Establishing the sensitivity diagram of the inertia impact mechanism in the V-25 fuze

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ABSTRACT

The paper presents the construction of a sensitivity diagram for the inertia impact mechanism with two mass-dispersing side cushions, based on the construction of a mathematical model that describes the mechanism's operation upon target impact. The reliability of the inertia impact mechanism under various impact angles is determined using analytical methods, with input parameters of the inertia impact mechanism in the V-25 fuze. The research results enable an evaluation of the operational capability of the V-25 fuze's inertia impact mechanism and can serve as a basis for researching and designing the inertia impact mechanisms with of two mass-dispersing side cushions in the fuze.

Keywords: Inertia impact mechanism; Side cushion; Impact fuze; Sensitivity.

1. INTRODUCTION

The inertia impact mechanism operates under the effect of inertial forces generated when the projectile strikes an obstacle. In its simplest structural form, the basic components of the inertia impact mechanism include a firing pin, a primer (or detonator) and an inertial mass. This type of mechanism is widely employed in base fuzes such as the MD-8, MD-10, KTD; and it also serves as a critical component in various nose fuzes such as the M-12, RGM, KTM-1, KTM-2, and KTMZ-1 in order to enhance and ensure the operational reliability of the fuze when the setback mechanism is not functioning.

To enhance the reliability of the inertia mechanism's activation under impact conditions with large impact angles (the impact angle in this paper is defined as the angle between the projectile axis and the normal to the target surface), additional side cushion components sensitive to lateral inertial forces are incorporated into fuzes such as TS-1, TS-2, DK-2, GK-2, DBR, DBT, and V-25. The side cushion component in the fuzes can be a single block or a two-block, or a three-block side type, as shown in figure 1.

The sensitivity diagram for the fuze is an effective research method in evaluating the performance of the fuze under impact conditions. In the inertial impact mechanism, the diagram shows the relationship between the impact acceleration required for the fuze to work and the angle of impact. Several scientific publications have used this method while researching the fuze [1-3].

The V-25 fuze, intended for use with the M-14OF projectile, incorporates an inertial impact mechanism featuring two mass-dispersing side cushions. To evaluate the operational characteristics of this mechanism, the paper develops a mathematical model describing its functioning process and applies an analytical method to construct the sensitivity diagram of the mechanism. The sensitivity diagram represents the relationship between the impact angle and parameters characterizing the initiation conditions, such as the required overload *(G)* or the required impact velocity *(v_c)*. Based on this diagram, the mechanism's performance can be assessed at various impact angles, thereby determining the effective angle range that ensures reliable operation.

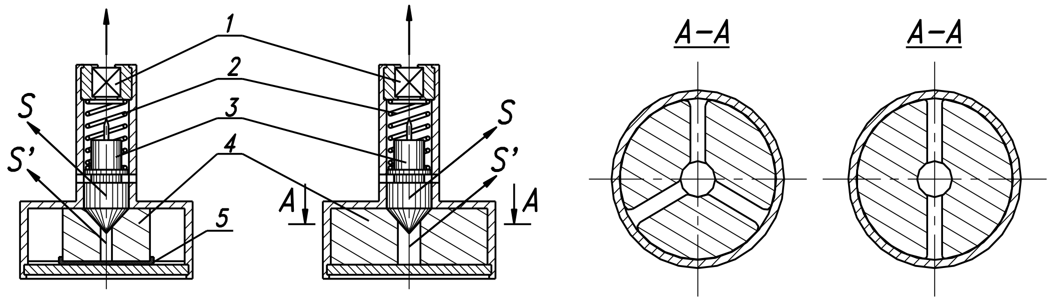

Figure 1. *Some structural forms of the inertial impact mechanism with a side cushion: 1 - Primer; 2 - Spring; 3 - Inertial block; 4 - Side cushion; 5 - Hard safety lug.*

This research method can be applied to study similar inertial impact mechanisms with side cushions, aiding in the calculation and design process of such mechanisms.

