Center of ultrasonic technologies

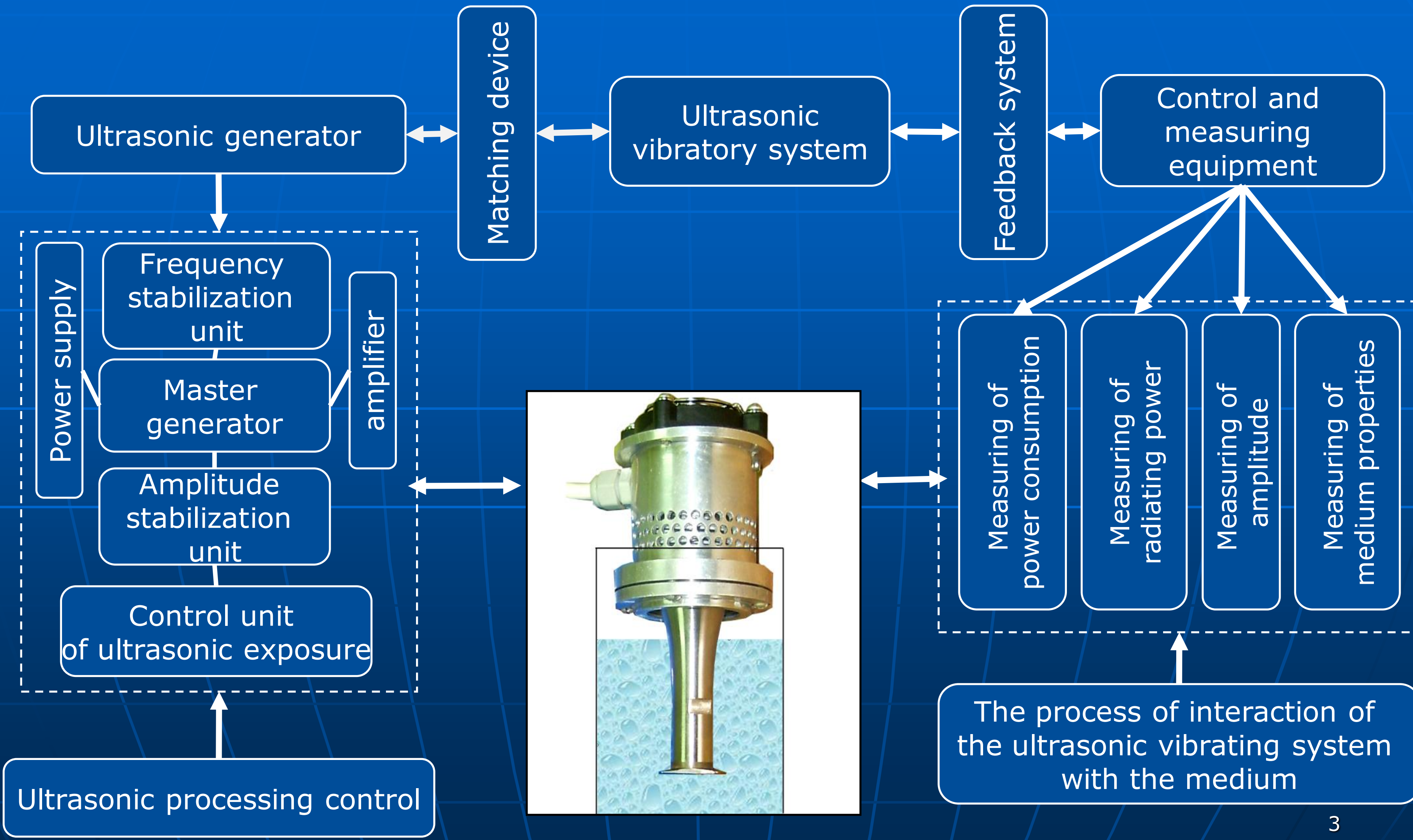
Piezoelectric radiators for generation of ultrasonic vibrations

Khmelev Vladimir Nikolaevich

Doctor of Technical Sciences, Professor, Honored Inventor of the Russian Federation, Senior Member IEEE. Laureate of the Russian Government Award in the field of science and technology, author of more than 900 scientific publications (including more than 100 patents, more than 20 monographs and textbooks), Deputy Director for Scientific Work of the Biysk Technological Institute of the Altai State Technical University.

+7 9039925120
vnh@u-sonic.ru

Ultrasonic industrial device



Work of ultrasonic device

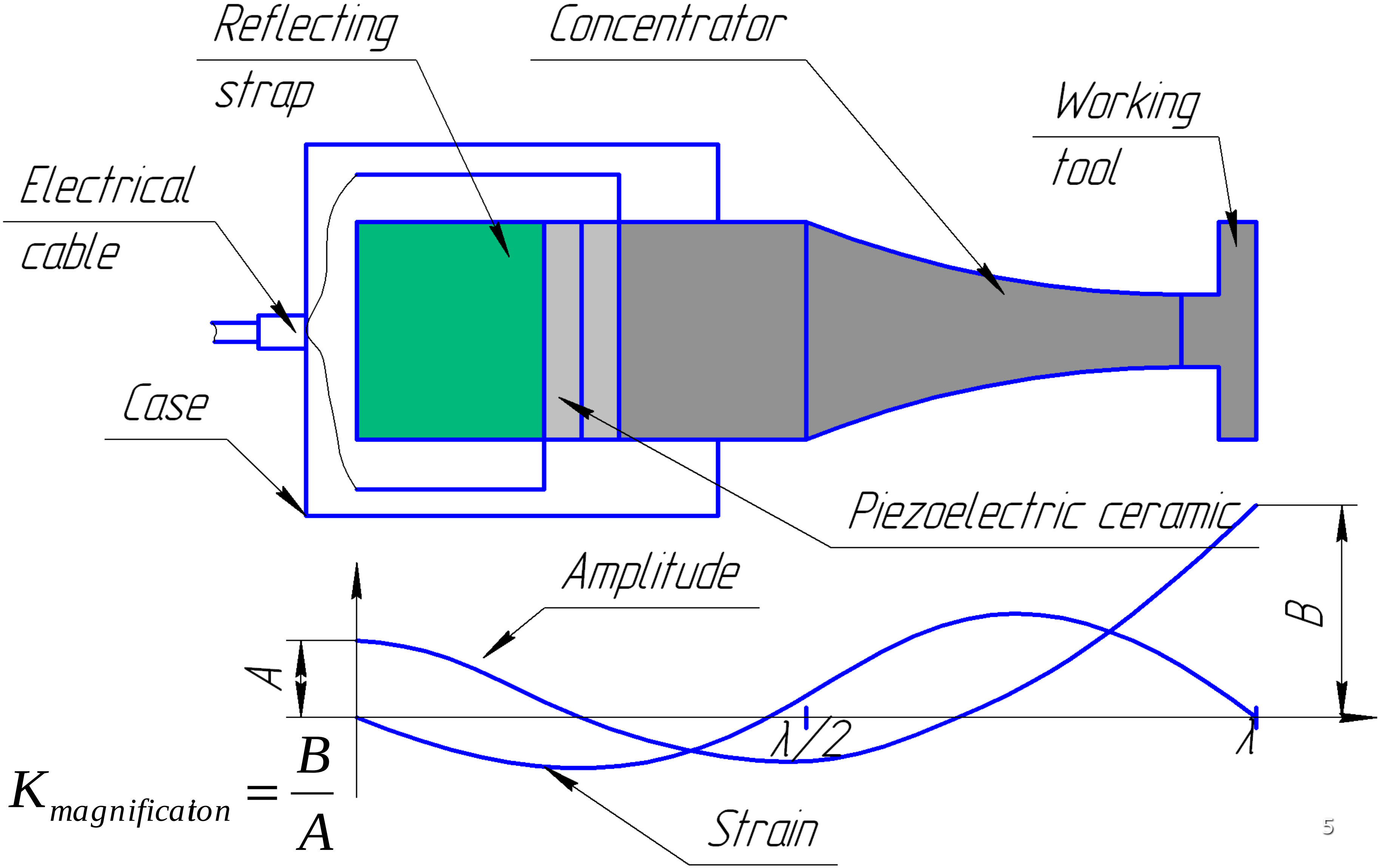
When using modern ultrasonic devices, the simultaneous volume of the processed liquid is:

$V_{max} \leq 6\pi \cdot h\ cm^3 = 18{,}8 \cdot h\ cm^3$

h = 0,1..10 cm depend on liquid viscosity.

$V_{max} \leq 2 \ldots 200\ cm^3$

Ultrasonic oscillation system



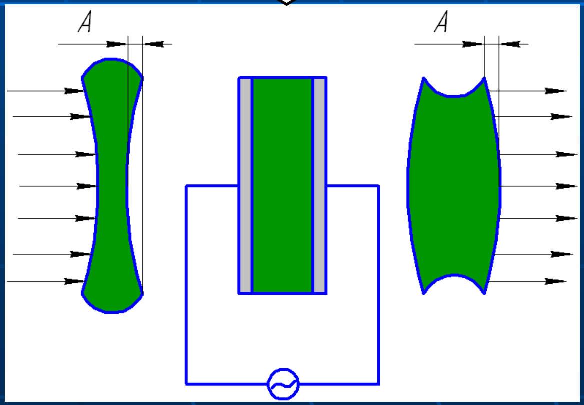
$$K_{magnificaton} = \frac{B}{A}$$

Piezoelectric transducers

Piezoelectric effect

Polarization of a dielectric at squeezing

Inverse piezoelectric effect



Piezoelectric materials

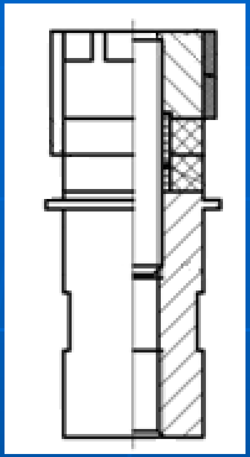
Natural quartz

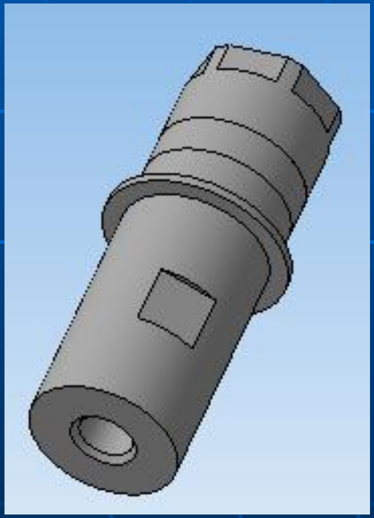
1000V- 1μm/cm

Synthetic piezoelectric materials
1000V-50 μm/cm
Zirconate – titanate of plumbum
PZT-5, PZT-8
(ZTP-23), APC-841

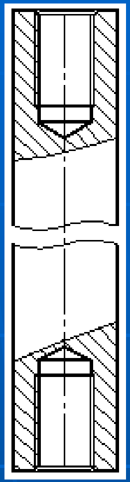
Piezoelectric elements

Parts of ultrasonic vibratory system





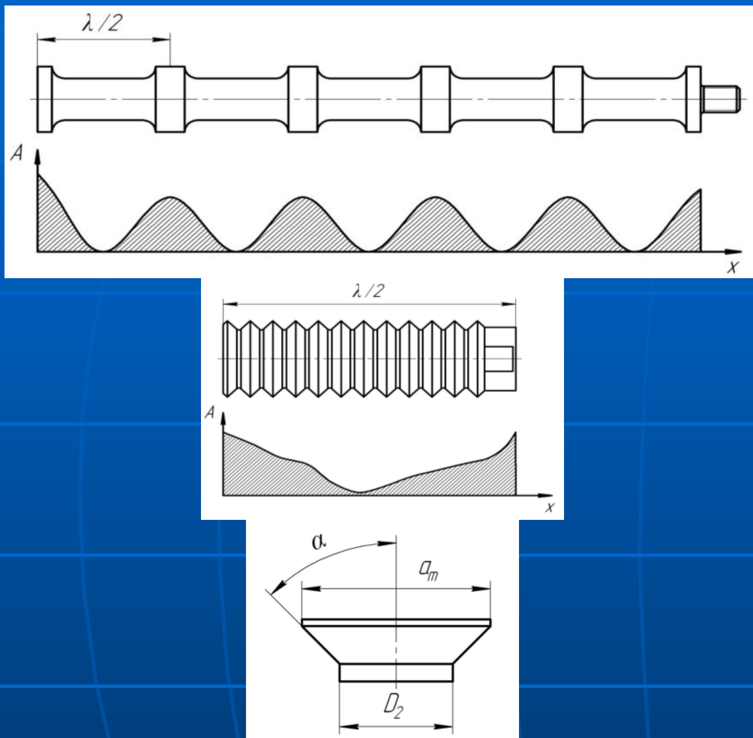
Piezoelectric transducer

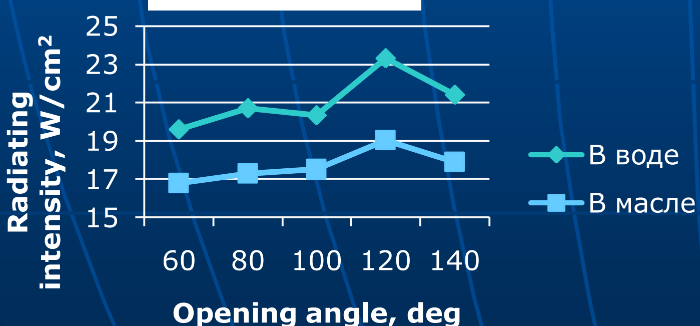


Intermediate sonotrode

Ultrasonic radiators

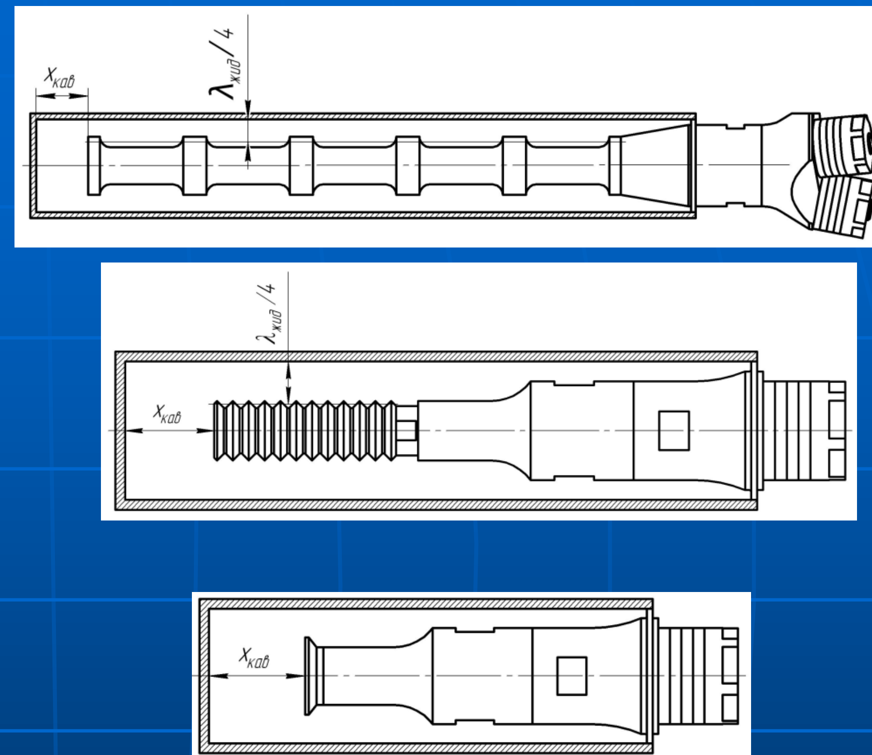
Mono-frequency radiator

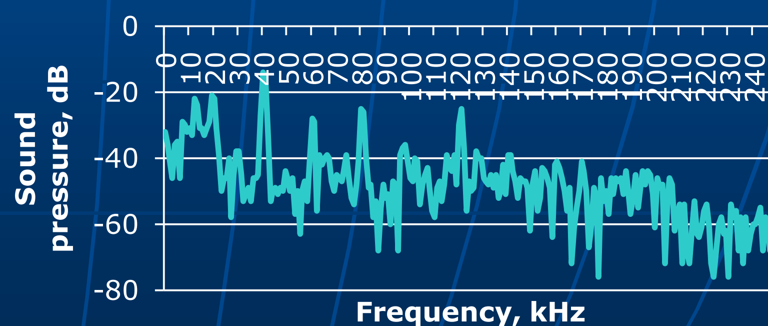




The intensity of ultrasonic vibrations radiated a mushroom-shaped working tool on the opening angle 2α

Broadband radiators

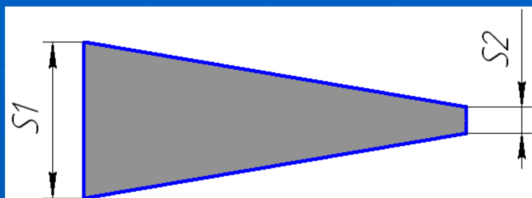




Amplitude-frequency response of vibrations of the sound-conducting volume surface

