Rules And Features Of The Design Of Piezoelectric Sources Of High-Intensity Ultrasonic Action

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***Abstract* – In the article the rules and consequence of the design of separate units (piezoelectric transducers, boosters, concentrators and working tools) at the production of piezoelectric vibrating systems – sources of ultrasonic action on different technological processes are introduced. Proposed rules provide the development of the ultrasonic vibrating systems with necessary parameters of ultrasonic action, such as power, intensity of radiation, frequency, radiating surface, diraction of radiation, etc.**

***Index terms* - Ultrasound, ultrasonic technological equipment, ultrasonic vibrating system, concentrator.**

I. INTRODUCTION

ULTRASONIC TECHNOLOGIES are widespread in different branches of industry, as they allow to develop new and intensify well-known technological processes [1].

All known ultrasonic technologies are realized by the application of universal or specialized ultrasonic technological apparatuses, which have an ultrasonic vibrating system and an ultrasonic generator for its power supply.

The ultrasonic vibrating system is the main unit of the technological apparatus, as it provides transformation of electric oscillations into mechanical vibrations of defined frequency and intensity, amplification of their amplitude upto the values, which are able to provide the realization of technological processes, introduction of vibrations into technological media by working tools, which differ from each other in area and form of radiating surface.

Depending on specific features of realized technological process, volumes of processed media there is a need to use ultrasonic apparatuses with different power and kitting, i.e. the application of certain vibrating systems and electronic generators of various power for their power supply. At the development and application of electronic generators they are classified by consumed electric power [2]. Such classification can be proved by the fact, that although all generators are made by close structural and circuit diagrams, have similar units of driving generators, feedback systems, they essentially vary in power, structural and overall features of output stages, sources of power supply and control systems of output stages. That is why, used in practice ultrasonic apparatuses are conventionally divided into several classes according to consumed electric power of the generators– upto 100 W, upto 400 W, upto 1000 W, upto 3000 W, upto 8000 W and more than 8000 W.

Accordingly there are limitations of radiated acoustic power for ultrasonic vibrating systems used as a part of the apparatuses, and within the bounds of groups of vibrating systems of similar power the size and the construction diagrams of vibrating systems remain unchanged.

However besides radiation power at development and application of vibrating systems there is a great number of more important limiting parameters – frequency, intensity, introduced volume acoustic energy, surface and direction of radiation. These limitations determine construction diagram, size and number of piezoelectric elements in the transducer, number of half-wave links, overall dimensions, form and size of the tools.

That is why, all used in practice ultrasonic vibrating systems consist of specified set of structural elements, their form and overall dimensions are determined by the requirements of solved technical task – necessity of effective realization of technological processes. To provide required ultrasonic action at the realization of the process with defined productivity it is necessary to determine power of the transducer, number, form and size of structural elements of vibrating system (concentrators, boosters, working tools), as it is shown in Fig.1.

II. TECHNOLOGY

As the realization of technological processes requires defined energy action, determinative parameter of vibrating system is an intensity of radiation (cavitation influence on liquid media) or vibration amplitude of working tool (dimensional processing or welding of thermoplastic materials). At that there is a need to provide certain conditions of influence (flowing treatment or processing of the volume, value of volume energy, uniformity of action, etc.).

To provide energy action in specified conditions (volume, viscosity, disperse composition of processed material, flow rate, direction and uniformity of radiation, etc.) is possible in the case, when piezoelectric transducer, concentrator, working tool are chosen correctly and when developed vibrating system is applied efficiently.

The possibility of generation of vibrations of specified frequency and power determines the choice of piezoelectric transducer. That is why, the choice and the design of any source of ultrasonic action – ultrasonic vibrating system begins with the development of the piezoelectric transducer, which is necessary and sufficient for support of required parameters.

