FEATURES OF ULTRASONIC EXPOSURE
IN EXTREME CONDITIONS
(Practical designs of small-sized devices)

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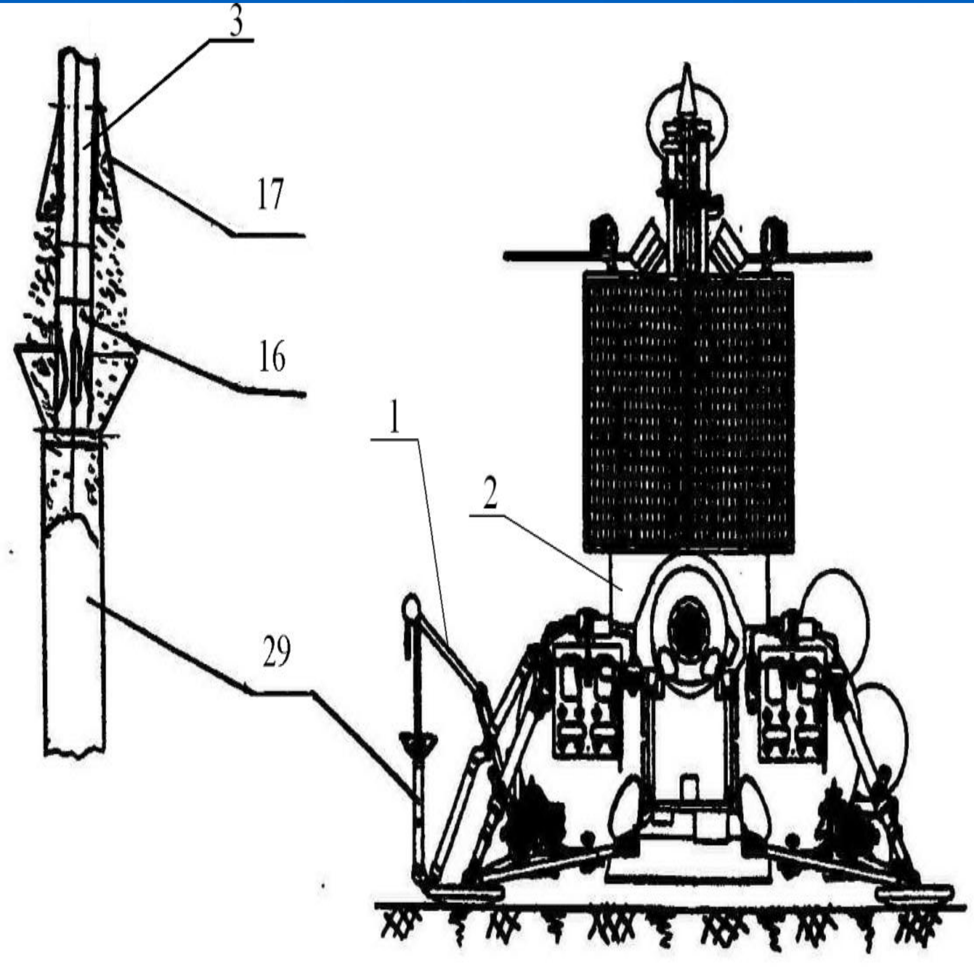
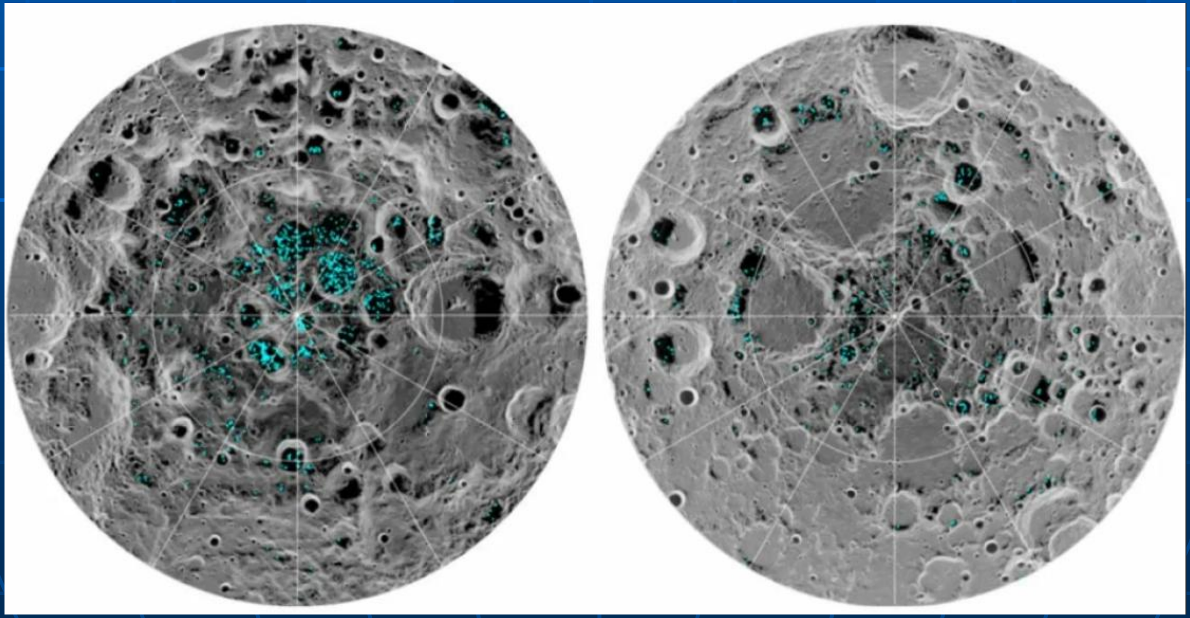
Drilling of soil on planets and asteroids (T from 0 K to 1000 K)



The need for drilling on planets and asteroids

- Great scientific interest (possible existence of life, conducting experiments impossible on earth);
- Possibility of colonization (extraction of oxygen, cultivation of plants, survival of mankind in case of global catastrophes on Earth);
- Extraction of hydrogen for fuel (launching spacecraft from the Moon for deep space exploration).

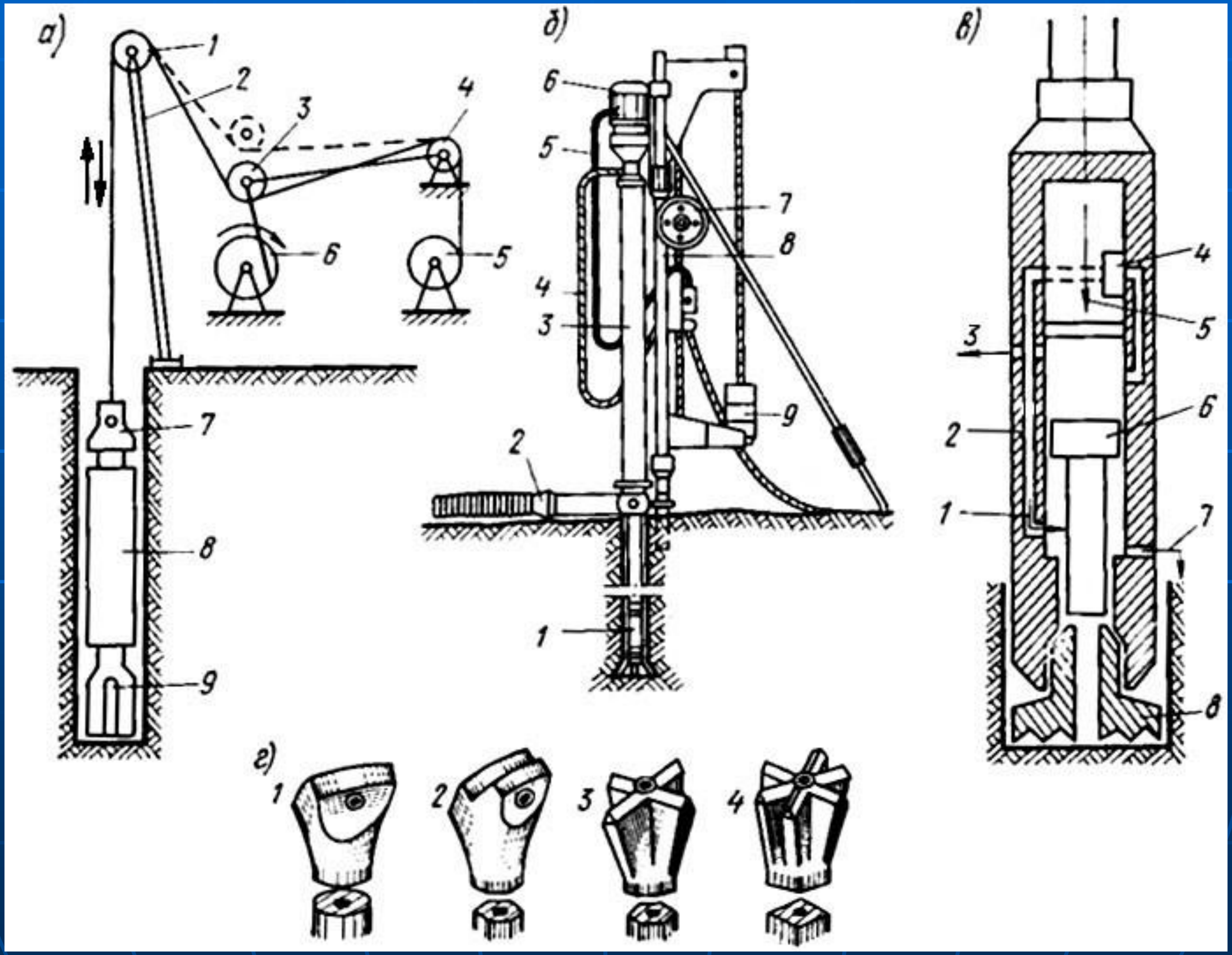


Solved problems of extraterrestrial drilling

- Accelerated mounting of landing modules on objects with low gravity and unknown soil composition (for example, asteroids).
- Identification of the composition and properties of the unknown soil before planting:
- 1. for the presence of volatile and easily evaporating substances at various depths with minimal influence of the research tool on the composition of the soil and the safety of valuable substances.
- 2. to optimize the modes and conditions of impact (drilling) in order to ensure maximum speed with minimal energy consumption

