FEATURES OF ULTRASONIC EXPOSURE
IN EXTREME CONDITIONS
(Experimental studies)

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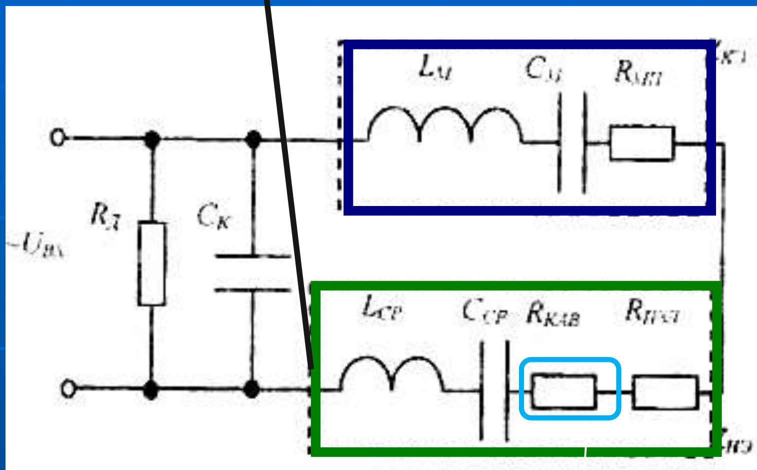
Equivalent electrical circuit of an ultrasonic vibratory system

Mechanical impedance *Z*



Current of mechanical branch

Active resistance due to the load from the medium R (consumes active power P)

GENERAL PROBLEMS OF ULTRASONIC EXPOSURE IN EXTREME CONDITIONS.

The limited temperature range of the piezoelectric element, at which it retains piezoelectric properties.

The capacity of the piezoelectric element C_K changes -> the resonant frequency of the vibratory system changes with a change in temperature.

The mechanical properties of the radiator material change (the tensile and compressive strength decreases, the maximum number of loading cycles decreases, initial stresses arise).

ULTRASONIC EXPOSURE ON SOLID MEDIA IN EXTREME CONDITIONS

Implementation of ultrasonic treatment at extremely low temperatures and extremely high temperatures when solids melt or pass into steam.

Studies ultrasonic exposure at low temperatures

Stand for experimental studies at low temperature provided by liquid nitrogen

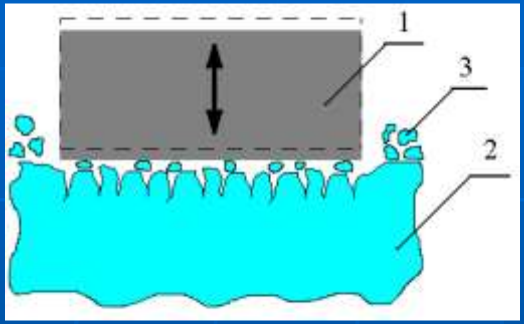
Experimental studies

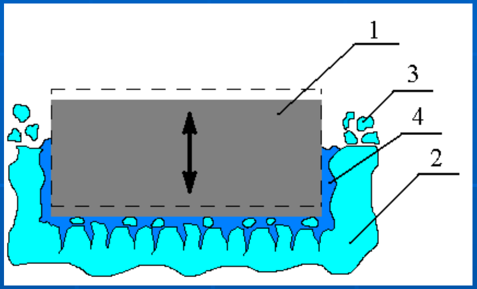
Frozen sand-water and sand-oil mixture

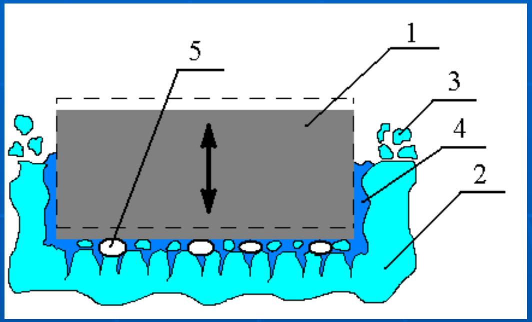
The amplitude of vibrations at the end of the working tool is 30 um;
Power consumption during drilling – up to 75 W;
The diameter of the created channel is 25 mm.

The ultimate case of ultrasonic exposure to solid media under extreme conditions

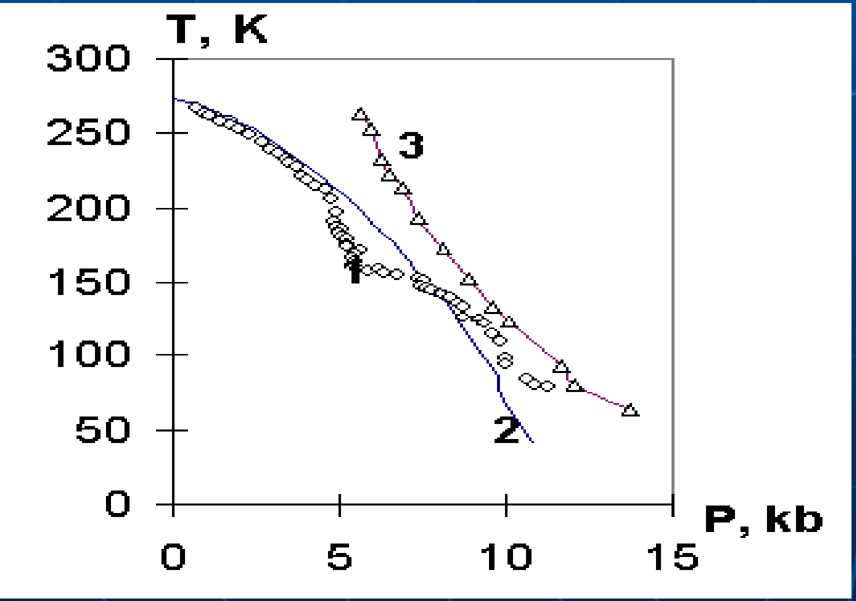
Ice drilling







1 – ultrasonic working tool; 2 – ice; 3 – ice fragments; 4 – water; 5 – cavitation bubbles

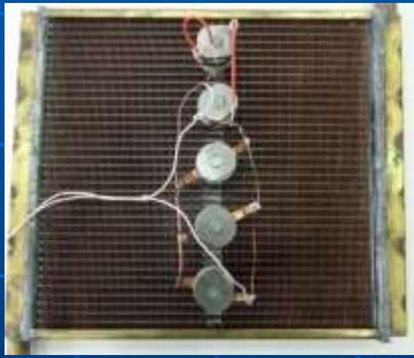


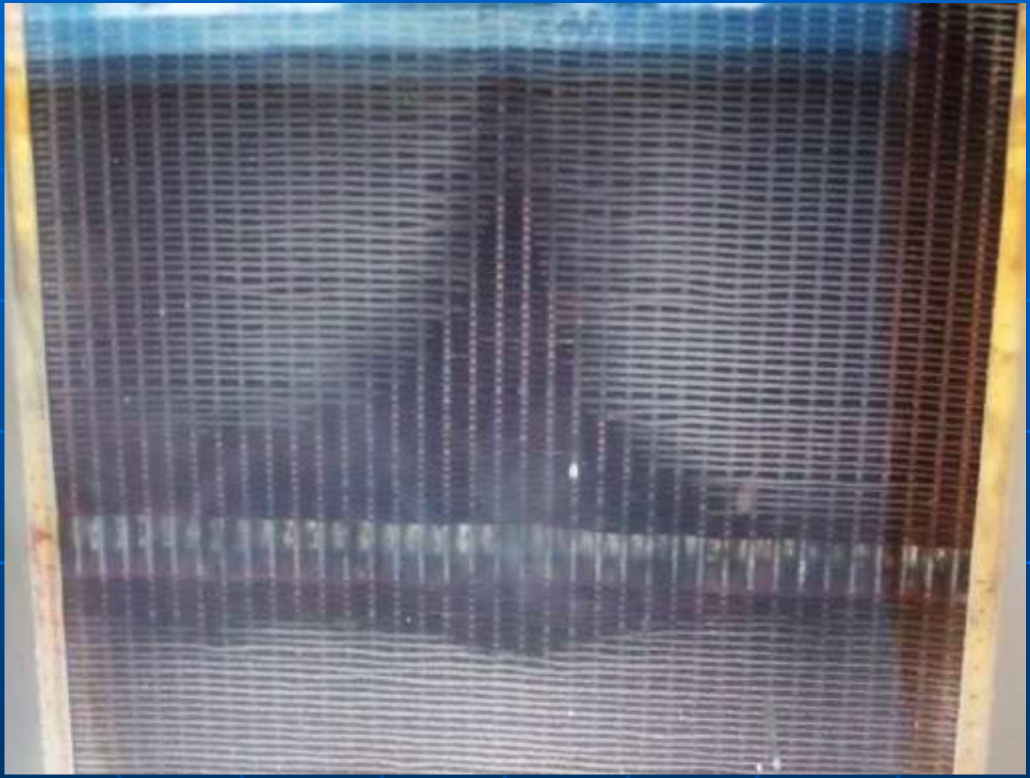
Dependence of ice melting temperature on external pressure according to various experimental and theoretical data

The main processes of ultrasonic exposure to solid media in extreme conditions

Removal of ice from the surface of technological installations

The appearance of the technological installation (on the example of a radiator) with fixed ultrasonic radiators

