cultivator reduces the traction resistance of the tillage machines due to the effect of vibration when interacting with the soil, and also improves the quality indicators of the tillage process by adjusting the rigidity of the stand.

To calculate stresses and strains, the finite element method implemented in the ANSYS program was used.

To ensure trouble-free operation of the cultivator it is necessary to solve the following problems:
1. Building a grid model of a tubular element;
2. Determining the horizontal component of the force $R_n - R_{nx}$ of the impact of the soil on the opener, at which buckling occurs;
3. Evaluating the influence of the geometric characteristics of the tube on $R_{nx}$.

3. Theory

The accuracy of the calculations will directly depend on the quality of the grid model of the structure under consideration. A rigid restraint (attachment point) and a tip (working member) are built by default using the Sweep method, and to build a grid model, it is necessary to determine the best grid generation method (Tetrahedrons or Sweep) and the minimum size of elements ensuring the correctness of the solution without the loss of accuracy.
Let us estimate how the displacement of the free end of the tube when the horizontal force (1000 N) affects the free end will change when the method and size of the design model elements change, the calculations in the toolbox Static Structural are shown in Fig. 2.

The results of the calculations are presented in Fig. 3.

Analyzing the obtained results, we can conclude that as the size of the elements of the grid model of the tube decreases, the values of the displacement of the free end tend to a certain limit. A “smoother” solution is obtained by the Sweep method; the minimum element size for which the deviation of the calculation results is less than 0.5% is 5 mm.

4. Experimental results

Results of the calculations of the cultivator stand under the action of longitudinal force.
Geometrical characteristics of the opener: the central angle is 180 degrees, the radius of curvature is 500 mm., the large semi-axis of the cross-section is 25 mm., the small semi-axis of the cross-section is 12.5 mm, and the wall thickness is 2.5 mm.

Buckling was calculated in the toolbox Eigenvalue Buckling, stress was calculated in the toolbox Static Structural.

The calculation results have shown that buckling will occur when the value of the horizontal component of the force $R_{nx}$ is 12.8 kN. Maximum stresses, as well as violation of the integrity of the tube, are observed at the base of the rigid restraint (at the attachment point).

To increase the allowable value of the horizontal component of the force $R_{nx}$, it is necessary to investigate the influence of the parameters of the stand and determine the most optimal geometrical characteristics.

We investigate the influence of the section shape of the tubular element on the allowable horizontal component $R_n$. A variety of design solutions are considered in [4]. Next, the effect of the following section shapes will be considered: flat-oval, elliptical, 8-shaped (Fig. 4).

The results of evaluating the influence of the dimensions of the flat-oval section have shown that with a decrease in the ratio of the major and minor axes, the allowable load decreases, just as for the elliptical section.

The results of evaluating the influence of the dimensions of the 8-shaped section have shown that a more “flattened” shape, with other things being equal, will withstand a greater load.

However, preference should be given to the flat-oval form as the most technological one.

To improve the strength characteristics of tubular springs, it is proposed [4] to use tubes with a variable cross-section along the central axis and wall thickness (Fig. 5).
Next, the effect of a change in the thickness of the opener wall on Rnx was investigated. The results are presented in Fig. 6.

**Figure 5.** Designs of tubes with a variable cross-section.

**Figure 6.** The effect of changing the wall thickness along the length of the tube.

The results of the evaluation have shown that although the greatest stresses occur at the base of the tube, increasing the wall thickness only near the base will increase the value of Rnx by only 10%.

**Discussion of results**

When performing mathematical calculations of the cultivator stand in the form of a flexible tubular element, it was found that the best method of building a grid (Tetrahedrons or Sweep) and the minimum size of elements that ensure the correctness of the solution without the loss of accuracy is 1 mm. Analysis of the stress-strain state of the stand under the action of an external force of 1000 N has shown that the displacement of the chisel point will be 30 mm. For the proposed cultivator stand to buckle, a horizontal force of at least 12800 N is required. This confirms an adequate margin of safety for the stand. Evaluation of the influence of the dimensions of the cross-section of the element has
shown that as the ratio of the major and minor axes decreases, the allowable load increases regardless of the shape.

6. Conclusions

Mathematical analysis of the use of a flexible tubular element as a stand of a cultivator point has shown that a soil resistance force of 1000 N causes the cultivator point to move up to 30 mm. The proposed cross-section retains its stability under the action of a soil resistance force up to 12800 N, which, in reality, proves the possibility of using the proposed design even on heavy soils. The use of pulsating hydraulic pressure within the strength limits of the material will create a vibration effect of the point on the soil and will help reduce the traction resistance.

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