Method of studying the movement of the impact device case in the well taking into account the reaction of the rock massif

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Abstract A technique of experimental study of the movements of the impact device case in the well has been developed, including the use of “low-frequency” (current-vortex) displacement sensors and “high-frequency” (accelerometers) acceleration sensors. After registration, software signal processing was performed, including double integration of accelerations and determination of points of interface of displacements obtained after integration and direct registration. Oscillograms of measurements at different values reaction from the rock mass are given. The quantitative aspects of the phenomenon are discussed, and an attempt is made to identify the relationship between the quantitative indicators of impact pulses and the movement of impact device body.

1. Introduction
One of the problems that arise when drilling and using special equipment in already drilled wells is its jamming during technological operations [1–3]. This leads to the loss of the equipment used and the failure of the well, which significantly increases the cost of work. Similar problems arise when laying underground utilities in the ground using special impact devices – pneumatic perforators [4–7]. The use of impact devices, including reversible ones [8], to solve these and other similar tasks allows many times to increase the efforts applied to the equipment to release it and effectively overcome jamming.

For a correct understanding of the processes occurring during the moving of the impact device in the well or ground, it is necessary to know the real dynamics of its body by the action of shock loads. For this purpose, the stand and the methodology for studying the dynamics of the body of an impact device were developed when exposed to shock load and friction force.

2. Stand and experimental technique
The stand for modeling the movement of the body of the impact device in the well is a clamping device assembled on a common base with a mock-up of the body with an anvil and a pendulum coper (Figure 1). The base 1 is fixed with bolts on a metal table, which in turn is rigidly attached to a massive concrete base. The pendulum coper consists of a frame 2 and a shock mass (striker) 3 suspended from the frame on steel strings. The clamping device consists of a frame (interconnected by four hexagonal rods of metal plates) fixed on the base 1.

A ring with a punchen 10 is fixed to the lower plate. Holder-segments with inserts made of model friction material 11 were inserted into the ring. A mock-up of the impact device body 5 with an anvil 4 was placed between the friction inserts. A bolt 8 was screwed into the upper plate and created a
force acting through a measuring dynamometer 9, on puncheon in the ring 10, which pushed on the holder-segments with inserts 11. Friction force clamped the mock-up of the impact device body 5. The bolt 8 was screwed into the upper plate and pressed through the measuring dynamometer 9 on the puncheon in the ring 10, which pressed on the holder-segments with inserts 11. The friction force clamped the mock-up of body 5.

Figure 1. Photos of the stand: a – general view, b – clamping device
1 – base; 2 – frame with suspension; 3 – striker; 4 – anvil; 5 – mock-up of the impact device body; 7 – clamping device frame; 8 – bolt; 9 – dynamometer DOSM-3-5; 10 – ring with a punch; 11 – holder-segments with friction inserts; 12 – optical sensor for measuring the pre- and post-impact velocity of the striker (two pairs “laser – photodiode”); 13 – accelerometer Kistler Type 8042; 14 – displacement sensor IPIE-50.

The schema of the experiment is shown in Figure 2. In the experiments, the striker 3 was raised to a fixed height. After it was dropped and hit the anvil 4, fixed in the mock-up of the body 5.

Figure 2. Experimental scheme: 3 – striker; 4 – anvil; 5 – mock-up of body; 9 – dynamometer (DOSM-3-5); 10 – ring with puncheon; 11 – holder-segment with friction
inserts; 12 – optical sensor for measuring the pre- and post-impact speed of the striker (two pairs of “laser–photodiode”); 13 – accelerometer (Kistler Type 8042); 14 – displacement sensor (IPIE-50); 15 – charge amplifier (Kistler Amplifier Type 5001); 16 – matching device; 17 – analog-to-digital converter (L-Card E-440); 18 – personal computer.

The special joint of the suspension with the striker allowed to separate them at the moment of impact. The impact device body model of was held in the holder inserts by frictional force. Kistler type 8042 accelerometers 13 were attached to opposite ends of these elements by threaded joints and were used to record the accelerations of the striker and the mock-up of body. To determine the velocities of the striker before and after the impact, an optical sensor 12 was used, which is two pairs of "laser – photodiode" located in front of the anvil [9]. The displacement sensor 14 (IPIE-50) was used to register the movement of the mock-up of body 5. The signals from the acceleration sensors 13 were converted by the charge amplifiers 15 (Kistler Amplifier Type 5001). The signals from the optical sensor and the displacement sensor were transmitted to the matching device 16. Then all the signals were transformed to the analog-digital converter L-Card E-440 17 and transferred to PC 18. PowerGraph 3.3 was used to process the experimental data. In the experiments, a cylindrical striker weighing 5.4 kg and a length of 520 mm was used, the mass of the mock-up of body with the anvil was 4.4 kg, and the length was 0.15 m.