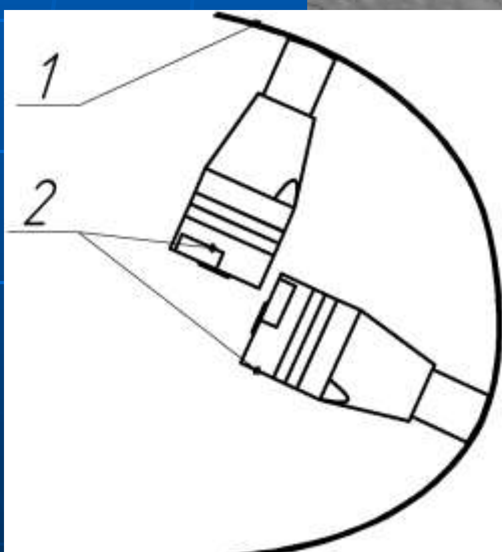




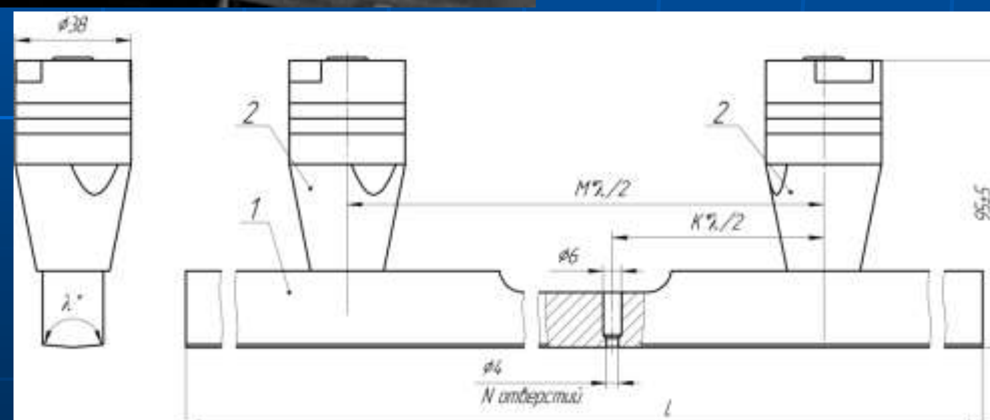
The result of ultrasonic exposure to an icy surface for 15 minutes

Ultrasonic anti-icing system of aircraft

Ice crust destroyed by ultrasonic vibrations



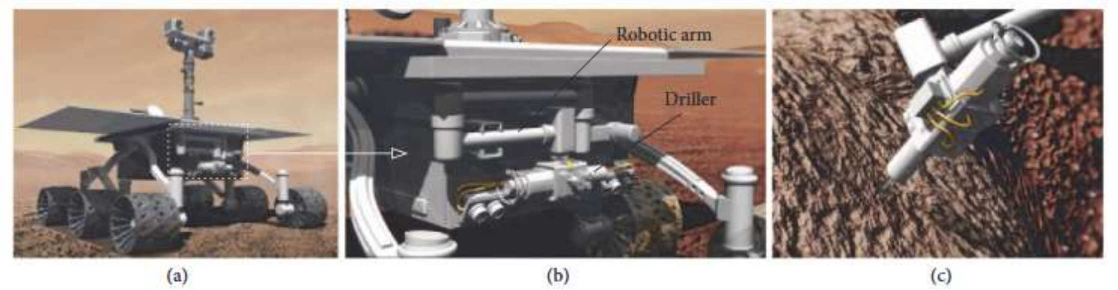
Attachment points of the vibratory system to the wing:
1 – wing;
2 – ultrasonic vibratory system



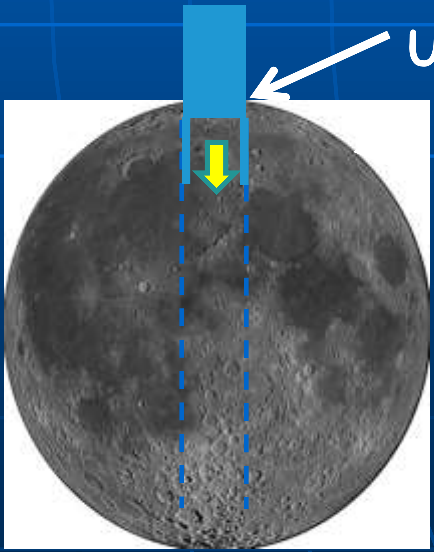
Ultrasonic vibratory system design:
1 – ultrasonic vibration distributor;
2 – piezoelectric transducer

Processes of ultrasonic exposure on solid media under extreme conditions

Drilling of space objects



(a) (b) (c)

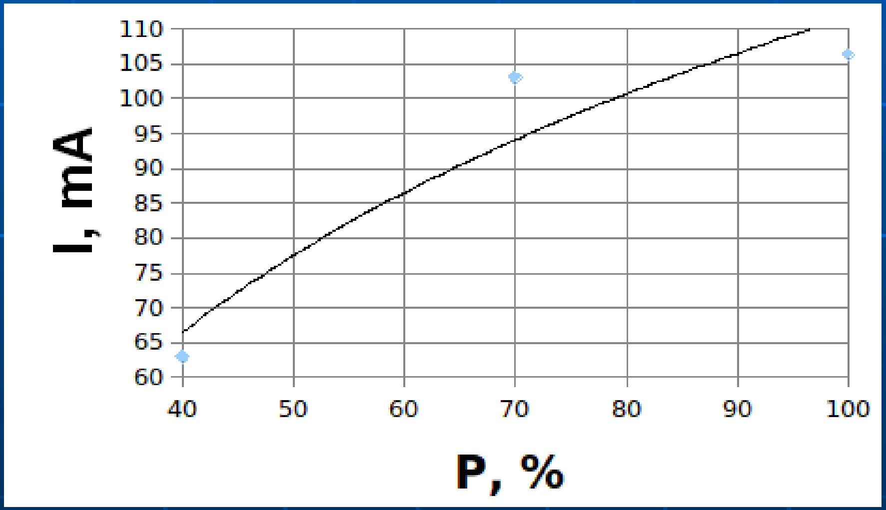


Materials used in conducting ultrasonic drilling experiments

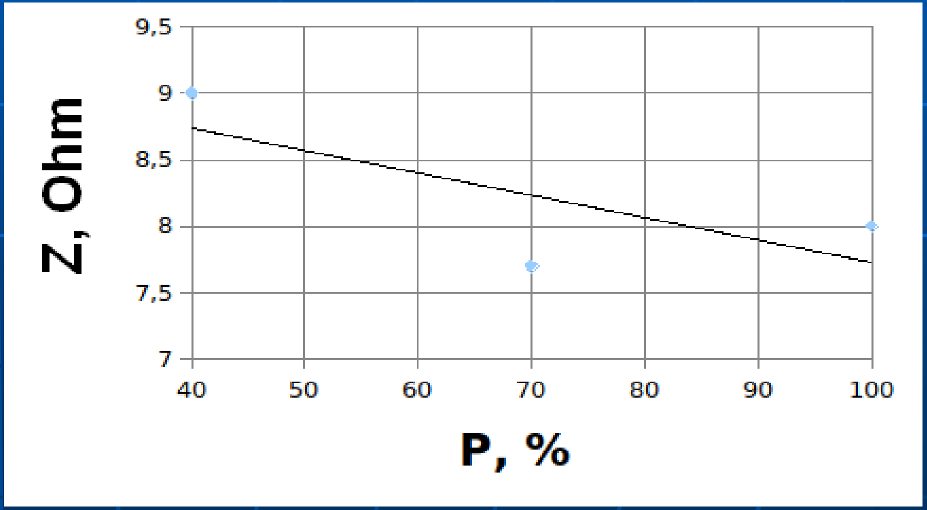
- Loose sand
- Silicate Brick
- Frozen sand – simulator of lunar soil (particle size – no more than 1 mm, moisture content by weight – 4%)

The dependence of the electrical parameters of the ultrasonic vibratory system on the power

Material is frozen sand (lunar soil imitator),
clamping force is 7.5 N, frequency is 22 kHz,
temperature is -70ºC.
Here and further, the power is indicated in % of the maximum.
The maximum power is 50 W.



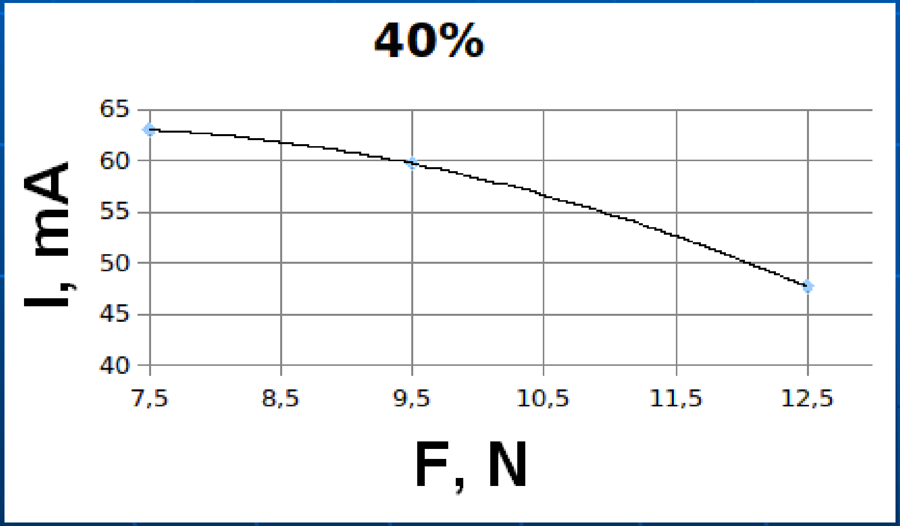
a) current of mechanical branch



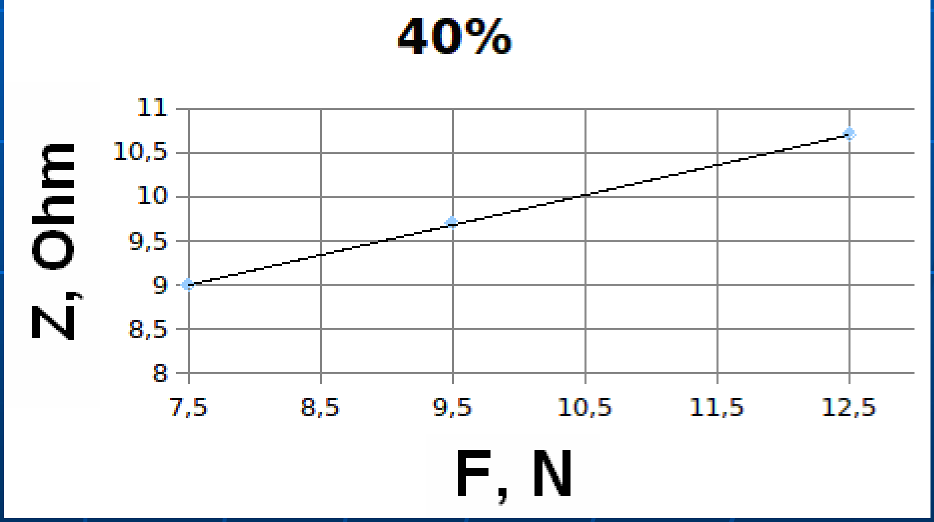
b) impedance of mechanical branch

The dependence of the electrical parameters of the ultrasonic vibratory system on clamping force.