2. MATHEMATICAL MODEL OF THE TWO-BLOCK SIDE CUSHION IMPACT MECHANISM

2.1. Assumptions

The following assumptions are used when constructing the mathematical model:

- The mechanism operates when the inertial block moves a distance of 3 mm (the distance required for the firing pin to strike the primer in the V-25 fuze);

- Neglecting the change in angular velocity of the projectile and assuming it to be the angular velocity at the moment the projectile collides with the obstacle [4];

- Neglecting the change in direction and magnitude of the centrifugal force acting on the side cushion block during the movement of the impact block;

- The coefficient of friction is taken to be the same on the moving surfaces in the mechanism;

- When determining the deceleration of the projectile at the moment it collides with the target: the impact environment is a compacted sand substrate, homogeneous, with the projectile tip remaining intact and not being destroyed during penetration, and the recoil impact mechanism is inactive (only considering the effect of the inertial block). It should be noted that in structural studies, the acceleration of the impact block can be assumed to be constant during the impact process, as this assumption does not introduce significant errors [4].

2.2. Geometric model

Consider the inertial impact mechanism with a two-block side cushion, as shown in figure 2.

Apply the force and write the motion equation of the impact block and side cushion in the XOY coordinate system as follows:

Similarly, for the impact mechanism with a single solid side cushion as shown above, the force components, including the inertial forces along axes S_1, S_2, and S_3, are applied to the impact block and side cushions m_2 and m_3. As shown in figure 2, the force components and angles are as follows:

S_{2yz} : The inertial force component S_2 in the YOZ plane;

S_{3yz} : The inertial force component S_3 in the YOZ plane;

C: Centrifugal force acting on the two inertial blocks;

Angle γ: Side cushion cone angle;

Impact angle φ: The angle formed by the inertial force S_1 and the OX axis;

Angle β: The angle formed by the inertial force S_{2yz} and S_{3yz} with the OY axis.

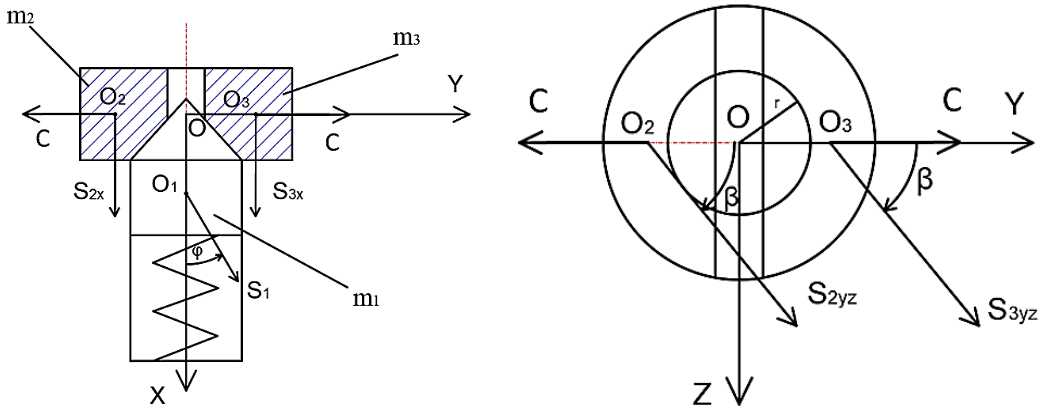

Figure 2. *Force diagram acting on the inertial impact mechanism with a two-block side cushion.*

Assume that the inertial impact mechanism has a symmetrical structure (figure 2), with the centroids of the inertial block m1 and the side cushions m2 and m3 located at points O_1, O_2, and O_3, respectively, on the XOY plane. The centroids O_2 and O_3 of the side cushions m_2 and m_3 are at a distance l from the OX axis.

