THE ANALYSIS OF THE MOTION OF BOLT CARRIER FOR THE AMPHIBIOUS RIFLES WHEN SHOOTING UNDERWATER IN THE INITIAL PERIOD

Nguyen Van Hung[1*], Dao Van Doan, Nguyen Van Dung

Abstract: *The paper is focused on the establishment of a mathematical model describing the motion of bolt carrier for the amphibious rifles when shooting underwater in the period of the projectile moving to the position of the gas port. Besides, the conditions for bolt carrier motion are studied. The object of this paper is the bolt carrier assembly of the 5.56 mm amphibious rifle according to the designing of the research project of the ministry of defense 2017.73.034. The result of this research indicates that: for the 5.56 mm amphibious rifle, the bolt carrier is only moving when the velocity of the projectile at the position of the gas vent is larger 360.25 m/s. The result of this research can be applied to the dynamic analysis of the automatic mechanism of gas-operated rifles when shooting underwater.*

Keywords: Gas-operated rifle; Bolt carrier assembly; Amphibious rifle; Fluid dynamic.

1. INTRODUCTION

The amphibious rifles are designed for shooting in air and underwater. Until now, the famous amphibious rifles are the 5.45 mm ASM-DT and ADS rifles of Russia, 5.8 mm QBS-6 of China (Fig.1). However, Vietnam has just been interested in this weapon in recent years. The operation of amphibious rifles is based on the principle of the gas-operated rifles. It uses the propellant gases taken from ports in the barrel bore to drive the automatic system. The gas-driven system consists of a gas block connected through a gas port with the barrel bore and a piston positioned in a cylinder (Fig.1) [1].

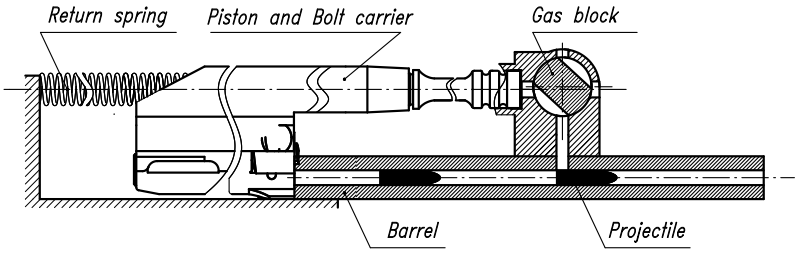


Figure 1. *Schematic of the amphibious rifles.*

Compared to the shooting in the air, the operation of the gas-driven system when shooting underwater is different as follows: In case of shooting in the air, before the projectile is not moving to the gas vent, the propellant cannot enter the cylinder of the gas block. Therefore, the gas force imparts on the piston is has not appeared. However, in the case of shooting underwater, the cylinder of the gas block had filled with water before shooting. Thus, when the projectile starts moving, the water in the barrel bore and cylinder move immediately. The water in the cylinder is divided into two parts: One part flows through the gap between the piston and the cylinder and another part impact the piston. But the problem must solve is the velocity of water is large enough to make the piston movement in this period. Besides, current solutions to study the piston movement in this period are unsatisfactory.

To solve this problem, the paper presents a model to investigate the motion of the bolt carrier of gas-operated rifles when firing underwater in the period of the projectile moving to the position of the gas port. This mathematical model is derived from the theory of fluid dynamics.

2. THE MATHEMATICAL MODEL

2.1. The hypotheses and model

In order to build the mathematical model, the following assumptions are used:

- Water is incompressible and viscosious;
- The rifle is fully immersed under water;
- Piston joints with the bolt carrier form a body and it is called bolt carrier;
- The barrel of the rifle is placed horizontally, and water is in a static state;
- The velocity of the water ahead of the projectile during its movement inside the barrel bore is the same as the projectile velocity;
- The impact point of the water forces acting on the bolt carrier is the center of the piston's surface;

According to the above assumptions, the model of the piston movement in the period of the projectile moving to the position of the gas port when shooting underwater is shown in Fig.2.

