

SURVEYING THE EFFECT OF GAS-VENT HOLE DIAMETER AND CLEARANCE BETWEEN PISTON AND CYLINDER ON AUTOMATIC FIRING SYSTEM OF 23mm 3Y23-2

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Abstract: *On the basis of analyzing the real model 23mm 3Y23-2, the paper chooses an alternative physics models, building a mathematical modeling dynamics, set up a system of equations and solve to find the cycle of operation on automatic firing system, change some parameters of cylinder and study on its affect to do automatic firing system; besides surveying the effect of gas-vent hole diameter and clearance between piston and cylinder on automatic firing system of 23mm 3Y23-2. The research method is based on the calculation theory to ensure compliance with the manufacturer's gun design and use documents.*

Keywords: Automatic firing system; The gas-vent hole; Automatic firing system of 23mm 3Y23-2.

1. INTRODUCTION

In gas-operated automatic firing systems, when the projectile moves through the gas-vent hole on the barrel, a part of the propellant gas through the gas-vent hole enters the cylinder, acting on the piston and pushing the recoil parts. The reverse provides power for an automatic firing system. On the other hand, when the recoil parts are backward, the return spring is compressed to reserve energy for the counter-recoil process. Thus, energy provided for the automatic firing system is the gas propellant force transmitting through the intermediate stage of the gas-operated device.

There are many parameters such as gas-vent position, gas-vent hole diameter, piston face area, clearance between piston and cylinder, the initial volume of the cylinder, the mass of recoiling parts, the heating conditions of the cylinder, etc. However, the paper only studies the effect of gas-vent hole diameter and clearance between piston and cylinder on automatic firing system of 23mm 3Y23-2 anti-aircraft gun. The result of the calculation has instructional significance for improving, increasing the firing accuracy.

2. DYNAMIC MODEL OF AUTOMATIC FIRING SYSTEM 23mm 3Y23-2

2.1. Structure and operating principle of the gas-operated 23 mm [6, 7]

The structure includes a cylinder and gas regulator (Fig.1).

When the projectile moves through the gas-vent hole on the barrel, a part of the propellant gas through the gas-vent hole and gas passage enters the cylinder, acting on the piston and pushing the recoil parts.

The gas regulator has two gas passage holes with diameters of 3.2 mm and 3.4 mm; a blowhole. One of the two gas passage holes coincides with the gas-vent holes of the cylinder and the bore. It has the effect of changing the flow of gas into the cylinder, leading to pressure in the cylinder is changed to ensure reliable operation of the automatic firing system in different conditions (the new gun is placed at the 3.4 mm hole after 1000 shots switch to 3.2 mm hole).

2.2. The problem of interior ballistics and automatic firing system

2.2.1. Interior ballistics assumptions [4]

The propellant burns on the base of geometric law:

The secondary works of propellant associated with projectile movement along with the bore and is applied to the coefficient of secondary work φ ; all propelling charges burn on the same pressure and are equal to the value of average ballistic pressure p ; for provision of burning stability the main charge ignition pressure; at the time on burning of propellant charge the in-bore, pressure growth and after that it will achieve value greater of short start pressure p_0 the projectile begins to travel along a bore.

Adiabatic coefficient θ is constant and equal to value average its from a moment of complete burning out of propellant and continuous till the moment when the projectile base will be replaced at the muzzle face of the barrel.

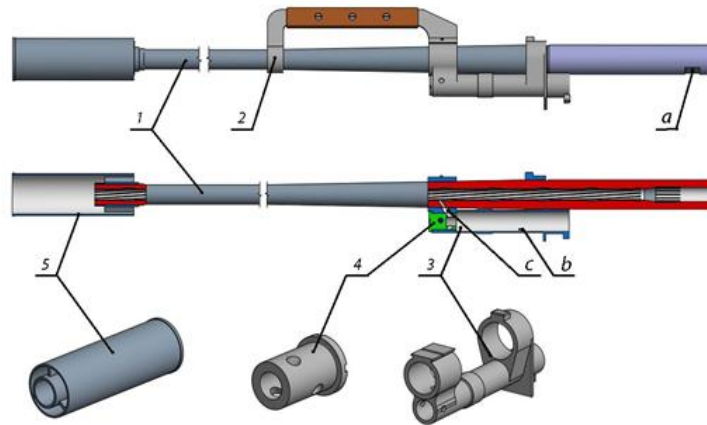


Figure 1. Structure of barrell and gas-operated device.

