The Development of Experimental Sample of Ultrasonic Equipment for The Intake of Lunar Soil

Vladimir N. Khmelev[1], *Senior Member, IEEE*, Viktor A. Nesterov[1], S*tudent Member, IEEE,*
Sergey S. Khmelev[1], Dmitry V. Genne[1], Sergey N. Tsyganok[1], Valery I. Kostenko[2]
[1]Center of Ultrasonic Technologies, Biysk, Russia
[2]Space Research Institute Russian Academy of Science, Moscow, Russia

***Abstract* – The article is devoted to the development of experimental sample of ultrasonic equipment for carrying out investigations on drilling of the simulator of lunar soil. Carried out studies show possibility in principle of drilling of the simulator (intake) of lunar soil at application of ultrasonic vibrations on working tool.**

***Index Terms* – Ultrasound, transducer, drilling, working tool, lunar soil.**

I. INTRODUCTION

DRILLING of nonterrestrial soil by making holes of small diameter and intake of samples without changes of their structure and composition remains one of the most difficult problems at the investigation of the surface of other planets [1].

It is known, that at the application of drilling and mortising equipment the most thermo loaded areas are the contact zones of the tool with processed material. Such processing requires significant hold-down pressure of the tool and it is characterized by high heating of processed soil and high values of consumed power.

That is why, one of the main problems appearing during the intake of samples in nonearthy conditions is the imbility to provide undamaged state of frozen and volatile components in taken samples due to intense heating of working tool owing to friction.

In this connection one of the most perspective way of the perfection of the technology of holemaking of small diameter for the intake of the samples of nonterrestrial soil is application of high-intensity ultrasonic vibrations on working tool. The perspective of the method is caused by its certain advantages, which are the following:

- high speed of drilling at relatively low power consumption;
- insignificant pressing force of working tool to soil;
- low energy liberation for heating of working tool and processed soil;
- absence of damage of the structure and composition of studied material;
- low wear of working tool.

II. PROBLEM DEFINITION

As it is known at the application of ultrasonic vibrations on working tool for drilling there are some disadvantages:

- decrease of drilling speed with increase of depth of drilling due to damping of the tool;
- heating owing to the friction of the tool and processed soil and absorption of vibrations;
- insufficient heat removal from working tool due to low heat conductivity of titanium alloys, that causes the use of steels and leads to decrease of drilling productivity.

In this connection there is a need to develop model samples of the equipment for drilling of the simulator of lunar soil, carry out laboratory tests of functional possibilities of developed sample for further analysis and formulation of proposals on practical realization of the design equipment for the fulfillment of tasks in nonearthy conditions.

III. THEORY

1 The Development of Model Sample of The Ultrasonic Vibrating System

Model sample of the equipment for carrying out ultrasonic drilling of the simulator of lunar soil should have an ultrasonic vibrating system with the piezoelectric transducer transforming electric energy into energy of high-intensity mechanical vibrations of ultrasonic frequency and an electronic generator intended for power supply of the transducer. In this connection the development of separate elements and units of the model sample is considered further.

1.1 The Development of The Piezoelectric Transducer

Piezoelectric transducer used in ultrasonic equipment are resonance systems operating at the frequencies of the main resonance. More often compound or packet transducers (Langevin transducers) are used. Such transducer is compact, has high efficiency, it matches well with different removable tools.

At the development of the piezoelectric transducer as well as other components of the ultrasonic vibrating system the calculation is carried out with the help of the procedure of engineering calculation proposed in the works of different authors [2] – [5].

Developed construction of the piezoelectric transducer is shown in Fig. 1.

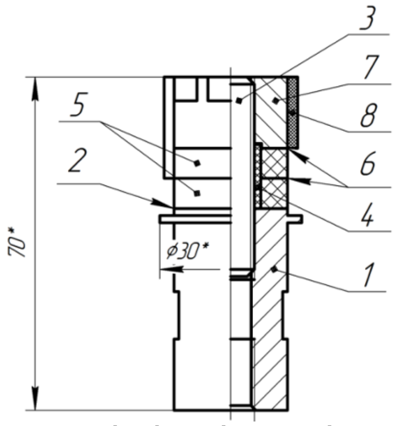


Fig. 1. Developed piezoelectric transducer.

