Study of the stress-strain state of a flexible tubular element of the working body of a tillage machine

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Abstract. The designs of the working bodies of tillage and sowing machines are subject to requirements to ensure optimal agrotechnical requirements and minimize energy costs. This can be achieved by creating machines with controlled working bodies that are able to accurately comply with agrotechnical requirements and respond in a timely manner to changing external conditions. Known are designs of the working bodies of tillage machines, in which a flexible tubular element (manometric tubular spring) is used as a stand.

When applying variable pressure to the cavity of the tubular element, its end performs a reciprocating motion, which improves the quality of tillage. The paper presents the results of a study of the stress-strain state of the tubular element of the coulter using the ANSYS software package. The authors built a grid model of a tubular element, determined the horizontal component of the force of the soil impact on the coulter, at which stability loss is observed, and studied the influence of the geometric characteristics of the tubular element—the shape of the section, the opening angle, and the bending radius—on the critical force value. Tubular elements with a section variable in length were also investigated and their effectiveness was shown.

Keywords. working body of a tillage machine, flexible tubular element, manometric tubular spring, vibration, stress, strain, ANSYS.

1 Introduction.

Studies in [2-6,8] show that the vibrational effect of the working body of tillage machines on the soil makes it possible to ensure optimal agrotechnical requirements, as well as to reduce energy costs. So, as an alternative to a stationary coulter, it is proposed to use a design where the working body is a flexible tubular element—a manometric tubular spring (MTS), at the end of which a cultivator shovel is attached [9,10] (Fig. 1).

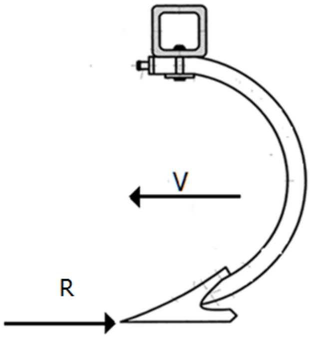

Fig.1. Coulter working body

A change in pressure in the internal cavity of the manometric tubular spring causes the cross sections to deform and the free end with the cultivator shovel reciprocates. A variable change in pressure will lead to oscillatory movements with a certain amplitude and frequency, which depend on the parameters of the supplied pressure.

The use of flexible tubular elements in agricultural machinery makes it possible to reduce the traction resistance of tillage machines due to the effect of vibration when interacting with the soil, as well as to improve the quality indicators of the tillage process by adjusting the rigidity of the stand.

When the cultivator interacts with the cultivated soil, it is necessary to limit the cultivator's movement speed, since exceeding the limit value of the movement speed leads to a violation of the integrity of the flexible tubular elements and, as a result, to the breakdown of the entire structure.

2 Methods

The aim of the study is to ensure the trouble-free operation of the "modification" of the coulter by ensuring its strength and rigidity.

To do this, we need to:

1. Build a grid model of the coulter to calculate buckling;
2. Determine the horizontal component of the Rn-Rnx force of the impact of the soil on the coulter causing loss of stability;
3. Estimate the influence of the geometric characteristics of the MTS on Rnx;

The studies were carried out using the ANSYS software package. The accuracy of calculations depends on the quality of the grid model of the structure under consideration.

To construct a grid model of the MTS, it is necessary to determine the best method for constructing a grid (Tetrahedrons or Sweep) and the minimum size of elements that ensure the correctness of the solution without loss of accuracy. The grid models under consideration are shown in Fig. 2