1. Barrell; 2. Carrying handle; 3. Cylinder; 4. Gas regulator;

5. Flash hider; a. Passage barrel lock lever; b. Blow hole; c. Gas-vent hole.

2.2.2. Assumptions of automatic firing system [2, 8]

Springs are elastic detail, automatic firing system's other parts are absolute solid objects; the links of automatic firing systems are planar kinematics; the mass of objects is collapsed and placed at the center of the object. For the link of translation motion, the reduced mass (m) is equal to its mass (M): $m = M$; for the link of rotation movement, the reduced mass (m) is used to $m.r^2 = J_0$ in which: m – The reduced mass of link; r – Distance from the point of placing the reduced mass to the axis of rotation; J_0 - The moment of inertia of the link to the axis of rotation.

Based on the structure of automatic ffiring system and assumptions, diagram of operation principle of 23 mm automatic firing system 3Y23-2 as following.

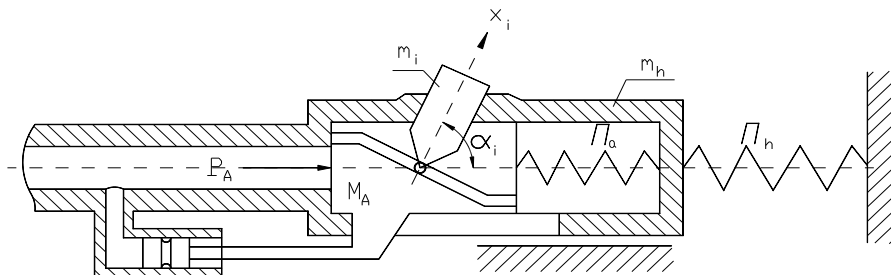


Figure 2. Diagram of operation principle of 23 mm automatic firing system 3Y23-2.

2.2.3. Interior ballistic equations [2, 4]

$$\left\{ \begin{aligned} \dot{l} &= \xi_1 \cdot v \\ \dot{v} &= \xi_1 \cdot \frac{p \cdot s}{\phi \cdot m} \\ \dot{z} &= \frac{p}{I_k} \cdot \xi_2 \\ \dot{\omega}_k &= \chi \cdot \omega \cdot (1 + 2 \cdot \lambda \cdot z) \cdot \dot{z} \cdot \xi_2 - G \cdot (1 - \xi_3) - G_b \cdot \xi_4 \\ \dot{W} &= \frac{1 - \alpha \cdot \delta}{\delta} \cdot \chi \cdot \omega \cdot (1 + 2 \cdot \lambda \cdot z) \cdot \dot{z} \cdot \xi_2 + s \cdot v \cdot \xi_3 + s \cdot \dot{x} \cdot \xi_x \\ \dot{p} &= \frac{1}{W} \cdot \left[f \cdot \chi \cdot \omega \cdot (1 + 2 \cdot \lambda \cdot z) \cdot \dot{z} \cdot \xi_2 - K_T \cdot p - k \cdot p \cdot \dot{W} - K_p \cdot G \cdot (1 - \xi_3) - K_p \cdot G_b \cdot \xi_4 \right] \end{aligned} \right. \quad (1)$$

In which:

- K_T : Temperature losses function: $K_T = \frac{(k-1) \cdot A \cdot v_1 \cdot \sigma_T \cdot (F_k + \Pi \cdot d \cdot l)}{R}$;
- K_p : Flow function: $K_p = \frac{k \cdot p \cdot W}{\omega_k}$;
- W - The Volume for propellant gases; l - Projectile travel way inside a bore; v - Projectile velocity way inside a bore; z - Relative thickness of burn out layer of grain; p - Value of gas pressure inside a bore; ω - Mass of charge; ω_k - Mass of gas; s - Bore area; m - Mass of projectile; ϕ - Coefficient of secondary works; I_k - Charge burn's Impulse; G - Gas injection inside a bore; G_b - Gas injection inside a gas-vent hole; α - Covolume of propellant gases; δ - Propellant density; k - Adiabatic conditions of flow; χ , λ - Form function coefficients of powder grain; d - Calibre gun; R - Effective value of gas; σ_T - Coefficient transmission.

