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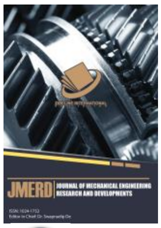

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RESEARCH ARTICLE

AUTOMATION OF CALCULATIONS OF TECHNICAL CHARACTERISTICS OF MANOMETRIC TUBULAR SPRINGS

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ABSTRACT

Tubular springs have received the name "Manometric" thanks to their initial use in manometric devices. For the wide use of tubular springs in various spheres of human activity, relevant methods of calculating their static and dynamic characteristics are needed. Many works have discussed the study of manometric tubular springs. The main method for calculating static characteristics of springs is the semi-membrane theory of shells, and to calculate the frequencies of natural oscillations, the spring was considered as a rod with a deformable cross-section. The article considers algorithms for calculation of static characteristics and frequencies of natural oscillations of manometric tubular springs with known geometric parameters of a spring and physical properties of a material. For calculations, in general, numerical methods were used, so for their implementation, it was required to develop programs for automatic design, in which the algorithms are implemented. The article describes the software systems for calculating the characteristics of springs: "Module" and "PCRMTP", which allow investigating the stress-strain state of the cross-section of tubular springs, determine their static characteristics with known geometric parameters, spring material, internal pressure and operating conditions. In addition, in the complex "PCRMTP" the possibility of calculating the frequencies of natural oscillations of tubular springs is realized. The automation of the design of tubular springs significantly reduces the labour input of selecting springs with the necessary characteristics and thereby eliminates the deterrent factor of introducing new designs.

KEYWORDS

Manometric tubular spring, Bourdon tube, automation, calculation algorithm.

1. INTRODUCTION

A manometric tubular spring is a tube of a non-circular cross-section curved along a certain radius, one end of which is sealed and the other is fixed in the holder. In the holder, there is an opening for supplying pressure to the inner cavity of the spring. Under the influence of internal pressure, the cross-sections of the tube deform, tending to a circular shape, while the tube tends to straighten, and its free end moves. Initially, tubular springs were used in pressure measuring devices, and then it was suggested to use them in other engineering fields [1-5].
A large number of works have dealt with the study of manometric tubular springs. The main method for calculating the static characteristics of springs is the semi-membrane theory of shells, and to calculate the natural oscillation frequencies, the spring was considered as a rod with a deformable cross-section [6-11]. As a rule, numerical methods were used for calculations, therefore for their implementation, it was required to develop programs for automatic design. The automation of the design of tubular springs significantly reduces the labour input of selecting springs with the necessary characteristics and thereby eliminates the deterrent factor of introducing new designs.

2. SUBJECTS AND METHODS

Algorithm for automatic design of springs with perimeter change of the wall thickness:

1. Calculation of all possible geometrical parameters of the tube cross-section which can be made from a standard tube-workpiece with the given values of the wall thickness h, the diameter of the tube d and the large semi-axis of the cross-section of the spring A.

2. Determination of the cross-sectional shape suitable for the strength of these versions of springs with a constant wall thickness.

3. Testing the possibility to improve the technical characteristics of the spring by reducing the wall thickness at the junction points of the middle and side sections of the cross-section without loss in strength.

4. Calculation of the working stroke λp of the selected spring.

5. Creation of a database of springs designed for a certain pressure and value of the working stroke of the end of the spring by repeating the procedures described above. This takes into account the manufacture of springs from tube-workpieces of a certain diameter and wall thickness. In addition, we take into account that each spring can change the ratio of the semi-axes of the cross-section, the radius of curvature of the central axis, the working central angle.

6. Selection of the optimal design from the set obtained.

According to the above algorithm, a computer program was developed in the MATLAB environment for the automatic design of manometric tubular springs having a variable wall thickness along the perimeter of the spring cross-section [12]. Based on a study, dealing with the calculation of the static characteristics of manometric tubular springs with a variable cross-section along the length of the central axis, the task was to determine the stress-strain state for known spring geometric parameters, internal pressure, and operating conditions [13]. In the process of work, the following algorithm was proposed.

1. Enter the value of internal pressure, material characteristics, geometric characteristics of the spring.

2. Select the operating mode (power compensation or kinematic mode).

3. Break the spring into the required number of sections along the length of the longitudinal axis (to ensure an acceptable error in the solution).

4. Calculate geometric characteristics of the cross-sections at each section, solve the system of equations for each of the parts with a constant section.

5. Calculate either the amount of displacement of the free end of the tubular spring or the value of the traction force developed by the spring.

6. Check the relative error of the calculation result. If the error is large, then increase the number of sections of the spring break and repeat the process from the fifth point. If the error is acceptable, then conduct a full calculation of the technical characteristics of the spring and visualization of the calculation results.