The transducer consists of a quarter-wave frequency lowering radiating cover plate 1, ring copper spacer 2, tightening pin 3, insulating tube 4, piezoelectric elements 5, ring copper spacers – electrodes 6, reflecting frequency lowering cover plate 7, insulating elements 8.

At the development of the transducer piezoelectric elements of the size 24x12.6x6.35 obtained by the modification of standard piezoelectric rings with standard size of 38x12.6x6.35 of the mark ARS-841 [6]. Used piezoelectric material is characterized by high piezoelectric modulus, high Q factor, low dielectric loss, low hygroscopicity, comparatively high electric and mechanical strength.

The attachment to the piezoelectric elements 5 additional masses of frequency lowering cover plates increases total height of the half-wave transducer and reduces its frequency. Radiating cover plate 1 in developed transducer is made of aluminum alloy (D16T), and reflcting cover plate is made of steel (Steel 45). Such choice of the material provides the increase of the efficiency of the transducer (rise of amplification coefficient) regarding to wave resistance of reflecting and radiating cover plates.

The increase of the efficiency of the transducer is provided due to the fact, that piezoelectric elements are clamped between radiating cover plate 1 and reflecting cover plate 7 with the force, which multiply exceeds the value of alternating force generated by the piezoelectric elements. Tightening force is provided by reflecting frequency lowering cover plate 7 and the pin 3.

The correction of the transducer sizes defined by the procedures of engineering calculations was carried out with the help of the programs based on the finite-element method (FEM). Modeling of the operation of the ultrasonic vibrating system was realized in the system of “AUTODESK INVENTOR”. The development of 3-D solid models of the units of the ultrasonic vibrating system was carried out by the CAD system “KOMPAS-3D”. For design automation well-known approach [7] – [8] was used. Obtained model of the transducer with the distribution of vibrations along acoustic axis is shown in Fig. 2.

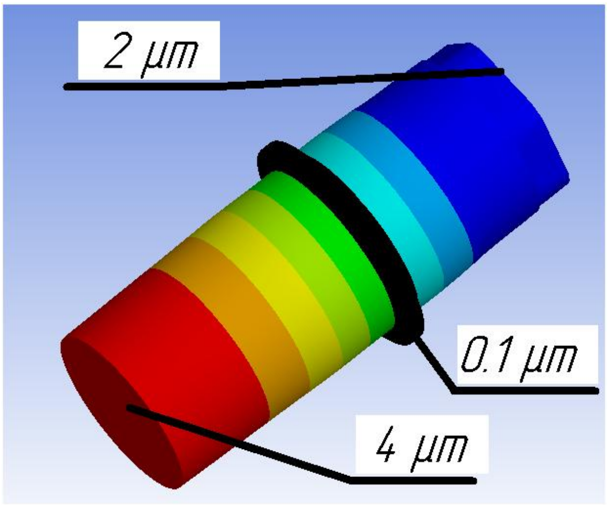


Fig. 2. The results of modeling of the transducer.

For assembling of the ultrasonic vibrating system into technoloquipment fastening belt placed in the minimum of mechanical vibrations (“vibration zero”) of the transducer can be used.

From Fig. 2 it is evident, that fastening belt is located in the minimum of mechanical vibrations (0.1 µm), that excludes transfer of ultrasonic vibrations to the elements of the body and the constructions.

1.2 The Development of The Transformer of Vibrational Speed

Transfer and simultaneous concentration (gain) of acoustic energy (vibration amplitude) from the end radiating surface of the piezoelectric transducer to working tool are realized through the transformer of vibrational speed – concentrator. The necessity of the application of the concentrator is caused by the impossibility of the increase of vibration amplitude generated by the radiator made according Lagevin circuit.