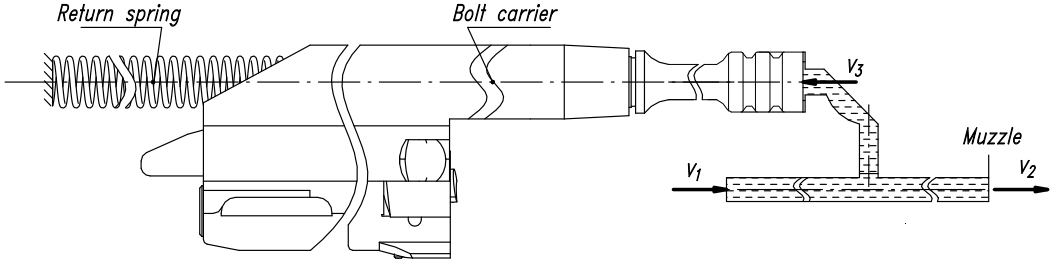


Figure 2. *The model of the piston movement in the period of the projectile moving to the position of the gas port when shooting underwater.*

where: $\vec{v}_1$ is the velocity of the water ahead of the projectile. This velocity is the velocity of the projectile and it is calculated with interior ballistic [2, 3]; $\vec{v}_2$ is the velocity of water discharge from the muzzle; $\vec{v}_3$ is the velocity of water impact on the piston.

In the period of the projectile moving to the position of gas port, the impact of the force on the bolt carrier includes (Fig.3):

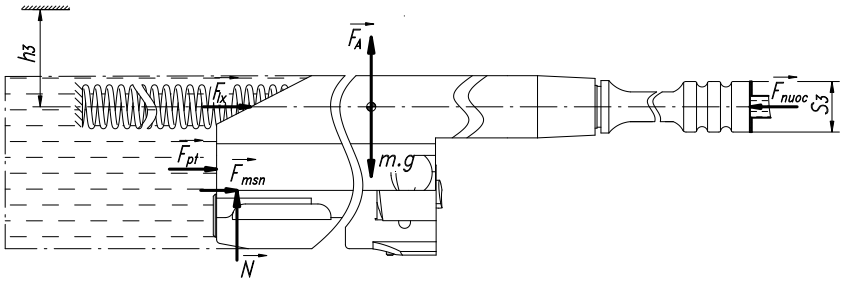


Figure 3. *The forces impact on the bolt carrier.*

- The buoyant force ($\vec{F}_A$). According to Archimedes, the buoyant force is determined [4]:

$$F_A = V_{bk}\rho_n g \tag{1}$$

where: V_{bk} is the volume of the bolt carrier assembly below the surface of the water; ρ_n is the density of water; g is the acceleration of gravity.

- Gravity force ($m.g$);

- The normal force caused by the receiver ($\vec{N}$):

$$N = mg - F_A \tag{2}$$

- The force of return spring ($\vec{F}_{lx}$).

- Drag force of water ($\vec{F}_{nuoc}$). It includes the drag force caused by hydrostatic pressure and the drag force caused by hydrodynamic pressure [5]. So, it can be calculated by:

$$F_{nuoc} = \rho_n g h_3 . S_3 + \frac{1}{2} \rho_n . v_3^{\,2} . S_3 \tag{3}$$

where: S_3 is the surface area of the piston; h_3 is the distance between the surface of the water and the axis of the bolt carrier.

- The static friction force between the bolt carrier assembly with the guiding ribs on the receiver ($\vec{F}_{msn}$):

$$F_{msn} = f_b \left(mg - F_A \right) = f_b \left(mg - V_{bk} \rho_n g \right) \tag{4}$$

where: f_b is the coefficient of static friction between the bolt carrier assembly with the guiding ribs on the receiver.

- The pressure drag caused by hydrostatic pressure ($\vec{F}_{pt}$):

$$F_{pt} = \rho_n g h_3 . S_{bk} \tag{5}$$

where: S_{bk} is the section area of the bolt carrier assembly.

2.2. Conditions for bolt carrier motion

The bolt carrier moving when the force of water is larger the total force acting on the piston. This means that:

$$F_{nuoc} \geq F_{lx0} + F_{pt} + F_{msn} \tag{6}$$

Substituting equations from Eq. (1) to Eq. (5) into Eq. (6) we get:

$$\rho_n g h_3 . S_3 + \frac{1}{2} \rho_n . v_3^{\,2} . S_3 \geq F_{lx0} + \rho_n g h_3 . S_{bk} + f_b \left(mg - V_{bk} \rho_n g \right) \tag{7}$$

So, the conditions for bolt carrier motion as

$$v_3 \geq \sqrt{\frac{2\left[F_{lx0} - \rho_n g h_3 . S_3 + \rho_n g h_3 . S_{bk} + f_b \left(mg - V_{bk} \rho_n g \right) \right]}{\rho_n . S_3}} \tag{8}$$

2.3. Calculation of the velocity of water impact on the piston

The purpose of this section is to determine the dependent of the water velocity ($\vec{v}_3$) on the projectile velocity ($\vec{v}_1$) to check the motion condition in Eq. (8). The calculation model has been made up with the next presumptions: Because of the movement distance of water in the gas block is short. So, ignore the friction between the wall of the gas block with the water, just interest in the friction between water with barrel bore ($\vec{F}_{ms1}, \vec{F}_{ms2}$). In addition, the flow of water is steady. The calculation model is shown in Fig.4.