Material is frozen sand (lunar soil imitator), frequency is 22 kHz, temperature is -70ºC, power is 20 W.



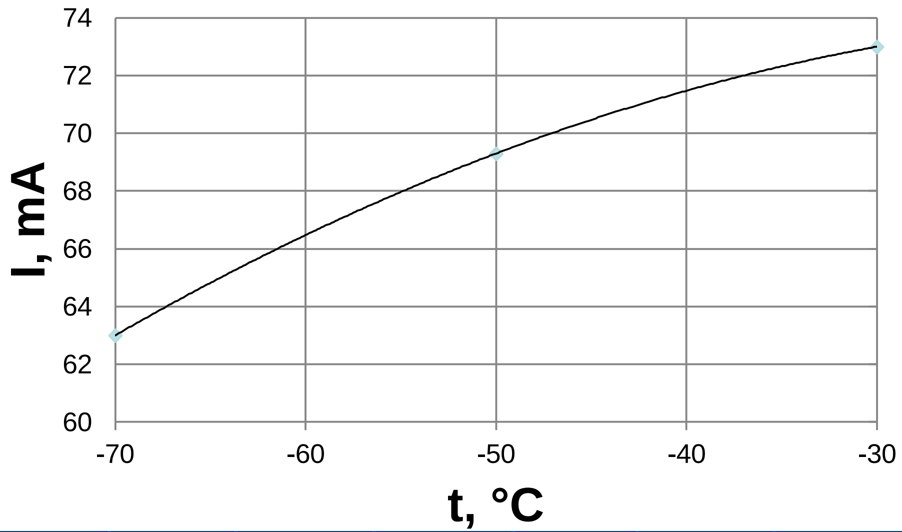
a) current of mechanical branch



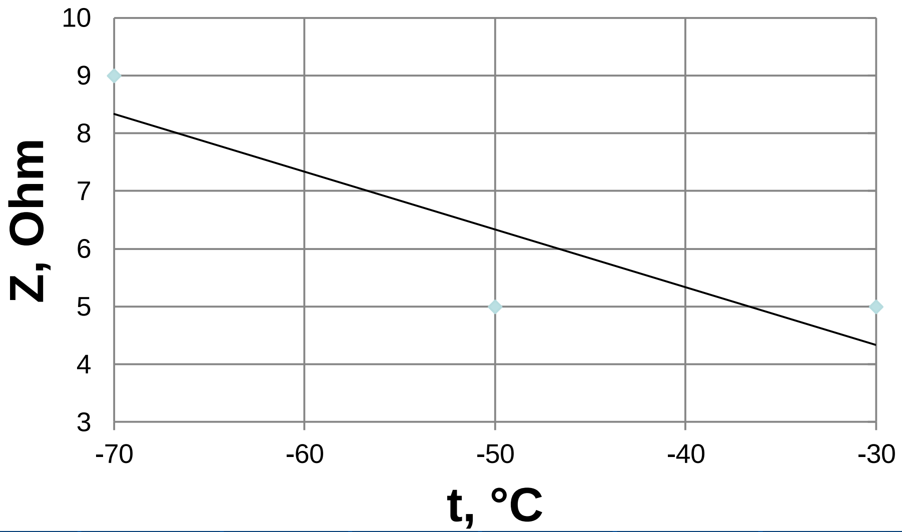
b) impedance of mechanical branch

The dependence of the electrical parameters of the ultrasonic vibratory system on temperature.

Material is frozen sand (lunar soil imitator),
clamping force is 7.5 N, frequency is 22 kHz,
temperature is -70ºC, power is 50 W.



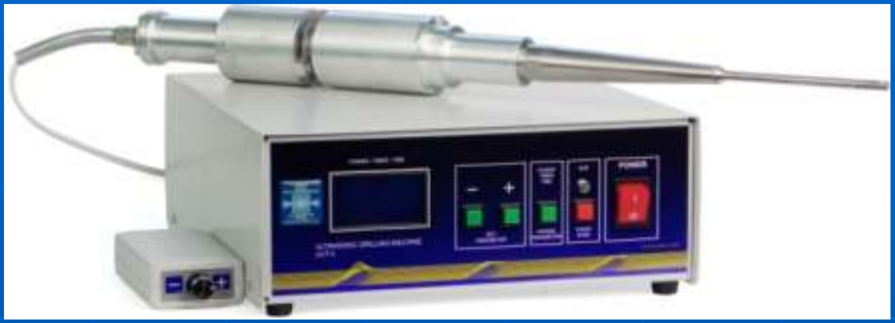
а) current of mechanical branch



б) impedance of mechanical branch

The exposure key feature: the temperature leads to a decrease of a mechanical branch current and an increase of a medium acoustic impedance. Consequently, the energy introduced into the processing material decreases. It is necessary to carry out additional shock-contact exposure by free mass.

Ultrasonic drilling at additional exposures



Ultrasonic generator with horn

Setup for ultrasonic drilling at room temperatures

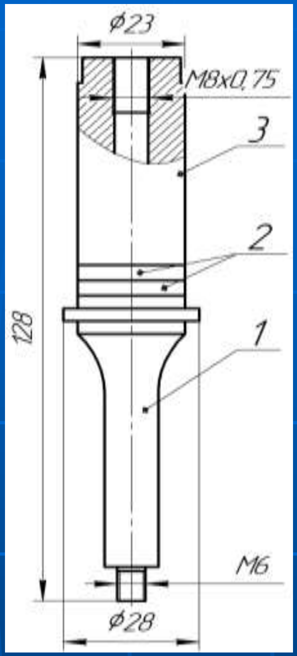
Static pressure, N	Drilling speed, mm/min				
	DR	UV	UV + DR	UV + LV	UV + LV + DR
Silicate brick					
20	4	27	30	30	42
10	2	16	17	18	24
5	2	14	16	16	24
Red brick					
20	3	9	11	10	13
10	1	14	14	15	17
5	1	13	13	14	18
Foam concrete					
20	11	122	134	136	154
10	10	91	102	100	136
5	5	55	59	60	102

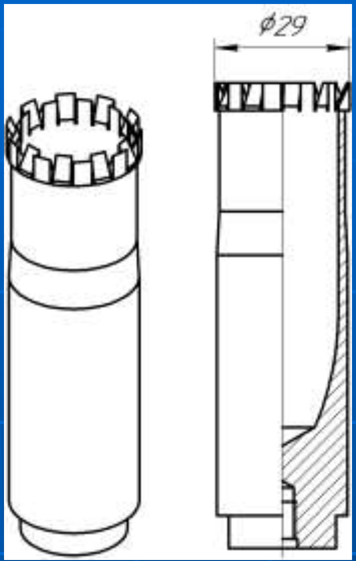
UV – ultrasonic vibrations

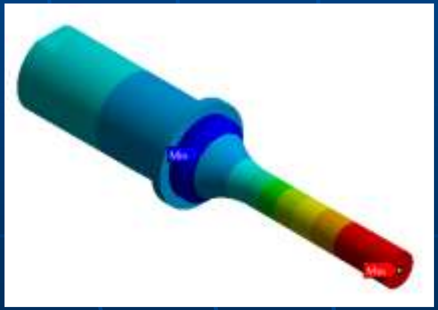
LV – low frequency shock vibrations due to additional mass

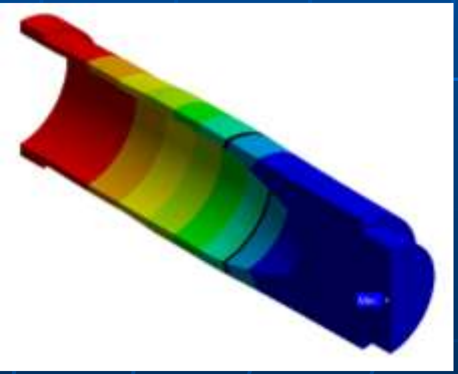
DR – pseudo-rotation

Ultrasonic vibratory system for drilling of ground (parts)

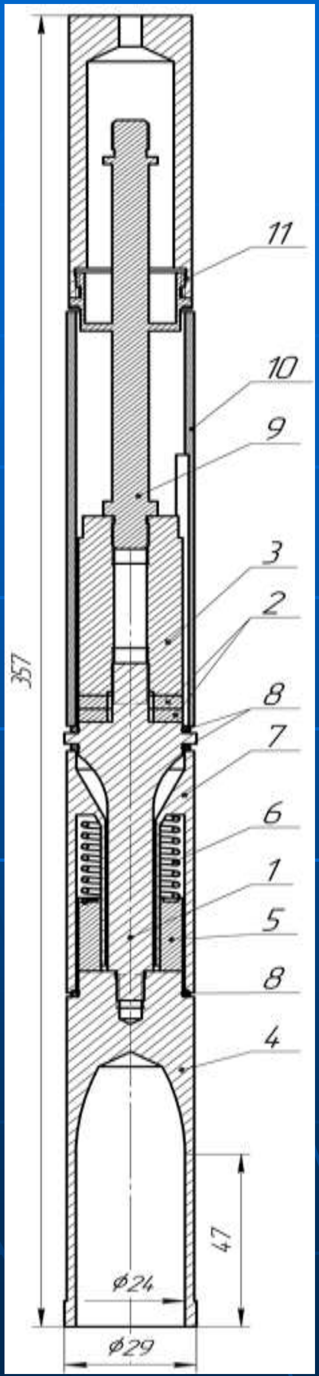








1 – booster; 2 – piezoelectric rings; 3 – reflect pad.



Ultrasonic vibratory system for drilling of ground (scheme)

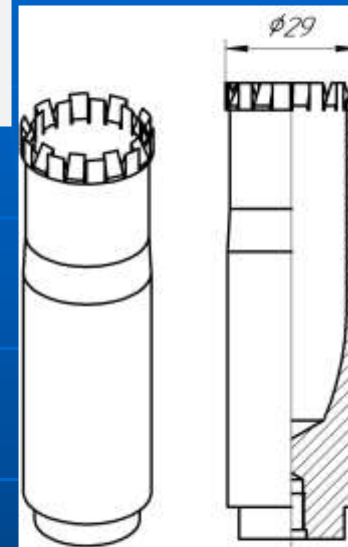
1-3 – piezoelectric transducer;
4 – working tool;
5 – free mass;
6 – spring;
7 – case;
8 – ring rubber seals;
9 – half-wave resonant sonotrode;
10 – transducer case;
11 – bracket.