In the general case the concentrator is a cross-section rod, in which vibrational energy density is distributed uneven along the length. At small output cross-section the speed decreases and displacement amplitude rises.

The calculation of the concentrator for solving of stated task was carried out by well-known procedures [9] – [10] and then it was specified according to the results of modeling.

Developed construction and the appearance of the concentrator made of titanium alloy VT-5 is shown in Fig. 3.

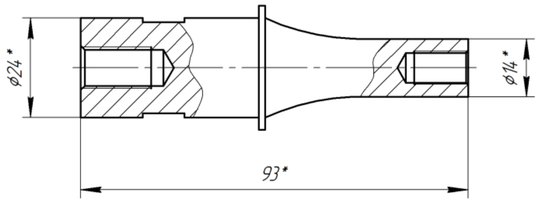


Fig. 3. Developed concentrator.

In the case of errors in the determining of the location of the fastening belt there is a danger of transfer of mechanical vibrations to the construction elements of the technological equipment and it reduces efficiency of ultrasonic influence. To avoid such errors and correction of the concentrator sizes modeling with the help of finite-element method was carried out.

Obtained model of the concentrator with the distribution of vibrations along the acoustic axis is shown in Fig. 4.

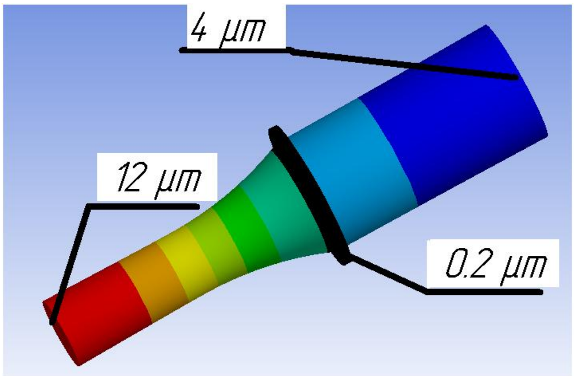


Fig. 4. The results of modeling of the concentrator.

Obtained results prove the possibility of practical application of developed concentrator and the use of fastening belt for additional fastening.

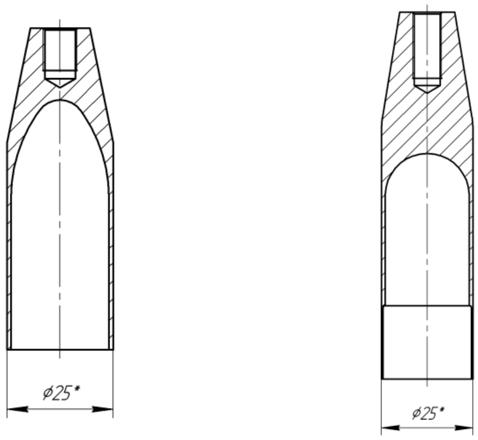
1.3 The Development of Working Tool

The piezoelectric transducer provides the formation of mechanical vibrations, the concentrator amplifies received mechanical vibrations and delivers them to working tool, which realizes ultrasonic influence on processed medium.

To provide the possibility of drilling and intake of soil two types of active working tools with internal profile of cross-section were developed. Constructive view of proposed tools is shown in Fig. 5.

The application of the tools of such construction allows to get additional vibration transformation ratio and improves strength properties of the tool in the place of transition to the thin wall.

As a material for the production of working tool steel (Steel 45) is chosen, as it is characterized by high wear resistance and high heat conductivity.



a) variant №1 б) variant №2

Fig. 5. Proposed types of working tools.

For the choice of optimum variant of the construction of working tool the amplitude of mechanical vibrations at the end of working edge was measured by stroboscopic method [11] – [12], and thermal conditions of the tool operation at normal conditions caused by the internal friction loss were studied.

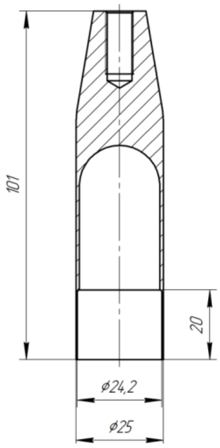
The results of carried out investigations of developed types of working tools are given in summary Tab. I.

