USING PIEZOMETRY TO ASSESS THE DEGREE OF DEFORMATION MEASURING PROBES UNDER THE ACTION OF PULSED LOADS

M. Yu. Sotskiy, V.A. Veldanov, V. I. Pusev

Bauman Moscow State Technical University, Moscow, Russia

Introduction

A number of methods and technologies applied for investigating the kinematics of initial phase of functioning of an impulse device and its elements are known from the literature. One of the used variants of measuring technologies is the use of inertial measuring probes containing accelerometers in the housing, which record the parameters of the probe movement in the medium under study. The combination of the speed of approach of the probe body with the medium and the strength characteristics can cause plastic deformations of the body. The high degree of deformation of the body leads to errors in determining the values of the loads acting on the probe and the coefficients in the dependences of the dynamic strength resistance to penetration of the probe. The development of tools and technologies for the comprehensive study of percussion interactions is an urgent task for creating conditions for the safe exploration of outer space. Effective preparation of research missions using contact inertial probes is carried out using test benches that simulate the operation of dynamic contact sensing devices, taking into account the factors acting on the objects under study [1]. The mission specific tasks are:

- study of the dynamic mechanical properties of the surface and deep layers of planets and small celestial bodies;
- study of the processes of high-speed movement of probes in various rheological environments that make up an array of asteroids;
- penetration into small celestial bodies to prevent the danger of their collision with the Earth;
- penetration into small celestial bodies to study the composition of the body mass and the extraction of valuable elements.

The problem is further complicated by the fact that the continuum around the item under investigation has perturbed parameters, and high-energy flows, such as gas, heat, electromagnetic and particle, are present. Integral evaluation methods proved to be the most reliable under such conditions of impulse devices functioning. They include ballistic pendulums of various types (pendulum set-up, patent 2237844 RU), or, for example contact markings for powder impulse pressure storage (patent 2106510 RU). Usage of optical technical investigation equipment for high-speed processes [2] is complicated or impossible due to the reasons stated above. Laser measuring technologies [3], x-ray technologies [4] and radar technologies are applicable for measurements of device velocity. Piezometric technology is considered the most efficient technology [5] since it allows to obtain data on device acceleration change in time as well as other kinematic parameters by applying [6] precise integral operations. Below a diagnostics technique is presented [7] along with one of the testing methods [8,9], both based on piezometry technology. Application of this method allows to determine the amplitude of force impulse in the range of small times of action and high acceleration amplitudes. This is done by using using registrations of acceleration histories of a measuring rod. In the tests, the registration is implemented for acceleration amplitudes up to 10^8 m/s^2, impulse front from 4 μs and impact velocities up to 1500 m/s.

1. Experimental technique

Piezoelectric accelerometer, connected with cables to a recording unit, cannot always be installed on a tested device or in the region perturbed by a motion of an accelerated device. Figure 1 represents schematically device functioning in its initial phase of motion in the direction X, from its initial position - X_0 (at time t_0), to the point X_m (at time t_m) where its velocity is maximal – V_m.

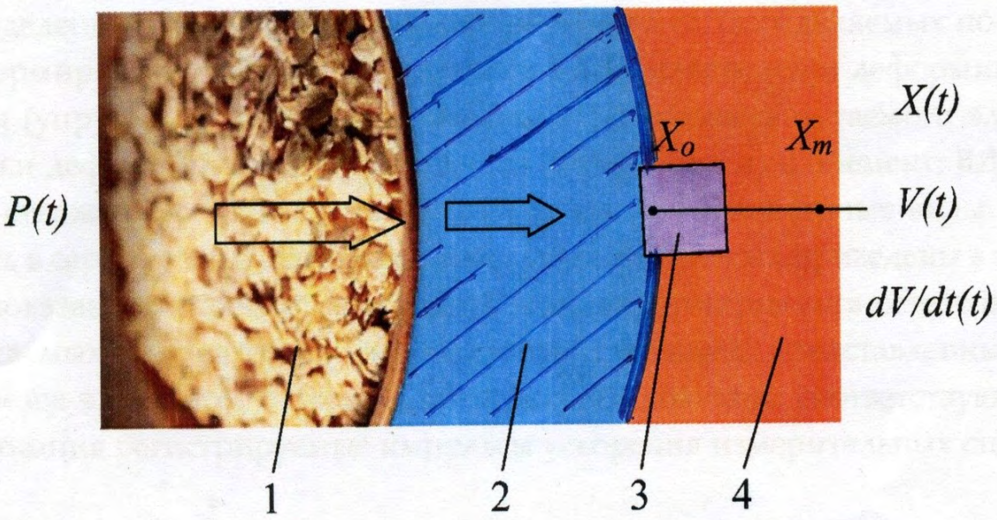


Figure 2. Initial stage of device motion

Energetic material 1 acts with transient pressure *P(t)* on the moving element of device 2. A piezoelectric accelerometer 3 is fixed in the point X_0 on the element. In point X_m the element reaches its maximal velocity in the *X* direction. The part with accelerometer is moving in the perturbed region 4 close to the element. The goal of this investigation is to obtain data on magnitudes and time dependency of kinematic parameters: acceleration *dV/dt(t)*, velocity *V(t)* and displacement *X(t)* from point X_0 to X_m . The private option of a test technology of piezometry is carried out in the conditions of an element throwing from the gas dynamic pulse device on a measuring probe in form of rod [8].

