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Vibration assisted spring loaded micro spray system for biomedical application

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1. Introduction

Manifestations of cardiovascular diseases associated with abnormal coronary, and cerebral arteries caused in the acute phase vessel occlusion by thrombus. In recent years, there has been an increase in the number of thromboembolic complications in various diseases, such as aterosklerotic syndroms, thrombo and others. At present, this problem is partly solved thanks to widespread use of treatments that contribute to the restoration of patency of the affected vessel by enzymatic or mechanical removing an intravascular thrombus. At the same time carry out these therapies to limit the term of thrombus formation, size, presence of comorbidities, the frequency of intra- and clinical postprocedure complications. This situation points to the need to develop new alternative treatments for arterial thrombosis, aimed at overcoming the disadvantages of conventional methods to overcome damaged vessel.

In recent years, much attention is paid cardiology ultrasound techniques as having the greatest prospects among alternative ways to restore vascular permeability. This is due to the broad therapeutic potential of action of ultrasound on biological tissues. In [1-3], the low-frequency low intensity ultrasound increases the elastic properties of the vascular wall and the compliance of the affected artery. Similar data have been obtained by other authors [4]. At the same time, we have shown that by using waveguides with a head at its distal end there is a considerable risk of deep arterial wall dissection followed by its perforations. This is due to a significant concentration of energy due to mechanical and ultrasonic vibrations head waveguide in a limited area of the vessel on a background of significant, sometimes irreversible, lesions of the vascular wall. All this suggests that we have developed for recanalization of occluded arterial segments waveguide catheter ultrasound system cannot be used without risk to improve the biomechanical properties of the arterial wall and its subsequent remodeling.

To improve the efficiency of ultrasound vascular recanalization, we have developed a waveguide tube type without working head to the distal end of a cylindrical slotted spring. This type of waveguide can handle the vessel wall as a mechanical action, and directed action saline jet emanating from the distal end of the hole, under the longitudinal ultrasonic vibrations.

To determine the pressure on the thrombus created jet contact the distal end of the waveguide is seen as a tubular core with slots (pores) through which saline is supplied, the rod is introduced into the artery and connected to a source of ultrasonic longitudinal vibrations whereby the fluid is ejected through the pores in the artery, and effect on thrombus on the vessel wall.

The unique feature of the tabular vibratory valve [5] consists in the fact that the sealing surface of the seat is facing towards the intake duct and is located in the node of the second natural mode of transverse vibration of the elastic pipe. The unique feature of the tabular vibratory valve consists in the fact that the sealing surface of the seat is facing towards the intake duct and is located in the node of the second natural mode of transverse vibration of the elastic pipe. In that work the main attention was devoted for the analysis of dynamic properties of the tube serving as the controlling organ of the vibratory valve. Nevertheless, the dynamics of the steel ball inside the vibrating tube has been not sufficiently reveled. Moreover, the experimental investigations had proved that the proper selection of the ball and vibration characteristics of the valve are critical for the successful operation of the system. The vibratory valve controlling liquid flow *1* (Fig. 1) operates in the following way. The liquid that is fed into the intake duct *4* by the force of the flow which depends on the pressure in the system brings the locking ball *6* into sealing contact with the seat *7*, the valve closes and the flow of liquid through the outlet duct is interrupted. When the driving generator *6* sends control signals the frequency of which corresponds to the second natural frequency of transverse vibration of the pipe to the vibrator *2*, the latter excites transverse vibration in the pipe. Since the frequency of the exciting oscillations of the vibrator *2* corresponds to the second natural frequency of transverse vibration of the pipe, it initiates transverse vibration in the second natural mode at the resonant frequency. As a result of that, the locking element *6*, overcomes the force of the flow, shifts to the point where the transverse vibration of the pipe reaches its maximum amplitude: the seat valve *7* is open and the liquid flows through the outlet duct *5*. Fig. 1 presents the design diagram of a vibrator valve for the control of liquid flow, and the second natural mode of transverse vibration of the pipe and the location of locking element in respect to the seat when the valve is opened. Fig. 1 presents the design diagram of a vibrator valve for the control of liquid flow, and the second natural mode of transverse vibration of the pipe and the location of locking element in respect to the seat when the valve is opened.

