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Theory of Controlled Impacts

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Abstract*: In this paper are presented research on the theory of a new kind of impact - controlled impact which is obtained using industrial rocket engine for driving of impact machines (hammers). Elastic and elastic-plastic deformation of impacting bodies are considered. It is shown that in elastic deformation with a controlled impact can be achieved e > 1. In the case of elastic-plastic deformation is derived a formula for determining the rebound force.*

Keywords: controlled impact, rocket engine, rocket engine trust, impact force, impact velocity, rebound force, impact machines

1. Introduction

In controlled impact are obtained the fallowing effects:

– the impact force is the sum of two forces: the force $P_{i,o}$ obtained in ordinary impact and rocket engine trust R;

- the rocket engine trust R can be changed previously (before the impact) or during impact;

- if the rebound force P_{RB} is known the trust R can be adjusted in advance so that R > P_{RB}. In this case will obtain impact without rebound (sticking impact);

when rocket engine trust R it is possible to reach different impact speed Vi in field of low velocity (Vi = 5 – 9 m/s) and of high velocity (Vi = 12 – 20 m/s) impact. [6]

2. Controlled impact parameters

In **Fig. 1.** are presented theoretical diagrams of impact force chang in controlled impact. It can be seen that if R > P_i : (i) impact without rebound is obtained; (ii) in the impact time t_i the impact device works as a combination of impact and hydraulic machines. This means that the effect of dynamic load is reduced at the expense of increase the static load which change the work conditions and improves the durability of the machines and tools. [3]

The parameters of controlled impact are:

impact speed at vertical movement down

$$V_i = \sqrt{2gH(\frac{R}{m_1} + 1)} \quad (1)$$

impact speed in inclined to the horizontal plane at an angle α movement

$$V_{i,\alpha} = \sqrt{2gH(\frac{R}{m_1} + sin\alpha)} \quad (2)$$

impact speed at vertical movement upwards

$$V_{i,-} = \sqrt{2gH(\frac{R}{m_1} - 1)} \quad (3)$$

impact force

$$P_{i,c} = P_{i,o} + R \quad (4)$$

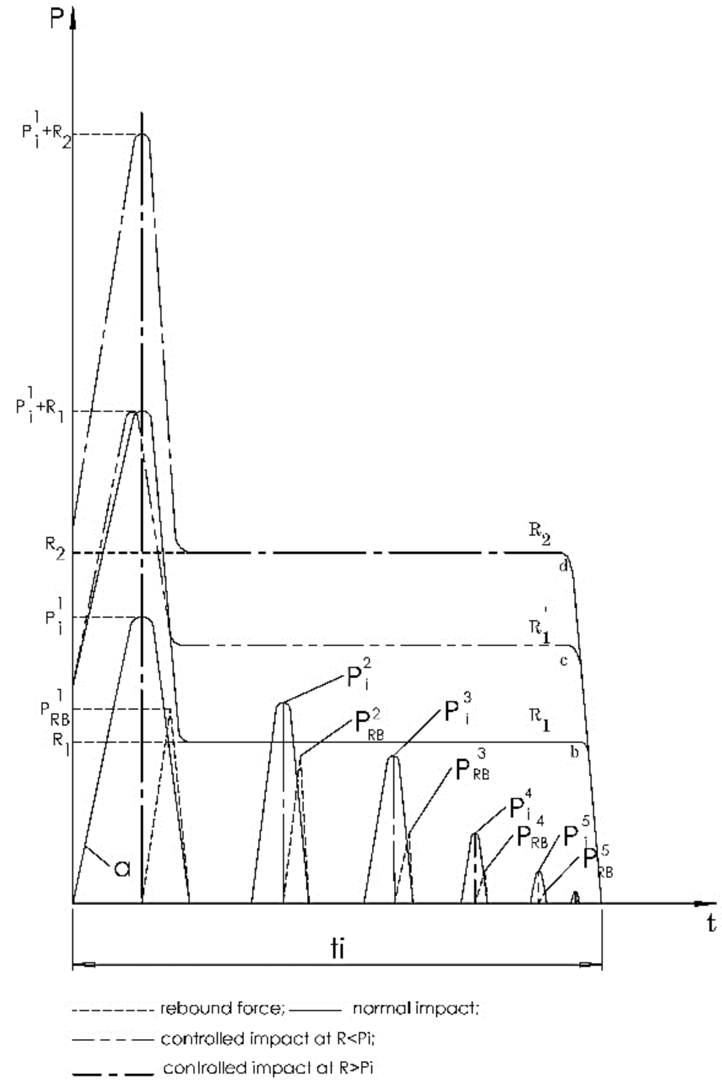

Fig. 1. Theoretical diagrams of impact force P_i and rebound force P_{RB} chang in controlled impact:

rebound force P_{RB} in ordinary impact;

impact force P_i in ordinary impact (curve a); impact force in controlled impact when: — $R=R_1 < P_i$, $R_1 < P_{RB}^1$ (curve b),

impact force in controlled impact when $R = R_1^{'} < P_i$, $R_1^{'} > P_{RB}^1$ (curve c);

impact force in controlled impact when $R=R_2 \geq P_i$ (curve d)