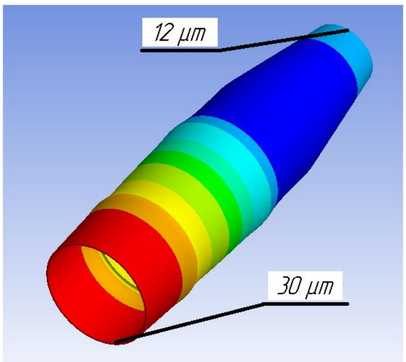
TABLE I
THE STUDY OF CHARACTERISTICS OF WORKING TOOLS

Characteristic	Value	
	Variant №1	Variant №2
Amplitude of mechanical vibrations, μm	20	30
Heating temperature of the tool, °C	55	45

As it is evident from the Tab I working tool of Variant 2 is more suitable for solving of stated task.

Fig. 6 shows constructive view (a), developed model (b) and the appearance of developed working tool (c).





a) constructive view b) model of the tool

в) appearance of developed working tool

Fig. 6. Developed working tool.

1.4 The Development of The Construction of The Ultrasonic Vibrating System in a Whole

The development of all components lets begin the design, matching and adjustment of final construction of the ultrasonic vibrating system.

The construction of the ultrasonic vibrating system is presented in Fig. 7.

It consists of a piezoelectric transducer in the case 1, a concentrator 2, tightening pin (M10x1.25) 3, multi hal-wave wave-guide 4, tightening pins (M8x0.75) 5, working tool 6.

The presence of the case in proposed construction provides the protection of the staff against electric injury and the possibility of introduction of power cable through the cable inlet. The presence of the multi half-wave wave-guide 4 is necessary to prevent heat transfer from piezoceramic elements to working tool and increase drilling depth. Turning of external surface of the wave-guide was not realized in order to increase heat elimination from its external surface.

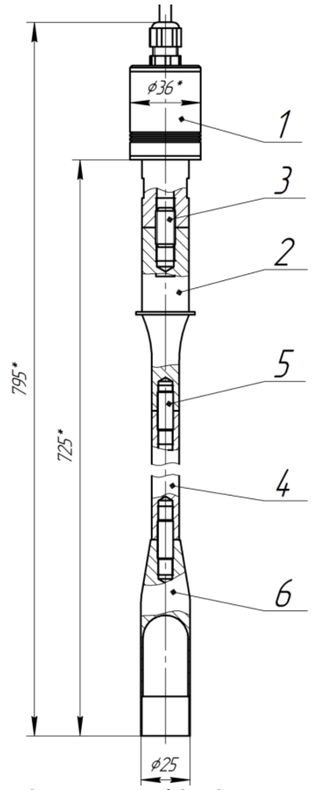


Fig. 7. Developed construction of the ultrasonic vibrating system.

Performance features of developed ultrasonic vibrating system are given in Tab. II.

TABLE II
PERFORMANCE FEATURES OF DEVELOPED ULTRASONIC VIBRATING SYSTEM

Feature	Value
Resonance frequency, kHz	30.73
Maximum amplitude of mechanical vibrations, μm	30
Mass, gr	950
Overall dimensions, mm * – of the case	25 (36*)x795

1.5 The Measurements of The Parameters of Model Sample of The Ultrasonic Vibrating System

For carrying out comparative measurements of the parameters of developed model sample to be exact vibration amplitude of radiating surface and resonance frequency of vibrating system measuring apparatus was made including low-voltage generator, to which vibrating system, piezoelectric probe with dry point contact connected to the oscillograph were connected [13].

Tab. III gives the results of measurements of resonance frequency of the elements of model sample of the ultrasonic vibrating system and designed resonance frequency of developed model of the ultrasonic vibrating system.

