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Nonlinear Process of Collision of Workpiece with Dropped Parts of Forging Hammer

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Abstract: The results of theoretical and experimental studies of collision interaction of a workpiece with dropped parts of a forging hammer are presented in the work. There is obtained a theoretical law for changes of dropped parts bounces height from the collision velocity and a workpiece parameters during the forging, allowing to partially formalize the process of forging, which is currently empirical. Theoretical results are compared with experimental data.

Key words: Dynamic calculation of forging hammers . a workpiece upsetting

INTRODUCTION

The strength of the forging hammer parts, as well as qualitative indicators of the machine depend on the strength of the forging deformation resistance. From industrial practice it is known that crackings on forging hammer workpieces and fragments, causing harm to life and health of the workers and leading to material losses in manufacturing, are not rare. Previously, the authors attempted to simulate the dropped parts of a forging hammer in the process of collision interaction with a workpiece of complex viscous-elastic rod system with distributed parameters, colliding with an obstacle [1], making it possible to perform the theoretical calculation of stresses and strains, arising in details of a forging hammer and a workpiece at a single collision [2]. In [2] there was used the frequency method of dynamic analysis of nonstationary oscillations of a forging hammer in the process of collision interaction with a workpiece, which is a modification of the finite element method [3-5] based on precise integration of a differential equation for a finite element [1].

However, collision interaction of dropped parts of a forging hammer with a workpiece is accompanied with a rebound. The process is discontinuous and substantially nonlinear [6-9]. Finding a theoretical law for changes of dropped parts bounces height will partially allow to formalize the process of forging, which is currently empirical.

The main part. High loading levels cause plastic deformations in a workpiece, leading to its upsetting. Under the collision load a workpiece material absorbs mechanical energy during the deformation for a short period of time. During the vibrations of a forging hammer structure a part of structural elements deformation energy is converted into thermal energy and is irreversibly dissipated into the surrounding space. Internal friction within the structure plays a dominant role in it.

Considering the structural damping, we can assume that damping forces are proportional to the amplitude of deformations and do not depend on oscillation frequency. In this case:

$$\overline{F}_v = -c_0 A \,\mathrm{sign}\,\overline{v}$$

where $\overline{F}_v$ is a damping force, c_0 is a damping coefficient, A is a variable oscillations amplitude.

In general dissipation of energy is nonlinear. But in case of sufficiently small deformations (occurring in all elements of the system, except for a workpiece) linear theory of elasticity can be used.

At hysteretic (structural) dissipation of energy the equation of free oscillations of systems with one degree of freedom can be written as follows:

$$m\ddot{x} + c_0 A \,\mathrm{sign}\,\dot{x} + cx = 0 \tag{1}$$

For a system with a linear power dissipation described by equation (1) the energy dissipation per cycle of motion is:

$$\begin{aligned}\Delta E &= \int_0^T F_v \cdot \dot{x}\,dt = \int_0^T c_0 A \,\mathrm{sign}\,\dot{x} \cdot \dot{x}\,dt \\ &= c_0 A \,\mathrm{sign}\,\dot{x}\,\omega^2 A^2 \int_0^T \cos^2(\omega t - \varphi)\,dt = c_0 A \,\mathrm{sign}\,\dot{x}\,\omega \pi A^2\end{aligned} \tag{2}$$

At dry friction:

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$$\overline{F}_v = -F\text{sign}\overline{v} \qquad (3)$$

Per one cycle a path performed by the mass is approximately equal to 4A.
Therefore, according to (3)

$$\Delta E = 4FA \qquad (4)$$

If the power dissipation is nonlinear, then equation (2) is to be used in order to find the equivalent damping coefficient (b_{eqv}):

$$\Delta E = b_{eqv}\omega\pi A^2 \qquad (5)$$

Therefore, according to (4 and 5):

$$b_{eqv} = 4\frac{F}{\omega\pi A} \qquad (6)$$

As you can see, b_{eqv} is a variable value depending on the value of F, oscillation frequency [omega] and displacement amplitude (A).

If the damping is small, the work of dissipative forces is t be expressed by a formula:

$$\Delta E = 4\, c_0 A^2$$

from which $b_{eqv} = 4\frac{c_0}{\omega\pi}$.

Taking into account the difference in occurring dynamic deformations, under which plastic deformations of a workpiece at a collision are quite large (a few millimeters), but deformations of elastic parts are of about one millimeter, let us consider the process of interaction of a workpiece with dropped parts as a system with one degree of freedom.

Let us consider an analytical description of this interaction, which can be found from energy considerations.