2.2.4. Gas-operated Equations [1, 3]

Gas-operated equations in cylinder is written as following:

$$\left\{ \begin{aligned} \dot{\omega}_b &= (G_b - G_\Delta) \cdot \xi_4 \\ \dot{W}_b &= S_p \cdot V_b \\ \dot{p}_b &= \frac{1}{W_b} \cdot \left[k \cdot G_b \cdot R \cdot T - k \cdot G_\Delta \cdot R \cdot T_b - k_{tb} \cdot P_b - k \cdot P_b \cdot \dot{W}_b \right] \cdot \xi_4 \end{aligned} \right. \quad (2)$$

In which:

$$k_{tb} = \frac{(k-1) \cdot A \cdot v_1 \cdot \sigma_T}{R} \cdot (F_{ob} + \Pi \cdot d_p \cdot X_b) \quad W_b = W_{ob} + S_p \cdot X_p \quad G_b = A_n \cdot \mu_n \cdot S_\varphi \cdot \frac{p_n}{\sqrt{RT_n}}$$

Where: G_b - Gas injection inside cylinder through gas-vent hole; G_Δ - Gas injection inside clearance between pistol and cylinder; F_{ob} - Initial surface area of cylinder; S_p -

Surface pistol area; p_n , T_n - Pressure and temperature in a bore; p_b , T_b - Pressure and temperature in the cylinder; ω_b - Mass of gas in cylinder; d_p - Pistol diameter; A_n - Mechanical equivalent of heat; μ_n - Coefficient of gas injection through gas-vent hole; μ_A - Coefficient of gas injection through clearance between pistol and cylinder; S_ϕ - Minimum cross-sectional area of gas-vent hole; S_Δ - Clearance between pistol and cylinder area; X - Distance of breech system and pistol; V - Velocity of breech system and pistol.

2.2.5. Automatic firing system equations [1, 3]

We apply the Lagrange equations in order to describe different equations of the automatic firing system, it yields [5]:

$$\frac{d}{dt} \left(\frac{\partial T}{\partial \dot{q}_j} \right) - \frac{\partial T}{\partial q_j} + \frac{\partial \Pi}{\partial q_j} = Q_j \quad (3)$$

In which: T - Kinetic energy function of the mechanical system; Π - Potential energy function of mechanical system; Q_j - Generalized force; q_j và $\dot{q}_j$ are the vector generalized coordinates and generalized velocity of the system.

- As [1], equation (3) may be written as following:

$$\left\{ \begin{array}{l} \left(M_A + \sum_{i=1}^n \frac{K_i^2}{\eta_i} m_i \right) \ddot{x} + \dot{x}^2 \sum_{i=1}^n \frac{K_i}{\eta_i} m_i \frac{\partial K_i}{\partial x} + \left(M_A + \sum_{i=1}^n \frac{K_i}{\eta_i} m_i \cos \alpha_i \right) \ddot{x}_h + C_A x \\ \quad = P_A - \Pi_{Ao} + \sum_{i=1}^n \frac{K_i}{\eta_i} P_i \\ \left(M_A + m_h + \sum_{i=1}^n m_i \right) \ddot{x}_h + \left(m_A + \sum_{i=1}^n K_i m_i \cos \alpha_i \right) \ddot{x} + \dot{x}^2 \sum_{i=1}^n K_i m_i \cos \alpha_i \frac{\partial K_i}{\partial x} + C_h x_h \\ \quad = P_h - \Pi_{ho} \text{Sign} x_h - F \text{sign} \dot{x}_h \end{array} \right. \quad (4)$$

In which: M_A - mass of base link; m_h - Mass of receiver; F - The friction force between cradle and receiver; P_A - External force acting on the base link; P_i - External force acting on link i -th; Π_A - The initial recoil spring force; F_{Ai} - The friction force of receiver acting on the base link; F_i - The projection of friction force acting on i -th link; P_h - External force acting on the receiver; Π_{ho} - The initial brake force; K_i - Gear ratio from i -th link to base link; R_i - The projection of reactive force into i -th link; R - The projection of reactive force into the base link.