Mechanical drilling of the earth's soil by rotation

Devices for mechanical drilling of soil

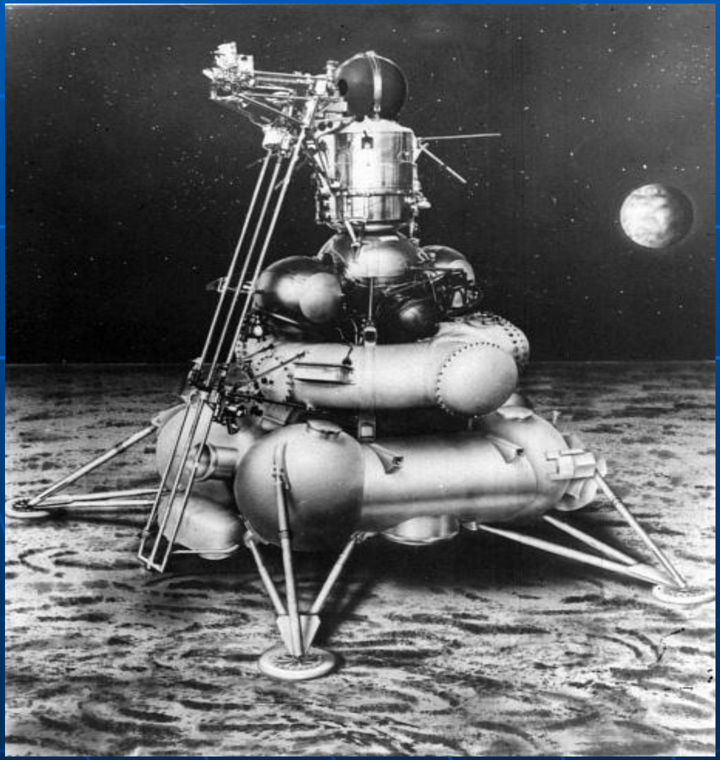


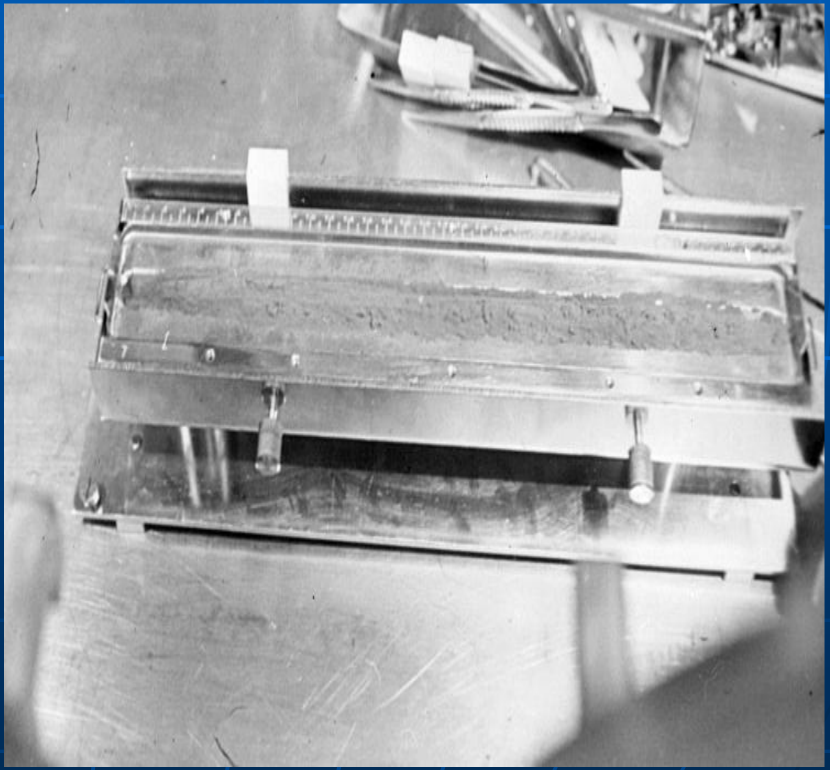
The experience of drilling lunar soil Luna-24.

Mechanical drilling was carried out to a depth of 2.25 m.

The station delivered samples of lunar soil weighing 170 grams to Earth.

The conducted research led to the discovery of water in the lunar soil



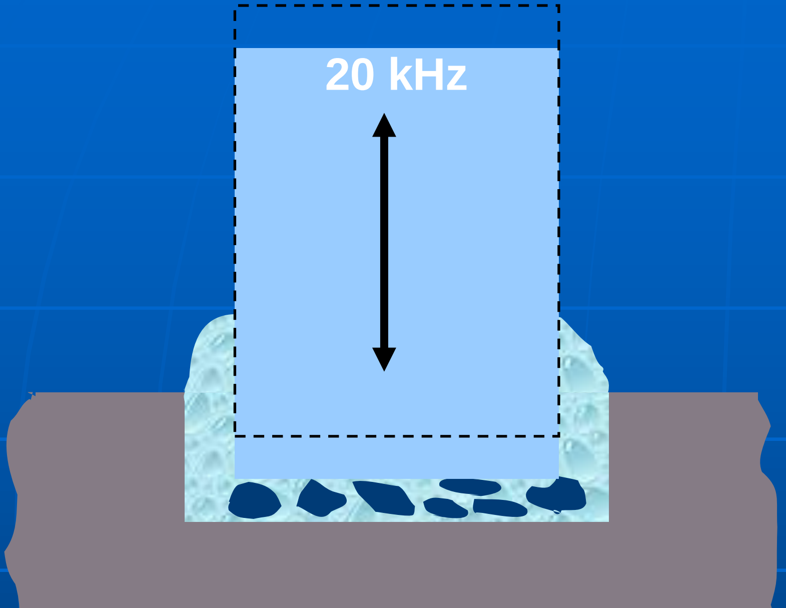


Drilling device of the American National Astronautics Agency (NASA)

Problems of mechanical drilling

- inability to drill on objects with low gravity to attach landing modules to asteroids (due to inertia forces preventing drilling that exceed gravitational forces);
- a high degree of heating of the soil due to friction forces, leading to evaporation, sublimation of traces of water and ice, volatile and other useful substances;
- the inability to obtain information about the properties and composition of the soil in real time without expensive delivery of soil samples to the Earth for detailed study.

Ultrasonic drilling



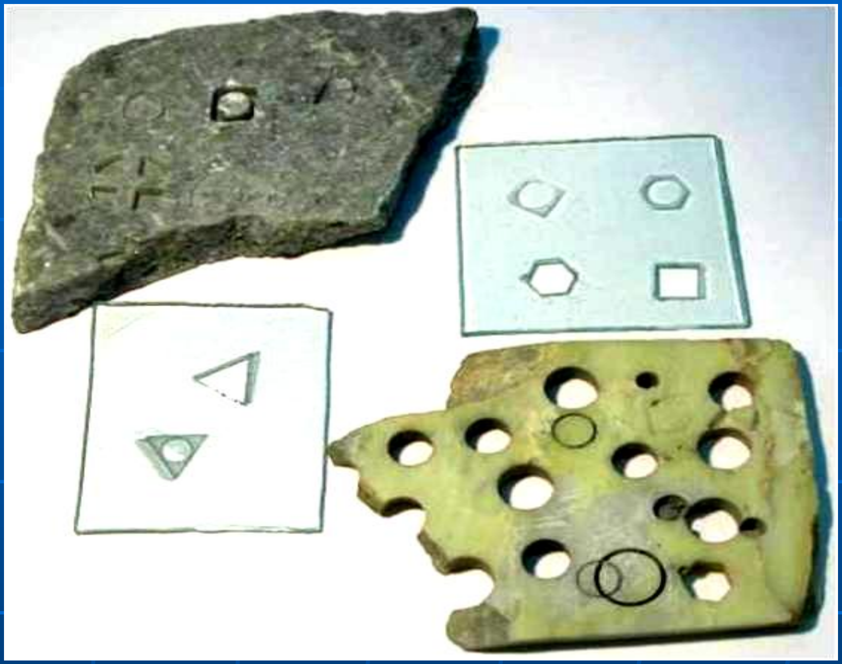
Possibilities

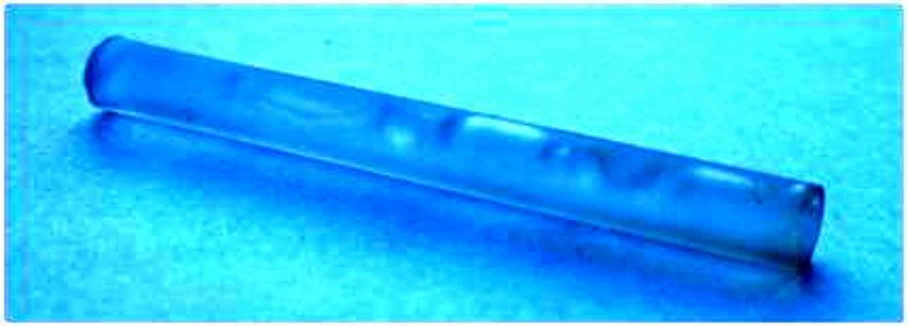
- Energy intensity < 10 J/cm^3
- Velocity > 10 mm/s
- No cracks
- Diameter from 1 to 120 mm

1. Impact influence of abrasive particles

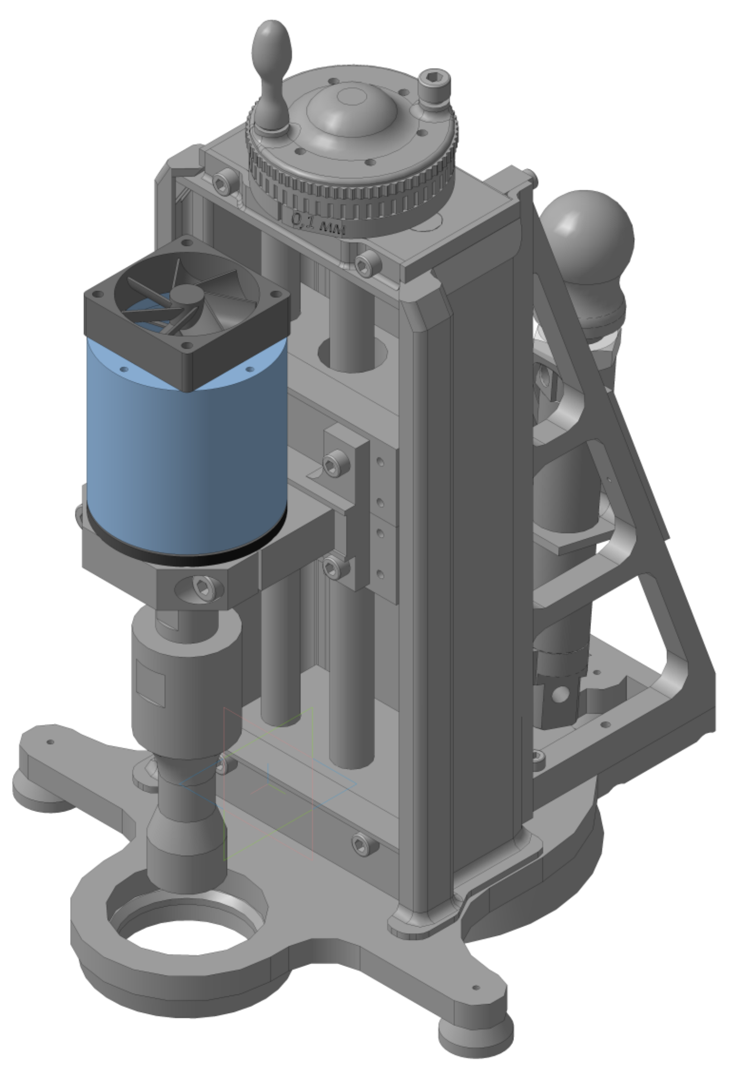
2. Circulation and changing of abrasive

Making of channels of various shapes and depths

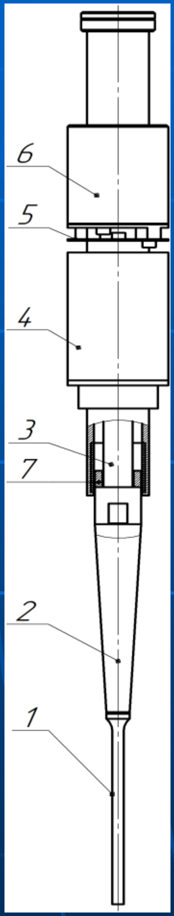


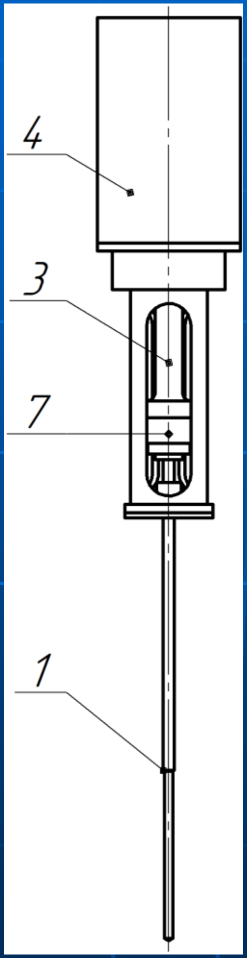


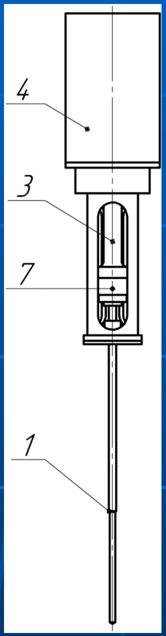
Ultrasonic machine for dimensional processing



