

Impact of Ultrasonic Exposure on Soil Adhesion to Working Bodies of Earth-Moving Machines

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Abstract - When the moist cohesive soil is excavated, the soil sticking and freezing to the working units of the earth-moving machines take place, which considerably reduces their efficiency. There are four main groups of methods intended for eliminating adhesion of soil to the surface of the working bodies of earth-moving machines. As for the nature and the operating principles of the methods, they can be divided into the preventive methods and the means for cleaning working units of earth-moving machines. PM3-4/18 (IIM3-4/18) magnetostriction transducer was used in the experiment as a source of ultrasonic oscillations. Ultrasonic exposure belongs to a group of combined methods of eliminating adhesion. In order to evaluate efficiency of ultrasonic exposure the experiments were carried out on shear bench. Environment temperature range for the experiments was limited from -25 to +15 °C. Ultrasonic exposure allows reducing soil adhesion to working bodies of earth-moving machines due to thermal and vibrational impact on contact surface.

Keywords – soil adhesion, magnetostriction transducer, ultrasonic exposure, combined methods.

I. INTRODUCTION

Mine excavators operating trial shows that when exploiting wet cohesive overburden rocks (especially under subzero temperature) freezing over and adhesion of ground on working bodies vaguely reduces machinery performance (figure 1). This performance decrease is caused by reduced useful capability of a bucket because of incomplete unloading, increase of cutting (digging) drag force resulted by wet ground adhesion to working tool, growth of ram drag of a bucket, longer machine downtime required for cleaning working tools [1-12].

There are four groups of ways to eliminate soil adhesion to working bodies of earth-moving machines [6]: methods of creating an intermediate layer at the interface of the contact; methods that promote the weakening of adhesion bonds due to external (intensifying) influence; constructive-technological methods; combined methods.

As for approach and principle of operation methods and ways of eliminating, soil adhesion and freezing to working bodies of earth-moving machines can be categorized as preventive ones (for eliminating adhesion proactively) and means for bucket cleaning (recovering evacuating property of soil). Combined methods that are conjoin advantages of two or more other methods are proved to be the most efficient ones,

vibrothermal method in particular [2.5.9.12]. The paper discusses applying ultrasonic treatment which is one of combined methods, as it conjoins high-frequency vibration and heat.

II. MATERIALS AND EQUIPMENT FOR RESEARCH

PM3-4/18 magnetostriction transducer was used as a source of ultrasonic oscillations for the experiment with operating frequency 18 ± 1.35 kHz. Operational heating temperature of the magnetostriction transducer can reach 90 °C, therefore it belongs to the group of combined methods of eliminating soil adhesion to working bodies of earth-moving machines.

UZG 3-4 (Y3Г 3-4) ultrasonic generator was used for converting electrical energy with industrial frequency into electrical energy with ultrasonic frequency and feeding the magnetostriction transducer.

The experiments for evaluating operating efficiency of PM3-4/18 magnetostriction transducer were carried out on a shearing bench, schematic circuit of which is shown on figure 2.

The bench (figure 2) consists of metal framework 1 with adjustment screws 2 and guide rails 4, fixed to the framework by bolt fixtures 3. A carriage 5 can slide along vertical axis using rolls 6 and has PM3-4/18 magnetostriction transducer 7 attached, with thermally insulated shroud 8 and emitting surface 9 (made of 12H18N9T (12X18H9T) steel). There is also a bottomless tubular yoke 10 which houses concentric extractor ring 11 and a molding tool 12 with cover cap 13. The molding tool 12 is rigidly connected to a bar 14 which can move vertically along pilot brush 15, fixed on the framework 1, and has a joint connection to a loading lever 16 that has a stand 17 on the loose end with replaceable loading weights 18. Bottomless yoke 10 is connected to the framework 1 by pins 19 and adjustable nuts 20 and is equipped with thermally insulated shroud 21 and two bolts 22 for fixing the extractor ring 11. The ring 11 is made of shock-resistant high-pressure polyethylene and has inner diameter which equals to outer diameter of the molding tool 12. The tool is hollow and has two holes 23-24 for coolant (50 % ethylene glycol solution) intake and output. The airtight cover cap 13 of the molding tool is made of material (copper, $\lambda=384$ Wt/(m · K)) that has

higher thermal conductivity than the molding tool itself (steel 45, $\lambda = 47 \text{ Wt/(m} \cdot \text{K)}$).