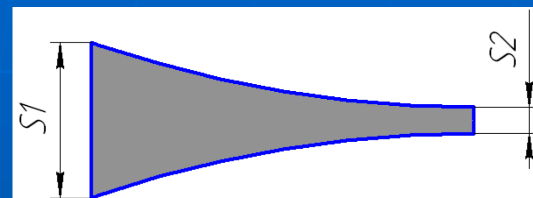
Magnifiers of ultrasonic oscillations

Conical



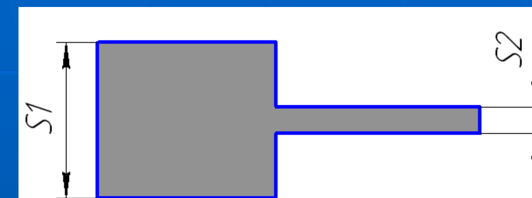
$$K = 0.8\sqrt{\frac{S_1}{S_2}} \quad Q=40$$

Exponential



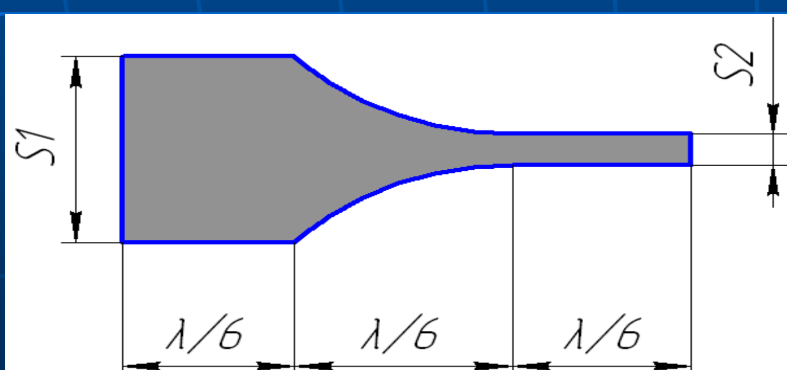
$$K = 1{,}1\sqrt{\frac{S_1}{S_2}} \quad Q=20$$

Stepping



$$K = \frac{S_1}{S_2} \quad Q=150$$

Stepping-exponential concentrator

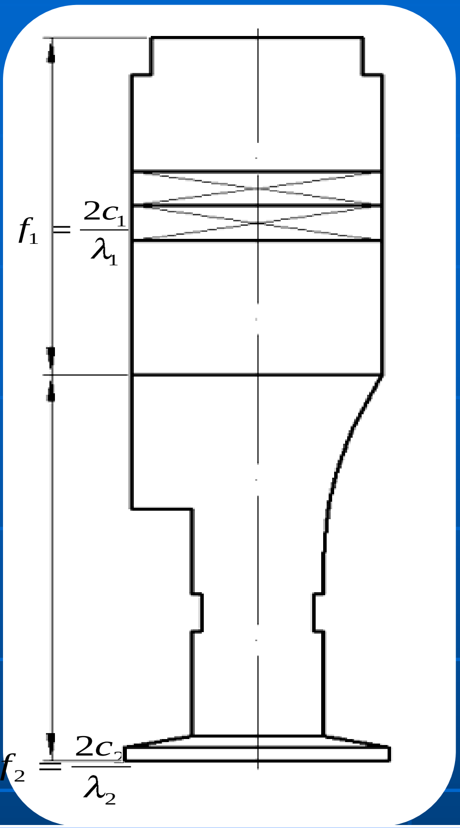


$$K = (0.8-0.9)\frac{S_1}{S_2}$$

Influence on radiator parameters

External influence

Influence of design



Metal heating
ΔF~f(Paк)

Piezoelement type
$\Delta F=f(c_{ceramic}\theta)$

Piezoelement heating
ΔF~f(T,U)

Booster type
ΔF=f(shape)

Influence of processing medium
(viscosity, dispersion)

Surface area and shape of working tool

Influence of technological processes

$F_{generator}$ - ?
(22±1,65 kHz)

Processing mode

Before cavitational
23,65 kHz

Cavitational
22 kHz

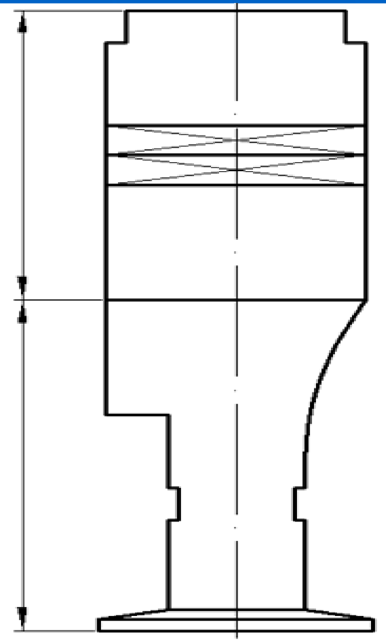
Intensive cavitational
20,35 kHz

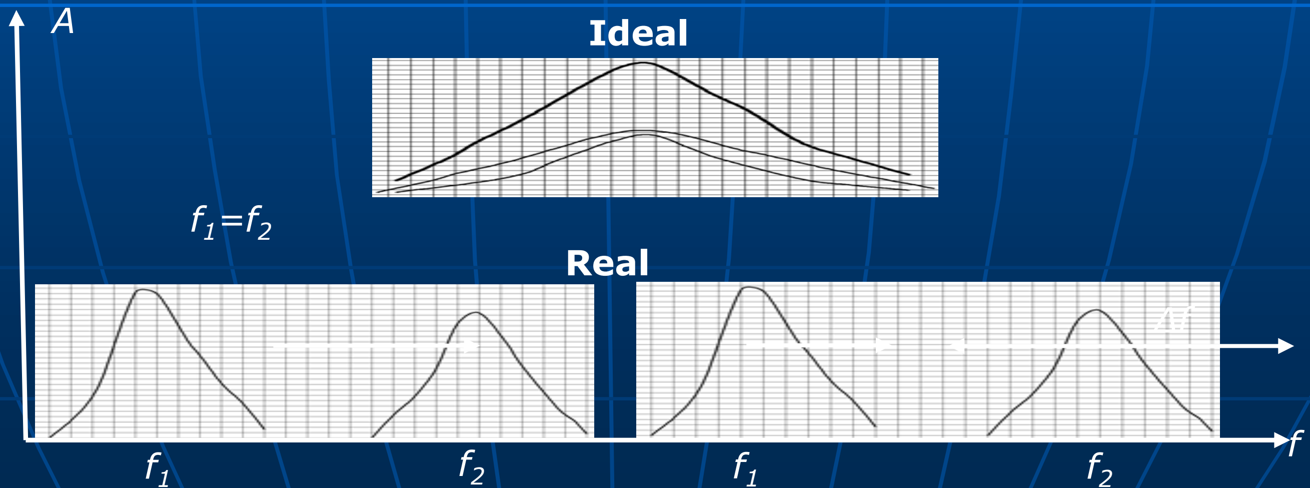
Main problem of vibratory system

1. Low efficiency (<50%)
2. High weight and length
3. Mismatch

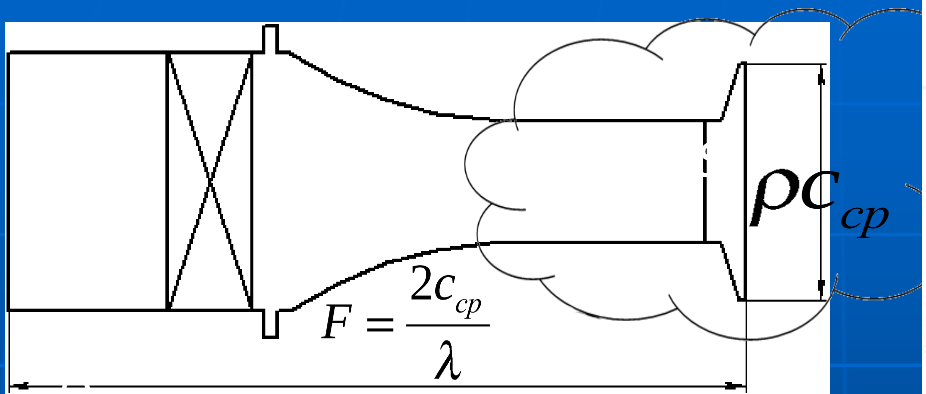
$$f_1 = \frac{2c_1}{\lambda_1}$$

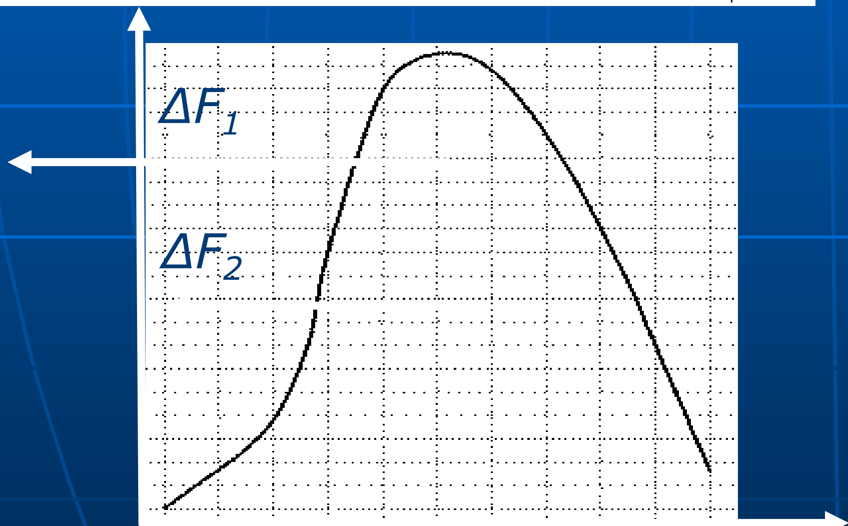
$$f_2 = \frac{2c_2}{\lambda_2}$$





Half-wave vibratory system





Efficiency ≤ 80%

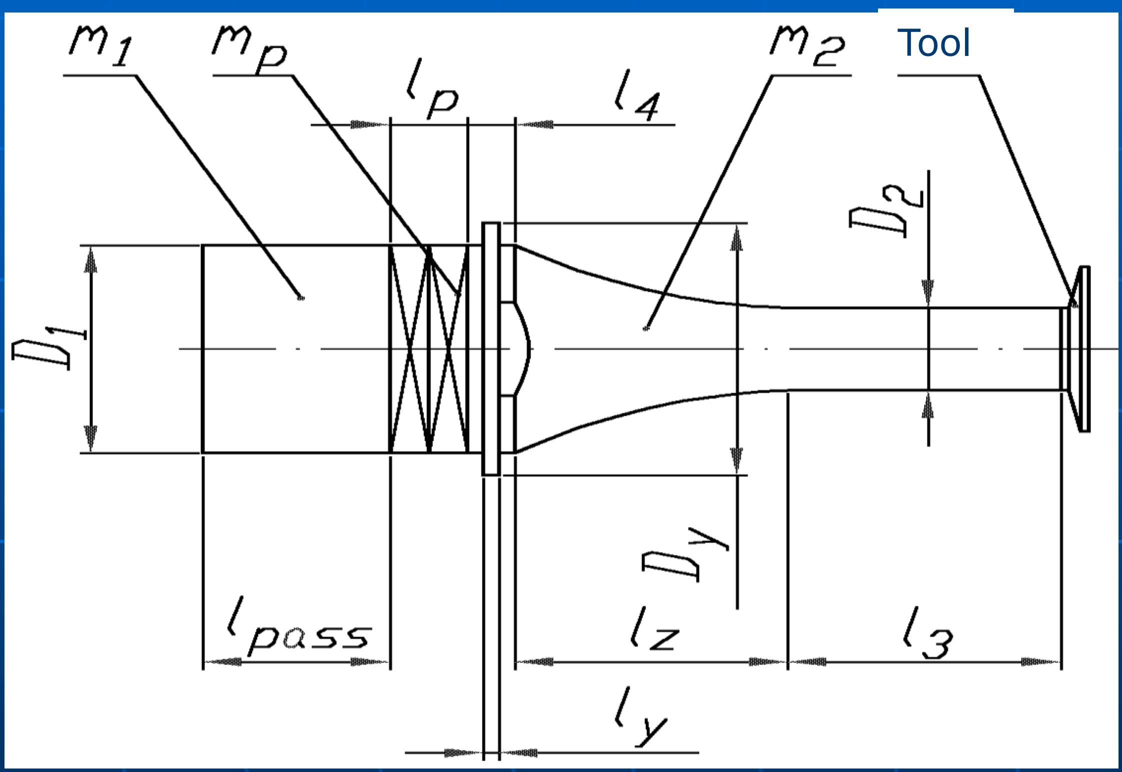
Vibration amplitude ≤100 um

Gain factor ≥20

$\Delta F_1 = f\ (S, \rho c_{medium})$

$\Delta F_2 = f\ (T, U)$

Design of half-wave vibratory system



l_3 – length of cylindrical area with diameter D_2 (material m_2)

l_4 – width of the mounting unit of the vibratory system in the case

D_y – diameter of mounting belt

l_y – length of mounting belt

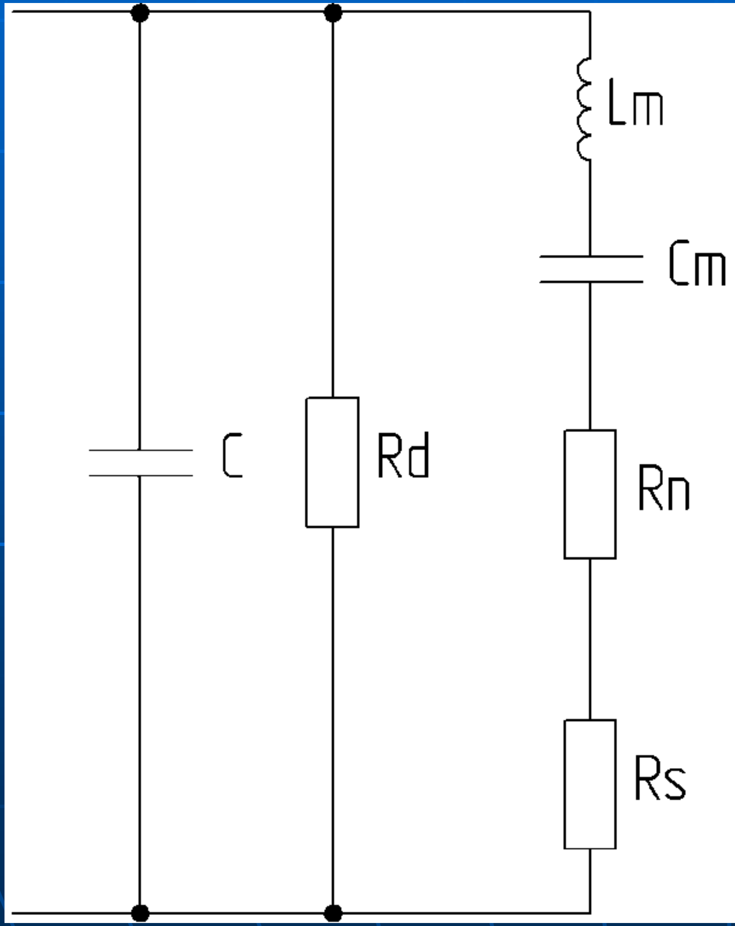
l_{pass} – length of passive reflector (material m_1) of diameter D_1

l_p – piezoelement length (material m_p)

l_z – length of smooth transition

Tool – replaceable working tool

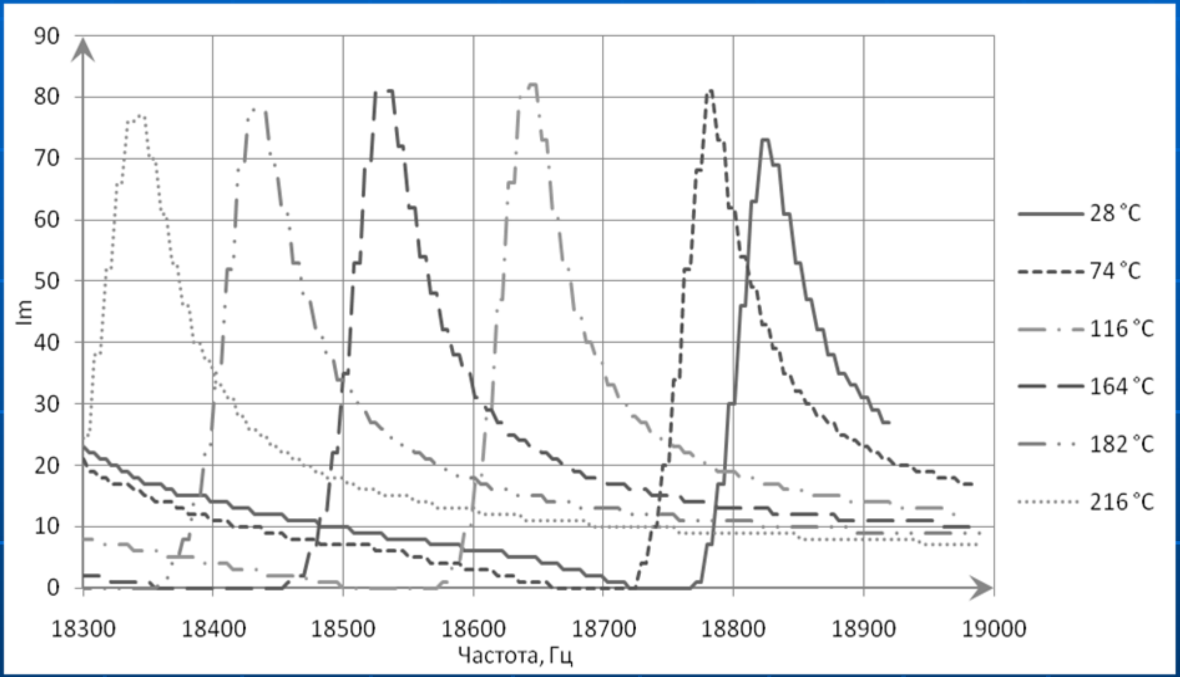
A model of the vibratory system as a physical equivalent circuit



C – static capacity of piezoelements;
Rd – dielectric loss resistance;
Lm – mechanical branch inductance (equivalent to the vibrating mass of the transducer);
Cm – mechanical branch capacity (equivalent to flexibility);
Rn – mechanical loss resistance;
Rs – radiation resistance.