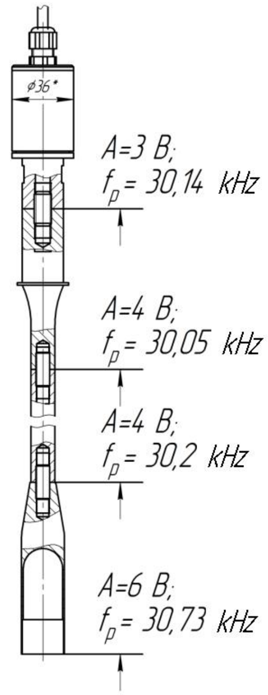


Fig. 8. The results of measurements of the parameters of model sample of the ultrasonic vibrating system.

TABLE III
THE RESULTS OF MEASUREMENTS OF RESONANCE FREQUENCY OF THE ELEMENTS OF DEVELOPED ULTRASONIC VIBRATING SYSTEM

Element	Frequency value f_p (kHz)	
	Theoretical	Practical
Piezoelectric transducer	30.27	30.14
Piezoelectric transducer + concentrator	30.16	30.5
Piezoelectric transducer + concentrator + spacer	29.5	30.2
Piezoelectric transducer + concentrator + spacer+ working tool	30.5	30.73

From the results of measurements it follows, that resonance frequency of each element differs from the calculations carried out with the help of engineering procedure and finite-element method no more than in 5 %. Attachment of each element does not bring essential frequency mismatch, that proves the accuracy of carried out calculations.

1.6 Carrying Out of Thermal Design of Developed Construction of The Ultrasonic Vibrating System

To exclude the possibility of destruction of volatile compounds (water) it is necessary to provide specified thermal conditions of the operation of vibrating system. That is why, while modeling there were following initial conditions:

– initial temperature of the parts of the construction was -130ºC;

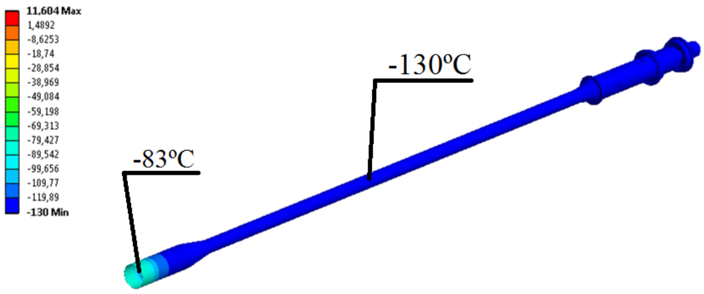
– there was no heat convection in environment;

– heat removal from working tool by porous soil is small and it was not taken into account;

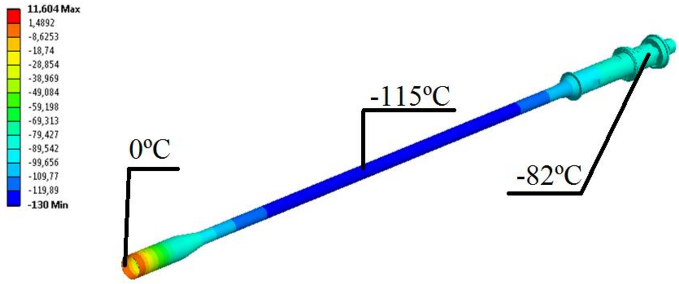
– internal generate of heat on working tool (internal friction in metal talking into consideration friction of soil on the tool) did not exceed 15 W.

Given quantity of heat is calculated according to following conditions. Mean consumed power of the ultrasonic vibrating system should not exceed 30 – 35 W. If the efficiency of the system is 50 %, the power supplied to the zone of drilling does not exceed 15 – 17 W. It is considered, that all energy is liberated in the contact zone of working tool with soil.

The results of thermal design of the operation of working tool are shown in Fig. 9.



a) in 14 sec after the begining of influence (maximum temperature on the tool was – 83 ºC)



b) in 950 sec after the begining of influence (maximum temperature on the tool was 0 ºC)

Fig. 9. The results of thermal design.