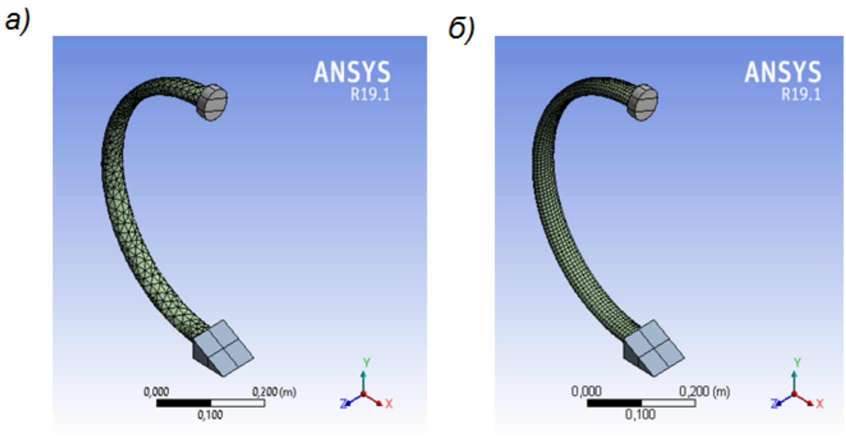

Fig. 2. Grid methods, a) –Tetrahedrons, b) - Sweep

Let us estimate how the displacement of the free end of the MTS will change when a horizontal force (1000 N) acts on the free end of the MTS when the method and size of the elements of the grid model are changed. The calculations in the toolbox-Static Structural are shown in Fig. 3

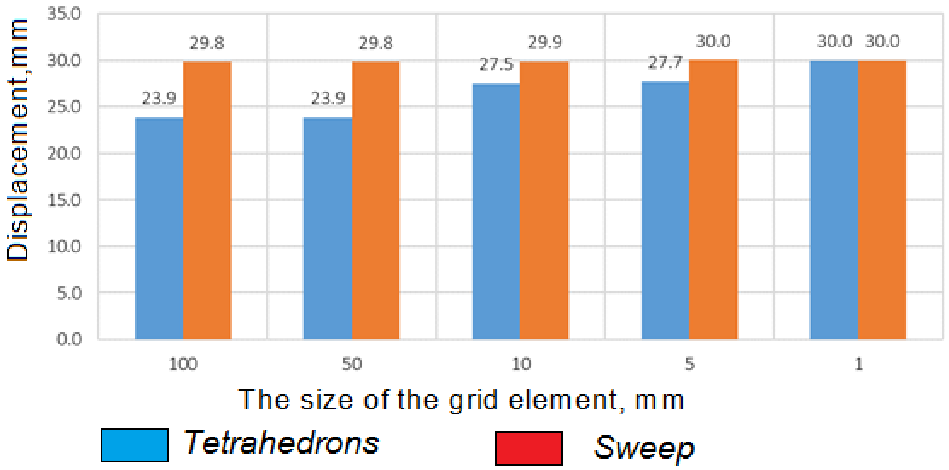

Fig.3. Dependence of displacements on grid methods and element size.

As we can see from the diagram, as the size of the MTS grid model elements decreases, the displacement values of the free end of the MTS tend to a certain limit. A more "smooth" solution is obtained when using the Sweep method; the minimum element size where there is a deviation of the calculation results of less than 0.5% is 5 mm.

3 Results

Calculation of buckling was carried out in the toolbox-Eigenvalue Buckling, and stress calculation—in the toolbox-Static Structural.

A sample with the following geometric characteristics was studied: central angle—180 degrees, radius of curvature—500 mm, major semi-axis of the cross section—25 mm, minor semi-axis of the cross section—12.5 mm, wall thickness—2.5 mm.

The results of the calculation showed that the loss of stability will occur if the value of the horizontal component of the Rnx force is 12.8 kN. The maximum stresses, as well as the violation of the integrity of the element, are observed at the base of the fixed edge restraint (at the attachment point).

To increase the allowable value of the horizontal component of the Rnx force, it is necessary to investigate the influence and determine the most optimal geometric characteristics of the tubular element.

