The measurement of deformation of elastic shapers of various stiffness and assessment of the influence of shaper deformation on the parameters of the shock pulse

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Abstract. In this paper the influence of the deformation of the shapers of various stiffness on the vibration characteristics of the impact is estimated. In particular, the influence of the deformation on the high-frequency vibrations that appears during the operation of the shapers is also estimated. Both analytical and experimental results of measuring of deformation of shapers are presented. The structure of the model of the shock testing machine developed in Peter the Great St. Petersburg Polytechnic University is described in details. An algorithm for the analysis of vibration characteristics obtained during the tests on the model of an impact machine is presented. The results of studies of the characteristics of the materials which the shock pulse shapers are made of are presented. The life of the shapers made of various materials is estimated. Analytic and experimental dependences of the shaper deformation on the lifting height of the shock table are presented. Conclusions about the effect of shaper deformation on impact parameters are drawn.

1. Introduction

A significant number of the machines related to mining engineering during life cycle are repeatedly exposed to various kinds of influences and loads: climatic, vibrational, shock [1,2]. In particular, mountain-tectonic impacts, mountain impacts with destruction of formation soil, sudden gas emissions and other phenomena can cause such loads. To confirm the operability of the various mining equipment and its quality, impact tests are carried out [3,4]. Such tests are performed on special equipment – a shock-testing machine. The main requirement for testing impact machines reduces creating accelerations of an established shape, peak values and duration [5]. For multiple-hits testing, the acceleration pulse repetition rate is also normalized.

The relevance of shock machines research is due to the growing quality requirements for the equipment, the need to comply with international standards and insufficiency of theoretical recommendations for modeling shock pulses. Several monographs of famous authors are devoted to the theory of shock effects [6,7,8]. However, these works do not provide an assessment of the adequacy of mathematical models and their verification is not performed. The most important parameter of shock machines – speed of the table before impact and its influence on the testing output parameters (reproducible peak shock accelerations, pulse durations and pulses shape) is not considered. In the studies the influence of the construction of the stands on the impact parameters is not assessed, in particular, the influence of the deformation of the pulse shapers on the shape,
amplitude and duration of the shock pulses is not determined. The influence of the shapers' wear on the vibration characteristics of the impact, in particular, on the high-frequency vibrations appearing during the exploitation of the shapers, is not evaluated. Therefore, the studies on research of elastic shock pulse shapers and the influence of its features on vibration characteristic are relevant and in demand.

2. Equipment for impact tests and pulse measurement methods
To study the impact parameters, the High School of Automatics and Robotics of Peter the Great St. Petersburg Polytechnic University set the task to create a prototype of the machine for impact tests, which included all the elements of industrial stands and used a modern element base, but involved the operation in the laboratory of the High School [9,10]. Figure 1 shows a 3D model of the machine’s mock-up and directly, the layout itself, located in the mechatronics laboratory of Peter the Great St. Petersburg Polytechnic University.

![Figure 1. Shock testing machine mock-up: a – 3D-model; b – Mock-up in a laboratory of Peter the Great St. Petersburg Polytechnic University](image)

The control rack and the source of compressed air are powered by a three-phase 380V supply line. The source of compressed air includes a low-pressure compressor, a receiver to ensure the required air-flow rate and a filter to clean the air before its entering in the pneumatic network. The pneumatic automation unit consists of: an electro-pressure transducer that converts a continuous DC signal into a proportional pneumatically continuous signal, in other words provides pressure control in the pneumatic network. A pneumatic valve controls the direction of the flow of compressed air; The air preparation unit provides adjustment of air pressure and its filtration before entering the pneumatic suspension, consisting of four pneumatic cylinders. Using cylinders instead of air bags allows to widely adjust the stiffness of the air suspension. The fifth pneumatic cylinder provides vertical movement of the shock table and it is one of the most important elements of a real shock machine. When air is supplied to the rod end of the pneumatic actuator, the shock table rises to its full-up position. On switching the air distributor, the shock table falls under gravity on the shock pulse shaper which is fixed on the anvil. The anvil is rigidly mounted on the base. A quad incremental encoder, rigidly mounted on the shock table, sends a signal to the control rack with information about the height
of ascent of the shock table above the base. In addition, there is a vibro-accelerometer mounted on the shock table, which registers the acceleration pulse at the moment of table hitting the shaper. The stiffness of the air suspension is adjusted by a mechanical pressure regulator, which is part of the air preparation unit. The stand also includes a set of elastic shock pulse shapers of various stiffness which allow to create an impact pulses with different parameters. The analysis of obtained vibro-characteristic in accordance with international standards, is carried out in the sequence shown in Figure 2:

![Figure 2](image)

**Figure 2.** The sequence of operations for assessing the shape of the pulse: a - waveform of the initial pulse (acceleration – duration); b - identification of the average profile of the pulses; c - normalized pulse shape; d - assessment of the pulse shape.