The inertial force acting on the inertial block creates an angle (impact angle) φ with the symmetry axis and an angle β with the OY axis, respectively (figure 2). Due to the symmetrical nature of the inertial impact mechanism, the angle φ can be examined from 0˚ to 180˚. In practice, the angle β changes as the projectile penetrates the target. However, for theoretical analysis, it is assumed that this angle remains constant during the study of the mechanism. In the case of a small β angle, only the side cushion m_2 exerts a force on the inertial block. There is a normal force N_1 exerted on the impact block by side cushion 2, and a corresponding reaction force N_2 exerted by the impact block on side cushion 2, with associated friction forces F_1 and F_2; the magnitudes of N_1 and N_2 are both equal to N; the spring resistance force R acts on the impact block, and the centrifugal force C arises from the projectile's rotational motion, additionally induced when the center of mass of the side cushion is displaced during its motion under the influence of S_{2y} (the Y-axis component of force S_2).

System of differential equations of motion:

$$\begin{cases} m_1\ddot{x} = S_{1x} + N_{1x} - R - F_{1x} - F_3 \\ m_2\ddot{y} = S_{2y} - C - N_{2y} - F_{2y} - F_4 \\ y = xtg\gamma \end{cases} \quad (1)$$

Where: x - The displacement of the impact block; y - The displacement of the side cushion; m_1, m_2 - The masses of the impact block and side cushion 2; $F_3 = f_3(S_{1y} + N_{1y} + F_{1y})$ - The frictional force due to the displacement of the impact block along the OX axis, caused by the component of the force directed along the OY axis; f_3 - The coefficient of friction between the impact block and the guiding surface; $F_4 = f_4(S_{2x} - N_{2x} + F_{2x})$ - The frictional force resisting the motion of the side cushion along the OY axis, caused by its contact with the guiding surface and the component of the force directed along the OY axis; f_4 - The coefficient of friction between the cushion and the guiding surface; $R = c(\lambda_l + x)$ - Spring resistance force; $C = m_2(y-l).\Omega^2$ - Centrifugal force; $F_{1,2}$ - Frictional forces; $S_1 = m_1.g.n; S_2 = m_2.g.n$ - Inertial force; n - Impact overload; N - The reaction force between the side cushion and the impact block; c - Spring stiffness; λ_l - Pre-compression of the spring; f_1 - Friction coefficient between side cushion 2 and the impact block.

After substituting the forces and transforming the system of equations (1), the equation of motion of the inertial block is obtained:

$$\ddot{x} - K_x.x = K_J \tag{2}$$

where:

$$K_J = \frac{m_1 cos\varphi J - c\lambda_l - f_3 m_1 sin\varphi J + K_f m_2 sin\varphi cos\beta J - K_f f_4 m_2 cos\varphi cos\beta J - K_f m_2 l\Omega^2}{m_1 + K_f m_2 tg\gamma};$$

$$K_x = \frac{m_2 tg\gamma\Omega^2 - c}{m_1 + K_f m_2 tg\gamma};\ K_f = \frac{sin\gamma - f_1\cos\gamma - f_3\cos\gamma - f_1 f_3 sin\gamma}{\cos\gamma + f_1 sin\gamma - f_4 sin\gamma + f_1 f_4\cos\gamma}.$$

Thus, from the complex system of equations (1), we have reduced it to a differential equation of motion for the inertial impact block (2).

However, equation (2) is valid only when the side cushion has moved; if the side cushion has not moved, then the mechanism operates solely with the inertial impact block, meaning the mechanism behaves as a simple impact mechanism, and the problem becomes that of a simple impact mechanism. In practice, with a small contact angle, only the impact block operates, while the side cushion only comes into play when the contact angle is large. To solve this problem, it is necessary to determine the transition condition, identify and distinguish between the case where only the inertial block moves or the case where both the side cushion and the inertial block are in operation. The condition for the side cushion to move is: the inertial force acting on the side cushion is greater than the frictional resistance force:

$$m_2\frac{dV}{dt}\sin\varphi\cos\beta > f_4 m_2\frac{dV}{dt}cos\varphi + m_2 l\Omega^2 \tag{3}$$