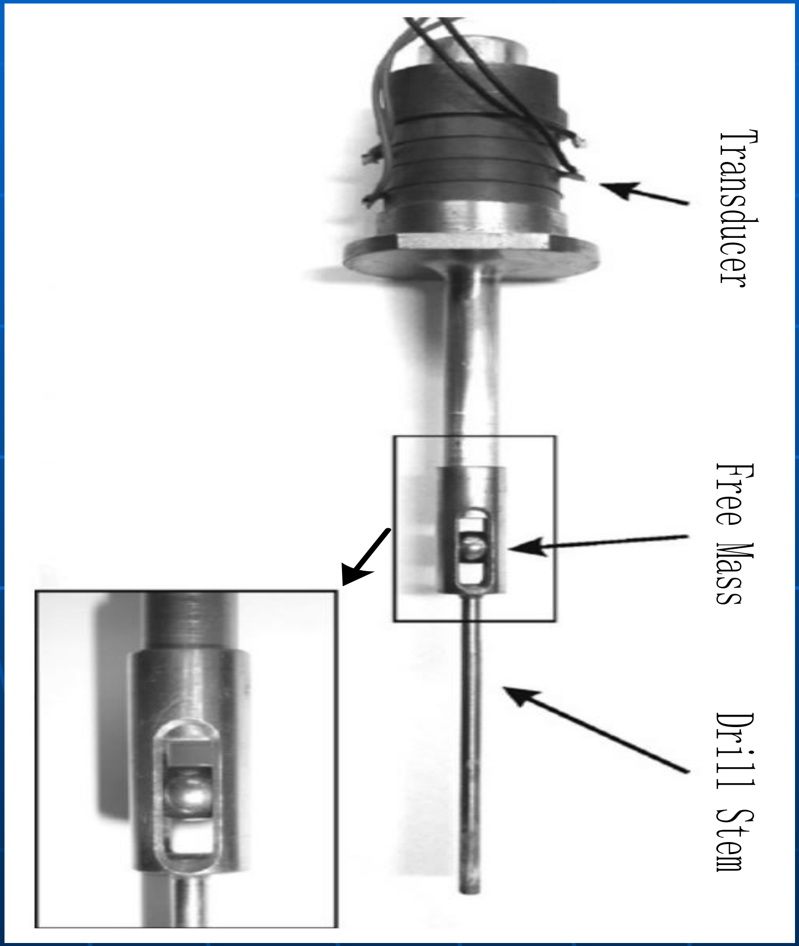
Devices for ultrasonic drilling

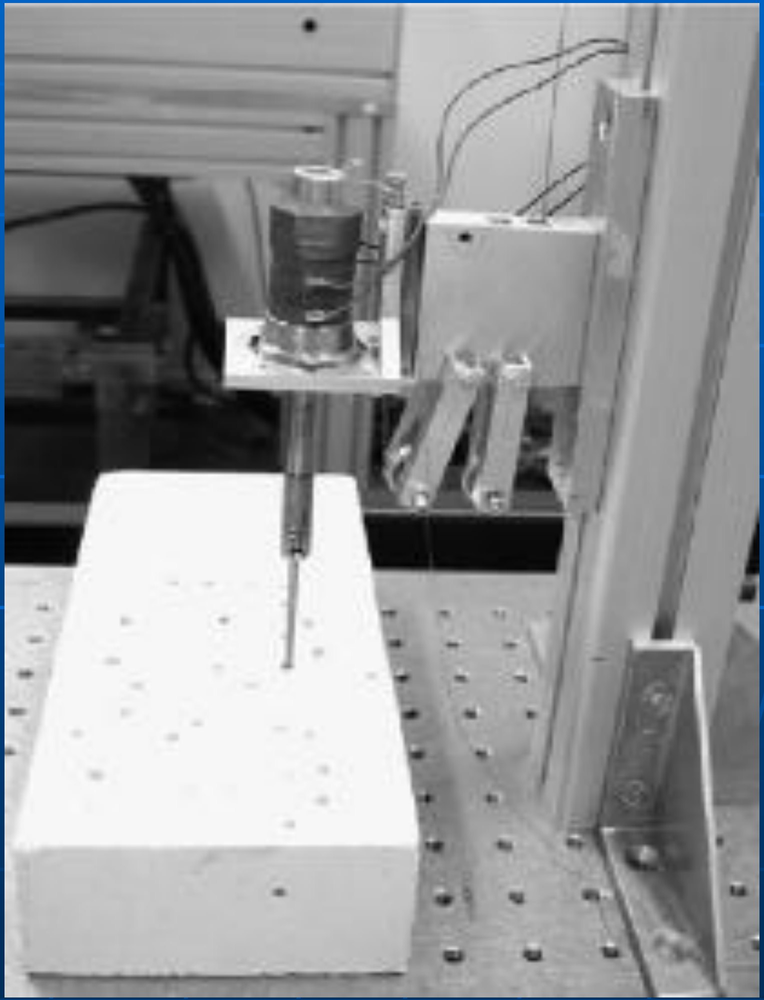




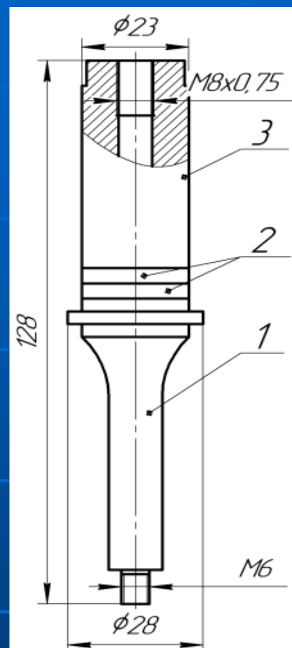


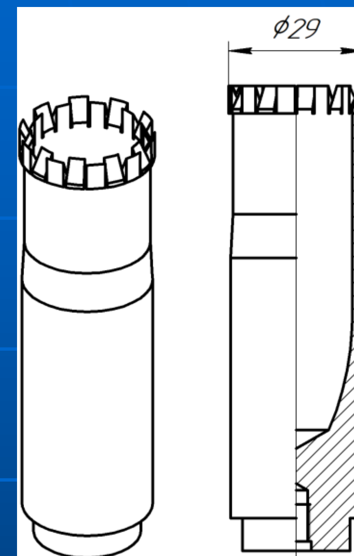
The device of ultrasonic drilling with free mass

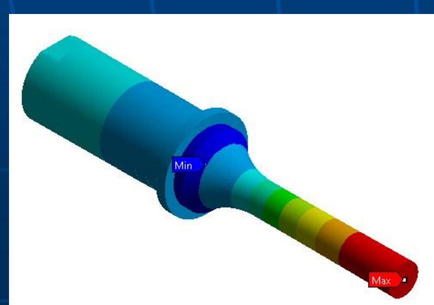


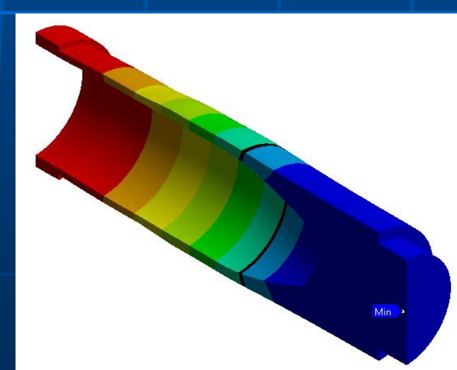


Ultrasonic vibratory system for drilling soil (components)



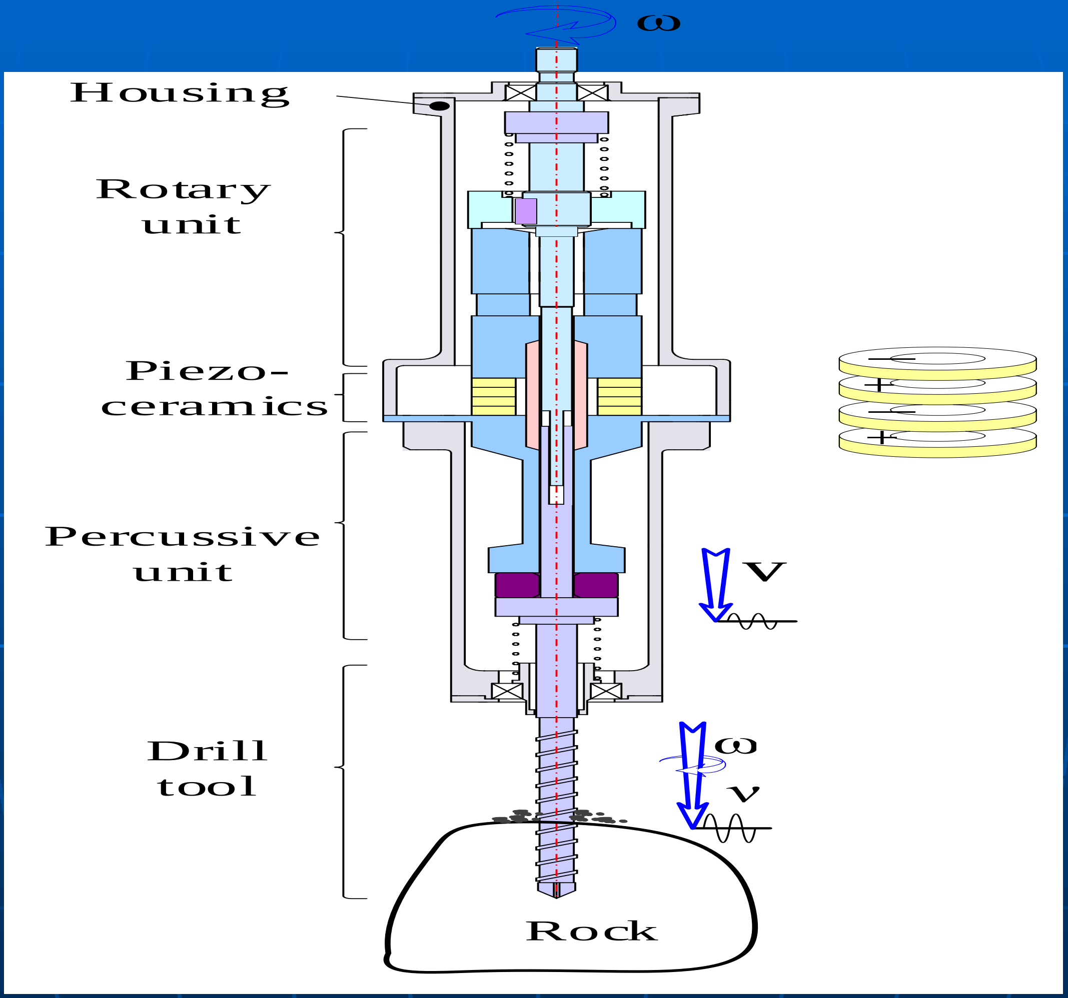






1 – booster; 2 – piezoelectric rings; 3 – reflector.