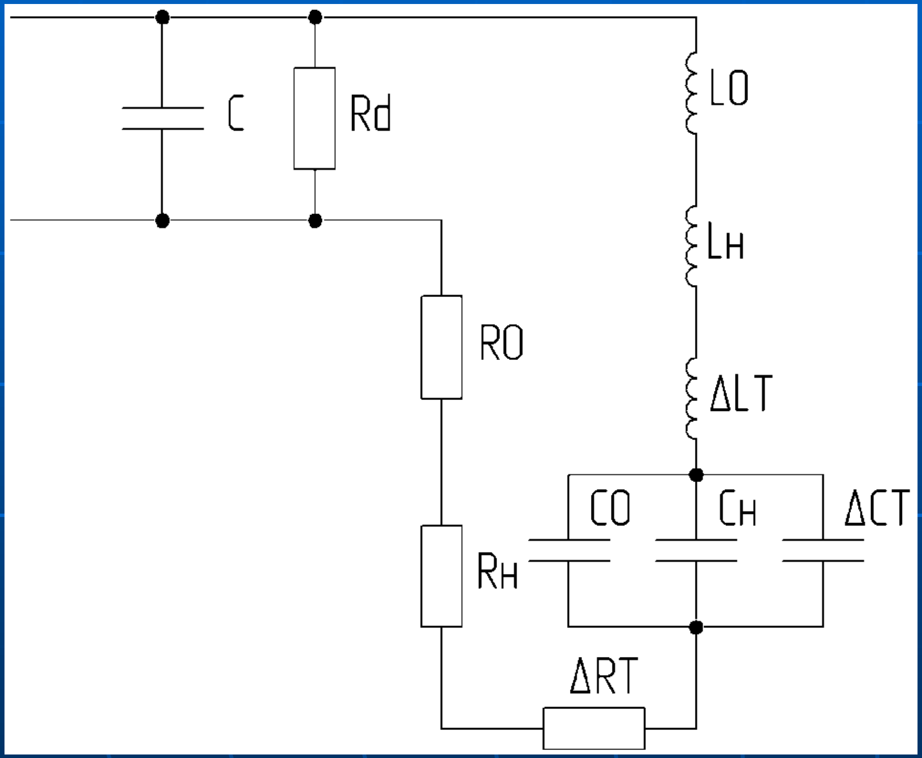
Influence of a radiating surface temperature

Ultrasonic device
“Solovey”



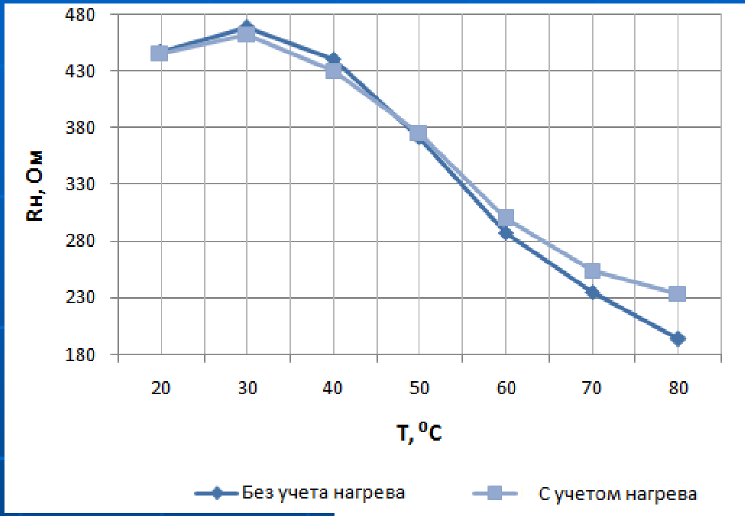
Frequency response of the current of the mechanical branch at different temperatures of the ultrasonic radiator (radiation into the gas medium)

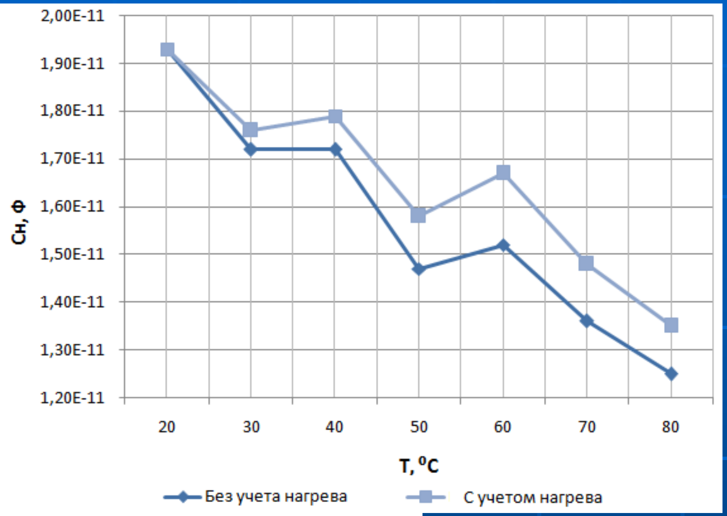
A vibratory system model that takes into account the influence of temperature

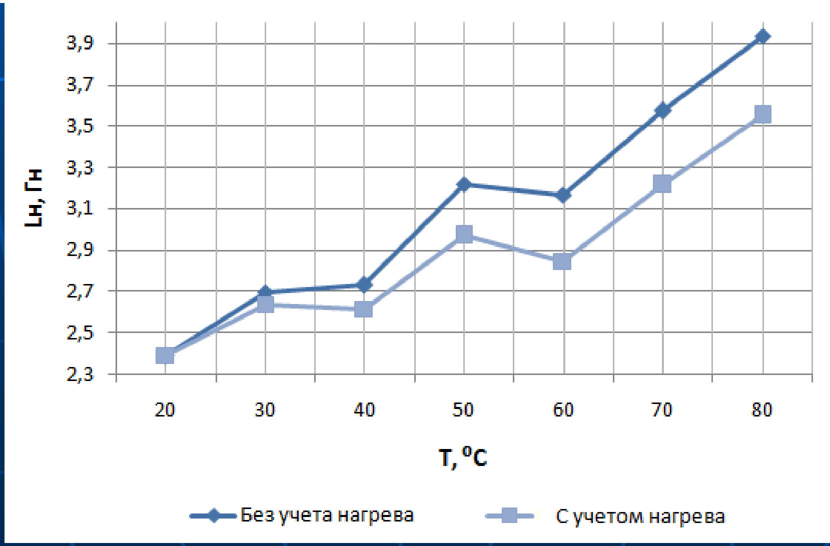


C – static capacity of piezoelements;
Rd – dielectric loss resistance of piezoelements;
L0 – inductance of the ultrasonic vibratory system;
C0 – capacitance of the ultrasonic vibratory system;
R0 – active resistance of the ultrasonic vibratory system;
Lн – acoustic load inductance;
Cн – acoustic load capacity;
Rн – active resistance of the acoustic load;
ΔLT – additional inductance caused by heating of the ultrasonic vibratory system;
ΔCT – additional capacitance caused by heating of the ultrasonic vibratory system;
ΔRT – additional capacitance caused by heating of the ultrasonic vibratory system.

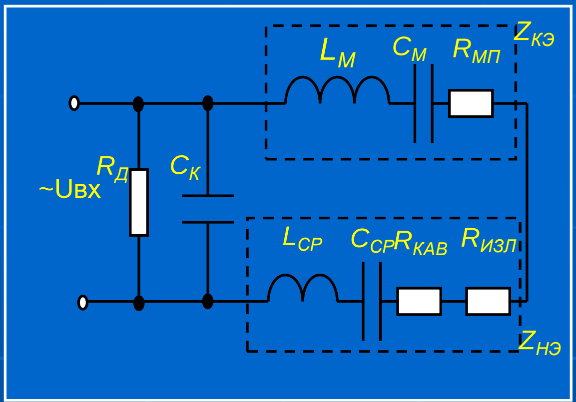
Influence of temperature on element parameters of **equivalent circuit**







Vibratory system as sensor of technological medium parameters



$R_д$ – resistance of dielectric losses;

$C_к$- capacity of piezoelements;

$R_{мп}$ – mechanical loss resistance;

$C_м$ – equivalent to the flexibility of the vibratory system material;

$L_м$ –equivalent to the mass of the material of the vibratory system;

$C_{ср}$, $L_{ср}$ – -elements that characterize the reactive properties of the processing medium;

$R_{изл}$ – element that characterizes the wave resistance of the medium;

$R_{кав}$ – an element that characterizes the energy costs for the creation and maintenance of cavitation;

$Z_{кэ}$ –impedance of the vibratory system;

$Z_{нэ}$ – impedance of the acoustic load.

$z=(z_{кэ}+z_{нэ})$;

$z_{нэ}=f(R_{кав}; R_{изл}; L_{ср})$;

$R_{изл}=f(\rho_{ср}c_{ср})$-output energy;

$L_{ср}=f(m_{присоед.})=f(\rho_{ср})$ Resonance properties;

$f_{рез}=f(\rho_{ср})$.

On the basis of the electrical equivalent circuit of the vibratory system, the dependences of its electrical parameters on the characteristics of the acoustic load and its own properties are obtained. This is makes it possible to measure the acoustic characteristics of medium.

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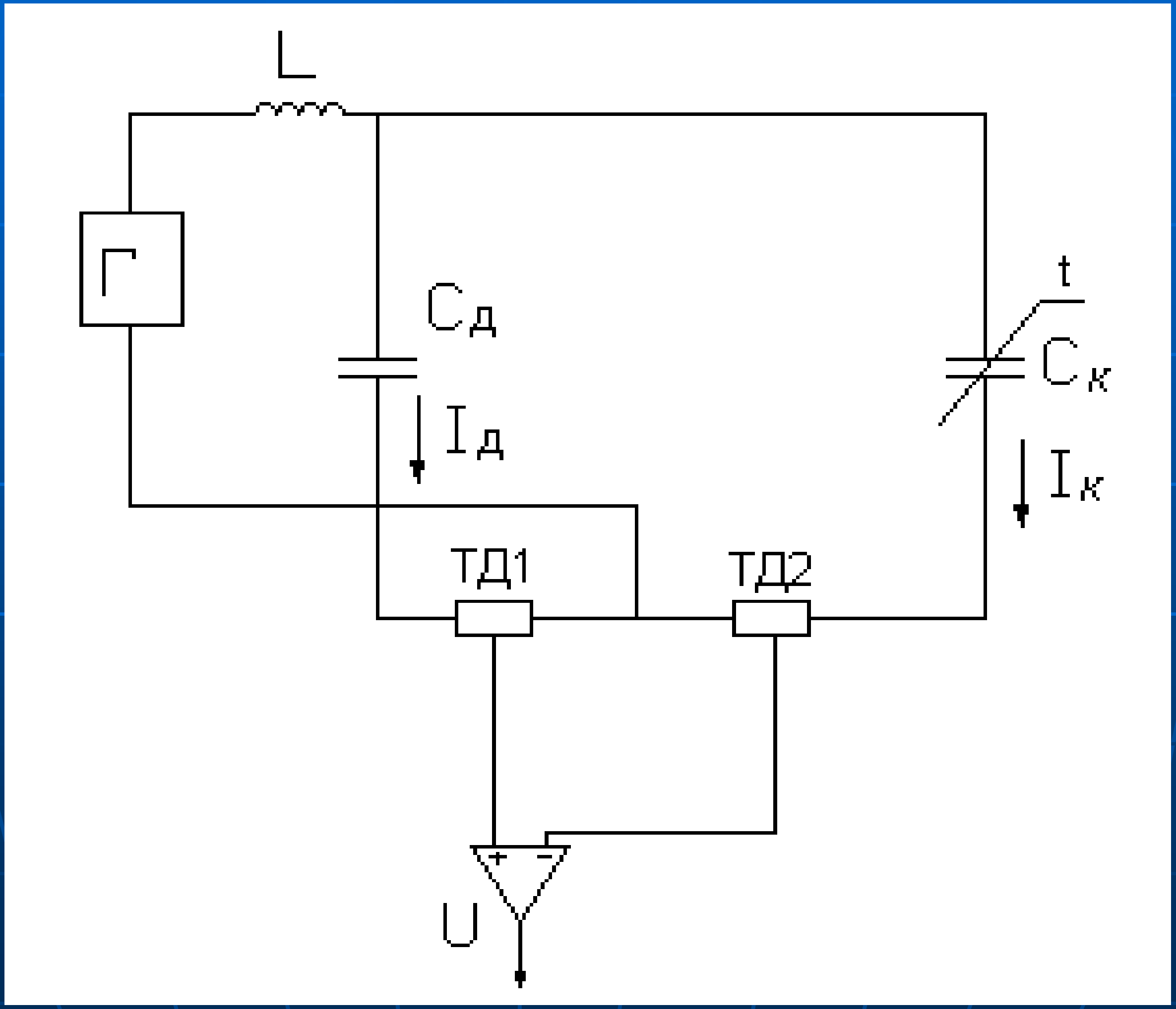
Control system



Limits

Maximum vibration amplitude of the radiator for the selected material

$$A_{MAX} = \frac{\sigma_{MAX}}{2\pi f \cdot \rho_{И} c_{И}}$$

Maximum intensity on the surface of the radiator

$$I_{\max} = \frac{1}{2}\sigma_{\max}\frac{\rho_{cp} c_{cp}}{\rho_{u}^{2} c_{u}^{2}}$$

Energy loss

Attenuation in the material

Radiator area

$$S$$

Power of the electronic generator

Radiating power

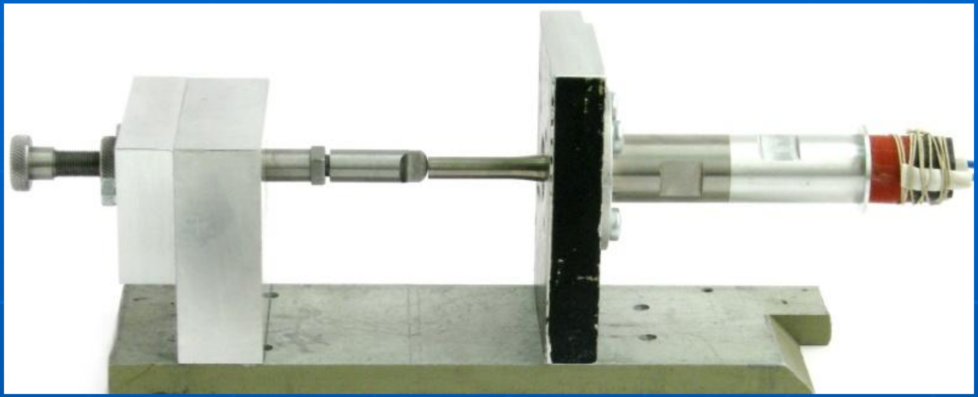
$$P_{MAX} = \int_{S} I_{\max}\, dS$$

Limiting vibration amplitudes for various metals

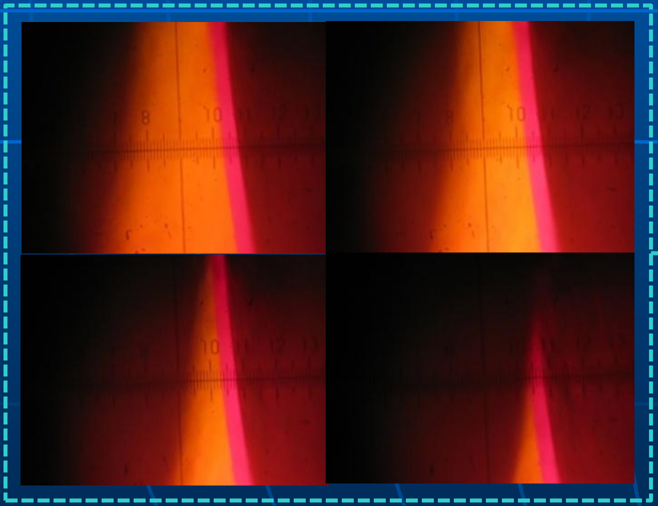
	Steel 40H	Aluminum alloy D16T	Titanium alloy VT16
Density, kg/m^3	7700	2700	4200
Acoustic resistance for longitudinal waves, $kg/(m^2s)10^7$	4,5	1,7	2,8
Acoustic resistance for transverse waves, $kg/(m^2s)10^7$	2,5	0,82	1,3
Ultimate strength, MPa	380-490	100	350
Attenuation , %	4-5	2,2-2,6	1,7-2
Maximum vibration amplitude, um	100…120	50…70	200…300

