STUDYING THE EFFECT OF FIRING TEMPERATURE ON THE INITIAL FLIGHT ANGLE OF BULLET WHEN FIRING SERIES

NGHIÊN CỨU ẢNH HƯỞNG CỦA NHIỆT ĐỘ PHÁT BẮN ĐẾN GÓC BAY RA CỦA ĐẦU ĐẠN KHI BẮN LOẠT

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ABSTRACT

In the article, the equation for determining the flight angle of the bullet taking into account the effect of the firing temperature is presented. The parameter of 37mm-K65 anti-aircraft gun are used to calculated. Research results show that: The firing temperature significantly affects the bullet's flight angle when firing series. This influence is gradually increased after each shot. The bullet's flight angle when firing the 5, 10, 15, 20, 25, and 30 shots is 0.0117, 0.015, 0.0175, 0.0185, 0.0199, and 0.0206 rad, respectively. This result is used as data to come up with effective barrel design solutions and cooling methods.

Keywords: *The firing temperature; Flight angle; Interior ballistic; Barrel design.*

TÓM TẮT

Trong bài báo, phương trình xác định góc bay ra của đạn pháo khi kể đến ảnh hưởng của nhiệt độ phát bắn được trình bày. Tính toán số được áp dụng cho pháo phòng không 37mm-K65. Kết quả nghiên cứu cho thấy: Nhiệt độ phát bắn ảnh hưởng đáng kể đến góc bay ra của đạn khi bắn loạt. Sự ảnh hướng đó thì tăng dần sau mỗi phát bắn. Góc bay ra của đạn khi bắn các viên đạn thứ 5, 10, và 15 lần lượt là 0.0117, 0.015, 0.0175, 0.0185, 0.0199 và 0.0206 rad. Kết quả này được sử dụng làm dữ liệu để đưa ra các giải pháp thiết kế nòng và phương pháp làm mát nòng hiệu quả.

Từ khóa: *Nhiệt độ phát bắn; Góc bay ra; Thuật phóng trong; Thiết kế nòng.*

1. INTRODUCTION

The angle of flight is created by the velocity vector of the warhead and the initial position of the tangent line to the actual barrel axis at the muzzle part of the cannon at the moment before firing. The flight angle is divided into 2 main components: Vertical flight angle, horizontal flight angle. The vertical flight angle and the horizontal flight angle are understood as projections of the flight angle in the respective plane onto the vertical and horizontal planes.

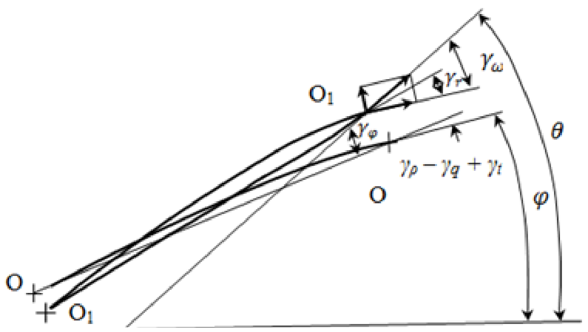

Figure 1. Model for determining the flight angle

The actual vertical flight angle is the geometric sum of the projections on the vertical plane of the six angles in space:

$$\gamma = \theta - \varphi = \pm\gamma_{\varsigma} - \gamma_{q} + \gamma_{\varphi} - \gamma_{\eta} + \gamma_{\omega} \pm \gamma_{T} \qquad (1)$$

Where:

θ - Lift angle; φ - range angle;

γ_{ς} - The angle at the mouth of the barrel occurs due to the curvature of the barrel;

γ_q - Angle created by the curvature of the barrel mouth due to gravity;

γ_η - The angle created when the barrel of the cannon is treated as an elastic body;

γ_φ - The angle created by the barrel's rotation around the pivot of the rotating part, which is measured as the angle between the tangent at the muzzle point in the stationary position before firing and at the time of firing;

γ_ω - The angle between the long velocity vector of the warhead and the composition vector of the long velocity vector with the horizontal velocity vector of the warhead at the moment the warhead exits the barrel;

γ_T - The angle is created due to uneven heating in the barrel wall when the wall thickness is different.

In the world, there have been many studies on the factors affecting the projectile's flight angle such as: the influence of the semi-link phase, the influence of the bullet structure... but there has been no research to mention the influence of the firing temperature to the bullet's flight angle. In the framework of this article, the author has studied, built a model, established the equation to determine the flight angle of the 37mmK65 anti-aircraft artillery bullet, taking into account the change in the firing temperature when firing in series.