Integation (4), we get the system of general differential equations for 23 mm anti-aircraft gun as follows:

$$\left\{ \begin{array}{l} \ddot{x} = \frac{1}{M_A} \left[P_A' - C_A x - M_{qt} V^2 - M_{\eta} \dot{V}_k \right] \\ \dot{x} = V \\ \ddot{V}_h = \frac{1}{M_h} \left[P_h' - C_h x_h - M_K \dot{V} - M_{K_s} V^2 \right] \\ \dot{x}_h = V_h \end{array} \right. \quad (5)$$

In which:

$$\begin{aligned}
 M'_A &= M_A + \sum_{i=1}^n \frac{K_i^2}{\eta_i} m_i; & M_h &= M_A + m_h + \sum_{i=1}^n m_i; \\
 M_K &= M_A + \sum_{i=1}^n K_i m_i \cos \alpha_i; & M_i &= \sum_{i=1}^n K_i m_i \cos \alpha_i \frac{dK_i}{dx}; \\
 M_{qt} &= \sum_{i=1}^n \frac{K_i}{\eta_i} m_i \frac{\partial K_i}{\partial x}; & M_\eta &= M_A + \sum_{i=1}^n \frac{K_i}{\eta_i} m_i \cos \alpha_i; & P'_A &= P_A - \Pi_{A0} + \sum_{i=1}^n \frac{K_i}{\eta_i} P_i.
 \end{aligned}$$

3. RESULTS AND DISCUSSION

3.1. The input parameters

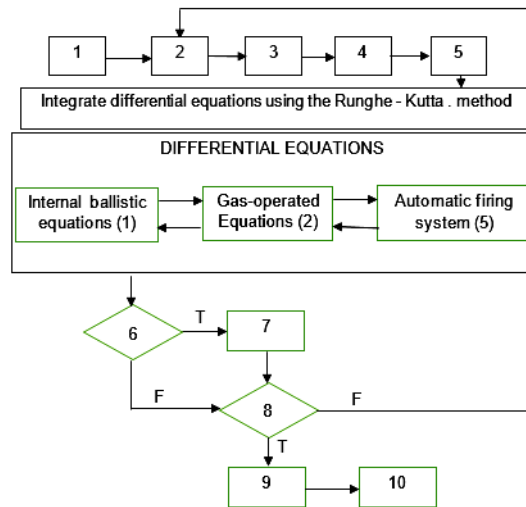
Table 1. The following table shows the parameters used to calculate.

No	Name	Symbol	Value	Dimensional
1	Calibre gun	d	0,023	m
2	Projectile travel way inside a bore	l_d	1,744	m
3	Bore area	s	0,000007065	m^2
4	Initial free chamber volume	W_o	0,000083	m^3
5	Shot start pressure	p_o	3924000	Pa
6	Powder force	f	931950	J/kg
7	Charge burn's Impulse	I_k	568980	$N.s/m^2$
8	Covolume of propellant gases	α	1000	m^3/kg
9	Propellant density	δ	1600	N/m^3
10	Form function coefficients of powder grain	λ χ	-0,056 1,05	
11	Adiabatic conditions of flow	k	1,25	
12	Coefficient of secondary works	φ	1,32	
13	Projectile mass	q	4.4145	N
14	Mass of charge	ω	0.75537	N
15	The value of projectile travel to moment of all burnt to gas-vent hole	l_φ	0,416	m
16	Pistol diameter	d_p	0,032	m
17	Gas-vent hole diameter	d_l	0,0032	m
18	Clearance between pistol and cylinder area	S_Δ	0,00005	m^2
19	Effective value of gas	R	320	kg.dm/kg.k
20	Mechanical equivalent of heat	A	1	J/N.m
21	Coefficient	ν_1	0,7	
22	Heat emission coefficient	δ_t	0,9	
23	The initial recoil spring force	Π_{ho}	4110...6798	N
24	The stiffness of recoil spring	k_o	27860,4	N/m

25	Mass of base link	m_o	613,4193	N
26	Mass of bolt	m_k	92,214	N
27	Mass of cartridge case	m_v	1,962	N
28	Mass of receiver	m_h	7357,5	N

3.2. The result of interior ballistic and automatic firing system

The pressure curves of bore and pressure curves of cylinder is determined by using the Maple software with input parameters as design document [1, 3] and solving systems of equations (1, 2, 5) by block diagram as follow:



1. Input data; 2. Forces acting on base link; 3. Determine the value of the resistance force;
4. Determine the value of k_i , μ_i ; 5. Determine the value of ζ_i ; 6. Collision of links; 7. The speed variation due to collision; 8. Analysis of the end condition; 9. Results; 10. Stop.

