

AN APPROACH METHOD FOR THE DYNAMIC ANALYSIS OF THE AMPHIBIOUS RIFLE WHEN SHOOTING UNDER-WATER

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Abstract: This paper focuses on establishing the dynamic model describing the motion of bolt-carrier for the amphibious rifles when shooting under-water. This dynamic model is applied for the 5.56 mm amphibious rifle designed by the research project of the ministry of defense. The model in this paper can be applied to study the influence of the structural parameters in rifles on the operation of the automatic system during shooting under-water and contributing to the adjustment, optimization designs.

Keywords: Dynamic; Automatic system; Amphibious rifles; Bolt-carrier; Under-water ammunition.

1. INTRODUCTION

The amphibious rifles are one of the kind weapons to solve many missions during combat in both the air and under-water. However, Vietnam has just been interested in this weapon in recent years. Since 2017, the department of weapon, Military technical academy, in cooperation with the Z111 factory has been conducting the research project purposed to design an amphibious rifle cal.5.56mm (Fig.1) [1]. The main aim of this project was focused on the manufacturing of a rifle in both the air and the water environments.



Figure 1. The 5.56mm amphibious rifles.

Compared to the shooting in the air, the dynamic of the automatic system when shooting underwater is different as follows:

- The internal ballistic and thermodynamic in the gas chamber of the gas block are differential in case of the environments shooting are differential.
- In case of shooting in the air, before the projectile is not moving to the gas vent, the gas cannot enter the cylinder of the gas block. Therefore, the gas force impacts 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.
- The forces acting on the bolt-carrier when shooting under-water are varied with the shooting in the air. Additionally the forces in the air, the bolt-carrier must be impacted by the water resistance force, the buoyant force, etc.

So, working on the under-water dynamic model it is necessary to solve many technical problems, for instance, internal ballistic, determining the forces, variety of mechanisms, etc. One of the most important aspects is to analyze the dynamic of the amphibious rifles when shooting under-water with as high as possible accuracy.

To solve this problem, the paper presents a dynamic model to investigate the dynamic of the automatic system for amphibious rifles when shooting under-water.

2. THE HYPOTHESES AND MODEL

The dynamic of the amphibious rifles is a combination of interior ballistic, thermodynamics of gas chamber of the gas block and the motion of slide parts. The internal ballistics and thermodynamics of the amphibious rifles have been studied by authors in reference [2]. So, this part of the paper focuses on the investigation of the motion of slide parts when shooting under-water.

The dynamic model is built based on the following assumptions:

1. All parts of the gun except springs are rigid.
2. During the whole action, the masses are not changed.
3. The elements including barrel, receiver, butt assembly, and magazine are considered as an object called the receiver assembly (BRA). The bolt carrier and piston are considered as an object called the Bolt carrier assembly (BCA). Besides, the BRA is not moving during the operation of automatic systems.
4. During the moving process, the bolt, firing pin, extractor, spring of extractor, the pin of firing pin, and the pin of extractor are considered as an object called the bolt assembly (BBA).
5. The mass of the objects is replaced by a centralized mass located at the gravity center of the objects.
6. This paper is focused on the research of the movement of BCA without solving the stability and oscillation of the rifle when shooting.
7. Ignore the spin, shake and vertical motion of BCA. Only study the motion of the BCA in the horizontal direction, along the axis of the barrel.
8. The amphibious rifle is fully immersed under-water.
9. The area of cross-sectional of the BCA is smaller than the outflow area of water in the amphibious rifle.

The scheme arrangement of the dynamic model of the amphibious rifle from Fig. 2 consists of oncoming parts: BCA, BBA, gas block, gas regulator barrel and return spring. The total mass of moving parts is m_z and it is variable during the operation process of the automatic mechanism.

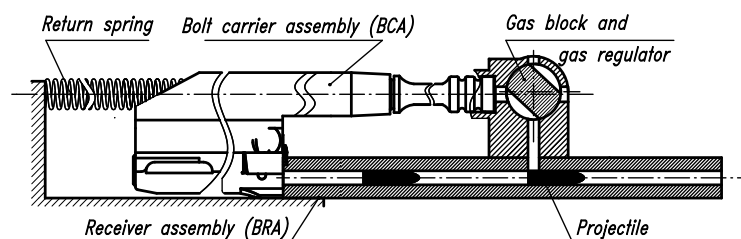


Figure 2. The scheme arrangement of the dynamic model of the amphibious rifle.

