The Ultrasonic Device for Treatment and Cosmetic Procedures

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***Abstract* – The article is devoted to the ways of efficiency increase of ultrasonic devices due to the optimization of operating modes of ultrasonic vibrating systems, realization of control mode of presence/absence of acoustic load. The results of the work are applied in ultrasonic device intended for treatment and cosmetic procedures.**

***Index Terms* –Ultrasound, medical equipment, liposuction, control, acoustic load.**

I. INTRODUCTION

ULTRASONIC DEVICES of different functions occupy considerable part in the sphere of medical equipment [1]. Ultrasonic devices are used in surgery, plastic surgery (invasive liposuction), stomatology, in therapeutic treatment, gynecology, cosmetology and others.

In medical practice the technologies of ultrasonic influence on dermatic and hypodermic tissues at the contact with the radiator are widely used. Such technologies nowadays are applied for the procedures of external (noninvasive) liposuction, introduction of medical treatments through coverlets, acne treatment, face peeling (in cosmetology).

Used in practice ultrasonic devices of Russian and foreign production have a number of disadvantages, the main of which is insufficient intensity of ultrasonic influence and short-term mode of operation limited by heat generation and heating of ultrasonic radiator.

To increase intensity of ultrasonic vibrations is a necessity to provide the procedure of external liposuction (cavitation destruction of hypodermic adipose tissues).

Heating of ultrasonic radiator can lead to a burn of the patient, it reduces service life of the radiator and decreases duration of treatment procedure.

The article is devoted to solving of problems restricting the possibility of intensity increase of ultrasonic radiation at simultaneous reduction of heating level of ultrasonic vibrating systems.

II. MAIN PART

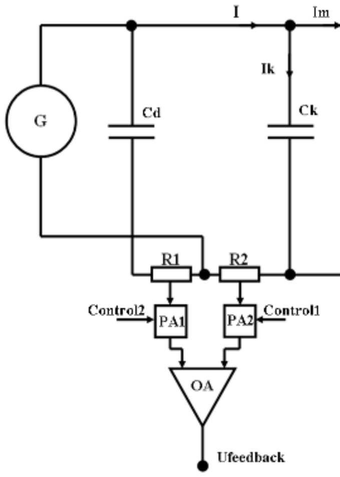
It is well-known, that heating of ultrasonic vibrating sytem depends on the value of mechanical vibration amplitude of radiating surface, materials of the system, its operating mode (resonance mode or operation near resonance).

Modern ultrasonic generators are equipped with systems of automatic frequency control. Their operation provides continuous frequency adjustment of setting generator guaranteeing the equality of frequencies of the generator and resonance frequency of the ultrasonic vibrating system. At that the criteria of adjustment of the ultrasonic generator on resonance frequency of the ultrasonic vibrating system is an equality to zero of phase shift between the signal of setting generator and the current consumed by the ultrasonic vibrating system. However this criteria does not provide fine adjustment of the generator on resonance frequency of the ultrasonic vibrating system, that causes its additional heating.

To reveal the reasons of impossibility of setting of operating frequency of the generator, which is equal to proper resonance frequency of vibrating system equivalent electric circuit of the ultrasonic vibrating system is considered [2], which is presented by the elements Cm, Lm, Rm and Ck, as it is shown in Fig. 1.

The value of the elements Cm, Lm, Rm are caused simultaneously by mechanical properties of the ultrasonic vibrating system and the properties of acoustic load. The element Ck is determined by the presence of static electric capacity of the piezoelectric transducer being a part of the construction of the ultrasonic vibrating system. Current I is a total current consumed by vibrating system, current Im is called a current of mechanical branch, which is electric analog of mechanical vibration amplitude of radiating surface.

From the equivalent circuit it follows, that the current consumed by the ultrasonic vibrating system is formed from the current of mechanical branch generated by the elements Cm, Lm, Rm and the current flowing through static capacity Ck. The presence of this electric capacity causes misadustment of the electronic generator on resonance frequency of the ultrasonic vibrating system.