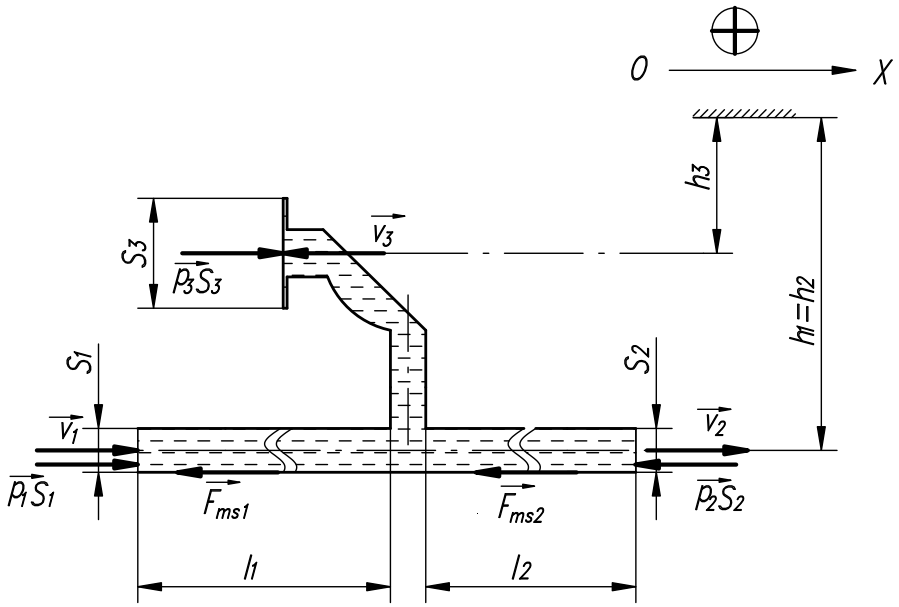


Figure 4. *The model for calculating the velocity of water impact on the piston.*

In this model, $h_1 = h_2$ are the distance from surface of water to the barrel axis (the depth of shooting); $S_1 = S_2 = \pi\left(\frac{d}{2}\right)^2$ is the section area of barrel bore; d is the diameter of barrel bore; l_1 is the distance between the nose of projectile and the position of gas vent; l_2 is the distance between the position of gas vent and the muzzle; F_{ms1}, F_{ms2} are the friction forces between the water and the barrel bore in the distance l_1, l_2.

According to the continuity equation, we obtain:

$$v_1 S_1 = v_2 S_2 + v_3 S_3 \tag{9}$$

Application of the momentum balance equation for a steady flow, we get:

$$\beta_2 \rho_n \vec{v}_2 \dot{m}_2 + \beta_3 \rho_n \vec{v}_3 \dot{m}_3 - \beta_1 \rho_n \vec{v}_1 \dot{m}_1 = \vec{p}_1 S_1 + \vec{p}_2 S_2 + \vec{p}_3 S_3 + \vec{F}_{ms1} + \vec{F}_{ms2} \tag{10}$$

where: $\beta_1, \beta_2, \beta_3$ - the correction coefficient of momentum and it depends on the type of flow. $\beta = \frac{4}{3}$ with the laminar flows and $\beta = 1,01 \div 1,05$ with the turbulent flows.

$\dot{m}_1, \dot{m}_2, \dot{m}_3$ - the mass flow rates and $\dot{m}_1 = v_1.\mathrm{S}_1; \dot{m}_2 = v_2.\mathrm{S}_2; \dot{m}_3 = v_3.\mathrm{S}_3$.

p_1, p_2, p_3 - the pressure at the sections S_1, S_2, S_3 and they are calculated by:

$$\begin{cases} p_1 = \rho_n g h_1 + \frac{1}{2}\rho_n {v_1}^2 \\ p_2 = \rho_n g h_2 + \frac{1}{2}\rho_n {v_2}^2 \\ p_3 = \rho_n g h_3 + \frac{1}{2}\rho_n {v_3}^2 \end{cases} \tag{11}$$

The friction forces between the water and the barrel bore in the distance l_1, l_2 can be calculated by:

$$\begin{cases} F_{ms1} = \dfrac{1}{2} C_{f1}.\rho_n.v_1^2.\pi.d.l_1 \\ F_{ms2} = \dfrac{1}{2} C_{f2}.\rho_n.v_2^2.\pi.d.l_2 \end{cases} \quad (12)$$

In Eq. (12), C_{f1}, C_{f2} are the skin friction coefficient. It depends on the Reynolds number Re and is calculated according to relations introduced in table 1 [6].