In order to analyze the dynamic of the amphibious rifle when shooting under-water, the motion process of BCA is divided into six stages:

Stage 1. Starting the shoot until the projectile moving. So, no forces acting on the BCA in this stage.

Stage 2. Continuity stage 1 until the bottom of the projectile passes the gas port of the gas block.

Stage 3. Continuity stage 2 until the recoil-moving finish.

Stage 4. Continuity stage 3 until the forward-moving finish.

According to the divided motion, the BCA is impacted by differential forces as table 1.

Table 1. The forces acting on the BCA.

The main forces	Symbol	Stage of motion			
		Stage 1	Stage 2	Stage 3	Stage 4
The diving force on the piston	F_p			★	
The return spring force	F_{lx}		★	★	★
The total friction force	F_T		★	★	★
The collision force	F_R			★	★
The mutual force between the bolt and the bolt carrier	F_{00}			★	
The water resistance force	F_{cn}		★	★	★

Note: ★ - Appearance

Besides, the above forces consist of element forces and it is determined to depend on the functional diagram. According to the second Newton law, the governing equation of the BCA motion can be expressed as

$$m_{\Sigma} \cdot \frac{d^2x}{dt} = \sum \vec{F}_i \quad (1)$$

where m_{Σ} is the total mass of moving parts and $\sum \vec{F}_i$ are forces acting on BCA during the moving process.

3. ANALYSIS OF FORCES ACTING ON THE BOLT-CARRIER DURING MOTION

3.1. Analysis of forces in stage 2

The motion of the bolt-carrier in stage 2 has been studied by authors in reference [3]. The results in this reference are shown that: with the 5.56 mm amphibious rifle designed by the research project of the ministry of defense, the bolt-carrier cannot move in the period of the projectile moving to the position of the gas port. It means that: no forces acting on the BCA in stage 2.

3.2. Analysis of forces in stage 3

In this stage, the BCA start moving under the acting of the following forces:

- The diving force on the piston (F_p).
- The return spring force (F_{lx}).
- The total friction force (F_T).
- The water resistance force (F_{cn}).
- The collision force (F_R).
- The mutual force between the bolt and the bolt carrier (F_{oo}).

*** The diving force on the piston**

The diving force on the piston F_p is delivered from the exhaust gas pressure at the port in the barrel. This force is determined by the area of the piston and the gas pressure acting on the piston, as follows:

$$F_p = S_p(p_c - p_{atm}) \quad (2)$$

where p_c is the pressure in the gas chamber, p_{atm} is the pressure of the atmosphere and S_p is the piston area.

*** The return spring force**

The return spring force is expressed by form Eq. (3):

$$F_{lx} = F_{lx0} + C.x.\eta \quad (3)$$

where C is the stiffness of spring, η is the efficiency of spring and F_{lx0} is the return spring pretension force.

*** The total friction force**

When determining the friction acting on the BCA, previous works have only focused on the friction between the BCA and guide rial on the BRA. In fact, the friction acting on the BCA not only this force but also difference forces (such as friction force between the bolt carrier and top ammunition in the magazine, the friction force between the feeding ammunition and top ammunition in the magazine, the friction force is caused by inertia movement, the friction force is caused by the collision, etc.). Besides, the friction force is the variable force during the movement of the BCA and it depended on a lot of factors. So, this paper gives a method to establish the total friction force formula. The model to determine the total friction force is shown in Fig.3.

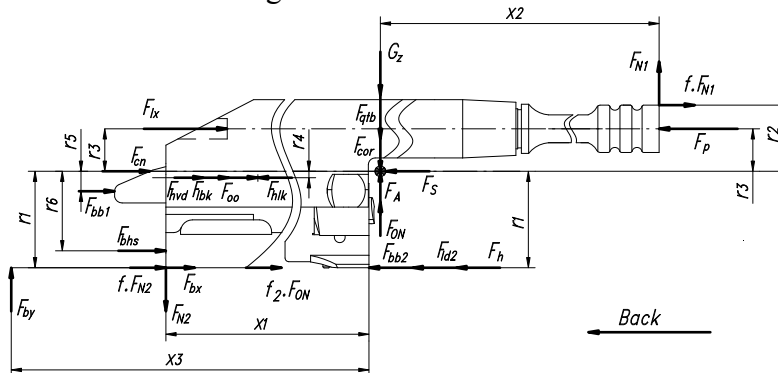


Figure 3. The model to determine the total friction force acting on the BCA when shooting under-water.