Characteristic	Value
Resonance frequency, kHz	23,5
Maximum amplitude (range) of mechanical vibrations of the working tool, um	60
Weight, g	700
Overall sizes, mm	29x357
Power consumption at idle, W	12
Power consumption under maximum load, W	50

Statement of the task of studying the process of ultrasonic drilling for the detection of water and ice

Drilling velocity $\frac{dh}{dt}(A,\Lambda)\rightarrow ?$

Mass fraction of evaporated water $\Delta\chi(A,\Lambda)\rightarrow ?$



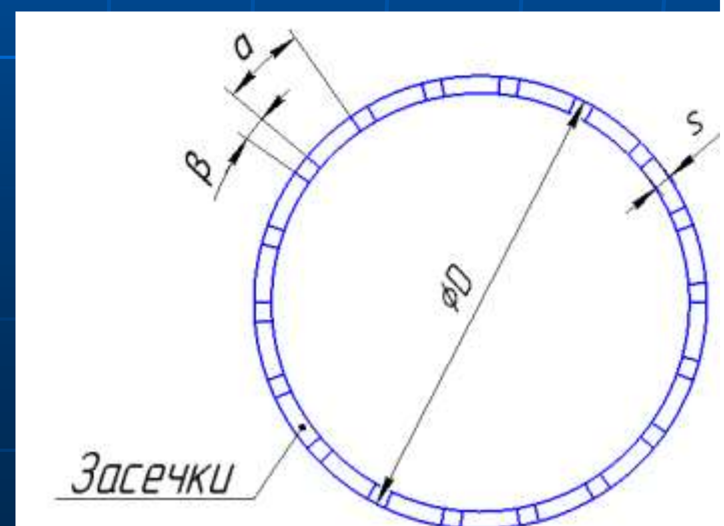
The criterion of optimality of the drilling process

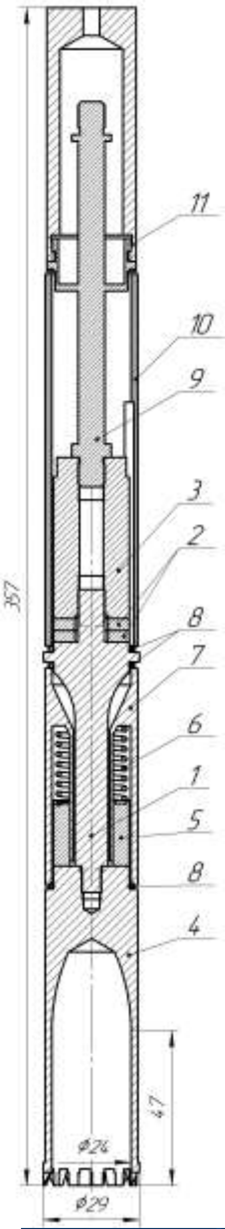
Minimum mass of evaporated water $\Delta\chi\rightarrow \min$

A – Vibration amplitude of working tool

Λ – Radiator characteristics

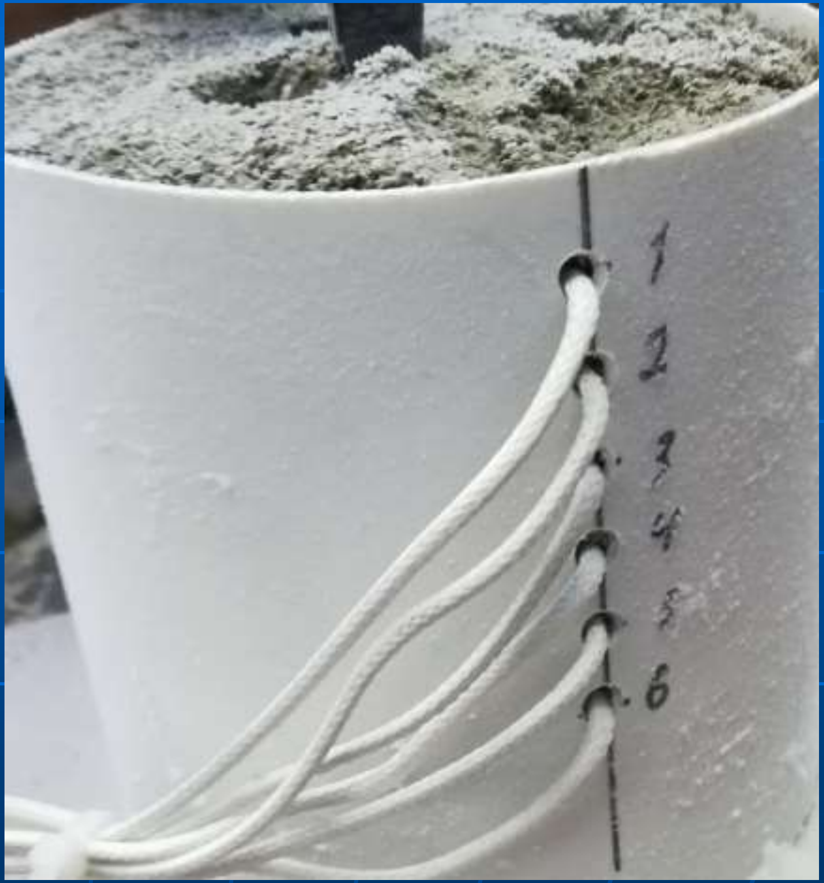
1. D – diameter;
2. S – thickness of serifs;
3. α/β – duty cycle;
4. n – number of serifs.





Ultrasonic drilling at low temperatures

Photos of the ultrasonic drilling process at different points in time at temperature -80°C



A sample of a frozen soil simulator with an embedded system of temperature sensors located at various depths

Ultrasonic drilling at low temperatures

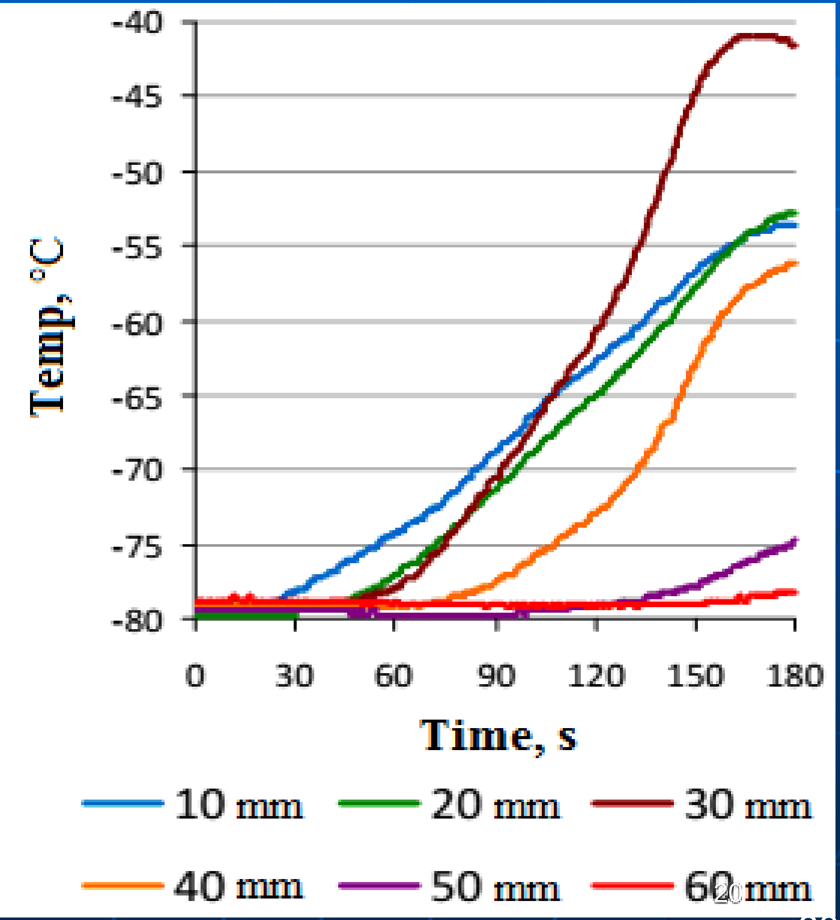
a) 0 min

b) 0.5 min

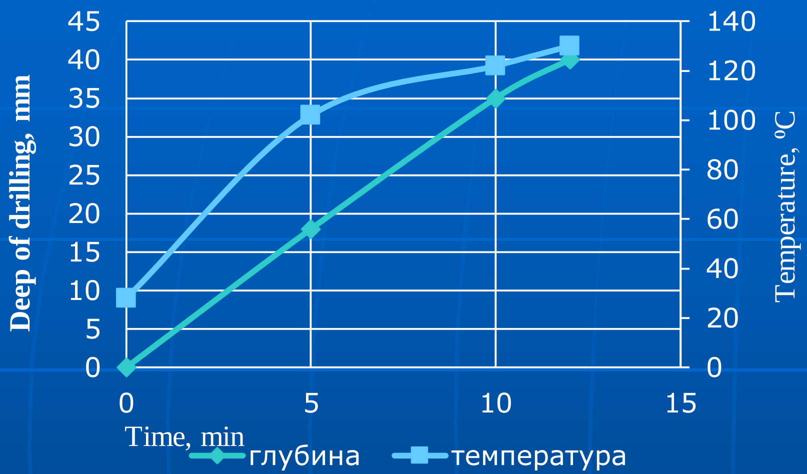
c) 1 min

d) 2 min

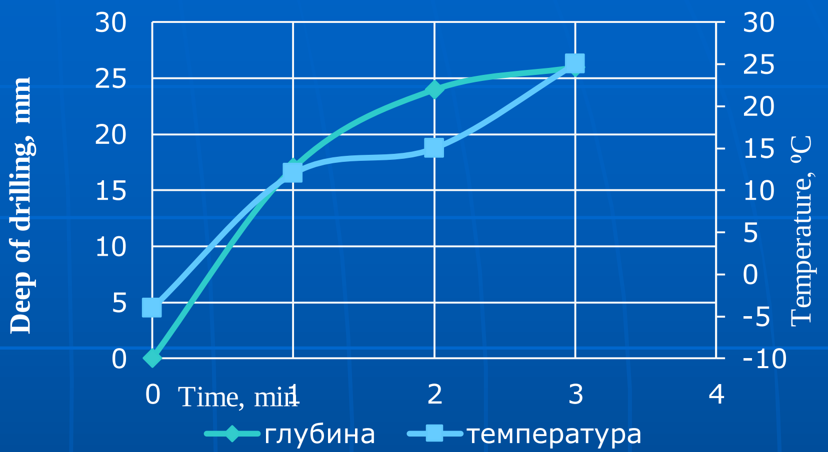
Dependences of the temperature of the soil simulator on the time of ultrasonic drilling at different depths