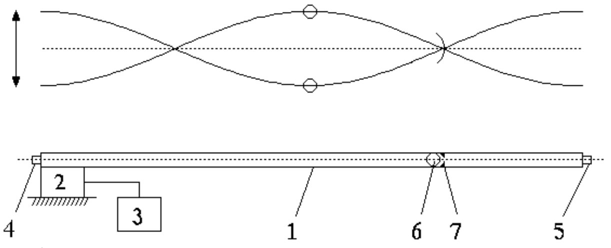


Fig. 1 Structural scheme of a tabular vibratory valve in an open and closed states: *1* - elastic pipe; *2* - vibrator; *3* - driving signal generator; *4* - intake; *5* - outlet; *6* - locking element; *7* - seat

The application of vibration mechanisms in the biomedical systems, considering the possibilities of the drug injection systems, the study presents the construction and the principle of the operation of vibration-assisted spring-loaded batcher, the necessary for its functioning vibration operation form and how it is related to vibration frequency and amplitude.

This paper is the further development fuel injection systems of the drug injection system [6]. We would like to offer the novel design of a spring – loaded micro spray system which may be used and adapted for drug injection in case cardiovascular diseases.

The study presents the design of vibration - assisted spring-loaded micro spray system, its principle of operation and the dependence of the vibration frequency and the amplitude on the dosed liquid drug are introduced too.

2. Vibration-assisted spring-loaded micro spray system. Design and principle of operation

The spring-loaded microspray system is a rigid steel spring made of turns without gaps and capable to ensure the system tightness in case of drug supplied under fixed pressure to the sealed spring. The spring-loaded batcher is shown in Fig. 2.

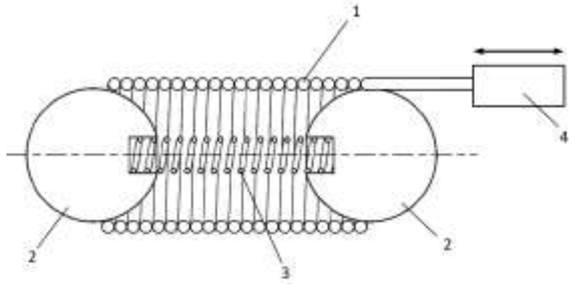
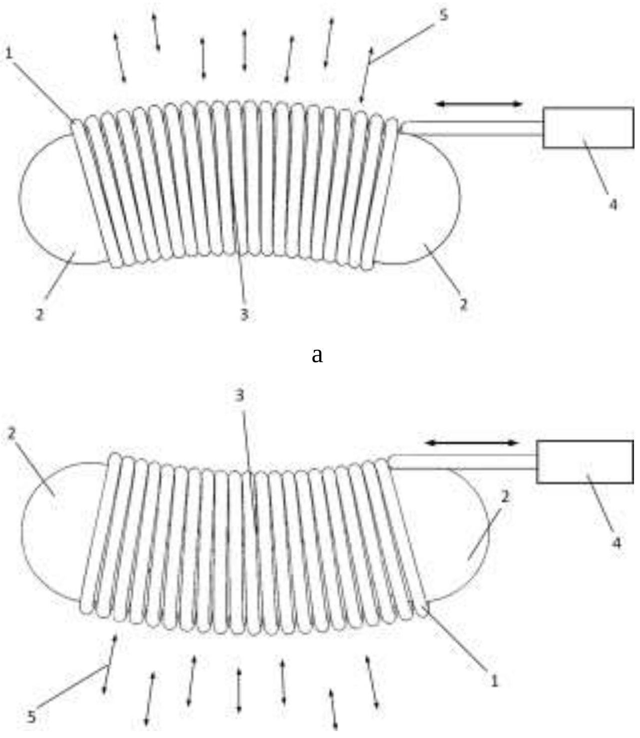


Fig. 2 Spring-loaded microspray system: *1* - spring; *2* - ball; *3* - connecting spring; *4* - transverse vibration vibrator

Let us suppose that the inlet opening of the spring-loaded microspray system is at the the middle of the spring. Another end of the spring *1* is tightened and fixed to transverse vibration vibrator *4*.