Drilling equipment with impact and rotational influence



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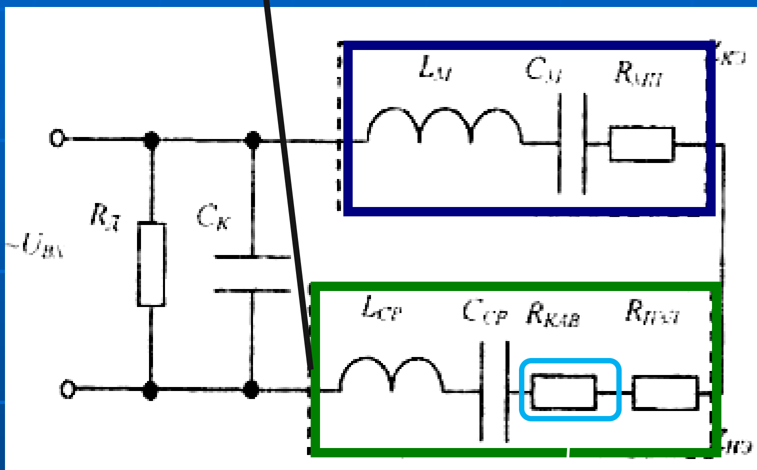
Influence of soil and temperature on the parameters of the ultrasonic vibratory system

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.

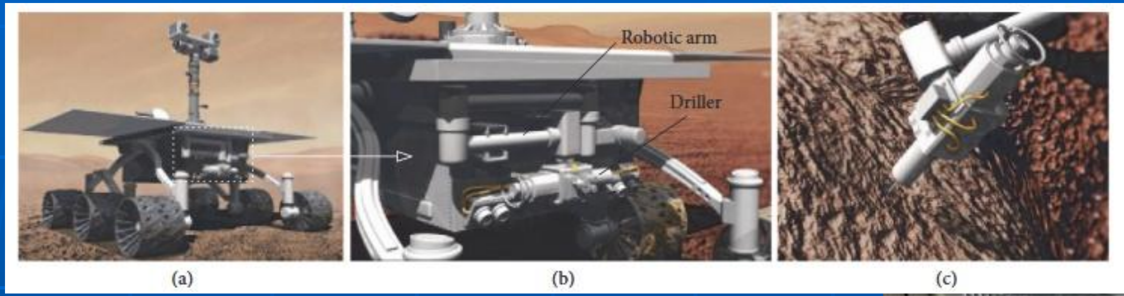
The limited temperature range of the piezoelectric element, at which it retains piezoelectric properties.

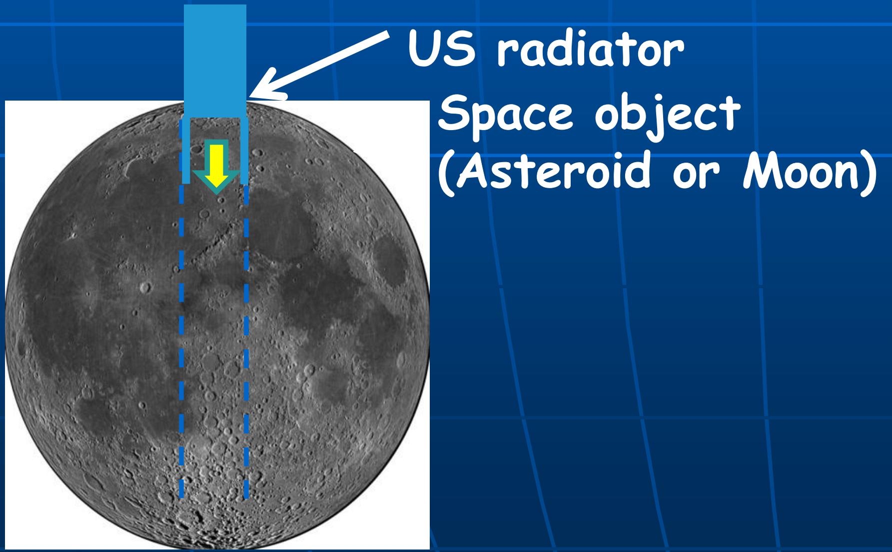
The capacity of the piezoelectric element C_K changes -> the resonant frequency of the vibratory system changes with a change in temperature.

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

Processes of ultrasonic exposure on solid media under extreme conditions

Drilling of cosmic objects





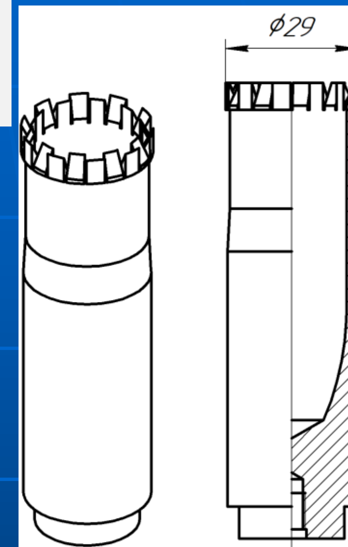
Statement of the task of studying the process of ultrasonic drilling for the detection of water and ice

Drilling velocity

$$\frac{dh}{dt}(A, \Lambda) \to ?$$

Mass fraction of evaporated water

$$\Delta\chi(A, \Lambda) \to ?$$



The criterion of optimality of the drilling process

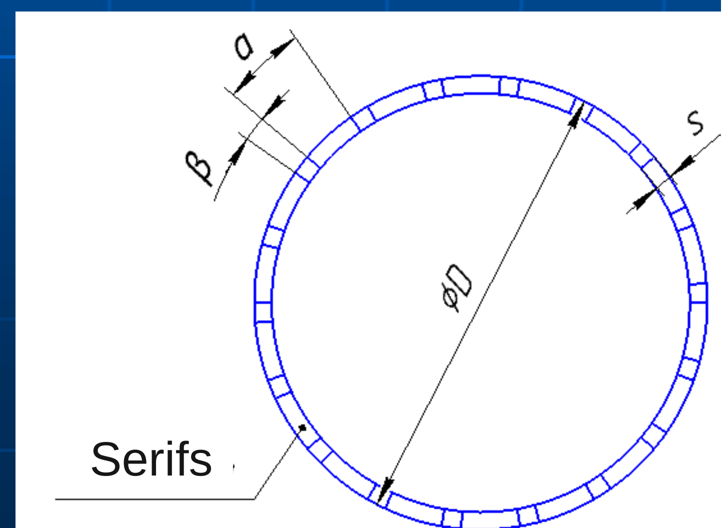
Minimum mass of evaporated water

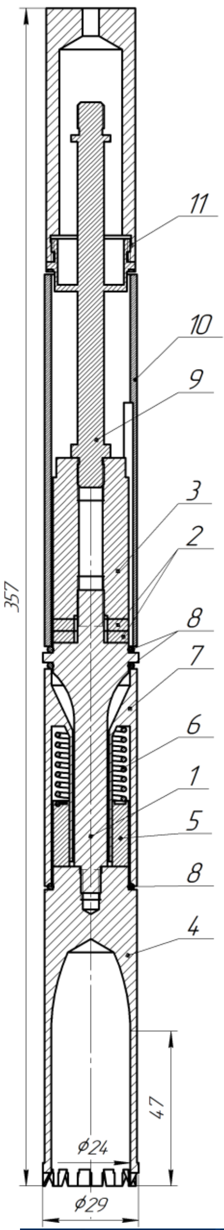
$$\Delta\chi \to \min$$

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.





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.

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%)

Device for drilling of simulators of lunar soil

Stand for researches of ultrasonic drilling

Results of ultrasonic drilling at additional influence

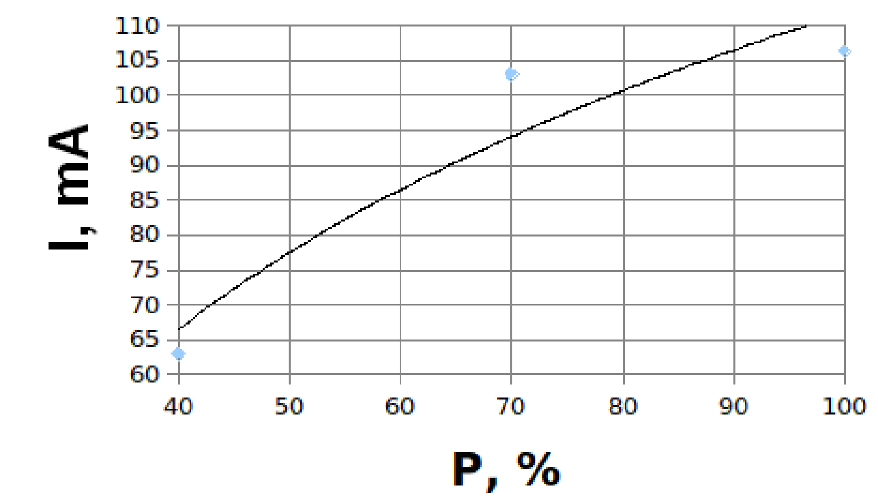
Static pressure, N	Drilling speed, mm/min				
	DR	UV	UV + DR	UV + LV	UV + LV + DR
Silicate brick					
20	4	27	30	30	42
10	2	16	17	18	24
5	2	14	16	16	24
Red brick					
20	3	9	11	10	13
10	1	14	14	15	17
5	1	13	13	14	18
Foam concrete					
20	11	122	134	136	154
10	10	91	102	100	136
5	5	55	59	60	102

UV – ultrasonic vibrations
LV – low frequency shock vibrations due to additional mass
DR – pseudo-rotation

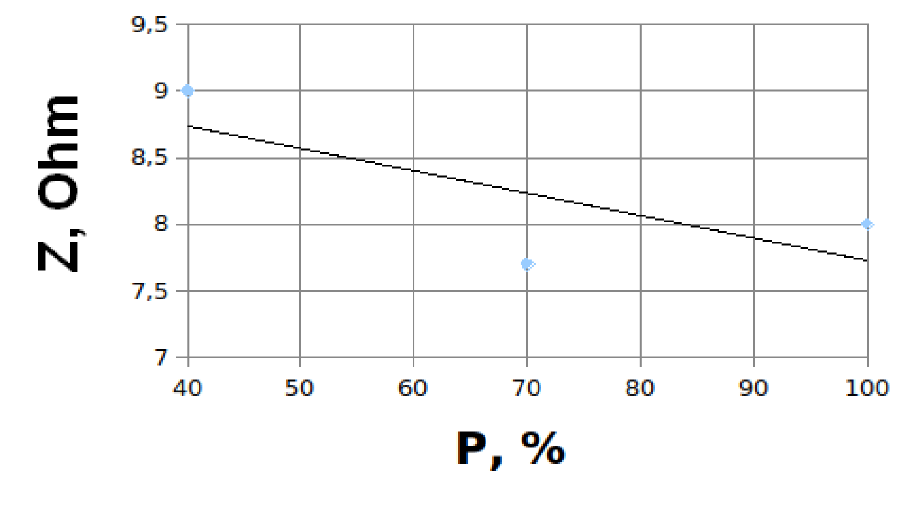
The dependence of the electrical parameters of the ultrasonic vibratory system on the power

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.



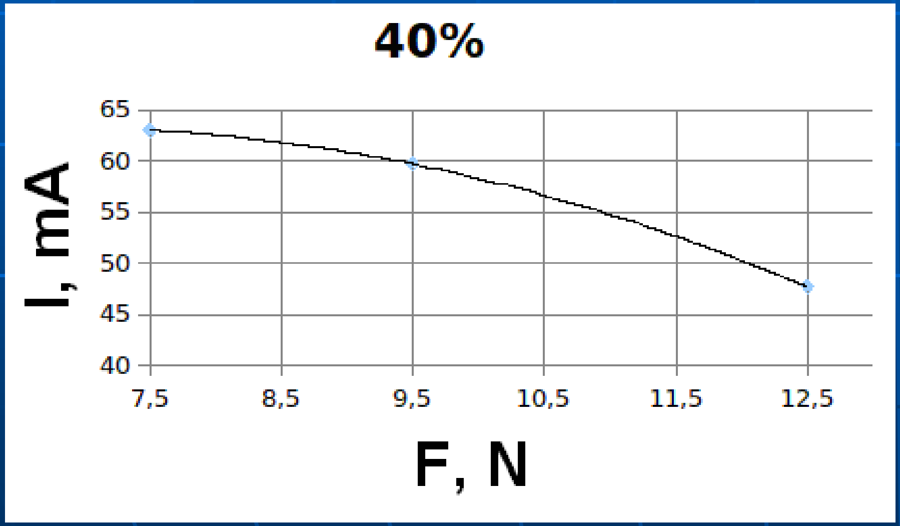
a) current of mechanical branch



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.



