Dynamic analysis of firing mechanism of underwater pistol

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Abstract — **The important problem of designing underwater pistol was analysed and calculated the dynamics of firing mechanism. On the basis of analyzing the performance of the underwater pistol, the paper presents a theoretical model for analysing the dynamics of firing mechanism of underwater pistol with the with the resistance of water acting on firing pin and slide. The result of this research can be applied to design the underwater pistol and underwater firearm.**

Index Terms—**Dynamics, Firing mechanism , Resistance of water, Underwater pistol.**

1 INTRODUCTION

THE underwater pistol is designed to destroy enemy personnel at ranges of up to 20m under water (depending on diving depth) [1]. Firing under water is possible from all swimmer positions as well as against surface targets from under water. The pistol is intended for combat swimmers. Two kinds of typical underwater pistol current are HKP11 of Germany (Fig.1a) and SPP-1M of Russian (Fig.1b) [2].

In Vietnam, the research on underwater pistol is limited and water commando forces have not been equipped with this weapon. The researches are mainly focused on projectile's motion under water. So design underwater pistol has become a hot topic.

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In the design process, the dynamic analysis of firing mechanism is a fundamental problem and very important [3]. So the article focuses on solving this problem with the research object is firing mechanism of SPP-1M underwater pistol.

a)

b)

Figure 1. Two kinds of typical underwater pistol
a. HKP11 underwater pistol; b. SPP-1M underwater pistol

2 DYNAMIC MODEL OF FIRING MECHANISM OF UNDERWATER PISTOL

The principle of operation of firing mechanism of underwater pistol based on the operation of typical pistol but it is improved to reduce the resistance of water [4]. The firing mechanism of underwater pistol consists of: trigger, slide, slide latch, firing pin, and return spring [5,6,7,8]. Fire process comprising two stages (fig.2):

Stage I: Slide and firing pin moves backward. After pulling the trigger, trigger (1) motions and impacts on B point on the slide (3) to make slide and firing pin moving backwards. Stage I ended when the catch (2) is not contact with B point on on the slide.

Stage II: Slide and firing pin moves forward. After the catch (2) is not contact with B point, Slide (3) and firing pin (4) move forward under the action of recoil force of the spring. Firing pin moving forward and strike the primer on bullet to fire.

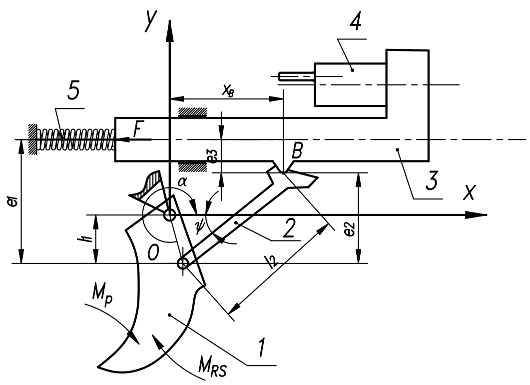


Figure 2. Structural diagram of firing mechanism of underwater pistol

1. Trigger; 2. Slide latch; 3. Slide; 4. firing pin; 5. return spring.

The dynamic model of firing mechanism of underwater pistol is built on the basis of the following assumptions:

1. The objects in the firing mechanism are absolute hard.
2. Ignore the resistance of water acting on the objects rotation in mechanism (Trigger and Slide latch).
3. Ignore the resistance of water acting on the return spring and Slide.
4. Ignore friction force acting on the objects when moving.
5. In stage II, Silde and firing pin are blocked into an object with mass is $m_{3,4}$ and it move forward. Hence the model of firing mechanism is simple model as shown in firgure 3.
6. Angular velocity of Trigger $\dot{\alpha}$ around origin O is constant.

In order to analyse dynamics of firing mechanism, at first we consider kinematic in stage I. In Fig.2 it is seen that:

$$\begin{cases} x_B = l_2\cos\psi + l_1\cos\alpha \\ e_3 = l_2\sin\psi + l_1\sin\alpha \end{cases} \quad (1)$$

Derivative equation system 1 we obtain:

$$\begin{cases} \dot{x}_B = -l_1\cos\alpha(\tan\psi + \tan\alpha)\dot{\alpha} \\ e_3 = l_2\sin\psi + l_1\sin\alpha \end{cases} \quad (2)$$

Derivative equation system 2 we obtain:

$$\begin{cases} \ddot{x}_B = -l_1\cos\alpha\begin{bmatrix}(\tan\psi + \tan\alpha)\ddot{\alpha} + \\ +(1-\tan\psi\tan\alpha)\dot{\alpha}^2\end{bmatrix} \\ e_3 = l_2\sin\psi + l_1\sin\alpha \end{cases} \quad (3)$$

In equation systems (1), (2), (3): $\pi \le \alpha \le 2\pi$

In stage I, external forces acting on the systerm as follows (Fig.1):

1. Elastic force of the return spring F.
2. The Moment of trigger pull of the gunner M_p.
3. The resistance moment of trigger spring M_{RS}.

