

DETERMINING IMPACT VELOCITY IN AN IMPACT TESTER USING A MATHEMATICAL MODEL

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Abstract

Testing on impact test hammer is one of the methods to evaluate the impact of impulses, accelerations, and stress waves on the details and parts of the test object in order to evaluate the operation or durability of the test object for research and testing. Those impacts depend on many factors such as the weight of the hammer, the weight of the test object, the hardness of the anvil, the angle of lifting the hammer, etc. The parameters of the hammer are only applicable to the default cases, other cases when necessary to determine velocity must be measured. The calculation method is suggested by this article to determine impact velocity so that it can be applied on all cases instead of having to measure many times. The calculation results are verified by experimentally measuring the hammer velocity on high-speed camera with an error not exceeding 3.42%.

Keywords: Impact test hammer; material durability test; bounce velocity; impact acceleration.

1. Introduction

Testing on impact test hammer is one of the impact assessment methods of impulses, accelerations, and stress waves on the components and parts of the test object in order to assess the operation or strength of the test object depending on the purpose of the test.

Weapons test includes many researches that require different velocity ranges when impacting. From the impact velocity and impact conditions (hammer material, anvil material), the impact acceleration, bounce rate due to the impact of stress waves on a certain moving part [1-3] or assess the strength of the part for research and testing.

Impact test hammers in the market are often used to measure the strength of materials, so their impact velocity is usually minor, size of 4 - 8 m/s [4-6]. These types of devices are not suitable for weapons research. Impact test hammer under research has a large velocity range (corresponding to each adjustment step on the hammer, referred to as teeth) that is suitable for many researches in the military field. For each tooth, the velocity of the hammer will be different in proportion to the mass of the jig to be installed on the hammer. Experiments show that large variations in acceleration values or stress

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waves are received at the same collision conditions when the velocity changes only slightly. Therefore, the calculation and determination of hammer velocity to form the test is of great significance in the process of research and testing.

The auxiliary parts of the impact test hammer are only suitable for certain cases. The impact velocity of other cases are determined by measuring. Instead of measuring multiple times, the hammer velocity calculating method and program is suggested by this article for general cases and the input parameters will be changed for the other cases. The calculation results are verified by using a high speed camera to measure the hammer velocity.

2. Structure and operation of impact test hammer

In Fig. 1, the impact test hammer consists of the following components: the hammer (1), the hammer handle (2), the roller (3) fastened together to form a rigid block (rotary unit) that rotates around O central line. The sample (4) fastened to the hammer to receive mechanical impacts when the hammer hits the anvil (5). The weight (6) is hung on a zipper (7) wound on the profile of the roller.

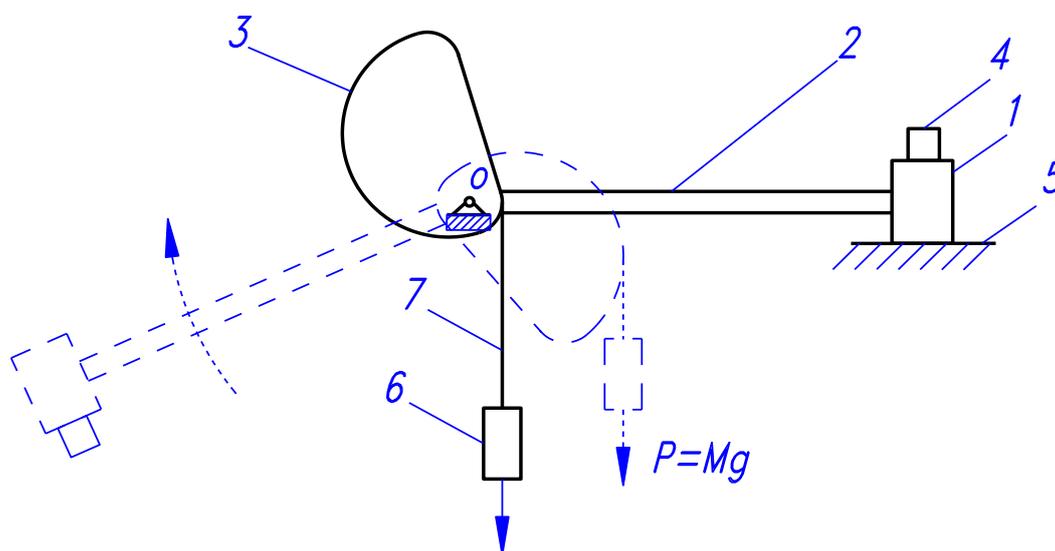


Fig. 1. Principle diagram of the impact test hammer

1 - hammer; 2 - hammer handle; 3 - roller; 4 - test objects; 5 - anvils; 6 - weights; 7 - rope.