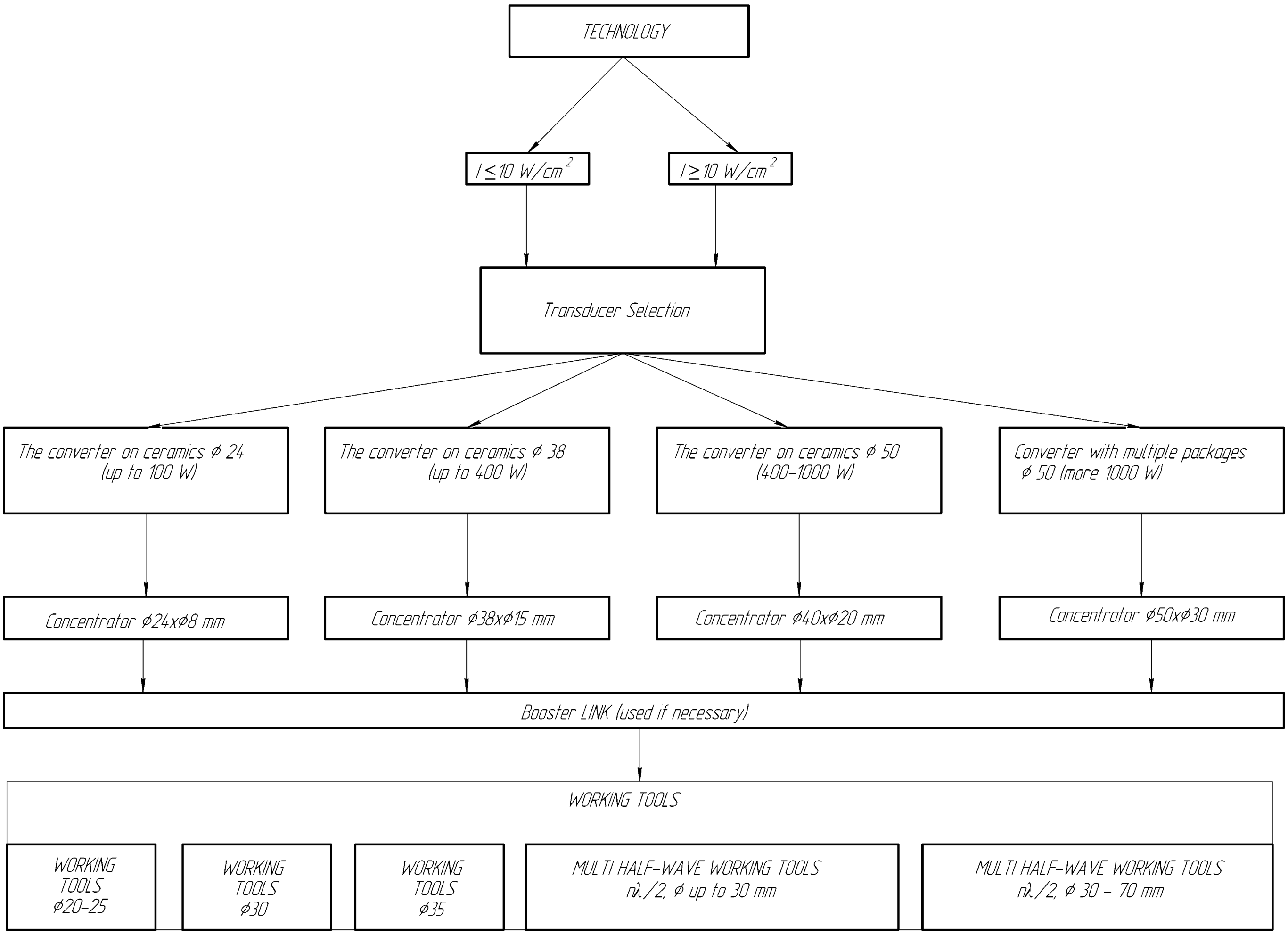

Fig. 1. Scheme of the choice of ultrasonic vibrating system

III. THE CHOICE OF THE PIEZOELECTRIC TRANSDUCER

The piezoelectric transducer is the base of any ultrasonic vibrating system, as it provides transformation of electric energy into mechanical vibrations of ultrasonic frequency. The piezoelectric transducer consists of placed in series, mechanically and acoustically coupled with each other metal frequency lowering reflecting plate, two piezoelectric elements, frequency lowering working plate, to which radiating surface the concentrator or the booster is attached.

