TRANSPORT PROBLEMS 2019 Volume 14 Issue 3
PROBLEMY TRANSPORTU DOI: 10.20858/tp.2019.14.3.4

Keywords: flexible tubular element; Bourdon tube; transportation device; tamping machine; paving slab layer; laser ablation

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CREATION OF PROMISING TRANSPORTATION DEVICES USING MECHANISMS BASED ON FLEXIBLE TUBULAR ELEMENTS

Summary. This article presents the design of various mechanisms, the main working element of which is a flexible tubular element. The principle of operation and advantages of flexible elements allowing to create perspective devices and mechanisms are described. The problems of selection of the geometrical parameters of flexible tubular springs and evaluation of the strength characteristics are solved.

1. INTRODUCTION

Development of modern transportation devices deals with some sophisticated problems, such as the development of cross-country vehicles. One of the most perspective types of such a machine is a walking machine [1]. Some walking machines may use the so-called Tchebyshevs plantigrade mechanism as its base, while others may use "legs" with an open kinematical chain [2]. Nevertheless, many researches show that this machine should be built on the base of tubular-element constructions from polymer materials to decrease its mass while its mechanical properties remain the same [3]. This is why it is necessary to develop a theory and computational methods for such elements.

Among all the tubular elements used in mechanical engineering, flexible tubular elements, or Bourdons tubes, are the most interesting in calculations and potential use.

Flexible elements shaped as a thin-walled elongated cross-section tube with a central axis curved along the circumference have traditionally been used to measure pressure. Bourdon first introduced the manometric tubular spring in 1851. The main property of the Bourdon spring is the ability to change the radius of curvature of the center axis depending on the pressure applied to the internal cavity.

In modern technology, tubular elements not only measure pressure. In some cases, multi-cell tubes are used to increase tube flexibility. In article [4], the behavior of a tube in which single tubes are built is considered and results of deformation of tubes with various configurations of internal tubes are considered. In this case, the tube cannot be attributed to the elastic elements; they do not provide greater flexibility. The scope of their application has expanded. The ability of the free end of the element to move by an amount depending on the internal pressure made it possible to create new mechanisms and machines. It is possible to use the property of the tubular spring in various fields of industry. The advantages of mechanisms that use the Bourdon spring are as follows:

- Providing the required working body stroke with small overall dimensions;
- Possibility of preserving the functionality of an elastic member when changing the operating pressure in a wide range;
- Simplicity of the mechanism design;
- High maintainability;
- Keeping the work environment clean.

There are studies of tubular elements. In article [5], the influence of parameters of a straight tube on its rigidity is considered. Modeling the deformation process of a curved tube requires solving a system with an additional equation.

The principles of the tubular element, the development of a mathematical model for its analysis, are described in the article [6]. The developed mathematical model allows to obtain the working characteristic of the element-the dependence of the free end of the element on the internal pressure. The research became the basis for the establishment of proposals for the creation of new machines and mechanisms based on Bourdon tubes.

The manufacture of tubular elements is possible by different processes. It is possible to manufacture from two pre-deformed sheets. Article [7] deals with one example of sheet metal forming, providing high geometric accuracy. In article [8], the influence of deviations of the location of the inclined dies in the manufacture of cold drawing as to the distribution of residual stresses.

2. PROMISING PROPOSALS IN THE DESIGN OF MACHINES

2.1. Tamping machine

A problem that is interesting for practice is the creation of vibrators for various purposes. To compact the ballast bed of the railway track permanently, a tamping machine is used. One of these machines is shown in Fig. 1. Working bodies are deepened in the ballast bed under a sleeper to be tamped and brought together, while supplying the ballast under the sleeper.

Fig. 1. Tamping machine

Cyclic action machines use oscillating vertical tamping picks, and continuous action machines use wedge-shaped tamping plates as the working bodies. Irrespective of the tamping machine type, the tamping unit design is bulky, with several kinematic constraints. The complex design forces reduce the maintainability of the machine. The need to lubricate the contiguous elements leads to environmental pollution. The use of a tubular spring allows the development of a simple compact design [9]. Fig. 2 shows a tamping unit with working bodies in the form of tubular springs.

Fig. 2 shows: 1 - hydraulic cylinder rod; 2 - working body (Bourdon tube); 3 - pulsating pressure; 4 - sleeper; 5 - ballast; and 6 - cross-sectional shape. Hydraulic cylinder rod 1 moves downwards under pressure and its own weight to be deepened into ballast 5. Pulsating pressure 3 is supplied into the working cavity of Bourdon tube 2 through rod 1, which makes the working bodies vibrate. The working bodies are deepened into the ballast, while redistributing it under sleepers 4. The free ends of Bourdon tube 2 shown in Fig. 2 receive the necessary output characteristics depending on the pressure applied into the internal cavity.