Vibration amplitude measuring

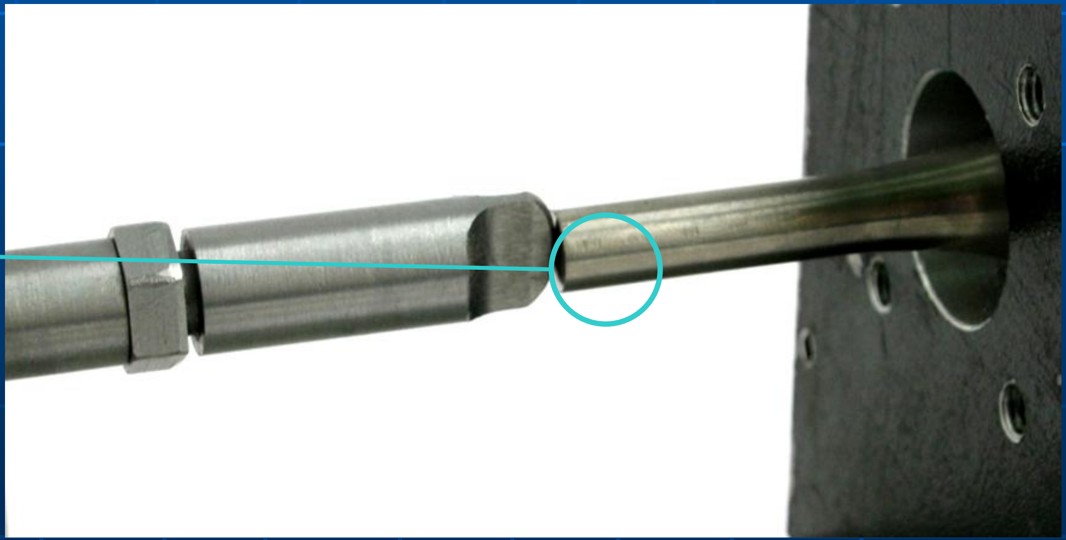
Ultrasonic device “Giminey-ultra”



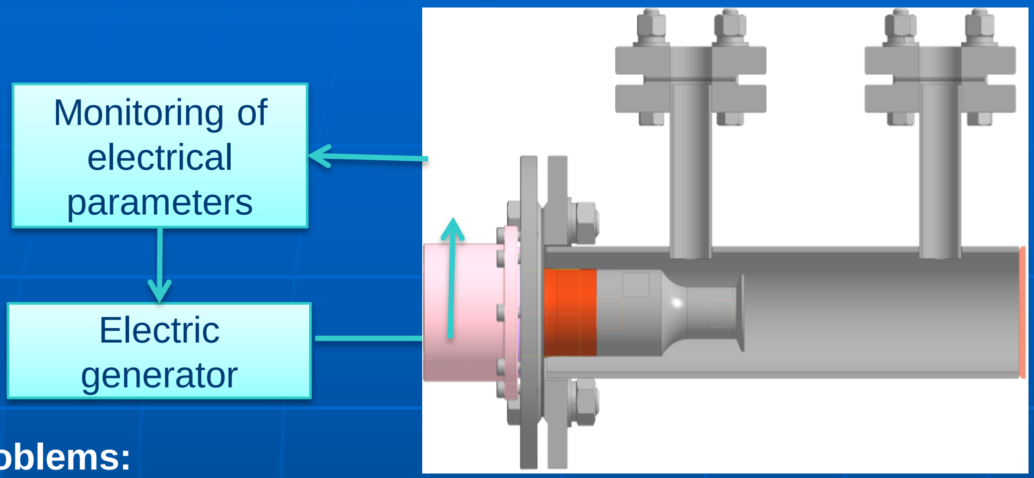
Appearance of the installation that allows you to change the clamping force to the radiating surface



A series of black-and-white images of the vibratory process at changing the clamping force



Problems of indirect methods of the amplitude measuring

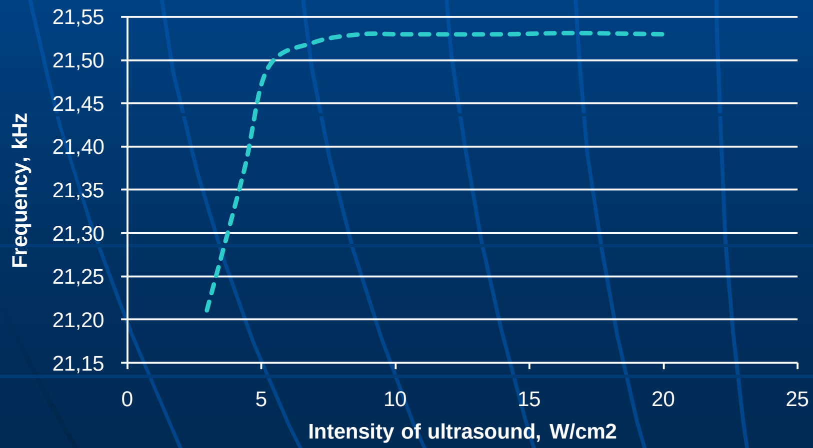


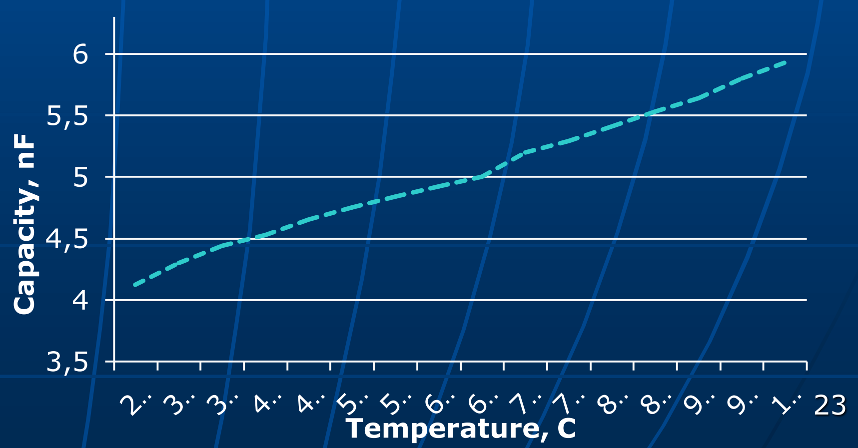
Flow-through ultrasound device

Problems:

1. **Absent of theoretical and experimental confirmation**
2. **Changing the parameters of the vibratory system;**
3. **Changing the parameters of the processing medium.**

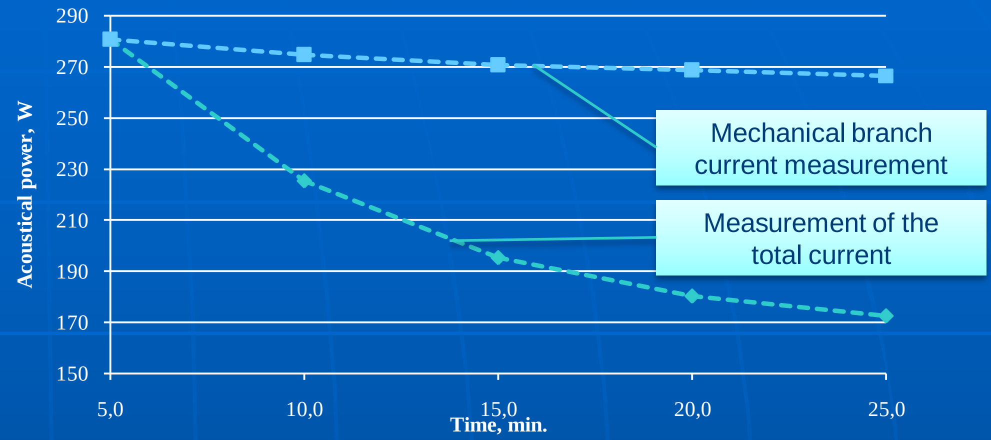
Characteristic dependences of piezoelectric transducer parameters





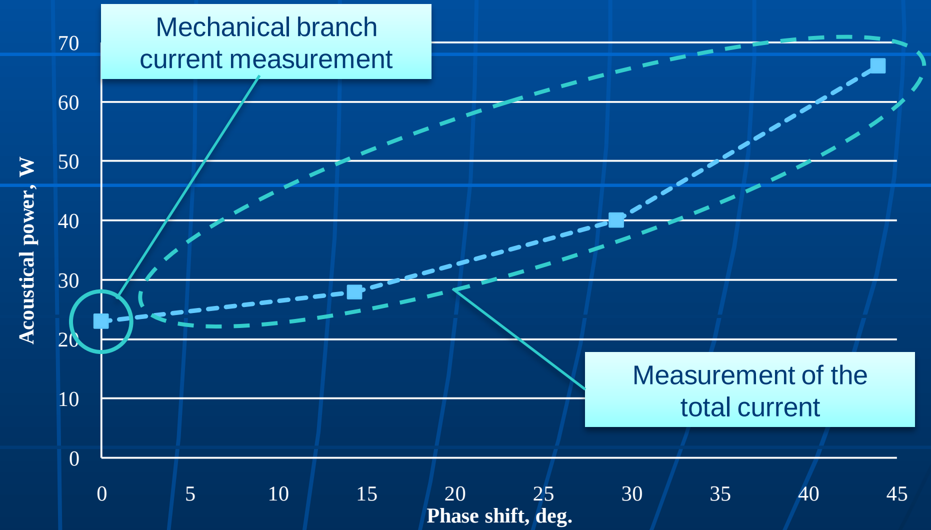
Control-based management

Ultrasonic device of the “Volna" series for cavitation processing of liquids



Change in the input acoustic power during the implementation of the technological process

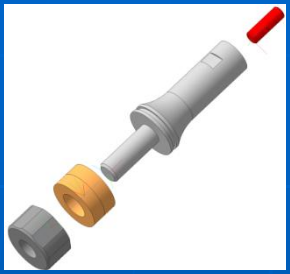
Ultrasonic device of the “Giminey-ultra “ series for welding of thermoplastic materials

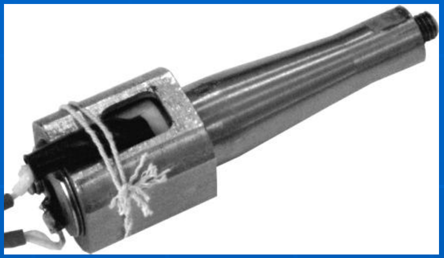


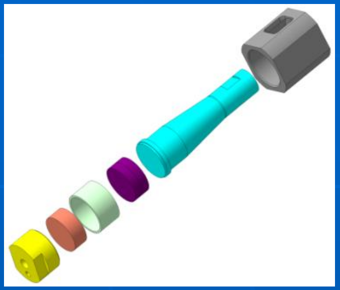
The change in the electrical power consumed by the piezoelectric transducer from the phase shift between the supply current and the voltage when the vibration amplitude is stabilized

Control-based design

Appearance and layout of the parts of the two transducers to be compared

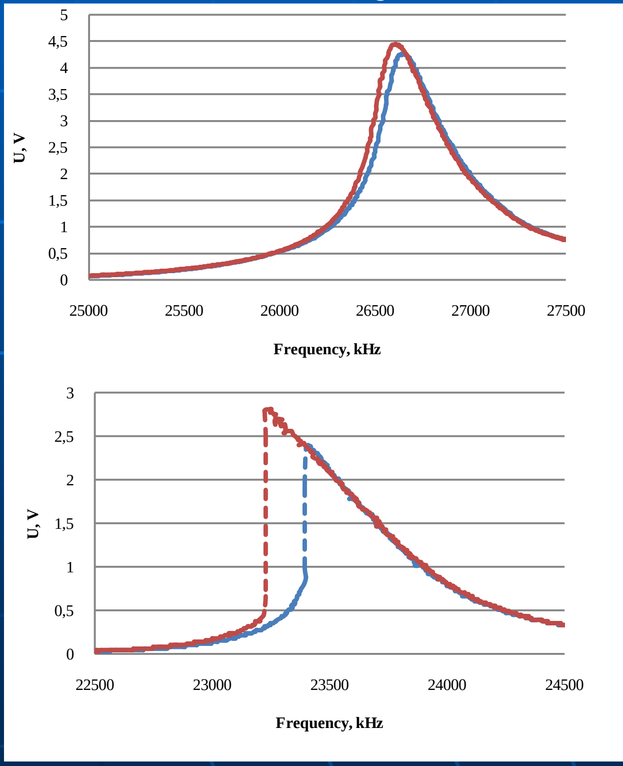


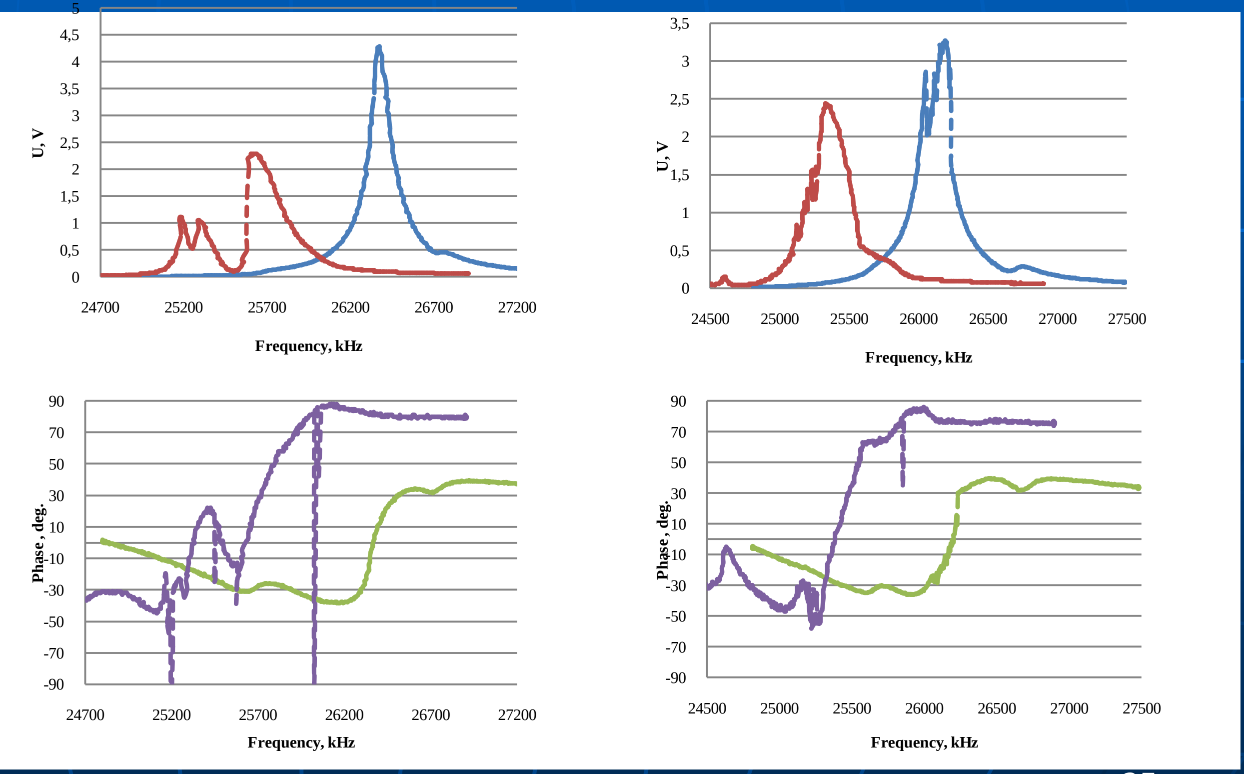




Frequency response of transducers without working tools

Frequency response of transducers with working tools



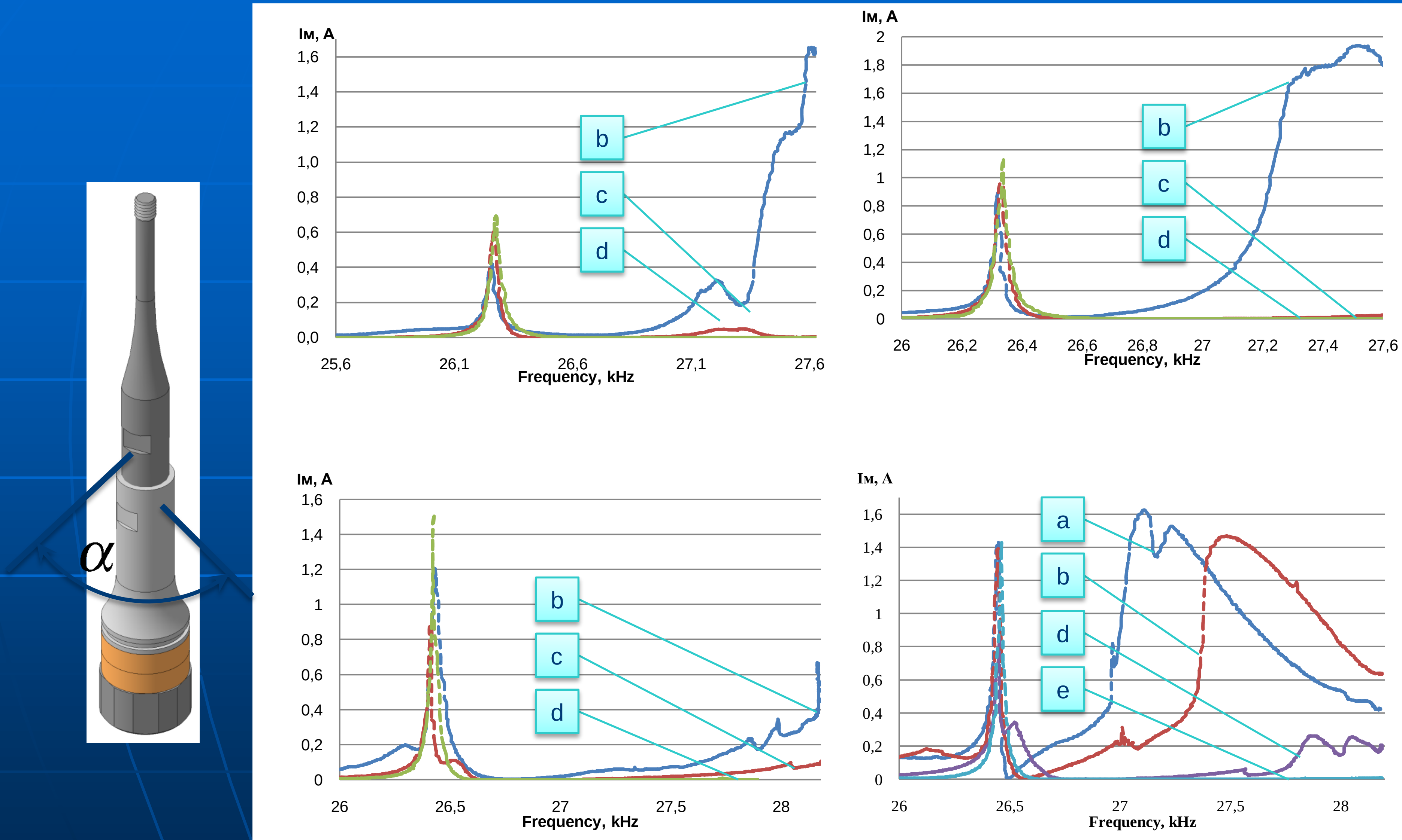


a – frequency response at increasing frequency
b – frequency response at decreasing frequency

half-wave working tool (air)

half-wave working tool (water)