At the problem statement of the choice and design of the piezoelectric transducer of electric oscillations first of all ultimate consumed power of the transducer, which is necessary to provide required parameters of ultrasonic action, is defined. As used in practice ultrasonic apparatuses are conventionally divided into several classes according to power characteristics of the electronic generators, it is rational to classify piezoelectric transducers (and vibrating systems in a whole) by similar principle.

All piezoelectric transducers are usually designed and produced on the base of standard ring piezoelectric elements, which maximum diameter does not exceed 50 mm. Minimum size of the piezoelectric elements can be less than 20 mm, however piezoelectric elements of ring form with the external diameter of more than 20-24 mm and the internal diameter of more than 10-12 mm are used in practice. The presence of internal diameter of stated size is necessary for threaded joint of the elements (plates and piezoelectric elements) of the transducer.

In this connection the choice of standard size of the piezoelectric elements of the transducer is realized from the conditions of providing of certain energy parameters of ultrasonic action, necessary transducer is designed according to the construction diagram (see Fig.2).

As it is shown in Fig.2 the main parameter at the choice of the construction diagram of the piezoelectric transducers is the size and the number of the piezoelectric elements, which are necessary and sufficient for the provision of required ultrasonic action.

On one acoustic axis it is possible to position no more than four piezoelectric elements placed in series, as further increase of transducer power by placement of piezoelectric elements in series is ineffective due to worsening of cooling conditions of the piezoelectric elements inside the packet. In this connection there is a need to sum power of separate packets of the piezoelectric elements located in different acoustic axes of the piezoelectric transducer.

Thus the presence of one or several acoustic axes, at which transformation of electric oscillations and their summation are realized, determines power characteristics of ultrasonic vibrating systems and all ultrasonic equipment as a whole.

The construction diagram of the ultrasonic vibrating system for the equipment of the first and second power group can unite the piezoelectric transducer and the concentrator [3], which function performs working frequency lowering plate made in the form of rotary body with variable diameter. Such transducer can be one construction ending by changeable or unchangeable working tool with radiating surface of certain form and area. As a rule the piezoelectric transducer being a part of described vibrating system contains two ring piezoelectric elements with the external diameter of 24-38 mm and the internal diameter of 12-16 mm.

