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Investigation of ultrasonic probe for medical purposes

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Introduction

The ultrasonic probe can be used to eliminate tissues, kidney-stones, clots of blood and other derivatives. Ordinary, the energy of ultrasonic probe is transferred in the form of high frequency ultrasonic waves. The ultrasonic wave destroy some tissues because of cavitation effect. During cavitation phenomenon the liquid is a effected by high ultrasonic frequency energy and therefore the small microscopic steam bubbles and cavities are created. These bubbles and cavities expand and explode. The explosion destroys some tissues. These ultrasonic devices by applying cavitation phenomenon are used to destroy some tissues for example to heal cancer, to clean blocked-up blood-vessels and for other treatment [1, 2, 3].

Design features

The main drawback of ultrasonic probe is it's slowness in comparison with chirurgical interference. The reason of this slowness could be explained that the longitudinal vibration of the end of the probe occur. The end of the probe vibrates in the longitudinal direction of the probe axis and destroying effect is created only on the end of a probe. One of the suggestions is to create the transversal waves, but in this case only the tip of a probe is used. The probe efficiency can be increased by applying a flexible rod, which creates standing wave with some knots and antinodes.

The prototype of the probe consists of these main parts: (Fig.1) generating device – 1, transducer of ultrasonic waves – 2, working flexible device – 3.

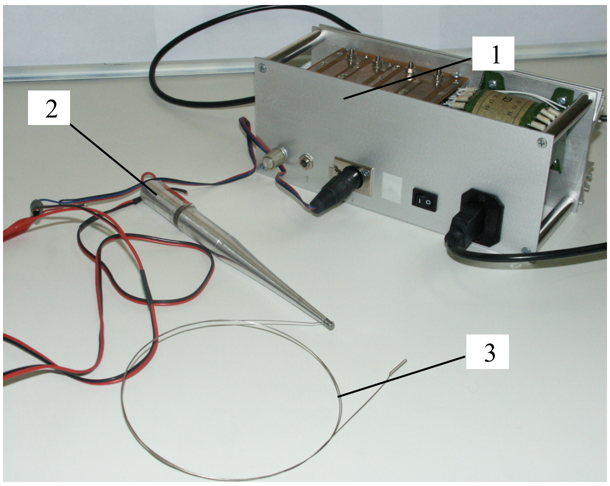

Fig.1. **The main parts of ultrasonic probe: 1 – generating device, 2 – creator of ultrasonic waves, 3 – working flexible device**

The transducer of ultrasonic waves generate vibrations in the longitudinal direction of its axis. Ultrasonic vibrations are transferred trough the ultrasonic unit and through one or some concentrators which intensifies vibrations. The flexible element is connected to the far end of the concentrator and is effected by longitudinal vibrations into the standing wave along its length. The standing wave creates some knots and antinodes along the flexible element. Each antinode creates cavitation effect which destroys biological tissues. In this case the flexible element works along the whole length and its surface could be used to destroy tissues.

The control device generated the electric signal with the frequency around 24 kHz. The vibration amplitude is 50 micrometers. The device controls ultrasonic vibration device and allows for operator to change frequency and amplitude of vibrations.

The moving part of the probe (Fig.2) is connected to the vibration device and it consists of the unit (8) and the flexible working element (9). The flexible working element (in this case – some wire) is connected to the concentrator of ultrasonic waves (1). The concentrator could be a rod produced of a proper material, for example, titanium and transfers vibrations energy from the vibration device to the flexible working element. During transfer the vibration amplitude is intensified because of the difference of answer sections of the concentrators. These transfer sections are selected so, that the concentrator generates proper vibrations.

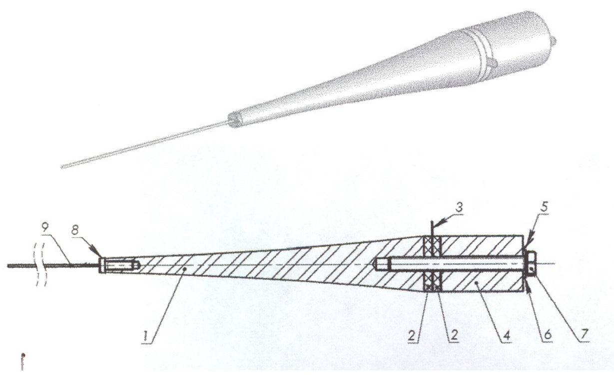

Fig.2. **Ultrasonic waves device: 1 – concentrator, 2 – piezoceramics, 3 – electrode, 4 – ballast, 5 – electrode, 6 – washer, 7 – bolt, 8 – connection unit, 9 – working element**

Usually, the stepped concentrator creates the maximum amplitude, but to transfer energy to a thin wire is complicated. It was established that the exponential concentrator is the most convenient for that purpose [4].

The flexural element – 9 (Fig.2) is produced of a thin <1 mm wire with rectangular, oval or quadrature cross-section. The length of this part and cross-section depends on probe application and can be various. It is very important to use proper material for flexural element. Titanium is better than aluminium or stainless steel because the deformation process in the liquid environment is more intensive.

The piezoceramic ultrasonic vibration device is shown in Fig.2. Piezoceramic plates are inserted between the concentrator of vibrations and the ballast part (4) and are pressed with the bolt (7). The electric signal of a certain frequency and amplitude is established in the control part and is connected to the electrodes 3 and 5.