The proposed algorithm is implemented in the package of application programs "Module" [14]. A study of the convergence of the solution on the examples of three types of tubular springs showed that, in most of cases, the division into 25 sections yields an acceptable error in the calculations, therefore, this number of sections is set as a minimum in the software package. The tolerable error is set at 0.1%. The shape of the cross-section at each of the sections of the partition is given by elements of constant curvature, this allows the calculation of springs of a variable cross-section of various types. The developed interface facilitates the process of entering data necessary for calculation, monitoring the geometric parameters of the spring and visualizing the calculation results. In addition, the calculation of springs with the cross-section constant along the length of the central axis is provided. Due to the fact that manometric tubular springs often operate under conditions of pulsation of pressure and vibrations of the equipment on which they are installed, there is a need to calculate and dynamically characterize tubular springs. One of the main dynamic characteristics is the frequency of natural oscillations. Automation of calculation of this value allows minimizing the possibility of the resonance phenomenon which negatively affects the operation of tubular springs. The method of such determination of the frequencies of natural oscillations with known geometric parameters of the spring and the physical properties of the material is described in detail in [15]. It underlies the following calculation algorithm.

1. Entering the geometric parameters of the spring and the physical characteristics of the material.

2. Setting the initial and final values of the interval of the expected location of the natural oscillation frequency, as well as the step of changing the frequency.

3. Determining the geometric parameters of the cross sections, the Karman coefficient and the moment of inertia. Calculating the determinant of the system of equations for each value from the frequency interval.

4. Comparing two adjacent values of the determinant. If there is a change in the sign (from + to - or from - to +), then find the arithmetic mean between the frequencies at which these determinants were calculated or the value of the frequency at which the determinant is zero.

The proposed algorithm is implemented in the package of applied programs "PCRMTP" [16]. The software package is written in the high-level language of the computer mathematics system "MATLAB". To calculate the determinant, we use the standard function det. Since the lowest frequencies are of the greatest practical importance, the program provides for the calculation of the first five natural frequencies.

3. RESULTS AND DISCUSSION

The package "PCRMTP" implements algorithms for calculating the static characteristics of manometric tubular springs and frequencies of natural oscillations.

Figure 1 shows windows for starting and entering the calculation data, Figure 2 and 3 – windows for visualizing the results of calculations of the characteristics of the spring and the stress diagram.

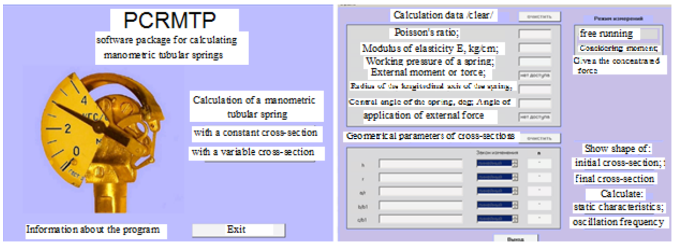

Figure 1: Windows for starting and entering calculation data

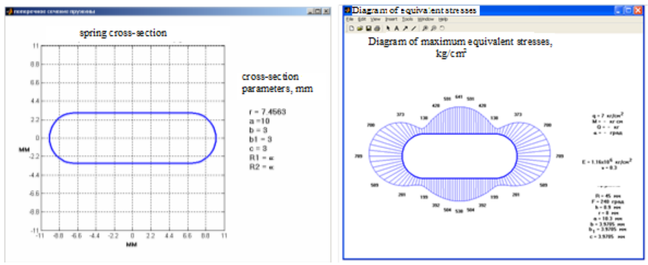

Figure 2: Windows for visualizing the results of calculating the cross-section of a spring and a stress diagram

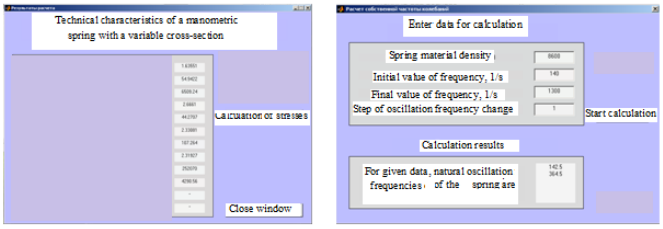

Figure 3: Window for visualizing the results of calculating the characteristics of the spring

With the help of this software package, the sensitivity, traction forces, stresses and vibration parameters for tubular springs of various designs - with a constant and variable wall thickness, with variable cross-sectional lengths, with different geometric dimensions, were studied, and optimum designs for various operating conditions were determined.

4. CONCLUSION

The developed computer technologies for calculating displacements, traction forces, stresses, natural oscillation frequencies allow designing tubular manometric springs with specified properties in the shortest possible time, which makes it possible to use them in various technical systems.

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