Modelling the stress-strain state of tubular springs in the ANSYS software package

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Abstract. The paper presents the results of calculating the stresses and strains of manometric tubular springs under loading by internal pressure and external force. For research, the finite element method implemented in the ANSYS program was used. The problems of constructing a grid model of the tubular element were solved, the displacements of the free end and stresses from internal pressure were determined, and the maximum permissible pressure value was found.

1. Introduction
A manometric tubular spring is a curved non-circular tube. Under the influence of internal pressure, the tube straightens, and its end experiences displacement.

Tubular springs were originally proposed as elastic sensing elements of manometric devices, and now they are widely used as power elements of various mechanisms (brakes, manipulators, agricultural machines). [1-3]

2. Formulation of the problem
Figure 1 shows a diagram of a manometric tubular spring.

Many researchers study manometric tubular springs. The main calculation methods were energy methods [4] and the theory of flexible shells [5-8].

Figure 1. A manometric tubular spring.
Significant drawbacks of all methods were that they described the stress-strain state of the tubes without taking into account the end sections, which strongly affect the distribution of stresses. In addition, only small displacements were considered, that is, the geometrical nonlinearity arising from sufficiently large displacements of the tube end was not taken into account. Also, these methods did not allow studying the conditions of stability loss.

To eliminate these drawbacks, it was proposed to simulate the stress-strain state of tubular springs by the finite element method in the ANSYS software package. The application of this method also allows one to determine the natural frequencies of vibrations.

3. Theory
The accuracy of the calculations will directly depend on the quality of the grid model of the structure under consideration. A rigid constraint (attachment point) and a tip are constructed by default using the Sweep method, and in order to construct the grid model of a manometric spring, it is necessary to determine the best grid method (Tetrahedrons or Sweep) and the minimum size of the elements, which ensures the correct solution without the loss of accuracy.

**Figure 2. Building a grid model.**

A tube with the following geometric characteristics was taken as a sample: the central angle is 180 degrees, the radius of curvature is 500 mm, the semi-major axis of the cross-section is 25 mm, the semi-minor axis of the cross-section is 12.5 mm, the wall thickness is 2.5 mm, the material is 36NHTY steel.

To assess the influence of methods for building the grid and element sizes, we determined the displacement of the free end of the tube under the influence of a horizontal force of 1000 N on the free end of the tube. Grid models are shown in Figure 2.

The calculations were made in toolbox - Static Structural, the results are presented in Figure 3.

Analyzing the obtained results, we can conclude that with a decrease in the size of the elements of the grid model of the tube, the values of the free end displacement tend to a certain limit. A smoother solution is obtained using the Sweep method; the minimum element size at which deviation of the calculation results is less than 0.5% is 5 mm.
Results of the evaluation of the displacements of the free end of the manometric tubular spring

| Grid element size, mm | Displacement, mm |
|-----------------------|------------------|
| 100                   | 23.9             |
| 50                    | 23.9             |
| 10                    | 29.8             |
| 5                     | 27.5             |
| 1                     | 29.9             |
| 0.5                   | 27.7             |
| 0.1                   | 30.0             |

Figure 3. Results of the evaluation of the displacements of the free end of the tube.

4. Experiment results

Maximum stresses, MPa

| Internal pressure, MPa | Maximum stresses, MPa |
|------------------------|----------------------|
| 0.25                   | 136                  |
| 0.5                    | 273                  |
| 1                      | 546                  |
| 2                      | 1090                 |
| 4                      | 2180                 |

Figure 4. Influence of internal pressure on maximum stresses.

Figures 4 and 5 show the results of computational experiments to determine the maximum stresses and displacements of the tube end.

We also set and solved the task to determine the maximum value of the horizontal force R applied to the end of the tube, at which a loss of stability is observed.

The calculations were made in toolbox – Eigenvalue Buckling.

The calculation results showed that the loss of stability will occur at a force value of 12.8 kN. The maximum stresses, as well as the violation of the integrity of the manometric tubular spring, are observed at the base of the rigid restraint.
5. Discussion
When performing mathematical calculations of a tubular spring, it was found that the best way to build a grid and the minimum size of the elements, providing the correct solution without loss of accuracy, is 1 mm. Analysis of the stress-strain state under the action of an external force of 1000 N showed that the movement of the end of the tube will be 30 mm. For stability loss, the required horizontal force is at least 12800 N. This confirms a sufficient margin of safety.

An analysis of the dependences of displacements and stresses on internal pressure shows that at the initial stage of loading, at pressures up to 4 MPa, a linear increase in stresses and displacements is observed; at high pressures, a deviation from the linear dependence occurs.

6. Conclusions
The study of stresses and strains by the finite element method in the ANSYS software package showed that this method can be successfully used to determine the stresses, displacements, and stability of manometric tubular springs under the influence of external forces and internal pressure.

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