In Fig.3:

- | | |
|--|--|
| F_T - The total force. | F_{hvd} - The cartridge case extraction force. |
| f_1 - The coefficient between bolt carrier, receiver, and bolt. | F_{lbk} - The collision force between the bolt and the bolt carrier. |
| f_2 - The coefficient between the bolt-carrier and cartridge. | F_{hlk} - The collision force between the bolt and the receiver. |
| f_3 - The coefficient between cartridge and cartridge. | F_{00} - The total force acting on BCA when unlocking the bolt. |
| F_h - The brake force which is caused by the friction between the bottom of the cartridge and bolt in the feeding process. | F_{bb1} - The force of the hammer acting on the BCA when back. |
| | F_{cn} - The water-resistance force. |
| F_{ON} - The normal force between the ammunition in the magazine and BCA. | F_{bb2} - The force of the hammer acting on the BCA when returning. |
| F_{Ty} - The total normal force in the y-direction. | F_{ld2} - The collision force between the bolt and the ammunition in the magazine. |
| F_{by} - The force of the hammer acting on the BCA in the y-direction. | F_{bx} - The force of firing mechanism acting on the BCA in the x-direction. |
| G_z - The gravity force. | F_{bhs} - The collision force between the BCA and the receiver at the rear position. |
| F_A - Buoyant force. | F_{oz} - The mutual force between the bolt and the bolt carrier during the movement of the bolt on the slot of the bolt carrier. |
| F_{qtb} - The inertial force which rested the BCA on the guide rail in the receiver. | F_p - The diving force on the piston. |
| F_{cor} - The Coriolis force. | F_{lx} - The return spring force. |
| F_{N1}, F_{N2} - The normal forces. | x_1 - The distance from the F_{N2} to the center of BCA in the x-direction. |
| $r_1...r_6$ - The length of the arms of the forces | |
| x_2 - The distance from the F_{N1} to the center of BCA in the x-direction. | |

By projecting all forces on the x-direction, we obtain

$$f_1 \cdot F_{N1} + f_1 \cdot F_{N2} - F_S - F_p - F_{bb2} - F_{ld2} + F_{hvd} + F_{lbk} + F_{00} - F_{hlk} + F_{bb1} + F_{bhs} + F_{lx} + F_{bx} + f_2 \cdot F_{ON} - F_h = 0 \quad (4)$$

By projecting all forces on the x-direction, we acquire

$$-G_z - F_{qtb} - F_{cor} + F_{ON} + F_{N1} - F_{N2} + F_{by} = 0 \quad (5)$$

Moment forces acting on the BCA as

$$-F_{by} \cdot x_3 + F_{N2} \cdot x_1 + F_{bhs} \cdot x_6 + F_{bb1} \cdot x_5 - f_1 \cdot F_{N1} \cdot x_2 + f_1 \cdot F_{N2} \cdot x_1 + (F_p - F_{lx}) \cdot x_3 + F_{OZ} \cdot x_4 - (F_{bb2} + F_{ld2} + F_h - F_{bx} - f_2 \cdot F_{ON}) \cdot x_1 + F_{N1} \cdot x_2 = 0 \quad (6)$$

Substituting equations Eq. (4), Eq. (5) into Eq. (6) we get:

$$F_{N1} = \frac{F_{by} \cdot x_3 + F_{Tx} \cdot r_1 + F_{Ty} \cdot (f_1 \cdot r_1 - x_1) - F_{bhs} \cdot r_6 - F_{bb1} \cdot r_5 - (F_p - F_{lx}) \cdot r_3 - F_{OZ} \cdot r_4}{f_1 \cdot (r_2 - r_1) + x_2 + x_1} \quad (7)$$

where:

$$\begin{cases} F_{Ty} = F_{by} - G_z - F_{qtb} - F_{cor} + F_{ON} \\ F_{OZ} = F_{hvd} + F_{lbk} + F_{00} - F_{hlk} \\ F_{Tx} = F_{bb2} + F_{ld2} + F_h - F_{bx} - f_2 \cdot F_{ON} \end{cases} \quad (8)$$

The total friction force acting on the BCA consists of $f_1 \cdot F_{N1}$, $f_1 \cdot F_{N2}$, F_h , $f_2 \cdot F_{ON}$.