The cavities of the molding tool 12 and the shroud 8 of magnetostriction transducer 7 are filled with coolant (50 % ethylene glycol solution) and connected between each other by thermally insulated tubes via a t-valve 25, a cooler 26, a tap 27 with coolant storage tank 28.

All bench elements containing the coolant and the tubes are thermally insulated with mineral wool mats (GOST 21880-86 (GOST 21880-86)) and foamed polystyrene (GOST 15588-86 (GOST 15588-86 (GOST 15588-86))), coated with aluminum foil.

Coolant storage tank consists of two cylindric containers. The inner container is made of carbon steel 20. Tubes that connect the inner container with the environment are made of copper-nickel alloy with low thermal conductivity. 30 mm interstitial space is filled with 2.5 kg of mixture of aerogel with bronze powder. Trim materials in tube junctions are frost-resistant rubber 14K-10 and FUM seal tape, which can stand temperature drop up to 210 K without losing its sealing properties.

The carriage with the magnetostriction transducer 7 is connected through the load cell (model ST) 29 to the drive mechanism 30 consisting of a traction winch, a P-21 (P-21) DC motor (powered from the mains via a RNO-250-2 (RNO-250-2) transformer and a power diodes rectifier VL-200 (VL-200)), worm-gear reducer RCh-3 (PЧ-3), V-belt drive, cam clutch located on the winch shaft.



Fig. 1. Excavator bucket with frozen over soil.

The stand is equipped with a set of strain gauges 31 (an electronic dynamometer DOR-3-5I (ДОР-3-5И)) and a device for measuring temperature and humidity 33 (with thermal moisture meter CENTER 315).

The research of the effect of ultrasonic exposure on

adfreezing strength between soil and metal surface is carried out as follows.

Carriage 5 with magnetostriction transducer 7 is set beyond the yoke in the extreme right position, while the lever 16 with the bar 14 and the molding tool 12 is set to the uppermost position and fixed. Ring 11 with the soil being tested is put into the yoke 10 and fixed with the bolts 22. Then the carriage 5 is placed under the center of the ring 11 with the soil sample. Bolt fixtures 3 are loosen up and the rails 4 are adjusted using the screws 2 with an angle, when the emitting surface 9 becomes parallel to the ring 11 with the soil sample. Pins 19 and nuts 20 are used to make a gap enough to insert thermal-insulation blanket (not shown on the figure). Bolt fixtures 3 are tightened afterwards.

With the help of the t-valve 25 and thermally insulated tubes coolant is fed from the tank 28 to the cavities of molding tool 12 and shroud 8 of the magnetostriction transducer 7 simultaneously or separately depending on the required experiment conditions. The lever 16 and the bar 14 are used to bring the cap 13 of the molding tool 12 (which is coated by thin layer of glycerin beforehand in order to prevent freezing) into contact with the soil sample. Via the cap 13, which is made of material with higher thermal conductivity than material of the molding tool 12, thermal exchange takes place – the soil sample is cooled down by the coolant to the temperature required. Emitting metal surface 9 is cooled down to the temperature required by feeding the coolant into the cavity of the shroud 8 of intensifying influence source 7.

After cooling down the soil sample and emitting metal surface 9 to the temperature required, the lever 16 is moved to the uppermost position. The yoke 10 with the ring 11 and the soil is lifted using the nuts 20 and the thermal-insulation blanket is removed. By lowering the lever 16 the soil sample in the ring 11 is moved via the bar 14 and the molding tool 12 until it touches the emitting surface 9. Thus, the temperature conditions required are provided in the shearing area.

Coolant temperature, which defines the temperature conditions required in the shearing area, is regulated by the cooler 26 (liquid nitrogen), which contacts the coolant, while its flow is controlled by the taps 25 and 27. Temperature of the coolant, soil sample and the emitting surface 9 is controlled and measured by a device for temperature measurements using contact method (thermal moisture meter CENTER 315).