When the side cushion is not yet engaged, the equation of motion for the inertial block becomes simpler, with the following coefficients:

$$K_x = -\frac{c}{m_1};\ K_J = \left(\cos\varphi - fsin\varphi\right)J - \frac{c.\lambda_l}{m_1}$$

2.3. Method for constructing the sensitivity diagram

For the problem of constructing the sensitivity diagram, a function $v_{kh} = f_v(Vc)$ can be established. That is, under a specific condition, for each impact velocity, there is a corresponding value of the firing pin velocity when it strikes the target. As the impact velocity increases, the overload increases, and the velocity of the firing pin will be higher. Therefore, the function $f_v(Vc)$ is an increasing function of the impact velocity. Thus, for each impact angle, the solution to the equation $f = f_v(Vc) - v_{h0} = 0$ can be determined [3, 6]. To determine the required overload corresponding to each specific impact angle, the bisection method is used.

The algorithmic flowchart for constructing the sensitivity diagram of the mechanism is shown in figure 3. Where φ_o is calculated from condition (3), while f_v and $f_v^{'}$ are functions describing the relationship between v_c and φ for the cases with lateral buffer displacement and without lateral buffer displacement, respectively.

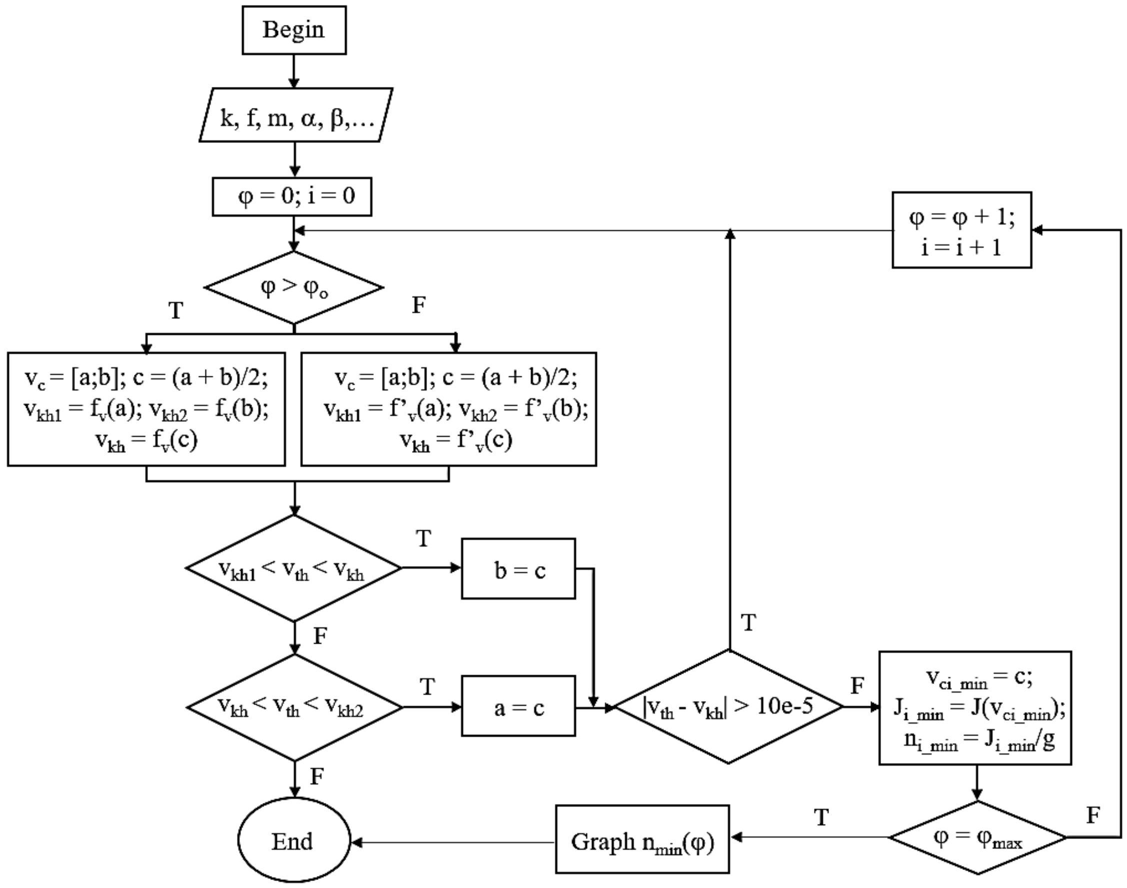

Figure 3. *Algorithmic flowchart for constructing the sensitivity diagram of the mechanism.*

3. SENSITIVITY DIAGRAM OF THE INERTIAL IMPACT MECHANISM IN THE V-25 FUZE

3.1. Input parameters

The M-14OΦ projectile is designed for launchers mounted on the BM-14-16 or BM-14-17 combat vehicles. It is an unguided rocket with blast-fragmentation effects, stabilized in flight by the gyroscopic principle. To construct the sensitivity diagram of the inertial impact mechanism in the V-25 fuze used in the M-14OΦ projectile, the paper uses the input parameters as shown in table 1.