Fig. 4 shows the most common cross-sectional shapes [1]

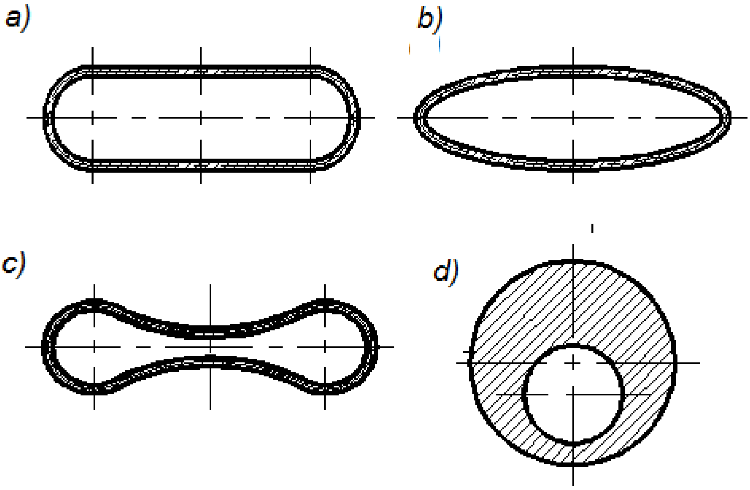

Fig.4. Sectional shapes of the tubular element: a) flat-oval, b) elliptical, c) figure-of-eight, d) Nagatkin spring (with an eccentric axial channel)

The flat-oval section provides sufficient sensitivity, greater than the figure-of-eight section, and at the same time contributes to the manufacturability of the design.

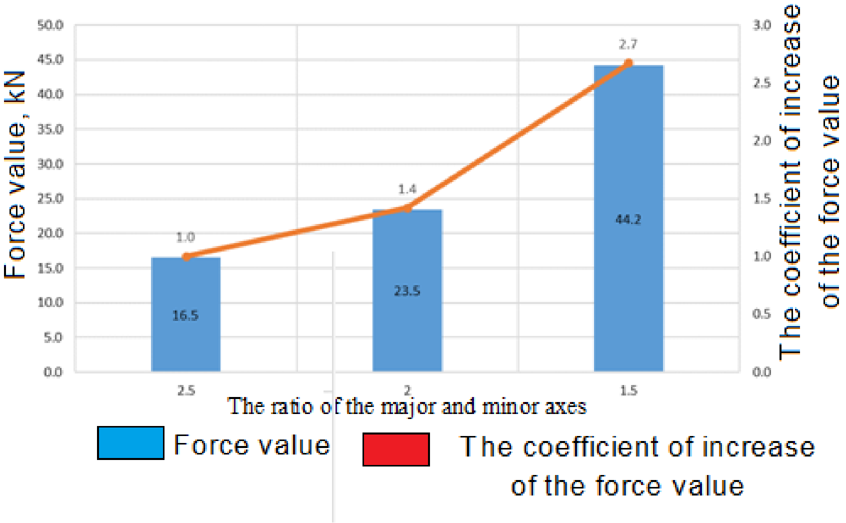

Fig.5. Results of the study of the flat-oval section

We can see from the figure that as the size of the semi-major axis of the section increases, the tube will withstand a larger load.

Similar results were obtained in the study of tubes of elliptical cross-section (Fig. 6).

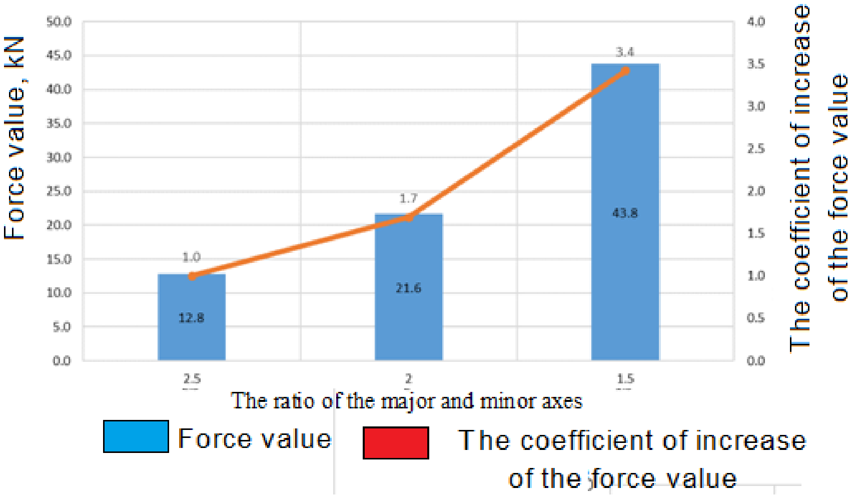

Fig.6. Results of the study of the elliptical section

The figure-of-eight section had the following parameters: major axis—50 mm, minor axis at the boundaries of the section—20, 25, and 34 mm, minor axis in the center—20, 25, and 34 mm.