When the spring is at rest it does not leak out the liquid drug between the turns (the close contact between the turns provides the tightness of the spring).

Then, when the transverse vibrations are excited by the help of the vibrator in the form of standing wave in the spring, the spaces between the turns appear, which provide the possibilities for the drug leak out. The half-wave are excited in order to ensure that their amplitude peak phases appeared at the liquid centers of inlet manifold (Fig. 3)



a

b

Fig. 3 Spring loaded micro spray system: a - micro spray to spring moving upper direction; b - micro spray at spring is moved to down position

It is obvious, that when the piston moves down the rarefaction is caused, which intakes the liquid drug into the vessels.

This is shown only one of the possibilities to arrange the spring loaded micro spray system. The other solution could be to arrange the spring-loaded system in case when we need to excite transverse vibrations, e.g. in the shape of a single half-wave. This would provide the possibility for a separate spring micro spray system loaded to operate independently.

3. Theoretical substantiation of possibilities for the batcher functioning

The rigid coiled spring could be considered as a duct.

Let us suppose, that within the range of spring strains analyzed, the material elasticity is constant, therefore, dependence on the strain amount from the applied force is directly proportional.

If the spring is affected by the axis strength force, the existing winding area will be proportional to the spring elongation.

The increased surface of elongated spring will be determined, when it is coiled into the arc. The calculation scheme is presented in Fig. 4.

In the inner part of bended spring the turns touch each other tightly.

The inner arc curvature range is ρ_0. It is equal to:

$$\rho_0 = \frac{L}{\pi} \tag{1}$$

The length of the arc L is equal to:

$$L = \frac{2\pi\rho_0}{2} = \pi\rho_0 \tag{2}$$

The outer part of the arc between the turns will have the gap δ, which being in the shape of spiral, decreases to 0 in the inner part of the arc. Thus, the gap of spiral shifting width gap is produced.

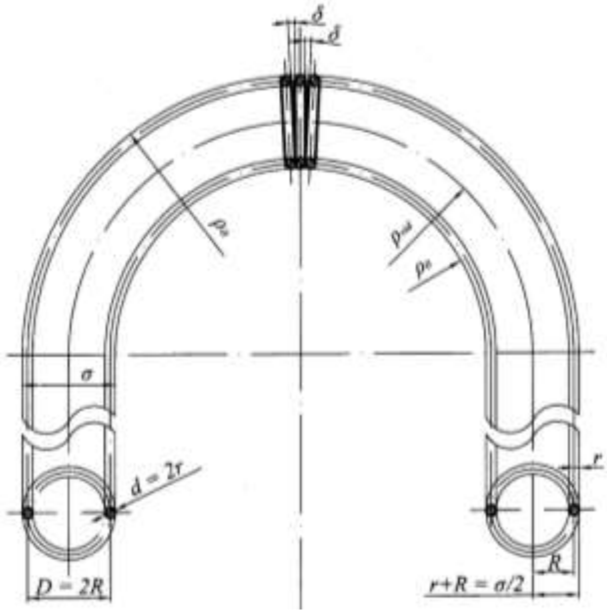


Fig. 4 Calculation scheme of the spring elongation

The outer arc radius ρ_{ext} is equal:

$$\rho_{ext} = \rho_0 + 2(R+r). \tag{3}$$

The outer arc length L_{ext} is:

$$L_{ext} = \pi\rho_{ext} = \pi\left[\rho_0 + 2(R+r)\right] = \pi(\rho_0 + \sigma), \tag{4}$$