Regarding the projectile's rotational speed, the study assumes that the spin rate at the moment of impact is 70% of the projectile's maximum spin rate [4]. The maximum spin rate of the M-14OF projectile is approximately 18,000 revolutions per minute (equivalent to 1885 rad/s); therefore, the spin rate at the moment of impact is taken as 1320 rad/s.

The required penetration velocity to ignite the primer is calculated using the formula proposed by B.L. Kraxnoponski [4]. With the mass of the impact block being m_{vd} = 4,4 g, the required impact velocity for MD-5 is calculated to be 5 m/s.

In this paper, it is assumed that the angle $\beta = 0$ (figure 2). This assumption is acceptable because this angle changes during the operation of the mechanism, and is used for theoretical evaluation.

Table 1. *Input parameters of the M-14OF projectile and V-25 fuze in constructing the sensitivity diagram of the inertial impact mechanism [5].*

No.	Calculation parameters	Value
1	Projectile mass upon impact with the target, M (kg)	31,95
3	Projectile size, d (mm)	140
4	Projectile nose height, H (mm)	428
5	Projectile nose curvature radius, R_m (mm)	1343
6	Side cushion mass, m_1 (gam)	11,5
7	Inertial mass including the primer, $m_{vđ}$ (gam)	4,4
8	Distance between the two side cushions, h (mm)	2,8
9	Cone angle of the side cushion and the inertial block, φ (degree)	45
10	Distance from the primer to the firing pin, a (mm)	3,0
11	Spring stiffness of the safety mechanism, k (N/mm)	1,14
12	Initial compression of the spring, x_o (mm)	7,0
13	Friction coefficient between the side cushion and the guide surface (f_1), between the inertial block and the guide surface of the fuze body (f_2), between the side cushion and the inertial block (f_3)	0,1

3.2. Sensitivity diagram of the inertial firing mechanism of the V-25 fuze

With the input parameters as mentioned above, solving the mathematical model results in the sensitivity diagram shown in figure 4. Additionally, the study also constructs the sensitivity diagram of the fuze in the case where the effect of centrifugal force is neglected (figure 5).