Contact time between the material and the emitting surface is controlled by using a timer according to the terms of the experiment.

Specific pressure of the soil sample to metal emitting surface 9 of the magnetostriction transducer 7 is passed to the soil sample via the molding tool 12, the bar 14 and the loading lever 16. This pressure is adjusted by changing replaceable weights 18 on the stand 17.

Piezoceramic radiators 7 are powered by the ultrasonic generator 32 (UZG 3-4), and the drive mechanism 30 for moving the carriage 5 is switched on. At the same time a set of

telemetry equipment 31 is used to keep track of soil shearing force. Shearing occurs along the contact surface of the soil sample with metal emitting surface 9. The maximum contact area required for the experiment equals to the area of a circle with the inner diameter of the extractor ring 11. This condition is reached by setting the emitting surface 9 in parallel to the extractor ring 11 with the soil sample. The carriage is stopped automatically by a limit switch which is connected to the electric circuit of drive mechanism 30 DC motor.

Shear velocity is defined by rotation speed of the DC motor of the drive mechanism 30 and can be adjusting by altering voltage in the actuating coil. During the shear, rigid fixture between the pilot brush 15 and the frame 1 increases total rigidity of bench elements that hold the extractor ring 11 with the soil sample in horizontal position in parallel to the emitting surface 9.

When the experiment is finished, the ring 11 is cleaned from the soil. In order to do that, the carriage 5 is moved to the extreme right position, and the soil is removed from the ring 11 by the molding tool 12 and surcharge weights. The lever 16 is then switched to the uppermost position and fixed, and the bench is ready to a new experiment.

Soil shearing on the metal without intensifying influence is carried out in the same manner when the magnetostriction transducer 7 is switched off.

Thermal insulation of both the shroud 21 and the shroud 8 with the tubes that are used for supplying the coolant prevents freeze leaks into the environment.

Movable connection of the bar 14 with the option of vertical movement in the pilot brush ensures constant centering of the molding tool 12 in the yoke 10 which allows to pass the loading along the bar axis exactly perpendicular to the shearing plane during the experiment and increases convenience of mounting the ring 11 with the soil sample in the yoke 10 when preparing the bench for the experiment.

The extractor ring 11 is made of plastic, which prevents soil adhesion and freezing over. Presence of thermal-insulation layer between the ring 11 with the soil sample and the emitting metal surface 9 prevent them from freezing to each other too early.

Shearing resistance was chosen as a response function (optimization parameter) for the influence of factors defining of the system under research. Shearing resistance meets all the requirements for optimization parameters: versatility; its capability to be expressed with a single term and quantitative presentation; statistical efficiency and easy computability; simplicity; existence for all possible conditions.

The effect was evaluated according to ratio magnitude of conditionally momentary distribution freezing coefficient. This coefficient is considered to be equal to shearing force τ , at the beginning of soil sample movement along the operating surface, which is defined by the following formula [6]:

$$\tau = \frac{P_s}{S},$$

where P_s – force required for soil sample shearing along the metal surface, N; S – operating area of the frozen soil sample, m^2 .

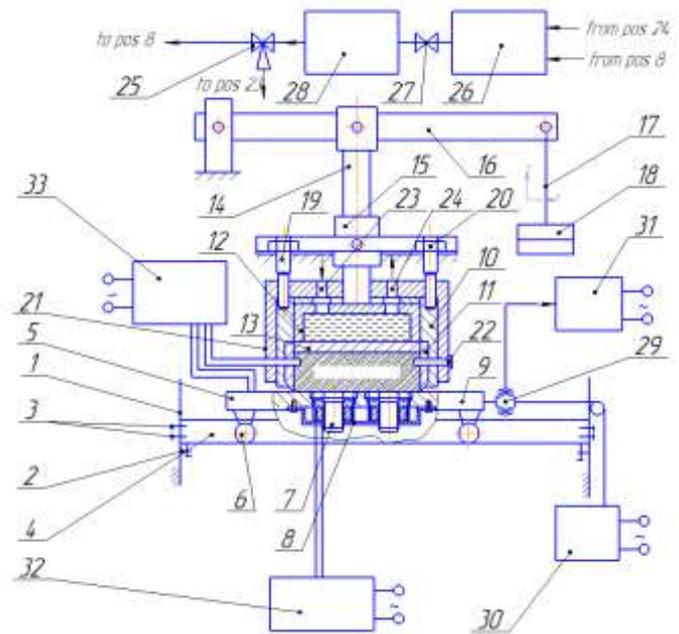


Fig. 2. Schematic circuit of experimental shear bench for researching influence of ultrasonic exposure on soil adfreezing strength.