Thus

$$\begin{aligned} F_T &= f \cdot F_{N1} + f \cdot F_{N2} + F_h + f_2 \cdot F_{ON} = \\ &= f_1 \cdot (F_{by} - G_z - F_{qtb} - F_{cor} + F_{ON} + 2 \cdot F_{N1}) + f_2 \cdot F_{ON} \end{aligned} \quad (9)$$

acquiring:

$$F_T = F_h + f_2 \cdot F_{ON} + f_1 \cdot \left(F_{Ty} + 2 \cdot \frac{F_{by} \cdot x_3 + F_{Tx} \cdot r_1 + F_{Ty} \cdot (f_1 \cdot r_1 - x_1)}{f_1 \cdot (r_2 - r_1) + x_2 + x_1} + \frac{-F_{bhs} \cdot r_6 - F_{bb1} \cdot r_5 - (F_p - F_{lx}) \cdot r_3 - F_{OZ} \cdot r_4}{f_1 \cdot (r_2 - r_1) + x_2 + x_1} \right) \quad (10)$$

*** The water resistance force**

The water resistance force has been determined by authors in reference [4] and it is expressed by form Eq. (4):

$$F_{cn} = \rho g h S + (C_D \cdot A + S + C_f \cdot S_{xp}) \frac{1}{2} \rho v^2 \quad (11)$$

where g - Acceleration of gravity; h - Depth of firing; S - Cross-section of the bolt carrier assembly; S_{xq} - Lateral area of the bolt-carrier; C_f - Skin friction coefficient; A - Characteristic area; v - Velocity of BCA; ρ - Water density; C_D - Drag coefficient.

The BCA is effected by the water resistance force during the full moving process.

*** The collision force**

In this stage, the BCA moves an initial distance before unlocking. This moving distance makes the unlocking safe. Besides, BCA is impacted by some forces such as the collision force, the mutual force between the bolt and the bolt carrier, etc.

Once the initial movement finished, the BCA moves back to the collision position with the receiver. In order to study the collision in the automatic mechanism of the weapon, previous works have been used the collision theory of

Newton [5-7]. However, this theory has only focused on the kinetic energy of the collision and it cannot determine the forces which are appeared during the collision process. So, the impulse chart was used to calculate the collision force.

Accordingly, the impulse of an object when collisions are determined by formula (12):

$$J = m.(v_2 - v_1) = \int_0^{t_r} F(t) dt \quad (12)$$

Where: v_1, v_2 are the velocity object before and after happening the collision.

By using the hypothesis that the collisions are elastic, the collision force will change according to the cosine function as

$$F_R = \frac{A_r}{2} \cdot \left[\cos\left(\frac{2.\pi.t_k}{t_r}\right) - 1 \right] \quad (13)$$

where: F_R is the collision force; A_r is the active impulse; t_k is time; t_r is the time action of the active impulse.

So, if we determine the value of the time of the collision and the velocity before and after happening the collision, we will calculate the collision force. These values of the collision time, the velocity before and after happening the collision determined by the experiment.

During the moving back process, the BCA collided with the hammer. So, the BCA is impacted by $\vec{F}_b$ force. The $\vec{F}_b$ force is divided into 2 components: $\vec{F}_{bx}$ and $\vec{F}_{by}$. These forces are shown in Fig.4 and it is calculated as

$$\begin{cases} F_{bx} = F_b \cdot \cos\alpha_{bp} \\ F_{by} = F_b \cdot \sin\alpha_{bp} \end{cases} \quad (14)$$

where

$$\begin{cases} F_b = \frac{M_{bp}}{r_s} \\ M_{bp} = M_{bp0} + C_{bp} \cdot \alpha_{bp} \\ r_s = \sqrt{x_b^2 + y_b^2} \\ \alpha_{bp} = \arctan\left(\frac{x_b}{y_b}\right) \end{cases} \quad (15)$$

x_b is the distance from the impact point to the rotation center of the hammer in the x-direction; y_b is the distance from the impact point to the rotation center of the hammer in the y-direction; C_{bp} is the stiffness of spring; α_{bp} is the rotation angle of the hammer.

