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**THE DESIGN OF ULTRASONIC ENDOSURGICAL LONGITUDINALLY-FLEXURALLY VIBRATING BEAM TOOLS-CONCENTRATORS FOR SOFT TISSUE DISSECTION AND COAGULATION**

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*Existing tendencies of advanced endosurgical devices and techniques progress are analyzed with reference to problem of different biological tissues dissection (coagulation), for example parenchyma tissues dissection (coagulation). It is shown, that the integration of ultrasonic technologies into clinical practice, in spite of their advantages in endoscopic surgery, is being stopped as a result of modern ultrasonic endosurgical devices disadvantages. Existing methods to the design of ultrasonic devices and tools for biological tissues dissection (coagulation) during endosurgical interventions have been discussed. Quality upgrading lines of biological tissues dissection (coagulation) process by means of heat generation effectiveness increase in tool working blade zone have been suggested. Heat generation effectiveness increase have been achieved by means of selection of tool working blade material with high absorption, addition of zones with construction friction, excitation of longitudinally-flexurally coupling vibrations into blades. It is increases working blades deformation amplitudes, therefore heat losses in it.*

Now surgical interventions technologies, associated with endosurgical instruments use, become prevalent in many branches of modern surgical medicine and their part is forms 75-85% of operations in proctology, gynecology, urology and thoracic surgery. Usually these technologies contains stages of separation and (or) coagulation of biological tissues, therefore dissectors-coagulators are most prevalent type of endosurgical tools and being contains into standard set of working tools for endosurgical equipment, making by principal countries-producers (United States, Japan, Germany, Russia).

Most types of dissectors-coagulators are monopolar or bipolar electrosurgical tools, but more than half of a century of their clinical use achieved facts of serious injuries, for example, according to American College of Surgeons information [1], more than 18% surgeons collided with different complications, especially in transurethral prostate resection and gynecology. In the first phase, there are electrosurgical burn injuries, induced by active working process or action stopping time (when the surgeon forgot all about switch turn off), or burn injuries, induced by residual heat effect, since electrode activation stopping [2]. Also current tunneling (anomalous current propagation through minimal electrical resistance path) in tissues and electric shocks (heart fibrillation or muscles involution in consequence of low-frequency current propagation through patient's body) are an injuries. Some factors, such as electrode insulation defects, arising because of sterilization (desinfection) of instruments, friction contact with trocar, destructive or capacitive electrical breakdown are not last important in this process. Bipolar electrosurgical instruments use permits burn risk reduction, but sluggishness work and plural applications reduce to zero their advantages. Besides it is note, that smoke generation, induced by coagulation, reduces visualization systems work. Now the exististing technologies modifications perfections is being make (for example, Ligasure technology, developed by Valleylab Inc.), but it have not a progress.

Relative technologies, using mechanical or electromechanical instruments, not applies widely because of functional limitations. The ligation takes a lot of time, depends on knot tying techniques and seldom applicable for many surgical operations (for example, laparoscopic operations). The suturing for hemostasis needs 12-15 mm. trocar use and very expensive (cassettes cost is near 250 USD). Besides that, ligatures, sutures and clips fastening can bring to their seizing as contaminating material by human organism. Lasers have not wide use in endosurgery due to different factors, such as smoke generation by laser treatment in working process, eyes protection necessity, tissues necrosis risk and high cost, depending by absence of laser radiation systems for expecting power receiving through fiber.

However, in the last time techniques of ultrasonic dissection-coagulation, having not more of electrosurgical techniques injuries, are developing intensively [3-5]. Now the main designers of ultrasonic endosurgical equipment are Olympus Optical Company Ltd. (Sonosurg model apparatus), Ethicon Endo-Surgery Inc. (Ultracision), Orthosonics Ltd. (Lotus), United States Surgical Corporation (Autosonix), Erbe Electromedizin GmbH (Selector), Soring Medizintechnik GmbH (Sonoca). However, different disadvantages of modern ultrasonic dissectors-coagulators disadvantages are not allowing to realize technologies advantages in surgery.

The main problem, existing before developers of low-frequency ultrasonically vibrating systems through ultrasonic technologies foundation is losses minimization problem into vibrating systems, having many a lot of mechanical hysteresis losses. Therefore materials materials with low dissipation factor and low wave impedance  $\rho c$  (where  $\rho$  is density,  $c$  – sonic speed in material) are being preferred during the materials selection for ultrasonic tools-concentrators) [6,7]. For example, mechanical hysteresis losses (or thermal power dispersion) are being reducing on hundred times by substitution of St3 type steel for a VT5 titanium alloy.

In the present time tendencies of the ultrasonic coagulating (ablating) dissectors design development are being contouring. It is known, that [8], ultrasonic tissue cutting is accompanied by heat generation into cutting zone, becoming to tissue ablation in this zone and heat generation intensity is proportional to dissector vibration amplitude. However, theirs are not sufficient for effective coagulation and hemostasis, for parenchyma tissues cutting especially.

The heat generation effectiveness increasing can be increase by heat generation increasing in tools-concentrators working zone blade edges and tools-concentrators working blade edges points trajectory displacement. One of heat generation quality lines is the selection of tool-concentrator working blade with high absorption factor. For example, the heat generation increase in working blade zone can be increased on the order of 1-2 by low-carbon steel selection, in contrast to traditional titanium type alloy. Therefore, high heat generation in the blade edge zone of longitudinally vibrating ultrasonic system is being reached difficultly, because of dissector blade length, as a rule, less than  $\lambda/10$  ( $\lambda$  - longitudinal vibration wavelength) and interaction force between working blade and tissue is minimal, that is boundary condition for blade edge end have form  $u' = 0$  (where is  $u$  – longitudinal displacement, ' is differentiation with respect to  $z$ ,  $z$  – beam axis coordinate).