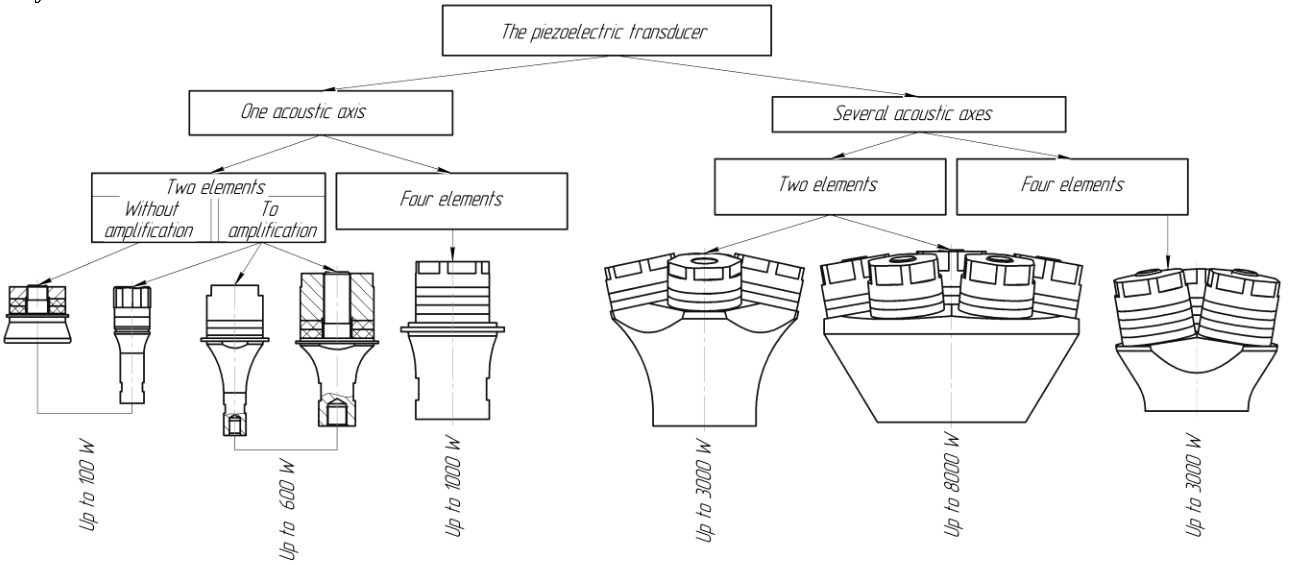

Fig. 2. Choice of the piezoelectric transducer

The piezoelectric transducers of the third power group are made on the base of the piezoelectric elements with the diameter of more than 40 mm and they are applied as a part of equipment with power from 400 upto 1000 W.

In this case the piezoelectric transducer is produced according to the construction diagram containing two or four piezoelectric elements with the diameter of 50 mm in one acoustic axis. The number of the piezoelectric elements in the transducer is selected even and it dependes on power generated by the ultrasonic vibrating system. The use of four ring piezoelectric elements with the external diameter of 50 mm and the internal diameter of 20 mm in the piezoelectric transducer provides efficient operation of the transducer as a part of the ultrasonic apparatuses with power of upto 1000 VA.

The application of more than four piezoelectric elements in the transducer is not rational, as effective increase of power due to two additional piezoelectric elements does not exceed 20%. The attempts of further power growth lead to the fact, that even at the presence of forced air cooling the piezoelectric elements inside the packet overheat, that causes their depolarization and failure of the transducer.

The piezoelectric transducers of the next power group are used as a part of the ultrasonic equipment with power of more than 1000 W. Such transducers have several acoustic axes, and they consist of three, four, seven or more piezoelectric packets located evenly along the surface of the transducer. Each of the packet contains two or four piezoelectric elements with the external diameter of 50 mm.

Such construction of the piezoelectric transducer allows to sum power of ultrasonic vibrations generated by a set of several packets containing standard piezoelectric elements. The number of piezoelectric elements in the packet should be even and it should not exceed four elements in the packet to prevent their overheating.

Further the developer of the ultrasonic vibrating system should solve the problem of mounting of vibrating system in the technological equipment. For this purpose the intermediate is used, which is called booster.

IV. THE CHOICE OF THE INTERMEDIATE

Taking into account size and number of piezoelectric elements composing the transducer of specified power booster (matching) link is chosen according to the scheme shown in Fig.3.

The intermediates are required to provide optimum matching of the units connected by the intermediate, maximum transfer of vibration power from its source to load, mounting of the ultrasonic vibrating system in the technological equipment, additional amplification of vibrations, and also performance of auxiliary functions such as formation of the unit of thermal cutoff, thermal separation of the piezoelectric transducer from the zones with higher temperature, from technological media of high chemical aggressivity, etc.

In general case the booster is a half-wave resonance metal construction of cylindrical form meant for operating frequency of the transducer. The production of the booster with different input and output diameters and different form of junction between the zones with various diameters lets change amplitude of mechanical vibrations generated by the transducer. The booster links providing amplification of amplitude of ultrasonic vibrations are widely used. However amplification of booster links does not exceed 2-4 units in practice.

Whereas ultrasonic vibrating system for the equipment of the first and second power group can combine the piezoelectric transducer with the concentrator, the choice of the booster is of current importance for the equipment relating to the third and fourth power groups.

V. The Choice Of The Concentrator And Working Tool

The ultrasonic working tool is a very important element, as it provides influence on technological media. Working tool generating vibrations of specified type enters ultrasonic vibrations into processed media through vibrating working (radiating) surface or it realizes mechanical influence through the contact of vibrating at ultrasonic frequency surface with an article or an object.