During the test, the sample is mounted on the hammer, the lower the position of the hammer is, the larger the rotation angle of the hammer is, so the velocity and acceleration obtained are higher. Depending on the test requirements, the initial position of the hammer is selected. The initial position of the hammer (corresponding to the initial rotation angle of the roller) is determined through preset notches on a ratchet mechanism, locking pin,

referred to as the hammer teeth. Each tooth of the ratchet corresponds to each initial rotation angle of the roller. The ratchet is divided into 30 teeth, the angle between two teeth is 12° . As the hammer shaft cannot rotate a full circle as it is stuck in the anvil, the hammer can only be tested from tooth number 1 to tooth number 23. Before testing, the hammer is fixed with a locking pin. When the locking pin is released, under the effect of load, the rotary unit returns to the position where the hammer head hits the anvil. Through the impact, the details and structures of the test object receives the necessary mechanical parameters.

3. Differential equation of mechanism motion and calculation results

The impact test hammer is considered as a mechanism consisting of a weight, hammer, hammer handle, and roller. The hammer, hammer handle and roller are fastened together, the rotation motion is a fixed axis; The weight moves vertically under the effect of gravity.

The circular arc of the roller consists of two parts: The large arc has an O_1 central line of radius R , and the small arc at the beginning has an O central line of radius r_0 (Fig. 2). These arcs produce various motion phases of the weight:

- *The first phase:* When the rope extends on the large arc (*From the initial position to the position where the line connecting the central line of rotation and the circular central line of radius R coincides with the Ox axis*), the weighty object engages in two motions: vertical motion and horizontal motion.

- *The second phase:* When the rope protrudes on a small arc (*From the position where the line connecting the central line of rotation and the circular central line of radius R coincides with the Ox shaft to the position where the hammer hits the anvil*) the weighty object only moves vertically.

In the case the weighty object motion is viewed in two directions, Ox and Oy .

It is supposed:

- Ignore the oscillation (shaking) of the weighty object during the motion of the system.
- Ignore the weight of the rope (5) and consider the rope to be inelastic and always vertical.

Equation of momentum moment variation of mechanism [7]:

$$\dot{Q} = \frac{dQ}{dt} = M_1 + M_2 - M_{ms} \quad (1)$$

in which M_1 is the gravitational moment of the weighty object with respect to the spin:

$$M_1 = Mgx \tag{2}$$

in which M is weighty object mass, g is gravitational acceleration, x is lever arm of gravity.

- M_2 is the gravity moment of the hammer handle, hammer and roller for the spin:

$$\begin{aligned} M_2 &= m_1gl \cdot \cos(\varphi_0 + \alpha_0 + \varphi) + \frac{1}{2}m_2gl \cdot \cos(\varphi_0 + \alpha_0 + \varphi) + m_3gl_1(\varphi_0 - \gamma_0 + \varphi) \\ &= (m_1 + \frac{1}{2}m_2)gl \cdot \cos(\varphi_0 + \alpha_0 + \varphi) + m_3gl_1 \cdot \cos(\varphi_0 - \gamma_0 + \varphi) \end{aligned} \tag{3}$$

in which m_1, m_2, m_3 are the weight of the hammer, hammer handle and roller, l is the length of the hammer handle, l_1 is the distance from the bary centre of the roller to the spin, α_0 is the angles between the hammer handle and OO_1 central line, γ_0 is $\angle GOO_1$ angle, G is the center of gravity of the roller.