2. Method development

The method is based on high-frequency piezoelectric accelerometer ASM-4 according to the patent 1741082 RU and mounting according to the patent 1799744 RU. The methodology is described in patent 1741082 RU. The possibility of registration and analysis of extreme shock impulses was determined in a series of tests for a wide range of impact velocities and material combinations “projectile - measuring rod”. The measuring rod is equipped with an ASM-4 accelerometer. Accelerometer in assembled state contains the following parts: base with mounting, detachable body, piezoelectric element, inertial element, communication cables and detachable bush. An example of accelerometer design and its mounting is shown in [9].

Depending on the particular material and deformation properties of the rod and the element, a large variety of the physical phenomena can be observed. Several specific cases have been identified based on dominant rod and the element deformation regimes:

Type I - Plastic deformations of the rod without mass loss (elastically deformed “rigid surface”);

Type II - Plastic deformation of the rod (without mass loss) and of the element.

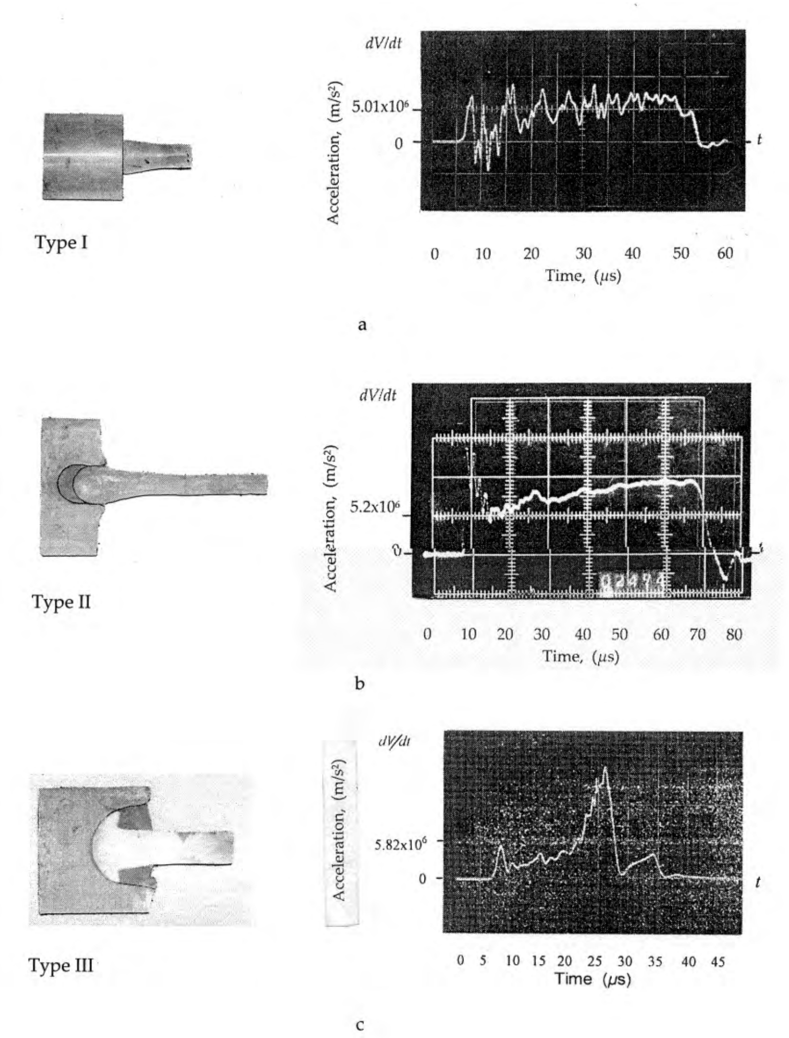
Type III - Plastic deformation of the rod (with erosion of material) and of the element.

The allocated types of deformation were reproduced in series of tests. These deformation types were observed in experiments with initial conditions presented in table 1. Registrations of history of acceleration are received with use of measuring rods with lengthening from 4 to 20 diameters of a rod. Except specified in the table there are also results of registration in series of tests with the rods made of other materials: copper M1, copper M2, M14, steel 40X.