The experiments were carried out with various environment temperature, from -25 to $+15$ °C. The soil chosen was dispersive cohesive loam with 20% moisture. Pressure between soil and the surface of PM3-4/18 transducer – 10 kPa, duration of contact between the soil and the surface – 10 min., soil temperature before touching transducer surface – 5 °C.

III. THE RESULTS OF THE EXPERIMENT

Figure 3 presents heating temperature of magnetostriction transducer versus operation time under various environment conditions (1, 2, 3, 4, 5 – environment temperature 15, 5, -5 , -15 , -25 °C accordingly).

As the figure shows, the magnetostriction transducer takes 8 to 11 minutes to heat up to 80 °C depending on environment temperature. The lower environment temperature is, the longer it takes for the transducer to heat up. Environment temperature difference of 40 °C corresponds to 3 minutes of difference in time required to heat the transducer up.

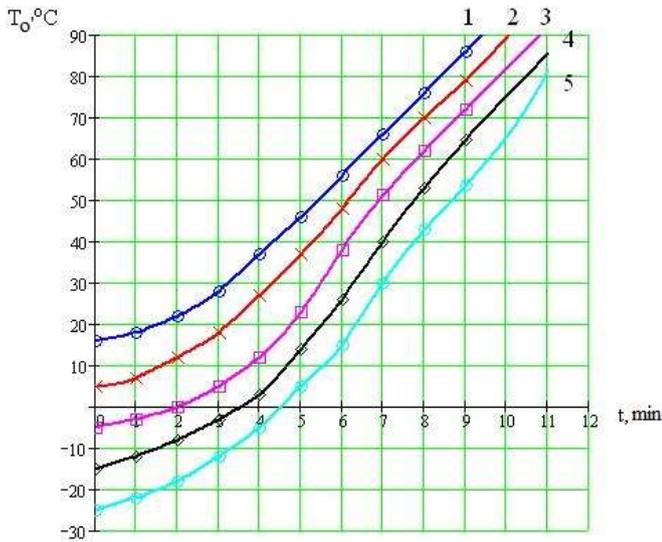


Fig. 3. Magnetostriiction transducer heating temperature versus its operating time.

Figure 4 shows relations between tangential shearing force of soil along metal surface and temperature of contact surface. Temperature increase from 0 to 80 °C results in a 2...2.2-time decrease of shearing force between soil and metal surface under thermal and ultrasonic exposure.

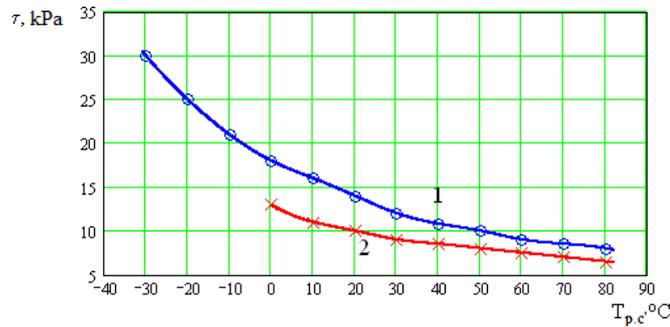


Fig. 4. Relations between tangential shearing force of soil along metal surface and temperature of contact surface (1 – heating ENGL-1 (ЭНГЛ-1) 24 V; 2 – with ultrasonic exposure by PM3-4/18).

One of the criteria for evaluating efficiency of complementary equipment is its energy density. Energy density of soil shearing process along metal surface is defined by the following expression [12]:

$$N_{den} = \frac{N_{tot}}{S_{sh}},$$

where N_{tot} – total power required for the shearing process, kWt; S_{sh} – area of soil sample, m².