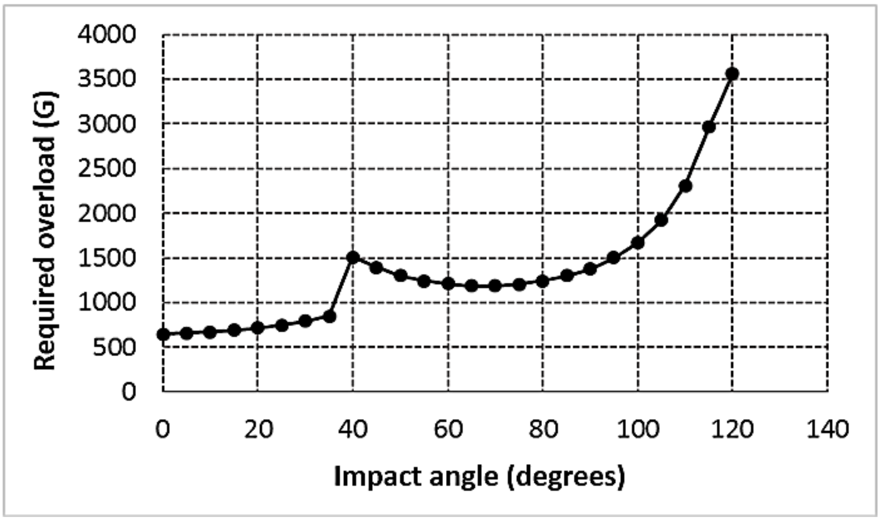

Figure 4. *Sensitivity diagram of the V-25 fuze.*

Analysis of the sensitivity diagram (figure 4) indicates that when the impact angle is less than 40°, only the inertial block containing the igniter element moves, while the side cushion does not yet participate in the process. This is guaranteed by the displacement condition of equation (3). For impact angles greater than 40°, the side cushion begins to move and exerts force on the inertial block. At the section of diagram above 40°, the graph sags down and then goes up again, because: we consider the side cushion and the inertial mass separately; when the angle of impact increases, the overload required to move the inertial mass increases, but the overload required to move the side cushion decreases; therefore, the graph will sag down due to these two correlations. The maximum impact angle at which the inertial impact mechanism can operate is 120°. In this case, the required impact velocity for the M-14OF projectile ranges from 146 to 394 m/s; at higher impact velocities (higher accelerations), the mechanism operates with greater reliability.

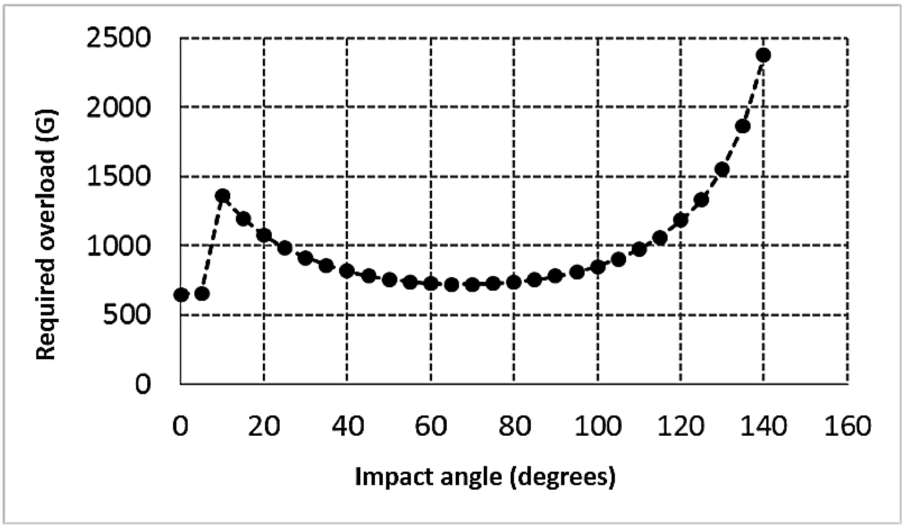

Figure 5. *Sensitivity diagram of the V-25 fuze when centrifugal force is neglected.*

In the case where the effect of centrifugal force is neglected (figure 5), the side cushion begins to act on the inertial block at a smaller impact angle. In this case, the side cushion becomes effective at impact angles greater than 10°, due to the absence of centrifugal force affecting the displacement of the inertial block. The maximum ignition angle in this case also increases to 140°.

Both cases demonstrate that the inertial impact mechanism with the side cushion operates reliably even at large impact angles.

To evaluate the influence of technological factors on the performance of the inertial impact mechanism in the fuze, the paper investigates the effect of the friction coefficient on the sensitivity of the inertial impact mechanism in the V-15 primer (figure 6).