Theoretical base

When the probe is operating, the longitudinal vibrations of the concentrator compels the flexural element to bend or stumble. This activity establishes standing wave with an antidote in the all length of the flexural element (wire) and creates the cavitation process in the liquid perpendicularly to the probes axis. Cavitation due to vacuum or bubbles explosions of which create shock waves. These shock waves destroy tissues. The cavitation process and the influence to tissues and other materials is described in [4]. The motion equations of the probes flexural element are established by using the second Niuton's law. The equation of transverse vibrations neglecting losses is:

$$\frac{\partial^4 \xi}{\partial x^4} + \frac{1}{(\kappa c)^2} \frac{\partial^2}{\partial t^2} = 0 . \qquad (1)$$

Here x is the distance in the longitudinal flexural part, t is the time in seconds, ξ is the transverse displacement, κ is the radius inertia, c is the velocity of sound in material.

Let us assume that the length of element is 1 (one) and boundary conditions are the following: one end is free and another is rigid, then the solution of Eq.1 is:

$$\xi = \cos(\omega t + \phi_n) \left(A\left(\cosh\omega \frac{x}{v} - \cos\omega \frac{x}{v} \right) + \right.$$

$$\left. + B\left(\sinh\omega \frac{x}{v} - \sin\omega \frac{x}{v} \right) \right) . \qquad (2)$$

From boundary conditions (2) the coordinates of knots can be found:

The first mode – x=0.
The second mode – x=0, x-0.7741.
The third mode – x=0, x-0.51, x=0.8681.
The fourth mode – x=0, x-0.3561, x=0.6441, x=0.0951.

The vibration forms of the flexural element are shown till the fourth mode are shown in Fig.3.

Practically, we have to estimate the transverse displacement of the flexural probe's element. It is necessary to estimate that the stresses increase with the increasing amplitude of a displacement. For cavitation process in liquid the transverse vibration's amplitude has to be no less than 25 microns. The frequency in that case is about 20 kHz. The highest frequency of ultrasonic vibration is about 80 kHz for the flexural titanium element.

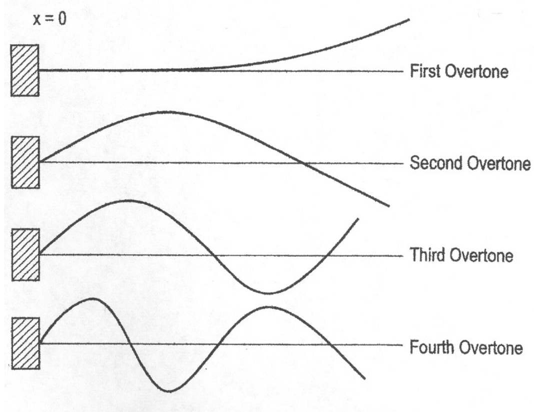

Fig.3. **Transverse vibration modes.**

Experimental research

The purpose of experimental investigation was to obtain the liquid cavitation process by the ultrasonic probe with an extremely small diameter wave guide. A low power acoustic wave has been tuned to oscillate at an ultrasonic frequency and was capable to create the cavitation bubbles cloud nearby the tip of the waveguide. The spiral form of the waveguide tip that generated the cavitation bubbles stream in axial direction is presented in Fig.4.

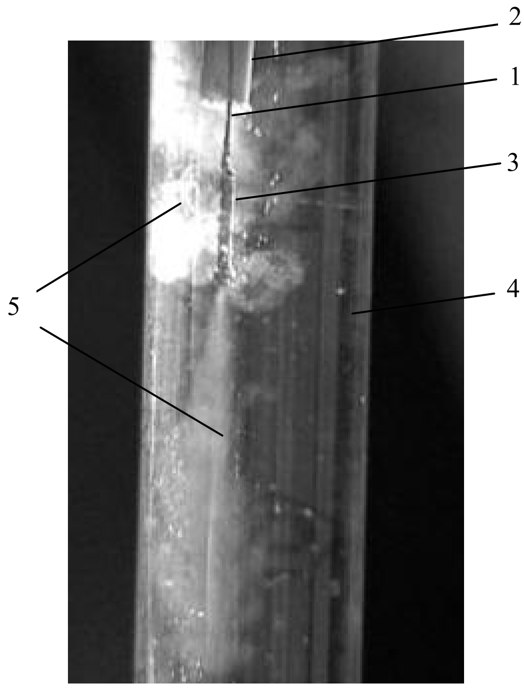

Fig.4. **Cavitation bubble cloud in the water generated by the ultrasonic waveguide: 1 – waveguide, 2 – catheter, 3 – special form flexible wire tip, 4 – glass tube, 5 – cavitation cloud**

Technical data of ultrasonic device (Fig.1):

Operating frequency, kHz	28 – 33;
Waveguide diameter, mm	0,3 – 05;
Waveguide tip vibration amplitude, mm	0,02 – 0,05;
Active radiating waveguide length, mm	10 – 15;

Operating mode – repeatedly – short – term;	
Mains requirements, V/Hz	220 –240/50;
Power supply, VA	no more than 150;
Generator overall dimensions, mm	260×130×105.

Conclusions

Some special features of ultrasonic probe construction are investigated. The theoretical investigation shows that the ultrasonic probe works more efficiently in the transverse vibration regime than in the longitudinal vibration regime.

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Medicininio ultragarsinio zondo tyrimas

Reziumė

Aprašyti medicininio ultragarsinio zondo konstravimo ypatumai. Pateikta zondo kraujagyslėms valyti konstrukcija, pagrįstas veikimo principas. Skaičiavimais nustatyta, kad zondas, dirbantis skersinių virpesių režimu, yra veiksmingesnis ir greičiau šalina nepageidaujamus biologinius darinius negu zondas, dirbantis išilginių virpesių režimu.

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