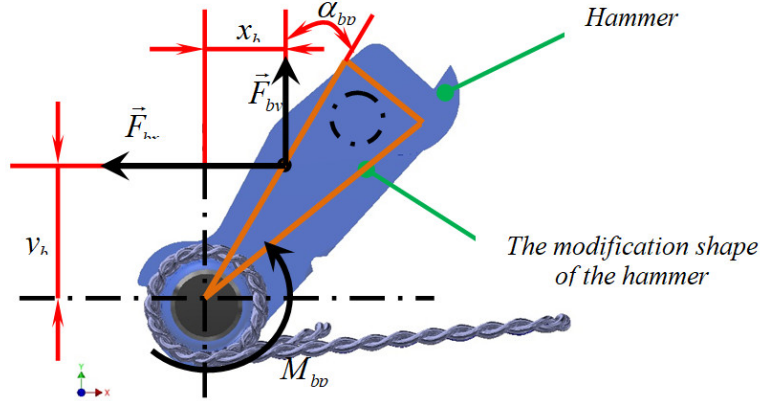


Figure 4. The model to determine the impact force acting on the BCA by the hammer.

**The mutual force*

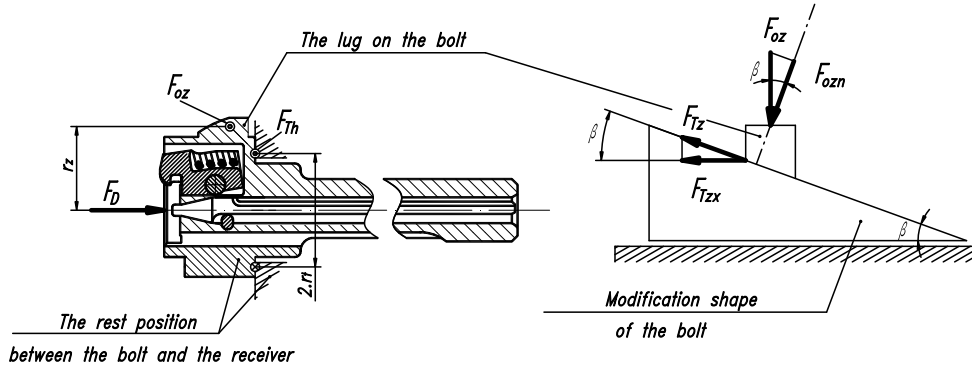


Figure 5. The model to determine the total force F_{00} acting on BCA in the unlocking process.

The continual motion is the unlocking process. In this process, appearing the total force F_{00} acting on BCA and it is determined by the model in Fig.5. According to this model, the F_{00} is calculated by the formula

$$F_{00} = F_{oz} \tan \beta + f_1 \cdot F_{oz} + f_1 \cdot F_{oz} \cdot \cos^2 \beta = f_1 \cdot \frac{(p_D \cdot \pi \cdot r_t \cdot d_{vl}^2)}{2 \cdot r_z} \cdot (\tan \beta + f_1 + f_1 \cdot \cos^2 \beta) \quad (16)$$

where F_{oz} is the mutual force between the bolt and the bolt carrier during the movement of the bolt on the slot of the bolt-carrier. This force is calculated as

$$F_{oz} = f_1 \cdot \frac{2 \cdot r_t}{r_z} \cdot F_D = 2 \cdot f_1 \cdot \left(\frac{p_D \cdot \pi \cdot r_t \cdot d_{vl}^2}{4 \cdot r_z} \right) \quad (17)$$

f_1 is the coefficient between the bolt carrier and the bolt; r_t is the distance from the rest point to the axis of the bolt; d_{vl} is the diameter of the bottom of the cartridge; r_z is the distance from the center of lug to the axis of the bolt; p_D is the pressure acting on the bottom of the cartridge and it is calculated as [8].

$$\left\{ \begin{array}{l} p_D = p_a \left[1 + \frac{\omega}{2m_t \cdot \left(\frac{Sp_a}{Sp_a - D} \right)} \right] \\ p_a = \frac{p_1 + \frac{1}{3} \cdot \frac{\omega \cdot D}{m_t \cdot S}}{1 + \frac{1}{3} \cdot \frac{\omega}{m_t}} \end{array} \right. \quad (18)$$

After finishing the unlocking process, the collision between the bolt and the bolt carrier will happen. This collision occurs simultaneously with the collision to pull cartridge. The force collision $\vec{F}_{lbk}$ of these collisions is calculated by the formula (11).