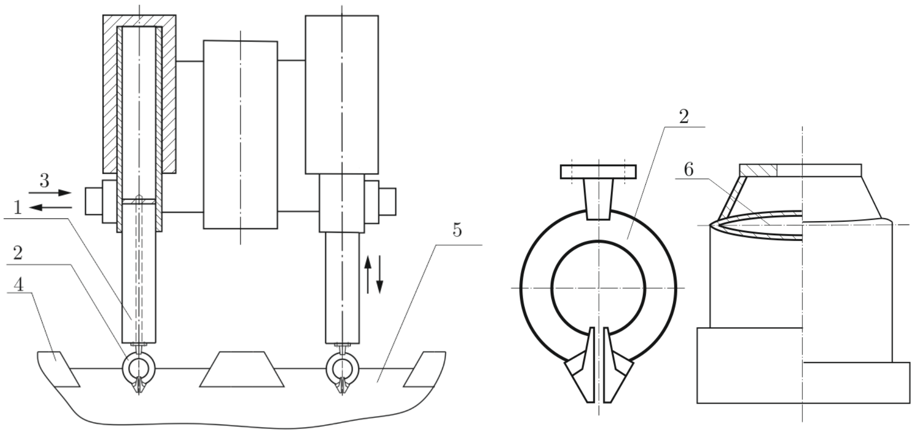

Fig. 2. Tamping unit schematic diagram

The use of a tubular spring as a working element of the machine allows to:

- Increase the efficiency,
- Reduce the size,
- Increase the maintainability,
- Simplify the design, and
- Increase the ecological safety of the work performed.

2.2. Machine to rivet paving slabs

The article offers several options for the use of tubular elements in machines for different purposes. When laying paving slabs, only manual labor is used to rivet them. Developing a machine to rivet paving slabs will significantly reduce the labor content and cost of the work, increase productivity, and minimize the negative impact of the human factor.

Fig. 3 shows a schematic diagram of a paving slab layer that uses a Bourdon tube as working bodies. This is an interesting opportunity to replace manual labor by a machine [10]. The principle of operation is based on the Bourdon tube 2 vibration under the action of pulsating pressure 3, which is fed into the inner cavity of the tube through the hydraulic cylinder rod 1. The vibration of the working body results in riveting the paving slab 4 on the sand bed 5. It is possible to develop this proposal in the creation of a pressure control system.

2.3. Mathematical model

A mathematical model that uses the variational principles of structural mechanics [11], namely the principle of minimizing the functional of potential energy of a mechanical system, has been developed for forces acting on tubular elements based on a three-dimensional isoparametric finite element. To analyze the three-dimensional stress state, a finite element with a different approximation of displacements in different directions has been used. Based on the mathematical model described above, a software package for personal computers has been developed that allows designing plates, thin-walled shell structures, rotational shells, and shells of medium thickness with the transition to three-dimensional bodies. The developed software complex is designed to analyze the three-dimensional stress–strain state of general form bodies under a distributed load. The analysis of result reliability for the proposed software package has been performed on test problems, for which exact analytical solutions are known.

The use of finite-element modeling can be taken into account for edge effects that are insignificant for springs with a large twist angle [12, 13]. However, for a small angle with a large cross-sectional wall thickness, edge effects must be considered. This may affect the performance of the feature to change the stress state.