3.2.1. The result of interior ballistic

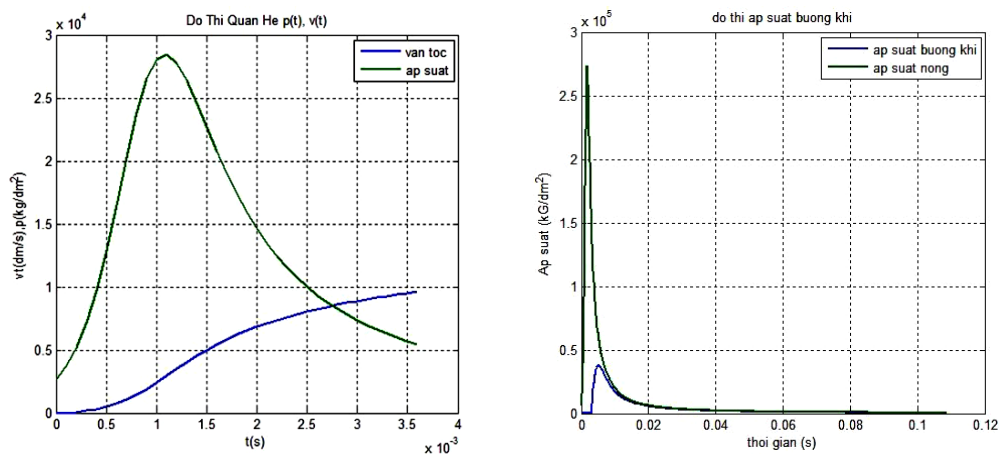


Figure 3. The pressure curves of bore and pressure curves of cylinder.

From figure 3, we get results as follow: The value maximum average pressure inside a bore is $p_{\max} = 2843,38 \text{ (kg/cm}^2\text{)}$, The maximum velocity of projectile is $v_{\max} = 962,84 \text{ m/s}$, the value maximum average pressure inside cylinder $p_{bk\max} = 376,49 \text{ (kg/cm}^2\text{)}$.

3.2.2. The result of automatic firing system

The cycle of operation given motion cycle of automatic firing system is shown in fig.4. A cycle of a shot is determined by 0,105 (s) same as the rate of fire is 882 shots/min. This result is matched with design documents [6, 7] about (800-1000) shots/min. So, a model of set automatic firing system is guaranteed reliability and can be used in surveying the effect of gas-vent hole diameter and clearance between piston and cylinder on automatic firing system of 23mm 3Y23-2 anti-aircraft gun.

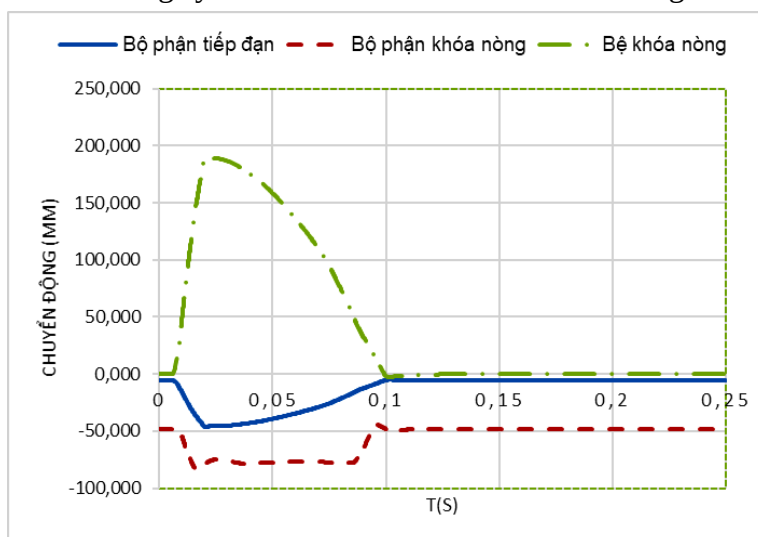


Figure 4. The cycle of operation on automatic firing system 23 mm.