The results of evaluating the influence of the dimensions of the figure-of-eight section (Fig. 7) showed that it is more flattened in its middle. Studies have shown that springs of figure-of-eight section have great strength and rigidity to the action of external forces compared to tubes of elliptical and flat oval sections. This shape, other things being equal, will withstand a larger load, but it must be taken into account that they are less sensitive to the action of internal pressure.

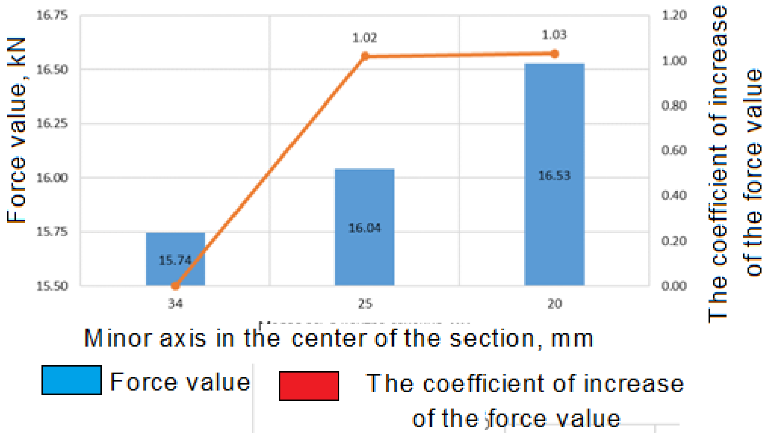

Fig.7. Results of evaluating the influence of the minor axis in the center of the section

Large stresses arising at the ends of the major axis of symmetry on the internal contour of the section limit the possibility of using tubular springs under the action of very high pressures.

In this case, the section of A.G. Nagatkin is used [1].

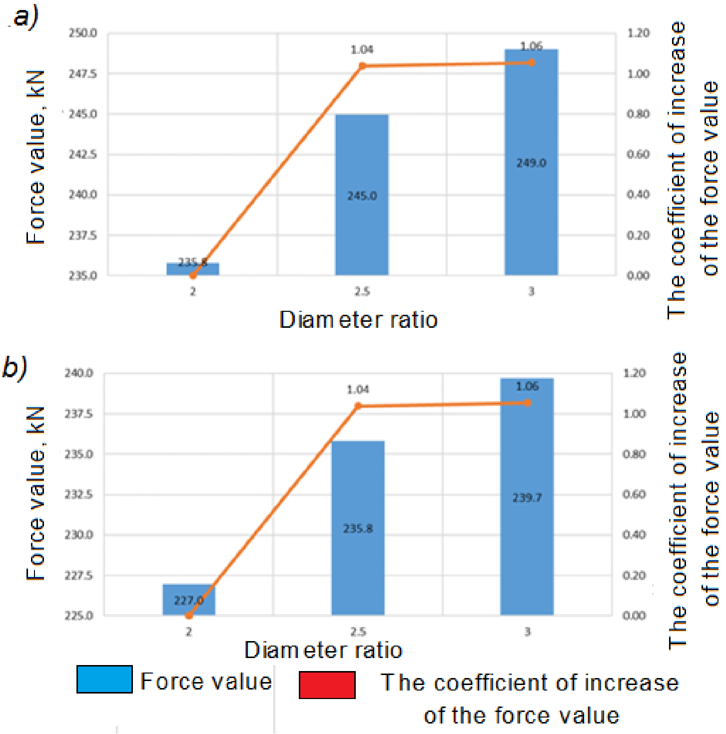

Fig.8. Results of evaluating the tube section named after A.G. Nagatkin, a) at 50% axle offset, b) at 100% axle offset

The results of evaluating the influence of the shape of the section named after. A.G. Nagatkina showed (Fig. 8) that this sectional shape can withstand an order of magnitude greater load than all the others, and an increase in eccentricity (shift of the axes) leads to a decrease in rigidity.