Let the change of the head potential energy between two neighboring rebounds be:

$$\Delta \text{Ï} = mg\left(h_0 - h_1\right) = mg\Delta h$$

where m is a mass of dropped parts, g is an acceleration of gravity, h_0 is a height of fall, h_1 is a lifting height at a rebound, Δh is a height difference.
The nature of the process is shown in Fig. 1.

In order to get an analytical solution of the problem it is necessary to eliminate the dependence, associated with determination of h value.

Knowing the speed of a collision of the first striker with a workpiece, we can determine the initial height (h) from the relation:

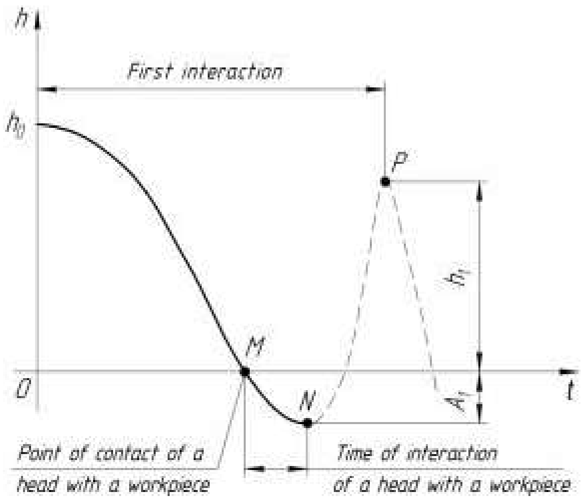

Fig. 1: The process of interaction of dropped parts of a forging hammer with a workpiece: h_0 is a height of fall; h_l is a lifting height at a rebound; A_1 is the amplitude of dropped parts compression; and t is time

$$\frac{mV^2}{2} = mgh\,,\ \ h_0 = \frac{V^2}{2g}$$

The value of V (the speed of collision of a workpiece with a hammer dropped parts) can be determined experimentally.

Let us estimate plastic deformations of a workpiece.

Assuming that internal friction in a stock, a head and a top striker is small and proportional to a compression amplitude A (this assumption gives a good approximation to the experience), the resistance force F^v can be found:

$$F^v = -c_0 A$$

where c_0 is a coefficient of resistance.

Now we consider the force of interaction between dropped parts and a workpiece constant, so energy change during the interaction is:

$$\Delta E = c_0 A^2$$

Neglecting the friction with air medium, equating the potential energy decrease $\Delta \text{Ï}$ to the value of energy dissipation in the head material ΔE, we get:

$$\text{ñ}_0 A^2 = mg\Delta h$$

At hysteretic dissipation of energy, if the damping is small, then the solutions of free vibrations equation can be obtained by energy balance method (according to which the work of resistance forces is equated with the change of potential energy of the system per one oscillation period):

$$\Delta \ddot{I}_k = \frac{CA_i^2}{2} - \frac{CA_{i+1}^2}{2} \approx CA\Delta A$$

where C is rigidity of a head, $\Delta A = A_i - A_{i+1}$, $A = A_i$.

Let us form the differential equation for the change of height of a head bounces. Let

$$\frac{\Delta h}{\Delta A} \approx \frac{dh}{dA}$$

at that

$$\frac{cA}{mg} = \frac{\Delta h}{\Delta A} \approx \frac{dh}{dA} \text{ and } \frac{cA^2}{2} = mgh$$

Approximately take:

$$\frac{\Delta A}{T} \approx \frac{dA}{dt}$$

whence

$$\Delta A = -O\frac{dA}{dt}$$

and thus

$$\Delta \ddot{I}_K = -\tilde{N}AT\frac{dA}{dt}$$

Thereby,

$$C_0A^2 = -\tilde{N}AT\frac{dA}{dt} \text{ or } C_0A^2 = -\tilde{N}T\frac{dA}{dt}$$

Substituting

$$dA = \frac{mg}{C}\frac{dh}{A}$$

we get

$$\frac{C_0A^2}{C} = -\frac{mgT}{C}\frac{dh}{dt}$$

The potential energy decrease is determined via the value of Δh, which is expressed through the speed of collision of dropped parts with a workpiece. Both these values are interdependent and can be determined experimentally.

$$h_1 = h_0 - \frac{1}{2g}\left(V_0^2 - V_1^2\right)$$

Let us assume that the damped oscillations of forging hammer dropped parts in the presence of resistance forces of the medium (a workpiece), which are proportional to the speed of collision, described by the following formula [10]:

$$x = e^{-nt} \cdot V \cdot t \qquad (1)$$

where $n = \frac{b}{2m}$ is a reduced coefficient of medium resistance, $b = \frac{\gamma \tilde{N}}{\omega}$.

