Simulation of the stress-strain state of the working body of the system for the development of the pipeline trench

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Abstract. The use of mechanical pressure gauges as pressure measuring devices is regulated by standard documentation. Also, manometric tubular springs – the sensitive elements of pressure gauges are used in various technology fields. Thus, the use of MTS in agricultural machinery allows reducing the traction resistance of tillage machines due to the effect of vibration when interacting with the soil, as well as improving the quality of the soil treatment process by adjusting the stiffness of the rack. This paper presents the results of calculating the stresses and deformations of the ripper shank structure, made in the form of a flexible tubular element when loaded with internal pressure and external force. The active development of the oil and gas industry is currently directed towards the remote territories of the Yamal peninsula and the territories of the Far East, which are characterized by complex natural and climatic conditions of construction. In this regard, it is necessary to develop new approaches and methods of construction in permafrost conditions. The paper presents the results of calculating the stresses and deformations of the structure of the ripper shank, made in the form of a flexible tubular element under loading by internal pressure and external force. The finite element method implemented in the "ANSYS" program was used for research.

1. Introduction

The development of the oil and gas industry is currently aimed at remote territories of the Yamal Peninsula and the territories of the Far East with promising deposits of hydrocarbon raw materials. The economic efficiency of the development of such deposits was influenced by the distance of fields from existing infrastructure, as well as by difficult natural and climatic conditions of construction.

In this regard, it is necessary to develop new approaches and methods of construction in the conditions of permafrost soil. According to the flow chart for pipeline trench development in permafrost conditions, the following process operations are included into the series of trunk line grid works:

- surface layout along the whole route using a bulldozer;
- geodesic survey of a trench;
- frozen soil loosening with a ripper-equipped bulldozer (Figure 1);
- excavation in a trench by a rotary bucket excavator;
- trench reworking by a single-bucket excavator up to project levels.
The operation of frozen soil loosening can be optimized. The works [1, 2] showed that the vibration impact of a working element of tillage and sowing machines on cultivated soils ensures optimal agricultural requirements and reduces energy consumption. Thus, as an alternative to a stationary ripper it is proposed to use a structure where the working element is a flexible tubular element – a manometric tubular spring with a ripping tooth on the end (Figure 2).

The pressure change in the internal cavity of the manometric tubular spring makes cross sections to deform and the free end with a ripping tooth to make reciprocal movements. Variable pressure change will lead to oscillatory movements with certain amplitude and frequency, which depend on applied pressure parameters.

2. Materials and methods

The works of many researchers are devoted to the study of manometric tubular springs (MTS) and their vibration parameters [1, 2]. When the proposed design interacts with permafrost soils, it is necessary to limit the bulldozer movement speed since exceeding the speed limit violates the MTS integrity and, as a result, leads to the failure of the entire structure. The calculation of MTS pressure and deformation shall be carried out using the finite-element method in ANSYS software system.

3. Results

The simulation results obtained in ANSYS depend on the quality of the grid model. Earlier, in [2], a grid model was obtained, which increases the stability of simulation results for a sample tube with the following geometric characteristics: central angle – 180°, radius of curvature – 500 mm, major semiaxis of cross section – 25 mm, minor semiaxis of cross section – 12.5 mm, wall thickness – 2.5 mm, material – 36NHTU steel.

The grid model characteristics ensuring the required accuracy are as follows: grid method – Sweep, element size – 5 mm.
Simulation experiments to assess the impact of internal pressure on the movement of the trenching unit working element and the maximum stresses in the considered structure were carried out. The results are shown in Figures 4 and 5.

**Figure 3.** Grid model

**Figure 4.** Impact of internal pressure on the end tube displacement

**Figure 5.** Impact of internal pressure on the maximum voltage
The analysis of the dependencies of movements and stresses on the internal pressure shows that at the initial loading – at 4 MPa – there is a linear increase of stresses and movements, while high pressures cause the deviation from linear dependence.

In order to determine the maximum speed of the bulldozer during the interaction of the proposed structure with permafrost soils, the dependence of the influence of the speed of movement of the bulldozer on the maximum horizontal force $R$ was defined.

The calculation of the maximum horizontal force, at which the loss of static stability is observed and as a result the failure of the working element, was carried out in work [2] for different MTS cross sections and parameters. Thus, for plane-oval tubes the maximum possible $R$ is 44.2 kN, for elliptical – 43.8 kN, for eight-shaped – 45.9 kN. The maximum stresses, as well as the violation of MTS integrity, are observed at the anchorage base.

Permafrost soil characteristics: density – 1020 kg/m$^3$; freezing-thawing start temperature – minus 0.3°C, total humidity – 5.19 unit fractions, quantity of non-frozen water in frozen soil at permafrost temperature – 2.47 unit fractions, elastic modulus – 14 MPa.

The impact of bulldozer speed on the maximum horizontal force was determined in toolbox – Eigenvalue Buckling. The results of calculations are given in Figure 6.

![Figure 6. Impact of the displacement speed on the resistance force](image)

The stress-strain analysis under the influence of the external force (1,000 N) showed that the end of the tube would move 30 mm. The necessary horizontal force for the buckling failure shall make at least 12,800 N. This confirms the sufficient strength of the considered structure.

4. Conclusion
The analysis of the dependencies of movements and stresses on the internal pressure shows that at the initial loading – at 4 MPa – there is a linear increase of stresses and movements, while high pressures cause the deviation from linear dependence.

The simulation of the working element in the form of MTS of the trenching unit showed that for the proposed MTS design the loss of stability will be observed at the horizontal force of 12.8 kN. In order to prevent buckling, it is necessary to limit the maximum speed of the bulldozer – not more than 25 km/h.

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