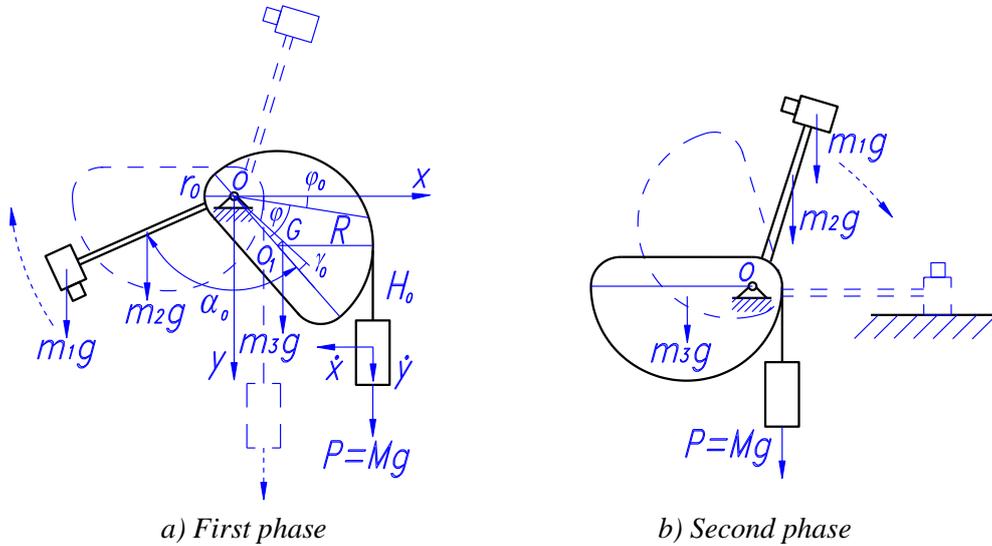


Fig. 2. Motion phases of mechanism.

- M_{ms} is the moment of friction at the rotary bearing [8]:

$$M_{ms} = \frac{fT\rho_0}{\sqrt{1+f^2}} \tag{4}$$

in which f is friction coefficient, T is combined force acting on the rotating joint: $T = (M + m_1 + m_2 + m_3)g$, ρ_0 is spin radius.

- Q is the momentum moment of mechanism: $Q = Q_1 + Q_2$, in which

+ Q_1 is the momentum moment of the rotary unit (including: hammer, hammer handle and roller):

$$Q_1 = (J_1 + J_2 + J_3)\dot{\varphi} = J_{kq}\dot{\varphi}$$

J_{kq} is the total inertia moment of the rotary units; J_1, J_2, J_3 is the inertia moment of the hammer, hammer handle and roller.

+ Q_2 is the momentum moment of the weighty object:

$$Q_2 = M(x\dot{y} - \dot{x}y)$$

Therefore:

$$Q = J_{kq}\dot{\varphi} + M(x\dot{y} - \dot{x}y) \quad (5)$$

From (1) and (5), a differential equation of mechanism motion:

$$\begin{aligned} \frac{d}{dt}[J_{kq}\dot{\varphi} + M(x\dot{y} - \dot{x}y)] &= M_1 + M_2 - M_{ms} \\ \rightarrow J_{kq}\ddot{\varphi} + M(x\ddot{y} - \ddot{x}y) &= M_1 + M_2 - M_{ms} \end{aligned} \quad (6)$$

where $\dot{x} = \frac{dx}{d\varphi}\dot{\varphi}$; $\dot{y} = x\dot{\varphi}$

$$\rightarrow \ddot{x} = \frac{d^2x}{d\varphi^2}\dot{\varphi}^2 + \frac{dx}{d\varphi}\ddot{\varphi}, \quad \ddot{y} = \frac{dx}{d\varphi}\dot{\varphi}^2 + x\ddot{\varphi}$$

Replace \ddot{x}, \ddot{y} to equation (6), the outcomes are:

$$\left[J_{kq} + M\left(x^2 - y\frac{dx}{d\varphi}\right) \right] \ddot{\varphi} + M\left(x\frac{dx}{d\varphi} - y\frac{d^2x}{d\varphi^2}\right) \dot{\varphi}^2 = M_1 + M_2 - M_{ms} \quad (7)$$

The mechanism motion is divided into 2 phases (Fig. 2).

- *First phase*: The weighty object participates in 2 motions, the coordinates of the centre of the weighty object:

$$\begin{cases} x = r(\varphi) = R + (R - r_0)\cos(\varphi + \varphi_0) \\ y = (R - r_0)\sin(\varphi + \varphi_0) + H_0 + R\varphi \end{cases} \quad (8)$$

in which H_0 is the initial protruding piece of the rope, corresponding to each angle φ_0 (corresponding to each tooth on the hammer) for a value H_0 .

$$\rightarrow \begin{cases} \frac{dx}{d\varphi} = -(R - r_0) \sin(\varphi + \varphi_0) \\ \frac{d^2x}{d\varphi^2} = -(R - r_0) \cos(\varphi + \varphi_0) \end{cases} \quad (9)$$

- *Second phase:* Weighty object only moves vertically. The differential equation of mechanism motion has a simple form:

$$(J_{kq} + Mr_0^2)\ddot{\varphi} = M_1 + M_2 - M_{ms} \quad (10)$$

Thus, the problem must be resolved in two phases: The first phase consists of equations (2), (3), (4), (7), (8), (9) with the first condition: $t_0 = 0, \varphi_0 = 0, \dot{\varphi}_0 = 0$ final condition: $\varphi_1 = \pi - \varphi_0$. The second phase consists of equations (2), (3), (4), (10) with the first condition being the parameters taken from the last condition of the first phase, with the final condition being: $\varphi_2 = 2\pi - \alpha_0 - \varphi_0$.