3. Experimental results
During testing of the technique, experiments were carried out with a change the pressing force F on the holder-segments 11, which pressed body model 4 by the friction force. In the experiments, aluminum inserts were used. In Figure 3 shows the oscillograms obtained by result of the experiment in the PowerGraph 3.3 program.

![Figure 3. Oscillograms of signals recorded in the PowerGraph 3.3 program: aI * , aP * – respectively, acceleration of the mock-up of the impact device body 5 and striker 3; xI * – mock-up of body movement; sO * – signal from the optical sensor.](image-url)
After registration, the signals were pre-processed in PowerGraph 3.3: clearing of digital noise (Filter→noise filter function) and offset of acceleration signals (Data→OFFSET function).

Double integration of acceleration signals in the PowerGraph 3.3 program was not possible to achieve a satisfactory correspondence between the displacements of the body model and the displacements measured by the IPIE-50 displacement sensor directly. It seems to us, this is due to the well-known effect of signal zero displacement at shock pulses measuring by piezoelectric sensors. For correct processing of acceleration signals, a special program was developed in the C#. The input and output of data in special program was carried out from text files of the PowerGraph 3.3 program. A special program made possible to shift the initial data and data obtained as a result of processing at a certain point in time, integrate them and put on view graphs of accelerations, velocities and displacements. The integration was carried out using the trapezoidal method in the program.

Since the striker before impact had a certain constant (before impact) velocity $v_{P+}$, which was measured optical sensors, the value of striker velocity after integration was shifted on amount equal to $v_{P+}$. The displacement of the striker $x_{P+}$, obtained after integrating the velocity, was shifted in such a way that its coordinate at the moment of impact with the anvil was equal to zero.

Oscillograms from acceleration sensors attached on the striker and mock-up of body and results of the described integration procedure are shown in Figure 4. Graphs of speeds and displacements of striker and mock-up of body are shown solid lines, as well as mock-up of body displacements measured by the IPIE-50 sensor are shown dashed lines. For convenience, signals from acceleration sensors and graphs of velocities and displacements are shifted to the left along the time axis $t$ that the moments of arrival of their impact impulses coincide. The values offset for the acceleration signals were selected that the displacements of the mock-up of body obtained by integration and the displacements of the direct measurement approximately coincided with each other, and the velocities of the striker before and after impact coincided with the measurements of the optical sensor. The value offset of acceleration for the impact device body model was 0.02–0.07% from the maximum value, for the striker – 0.03–0.76%.

In the presented experiments, the pre-impact velocity of the striker $v_{P+}$ was 1.97 m/s on Figure 4a, 1.90 m/s (Figure 4b), 1.97 m/s (Figure 4c), the pressing force of holder-segment with friction inserts to the mock-up of body $F$ was 3.4 kN on Figure 4a, 6.8 kN (Figure 4b), 10.3 kN (Figure 4c).

From the curves $x_{I}$ displacement, you can see the displacement measured by the IPIE-50 sensor correlates quite well with the displacement obtained by double integrating the acceleration from the sensor located on the mock-up of body. The discrepancy between the results does not exceed 10% in the specific range. Smoothing the front of curve the signal of the displacement sensor by comparison with a similar signal obtained by integrating acceleration indicates unsatisfactory frequency characteristics IPIE-50 sensor (frequency range 0–600 Hz [10]). For comparison, the resonant frequency of the Kistler Type 8042 accelerometers is 100 kHz.

It should also be noted a significant decrease of the positive phase duration of the velocity signal of the of the impact device body model from ~ 3 to ~ 1.5 ms at an increase of the pressing force of the inserts to the body model $F$ from 3.4 kN (Figure 4a) to 10.3 kN (Figure 4c), at almost the same maximum speed equal to ~ 2 m/s. This indicates an increase in the stiffness of the system with increasing force $F$, which affects on the duration of the generated signal after the impact in this case.
Figure 4. Oscillograms of dynamic characteristics in a series of experiments by changing force $F$, acting on the impact device body model: $t$ – time; $a_I$, $v_I$, $x_I$ – acceleration and speed of the impact device body model and striker, respectively; $x_P$ – displacement of the body model, obtained by integration (——) and measured by the sensor (-----); $x_P$ – displacement of the striker.
4. Conclusions
The article presents a stand and a experimental technique for studies of displacement of the body of the impact device using accelerometers under conditions that simulate the movement of the impact device in the well when it is jammed.

Using the procedures of double integration of acceleration signals, it was possible to obtain displacement graphs that correlate satisfactorily with directly measured displacement oscillograms.

While integrating the initial acceleration signal, it was necessary to shift it along the ordinate; this is due to the well-known effect of "zero shift" by using sensors of this type for recording impact processes. The purpose of further improving the technique is to determine the accurate offset parameters. One way to overcome these difficulties for determining displacement using acceleration sensors may be to use sensors made MEMS technology, which are accelerometers "without the effect of zero offset".

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