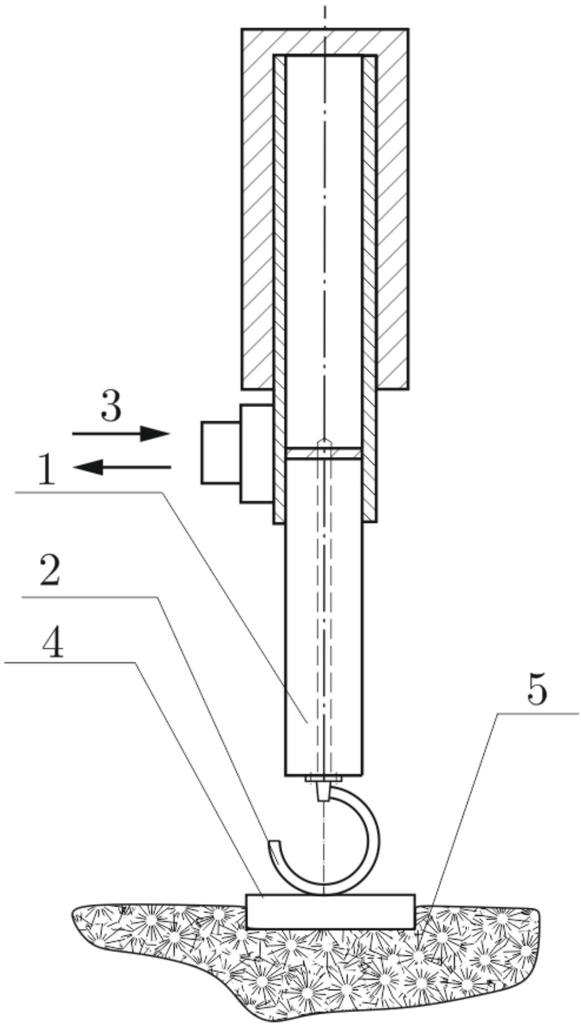

Fig. 3. Schematic diagram of a paving slab layer

Fig. 4 shows the process of deforming a tubular element and deforming its cross section. In work [11], the influence of geometrical parameters of a tubular element and a cross-sectional shape on the deformation of an element is investigated.

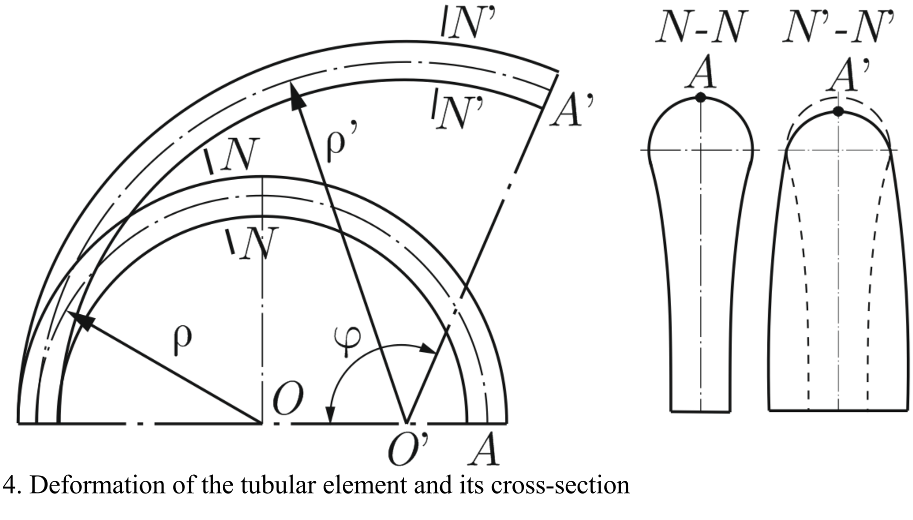

Fig. 4. Deformation of the tubular element and its cross-section

The dimensions of the basic tubular spring model have been determined based on the design considerations. The bending radius is ρ = 41.5 mm; the length of major axis a = 63.5 mm; the length of the minor axis is b = 10 mm; and the thickness is h - 3 mm.

To investigate the influence of geometrical dimensions on the spring stress–strain state, a number of calculations with resizing such parameters as the bending radius of the spring p and the tube thickness h, and output parameters. The bending radius of the spring was varied from 41.5 mm to 101.5 mm and the wall thickness was varied from 1 mm to 4 mm. The increase in the spring radius or reduction in the spring thickness corresponds almost equally to the increase in sensitivity. The lowest natural frequency of the spring has been calculated, which has been set equal to 123.8 Hz. This will allow developers of vibrating mechanisms to build adaptive resonance systems that will enable to handle more efficiently the compacted material with different characteristics under different climatic conditions. The use of a tubular spring in the design of various vibrators allows taking full advantage of Bourdon tubes.

2.4. Mechanism for laser ablation of selenium

Application of the tubular element in the design of machines may be in different industries. For example, in medicine and agriculture is use actively selenium as a stimulant of the immune system of humans and animals and means of increasing productivity. For these purposes it is necessary to have a selenium nano-solution, the production of which is possible with the use of laser ablation. The process of making the nano-solution has features. The use of a tubular spring allows to solve this problem. An example of the design of the device is described in article [14]. The feature of this process is a strict order of the laser position relative to the container with the solution in the process of ablation. To prepare the solution correctly, the laser head must be initially opposite to the upper solution layer, the next position must be opposite to the lower layer, and the third position must be opposite to the middle layer. To exclude the involvement of foreign elements in the process, it is proposed to use a flexible tubular element as a device that controls movements. Figs. 5 and 6 show a diagram for selenium laser ablation.