From the design it follows, that transition point through zero (water evaporation) at specified initial conditions takes place in 950 sec after the begining of drilling.

1.7 The Model Sample of The Ultrasonic Equipment

As a result of the work model sample (see Fig. 10) for the studies of possibilities of drilling of lunar soil simulator and intake of the samples in the form of cores using the application of ultrasonic vibrations on working tool was designed.

Fig. 10. The appearance of the experimental model.

IV. Experimental Results

2 The Investigation of Functional Facilities of Developed Model Sample of The Ultrasonic Apparatus

To define facilities of developed model sample laboratory researches on drilling of the simulator of lunar soil were carried out.

2.1 Used Experimental Equipment, Materials and Research Procedure

For carrying out investigations as a sample (object for drilling – the simulator of lunar soil) foamed concrete of the mark D400 was used.

To prove operating capacity and define performance features of the equipment a number of experiments were carried out, they were devoted to the definition of:

- drilling speed depending on amplitude of mechanical vibrations;
- temperature conditions of drilled sample;
- consumed electric power of the model sample.

Research procedure is drilling by end edge of working tool. For this purpose the tool is placed to the surface of drilled sample and pressed with the force of 5 – 10 kg, then mechanical vibrations are generated, under their action the destruction of the sample in contact zone of end part of working tool takes place with gradual penetration of the tool into the sample.

The illustration of the process and results of drilling is shown in Fig. 11.

Fig. 11. The drilling process of foamed concreteblock.

2.2 The Study of Temperature Conditions of Sample Drilling

To define temperature conditions measurements of the temperature of drilled sample were carried out. For this purpose the channel was made in foamed concrete, then thermocouple was placed there at the distance of 5 mm from the surface of the sample. It was drilled around placed thermocouple for 1 minute. The illustration of the temperature check place is shown in fig. 12.

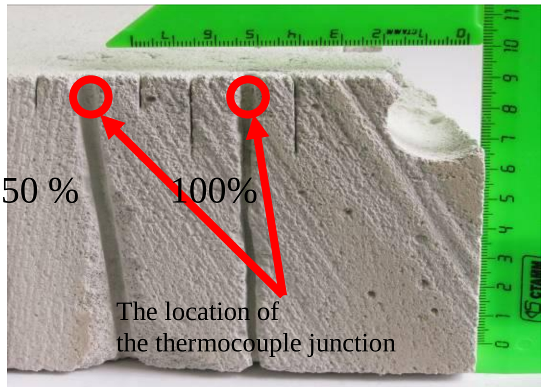


Fig 12. Cross cut of the sample (drilling was made at 50% and 100% of amplitude of ultrasonic vibrations).

For full view on temperature conditions the measurements were carried out at different levels of mechanical vibration amplitude.

The results of measurements allowed to state, that changes of temperature did not exceed 10°C at ultrasonic influence with 100% of amplitude, 7°C for influence with 75% of amplitude and 6°C for 50% of mechanical vibration amplitude.

2.3 The Definition of Drilling Speed

The measurements of drilling speed were carried out by measuring of depth of the track (length of drilled sample) obtained for 1 minute. The results are shown in Fig. 13. As it is evident from the Fig. 13 drilling speed changes in time (decreases), it is caused by damping of the walls of working tool, as it is deeped into the sample.

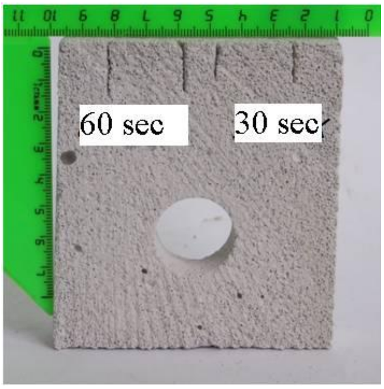


Fig. 13. Cross cut of drilling in the block, if drilling time was 60 and 30 sec.

Measurements of drilling speed, as well as temperature of the sample were carried out at different levels of mechanical vibration amplitude corresponding to 100%, 75% and 50% of maximum value. Measured values of drilling speed are 25, 13 and 9mm/min, respectively.