When the BCA moving back, the exhaust-gas hole is opened. The area of the exhaust-gas hole is calculated according to the model in Fig.6 and it is shown by the formula

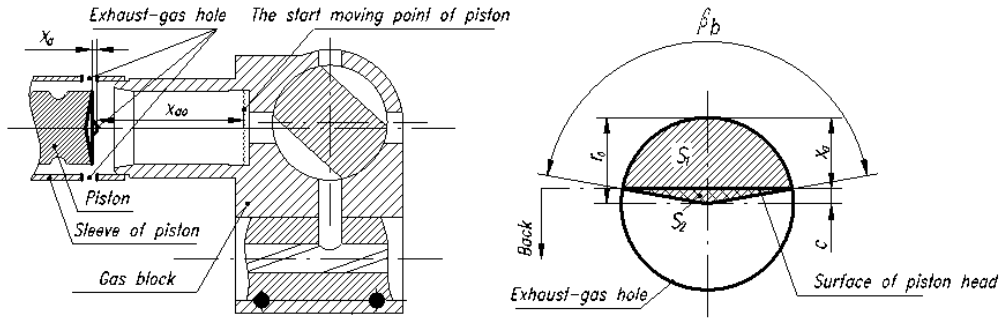


Figure 6. The motion model of the piston in the sleeve.

$$A_{25} = 4(S_1 - S_2) \quad (19)$$

where:

$$\left\{ \begin{array}{l} S_1 = r_0^2 \cdot \arccos\left(\frac{\beta_b}{2}\right) \\ S_2 = c \cdot \sqrt{r_0^2 - c^2} \\ r_0 = \frac{d_0}{2} \\ \cos\left(\frac{\beta_b}{2}\right) = \frac{c}{r_0} = 1 - \frac{x_a}{r_0} \\ c = r_0 - x_a \end{array} \right. \quad (20)$$

d_0 is the diameter of the exhaust-gas hole; x_a is the distance from the surface of the piston head to the edge of the exhaust-gas hole; d_0 is the angle of the piston head.

When the BCA moved about a 2/3 journey, it slides on the top ammunition in the magazine. So, the BCA is effect by the friction force $f_2 \cdot F_{ON}$. Where f_2 is the coefficient of friction between the bolt carrier and the cartridge case; F_{ON} is the normal force of the top ammunition acting on the surface below of BCA and it is calculated by the formula below (Fig.7).

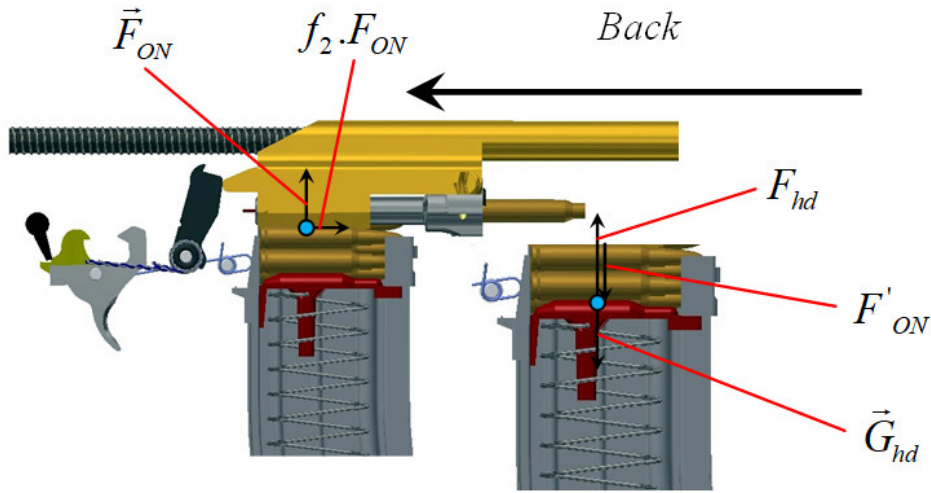


Figure 7. The model to determine the normal force F_{ON} of the top ammunition acting on the surface below of BCA.

$$F_{ON} = F_{hd} - g \cdot (n_{hd} \cdot m_{vd} + m_{bn}) \cdot \cos \varphi \quad (21)$$

where: F_{hd} is the force of the magazine spring; n_{hd} is the total ammunition in the magazine; m_{vd} is the mass of one ammunition; m_{bn} is the mass of follower of the magazine; φ is the rotation angle of BRA about the center of BRA.