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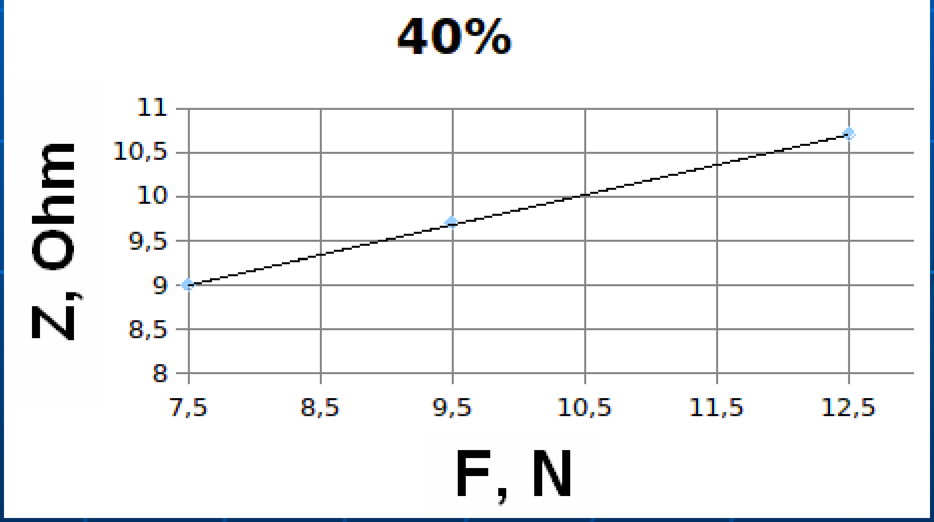
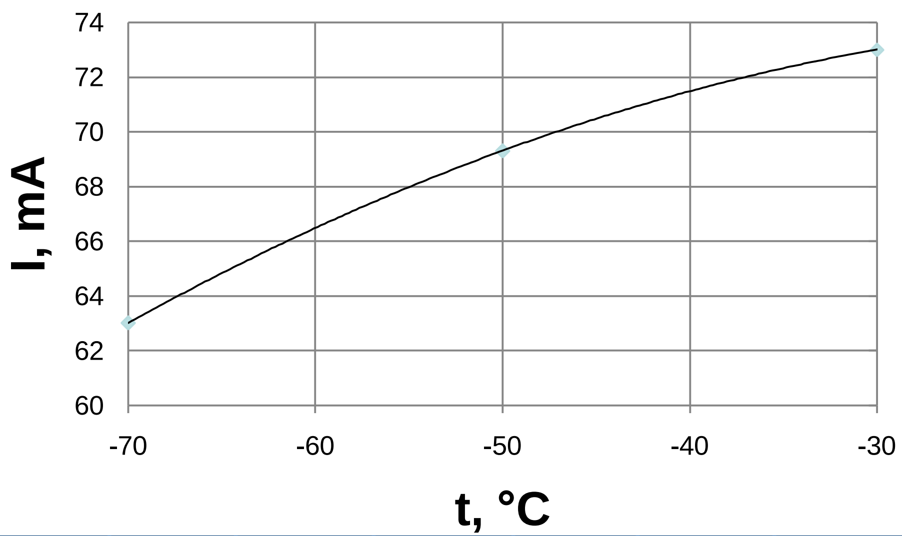


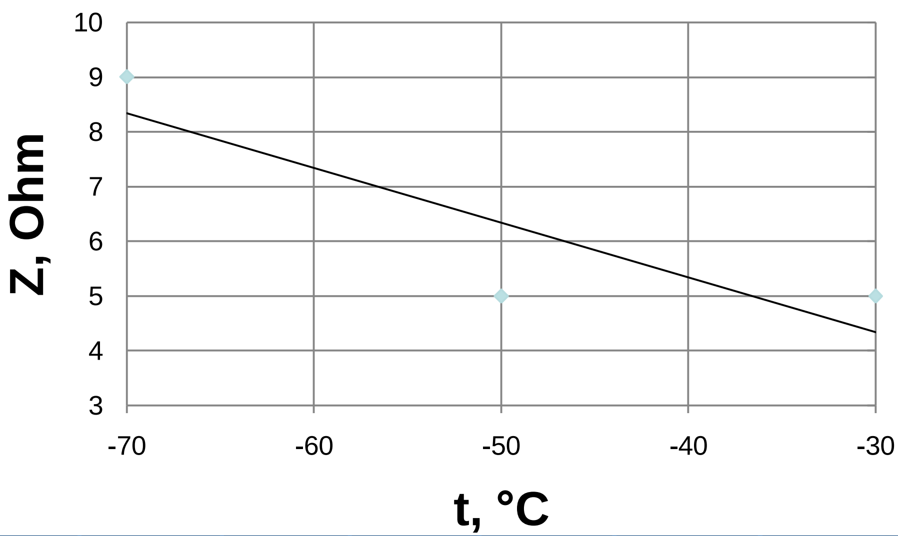
b) impedance of mechanical branch

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.



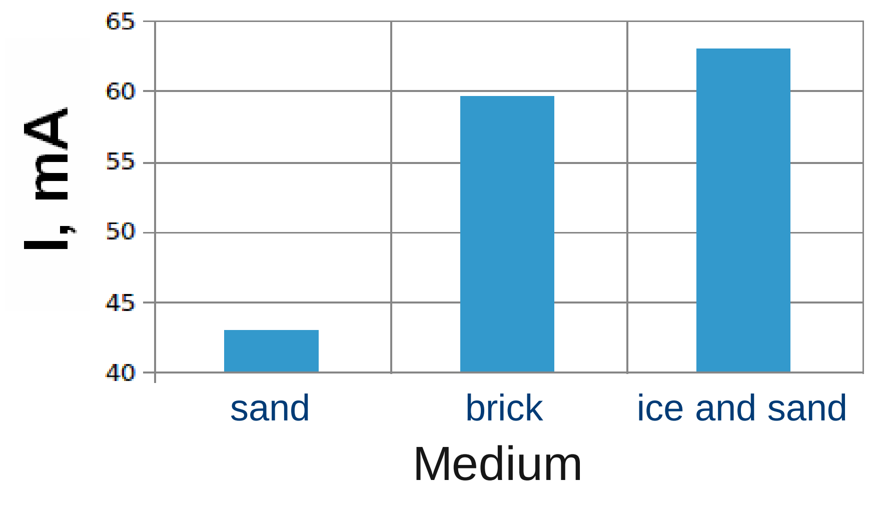
a) current of mechanical branch



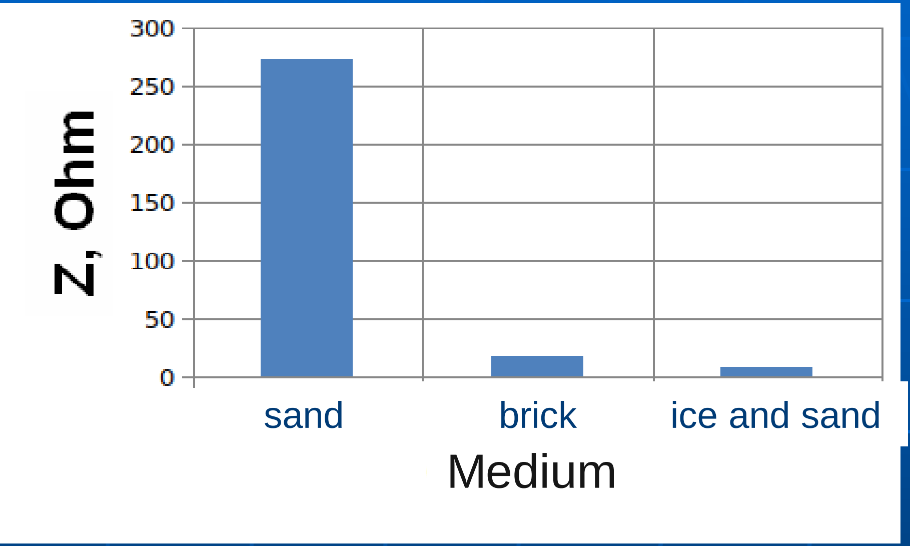
б) impedance of mechanical branch

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.

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



a) current of mechanical branch

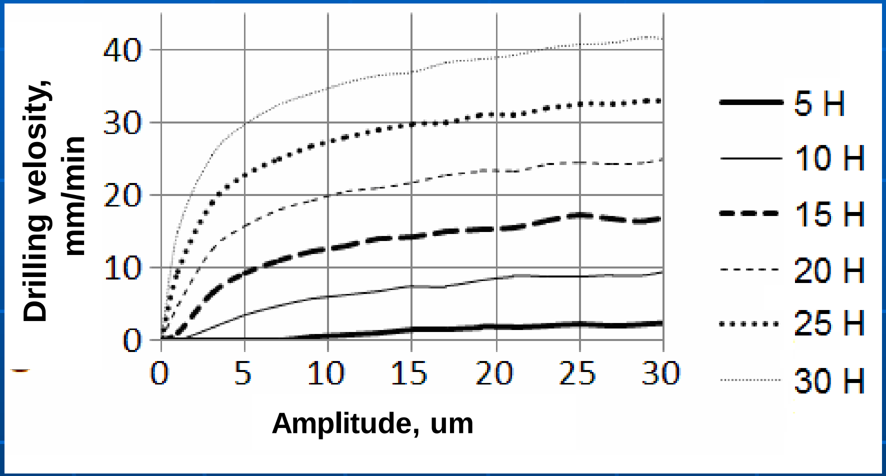


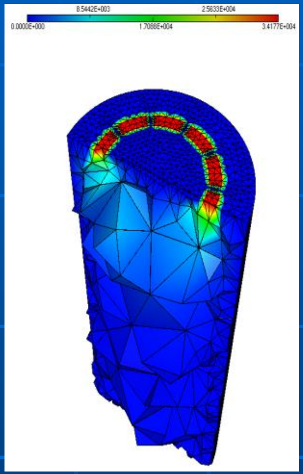
b) impedance of mechanical branch

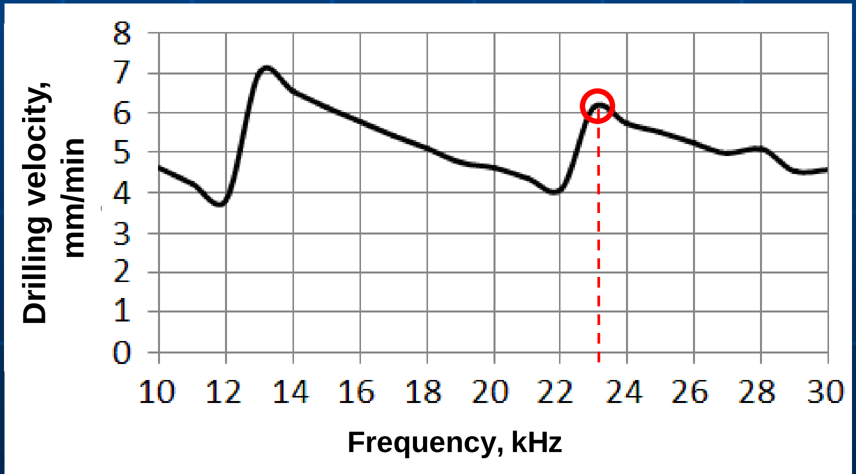
Measuring the radiator impedance characteristics allows you to determine the ground type in real time