2. ESTABLISHING THE EQUATION TO DETERMINE THE ANGLE OF FLIGHT OF THE BULLET TAKING INTO ACCOUNT THE TEMPERATURE OF THE FIRING

To establish the equation for the flight angle, several assumptions are used as follows:

- Let the values of the angles γ_ς, γ_q, γ_η, γ_φ, γ_ω be zero;

- The barrel wall is considered irregular in thickness;

- The horizontal flight angle is considered to be zero.

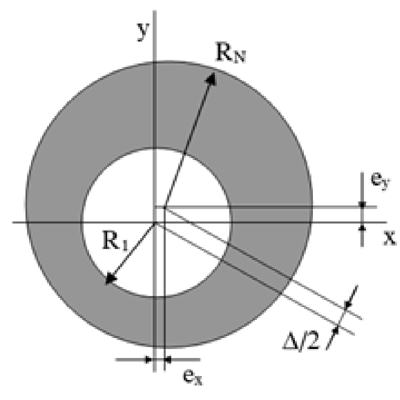

Figure 2. Model for determining the flight angle when the barrel wall thickness is different

Due to the uneven thickness of the barrel wall, the thin wall of the barrel cross ☞

section will be heated to a higher temperature than the thick barrel wall when fired. This is what causes the different elongations along the barrel axis. This elongation causes the barrel to bend and form a flight angle $\gamma_{т}$.

The relative elongation strain for a point of the barrel with coordinates θ and r with free expansion can be found by the formula:

$$\varepsilon_z^0 = \alpha \Delta T(\theta, r) - \frac{\sigma_z^0}{E} \tag{2}$$

Where: α - elongation coefficient; ΔT - surface temperature difference; σ_z^0 - The elongation stress at the point is determined by the coordinates θ and r.

When $\varepsilon_z^0 = 0$ then the elongation stress is determined:

$$\sigma_z^0 = \alpha \Delta T(\theta, r) E \tag{3}$$

Bending moment in each barrel cross section:

$$M_{и}^0 = \int_{R_1}^{R_N} \int_0^{2\pi} \sigma_z^0 r^2 . \sin\theta . dr . d\theta \tag{4}$$

or $$M_{и}^0 = \int_s \sigma_z^0 r \cos\theta ds \tag{5}$$

With ds = dθdr, Equation 5 can be rewritten as::

$$M_{и}^0 = \int_s \alpha \Delta T(\theta, r) E r \cos\theta d\theta dr \;. \tag{6}$$

The cross-sectional temperature distribution of barrel walls of different thicknesses is determined by the following formula:

$$\Delta T(\theta, r) = \frac{\Delta T_1 (1 + \cos\theta)}{2} + \frac{r - r_1}{r_2 - r_1} \frac{1 + \cos\theta}{2} (\Delta T_2 - \Delta T_1) \tag{7}$$

Where:

ΔT_1 - The maximum heat reduce on the inner surface of the barrel;

ΔT_2 - The maximum heat reduce on the outer surface of the barrel.

Substituting the value (7) into equation (6), the result obtained when integrating equation (6) is as follows:

$$M_{и}^0 = \alpha E (\Delta T_2 - \Delta T_1) \frac{\pi}{4} \left\{ 4 \left[\frac{\Delta T_1}{\Delta T_2 - \Delta T_1} - \frac{r_1}{r_2 - r_1} \right] \left(r_2^3 - r_1^3 \right) + 3 \frac{r_2^4 - r_1^4}{r_2 - r_1} \right\} \tag{8}$$

Bending moment can be determined by the following formula:

$$M_{и}^0 = \frac{EI}{\varsigma} \tag{9}$$

Where: ς - the radius of curvature of the barrel is considered.

Balancing the right side of equations (8) and (9), Value ς is determined:

$$\varsigma = \frac{b\left(r_2 - r_1\right)}{\alpha (\Delta T_2 - \Delta T_1) \left\{ 3 + 4 \frac{r_2^3 - r_1^3}{r_2^4 - r_1^4} \left[\frac{\Delta T_1}{\Delta T_2 - \Delta T_1} \left(r_2 - r_1 \right) - r_1 \right] \right\}} \tag{10}$$

Angle $\gamma_{т}$ is determined in ς terms of as follows:

$$\gamma_{т} = \frac{l}{2\varsigma} \tag{11}$$

The final expression for determining the flight angle $\gamma_{т}$ has the following form:

$$\gamma_{т} = \frac{\alpha l (\Delta T_2 - \Delta T_1) 10^2}{2\left(r_2 - r_1\right)} \left\{ 3 + 4 \frac{r_2^3 - r_1^3}{r_2^4 - r_1^4} \left[\frac{\Delta T_1}{\Delta T_2 - \Delta T_1} \left(r_2 - r_1 \right) - r_1 \right] \right\} \tag{12}$$