2.4 The Definition of Consumed Electric Power

The measurements of consumed electric power were carried out by the analyzer of quality of electric energy MT 1010 of the firm Motech [14].

Consumed electric power was 45W at maximum amplitude, 41W at 75% and 33W at 50% of mechanical vibration amplitude.

2.5 The Results and Recommendations

Tab. IV gives the results of the definition of different drilling parameters depending on mechanical vibration amplitude (maximum vibration amplitude corresponding to 100% was 28 – 30 µm).

TABLE IV
THE RESULTS OF MEASUREMENTS OF CONSUMED ELECTRIC POWER

Characteristic	Value		
Specified value of power, (%)	100	75	50
Average consumed power, (W)	45	41	33
Temperature in the center of the sample at the begining of drilling, (^{0}C)	24	24	24
Temperature in the center of the sample at the end of drilling, (^{0}C)	34	31	30
Drilling time (min)	1	1	1
Depth of drilling (mm)	25	13	9

Thus drilling was made upto the step on the internal surface of working tool at a depth of 25 mm with further breaking off and removing of the core. That is why, at the use of model sample to achieve great depths it is necessary to remove serially soil from the drilling zone.

VI. CONCLUSION

During the work the model sample of ultrasonic equipment was designed and it was determined the possibility of drilling of the simulator of lunar soil with the application of vibrations on working tool. At that following tasks have been solved:

1. The ultrasonic vibrating system has been developed, which is able to provide ultrasonic influence with an amplitude of upto 30 µm, that can be guaranteed by optimal performance and matching of working tool, multi half-wave wave-guide, concentrator and piezoelectric transducer.
2. The electronic generator is designed for power supply of piezoelectric elements of the ultrasonic vibrating system, which helps to provide stabilization of modes of operation, such as frequency and required mechanical vibration amplitude, at the presence of influences of temperature, load and other parameters of environment with minimized power consumption.
3. Carried out studies show the possibility of drilling of the simulator of lunar soil with maximum drilling speed of 25 mm/min at consumed power of 45 W.

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Vladimir N. Khmelev (SM'04) is deputy director for scientific and research activity at Biysk technological institute, professor and lecturer, Full Doctor of Science (ultrasound), honored inventor of Russia, laureate of Russian Government premium for achievements in science and engineering, IEEE member since 2000, IEEE Senior Member since 2004. His scientific interests are in field of application of ultrasound for an intensification of various technological processes. His biography published in 7th issue of book "Who is who in scientific and engineering".

Viktor A. Nesterov has got engineer's degree on information science and measuring engineering at 2010. He is post-graduate student of Biysk Technological Institute.. His research interests is finite-element modeling and designing ultrasonic oscillation system.

Sergey S. Khmelev has got engineer's degree at 2007 and Philosophy degree at 2011. He is leading specialist in development of ultrasonic vibration transducers, docent and lecturer in Biysk Technological Institute. His research interests are in field of designing and modeling of ultrasonic vibration transducers and in ultrasonic treating of high viscous liquid media.

Dmitry V. Genne has got engineer's degree on information science and measuring engineering at 2006. He is engineer and lecturer in Biysk Technological Institute. He is leading specialist in controlling of treating parameters of variously applied ultrasonic equipment. His research interests are in development of high -power electronic generators for ultrasonic technological devices.

Sergey N. Tsyganok has got engineer's degree at 1998 and Philosophy degree at 2005.He is leading specialist in designing of ultrasonic vibration transducers, laureate of Russian Government premium for achievements in science and engineering, docent and lecturer in Biysk Technological Institute. His research interests are in designing of ultrasonic technological equipment and in applying of ultrasonic vibrations of high intensity for intensifying of technological processes and for changing of materials and substances properties.

Valery I. Kostenko Doctor of technical sciences, head of the Laboratory of technological support of scientific experiments Space Research Institute RAS. He graduated from the Moscow Aviation Institute at 1962. His research interest is space equipment.