Velocity and temperature



Foam concrete



Frozen sand-water mixture

Material	Average power consumption, W	Drilling speed, mm/min	Average temperature increase per minute, ºC/min
Foam concrete	56	3	30
Frozen sand-water mixture	72	5	10
Sand-oil mixture	63	6	18

Influence of the substance on the electrical parameters of the ultrasonic vibratory system

a) current of mechanical branch

b) impedance of mechanical branch

Measuring the radiator impedance characteristics allows you to determine the ground type in real time

ULTRASONIC INFLUENCE ON GASEOUS MEDIA AT EXTREME TEMPERATURES

23

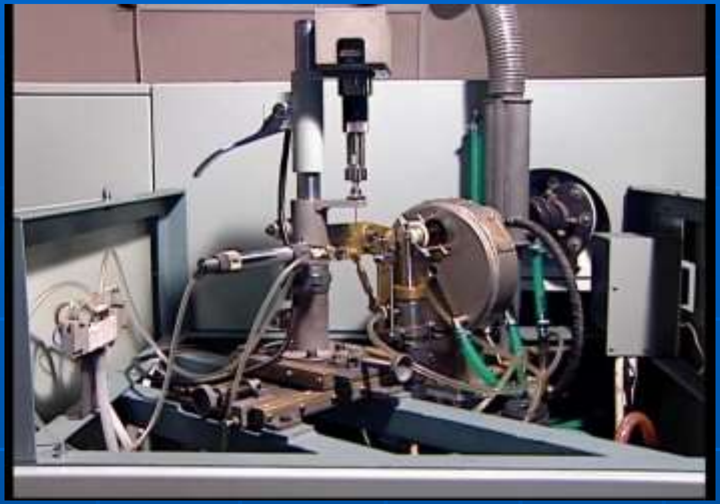
The main processes of ultrasonic exposure to gaseous media at high temperatures

1) Aerosol coagulation (coagulation of disperse emissions in flue gases)

2) Intensification of combustion process

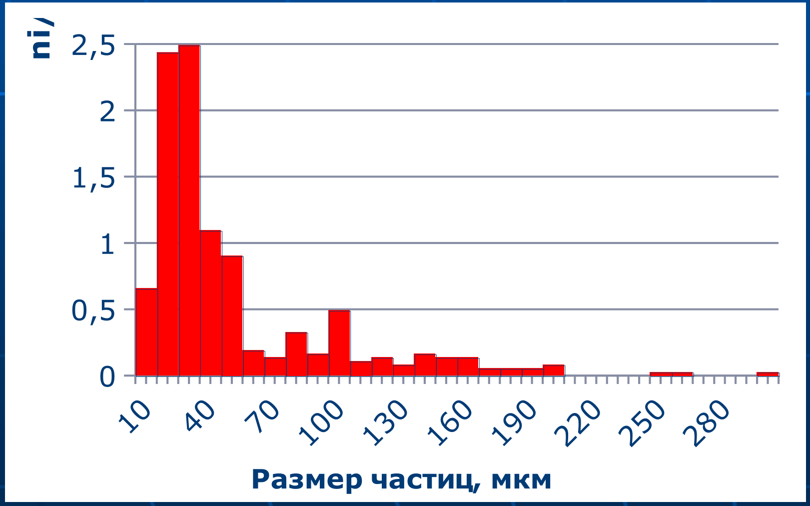
3) Spraying of aviation oils for combustion in a particle analyzer

Spraying of aviation oils for combustion in a particle analyzer



Device for spectral analysis of aviation oils at high temperatures

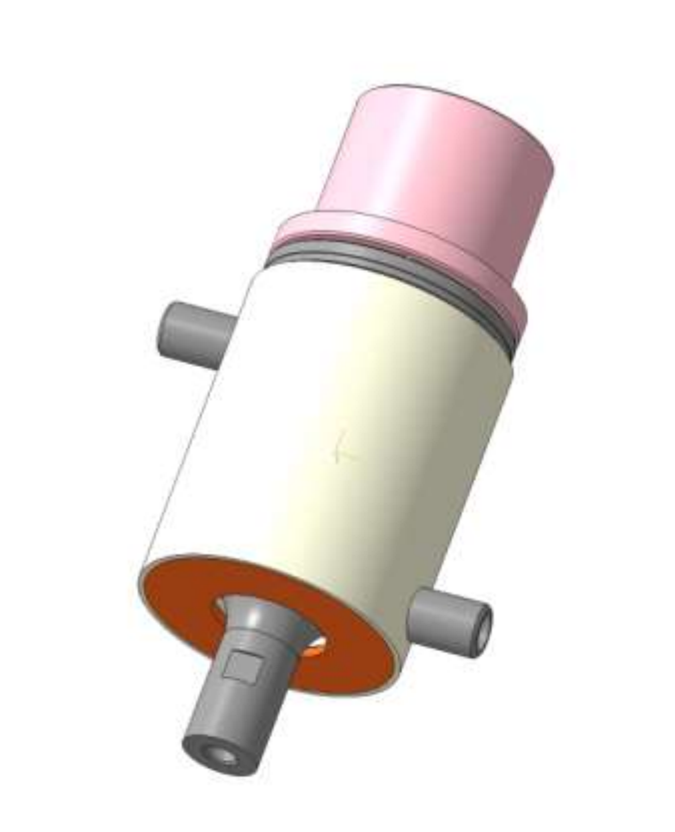
Ultrasonic atomizer mounted in a plasma burner



The dispersed composition of droplets when atomized at a frequency of 60 kHz

The dispersed composition of droplets when atomized at a frequency of 22 kHz

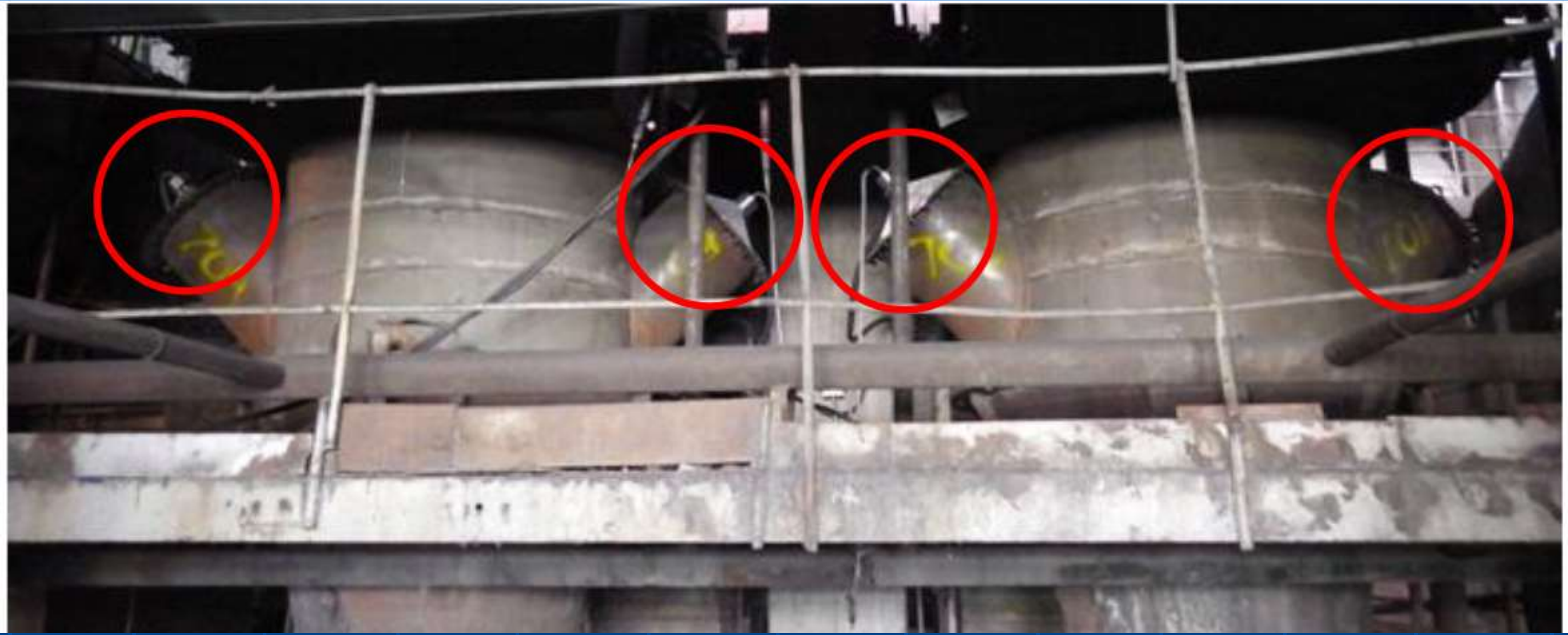
Ultrasonic atomization of aluminum melt



Ultrasonic vibratory system for imposing vibrations on the atomizer nozzle

Block for imposing ultrasonic vibrations

Ultrasonic coagulation of disperse emissions in flue gases **(Chita thermal power station)**

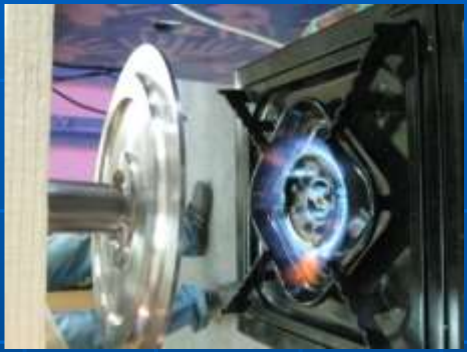


Before coagulation

After coagulation

Ultrasonic radiators for work at high temperatures (as part of experimental installations for testing radiators)

