Effect of section shape on frequencies of natural oscillations of tubular springs

S P Pirogov 1,2, A Yu Chuba 2 and D A Cherentsov 1

1 Industrial University of Tyumen, 38 Volodarskogo Str., Tyumen, 625000, Russia
2 State Agrarian University of the Northern Trans-Urals, 5 Republic Str., Tyumen, 625003, Russia
E-mail: cherentsovda@bk.ru, voronin_tsogu@mail.ru

Abstract. The necessity of determining the frequencies of natural oscillations of manometric tubular springs is substantiated. Based on the mathematical model and computer program, numerical experiments were performed that allowed us to reveal the effect of geometric parameters on the frequencies of free oscillations of manometric tubular springs.

1. Introduction
Tubular springs are the main elastic sensing element of manometric devices. Pressure gauges often have to work in the conditions of vibrations and pulsations of the working environment, which is typical for the oil and gas industry, so manometric tubular springs in these devices oscillate, which makes it difficult to accurately record instrument readings and adversely affects the precision of measurements. It is necessary to prevent the manifestation of these shortcomings at the design stage. Great attention should be given to the dynamic calculations of tubular springs, in particular, the definition of vibration resistance.

Vibration frequency is the main characteristic of vibration resistance; therefore, an important task is to study the influence of factors on this characteristic, in particular, the influence of geometric parameters of a tubular spring. Mathematical models of oscillatory motion of tubular springs are given in [1-3].

2. Materials and methods
The manometric tubular spring is a tube bent with radius R of the central axis and having a cross-sectional shape different from the circumference (Fig. 1). The cross-section has one or two mutually perpendicular axes and is arranged so that one of its axes is an extension of the radius of curvature of the central axis.

One end of tube 2 is hermetically sealed by tip 4 and the other end is fixed in holder 1. Through the opening in the holder, pressure in the inner cavity of the tubular spring changes, leading to a deformation of the cross-section and changes in the curvature of central axis 3, and the free end of tube performs displacement $\lambda$. The free end of the tube is connected to the mechanism of the manometer, by means of which the movement is transmitted to the indicator of the device.
The geometric parameters of the tubular spring determining its dimensions are the radius of curvature of the longitudinal axis – $R$, the central angle of the opening – $\gamma$, the wall thickness – $h$, the major semiaxis – $a$, and the minor semiaxis – $b$.

At present, manometric springs of constant cross-section along the length of the tube are the most common; the main cross-sectional shapes are elliptical, flat-oval and 8-shaped. To improve the characteristics of manometric springs, a number of spring designs with a cross-section and wall thickness varying along the central axis [6-11] are proposed, which may have better performance characteristics than springs of constant cross-section. There are tubular springs with a variable cross-section of the tube, both along the perimeter of the cross section, and along the longitudinal axis of the tube. In this case, the variables can be either the dimensions or the shape of the section.

3. Study
To compare the properties of tubes of a constant cross section, their shape was represented by a universal section (Fig. 2).
By changing ratio $b/b_1$, one can move from elliptical ($b/b_1 > 1$) to 8-shaped ($b/b_1 < 1$). For a flat-oval cross-section, $b/b_1 = 1$.

For all compared springs, the same geometric parameters will be: $R=40$ mm, $h=0.4$ mm. The cross-sectional height of all springs is the same.

The graph of the dependence of the natural oscillation frequency on the shape of the cross-section is shown in Fig. 3.

The graph shows that the most rational is the flat-oval shape; for the elliptical one there is a significant reduction in frequency, and for the 8-shaped - a slight increase.

Let us investigate the effect of changing the cross-sectional shape of springs of a variable cross-section on the example of nine brass springs with the geometric parameters: the radius of the workpiece tube is $r=6$ mm, the radius of curvature of the central axis is $R=40$ mm, the wall thickness is $h=0.4$ mm, the value of the central angle of springs is $\gamma=230^\circ$. The cross-section of the springs varies from the rigidly fixed to the free end as follows:

1) from 8-shaped to flat-oval;
2) from 8-shaped to elliptical;
3) from flat-oval to 8-shaped;
4) from elliptical to 8-shaped;
5) from elliptical to flat-oval;
6) from flat-oval to elliptical;
7) from flat-oval to more flattened flat-oval;
8) from elliptical to more flattened elliptical;
9) from 8-shaped to more flattened 8-shaped.

Flat-oval sections have the following characteristics: $a/r=1.34$, $b/b_1=1$; elliptical: $a/r=1.4$, $b/b_1=1.42298$; 8-shaped: $a/r=1.26$, $b/b_1=0.1965$. Fig. 4 shows the results of the calculations.

Figure 3. Dependence of the natural oscillation frequency on the shape of the cross-section
4. Conclusion

Analysis of the results of numerical experiments showed that for tubes with a constant wall thickness, the most advantageous is the flat-oval cross-section.

It has been confirmed that variable-section springs have higher frequencies of natural oscillations than springs of a constant cross-section. In particular, it has been found that springs with a variable cross-section ranging from 8-shaped to flat-oval, as well as springs made from conical tubes, have frequencies of natural oscillations 20-40% higher than similar ones of a constant cross-sections.

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