For determination of the rebound force at controlled impact consider the case of die forging hammer. This machines realize deformation of high temperature metal which is presented as elastic - plastic medium. If we denote by m_1, m_2 masses of anvil and ram; with v_1, v_2 impact speeds, with u_1, u_2 rebound speeds of anvil and ram and take into account that $v_1 = 0$, from (3) we get

$$e = \frac{u_2 - u_1}{-v_2} \tag{5}$$

and for u_1 is obtained

$$u_1 = u_2 + v_2 e \tag{6}$$

The impact energy $E_i = m_2 v_2^2 / 2$ is used up on [1], [2]: deformation of the work-piece (E_d); elastic deformation of the dies and the machine (E_{el}); friction in die and machine guide elements (E_f); for overcome of the air drag (E_{ar}); for spring back of the ram (E_m); for spring back of the anvil (E_a), i.e.

$$E_i = E_d + E_{el} + E_f + E_{ar} + E_m + E_A\,. \tag{7}$$

The impact efficiency η_i is

$$\eta_i = \frac{E_d}{E_i}\quad .$$

Then $E_d = \eta_i E_i$, and after substitution in (13) we have

$$(1-\eta_i)E_i = E_{el} + E_f + E_{ar} + E_m + E_a. \tag{8}$$

The value of $(E_a + E_m)$ is very large in comparison with value of $(E_{el} + E_f + E_{ar})$ which may be ignored and (2.20) becomes

$$(1-\eta_i)E_i = E_m + E_a$$

or

$$(1-\eta_i)\frac{m_2 v_2^2}{2} = \frac{m_2 u_2^2}{2} + \frac{m_1 u_1}{2}\quad . \tag{9}$$

After substitution of (2.18) in (2.21) we have

$$(1-\eta_i)m_2 v_2^2 = m_2 u_2^2 + m_1(u_2 + v_2 e)^2 \tag{10}$$

and after transformation of (10) it is received

$$(m_1 + m_2)u_2^2 + 2m_1 e v_2 u_2 + v_2^2(m_1 e^2 + \eta_i - m_2) = 0 \tag{11}$$

This quadratic equation in relation the unknown ram rebound speed u_2 has solution

$$u_{2(1,2)} = \frac{2m_1 e v_2 \pm \sqrt{(2m_1 e v_2)^2 - 4(m_1 + m_2)v_2^2(m_1 e^2 + \eta_i - m_2)}}{4(m_1 + m_2)} \tag{12}$$

or

$$u_{2(1,2)} = \frac{v_2 \left\{m_1 e \pm \sqrt{m_2^2(1-\eta) + m_1 m_2(1-\eta-e^2)}\right\}}{2(m_1 + m_2)} \;. \tag{13}$$

After substitution of (1) in (13) it is received that:

$$u_{2(1,2)} = \frac{\sqrt{2gH\left(\frac{R}{m_2}+1\right)}\left\{m_1 e \pm \sqrt{m_2^2(1-\eta) + m_1 m_2(1-\eta-e^2)}\right\}}{2(m_1 + m_2)} \;. \tag{14}$$

It is not clear which of solutions $u_{2,1}(+)$ $u_{2,2}$ (-) is true. In **Fig.2** the values of $u_{2,1}$ and $u_{2,2}$ for:

H = 1 m; g = 9.81 m/s^2;

R = 500 kg, 1000 kg, 1500 kg, 2000 kg;

m_1= 22000 kg; m_2 = 220 kg;

η = 0.9 (maximum value of η);

e = 0.5; 0.1; 0.15; 0.2; 0.25; 0.3.

From **Fig. 2** it that the differences between $u_{2,1}$ and $u_{2,2}$ are greatest in the small values of the coefficient of restitution. With increasing of **e** these differences are reduced and for e = 0.3 are very small. This may be explained by an increase in the elastic component of deformation upon cooling of the deformed medium. [4, 5]

Taking into account that the height of fall H is the traveled down ram path S the equation (14) is written in the form:

$$u_{2(1,2)} = \frac{\sqrt{2gS\left(\frac{R}{m_2}+1\right)}\left\{m_1 e \pm \sqrt{m_2^2(1-\eta)+m_1 m_2\left(1-\eta-e^2\right)}\right\}}{2(m_1+m_2)} \qquad (15)$$