Ultrasonic disk radiators at 170 ºC and и выше

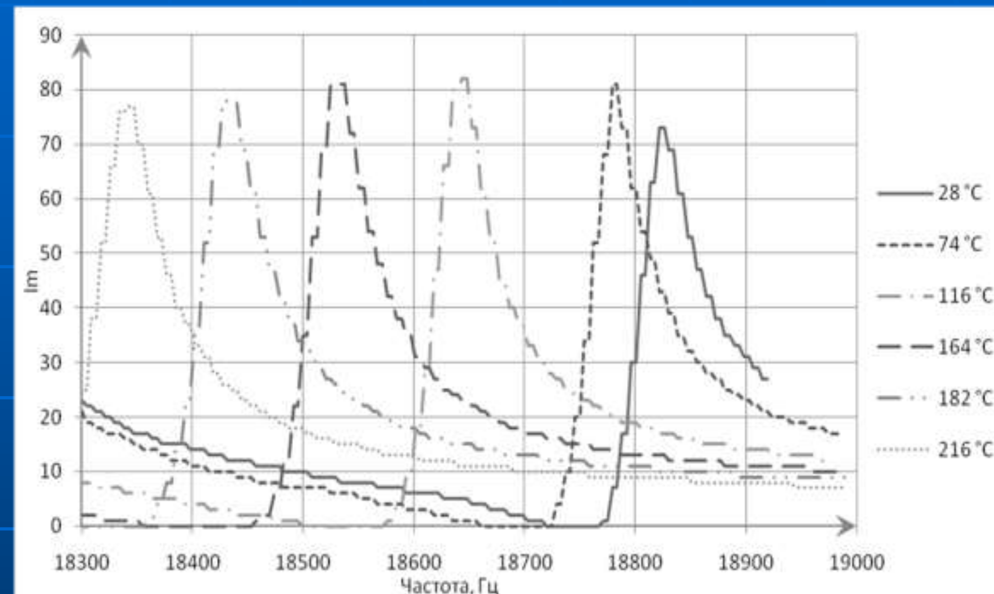


Ultrasonic atomizer for melt of fusible alloys
(at temperature 300 ºC)

Influence of gas temperature on an ultrasonic radiator parameters

Ultrasonic device for working in extreme conditions (on the left – an electronic generator, on the right – a disk radiator)

Dependence of current of ultrasonic radiator mechanical branch (I_m, mA) from frequency at various temperatures

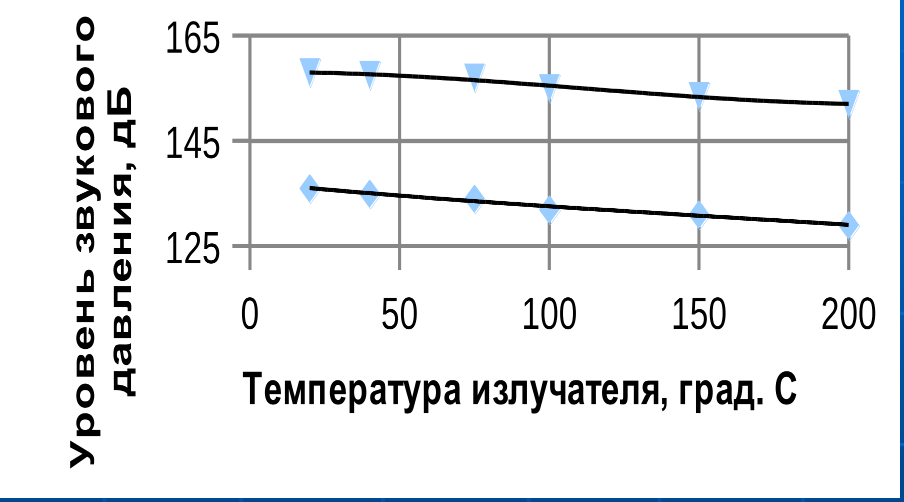


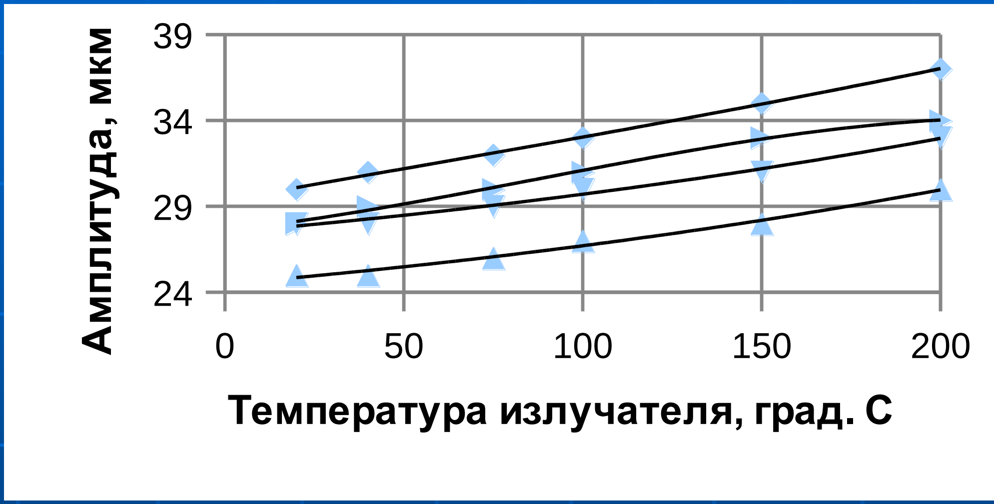
Ultrasonic radiator built into an industrial and technological installation(with air cooling systems of the concentrator and the working tool and water cooling of the primary piezoelectric transducer)

Внешний вид ультразвукового дискового излучателя

The key feature of the influence: changing temperature from 28 °C to 216 °C decrease the resonant frequency by 480 Hz. Therefore, it is necessary to implement a system of automatic frequency adjustment adapted to temperature changes.

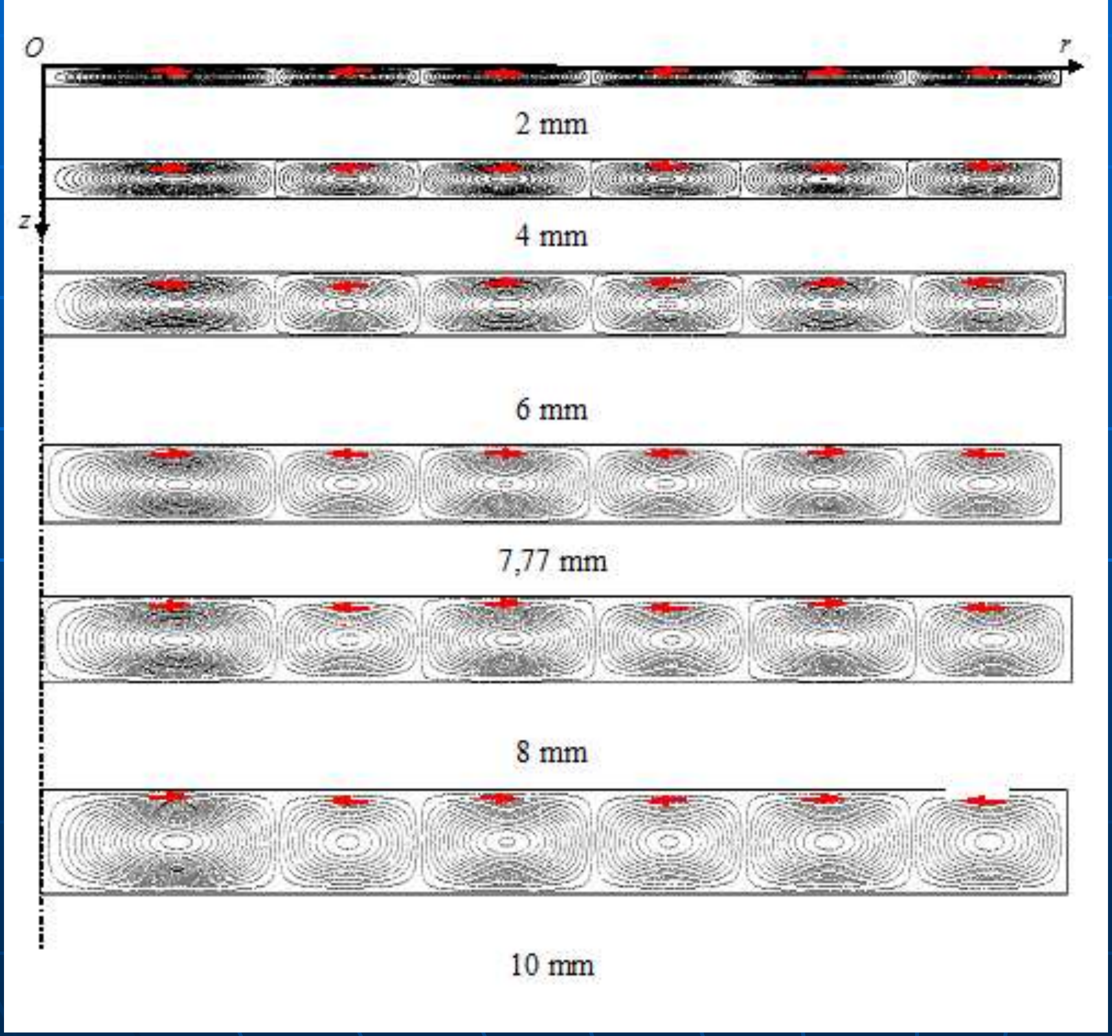
Influence of the gas temperature on the sound pressure





The sound pressure level decreases even the increase of the vibration amplitude when the temperature rises. Therefore, it is necessary to look for new nonlinear effects of ultrasound exposure.

Ultrasonic coagulation in resonant conditions under which vortex acoustic flows occur



A local increase of concentration occurs due to vortex flows (particles are partially carried away to the peripheral regions of the vortices due to inertia forces). Consequently, the efficiency of coagulation increases.