To improve the strength characteristics of flexible tubular elements, a number of spring designs were proposed with a cross-section and wall thickness that are variable along the central axis, for example, a manometric spring with a variable wall thickness increasing from the base to its free end [9] (Fig. 9), as well as consisting from several interconnected tubes, each of which has a constant wall thickness and the ratio of the semi-axes of the section, with the wall thickness and the size of the semi-axes of the section of the tubes increasing from the free end of the spring to the fixed one [7] (Fig. 10.).

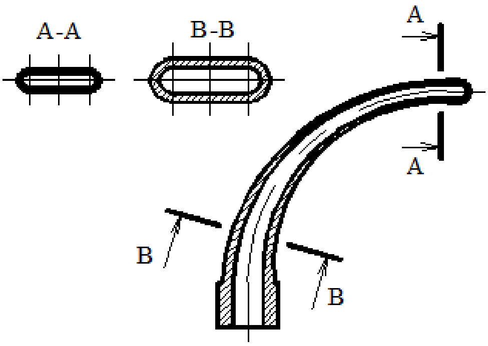

Fig.9. Variable section tube

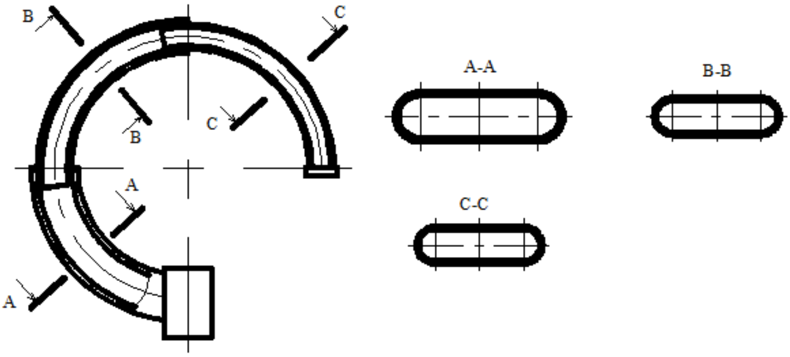

Fig.10. Composite tube

Let us investigate the effect of changing the wall thickness along the MTS on Rnx. Geometric characteristics of the MTSare as follows: central angle—180 degrees, radius of curvature—500 mm, major semi-axis of the cross section—25 mm, minor semi-axis of the cross section—12.5 mm, wall thickness—5 and 2.5 mm. Below are the results of the study.

The results showed (Fig. 10) that although the greatest stresses occur at the base of the MTS, an increase in the wall thickness only near the base will increase the value of the limiting force by only 10%. In the case of an increase in the wall thickness along the entire MTS, the limit value of Rn increases three-fold.

