Investigation and Development of Devices for Ultrasonic Laparoscopy

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Abstract – In this article the methods of defect elimination in existing equipment for ultrasonic laparoscopy are offered and the results of this equipment investigation are presented.

Index Terms – Ultrasonic laparoscopy, ultrasonic vibrating system, vibration amplitude.

I. INTRODUCTION

ENDEGENCIES OF MODERN SURGERY development are directed to the guaranteeing of rational and effective performance of many types of general and special surgical procedures. The main objective is minimization of concomitant injury damaged to the patient (so called “minimal invasive surgery”), that lets to reduce postoperative pain and shorten the terms of recovery.

As for operations made on the abdominal cavity of the patient this objective can be achieved due to the application of laparoscopy (Greek lapara - ingu en, belly and skopéö - look). For laparoscopic operations the laparoscope and special tools, which are entered along trocars through separate diminutive puncture (no more than 1cm) in abdominal cavity) are used. Diminutive punctures made during laparoscopic operations practically do not injure muscular tissues.

Lots of different laparoscopic operations are required the presence of appropriate modern tools and equipment. The most typical instruments used for laparoscopy are forceps for tissue capture, scissors for nibbled division, and instruments that let to seal wounds and control (coagulate) bleeding. Last procedure frequently is accomplished by laser beam or high-intensity electric current.

Unfortunately the main difficulties are connected with the use of these methods, which can occur during laparoscopic operations: heating of tissues during the coagulation leading to formation of the eschar, incomplete carbonization of tissue, smoke generation, which worsens visual field during the operation.

The application of high-amplitude vibrations of ultrasonic frequency imposed on the cutting edge or other working surface contacted with the wound lets to eliminate defects of mentioned above methods.

The authors of the article [1] studied in detail ultrasonic system for laparoscopy – design to creation. That is why the aim of this article is to carry out service tests of developed system under the conditions close to real and on basis of obtained data show the ways of upgrading.

II. INVESTIGATION OF ULTRASONIC VIBRATING SYSTEM

One of the main and most important parts of ultrasonic system for laparoscopy is ultrasonic vibrating system; it transforms electrical vibrations of ultrasonic frequency into mechanical ones. The efficiency of its functioning depends on such operating parameters of the device as maximum amplitude of ultrasonic vibrations, allowed time of continuous work, warming up of vibrating system and working tools.

Vibrating system was made on the base of half-wave construction arrangement combined electroacoustic (piezoelectric) transducer and concentrator. For investigation three embodiments of ultrasonic vibrating systems varied in longitudinal dimensions and diameters of end surface for connection of waveguides were made. Their appearance is shown in Fig. 1.

Upper transducer corresponds to initial variant by resonance frequency 30.5 kHz. Middle one has lengthening dimension of cylindrical area of smaller diameter that is why its resonance frequency is in 1.5 kHz lower than initial one. Lower transducer has larger diameter of cylindrical space. Its resonance frequency equals to the initial one.

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For obtaining of variants of ultrasonic vibrating system sequence with several half-wave working tools – waveguides all types of waveguides were connected to the developed transducers and the parameters were measured. Obtained data confirmed that two new variants of ultrasonic vibrating systems with waveguides showed a little bit worse results than initial variant of the ultrasonic vibrating system.
So all further investigations were carried out with help of the first variant of ultrasonic vibrating system, as it was the most optimal one.

III. INVESTIGATION OF WORKING TOOLS

To realize ultrasonic cutting and coagulation the necessary and sufficient condition is reaching the vibration amplitude of 150 micron. Unfortunately at this value of vibration amplitude the formation of bending vibrations is possible. The working tool deteriorates.

In order to avoid bending vibrations in the minimum points of longitudinal vibrations on the waveguides the turnings were performed; damper rings were placed, as it was shown in Fig. 2.

For different types of laparoscopic operations several changeable working tools (up to 10 pieces) are used, which are different in length, diameter and the form of endings. The length of all changeable working tools was chosen in order to provide multiplicity of wave half length of longitudinal ultrasonic vibrations in the tool material.

Short working tools 185±4 mm long are applied in open surgery, working tools 365±5 mm long are used for laparoscopy. The operating frequency equals 29±1.5 kHz, that satisfies the condition of transducer coordination with the working tool.

The waveguides are 6 mm and 3 mm in diameter. Thin tools are more preferable as they let to lessen the size of the puncture in patient’s abdominal cavity.

In Fig. 3 the appearance of waveguide 3 mm in diameter with working cutting ending and one damper ring is shown.