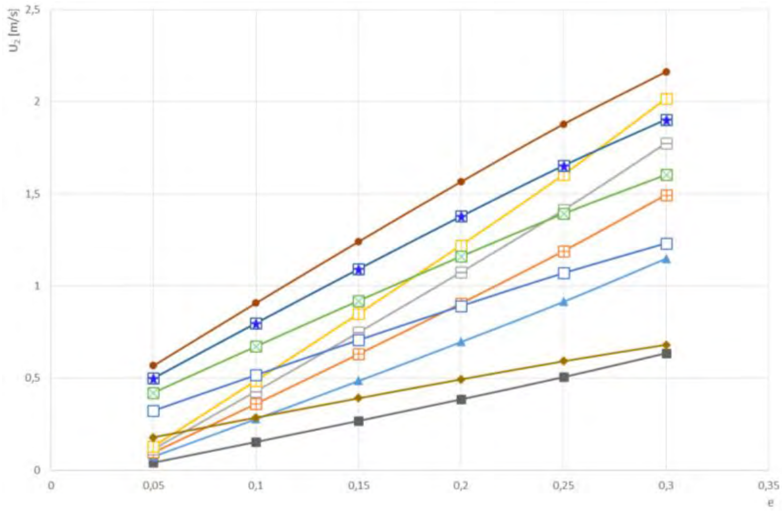

Fig. 2. Diagram for $u_2(e, R)$ as a solution of equation (2.26):

$u_{2,1}$ (+) R=0 R=500 R=1000 R=1500 R=2000 ;

$u_{2,2}$ (-) R=0 R=500 R=1000 R=1500 R=2000

If we replace

$$A = 2g\left(\frac{R}{m_2}+1\right) \; ; \quad B = \frac{m_1 e \pm \sqrt{m_2^2(1-\eta)+m_1 m_2\left(1-\eta-e^2\right)}}{2(m_1+m_2)},$$

equation (15) is transformed to

$$u_2 = B\sqrt{AS} \,. \qquad (16)$$

The rebound acceleration a_{RB} is

$$a_{RB} = \frac{dV_{RB}}{dt} = \frac{du_2}{dt} = \frac{BA}{2\sqrt{AS}} \cdot \frac{dS}{dt} \,. \qquad (17)$$

Taking into account that

$$\frac{dS}{dt} = V_i = \sqrt{2gS\left(\frac{R}{m_2} + 1\right)} = \sqrt{AS}$$

for a_{RB} is received

$$a_{RB} = \frac{BA}{2} \tag{18}$$

and for P_{RB} is received

$$P_{RB} = m_2 a_{RB} = \frac{m_2 BA}{2} = \frac{g(R+m_2)\left\{m_1 e \pm \sqrt{m_2^2(1-\eta) + m_1 m_2 (1-\eta-e^2)}\right\}}{2(m_1+m_2)} \tag{19}$$

Formula (19) is used to determine the magnitude of the thrust R of the engine to be operated in accordance with curves b, c, d of **Fig. 1**. The possibility of a preliminary choice of change of the impact force P_i for the time of impact t_i gives basis for setting this mode of operation as a "controlled impact". When adjusting the engine to operate in accordance with the curve “c” of **Fig. 1** ($R > P_{RB}$) it is received impact without rebound (sticking impact), leading to big improvement of the durability of the dies and of the machine. In this case a greater plastic deformation of the billet for one impact, resulting in decreasing of the processing time.

It can be seen from (19) that rebound force P_{RB} depends on: rocket engine trust R; masses m_1, m_2; efficiency η_i; coefficient of restitution **e**

$$P_{RB} = f\,(R, m_1, m_2, \eta_i, e) \tag{20}$$

Taking into account that

$$\eta_i = \frac{m_1}{(m_1+m_2)}(1-e^2) \tag{21}$$

for each machine m_1, m_2 are constant, and for given R from (20), (21) is obtained

$$P_{RB} = f\,(e) \tag{22}$$

CONCLUSION

A theoretical analysis of the behavior of banging bodies in a controlled impact shows that this impact can be achieved effects that can not be realized in a simple imapct:

- Impact of elastic bodies can be achieved recovery ratio is> 1;
- Impact of elastic-plastic bodies can be achieved without impact rebound. A prerequisite for this is to know the strength of the bounce Rots to be able to choose the thrust of a rocket motor R must be R ≥ Rots. Displayed formula for determining Rots, in the case of hammer for bulk stamping powered industrial rocket engine.

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Теория управляемых ударов

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Р е з ю м е

В данной работе представлены исследований по теории нового вида воздействия - контролируемое воздействие, которое получается с помощью промышленного ракетного двигателя для приведения в движение ударных машин (молотки). Рассматриваются упругая и упруго-пластическая деформация тел. Показано, что при упругой деформации с контролируемым воздействием может быть достигнуто е> 1. В случае упруго-пластической деформации была выведена формула для определения отскока силы.