ULTRASONIC EXPOSURE OF LIQUIDS AT EXTREMAL TEMPERATURES

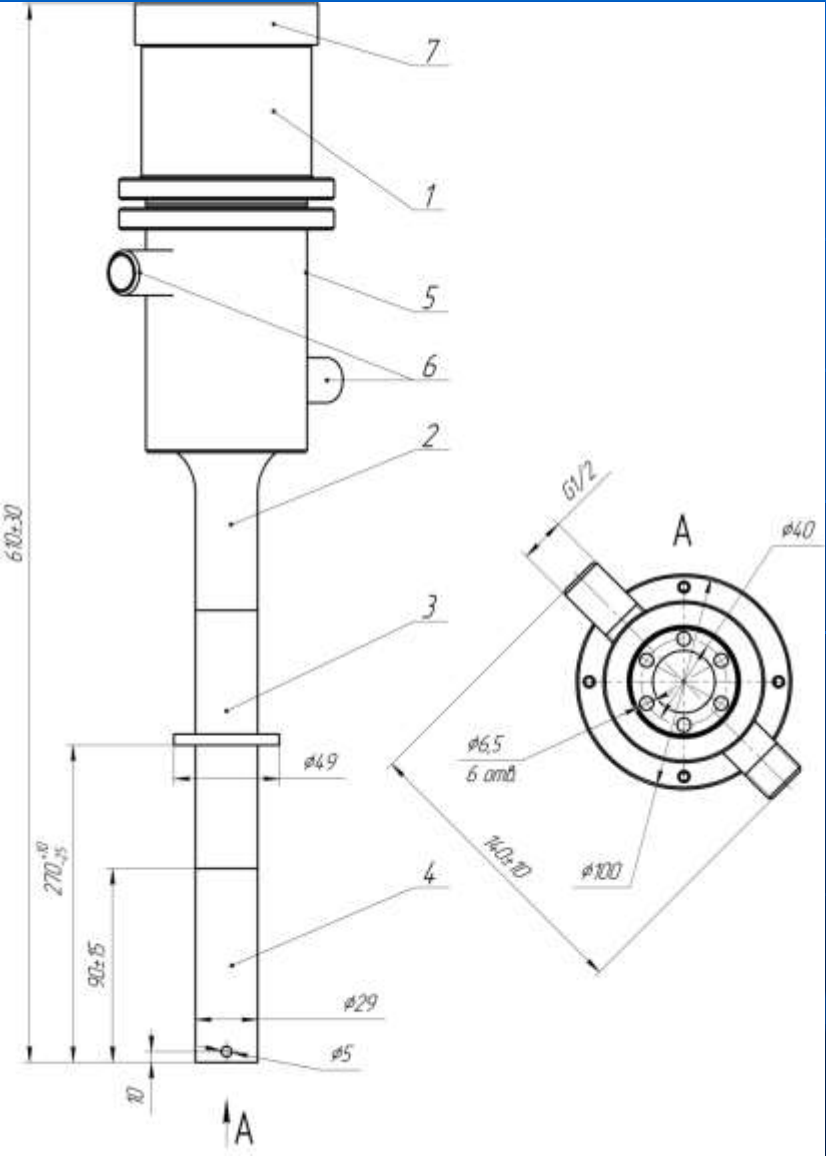
Stand for high-temperature research (melting of metals)

Appearance of fireproof chamber

The main processes implemented in liquids at extreme temperatures

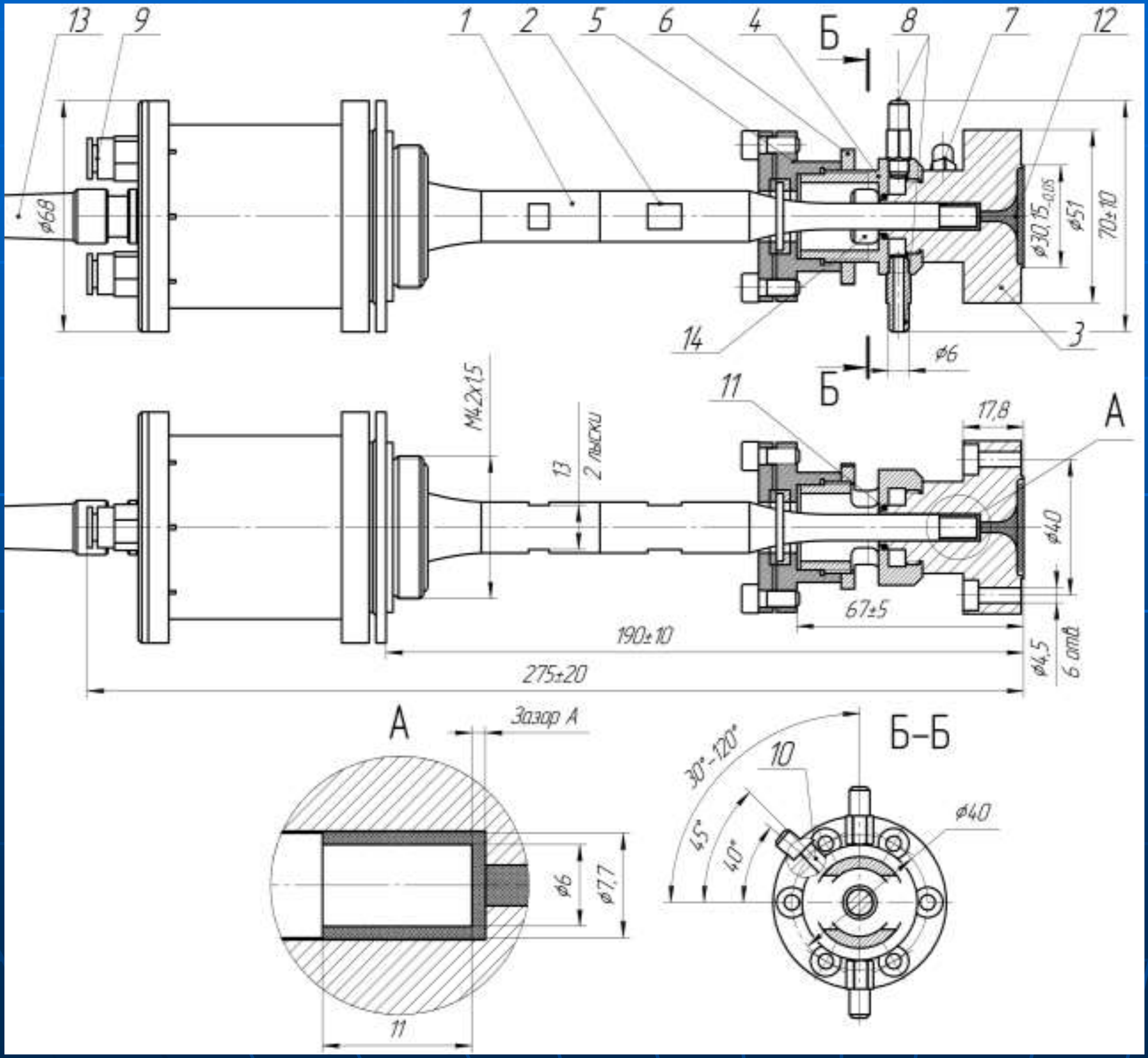
1) Cavitation treatment of cryogenic liquids
2) Cavitation treatment of polymer melts
3) Cavitation treatment of melts of fusible alloys

Treatment of aluminum melt (carbon fiber impregnation)



1 – piezoelectric transducer in case; 2 – booster (titanium); 3 – two-half-wave sonotrode (steel); 4 – working tool (niobium); 5 – cooling jacket; 6 – branch fittings; 7 – fan

Ultrasonic vibratory system for treatment of polymer melts



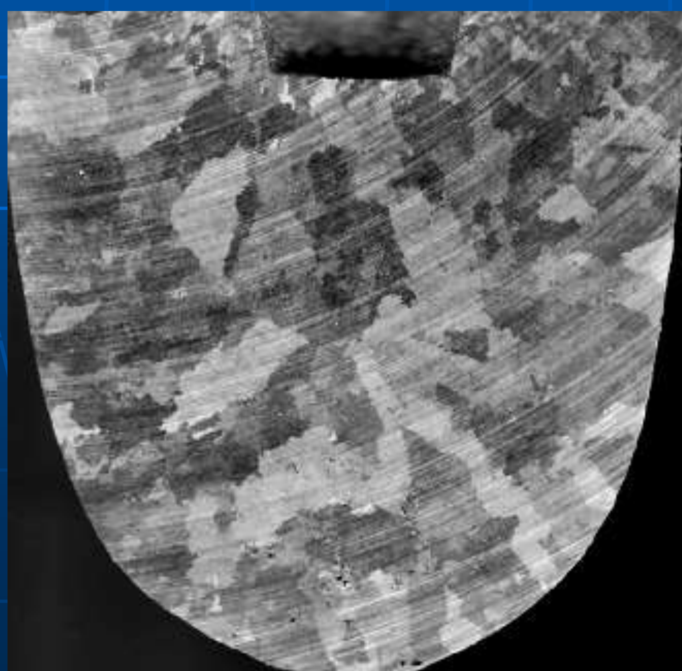
1 – piezoelectric transducer in the case; 2 – working tool; 3 – head; 4 – guide; 5 – ultrasonic vibratory system flange; 6 – nut; 7 – polymer outlet fitting; 8 – pneumatic system fittings for local polymer cooling; 9 – pneumatic system fittings for piezoelectric transducer cooling; 10 – hole for temperature sensor installation; 11 – o-ring; 12 –polymer melt; 13 – cable entry; 14 – viewing window