When the case extraction process happens, the extraction force $\vec{F}_{hvd}$ is calculated by Eq. (10) and Eq. (11). The final force acting on the BCA in stage 5 is the collision force $\vec{F}_{bhs}$ at the rear position. This force will continually effect during stage 6 and it is also calculated by Eq. (10) and Eq. (11).

3.3. Analysis of forces in stage 4

In stage 6, the return spring force $\vec{F}_{lx}$ is reversed direction and the efficiency of recoil spring is about 85% ÷ 95% [9]. When the motion direction of BCA is reversed, the direction of forces is also reversed. During the forward motion, the BCA came into collision with the hammer and the ammunition by the $\vec{F}_{bb2}$ force and the $\vec{F}_{bd2}$ force respectively. The analysis of forces in stage 6 is done similarly when the back moving.

In summary, the dynamic analysis of the automatic mechanism for the amphibious rifle when shooting in under-water should be done according to the functional diagram.

4. RESULTS AND DISCUSSION

The dynamic model above was applied to the 5.56 mm amphibious rifle which was designed by the Department of Weapon at Military Technical Academy [1]. In order to identify the effect of the shooting environment, two kinds of ammo are used (5.56 mm under-water ammo and 5.56 x45 mm NATO ammo). When shooting under-water by 5.56 Under-water ammo, the adjustable part of the gas block is the “N” position and It is the “K” position when shooting in the air by 5.56 x45 mm NATO ammo. The numerical solving of differential equations describing the model with the ODE45 method was made by the MATLAB environment. The main input parameters to solve the differential equations of the dynamic model are given in table 2.

Table 2. The main input parameters for the solution.

5.56 mm Under-water ammo		5.56 mm amphibious rifle	
<i>Parameters</i>	<i>Value</i>	<i>Parameters</i>	<i>Value</i>
Initial volume of charge chamber (m^3)	1.727×10^{-6}	Caliber of gun (m)	5.56×10^{-3}
Mass of powder (kg)	0.8×10^{-3}	Length of barrel (m)	361×10^{-3}
Mass of projectile (kg)	13.7×10^{-3}	Cross-sectional area of discharge orifice between gas chamber of gas block and bore barrel (m^2)	10^{-5}
Length of the projectile (m)	50×10^{-3}	Distance of gas block from bore chamber (m)	200×10^{-3}
Condition of shooting		Diameter of piston (m)	13.937×10^{-3}
Shooting depth (m)	1	Inner diameter of gas chamber of gas block (m)	14.015×10^{-3}
Atmospheric pressure (Pa)	101325	Diameter of the exhaust-gas hole on the gas block (m)	2.0×10^{-3}
Temperature of water ($^{\circ}\text{C}$)	15	The number of exhaust-gas hole on the gas block	4
		Mass of BCA (kg)	0,4
		Mass of BBA (kg)	0,07
		Coefficient between bolt carrier-receiver-bolt [10]	0,337
		Coefficient between bolt carrier and cartridge [11]	0,449

The results of the solution in a single shoot are presented in graphs from Fig. 8 to Fig. 10. The selected results of the solution are shown in table 3. In this, the results of interior ballistics have been studied by authors in reference [2].

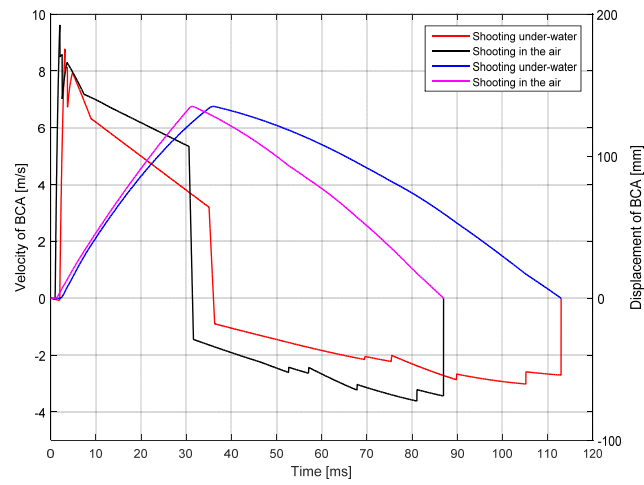


Figure 8. The displacement and velocity of BCA vs time.