PA1, PA2 – preamplifiers with controlled amplification coefficient; R1, R2 – resistive current sensors; G – a generator of electric oscillations of ultrasonic frequency

Fig. 1. Equivalent circuit of the ultrasonic vibrating system with separation circuit of the mechanical branch current

The analysis of the equivalent circuit allows to obtain amplitude-frequency characteristics of the ultrasonic vibrating system, presented in Fig. 2. Curve 1 is an amplitude-frequency characteristic of vibrating system, 2 is a phase-frequency characteristic of vibrating system, 3 is a phase-frequency characteristic of the current consumed by vibrating system.

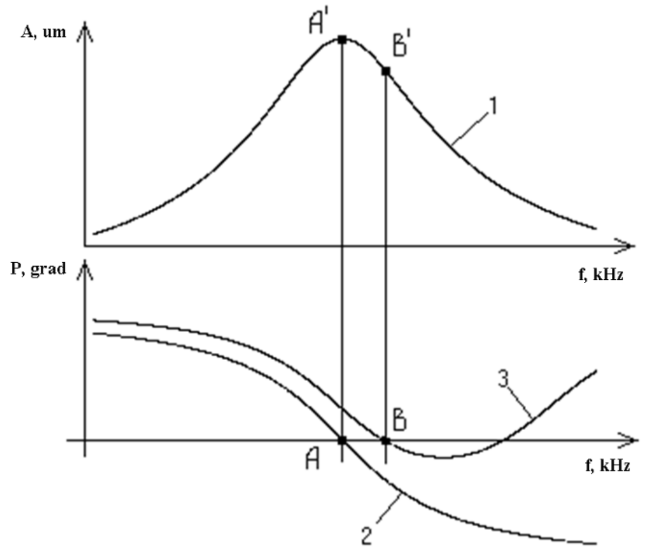


Fig. 2. The amplitude-frequency characteristics of the ultrasonic vibrating system

From the analysis of the curves in Fig. 2 it follows, that the point of zero equality of phase-frequency characteristics of the current consumed by the ultrasonic vibrating system (point B) corresponds to point B` at amplitude-frequency characteristic, which does not coincide with maximum on the curve. While the transition point through zero of phase-frequency characteristic of ultrasonic radiator as a mechanical system (point A) corresponds to maximum on amplitude-frequency characteristic (point A`).

For finer adjustment of the electronic generator to resonance frequecny of the ultrasonic vibrating system it is proposed as a criteria of adjustment to resonance to use equality to zero of phase-frequency characteristic of mechanical branch current, which is free from the influence of static capacity of piezoceramic elements.

For isolation of mechanical branch current of vibrating system differential circuit, shown in Fig. 1, was proposed. At the operation of the circuit amplification of difference of current flowing in series capacitor Cd and current I takes place. Thus amplitude-frequency characteristics of signal Uos correspond to amplitude-frequency characteristics of the ultrasonic vibrating system as a mechanical vibrating system [3].

The application of new criteria of adjustment of ultrasonic generator to resonance of vibrating system [3] allows to reduce heating of vibrating system and thereby to increase amplitude of mechanical vibrations of radiating surface.

At the same time at continuous operation of the ultrasonic vibrating system its heating occurs in spite of application of new criteria of adjustment of ultrasonic generator to resonance of vibrating system.

The analysis of treatment procedures with the help of ultrasonic device for external liposuction lets reveal, that most of the time ultrasonic radiator runs free, i.e. it does not provide introduction of ultrasonic mechanical vibrations in the zone of treatment.

Continuous free running of the ultrasonic radiator can lead to overheating of piezoceramic elements being a part of electromechanical transducer of the radiator, overheating of working tool, reduction of service life of the radiator and the electronic generator and to high consumption of electric energy.

In this connection it is necessary to design the system allowing to “activate” ultrasonic radiator only in the moments of occurance of acoustic load.