where σ - spring-duct diameter. It is equal to:

$$\sigma = 2(R+r). \tag{5}$$

Thus outer arc length L_{ext} is:

$$L_{ext} = \pi\left(\frac{L}{\pi} + \sigma\right) = L + \pi\sigma. \tag{6}$$

Outer arc elongation ΔL is equal to:

$$\Delta L = L_{ext} - L = L + \pi\sigma - L = \pi\sigma. \tag{7}$$

Thus average elongation of the spring ΔL_{ave} is equal to:

$$\Delta L_{ave} = \frac{\Delta L}{2} = \pi(8+r). \tag{8}$$

Increased surface of average elongated spring ΔS_{ave} will be equal to:

$$\Delta S_{ave} = 2\pi R \Delta L_{ave} = 2\pi^2 R(R+r). \tag{9}$$

This is the space for the leak out of the part of fuel.

Let us analyze the case, when the spring-duct axis is in the shape of curve, which is presented in (Fig. 5).

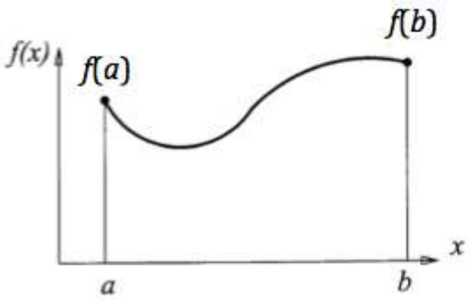


Fig. 5 Spring axis as curve

In general case between $f(a)$ and $f(b)$:

$$l = \int_a^b \sqrt{1+\left[f'(x)\right]^2}\,. \tag{10}$$

If the excited vibrations are in the shape of sine, the half of its length L_p will be (Fig. 4):

$$L_p = \int_0^{1/4} \sqrt{1+\left[\sin' x\right]^2} = \int_0^{1/4} \sqrt{1+\cos^2 x}\,. \tag{11}$$

The spring-duct elongation half-waves ΔL_p will be:

$$\Delta L_p = L_p - \frac{l}{4}. \tag{12}$$

This elongation of the spring affects the increase of its inner surface:

$$\Delta S_{ave} = 2\pi R \Delta L. \tag{13}$$

Thus, the outer surface S area change could be expressed as:

$$S = A_0 \cos\left(\frac{2\pi}{\lambda}x\right)\sin(2\omega t); \tag{14}$$

$$\omega = 2\pi f, \tag{15}$$

where A_0 - maximum amplitude of standing waves; x – spring-duct coordinate along axis; λ - length of wave; f - frequency, Hz.

Thus, we could confirm, that the higher the amplitude of spring vibration, the wider the space between the spring turns and more fuel will leak out between them.

4 Experimental analysis of the spring

In order to calculate amplitude of vibrating spring the methodology is presented in papers [5-7].

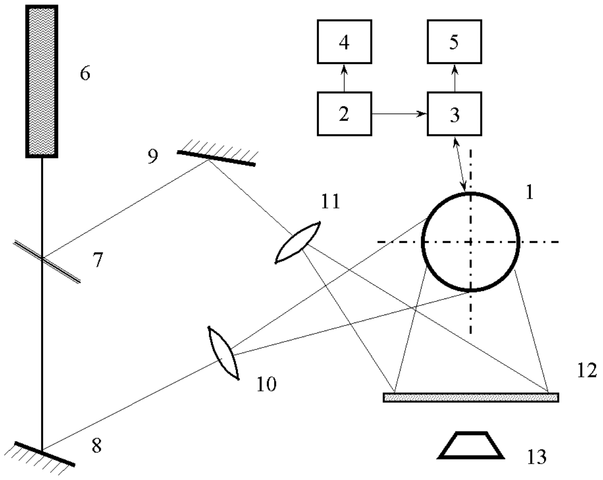


Fig. 6 Optical scheme of the laser holographic interferometry system: *1* - tubular working tube; *2* - high-frequency signal generator; *3* - amplifier; *4* - frequency meter; *5* - voltmeter; *6* - laser; *7* - beam splitter; *8*, *9* - mirror; *10*, *11* - lens; *12* - photographic plate; *13* - recorder