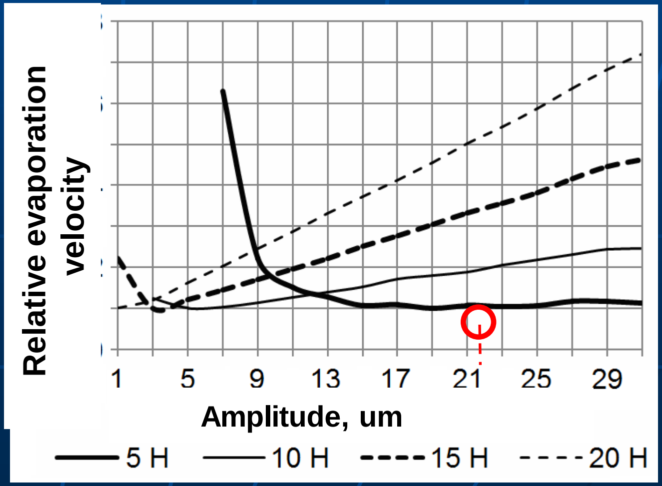
Definition of optimal modes of ultrasonic drilling

Modeling of ultrasonic destruction of solid material at extreme temperatures



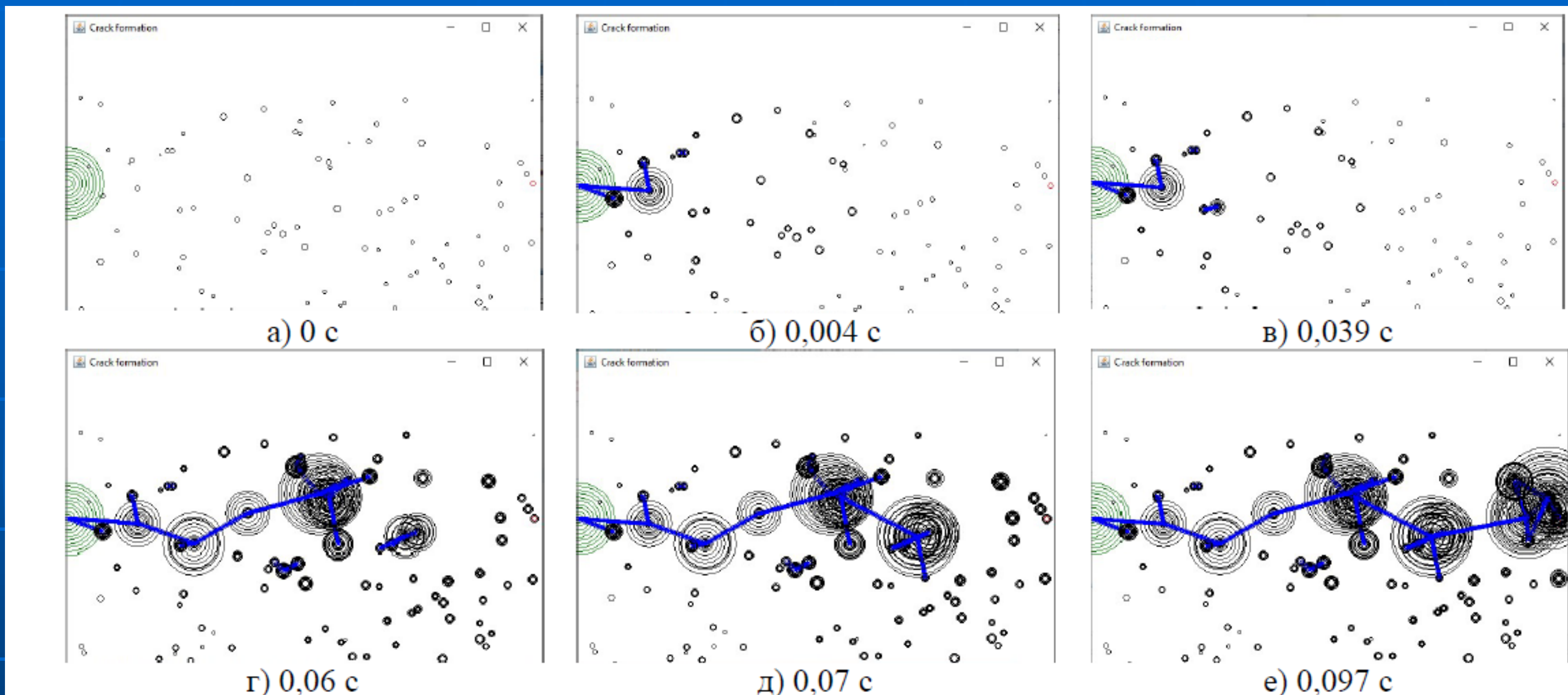




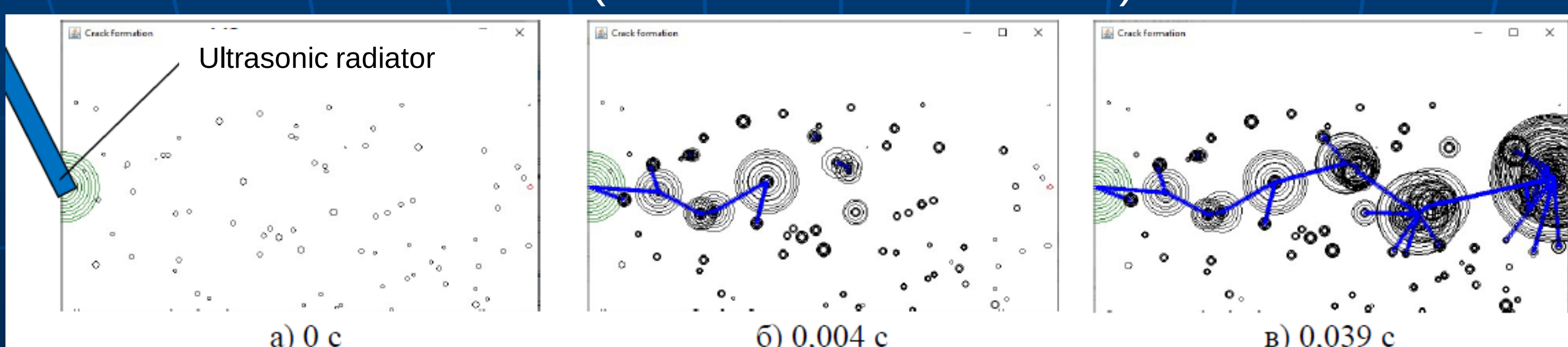


Visualization of microtrack forming process in solid soil

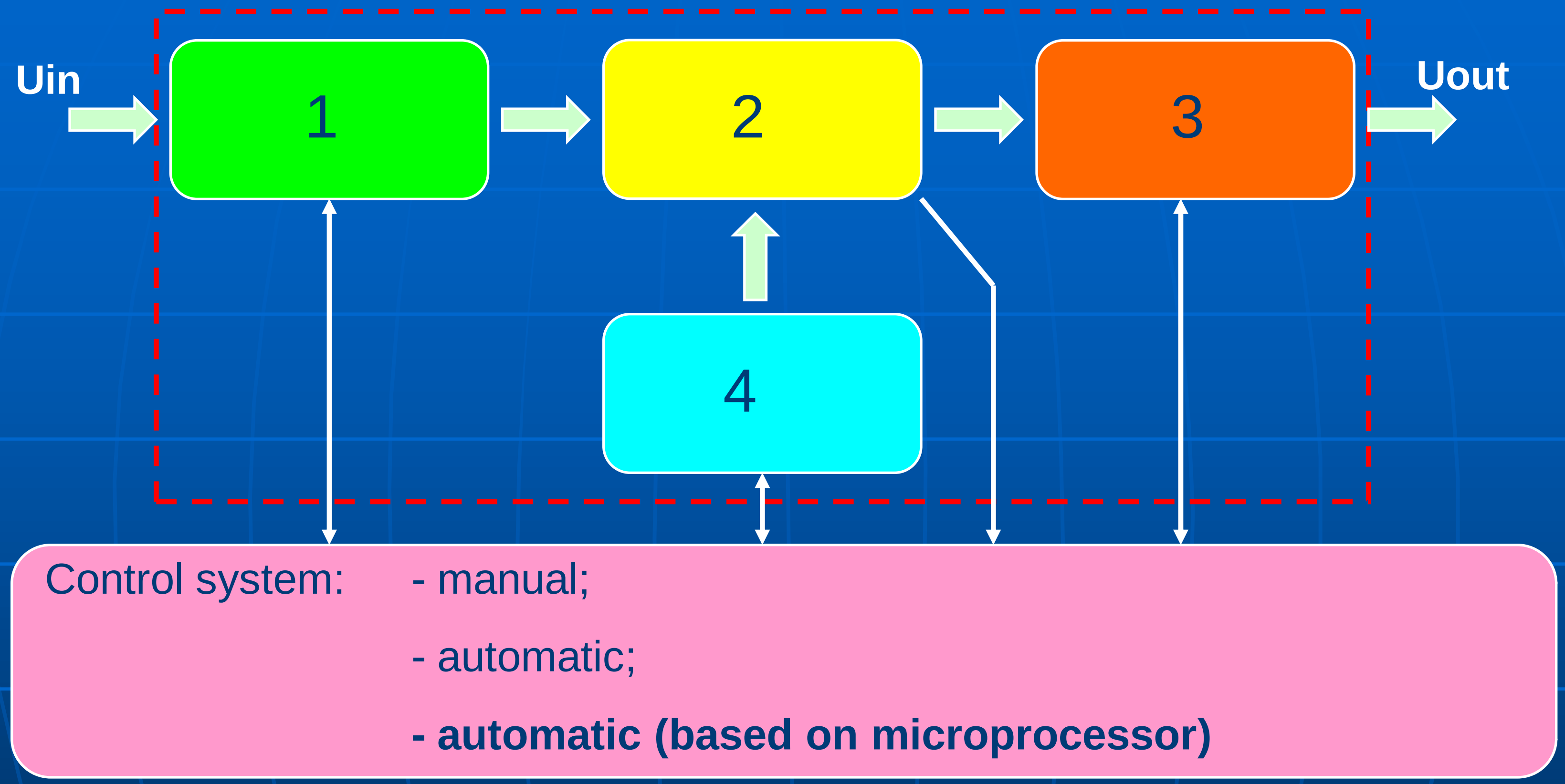
Classic ultrasonic exposure



Ultrasonic exposure with low-frequency impacts
(from attached free mass)



Structure of ultrasonic electronic generator



1 Input power circuit.

2 HF converter.

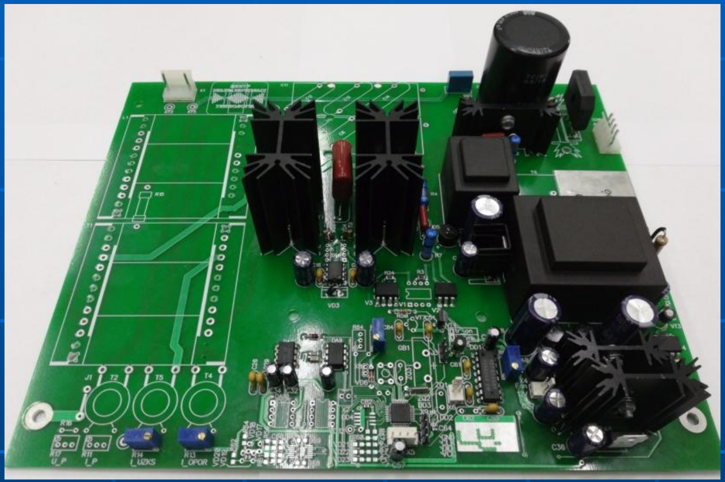
3 Matching network.