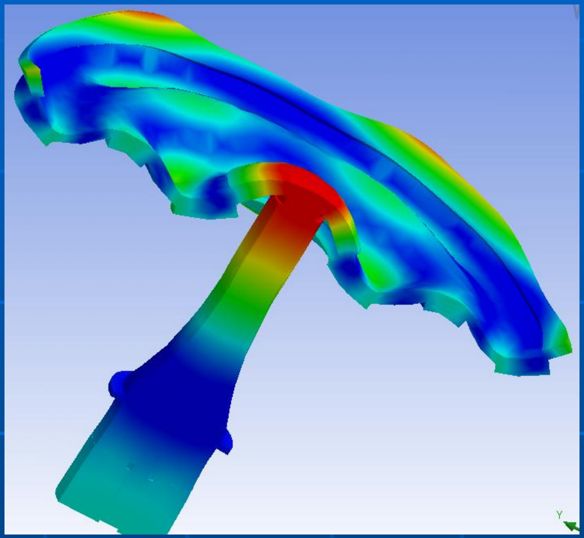
Operation during monitoring



Working tools of three-half-wave length

a – rotation angle 0°, b-rotation angle 8°, c-rotation angle 16°, d-rotation angle 24°, e-rotation angle 32°

Limitations of radiation efficiency



Use of steel:
+ high strength
-big attenuation
-big mass

Main limitations:
acoustic power <130…300 W,

The threaded connection of the disk radiator and the booster can lead to the mechanical failure

Limited diameter:
+ ability to mounting to existing equipment
- limited power

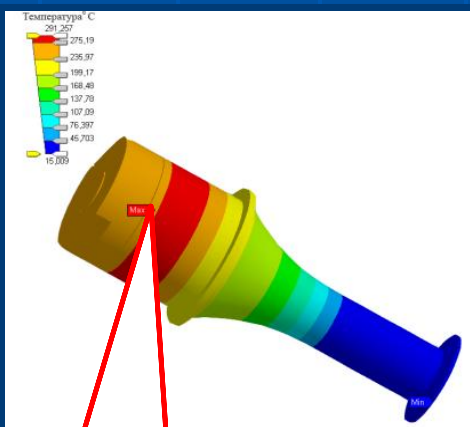
Disadvantages of vibratory systems

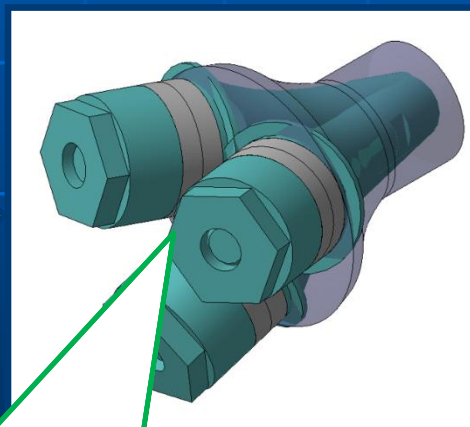
Insufficient radiation surface area

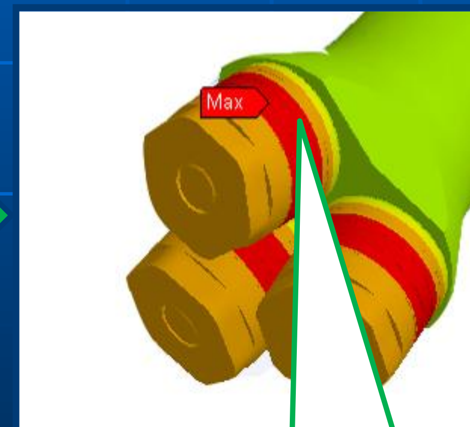
Poor alignment with the processing medium

The need to develop new designs of radiating elements

Insufficient power







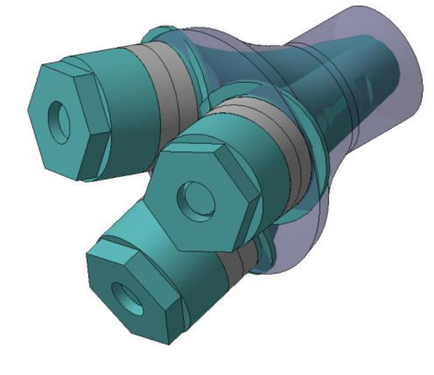
Overheating at a power of more than 150 W

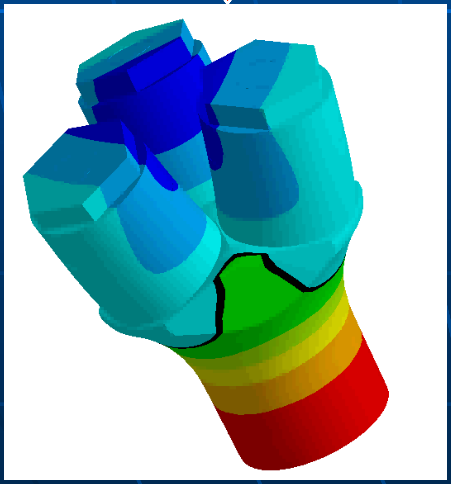
Development of a multi-element transducer – electrical power is distributed among the elements, mechanical vibrations are summed up

No overheating up to 300 W without forced cooling

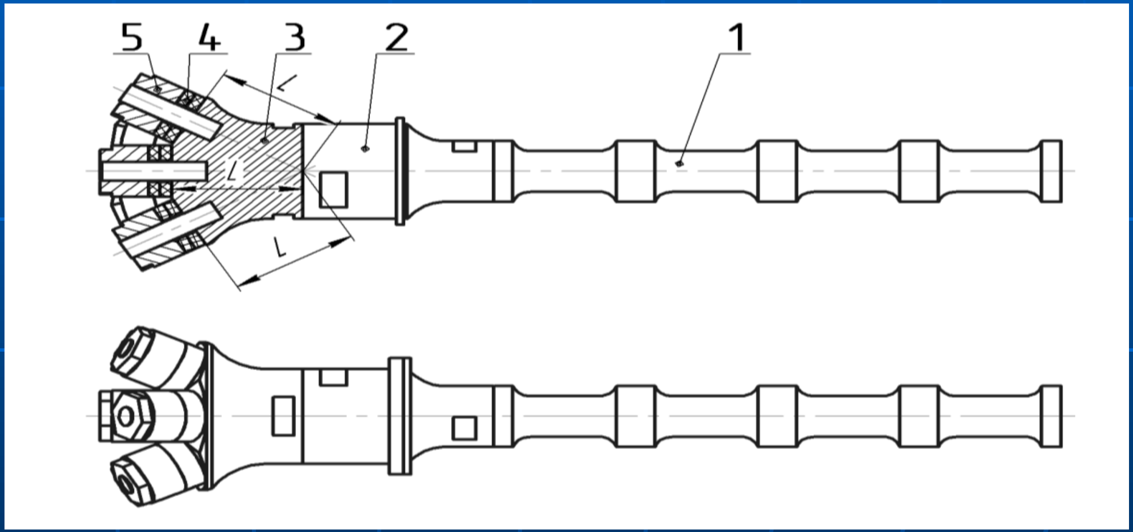
Increasing of power and radiating surface

Multi-element piezoelectric transducer



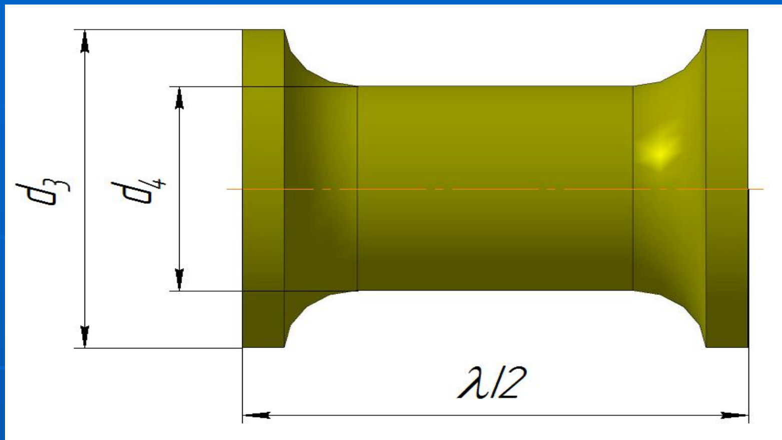


Multi-element piezoelectric transducer with multi-half-wave working tool

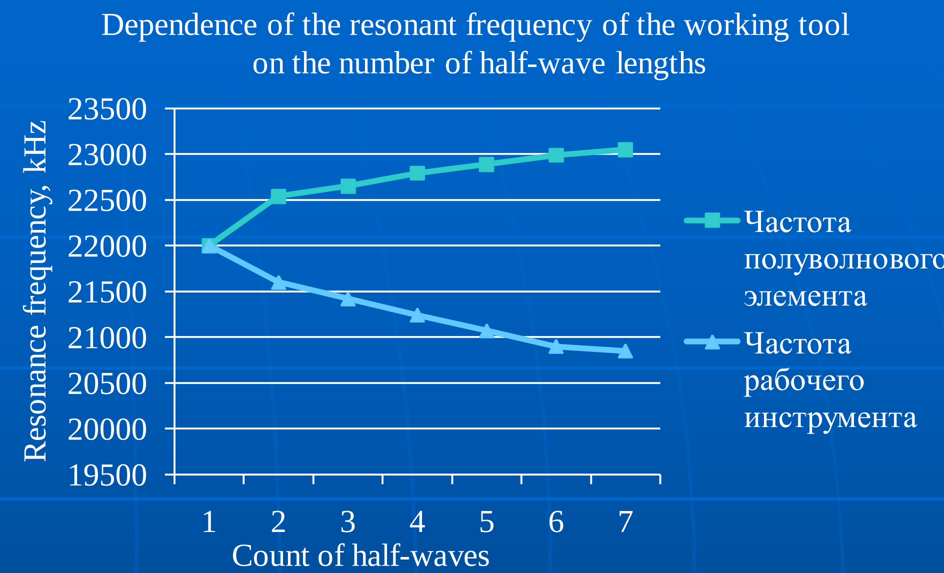


1 – active working tool with increasing radiating surface; 2 – matching acoustic transformer (booster); 3-working frequency-reducing pad;4-piezoelectric elements; 5-reflective frequency-reducing pads

Increasing the radiation surface

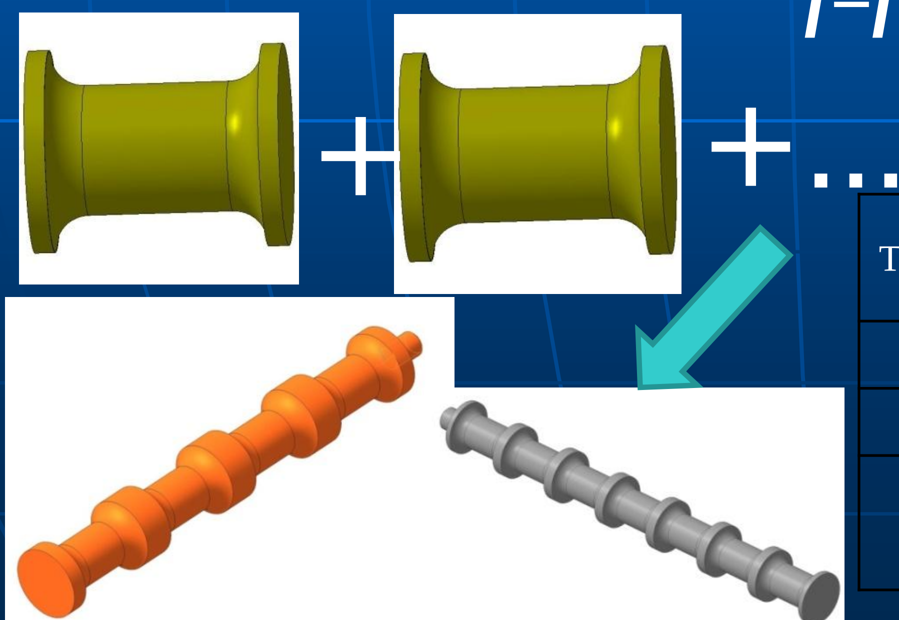


d_3 – depending on the selected booster link and radiating pad;
d_4 – depending on the required radiation area, but not less than $0,6d_3$.



$$f=f_0\,n^{-0,026}$$

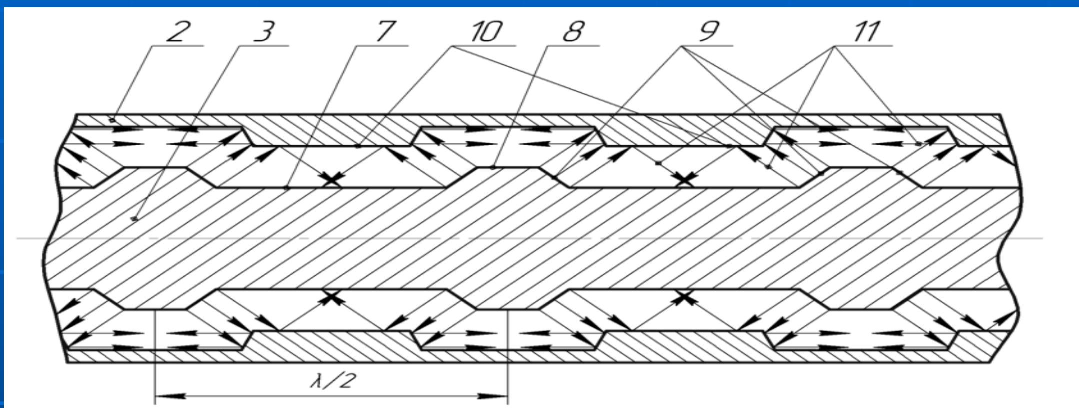
f – resonance frequency of sonotrode n;
f_0 - required working frequency of the working tool;
n – count of half-waves (n = 1,2…7).