In the Fig. 6 it is showns optical scheme for recording holographic interferograms of the vibrating spring: *1* - vibrating spring; *2* - high-frequency signal generator; *3* - amplifier. The signal monitoring means are; *4* - frequency meter, *5* -the voltage amplitude of the power supply is monitored by the voltmeter. The optical scheme includes a holographic table with a helium-neon laser which serves as a source of coherent radiation. At first the beam from the optical laser *6* splits into two coherent beams and one of them is passing through the beam splitter *7*. The another one, so called object beam, reflected from the mirror *8*, and widespread lens *10* and illuminates the surface of the vibrating spring *1* and, after reflecting from it, illuminates the photographic plate *12*. The reference beam, reflected by the mirror *9*, and by the lens *11*, illuminates the holographic plate *12* where the interference of these two beams is recorded.

The characteristic function defining distribution interference on the surface of the vibrating spring is presented in (16).

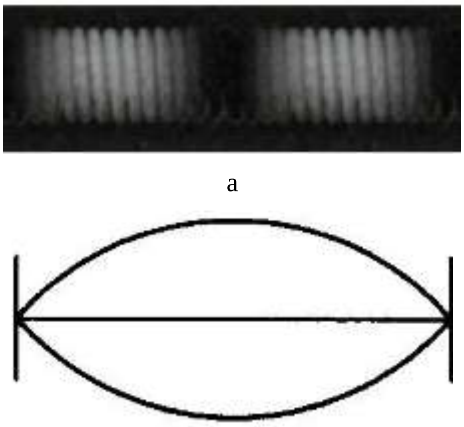
$$M_T = \lim_{T\to\infty} \frac{1}{T}\int_0^T exp\left(i\left(\frac{4\pi}{\lambda}\right) Z\left(x\right) sin\,\omega t \right) dt = \\ = J_0\left(\left(\frac{4\pi}{\lambda}\right) Z\left(x\right)\right), \quad (16)$$

where T is the exposure time vibrating spring onto the hologram, ($T >> 1/\omega$); ω is the frequency of vibration of spring, λ is the laser wavelength of used for recording holographic interferogram; J_0 is zero order Bessel function of the first type.

Then, the resulting intensity I of the point (x, y) on the holographic interferogram of vibrating spring is follows:

$$I\left(x,y\right) = a^2\left(x,y\right)\left|M_T\right|^2, \quad (17)$$

where $a(x,y)$ defines the distribution of the amplitude of the incident laser beam. The usage of the method of time averaging holographic interferometry allows to measure steady state vibration. Results of experimental analysis vibrating spring are presented in Fig. 7.



a

b

Fig. 7 Results of experimental analysis: a - holographic interferogram of vibrating spring at frequency 1,24 kHz; b - distribution amplitude of vibration of spring

5. Conclusions

The vibration-assisted spring-loaded microspray system may be applied for the use of treatments that contribute to the restoration of patency of the affected vessel by enzymatic or mechanical removing an intravascular thrombus. The construction of microspray system is simple, they are easily and exactly controlled, while achieving proper values of vibration amplitudes.

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VIBRATION ASSISTED SPRING LOADED MICRO SPRAY SYSTEM FOR BIOMEDICAL APPLICATION

Summary

The paper presents the construction of vibration - assisted spring-loaded batcher, its principle of operation is described, the spring-loaded batcher transverse vibration forms and the dependence of the vibration frequency and the amplitude on the dosed liquid are introduced. Mathematical modelling and the experimental results are presented in the paper.

Keywords: batcher, spring vibration, transverse vibrations, vibration waves, vibration frequency.

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