At the change of acoustic load the values of elements Cm, Lm, Rm change, that leads to changes of mechanical branch current. In this case at the operation of the ultrasonic device at the output of the differential circuit signa Uos appears, which value is in proportion to the amplitude of mechanical vibrations of working surface of the radiator. When there is no contact of the radiator (idling mode) with treated object or medium, amplitude of mechanical vibrations and respectively current amplitude flowing through piezoelectric elements of the ultrasonic vibrating system remain stable.

At the occurrence of acoustic load (contact of the radiator with treated medium or object) amplitude of mechanical vibrations of working surface of the tool changes and in turn the value of mechanical branch current changes, too. Moreover the character and amplitude modulation depth depend on unevenness of pressure of ultrasonic vibrating system to treated object, wave impedance of medium, stability of acoustic contact, etc.

Amplitude change of electric current in time at different modes of operation (load mode and idling mode) can be represented, as it is shown in Fig. 3.

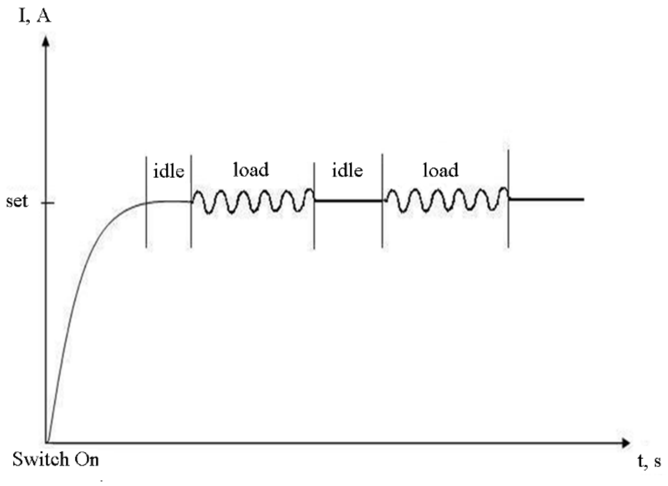


Fig. 3. Current modulation of the ultrasonic vibrating system at the occurrence of acoustic load

Thus the occurrence and value of amplitude modulations of mechanical branch current of the ultrasonic vibrating system are the criteria of presence or absence of acoustic load on the ultrasonic radiator.

For practical realization the control method of the process of ultrasonic influence based on continuous check of mechanical branch current, detection of amplitude modulations and control of amplitude of mechanical vibrations of the radiator (switching on/ off of ultrasonic generation of the device) was proposed.

For practical use of proposed the control method of the process of ultrasonic influence the block diagram of the device was developed, shown in Fig. 4.

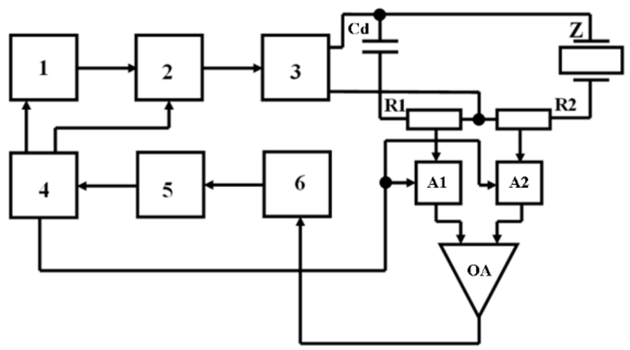


Fig. 4. The block diagram of the ultrasonic generator implementing proposed control method