Analysis of the sensitivity diagram (figure 3) indicates that the friction coefficient has a significant influence on the performance of the inertial impact mechanism. When the friction coefficient increases from 0.1 to 0.3, the maximum ignition angle of the mechanism decreases from 120° to 80° (a reduction of 33%). Therefore, during the manufacturing of components, attention should be given to the surface roughness of the sliding surfaces of the mechanism.

The results on the maximum ignition angle are consistent with studies on semi-allways action mechanism. The working angle is usually greater than 90 degrees, up to 120 degrees [7].

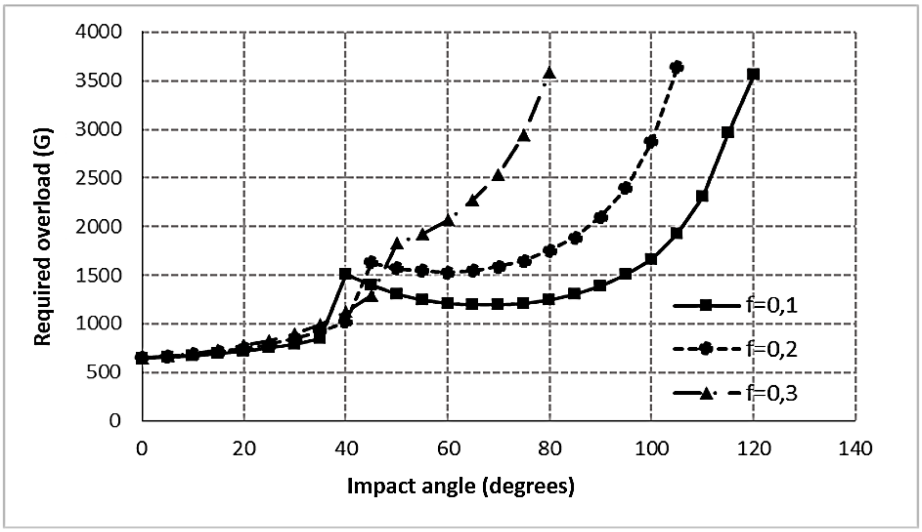

Figure 6. *Sensitivity diagram of the V-25 fuze when centrifugal force is neglected.*

4. CONCLUSIONS

The paper has constructed a mathematical model to describe the operation of the inertial impact mechanism with a two-block side cushion. The mathematical model was applied to construct the sensitivity diagram of the inertial impact mechanism in the V-25 fuze. The results indicate that the V-25 fuze exhibits relatively high sensitivity, with a large ignition angle (up to 120°) even when the effect of centrifugal force is neglected. The results of the investigation also indicate that the friction coefficient has a significant influence on the performance of the mechanism. The results also showed that the projectile M-14OF can work well when fired in complex terrain, mountain slopes, etc.

The research method presented in this paper can be applied to study inertial impact mechanisms in general, as well as the various structural forms of side cushions in the fuze.

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TÓM TẮT

Nghiên cứu xây dựng giản đồ độ nhạy của cơ cấu va đập quán tính ngòi V-25

Bài báo xây dựng giản đồ độ nhạy của cơ cấu va đập quán tính có đệm bên loại hai khối, trên cơ sở xây dựng mô hình toán học mô tả hoạt động của cơ cấu khi đạn chạm mục tiêu. Bài báo xác định độ tin cậy làm việc của cơ cấu va đập quán tính với các góc chạm khác nhau bằng phương pháp giải tích với các tham số đầu vào của cơ cấu va đập quán tính trong ngòi V-25. Kết quả nghiên cứu cho phép đánh giá khả năng làm việc của cơ cấu va đập quán tính ngòi V-25 và có thể làm cơ sở cho việc nghiên cứu thiết kế cơ cấu va đập quán tính có đệm bên loại hai khối trong ngòi đạn.

Từ khóa: Cơ cấu va đập quán tính; Đệm bên; Ngòi chạm nổ; Độ nhạy.