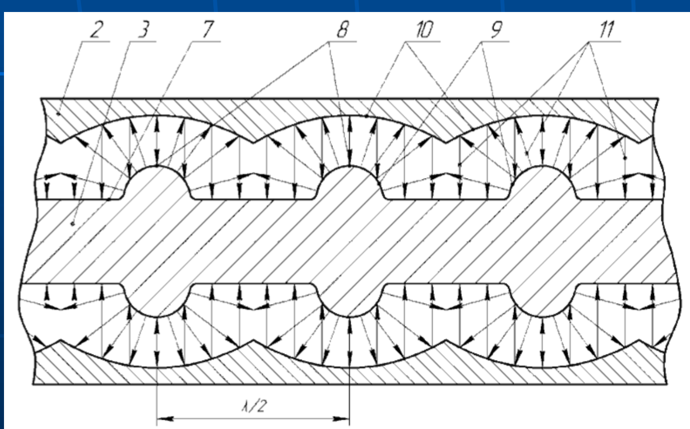


Parameters of the developed working tools

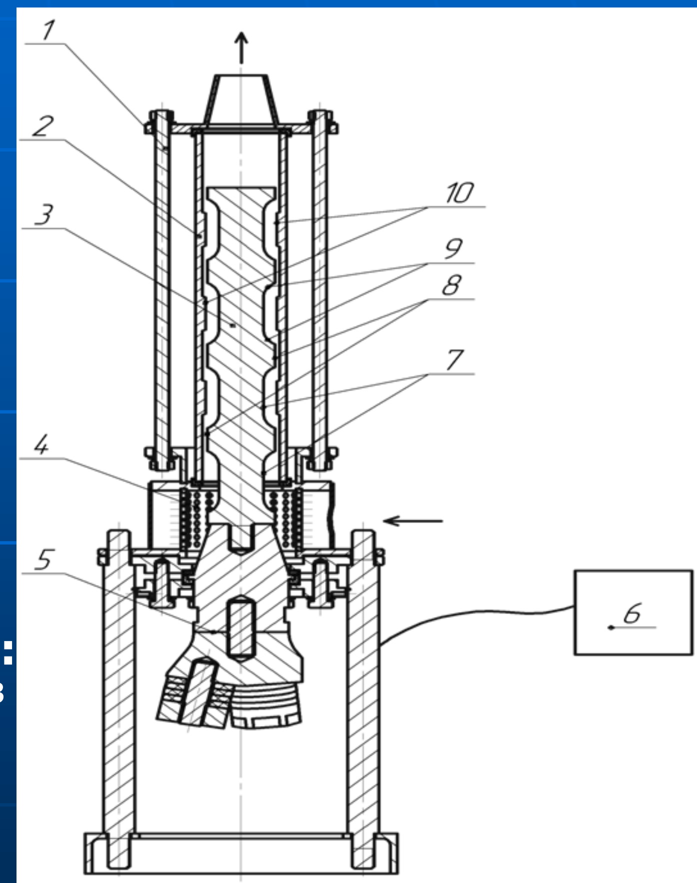
Transducer power, W	d_3/d_4, mm	$S_{изл}$, cm^2	$n\lambda/2$
3000	50/35	100	4
4000	50/35	150	6
7000	70/50	310	6
	70/45	350	7

Increase in efficiency due to resonant phenomena

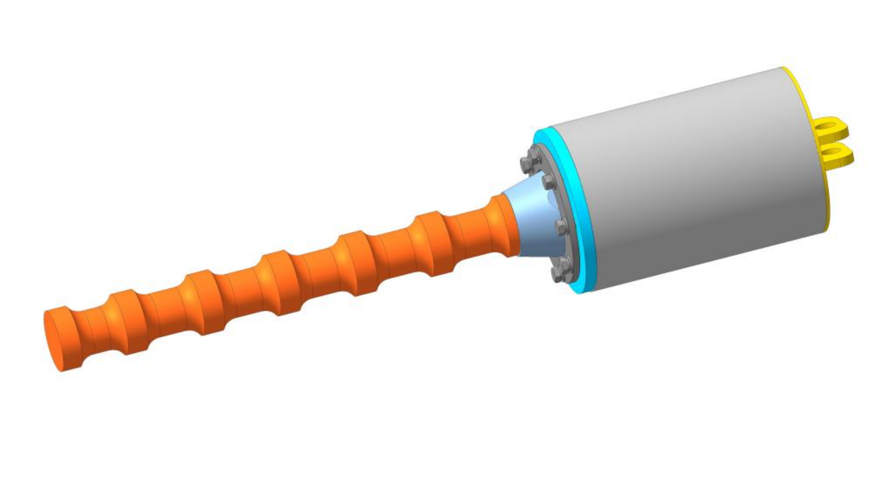


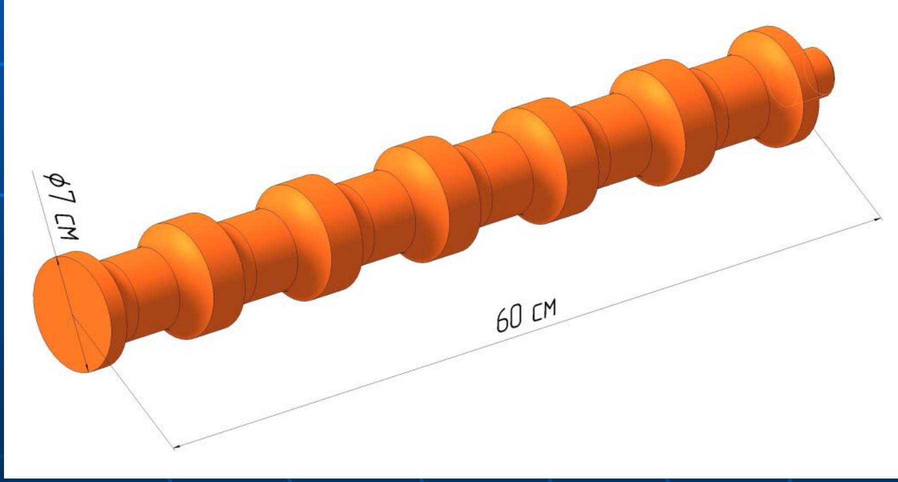


Expected result :
$V_{max} \geq 1000\ cm^3$



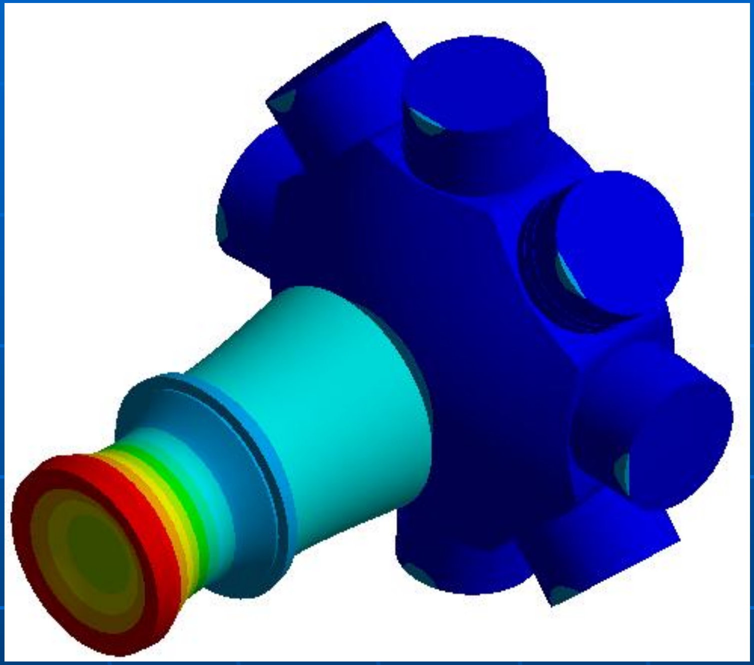
Using multi-zone radiators

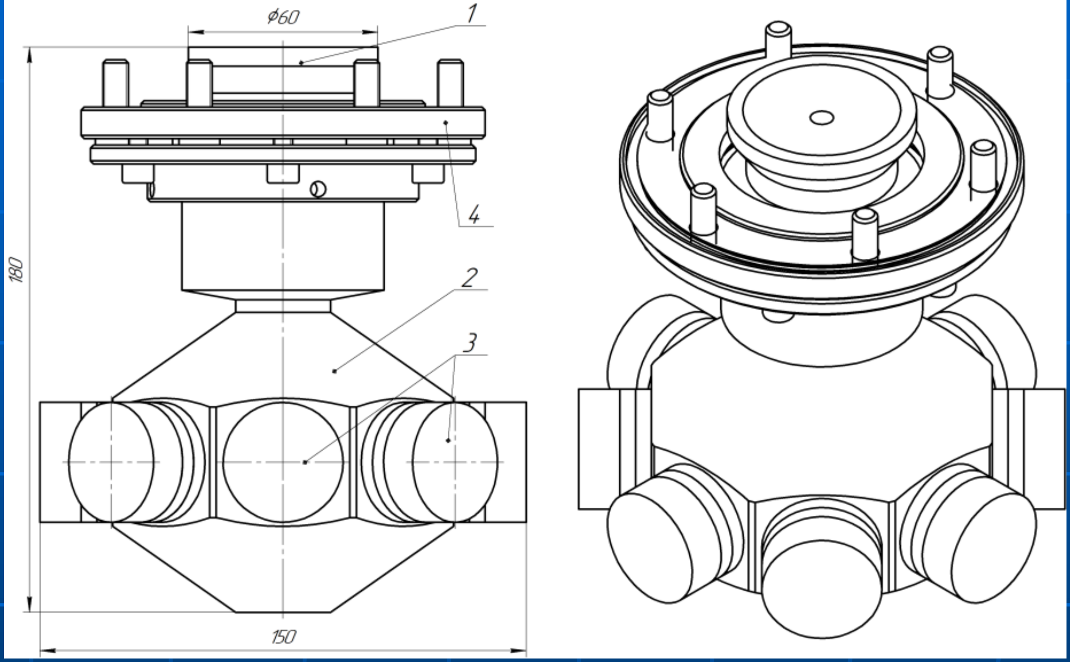




Problem: selection of optimal radiator shapes and flow volumes, processing modes and conditions.

High-frequency (30 kHz) vibratory system of increased power

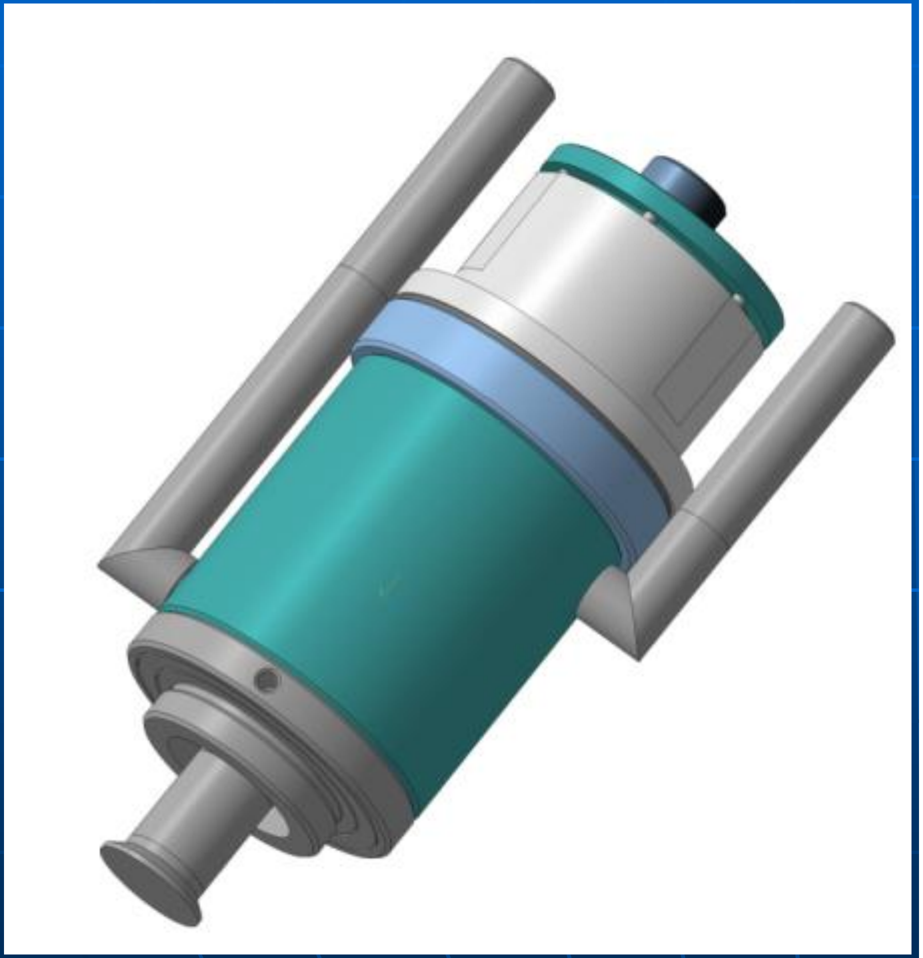


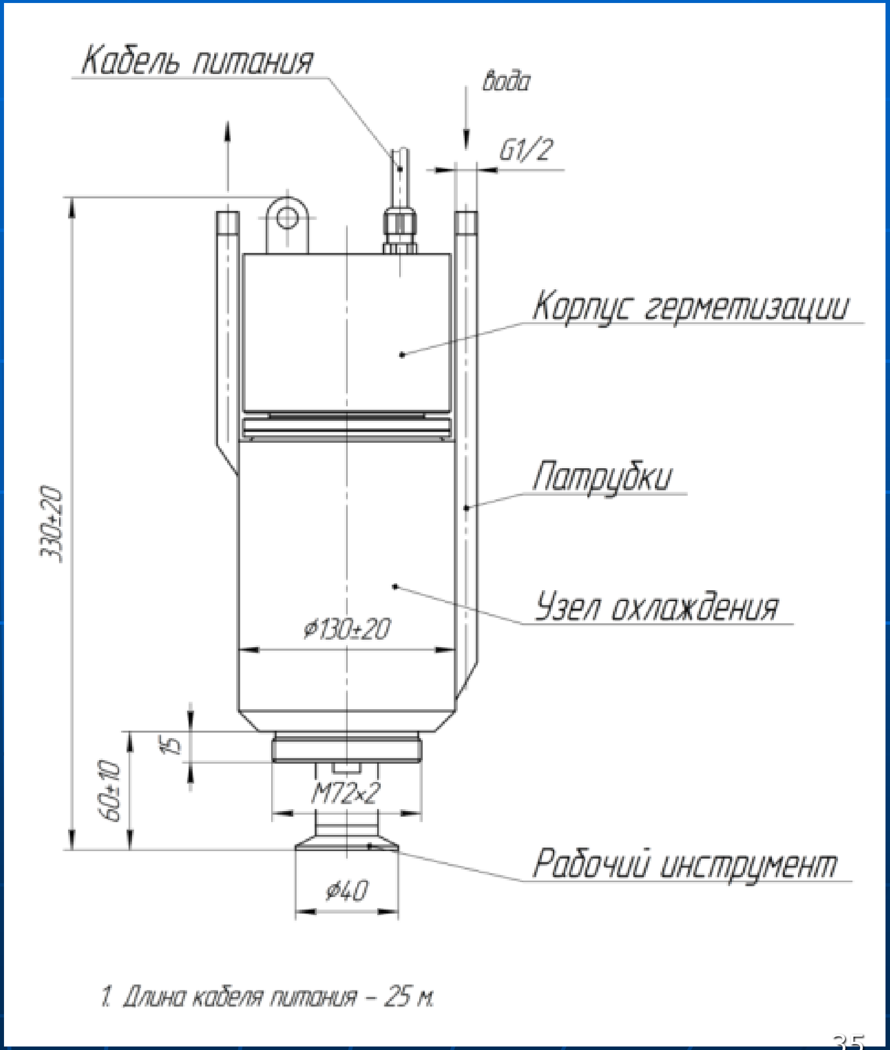


1- booster - working tool;
2-frequency-reducing common pad;
3 - stack of piezoelectric elements with reflectors

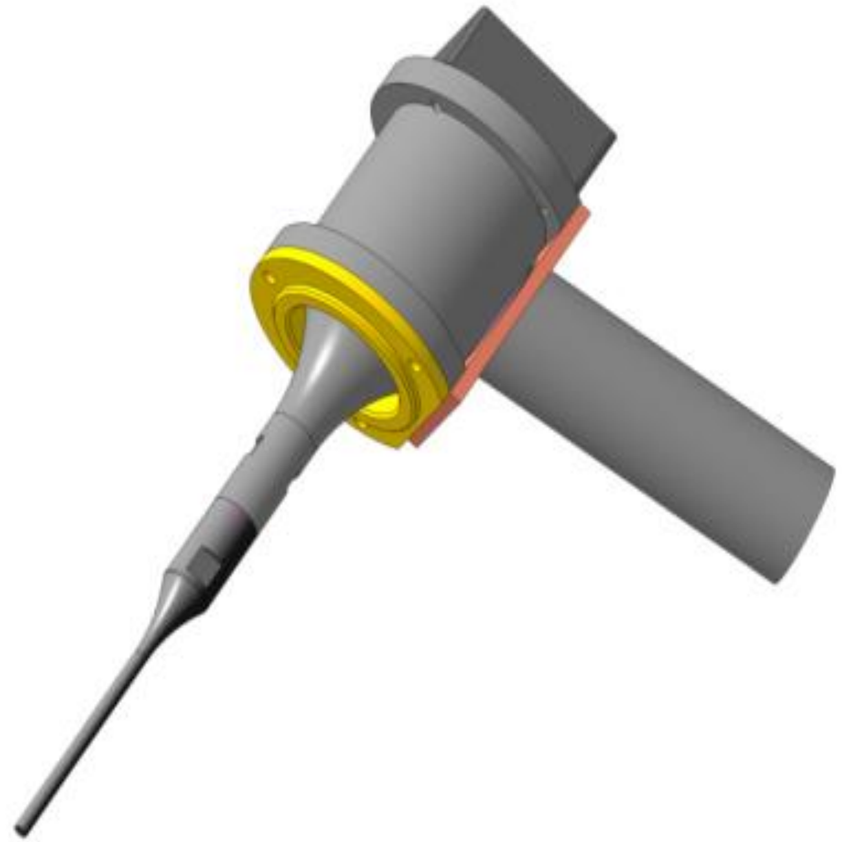
Realization of vibratory systems

Vibratory system in a hermetic case with liquid cooling





Vibratory system for clearing of diesel engine injector channels



Features:
- mounting on industrial clearing line;
- simultaneous clearing of 4 injectors.

Systems for surgery through punctures

TECHNICAL SPECIFICATIONS	
AC power supply voltage, V	220
Frequency of mechanical vibrations, kHz	27±3,3
Maximum power consumption, VA, max	100
The number of levels of setting the amplitude from the rated power	5
Overall dimensions of the electronic unit, mm	300x269 x130
Weight of the vibratory system, kg	0,5
The amplitude of vibrations on the end surface of the working tool at maximum power, um, not less than	150
Number of replaceable working tools, pcs	8
Weight of the electronic unit, kg, not more than	3
Continuous operation time, min, max	10

Vibratory system for ultrasonic liposuction

Patent RU2141386, RU2239383.