3.3. Surveying the effect of gas-vent hole diameter and clearance between pistol and cylinder on automatic firing system of 23mm 3Y23-2 anti-aircraft gun

3.3.1. The effect of gas-vent hole diameter

The larger the area of the gas-vent hole, the greater the amount of charge entering the cylinder. Gas injection inside the gas-vent hole is reduced, the pressure in the cylinder is increased. Therefore, the change of the gas-vent hole area greatly affects to pressure and momentum of the charge in the cylinder. If the area of the gas-vent hole area is increased to a certain value, the amount of gas flowing from a bore into the cylinder is large, making the pressure of the gas-operated quickly equalize the pressure inside a bore. Then the area of the gas-vent hole continues to increase, the pressure of gas in the cylinder will not increase. If changing the diameter of the gas-vent hole to get the maximum value of cylinder and fire rate of the gun according to table 2 and figure 5, figure 6.

Table 2. The result of changing gas-vent hole diameter.

Gas-vent hole diameter(dm)	0,027	0.03	0,032	0,035	0.037
The value maximum pressure inside cylinder (kg/cm ²)	275,98	335,3	376,49	444,51	488,39
The rate of fire (shot/min)	692	830	882	912	934
The maximum velocity of breech block carrier (dm/s)	107,67	120,45	129,38	136,26	140,01

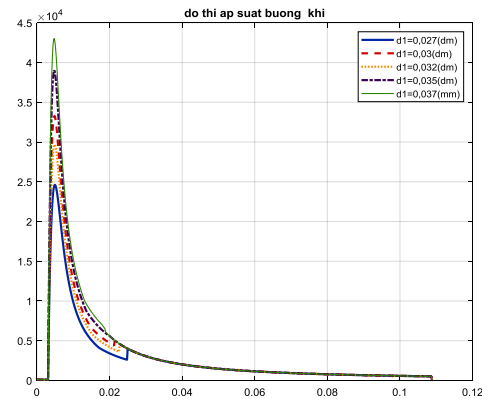
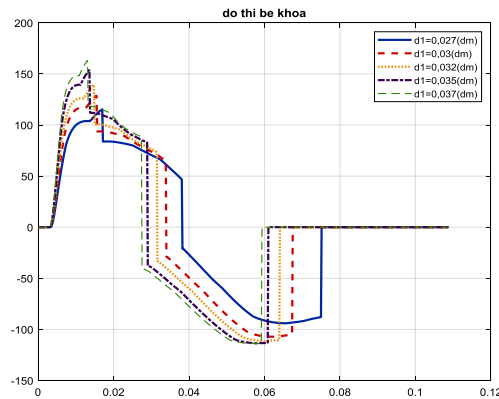


Figure 5. The velocity of breech block carrier when gas-vent hole diameter is changed. **Figure 6.** The value pressure inside cylinder when gas-vent hole diameter is changed.

Conclusion:

Initial gas-vent hole diameter $d_1 = 0,032$ (dm) corresponding to the value maximum pressure inside cylinder $376,48$ (kg/cm^2), the rate of fire: 882 (shot/min); the maximum velocity of breech block carrier: $129,397$ (dm/s). when gas-vent hole diameter is changed $d_1 = 0,037$ (dm) (increase $0,005$ dm) the value maximum pressure inside cylinder: $488,38$ (kg/cm^2) (increase $111,9$ kg/cm^2); the rate of fire: 934 shot/min (increase 52 shot/min); the maximum velocity of breech block carrier $140,01$ dm/s (increase $10,61$ dm/s).

Therefore, when making a barrel gun 23 mm, the larger the gas-vent hole is drilled, the more it affects the number of grooves and makes the projectile difficult to rotate in the barrel. If the gas-vent hole diameter is larger, the mass of powder charge hasn't burnt yet will still hit the surface of the pistol and will break, damage it. When the gas-vent hole diameter is increased, the pressure of the cylinder increases, which affects the durability of the piston and the breech block carrier.

3.3.2. The effect of clearance between pistol and cylinder

Table 3. Result of changing clearance between pistol and cylinder.

Clearance between pistol and cylinder (dm)	0.0045	0,005	0,0055	0,0057
The value of maximum pressure inside cylinder (kg/cm^2)	391,96	376,48	367,865	362,19
The rate of fire (shot/min)	894	882	865	859
The maximum velocity of breech block carrier (dm/s)	133,18	129,38	126,16	124,78

Initial clearance between pistol and cylinder $s_k = 0,005$ (dm) corresponding to the value maximum pressure inside cylinder $376,48$ (kg/cm^2), the rate of fire: 882 (shot/min); the maximum velocity of breech block carrier: $129,38$ (dm/s). when clearance between pistol and cylinder is changed $s_k = 0,0055$ [dm] (increase $0,0005$ dm) the value maximum pressure inside cylinder: $367,9$ (kg/cm^2) (decrease $9,42$ kg/cm^2); the rate of fire: 865 shot/min (decrease 23 shot/min); the maximum velocity of breech block carrier $126,16$ dm/s (decrease $3,32$ dm/s).