Table 1. *The dependence of skin friction coefficient on the Reynolds number.*

Reynolds number (Re **)**	**Skin friction coefficient (** C_f **)**
$0 < \mathrm{Re} < 2300$	$C_f = \dfrac{64}{\mathrm{Re}}$
$2300 \le \mathrm{Re} < 4000$	$C_f = \dfrac{2.7}{\mathrm{Re}^{0.53}}$
$\mathrm{Re} \ge 4000$	$C_f = \dfrac{1}{\left[1.8 \times \log(\mathrm{Re}) - 1.5\right]^2}$

In table 1, the Reynolds number is given by the formula $R_e = vd/\mu$, where μ is the kinematic viscosity of the fluid.

By rewriting the Eq. (10) according to the Ox axis, we obtain:

$$-\beta_1\rho_n {v_1}^2 S_1 + \beta_2\rho_n {v_2}^2 S_2 - \beta_3\rho_n {v_3}^2 S_3 = p_1 S_1 - p_2 S_2 + p_3 S_3 - F_{ms1} - F_{ms2} \quad (13)$$

By substituting Eq. (11), Eq. (12) into Eq. (13) we get:

$$\begin{aligned} &\left(-\beta_1 S_1 - \frac{1}{2}S_1 + \frac{1}{2}C_{f1}.\pi.d.l_1\right).v_1^2 + \left(\beta_2 S_2 + \frac{1}{2}S_2 + \frac{1}{2}C_{f2}.\pi.d.l_2\right).v_2^2 + \left(-\beta_3 S_3 - \frac{1}{2}S_3\right).v_3^2 \\ &\qquad = gh_1 S_1 - gh_2 S_2 + gh_3 S_3 \end{aligned} \quad (14)$$

Combining the Eq. (9) and Eq. (14), we have the equation system for calculating the velocity of water impact on the piston as:

$$\begin{cases} v_1 S_1 = v_2 S_2 + v_3 S_3 \\ \left(-\beta_1 S_1 - \dfrac{1}{2}S_1 + \dfrac{1}{2}C_{f1}.\pi.d.l_1\right).v_1^2 + \left(\beta_2 S_2 + \dfrac{1}{2}S_2 + \dfrac{1}{2}C_{f2}.\pi.d.l_2\right).v_2^2 + \\ \qquad + \left(-\beta_3 S_3 - \dfrac{1}{2}S_3\right).v_3^2 = gh_1 S_1 - gh_2 S_2 + gh_3 S_3 \end{cases} \quad (15)$$

3. RESULTS AND DISCUSSION

The mathematical model is established above is applied for the 5.56 mm amphibious rifle according to the designing of the research project of the ministry of defense 2017.74.03 [7]. The input parameters are given in table 2.

In table 2, the values of the section area of the bolt carrier assembly (S_{bk}) and the volume of the bolt carrier assembly below the surface of the water area (V_{bk}) are calculated by Autodesk Inventor software. The initial force of return spring (F_{lx0}) and the mass of the bolt carrier assembly (m) are determined by experiment as figure 5. The coefficient of static friction between the bolt carrier assembly with the guiding ribs on the receiver is investigated in references [8, 9].

Table 2. *The main input parameters for the solution.*

Parameters	Notation	Unit	Value
Diameter of barrel bore	d	(m)	
Initial force of return spring	F_{lx0}	(N)	3
Density of water	ρ_n	$\left(\frac{kg}{m^3}\right)$	1000
Distance between the surface of the water and the axis of the bolt carrier.	h_3	(m)	975.10^{-3}
Acceleration of gravity	g	$\left(\frac{m}{s^2}\right)$	9.81
Diameter of piston surface	d_3	(mm)	13.94
Section area of the bolt carrier assembly	S_{bk}	$\left(m^2\right)$	$1059.26.10^{-3}$
Coefficient of static friction between the bolt carrier assembly with the guiding ribs on the receiver	f_b		0,29
Volume of the bolt carrier assembly below the surface of the water	V_{bk}	$\left(m^3\right)$	74.10^{-6}
Mass of the bolt carrier assembly	m	(kg)	0.47
Depth of shooting	$h_1 = h_2$	(m)	1
Distance between the nose of the projectile and the position of the gas vent	l_1	(m)	$144.43.10^{-3}$
Distance between the position of the gas vent and the muzzle	l_2		161.10^{-3}



(a) *(b)*

Figure 5. *Determine the initial force of return spring (a) and the mass of the bolt carrier assembly (b).*