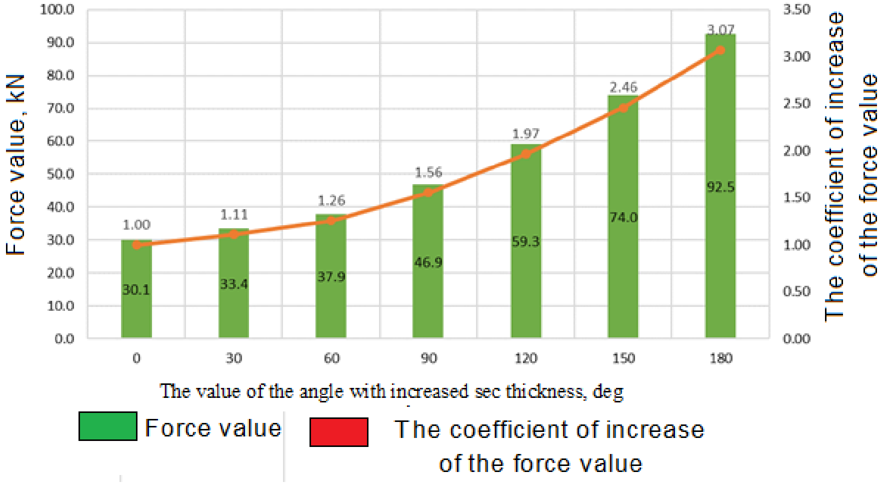

Fig.11. Results of evaluating the influence of changing the wall thickness

Figs. 12 and 13 show the dependence of the force at which the structure loses stability on the central angle and bend radius of the tube.

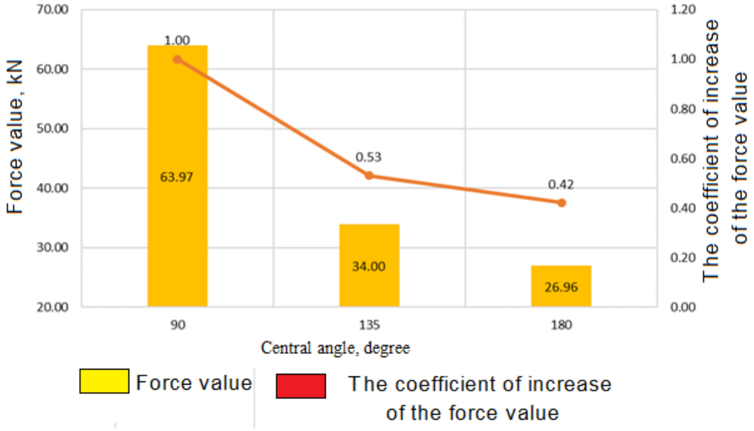

Fig.12. Results of evaluating the influence of the central angle

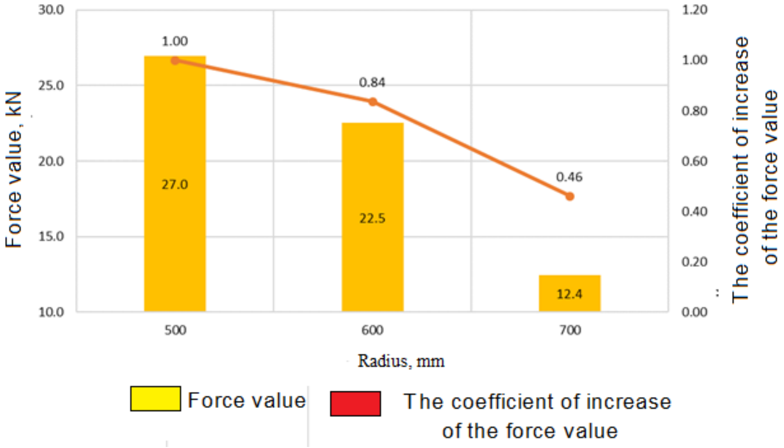

Fig.13. Results of evaluating the influence of the radius of curvature

4 Discussion

The performed studies of the stress-strain state of the tubular element of the working body of a tillage machine using modeling in the ANSYS software package made it possible to determine the maximum load at which the element loses stability, depending on the section shape and geometric dimensions.

The most technologically advanced and at the same time quite strong is the flat-oval cross-sectional shape, and the eight-shaped tube has the greatest rigidity and withstands a larger external force without loss of stability.

The use of the Nagatkin spring is hardly advisable, since it has low sensitivity with high rigidity, and a lot of pressure is required to set it in motion—about 100-150 MPa.

The most advantageous is the use of a tubular element with a cross-section variable along the length; an increase in the wall thickness towards the base of the tube makes it possible to increase the load up to three times.

Reducing the radius of curvature and the central angle naturally leads to an increase in the critical force, and these parameters must be chosen constructively.

5 Conclusion

Thus, the developed method for studying the stress-strain state of a tubular element makes it possible to design an element of the working body of a tillage machine with specified characteristics and ensure its strength when working in the soil.

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