Survey parameters on the hammer: $J_{kq} = 0.975 \text{ kgm}^2, g = 9.81 \text{ m/s}^2, R = 0.248 \text{ m}, r_0 = 0.058 \text{ m}, \alpha_0 = 110^\circ, \gamma_0 = 10^\circ, \rho_0 = 0.0165 \text{ m}, M = 37 \text{ kg}, m_1 = 0.65 \text{ kg}, m_2 = 2.5 \text{ kg}, m_3 = 2 \text{ kg}, l = 0.810 \text{ m}, f = 0.1, H_0$ has a length that corresponds to the original angle φ_0 .

The differential equation resolving with numerical method on Matlab software gives the outcomes of angular velocity and hammer velocity ($v = l\omega$) of the mechanism over time. The survey results of H_0 corresponding to the initial angle φ_0 and the calculating outcomes of the hammer velocity at the teeth from 15 - 23 are included in Table 1.

Table 1. Table of H_0 and φ_0 values through survey and results of calculation of hammer velocity

Tooth	15	16	17	18	19	20	21	22	23
H_0 (m)	0.952	0.895	0.828	0.751	0.671	0.591	0.501	0.411	0.321
φ_0 (°)	96	84	72	60	48	36	24	12	0
v (m/s)	9.3	10.1	11.0	11.9	12.9	14.0	15.1	16.2	17.3

Figure 3 is a graph of hammer velocity over time in the 18th tooth (usually tested with mortar) and 23rd tooth (usually tested with artillery).

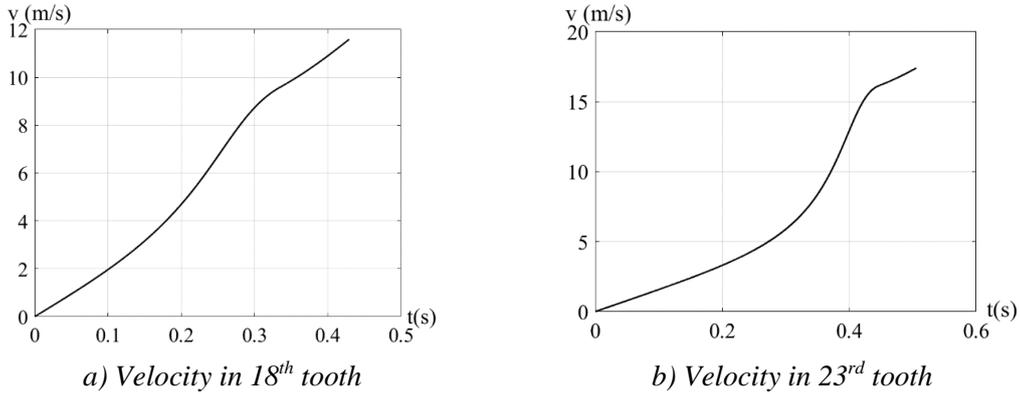


Fig. 3. Calculating outcomes of hammer velocity at 18th and 23rd tooth.

4. Hammer velocity measurement test

To test the model, the author measured the hammer velocity at the time the hammer hit the anvil with the Phantom v711 High-Velocity Digital Camera (Fig. 4).



Fig. 4. Hammer velocity measurement test.

Test description: The camera lens is placed horizontally, pointing at the position of the hammer just before the hammer hits the anvil. An engraved mark affixed on the hammer as a ruler to determine the pixel pitch in the camera (Fig. 5). The pitch on the hammer is 20 mm, and after input into the processing software, the pixel pitch ratio is 1.156 (1 mm in the figure is equivalent to 1.156 mm in the outside). The camera sets at the mode to 10,000 shots per second.

The measurement results at 23rd tooth at the time of hammer impact the anvil are as follows:

- Distance of 5 figures (of any mark on the hammer): 7.35 mm (determined by the pixel pitch on the figures for the software to calculate the distance);
- Scanning time of 5 figures: $5/10,000 = 5 \cdot 10^{-4}$ s;

- Hammer velocity: $v = 7.35 \times 1.156/0.0005 = 16993.2$ (mm/s).