This solution of oscillations differential equation is obtained when n = k, where $k = \sqrt{\frac{\tilde{N}}{m}}$ is a frequency of free undamped oscillations of dropped parts of a forging hammer; m is a weight of dropped parts, $\tilde{N}$ is rigidity of a workpiece, $\tilde{N} = \frac{\AA F}{l}$, E is a modulus of elasticity of a workpiece; F is a cross sectional area of a workpiece; l is a length of a workpiece; [gamma] is a coefficient of resistance; $\omega_1 = \omega\sqrt{1 - \frac{\gamma^2}{4}}$ is a frequency of free oscillations, considering the attenuation; $\omega = \sqrt{\frac{\tilde{N}}{m}}$ is a frequency of free oscillations.

Since the process is aperiodic, solution (1) is authorized when $\omega_1 = 0$ and it means that the minimum value of $\gamma = 2$.

As an example let us consider the collision of dropped parts of M1345 forging hammer with workpiece shown in Table 1.

Table 1: Results of experimental studies

No.	Workpiece material	Forging temperature (°C)	Form and dimensions of workpiece (mm)	Distance from Workpiece to top striker (before Hitting) (mm)	Rebound bandwidth (mm)	Dimensions of workpiece after hitting (mm)	Workpiece upsetting (mm)
1	AK6	470	∅50×90	860	20	∅54×75	15
2	AK6	470	∅250×327	623	150	∅254×317	10
3	12H18N10T	1180	∅105×137	813	18	∅108×130	7
4	30HGSA	1180	∅50×70	880	20	∅54×60	10
5	VT-22	950	∅170×272	678	20	∅174×260	12
6	VT-6	980	∅70×120	830	50	∅73×110	10

Table 2: Comparison of theoretical and experimental results

No. of workpiece in table 1	workpiece Material	Estimated frequency of natural oscillations (sec^{-1})	Workpiece upsetting (mm)		
			Experiment	Calculation	Discrepancy (%)
1	AK6	120	15	19,1	27
2	AK6	313	10	7,2	28
3	12H18N10T	375	7	5,8	21
4	30HGSA	250	10	8,8	17
5	VT-22	325	12	7,9	34
6	VT-6	202	10	12,8	28

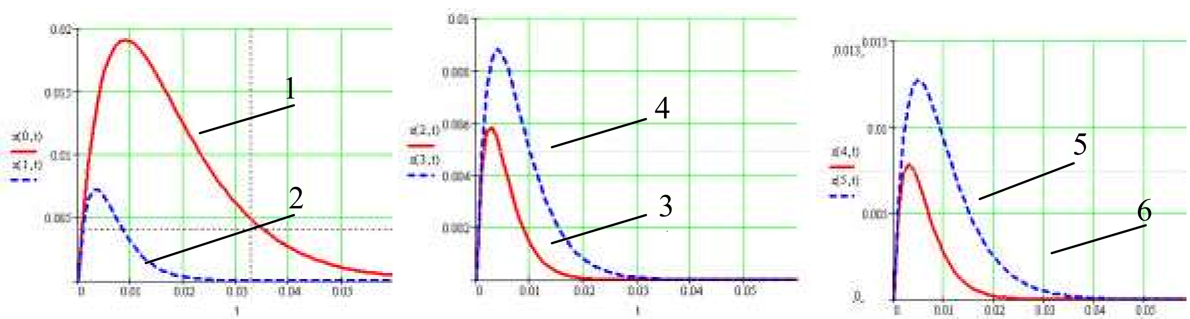

Fig. 2: Graphs of motion of dropped parts constructed in MathCAD2001 system, according to formula (1): 1, 2, 3, 4, 5, 6 - numbers of workpieces from Table 1

As a result of numerical calculations performed with the help of MathCAD2001 software package, we obtained the graph of motion of forging hammer dropped parts in the process of collision interaction with workpieces (Fig. 2), using initial data presented in Table 1. The weight of dropped parts of M1345 forging hammer is 3,150 kg, the maximum velocity of collision is 7 m/s.

Area of increase in Fig. 2 characterizes the interaction of dropped parts of a forging hammer with a workpiece after the collision until a rebound (from the moment of a rebound the curve in Fig. 2 decreases and a real law of motion of dropped parts in this section will no longer comply with law (1)).

Results of the comparison of theoretical and experimental results are presented in Table 2.

The average discrepancy between theoretical and experimental values is 25.8%. The resulting error is due to the degree of adequacy of constructed mathematical models, taken minimum coefficient of resistance [gamma], requiring clarification for different materials and other factors, an average value of collision velocity.

CONCLUSION

Obtaining a theoretical law for the motion of dropped parts after the collision with a workpiece during forging has practical significance for the determination of workpieces upsetting at subsequent collisions, considering the problem with new initial data.

This approach to estimation of workpieces plastic deformations, depending on collision velocity, was obtained for the first time.

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