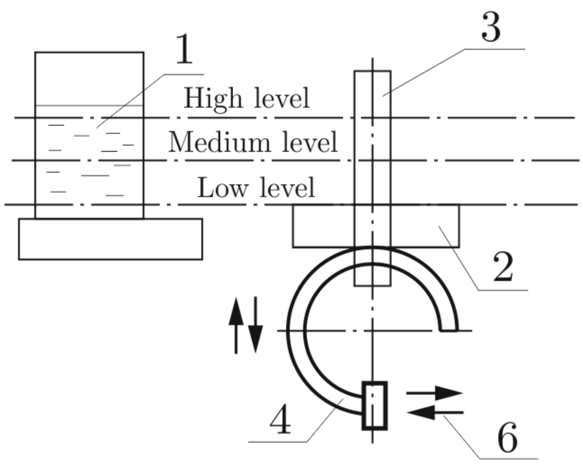

Fig. 5. Schematic diagram of a mechanism using a single-turn spring

A stock solution of selenium is placed in container 1. Platform 2, on which the laser head is located, moves along vertical guides 3 under the action of tubular spring 4 or 5 force. In the initial position, the laser head is situated at the lower level.

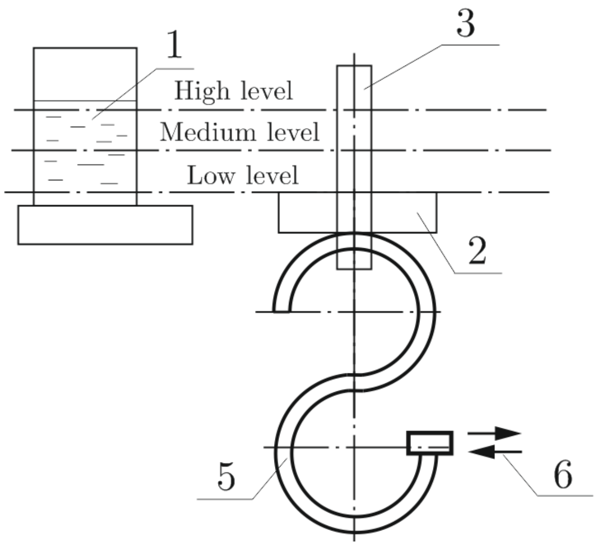

Fig. 6. Schematic diagram of a mechanism using a two-turn spring

There are two ways to move platform 2 to the medium and upper layer levels:

- apply pressure 6 of different values to the interior cavity of spring 4 (single-turn spring),
- apply pressure of a certain value to different springs 5 (two-turn spring).

Structurally, the second method is much easier to implement. The use of constant internal pressure, which does not change over time, greatly simplifies the pressure control system.

Under atmospheric pressure, both springs have the original geometry and platform 2 occupies the lowest position. When pressure is applied to the S-shaped spring, platform 2 moves to the upper position and the laser head is positioned at the upper layer level. The second ablation step occurs at the lower level, while there is no overpressure inside both springs. To complete the process of laser ablation, pressure is applied to tubular spring 4 and the laser head is positioned at the level of the middle layer.

The use of a tubular spring in the laser head movement mechanism provides precision and minimal wear. The guides ensure that the linear laser head moves without skewing. The clamps provide the required laser positioning.

There are many examples of different applications of tubular springs. Article [15] deals with a shock absorber that absorbs energy in a side impact of a ship. To do this, it is proposed to use a thin-walled structure filled with foam. Such a shock absorber can effectively serve as a Bourdon tube.

In modern conditions of welding production development, the quality control of weld joints became necessary. The quality is assessed using laser technology; here, the welded joint scanning area must be free from foreign microparticles. A clean work environment can only be ensured by using a mechanism based on a manometric tubular spring. In this case, the structure itself has several advantages: simplicity, reliability, high accuracy of the laser head path, purity of the working environment, accurate assessment of welded joint quality, and high maintainability.

3. CONCLUSION

As the article shows, the application of tubular springs can be different. The initial data for the design are as follows:

- Displacement of the spring end,
- Value of the internal pressure,
- Pressure force of the spring end on the object,
- Type of movement of the end of the element (smooth or vibration).

The problem under consideration determines the significance of each of these parameters.

When designing an elastic element with the shape of a Bourdon tube, the following has to be chosen:

- Cross-sectional shape;
- Central axis bending radius; and
- Cross-sectional size ratio.

Use of an elastic tubular spring as a working body of machines allows simplifying significantly the design, increasing maintainability, and reducing the cost of the machine set. Depending on the problem to be solved, the design parameters of the tubular spring can vary significantly. But it retains all these advantages of mechanisms based on Bourdon tubes. An important achievement is environmental safety, which is provided by the tubular element.

The results of the research are the following achievements:

1. the structural schemes of several mechanisms have been developed;
2. a computational model based on the theory of shells is developed;
3. the geometrical parameters of tubular springs providing the necessary deformation of the flexible element are determined; and
4. the process of deformation of a flexible element using the finite element method is studied.

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Received 10.02.2018; accepted in revised form 24.08.2019