4 Controlled low voltage generator of ultrasonic band

Uin, Uout – input and output generator voltage

Ultrasonic generator main function

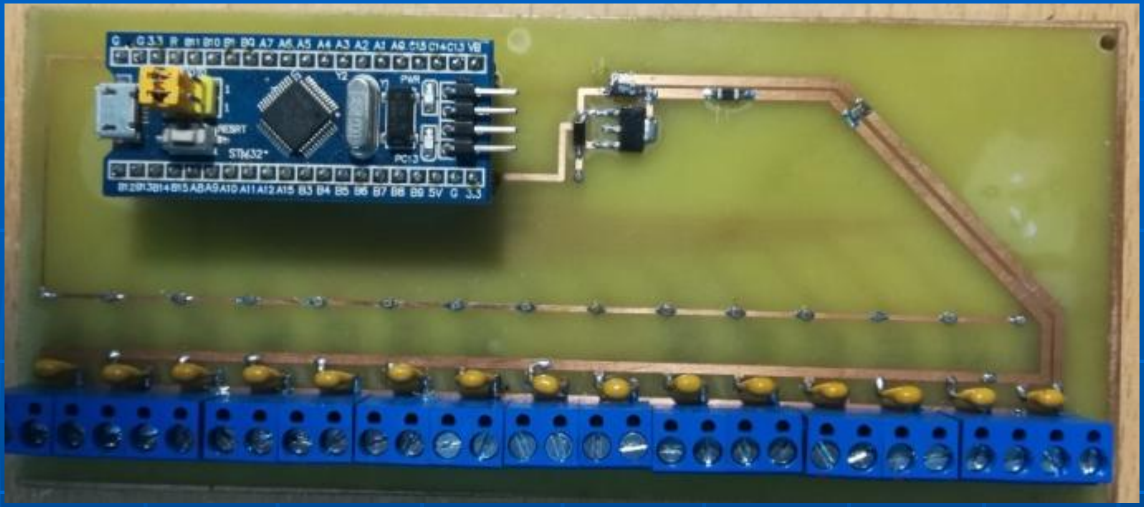
Main board



Features :

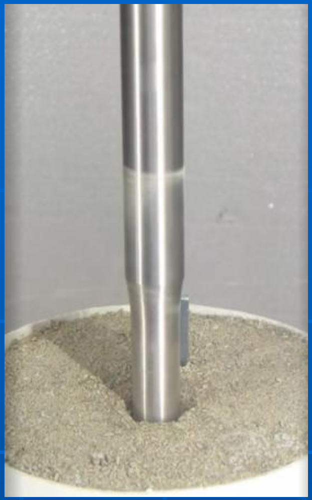
- Control unit: microprocessor;
- Microprocessor type: stm32f103;
- Amplitude stabilization: present;
- External control: present;
- Resonance loss restart system: present;
- Vibratory system type: piezoelectric;
- Power supply : AC power;
- Automatic frequency control system: present;
- Transducer parameter monitoring system: present;
- Power measuring: present;

Data collection module



Ultrasonic drilling at low temperatures

a) 0 min

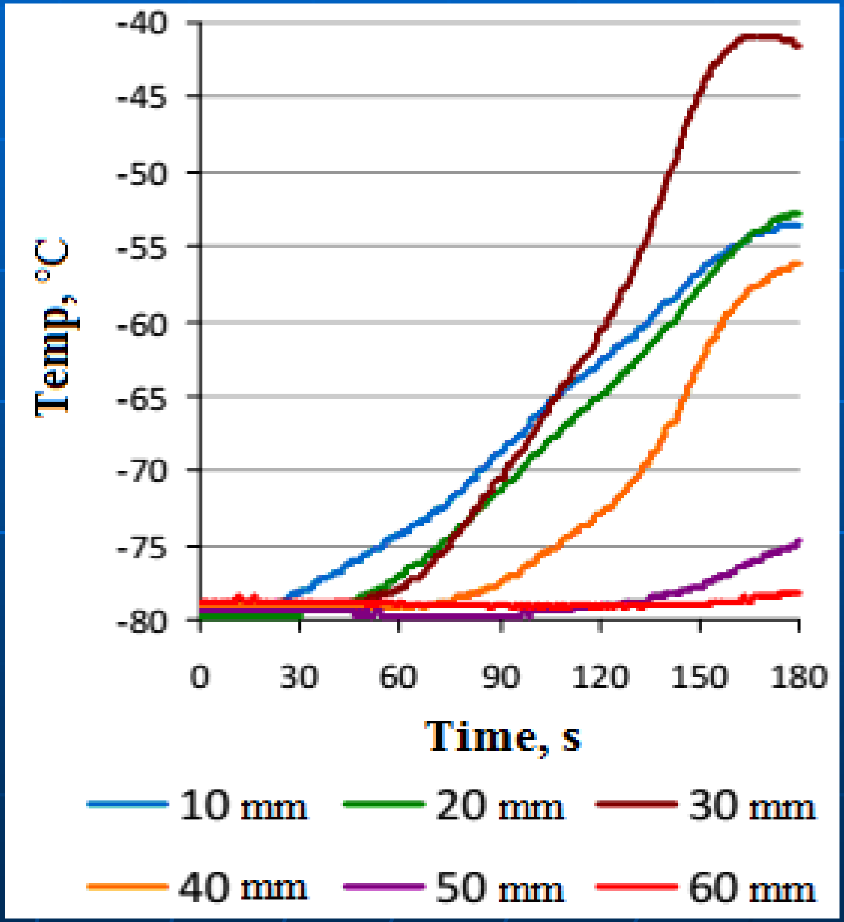


b) 0.5 min

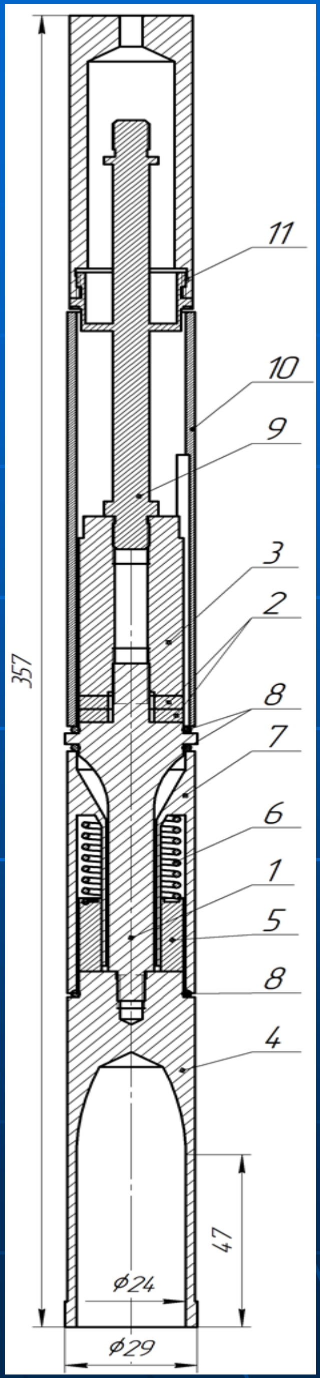
c) 1 min

d) 2 min

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



Ultrasonic vibratory system for drilling of ground (scheme)



1-3 – piezoelectric transducer;

4 – working tool;

5 – free mass;

6 – spring;

7 – case;

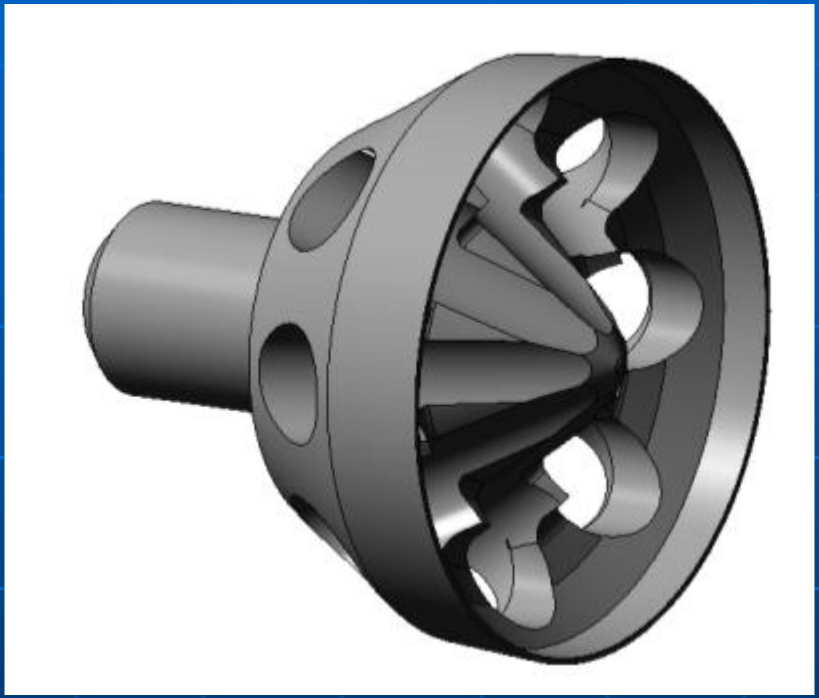
8 – ring rubber seals;

9 – half-wave resonant sonotrode;

10 – transducer case;

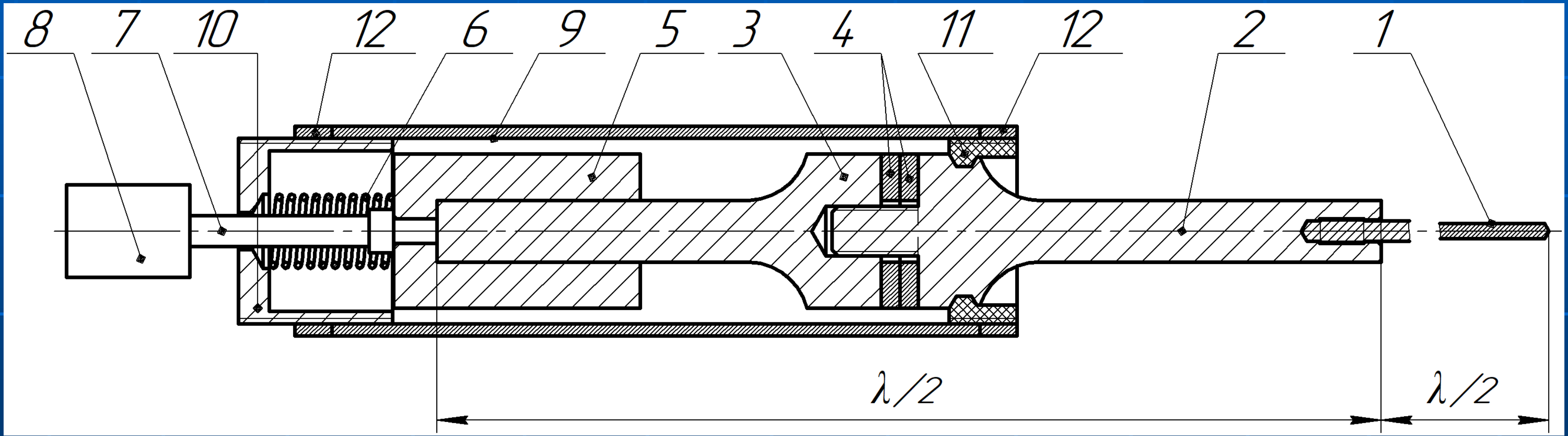
11 – bracket.