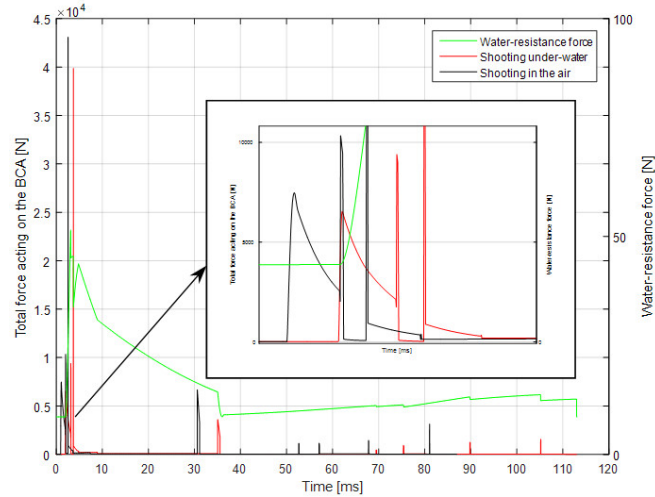


Figure 9. The total force and the water-resistance vs time.

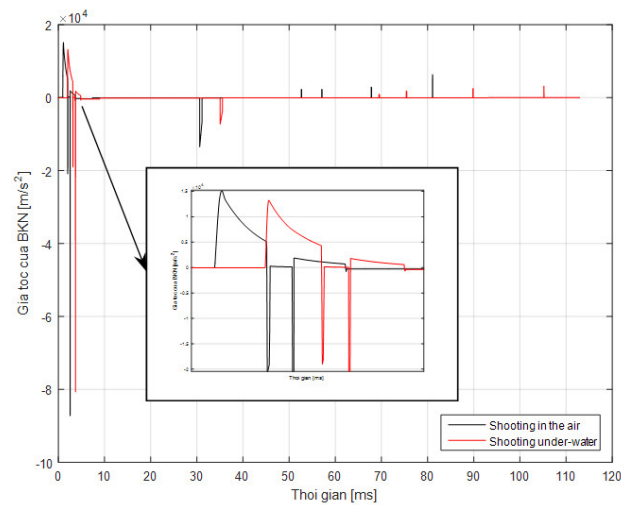


Figure 10. The acceleration of BCA vs time.

Table 3. Selected results of the solution.

<i>Parameter</i>	<i>Unit</i>	<i>Value</i>	
		<i>Shooting in the air by 5.56x45mm NATO ammo</i>	<i>Shooting under- water by under- water ammo</i>
The total time moving of BCA	ms	87	113,1
The back time of BCA	ms	31,39	36,01
The forward time of BCA	ms	55,61	77
The maximum velocity of BCA	m/s	9,62	8,77
The time when the velocity of BCA is maximum	ms	2,01	3,13

The above results indicate that: when shooting under-water by 5.56x45mm NATO ammo, the pressure in the bore and gas block, the velocity of BCA is larger than shooting under-water by under-water ammo. So, the total time moving of BCA during the shooting process is shorter.

4. CONCLUSION

In this paper, the dynamic model of the amphibious rifle when shooting under-water has been established by the combination of internal ballistic [2] and the motion of slide parts. This model is applied for the 5.56 mm amphibious rifle to analyse the motion of bolt-carrier. 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.

This research clearly has some limitations. It has only theoretically investigated the displacement and velocity of BCA when shooting under-water. Nevertheless, we believe our study could be a starting point and the new method to approach the dynamic of the amphibious rifle. Future research will focus on the experimental study.

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TÓM TẮT

VỀ MỘT PHƯƠNG PHÁP TIẾP CẬN ĐỂ PHÂN TÍCH ĐỘNG LỰC HỌC SÚNG BẮN HAI MÔI TRƯỜNG KHI BẮN DƯỚI NƯỚC

Bài báo tập trung xây dựng mô hình động lực học mô tả chuyển động của bộ khóa nòng súng bắn hai môi trường khi bắn dưới nước. Mô hình động lực học này được áp dụng cho súng bắn hai môi trường cỡ 5,56mm theo thiết kế của đề tài cấp Bộ quốc phòng. Mô hình trong bài báo có thể ứng dụng để nghiên cứu ảnh hưởng của các tham số kết cấu trong súng đến hoạt động của máy tự động khi bắn dưới nước, đồng thời góp phần hiệu chỉnh, tối ưu thiết kế súng.

Từ khóa: Động lực học; Máy tự động; Súng bắn hai môi trường; Bộ khóa nòng; Đạn bắn dưới nước.

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