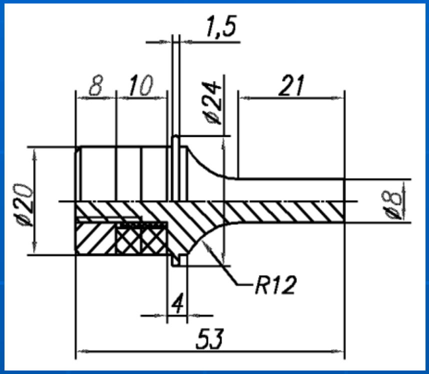
13 working tools instead of 4 in an American-made device

Radiation efficiency increased by 10 times

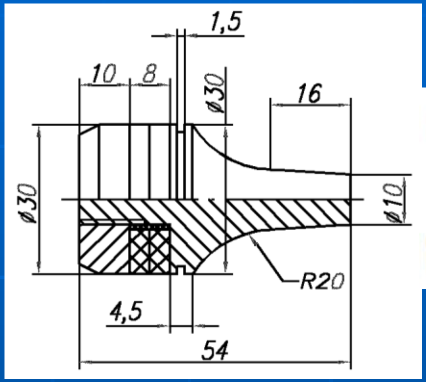
Ultrasonic welding systems

(sealing of blood containers)

Half-wave vibratory system for sealing of blood containers



a) - a sketch of a manual vibratory system;



a) b) - a sketch of a stationary vibratory system;

c) – Appearance of vibratory system

Blood containers for storing blood components

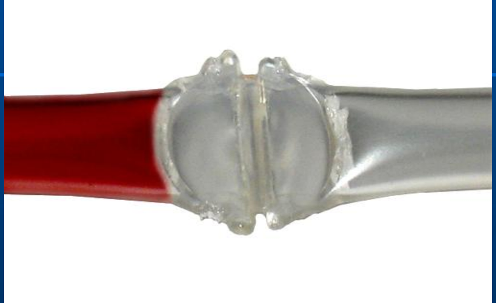
Ultrasonic welding machines for sealing blood containers

a) Manual type;

b) Stationary type;

c) Combined type

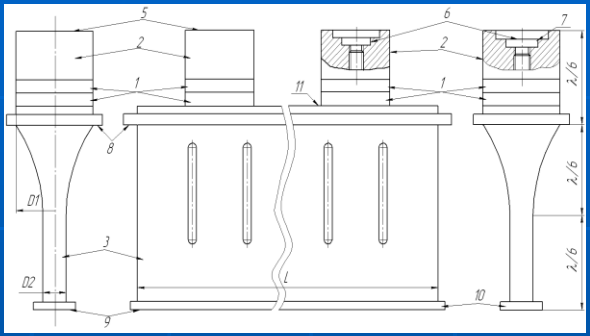
Welded connection of blood containers



Patent RU2267316 "Device for ultrasonic sealing and segmentation of transfusion systems»

Ultrasonic and systems for press seam-step welding

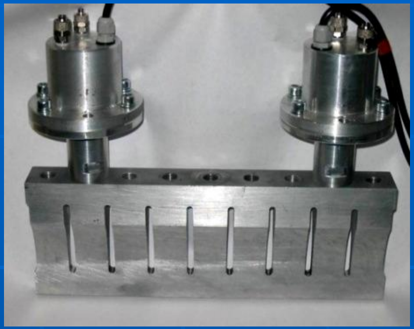
Half-wave and two-half-wave systems for performing extended seams with a length of 150, 220, 360 mm



a) - sketch of the half-wave vibratory system;

b) two-half-wave vibratory system for seams of 150 mm;

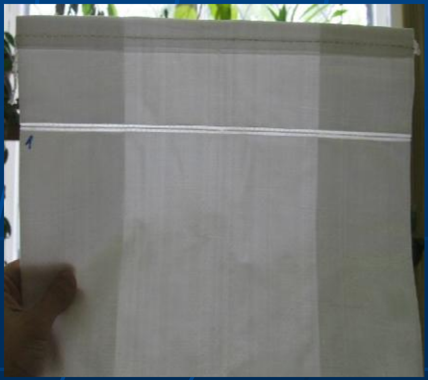
в) - two-half-wave vibratory system for seams of 220 mm;



г) - two-half-wave vibratory system for seams of 360 mm;

Ultrasonic welding machines for extended seams

Products with extended seams of 220 and 360 mm



Ultrasonic welders of various power

630 W

800 W

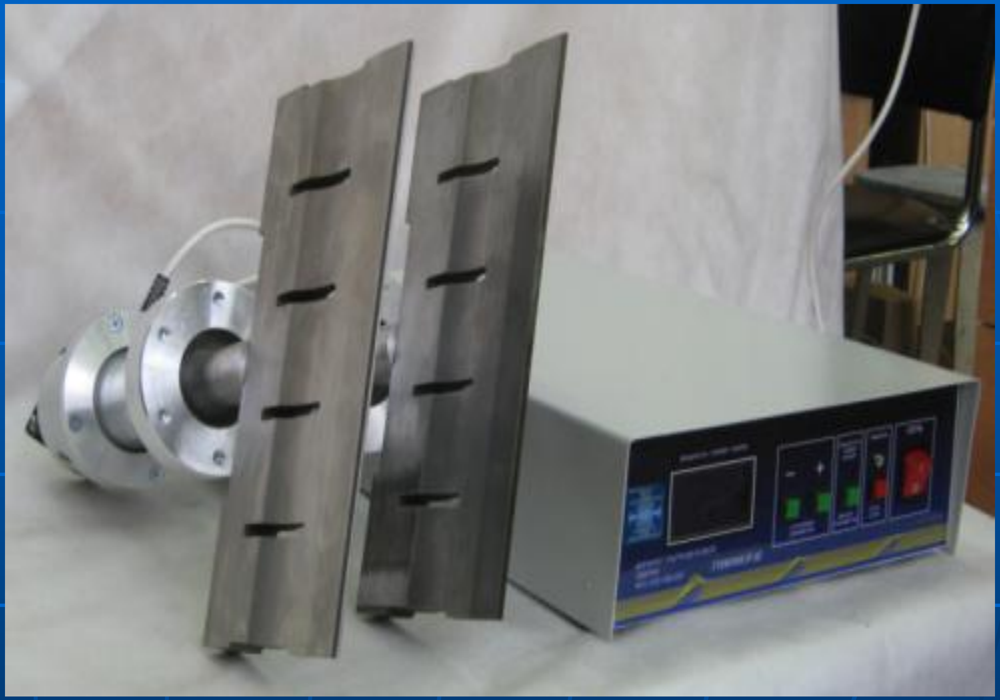
1000 W

3000 W

Length of surface width

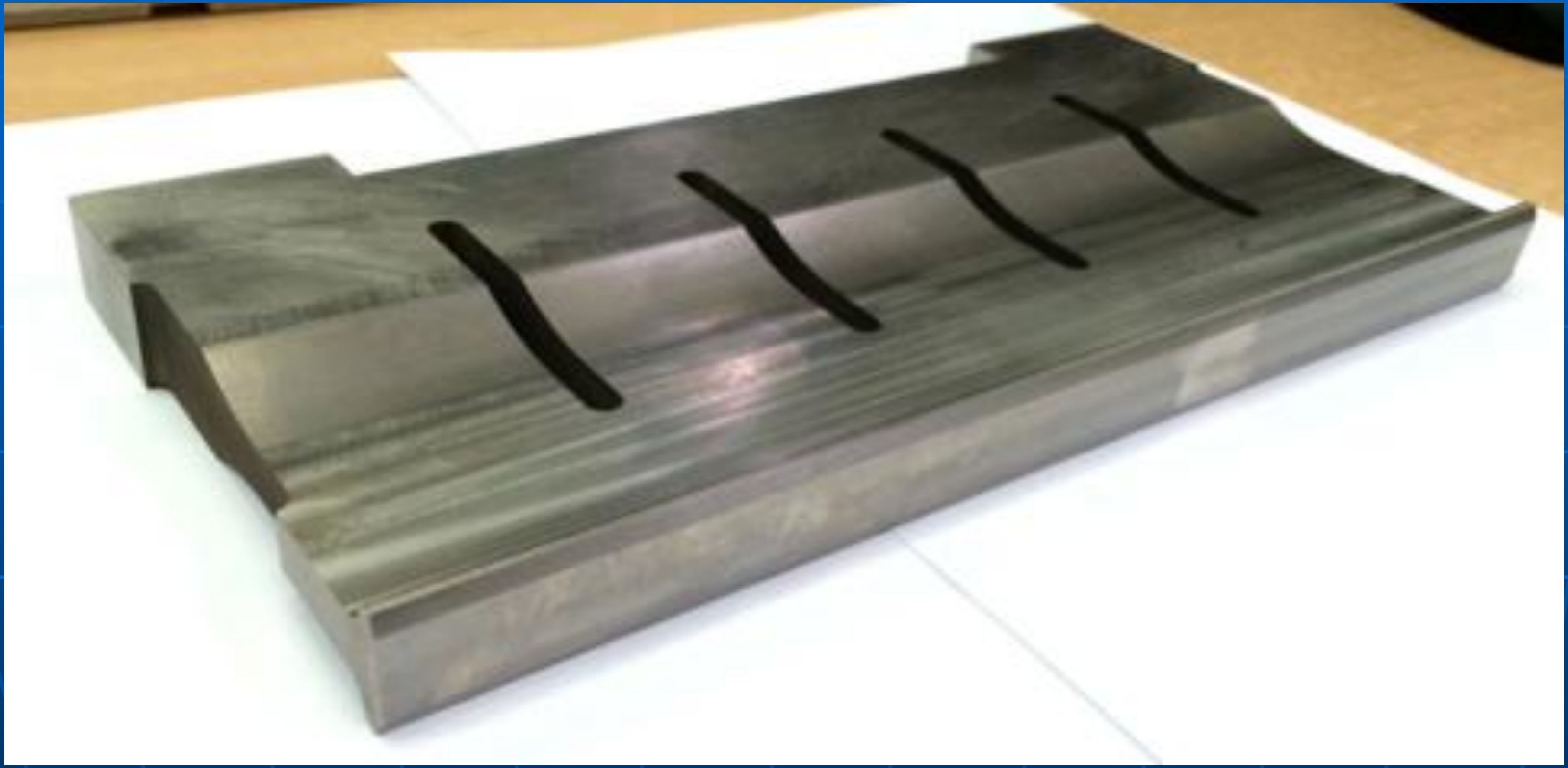
630 W	800 W	1000 W	3000 W
50-100 mm	100-180 mm	180-220 mm	220-350 mm

Ultrasonic welding and cutting systems



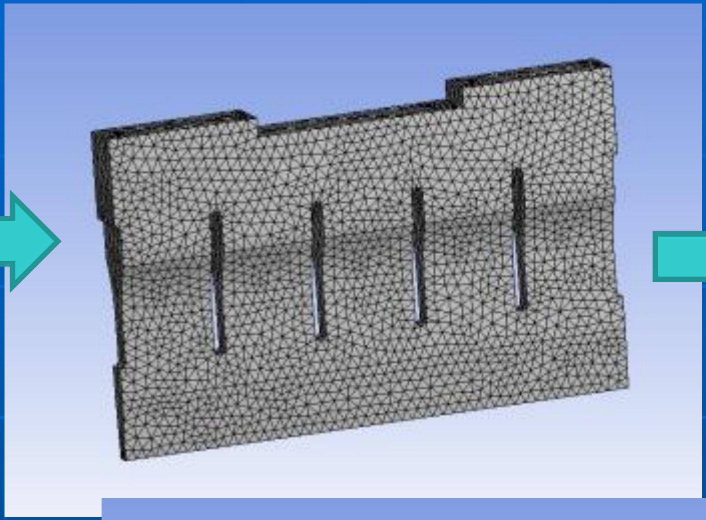
Width of the radiating surface – **270…360 mm**

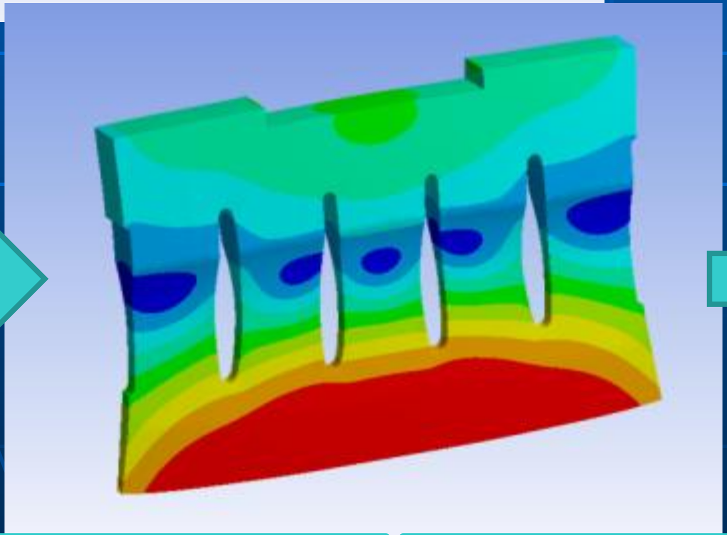
Impregnation



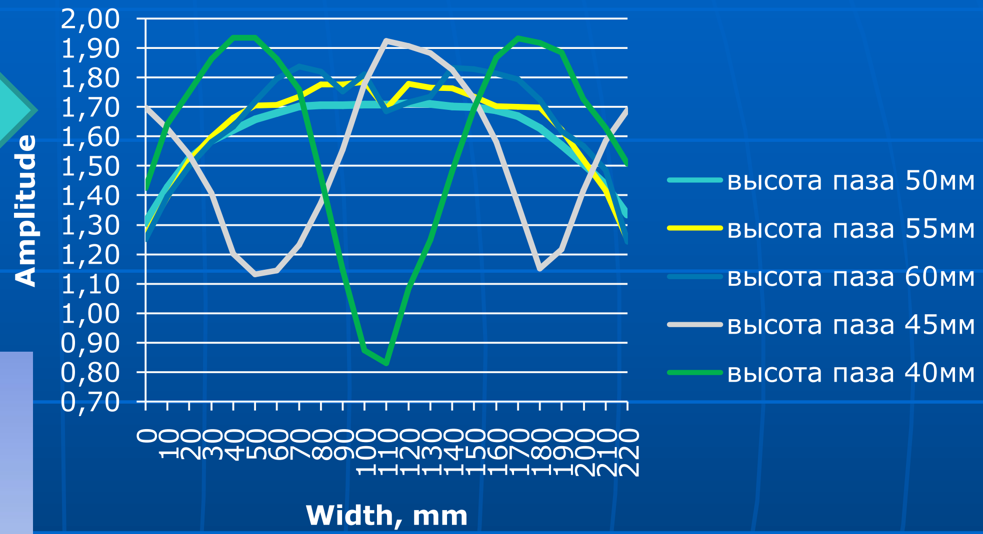
The area of the radiating surface is (35X2) cm2.

Designing of welding tools with large width





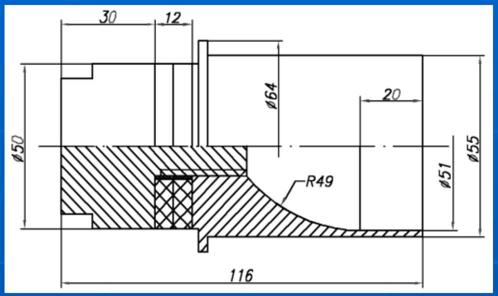
Vibration amplitude distribution at changing of groove height



1) Identification of the most optimal ratios between influencing factors
2) Development of calculation methods for tools with a width of 150, 220, 320 mm

Ultrasonic Girth Welders

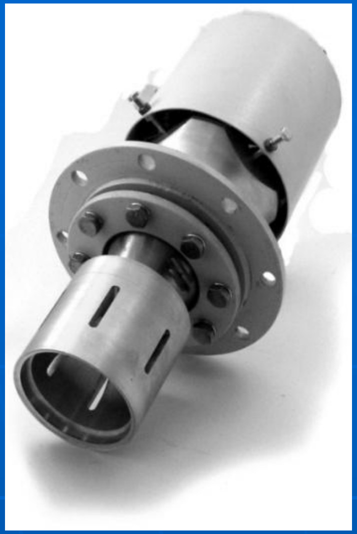
Half-wave, two-half-wave, and three-half-wave vibrating systems for seam with diameter up to 100 mm



a) Draft of half-wave vibratory system

b) half-wave vibratory system for seam with diameter 50 mm

c) two-half-wave vibratory system for seam with diameter 60 mm



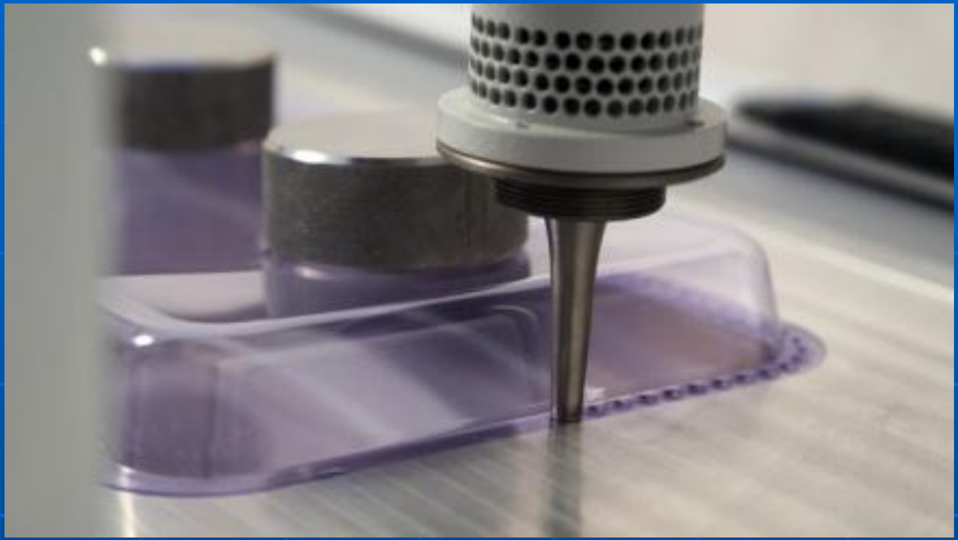
d) three-half-wave vibratory system for seam with diameter 100 mm