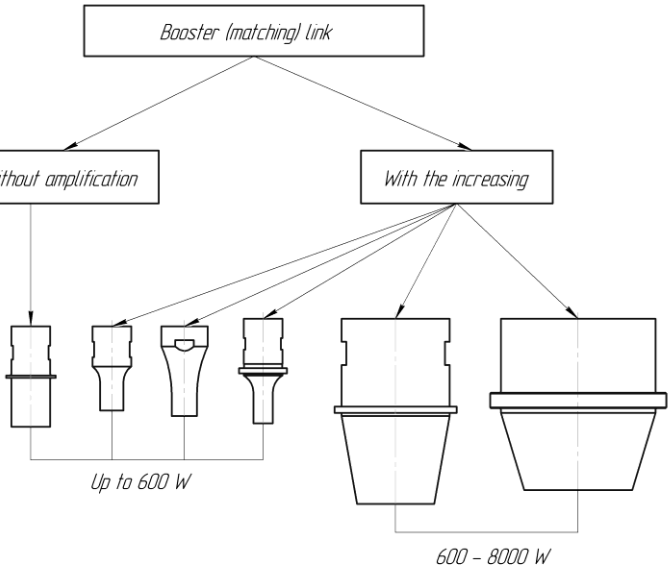

Fig. 3. Scheme of the choice of the booster

Depending on the form and the size of working tools, behavior of their influence on vibrating system all tools of the ultrasonic devices can be conventionally divided into passive and active (resonance).

That is why, final stage of the design of the ultrasonic vibrating systems is the choice of working tool. The scheme explaining the possibility of the choice of different working tools is shown in Fig.4.

For the ultrasonic equipment of the first, the second and the third power groups passive working tools of mushroom-shaped form varying in diameter and area of radiating surface are the most commonly used.