Setting generator 1 produces low-voltage signal of ultrasonic frequency, which comes to the amplifier 2, where it is amplified to required amplitude. The signal from the output of the amplifier through resistive current sensors R1 and R2 comes to the piezoceramic elements Z of the ultrasonic vibrating system and series capacitor Cd through matching link 3. Current sensors R1 and R2 are used for measuring the value of current flowing through piezoceramic elements of the ultrasonic vibrating system and current flowing through the capacitor Cd. The signals from the current sensors R1 and R2 through controlled amplifiers A1 and A2 go to differential amplifier 7, where their subtraction is performed. Amplitude value of the signal obtained as a result of operation of differential amplifier is isolated by the amplitude detector 6, which further comes to the input of analog-digital transducer 5. Digital amplitude value of mechanical branch current enters to the microcontroller 4, under control of which all units and systems of the electronic generator operate, in particular microcontroller manages voltage at the output of the amplifier 2, on which value vibration amplitude of working surface of of the ultrasonic vibrating system depends. At switching on the electronic generator electric voltage is supplied to the ultrasonic vibrating system, at which intensity of ultrasonic vibrations corresponds to the level, which is enough for carrying out the procedure of external liposuction. During the operation of the ultrasonic device the microcontroller 4 uninterruptedly analyzes the value of amplitude modulations of mechanical branch current of the ultrasonic vibrating system. In the case, when the value of amplitude modulations of mechanical branch current of the ultrasonic vibrating system does not exceeds 1% from current amplitude, e.g. for 5 seconds, the microcontroller generates a signal for reduction of supply voltage of the radiator up to the level, at which it can run for a long period of time without heating of the radiator (energy saving mode). In this mode the ultrasonic generator operates till during 0.5 sec or more the value of amplitude modulations exceeds 3% from current amplitude of mechanical branch current of the ultrasonic vibrating system. If the value of amplitude modulations exceeding 3% from running amplitude of the current lasts more than 0.5 sec, the microcontroller 4 generates a signal for increase of supply voltage of vibrating system up to the level, which is necessary for realization of technological process. Further the process repeats.

Fig. 5 shows the changes of mechanical branch current of the ultrasonic vibrating system at the operation of developed system.

Thus if acoustic load is applied to the ultrasonic vibrating system, intensity of ultrasonic vibrations has necessary maximum level.

In the case if there is no acoustic load or it is unchanged during long period of time, intensity of ultrasonic vibrations decreases to the level, at which there is no heating of the ultrasonic vibrating system.

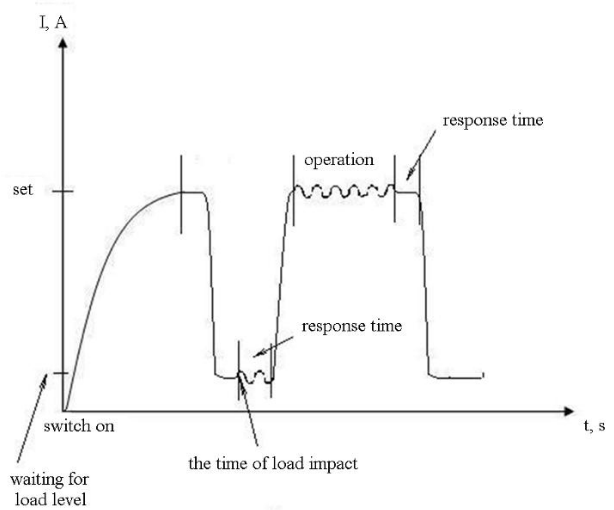


Fig. 5. The mechanical branch current of the ultrasonic vibrating system during the operation of the ultrasonic generator in integrate control system of acoustic load

III. CONCLUSION

Studied control methods of the operation of the ultrasonic generator are realized and approved in the medical device "Nezhnost" (see Fig. 6) intended for carrying out procedures of external liposuction, introduction of medicines to hypodermic layers of humans, massage [4].

Fig. 6. The ultrasonic device "Nezhnost"

At the absence of acoustic load (idling mode) the device generates ultrasonic vibrations with power of less than 15 W. At the presence of acoustic load (contact of the radiator with coverlets of the patient) the device produces nominal power (about 60 W). As the absence of modulations in the chain of the ultrasonic radiator indicates not only the absence of load, but stability of load. The device is also switched off in the case of static contact of the radiator with the body of the patient, that excludes the possibility of the burn of patient's tissues. For the control method of acoustic load realized in the device "Nezhnost" the patent of Russian Federation №2440165 [5] was received.

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