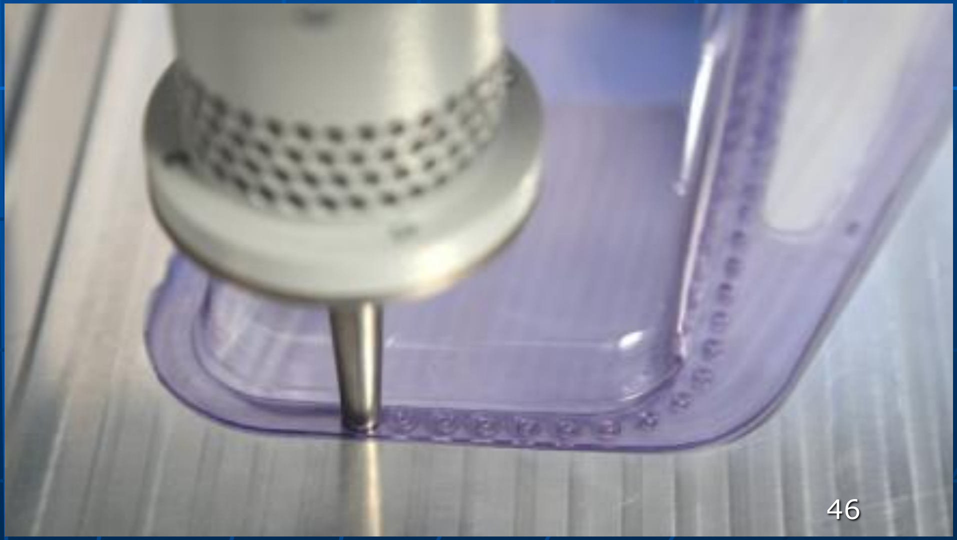
Ultrasonic girth welders

Products with girth seams

Protected by the patent RU2241599 “Method of sealing water purification cartridges”

System for automated welding of products on a complex contour

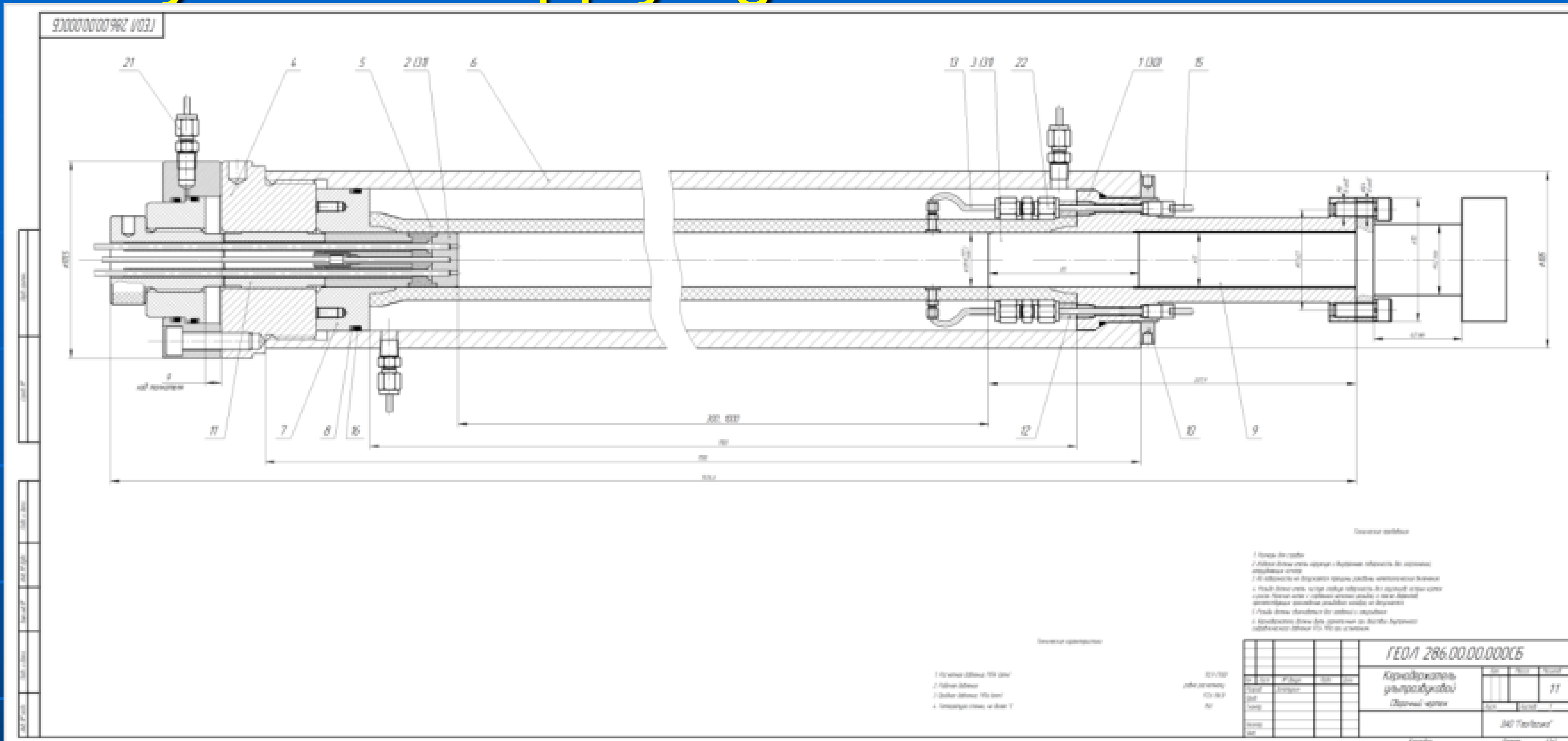


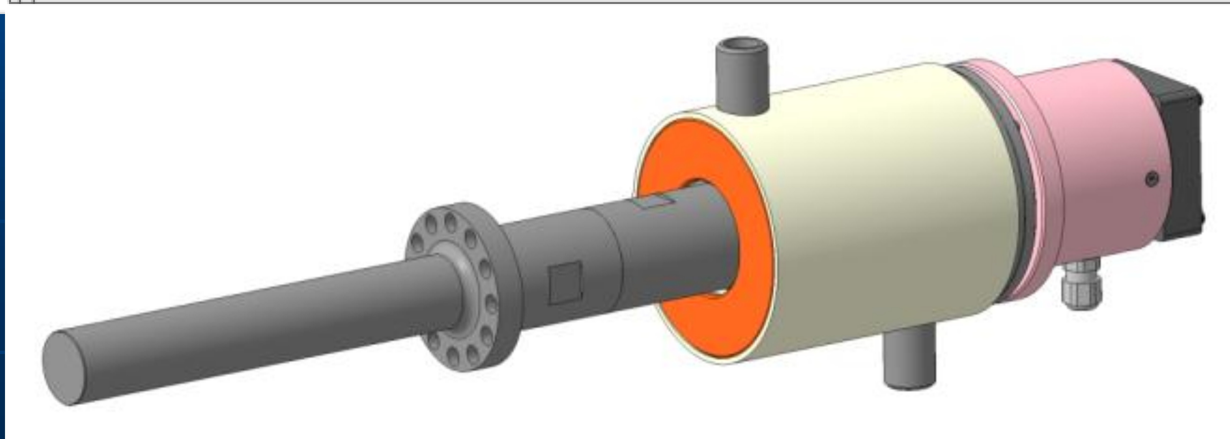


Systems for ultrasonic welding of automobile clips

Features:
1. A complex-shaped working tools;
2. matching 2 types of tools
per converter.

System for applying vibrations to the core

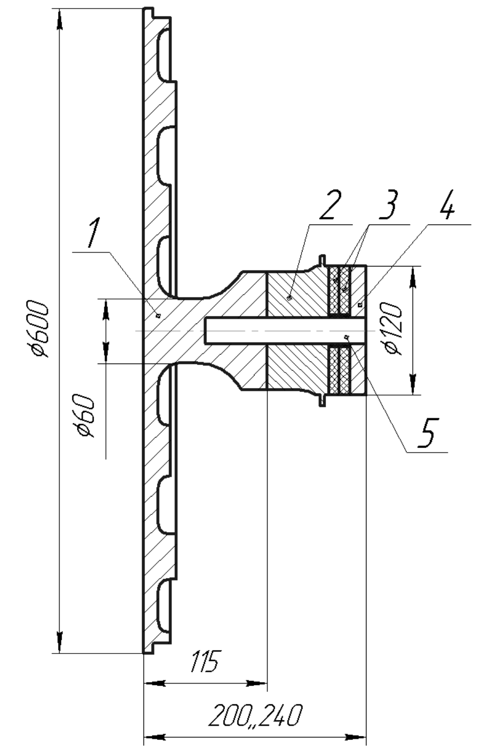




Features:
Liquid cooling;
Operation at high pressure on the radiating surface

Increasing the diameter of the radiating surface

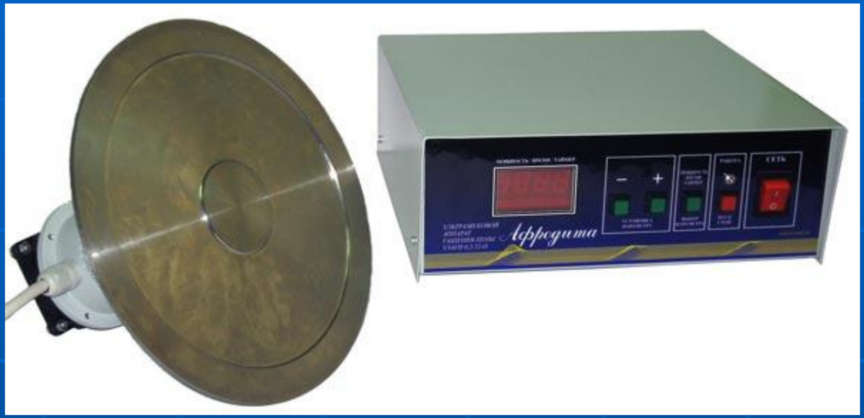
- D=200 mm → P_{ac}=150 W
- D=300 mm → P_{ac}=250 W
- D=400 mm → P_{ac}=400 W
- D=500 mm → P_{ac}=600 W
- D=600 mm → P_{ac}=1000 W



1- disk radiator with a transducer, 2-front frequency reducing pad, 3-piezoelectric elements, 4-rear frequency-reducing pad, 5 - stud

The figure shows the maximum possible dimensions

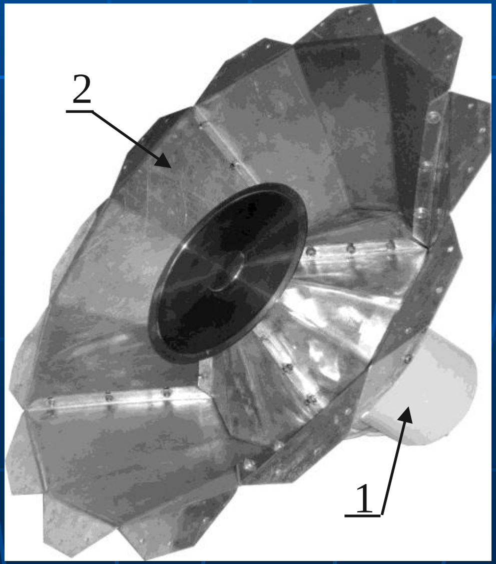
Ultrasonic system for gases



The radiator and electronic generator

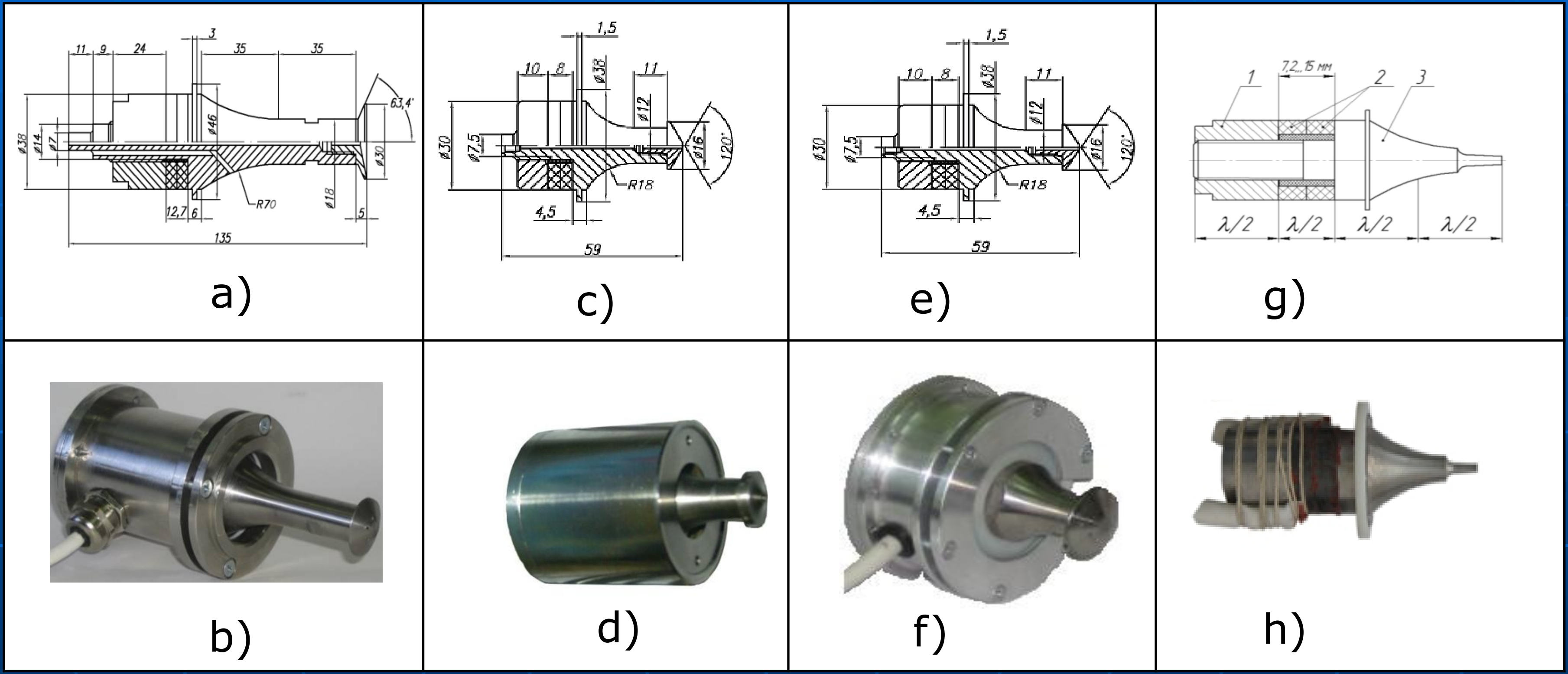
Radiator with phase-leveling elements

Multi-element vibratory system with a focusing radiator



Radiator assembly with reflector
1-ultrasonic vibration system;
2-reflector

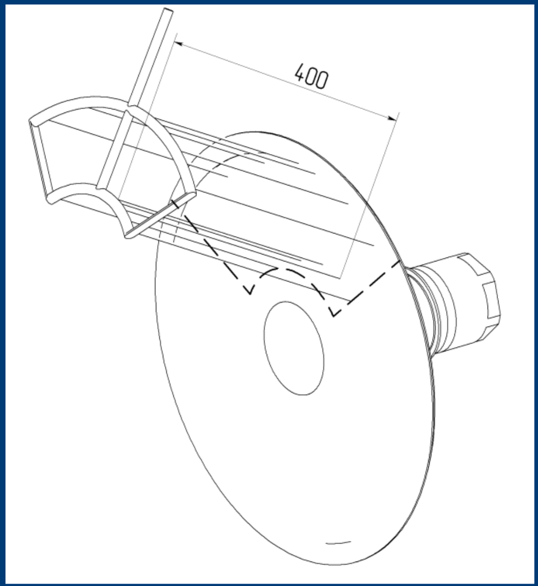
VIBRATING SYSTEMS FOR SPRAYING



a, b – the resonance frequency is 22 kHz;
c, d – the resonance frequency is 44 kHz;

e, f – the resonance frequency is 60 kHz
g, h – the resonance frequency is 130 kHz

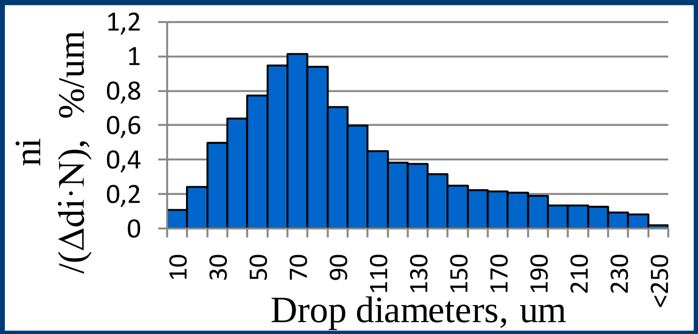
Ultrasonic nebulizing of liquids



Fluid flow diagram

Nebulizing process

Portable version



Distribution histogram of drop diameters

Technical characteristics:

Average diameter of drops (d_{32}), um	100 (197)
Standard deviation, um	68
Performance (disk radiator D=400 мм), l/h	1100
Power consumption, kW/h	0,35

Comparison of the energy efficiency of nebulizing methods

Ultrasonic **from 0,35 kW/t** < Hydraulic 2 – 4 kW/t < Mechanical 15–23 kW/t < Pneumatic 50–60 kW/t

Monograph about ultrasonic vibration systems