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

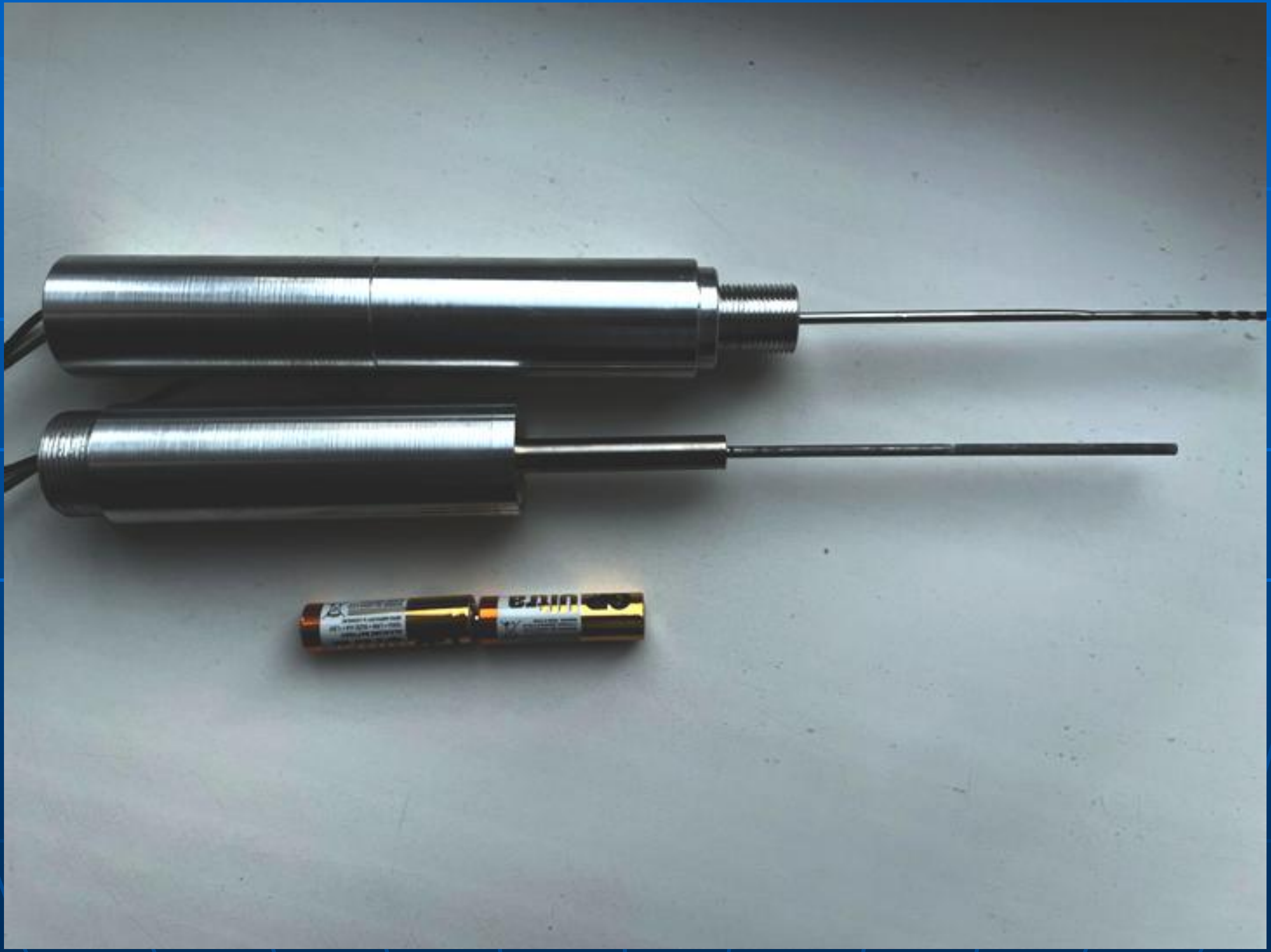


Features:
- Outer cutting part for channel formation
- Internal working cavity for additional soil destruction
- Holes for the exit of crushed soil from the working cavity

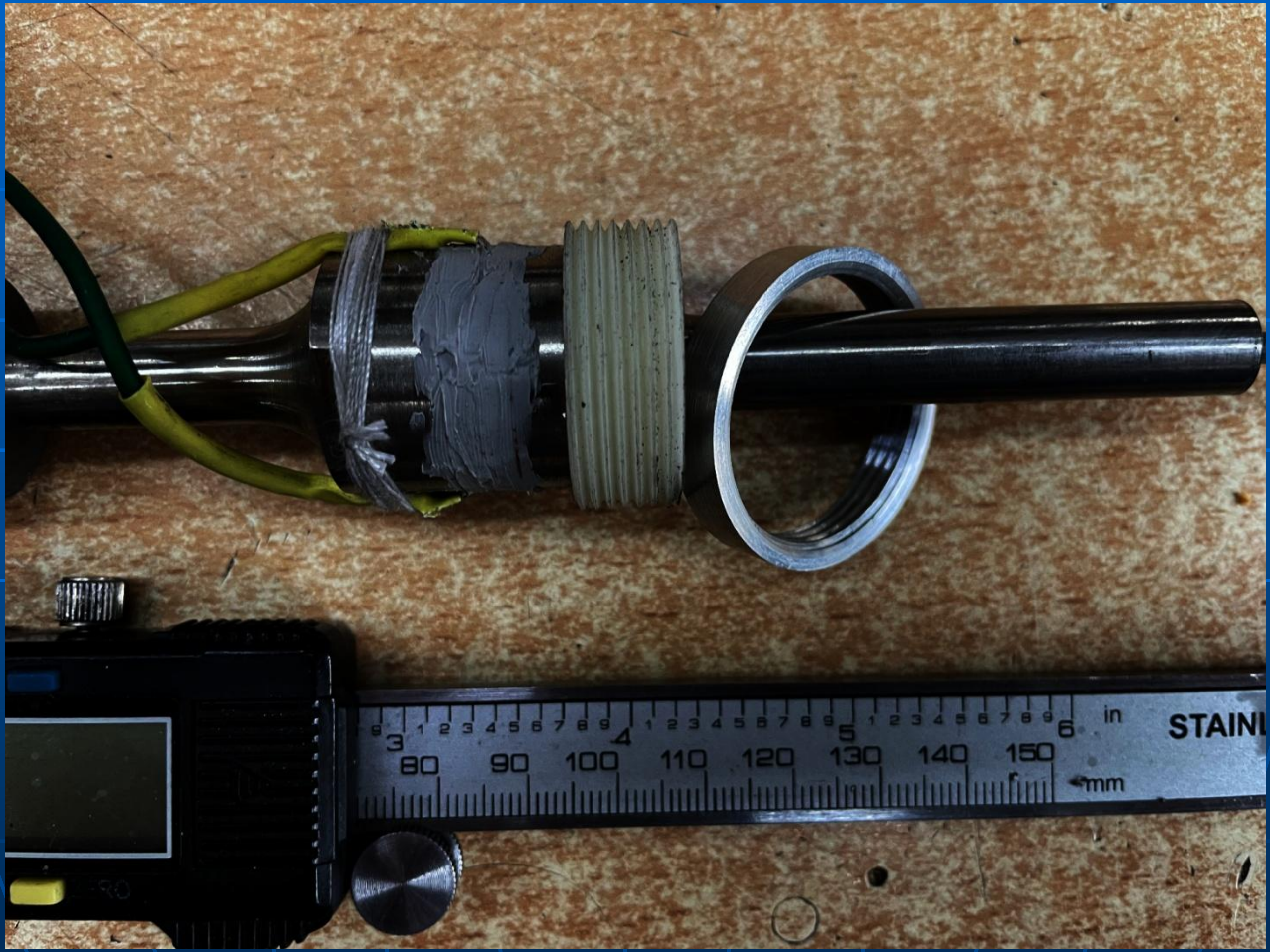
Small-sized ultrasonic drill



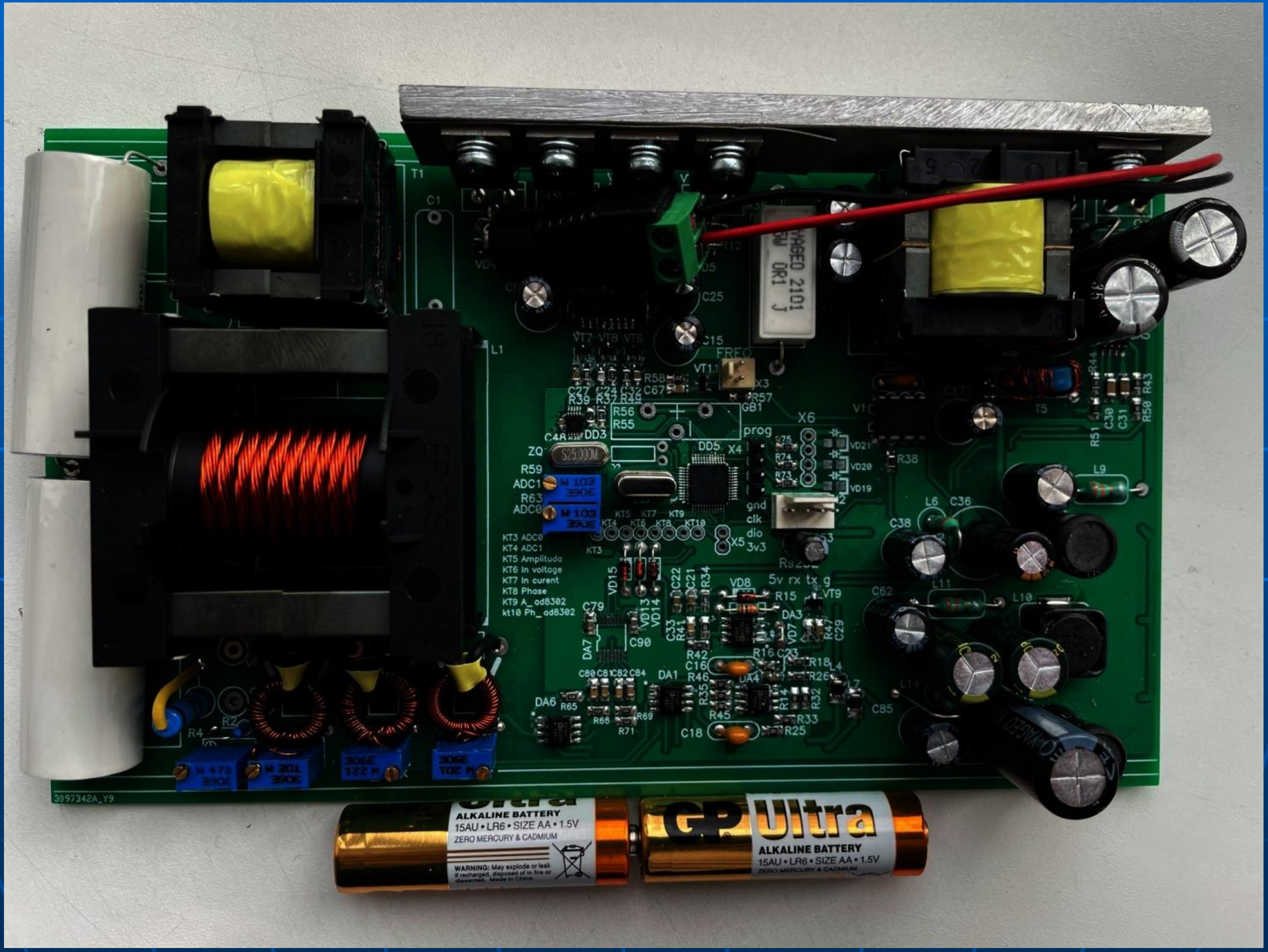
Appearance of ultrasonic drill



Construction of ultrasonic drill



Electronic generator board



Complete of drilling device