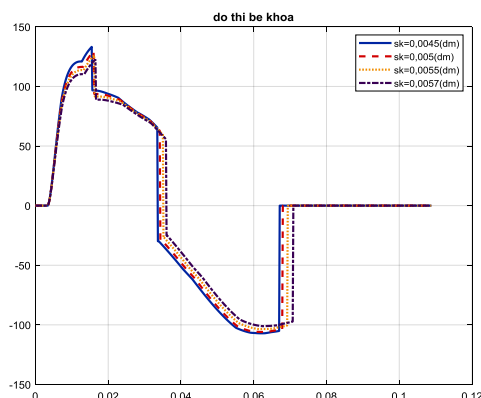


Figure 7. The velocity of breech block carrier when clearance between pistol and cylinder is changed.

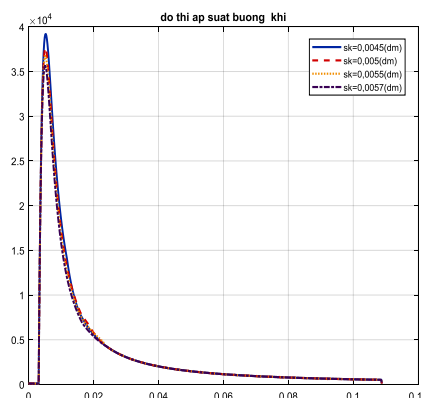


Figure 8. The value of pressure inside cylinder when clearance between pistol and cylinder is changed.

Conclusion:

- When clearance between piston and the cylinder increases, the value of maximum pressure inside the cylinder decreases. So, the value of pressure inside the cylinder is not enough to provide energy for the automatic firing system. This clearance value does not have a specific document. It only depends on the structure of the cylinder. When the pressure of the cylinder is maximum, there is a hole to let the air out.

- Therefore, to reduce the influence of the clearance between pistol and cylinder, it is not only to choose the smallest clearance that still ensures piston movement normally but also to choose an appropriate piston structure to reduce the amount of gas escaped, such as making the piston have a concave surface to avoid the formation of high pressure near the clearance between piston and the cylinder, making some grooves to reduce the rate of air release.

4. CONCLUSIONS

The paper has theoretical and practical significance as it does not only provides the theoretical basis but also surveys results effect of gas-vent hole diameter and clearance between pistol and cylinder on automatic firing system of 23mm 3Y23-2 anti-aircraft gun. The survey method is to change the value of gas-vent hole diameter so that the rate of fire is within the allowable range. However, this value should be consistent with the diameter of the gas regulator that the manufacturer made when the gun was new, using a hole with a diameter of 0.036 (dm); After use, the hole diameter is 0.032 (dm). The clearance between pistol and cylinder must be ensured so that the value of pressure inside cylinder reaches the required value. The survey method ensures the reliability in accordance with the production and manufacturing documents. The research results allow the study to build a model to calculate the stability of the gun when firing.

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TÓM TẮT

KHẢO SÁT ẢNH HƯỞNG CỦA ĐƯỜNG KÍNH LỖ TRÍCH KHÍ VÀ KHE HỖ GIỮA PISTON VỚI BUỒNG KHÍ ĐẾN HOẠT ĐỘNG MÁY TỰ ĐỘNG 23mm 3Y23-2

Trên cơ sở phân tích mô hình thực tế máy tự động 23mm 3Y23-2, bài báo lựa chọn mô hình vật lý thay thế, xây dựng mô hình bài toán động lực học, thiết lập hệ phương trình và giải bài toán để xây dựng đồ thị quy luật tuần hoàn của máy tự động, đồng thời khảo sát ảnh hưởng của đường kính lỗ trích khí và khe hở giữa piston với buồng khí đến quá trình làm việc của máy tự động. Phương pháp nghiên cứu dựa trên lý thuyết tính toán đảm bảo phù hợp với tài liệu thiết kế, sử dụng pháo của nhà sản xuất.

Từ khóa: Máy tự động; Lỗ trích khí; Máy tự động 23mm 3Y23-2.

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