In the developed mock-up of the impact testing machine, the measurement and analysis of the obtained impact characteristics are performed using the LabView software environment. At the first stage, the resulting vibration signal is smoothed using an inverse Chebyshev filter. Next step is the determination of the shock acceleration pulse peak, the start point and end point of the pulse are determined. Duration at a given level is defined as the time difference between the first occurrence of the desired signal value on the rising edge and the second occurrence on the descending edge. Then, real and smooth graphs of the shock pulse are displayed on the operator panel screen.
3. Elastic shock pulse shapers
The most important characteristics of shock machines are the shape, duration, and peak value of reproduced acceleration pulses [11,12]. The studying of impact kinematics is necessary for selecting both a pulse shaper and the type of a shock testing machine, which allows one to implement the necessary requirements for a shock. The most common type of shock is half sine. A half-sinusoidal pulse can be obtained by using elastic shapers, which are located between the table and the anvil. The shock pulse shaper is a cylindrical object made of an elastic material. If the upper part of the shaper is flat, significant high-frequency oscillations are observed at the beginning of the pulse, what complicates the determination of the initial point of the pulse. Therefore, the upper part of the shaper has a conical shape. It allows the shaper material to deform gradually under shock load, and the pulse shape is not distorted. A set of shapers manufactured at Peter the Great St. Petersburg Polytechnic University is shown in Figure 3.

![Figure 3. A set of shock pulse shapers](image)

The main variable parameters of the shapers in the experiments were height, polymer composition, and color. The color was referred to a certain Shore-A hardness and fitted with values of 65, 70 and 80 units. Shapers are made of elastomeric material glued to aluminum plates and have different heights: 20, 30, 50 mm. A large number of shapers provide a variety of combinations, and, consequently, a wider range of amplitudes and durations of shock pulses of a half-sinusoidal shape. Depending on the specific test setup and sample masses using shock pulse shapers with different parameters we obtained pulses of 3 to 50 ms duration and peak acceleration values of up to several hundred g. Shapers or shaper combinations can be mounted either on the anvil or on the bottom surface of the shock table, or on both places simultaneously.

4. Elastic shapers deformation measurement
There is a number of scientific publications devoted to the study of shapers [13,14,15]. However, at the present moment, there are no simple methods for selecting shapers which provide the required (specified during testing) parameters of shock pulses. The discrepancy between the parameters obtained analytically and experimental data is due to a number of reasons, including the wear of the pulse shapers and the neglect of the deformation of the shaper after impacts. The use of shapers with a deformed conical part leads to a noisy shock pulse and the high-frequency oscillations that impede the analysis of the received signal.

To assess the deformation of the shapers during an impact, it is necessary to evaluate the stiffness derivative of the material which shapers are made of. Samples for research are presented in Figure 4.
The experiments were carried out for samples of elastomeric materials, which are color-coded depending on the taken (maximum) dynamic load:

- yellow - Shore hardness – 80A, dynamic load is 9000 kgf;
- blue - Shore hardness – 70A, dynamic load is 8000 kgf;
- red - Shore hardness – 65A, dynamic load is 7000 kgf.

As a result of experimental studies, the dependences of the strains on the applied load during uniaxial compression of samples of elastomeric materials were found. The experiment was carried out at the Instron 5965 stand (Figure 5, a). The dependence of the deformation of the red material on the applied load is shown in Figure 5, b.

Using the obtained dependence allows to evaluate the nonlinearity of shaper stiffness characteristic for more accurate analytical calculation. The analytical dependence approximated by a second order polynomial of the shaper deformation on the height of the impact table with a mass of 8.6 kilograms is shown in Figure 6.
The experiments, carried out on the mock-up of the shock testing machine confirmed the analytical results with less than 10% divergence of results (figure 7):

Carrying out such studies allows one to evaluate the life of the shaper and to select more accurately the parameters of the shock pulse. Based on the obtained dependences, it is possible to estimate the number of experiments, after which the upper part of the shaper is deformed to an unacceptable state. Figure 8 shows the shock pulses with no filtering obtained experimentally. The parameters of the experiment are weight of the table – 8.6 kg; drop height of the shock table – 160 mm.
Figure 8. Impact impulse with different shaper wear-out: a – after 10 tests; b – after 200 tests

Experimental studies were carried out on the mock-up of the percussion machine presented above. It can be noticed that after several hundreds of tests the shaper deforms, the pulse amplitude decreases and high-frequency oscillations occur. In particular, when using a shaper with a hardness of 65A Shore (red) after 190 tests, the upper surface of the shaper is deformed by about one millimeter. As a result, there are noises that do not allow us to properly assess the signal level, since the vibration characteristic of the shock goes beyond the set values and the output signal does not correspond to the given half-sinusoidal shape. Previously obtained dependences allow one to evaluate the deformation of the shaper to correct the input experimental data. Also, it is possible to tentatively estimate the resource of the shaper before the direct impact tests.

5. Conclusion
Shock pulse shapers are consumables and it is extremely important to be aware of their service life. Carrying out experiments on the shaper materials and the shapers allows one to obtain dependencies on the basis of which it is possible to tentatively estimate the shaper resource, and adjust the experimental parameters for more accurate simulation of shock pulses taking into account the shaper deformation. The analytical dependence of the deformation, obtained from experiments of determining the stiffness of the material of the shaper, allows us to describe the mechanical model of the deformation of the shaper with an error of less than 10%, which points to the possibility of preliminary use of the analytical model in the manufacturing of shapers from the considered materials. The life of the shaper with a hardness of 65A (red) is approximately 190 strokes. The life of the shaper with a hardness of 70A (blue) is approximately 280 strokes. The life of the shaper with a hardness of 80A (yellow) is approximately 400 strokes. The result is presented for the following experimental parameters: the mass of the table is 8.6 kg., The height of the shock table is 160 mm. The use of the shapers above specified resource leads to the occurrence of high-frequency oscillations and the inability to process the obtained vibrational characteristics of the pulse. The results obtained in the process of the presented work allow one to optimize the time spent on the synthesis of the desired shock pulses and can be used for further research in the field of impacts.

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