By solving the Eq. (8), we have that the bolt carrier starts moving only when the velocity of the water impact on the piston (v_3) is larger 12.95 (m/s). After investigating

the system of equations (15) with the different input values (v_1), we obtain the result is shown in figure 6. These results indicate that:

- When the velocity of the projectile (v_1) is smaller than 360.25 (m/s), the system of equations (15) is impossible. This indicates that the velocity of water in the cylinder (v_3) has not appeared when the velocity of the projectile (v_1) is not reached 360.25 (m / s). At the time the velocity of the projectile is 360.25 (m/s), the velocity of water in the cylinder is 48.71 (m/s);

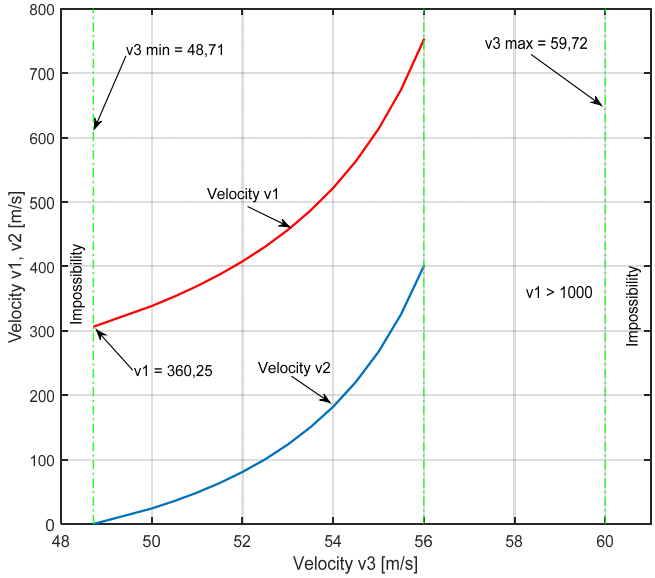


Figure 6. *The relationship between the velocities* v_1, v_2, v_3.

- The system of equations (15) is only possible when the velocity of the projectile is changed from 360.25 (m/s) to $1.05.10^7$ (m/s). At the time, the velocity of water in the cylinder is located between 48.7 (m/s) and 59.72 (m/s).

Comparing the movement conditions of the bolt carrier with the velocity of projectile in the internal ballistic of the amphibious rifle when shooting underwater, we found that the velocity of the projectile at the position of the gas vent is smaller 360.25 (m/s) [2, 3, 10]. So, the bolt carrier cannot move in the period of the projectile moving to the position of the gas port.

4. CONCLUSION

In this paper, the mathematical model of the motion of bolt carrier for the amphibious rifles when shooting underwater in the period of the projectile moving to the position of the gas port has been established. This model is applied for the 5.56 mm amphibious rifle to check the conditions for bolt carrier motion. The calculation result is shown that: with the 5.56 mm amphibious rifle according to the designing of the research project of the ministry of defense 2017.73.034, the bolt carrier cannot move in the period of the projectile moving to the position of the gas port. The model in this research can be used as a powerful tool for analyzing and designing the dynamic of gas-operated rifles when shooting underwater and especially the underwater and amphibious rifles.

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TÓM TẮT

PHÂN TÍCH CHUYỂN ĐỘNG CỦA BỆ KHÓA NÒNG SÚNG BẮN HAI MÔI TRƯỜNG TRONG GIAI ĐOẠN BAN ĐẦU KHI BẮN DƯỚI NƯỚC

Bài báo tập trung xây dựng mô hình toán học mô tả chuyển động của bệ khóa nòng súng bắn hai môi trường sử dụng nguyên lý trích khí khi bắn dưới nước trong giai đoạn đầu đạn chuyển động tới vị trí lỗ trích khí. Bên cạnh đó, điều kiện chuyển động của bệ khóa nòng cũng được nghiên cứu. Đối tượng của bài báo là súng bắn hai môi trường cỡ 5.56mm theo thiết kế của đề tài cấp Bộ quốc phòng mã số 2017.73.034. Kết quả nghiên cứu của bài báo đã chỉ ra rằng: đối với súng bắn hai môi trường cỡ 5.56mm, bệ khóa nòng chỉ chuyển động khi vận tốc đầu đạn tại vị trí lỗ trích khí lớn hơn 360.25 m/s. Kết quả của bài báo có thể áp dụng để phân tích động lực học máy tự động súng tiểu liên trích khí khi bắn dưới nước.

Từ khóa: Súng tiểu liên trích khí; Cụm bệ khóa nòng; Súng bắn hai môi trường; Thủy động lực học.

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