3. INVESTIGATE THE EFFECT OF FIRING TEMPERATURE ON THE FLIGHT ANGLE OF 37MMK65 ANTI-AIRCRAFT ARTILLERY

3.1. Input parameters

The 37mm K65 anti-aircraft gun is an automatic cannon, firing in tandem, with a rate of fire that can reach 160 to 180 rounds per minute. So the barrel temperature is different after each shot. This change is one of the causes of the change in flight angle after each shot. To determine the angle of flight after each shot taking into account the temperature change of the barrel, the flight angle of the 37mmK65 anti-aircraft gun is determined with the following input parameters:

Table 1. Input parameters for the heat problem of the 37mmK65 anti-aircraft gun barrel

Parameters	Symbol	Value
The temperature of the propellant	T	2100 ^{0}C
Inside diameter of barrel	r_1	18.5 mm
Outer diameter of barrel	r_2	45 mm
Length of barrel	l	2410 mm

The results of solving the problem of the heat of the barrel of the 37mmK65 anti-aircraft gun with 10 shots are as follows:

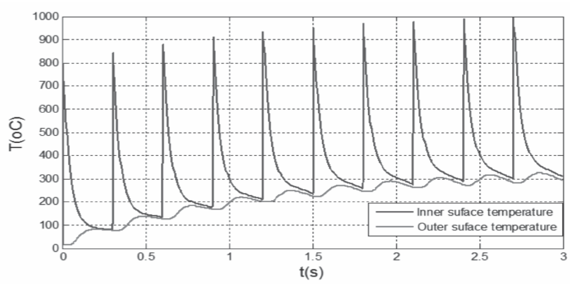

Figure 3. Temperature graph of inner and outer walls of the artillery

3.2. Investigate the effect of firing temperature on the flight angle of 37mmK65 anti-aircraft artillery

In order to investigate the effect of shot temperature on the deviation of the flight angle, the value of the flight angle is determined according to the number of shots respectively 5, 10, 15, 20, 25, 30 shots. Calculation results are shown in Table 2 .

Table 2. Calculation results of the flight angle according to the number of shots

Number of shot	ΔT_1(^{o}C)	ΔT_2(^{o}C)	ς (m)	γ_T(Rad)
5	300	250	250.97	0.0117
10	370	330	160.38	0.0150
15	420	390	137.86	0.0175
20	460	420	127.18	0.0185
25	490	440	120.61	0.0199
30	510	450	117.11	0.0206

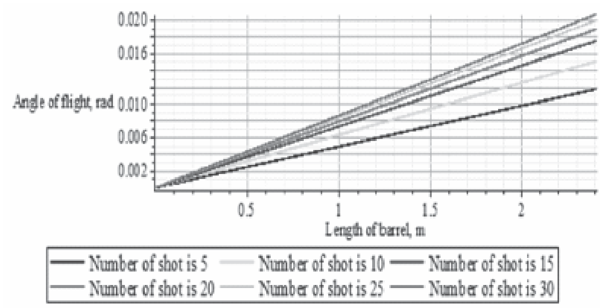

Figure 4. Graph of flight angle with different number of shots

Comment:

The results of calculating the difference between the outer surface temperature ΔT_2 and the inner surface temperature ΔT_1 are shown in Table 2. The temperature in the thick part $(R_N - R_1 + \Delta/2)$ of the barrel wall during firing is always lower than the temperature in the thin part (R_N - R_1 - Δ/2). During the firing time, the temperature difference between ΔT_1 and ΔT_2 increases rapidly.

The flight angle of the sections along the barrel length when firing series 5, 10, 15, 20, 25 and 30 is shown in figure 4. The figure also shows that the thin wall of the barrel will be heated faster after each shot, so the elongation will be greater than the thick wall. This temperature difference is larger the larger the number of shots. Therefore, the error of the automatic cannon's flight angle is greatly affected by the firing temperature.

4. CONCLUSION

In this paper, a model to determine the flight angle of shells is built taking into account the temperature change of the barrel during salvo firing. The equation for determining the fly-out angle is specifically established. The survey results show that:

- The difference in barrel wall temperature when the thickness of the barrel wall is different is the cause of the deviation of the flight angle when firing in series;

- For long-barreled cannons, the temperature of the shot has a greater effect on the angle of flight, so the error of the angle of fire is greater;

- Accurate determination of the cannon's flight angle is the basis for accurately determining the cannon's firing angle;

- Research results show that the deviation of the barrel wall thickness is the main cause of the flight angle deviation when firing series. Therefore, machining accuracy needs to be maximized when making cannon barrels.❖

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