Such type of the waveguide provides the amplitude of 150 micron and more without damper rings. After damper ring and protective tubule placing the characteristics of the waveguide did not change. However intense heating of the ring fixed on the waveguide was observed. During the operation the ring began to smoke. Resonance frequency of the waveguide with fixed damper rings and attached transducer was 29.76 kHz.

Similar behavior was registered in scissors-waveguides 369 mm long. The presence of damper rings on this type of waveguide lets to increase the amplitude up to 150 micron. Intense heating in the zone of the third from working ending turning was observed.

Resonance frequency of the waveguide with damper rings and attached transducer equaled 29.57 kHz. In Fig. 4 the appearance of the waveguide 3 mm in diameter with crescent-shaped cutting ending of with the fixed damper rings is shown.

The presence of damper rings with the use of protective tubule on this type of the waveguide did give any positive results. If the vibration amplitude is 56, the tool begins to “whistle”. Bending mode of vibrations most likely appears in the section between damper rings. Resonance frequency of the waveguide with damper rings and attached transducer equaled 29.19 kHz.

Fig. 5 shows the appearance of the waveguide 3 mm in diameter with working ending in the form of coagulator with fixed damper rings.
The presence of damper rings did not let to increase its amplitude for more than 42 micron in the first model and for more than 98 micron in the second model. The attempts to increase vibration amplitude generated in both cases the excitation of bending vibrations – “whistle”. Finally the waveguide with maximum amplitude 42 micron was broken in the place of maximum strain which was additionally weakened by turning. Resonance frequency of the waveguide with fixed damper rings and attached transducer was 29.54 kHz.

Thus, a part of working instruments – waveguides is not applied for laparoscopic operations. Taking into account the obtained data following ways to eliminate discovered defects were offered.

1. Replacement of stepped taper “waveguide – working ending” with smooth one (e.g. radial) to exclude destroying. As a rule breaking of the working ending was observed in 60% in the conditions of formation of bending vibration
2. If it is technically possible to exclude from the construction of transducer and waveguide element, which promote the generation of bending modes of vibration such as fastening flattened surface on the transducer screw nut, in the zone of acoustic uncoupling fastening, etc.
3. Switching on the increased frequency of the operation, i.e. producing of waveguides with transducer for higher frequency, for example, 44-60 kHz. Increasing the number of units (naught) on the waveguide it is possible to fix waveguide in the tubule by damper rings in greater number of places. At the same time the length of free parts of the waveguide, where bending wave is formed, reduces. If the frequency rises, vibration amplitude can be reduced in the number of times in which vibration frequency increases. Cutting speed and time of the coagulation will not be changed.

IV. THE DEVELOPMENT OF ULTRASONIC VIBRATING SYSTEM AND REPLACABLE WORKING TOOLS

Having analyzed all the methods of defect elimination one was chosen. It is an increase of frequency of ultrasonic vibrating system and working tools. It is necessary to ensure the conditions when all main geometrical dimensions of waveguides (total length, length and diameter of thin place, size and form of working ending) remain unchanged.

The process of new ultrasonic vibrating system development began with calculation and designing of the working tools.

In many researches carried out by the authors of this article and also made by other scientists adequacy and appropriateness of applying method of ending elements for simulation and calculation of elements for ultrasonic vibrating systems were proved [2], [3], [4]. Fig. 6-8 the simulated results of different working tools are demonstrated. Operating frequency was chosen within 55±1 kHz. Variation of working tool geometry is in the change of length and radius of smooth transition and also in the reduction of external diameter of waveguides.

Ultrasonic vibrating system was designed on the base of two half-wave construction arrangement. The simulated results and its appearance are shown in Fig. 9-10.

The appearance of improved and produced waveguides is shown in Fig. 11.

First fastening band provided anchorage into the case of transducer excluding the possibility of turning. Second it helped to achieve 100% sealing of the piezoelectric elements and it gave the possibility to sterilize contacted with the body parts of vibrating system by heated vapor.
Comparison of simulated results of initial variant and improved construction showed average increase of gain factor in 1.5-2 times.

Carried out measurements of produced constructions with the application of piezoelectric gauge-feeler with dry point contact confirmed the increase of amplitude vibration in 1.7-2.2 times in comparison with initial variant.

Resonance frequency of produced tools with ultrasonic vibrating system showed wider variation $53\pm2$ kHz.

VI. CONCLUSION

New ultrasonic piezoelectric vibrating system with improved working tools – waveguides at the existing geometrical limitations was designed, developed and produced.

Simulated results were proved by the measurements of practical constructions and showed the correctness of offered technical solutions. At the moment full-scale tests of produced constructions are carried out. We try to change vibration amplitude by feeding from electronic generator of ultrasonic frequency, which is the part of the system for ultrasonic laparoscopy.
REFERENCES


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