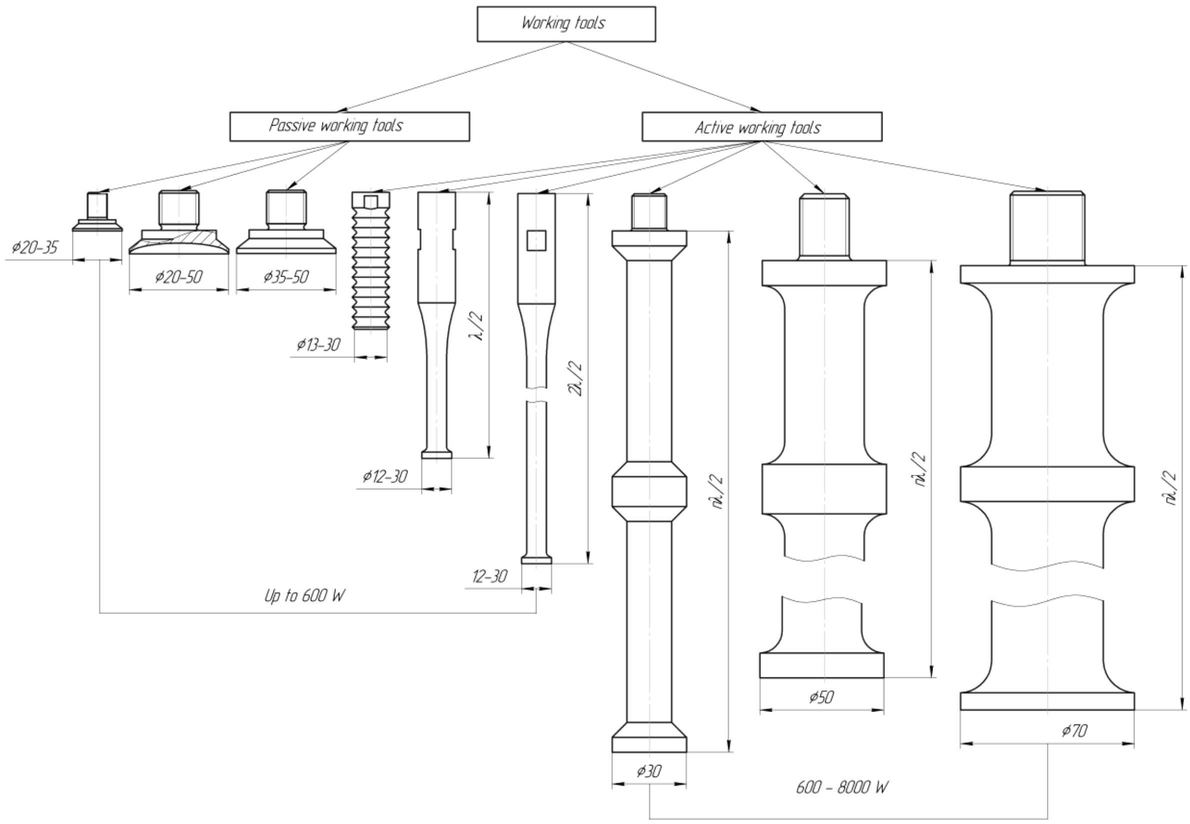

Fig. 4. Scheme of the choice of working tool

For the equipment with power of upto 100 W working tools with the diameter of 10-20 mm are applied, upto 400 W working tools with the diameter of 20-25 mm are used. For the equipment with power of 400 upto 1000 W working tools with the diameter of 25-35 mm can be applied. For the apparatuses with power of 400 upto 1000 W working tools with the diameter of 25-45 mm and more are used. In some cases it is possible to apply active two half-wave tools or tools having developed radiating surface of cross-section.

For the equipment with power of more than 1000 W beside working tools of mushroom-shaped form the active multi half-wave working tools are used, that allows to provide additional amplification of vibration amplitude at the application of more developed radiation surface.

For kitting of the ultrasonic apparatuses with power of upto 8000 W working tools with developed radiation surface containing waveguides of cylindrical form of variable diameter (from 70 mm), which are placed in series and in alignment, are used, that lets realize processing of larger volume of liquid medium in cavitation mode.

VI. The Example Of The Element Choice And The Construction Of The Ultrasonic Vibrating System

The example of the choice of the components and the construction of the ultrasonic vibrating system with power of upto 1000 W by step-by-step selection of separate structural components is shown in Fig.5.

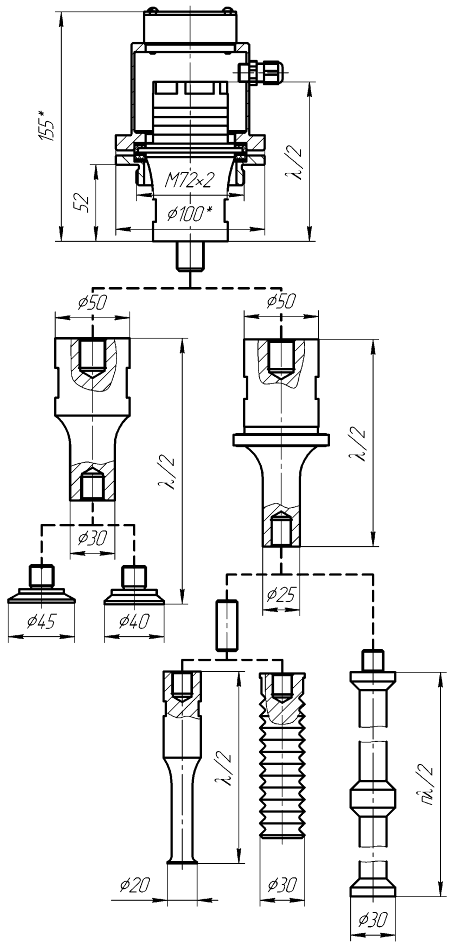

Fig. 5. Choice of the ultrasonic vibrating system by the step-by-step selection of single structural components

The choice of separate components and the construction diagram allows to design the ultrasonic vibrating system with required parameters of ultrasonic action – power, frequency, intensity of radiation, surface and direction of radiation, etc.

Fig.6 shows developed according to described approach typical ultrasonic vibrating systems of different power and function.

Fig. 6. Ultrasonic vibrating systems of different power and function

VII. CONCLUSION

Proposed approach provides rational choice and construction of ultrasonic vibrating systems at the design and application of modern ultrasonic vibrating systems reducing time for development and costs for their production.

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