Total power consumption for the shearing process under thermal exposure:

$$N_{heat} = N_{h.el.} * K_t + N_{sh},$$

where $N_{h.el.}$ – power of heating elements, kWt; K_t – coefficient that takes into account effective operating time of the elements; N_{sh} – power required for the shearing, kWt.

$$N_{sh} = \frac{A}{t} = \frac{P_{sh} * L}{t}$$

where A – work required for the shearing, kJ; t – shearing process duration, sec; P_{sh} – shearing resistance under the corresponding exposure (according to experiment results), kN; L – sample shift, m.

Total power consumption with ultrasonic exposure:

$$N_{tmt} = N_{te} * K_t + N_{ug} + N_{sh},$$

where N_{te} – total power of magnetostriction transducers, kWt; N_{ug} – power of ultrasonic oscillations generator, kWt.

Total power consumption for shearing process with acoustic exposure:

$$N_{ace} = N_{ae} * K_t + N_{nc} + N_{sh},$$

where N_{ae} – power of acoustic emitter, kWt [12].

Total power consumption for shearing process with low-frequency vibration exposure:

$$N_{VL} = N_{VG} * K_t + N_{sh},$$

where N_{VG} – power of vibration generator drive, kWt.

Results of calculating energy density of soil shearing process along metal surface with freezing and its dependency on temperature in the shearing plane are presented as graphs $N_{ed} = f(T)$ on figures 5-8. Analysis of the characteristics has proved energy density under ultrasonic exposure to be 10...15% lower than energy density under acoustic and thermal exposure.

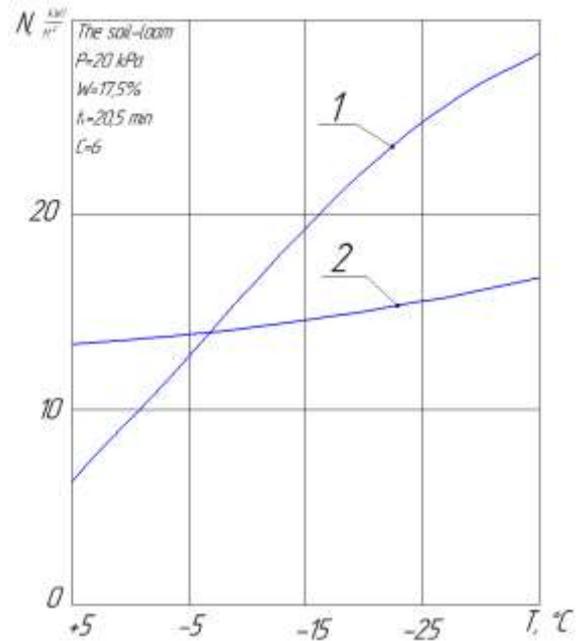


Fig. 5. Energy density of soil shearing on metal surface versus temperature in the shearing surface: 1 – without external influence; 2 – under thermal exposure ($T=85^{\circ}C$; $t_{exp}=26$ sec).

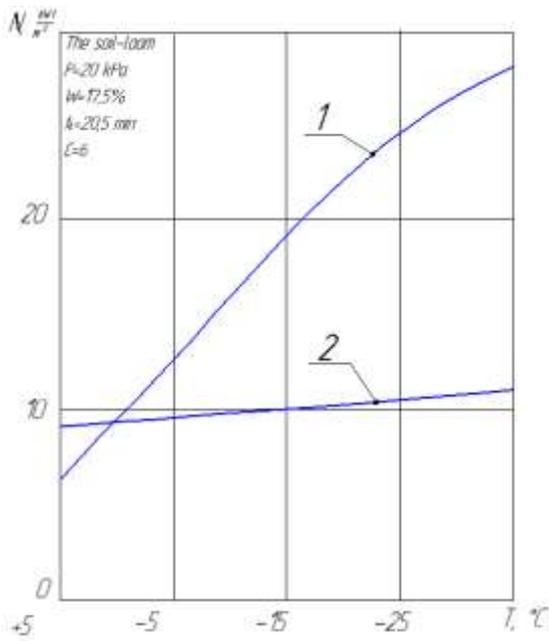


Fig. 6. Energy density of soil shearing on metal surface versus temperature in the shearing surface: 1 – without external influence; 2 – under ultrasonic exposure ($F=18 \text{ MHz}$; $A=0.005 \text{ mm}$; $T=20^\circ\text{C}$; $t_{\text{exp}}=15 \text{ sec}$).