Cavitation treatment of cryogenic liquids

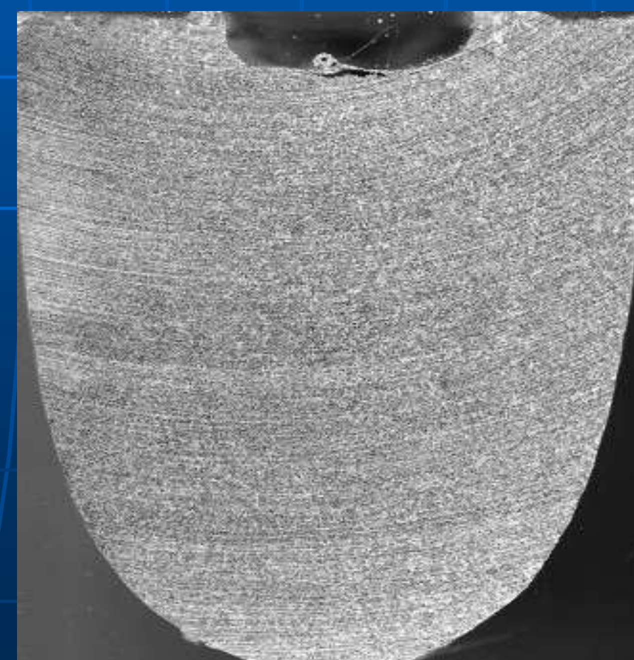
Cavitation treatment of polymer melts

Cavitation treatment of melts of fusible alloys

Crystallization of Al-4 % Cu without ultrasonic treatment



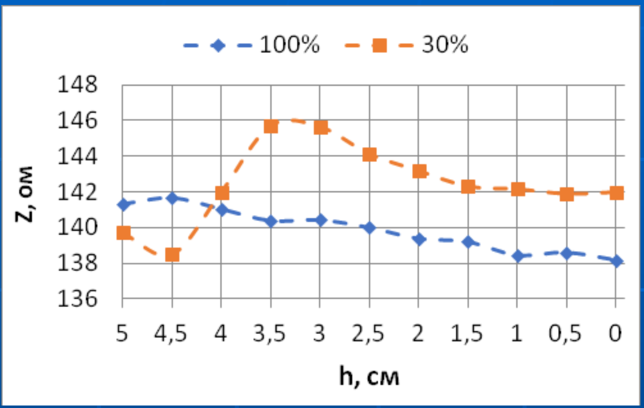
Crystallization of Al-4 % Cu with ultrasonic treatment

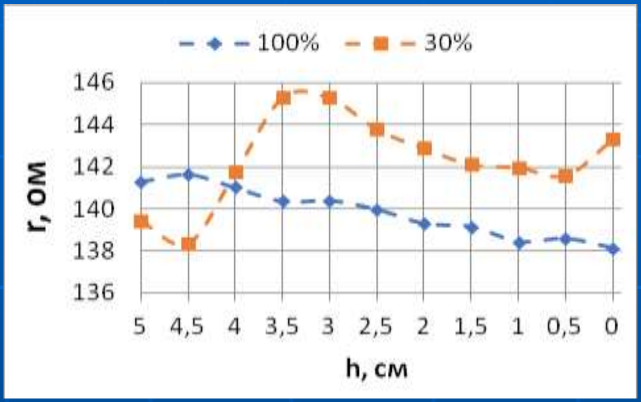


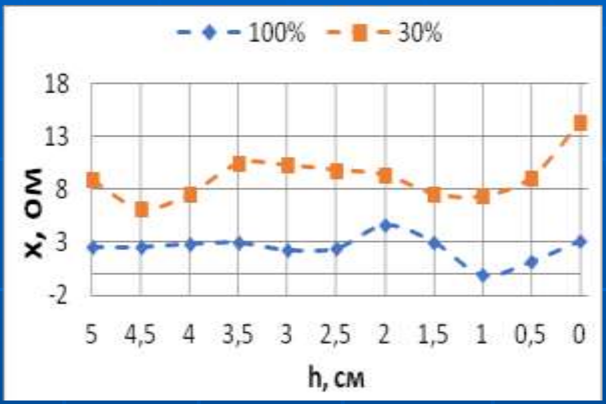
The influence of temperature on the impedance characteristics of the ultrasonic radiator during the treatment of melts (for example, aluminum)

A change in temperature leads to a decrease in the resonant frequency from 21 to 20.2 kHz. Therefore, it is necessary to carry out continuous monitoring of the acoustic load and automatic frequency adjustment. With an increase in temperature, the active resistance of internal losses of increases up to 3 times. Consequently, the power injected into the medium is reduced. To increase the effectiveness of the treatment, it is necessary to optimize the geometry of the processed volume.

Experimental studies of the influence of the distance between an ultrasonic radiator and a reflector on the impedance characteristics of an ultrasonic radiator in an aluminum melt







Z is impedance module
R is the active component of the impedance, which determines the proportion of the total vibration energy spent on maintaining cavitation
X is the reactive component of the impedance due to the elasticity of the medium

Power 30%: amplitude of sound pressure near of radiator is 500 kPa (high-intensive cavitation mode in the entire volume)
Power 100%: amplitude of sound pressure near of radiator is 1600 kPa (degenerate cavitation mode near the radiator)

The key feature of the treatment: it is necessary to make ultrasonic treatment at the optimal distance between the radiator and the reflecting surface (for aluminum melt – 3.2 cm) at intensity for high-intensive cavitation mode

Requirements for ultrasonic devices for exposure in extreme conditions

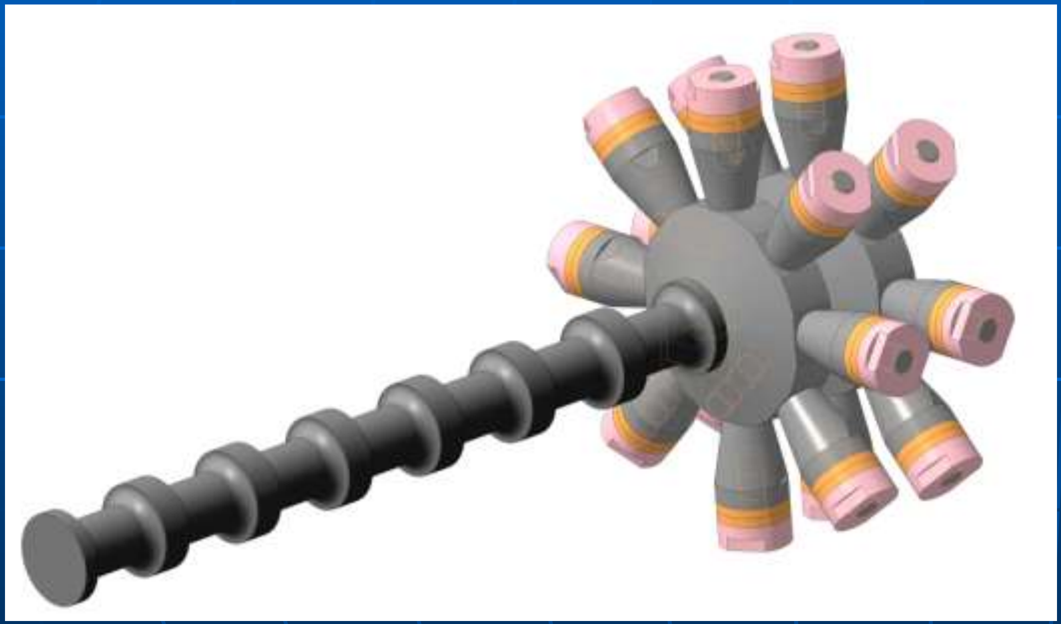
• Ultrasonic exposure of solid media should be supplemented by shock-contact action with free mass and pseudo-rotation.

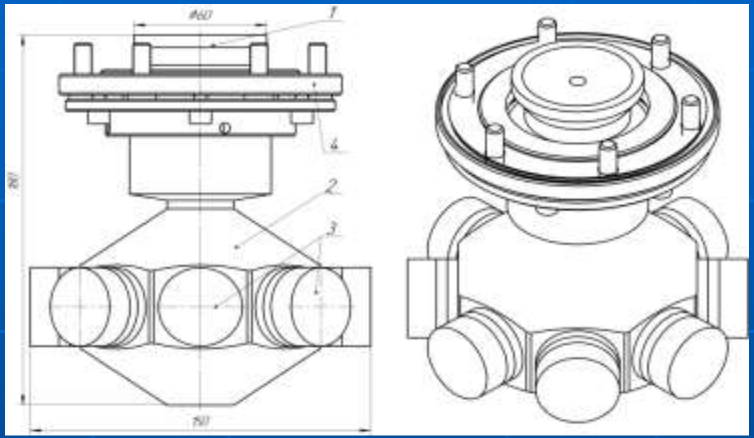
• Ultrasonic exposure to gases should be carried out with frequency adjustment depending on temperature. The ultrasonic radiator must be equipped with a dual cooling system (air and water).

• Ultrasonic exposure of liquids (melts) should be carried out at an optimal distance between the radiator and the reflecting surface.

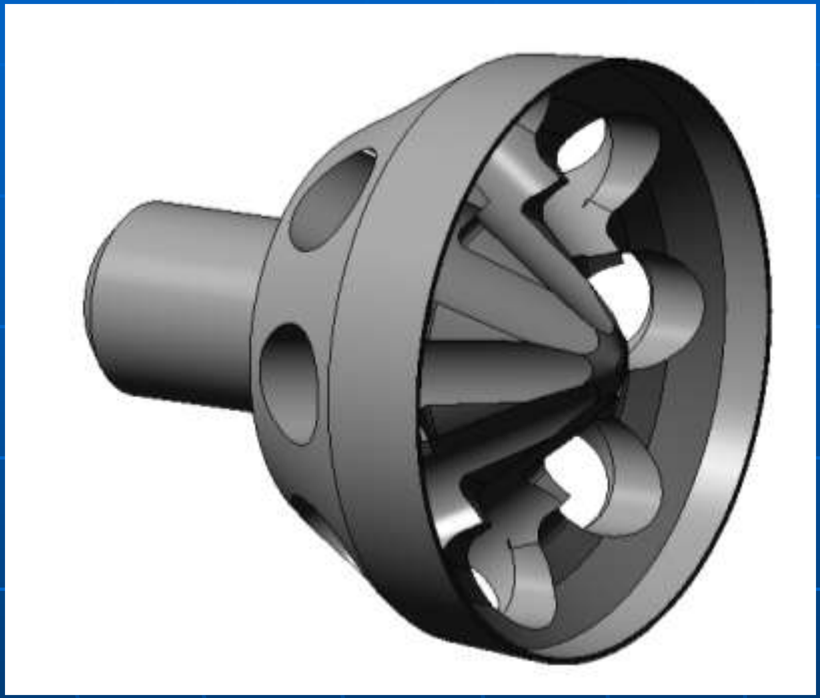
WAYS TO SOLVE THE PROBLEMS OF ULTRASOUND EXPOSURE (RESEARCH DIRECTIONS)

Creation of multi-pack piezoelectric transducer of increased power and frequency





Development of working tools for drilling of soil and treatment of mediums



Features:
- Outer cutting part for channel formation
- Internal working cavity for additional soil destruction
- Holes for the exit of crushed soil from the working cavity

Series of multi-frequency devices for supplying vibrations to the melt zone (welding)