Table 1. Initial conditions of experiments

Deformation type	Rod material	Elongation l_0 / d	Element material	Impact velocity V, m/s
I	Armco iron Steel C30	4 6	Steel 35HGSA Steel 35HGSA	218 430
II	Steel U10 Steel C30	15.2 15	Al alloy Steel C30	524 680
III	Steel C30 Steel C30 Steel C30	20 10 15	Steel C30 Steel C30 Steel C30	1320 1400 1078

Residual plastic deformations typical for each of the deformation types are shown in figure 2. In the right part of drawing the registered impulses of acceleration of measuring rods corresponding to the allocated types of deformation are shown.



a

b

c

Figure 2. Experimental results for deformation types I (a), II (b) and III (c)

The value of acceleration on ordinate A in final part of the registrations $A(t_k) = dV/dt\ (t_k)$ we takes as 1. On abscissa axis as 1 we look the registered time when acceleration amplitude exit to zero value. Figure 3 shows suggested way of coordinating oscillograms, using data corresponding to deformation type II as an examples (initial conditions from table 1). However, comparison of data for different deformation types shows a significant difference in dynamics of the processes.

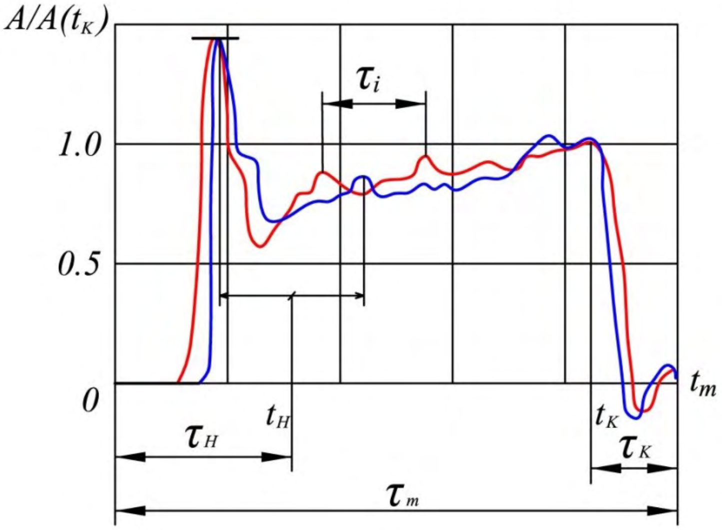


Figure 3. Analysis of a typical registration

3. Discussion

Dimensionless coefficients defined by kinematic and deformation characteristics were calculated for the particular oscillogram intervals. Several coefficients for three deformation types observed in the experiments are presented hereafter. Calculated values are summarized in Table 2.

Table 2. Coefficients connecting kinematic parameters of the model

Stage	Formula	Range of values, % for two deformation types		
		I	II	III
Initial stage	$K_1 = \frac{\tau_н}{\tau}$	19±7	25±5	25±5
Final stage	$K_2 = \frac{\tau_к}{\tau}$	30±5	18±3	35±3
Average acceleration in the initial stage	$K_3 = \frac{\dot{v}_{cp}(\tau_н)}{\dot{v}_{cp}(t_к)}$	35±9	79±5	14±3
Velocity drop in the initial stage	$K_4 = \frac{v_c - v(t_н)}{v_c}$	9±3	16±3	7±2
Velocity drop in the final stage	$K_5 = \frac{v(t_н)}{v_c}$	19±2	7±1	13±2
Length of the rigid part of the rod	$K_6 = \frac{l(t_н)}{l_0}$	35±5	29±3	45±3
Displacement related to the element	$K_7 = \frac{S(t_н)}{l_0}$	10±5	18±3	50±5

For the quantitative assessment, measurements were analyzed according to the following approach. Time step $t_{н}$ defined as the time interval between the first and the second peak acceleration magnitudes was selected (figure 3). Time period τ_{i} was used in order to determine the first value of the average within this period length of the tail part in the elastic deformation state. Thus, initial (from 0 to $t_{н}$) and final (from t_{k} to t_{m}) stages were selected. Correspondent time periods are denoted as $\tau_{н}$ and $\tau_{к}$. Later their relative duration with respect to the total process time $\tau_{пр}$ was computed.

Analysis of the results shows, that for deformation type I monotonous change in acceleration during the major part of the process is specific. At the final stage of the rod motion in the element elastic properties of the rod and element materials are pronounced as local peaks of the acceleration amplitude which usually do not exceed the value of $A(t_{k})$. Differences in the interaction conditions also lead to the differences in the acceleration evolution, kinematic and deformation parameters. Comparison of the results obtained in the experiments for different rod deformation types, reinforced these observations.

Conclusion

Analytical investigations of the interaction between an element and a rod are usually based on experimental data related to finite integral parameters of the interaction. Mutual coupling factors allow to study the process in detail. For example, average acceleration K_{3} and speed drop at the initial stage K_{4} show the deceleration of the elastic region of the rod with respect to the element at the time period from $t_{н}$ to $t_{к}$. The coefficient K_{6} characterizes the contraction of the rod. Each set of coefficients defines a particular pattern of the acceleration behavior and allows determining plastic deformation type of the rod.

The work was done with the financial support of the Russian Foundation for Basic Research (project code 19-08-00701 a) and using equipment GZ 3.6196.2017 / 7.8 and GZ 3.6257.2017 / 7.8.

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