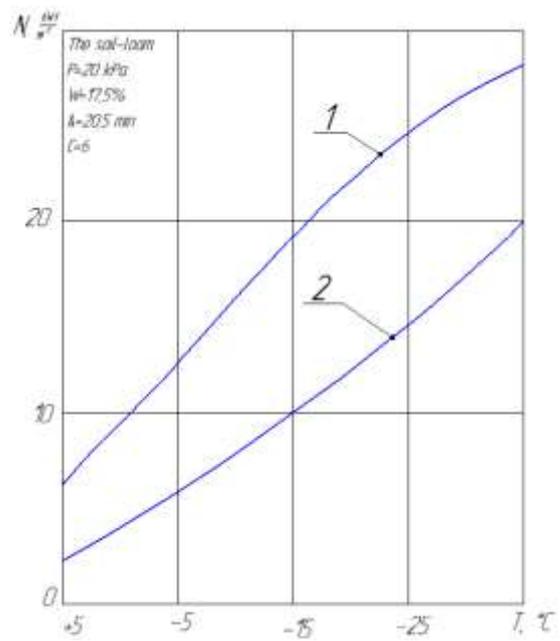


Fig. 8. Energy density of soil shearing on metal surface versus temperature in the shearing surface: 1 – without external influence; 2 – under low-frequency vibration exposure ($F=50 \text{ Hz}$; $A=2.35 \text{ mm}$; $t_{\text{exp}}=22 \text{ sec}$).

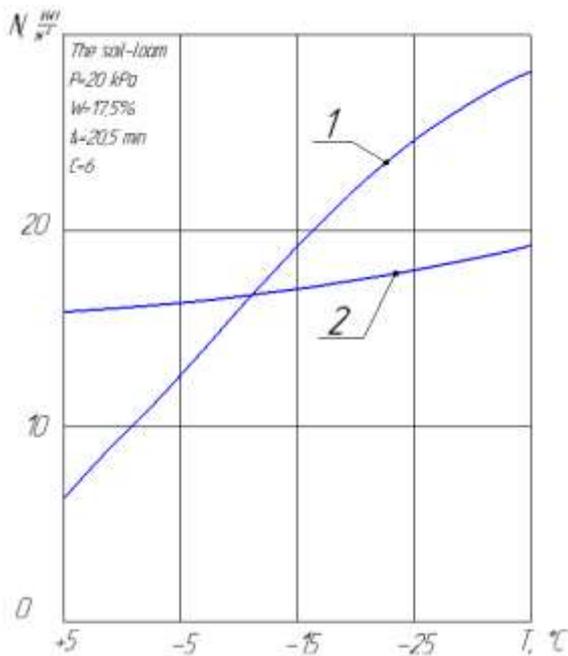


Fig. 7. Energy density of soil shearing on metal surface versus temperature in the shearing surface: 1 – without external influence; 2 – under high-frequency acoustic exposure ($F=5460 \text{ Hz}$; $A=0.16 \text{ mm}$; $t_{\text{exp}}=25 \text{ sec}$).

IV. CONCLUSION

Ultrasonic exposure reduces soil adhesion to working bodies of earth-moving machines due to thermal and vibration impact on the contact surface. In comparison with thermal exposure [6,10] by flexible electrical trace heating tapes (ENGL-1) applying the PM3-4/18 magnetostriction transducer to contact the surface with the temperature from 0 to 80 °C allows one to reach a 15...35 % decrease of shearing force. The most significant decrease takes place with the temperature from 0 to 30 °C.

Energy density of the shearing process under combined ultrasonic exposure is 10...15% lower than the energy density under acoustic and thermal exposure.

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