More greater deformations in the blade zone can be obtained by the excitation of flexural vibrations with frequency, coincide with longitudinal frequency. Since the flexural vibrations length can be as commensurable with blade length, so more lesser than blade length and working blades deformation increase is possible, consequently mechanical hysteresis losses increasing is possible also.

The energy, absorbing in tools-concentrators working blades elements in the result of mechanical hysteresis, transformates into the heat energy and dispersed into biological structures later. Thus, the internal heat supplies, having power, which proportional to absorbing energy, realizes constant heating of working blades. On the other hand, tools-concentrators blades receives thermal energy at surroundings by heat conduction, heat transport and heat transfer. The thermal field identification problem, that is coupled thermoelasticity problem solution, have been solved by heat transfer and heat transport process quantitative description and their processes coupling by heat conduction equation. Material dissipation factor precising value can be calculated and mechanical energy dissipation factor can be evaluated by temperature field.

It is limits by the model of longitudinally -flexurally vibrating ultrasonic systems, consists of bodies of revolution. Coupled longitudinal-flexural vibrations of variable cross-section sample with internal heat supplies, distributed along axis (out of mechanical hysteresis) and lateral axisymmetrical heat transfer will be considering.

It is limits by the one-dimensional model, proceedings from the assumption about the thermal field changes along the beam axis over and about thermal fields constancy along the cross-section. Also it is neglects of material properties dependence on temperature, since their changes are not more than 2-3% under ultrasonic systems heating on 30-50 Celsius degrees.

Within the range of adopted limitations, the model equations of coupling longitudinally-flexurally vibrating tools-concentrators working edges, according to their heat conduction and their heat transfer into, have the next form [9]:

$$\tilde{c}\rho \frac{\partial T}{\partial t} = \frac{\partial}{\partial z} \left[ \lambda(z) \frac{\partial T}{\partial z} \right] - \alpha_v(z) [T(z,t) - T_c] + q(z); \quad (1)$$

$$\frac{\partial N(z,t)}{\partial z} - \rho F(z) \frac{\partial^2 U(z,t)}{\partial t^2} = 0;$$

$$N(z,t) = EF(z) \left( \frac{\partial U}{\partial z} + \frac{\psi}{2\pi\omega} \frac{\partial^2 U}{\partial z \partial t} \right); \quad \frac{\partial w}{\partial z} = \theta(z,t); \quad \frac{\partial M}{\partial z} = Q(z,t); \quad (2)$$

$$M(z,t) = EJ_x(z) \left( \frac{\partial \theta}{\partial z} + \frac{\psi}{2\pi\omega} \frac{\partial^2 \theta}{\partial z \partial t} \right) - \frac{\partial Q(z,t)}{\partial z} + \rho F(z) \frac{\partial^2 w(z,t)}{\partial t^2} = 0;$$

Where  $T$  – current temperature;  $T_c$  – initial temperature;  $t$  – time;  $\rho$  – density;  $z$  – current cross section coordinate;  $\tilde{c}$  – thermal capacitance;  $\lambda(z)$  – thermal conductivity;  $q(z)$  – heat supply density, distributed along  $z$ -axis;  $\alpha_v(z, T)$  – heat removal into body unity ( $\alpha_v = \alpha P/F$ , where  $\alpha$  – heat removal coefficient;  $P$  – cross section perimeter),  $E$  – Young modulus;  $w(z,t)$  – lateral displacement;  $U(z,t)$  – longitudinal displacement;  $\theta(z,t)$  – cross section rotation angle;  $\psi$  – dissipation factor;  $M(z,t)$  – bending moment;  $Q(z,t)$  – lateral force;  $N(z,t)$  – longitudinal force;  $J_x(z)$  – cross section moment of inertia;  $F$  – square of cross section.

The third type boundary conditions on the tools-concentrators working blade ends consists in the fact, that the heat flux density is proportional to boundary temperature and tissue temperature difference:

$$[\pm \lambda \frac{\partial T}{\partial z} + \alpha_{0,l} T]_{z=0,l} = q_{0,l}. \quad (3)$$

where  $l$  – working blade edge length.

The initial temperature distribution in space coordinates for  $t=0$  supposed is constant -  $T(z,t)|_{t=0} = T_c$ .

Consolidating stationary harmonic tools vibrations, system (2) solving can be presented as  $v(z,t) = v(z) \exp j\omega t$  (where  $v(z,t)$  – one of phase variables of system (2),  $v(z)$  – amplitude value of corresponding phase variable,  $\omega$  – forced vibrations frequency). The mechanical energy, dissipating in the volume unit for one damping cycle  $\Delta U = \psi U$ , and heat flux density is

$$q(z) = \frac{\omega\psi}{4\pi} E \left\{ \left( \frac{du(z)}{dz} \right)^2 + \frac{J_x(z)}{F(z)} \left( \frac{d\theta(z)}{dz} \right)^2 \right\} \quad (4)$$

The heat conduction equation solution (1) for heat supplies density (4) and boundary conditions (3) allowed to calculate, the working blades temperature increase velocity, which constitutes 30-40 Celsius degrees per second for steel working blades at no-load conditions and for 40-60 mkm. Flexural vibrations amplitudes and 100 mkm. Longitudinal vibrations amplitudes. Thus, it can declares, that working blades of ultrasonic tools for dissection (coagulation) can be manufactured in steels with high mechanical hysteresis, for example 1X18H9T (absorbtion factor for flexural vibration is equal to 2,6-32%). The use of titanium working blades for tissue coagulation is inexpedient.

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