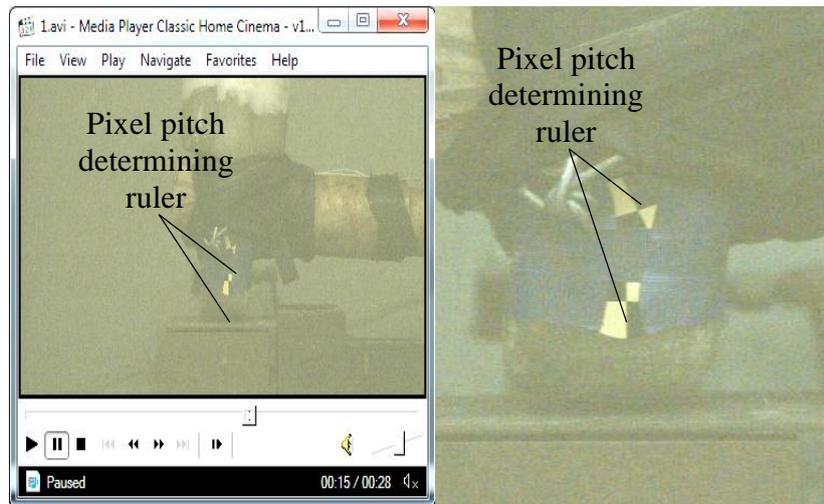


Fig. 5. Images extracted from video of high-velocity cameras.

In each tooth, the author measured 5 times to get the average value. The measured results are compared with the calculation outcomes in Table 2.

Table 2. Comparison sheet of hammer velocity measurement results between calculation and test

Tooth	15	16	17	18	19	20	21	22	23
v (m/s) - Calculation	9.3	10.1	11.0	11.9	12.9	14.0	15.1	16.2	17.3
v (m/s) - Test	9.4	10.3	11.3	12.2	12.8	14.2	14.6	15.8	17.0
Calculation errors from the test (%)	-1.06	-1.94	-2.65	-2.46	0.78	-1.41	3.42	2.53	1.76

The hammer velocity measurement test with teeth from 15 to 23 showed do not deviate much from the calculation from the model. The max deviation from the actual calculation value is 3.42%. These errors mainly come from measurement data, sampling to be included in the calculation model, deviations from the friction coefficient, deviations from the vibration motions of the hammer and the error of the measurement. However, with the above deviation, the model still has enough accuracy for reference and determine velocity before setting the test plan.

5. Conclusion

From the actual test devices, a mathematical model has been formed, as well as the value of the hammer velocity from the article. The outcomes have been verified by experiments with high-velocity cameras, giving results that are consistent with the calculation model. These are important parameters when setting up a test plan related to impact velocity. The model can be used to calculate the design of hammers with similar operating principles with various hammer velocity requirements.

For each hammer velocity value, the acceleration values, the stress wave spreading to the test components also depends on the hardness of the anvil material. Therefore, to get a complete set of parameters for a tested hammer, the tests to measure the acceleration value, the effect of the stress wave corresponding to the hammer velocity and the hardness of the anvil are required (the anvil can be buffered with elastic plates to adjust the impact time).

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XÁC ĐỊNH VẬN TỐC CỦA BÚA THỦ VÀ CHẠM BẰNG MÔ HÌNH TOÁN HỌC

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Tóm tắt: Thử nghiệm bằng búa thử va chạm là một trong những phương pháp đánh giá tác động của xung lực, gia tốc, sóng ứng suất lên các chi tiết, bộ phận của vật thử nghiệm nhằm đánh giá hoạt động hoặc độ bền của vật thử nghiệm phục vụ cho công tác nghiên cứu, thử nghiệm. Các tác động đó phụ thuộc vào nhiều yếu tố như khối lượng búa, khối lượng vật thử nghiệm, độ cứng của đe, góc giương của búa... Các thông số của búa thử chỉ áp dụng cho các trường hợp mặc định, các trường hợp khác khi cần xác định vận tốc búa cần phải tiến hành đo đạc. Thay cho việc phải thực hiện đo nhiều lần, bài báo đã đưa ra phương pháp tính toán xác định vận tốc va chạm để có thể tính toán cho mọi trường hợp. Kết quả tính toán được kiểm chứng bằng thực nghiệm đo tốc độ búa trên thiết bị camera tốc độ cao với sai lệch không quá 3,42%.

Từ khoá: Búa thử va đập; kiểm bền vật liệu; vận tốc nảy; gia tốc va chạm.

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