Assumption M_u is useful moment acting on trigger to fire, we have:

$$M_u = M_p - Fl_1\cos\alpha(\tan\psi\text{-}\tan\alpha)\text{-}M_{RS} \quad (4)$$

The total kinetic energy of the system given by [9]:

$$T = T_1 + T_2 + T_3 =$$
$$= \frac{1}{2}J_1\dot{\alpha}^2 + \frac{1}{2}m_2 l_1\dot{\alpha}^2 + \frac{1}{2}m_{3,4}l_1^2\cos^2\alpha(\tan\psi + \tan\alpha)^2\dot{\alpha}^2$$
$$= \frac{1}{2}[J_1 + m_2 l_1 + m_{3,4}l_1^2\cos^2\alpha(\tan\psi + \tan\alpha)^2]\dot{\alpha}^2 \quad (5)$$

where: T_1, T_2, T_3 are the kinetic energy of Trigger, Slide latch and Slide

J_1 is the moment of inertial of Trigger.

m_2 is the mass of Slide latch.

$m_{3,4}$ is the total mass of slide anf firing pin.

The dynamic equations of firing mechanism are in the Lagrangian form given by [10]:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\alpha}}\right) - \frac{\partial T}{\partial \alpha} = M_u \quad (6)$$

From Eq. (4), (5), (6) we have:

$$\left[J_1 + m_2 l_1^2 + m_{3,4}l_1^2\cos^2\alpha(\tan\psi + \tan\alpha)^2\right]\ddot{\alpha} +$$
$$+\frac{1}{2}m_{3,4}l_1^2[\sin2\alpha(\tan\psi + \tan\alpha)^2 - 2\sin2\alpha + \quad (7)$$
$$+2(\tan\psi + \tan\alpha)]\dot{\alpha}^2$$
$$= M_p - Fl_1\cos\alpha(\tan\psi\text{-}\tan\alpha)\text{-}M_{RS}$$

Because the angular velocity of Trigger is constant (assumption 6), so $\ddot{\alpha} = 0$. From Eq.7 we obtain:

$$M_p = Fl_1\cos\alpha(\tan\psi\text{-}\tan\alpha)\text{+}M_{RS} +$$
$$+\frac{1}{2}m_{3,4}l_1^2[(\tan\psi + \tan\alpha)^2 + \sin2\alpha - 2\sin2\alpha \quad (8)$$
$$+2(\tan\psi + \tan\alpha)]\dot{\alpha}^2$$

In stage II, the article only studying the dynamic of firing pin. So from the Fig.3 we have:

$$m_{3,4}\ddot{x} = (H - x)k - (R_1 + R_2) \quad (9)$$

where $m_{3,4}$ is the total mass of slide and firing pin.

H is the original length of the spring.

k is a constant factor characteristic of the spring.

R_1, R_2 are resistance forces of water acting on firing pin and its are determined by the formula [11]:

$$\begin{cases} R_1 = \frac{1}{2}\rho A_1 C_{d1}\dot{x}^2 \\ R_2 = \frac{1}{2}\rho A_2 C_{d2}\dot{x}^2 \end{cases} \quad (10)$$

where A_1, A_2 are the area of firing pin at nose and body; ρ is density of water; $\dot{x}$ is velocity of firing pin; C_{d1}, C_{d2} are drag coefficient. Because the shapes of nose and body section of firing pin are the same, so: $C_d = C_{d_1} = C_{d2} = 1.2$

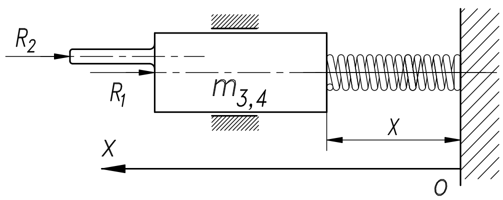


Figure 3. Model of firing mechanism of underwater pistol in stage II

From Eq.9, 10 we have:

$$m_{3,4}\ddot{x} = (H-x)k - \frac{1}{2}\rho C_d (A_1 + A_2)\dot{x}^2 = (H-x)k - \frac{1}{2}\rho C_d A\dot{x}^2 \quad (11)$$

where $A = A_1 + A_2$ is the section area of firing pin. Initial conditions to solve equations (11) are: $\dot{x}(0) = 0; x(0) = x_0$. So the dynamic equations of firing pin in stage II are:

TABLE 1

INPUT PARAMETERS

No.	Items	Symbol	Unit	Value
1	Geometric dimensions (Fig.2)	l_1	mm	16.9
		l_2	mm	44.4
		$e_3=e_1-e_2$	mm	1.2
1	Mass of slide and firing pin	$m_{3,4}$	kg	0.08
2	Resistance moment of trigger spring	M_{RS}	N/mm	0.14. 10^{-3}
3	Constant factor characteristic of the spring	k	N/mm	0.65
4	Mass of cartridge case	M_{vd}	kg	0,091
5	Angular velocity of Trigger	$\dot{\alpha}$	rad/s	1
6	Section area of firing pin	A	mm^2	254.7
7	Original length of the spring	H	mm	220
8	Density of water	ρ	kg/m^3	1030
9	Drag coefficient	C_d		1.2

$$\ddot{x} = \left(\frac{-\rho C_d A}{2m_{3,4}}\right)\dot{x}^2 - \frac{k}{m_{3,4}}x + \frac{Hk}{m_{3,4}} \quad (12)$$

3 CALCULATION RESULTS AND DISCUSSION

For the purpose of presenting results of solution, we chose object is the firing mechanism of SPP-1M underwater pistol. The values of the input parameters to analyse are listed in table 1.

The results calculated of displacement, velocity and acceleration of slide with $\alpha \in \left[270^0, 320^0\right]$ in stage I shown in figure 4. The displacement, velocity, acceleration of slide and firing pin with $t \in [0,6]ms$ in stage II shown in figure 5. We can see maximum velocity of slide in stage I is 18.29 mm/s at $\alpha = 289.9^0$.

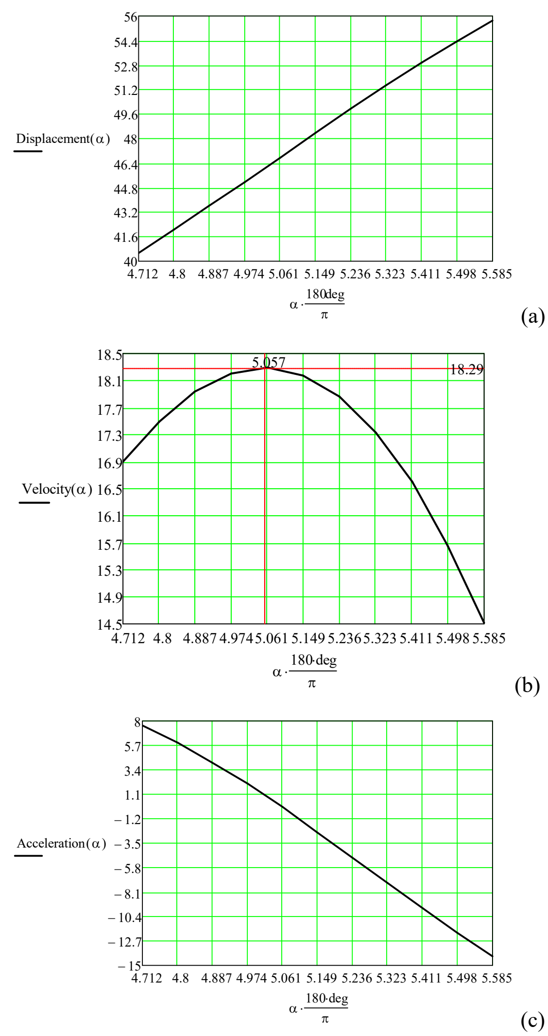
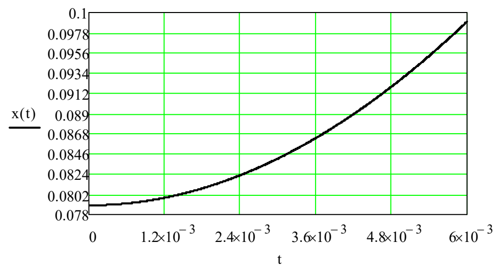
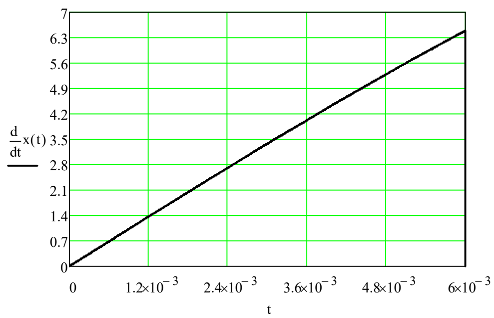


Figure 4. Displacement, velocity and acceleration of slide in stage I

a. Displacement; b. Velocity; c. Acceleration



a)



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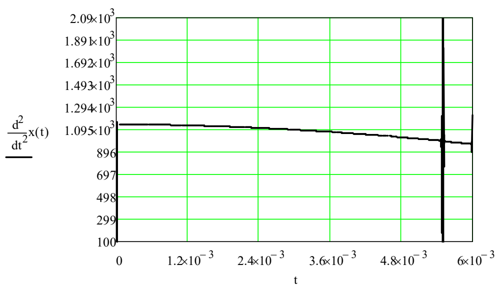

c)

Figure 5. Displacement, velocity and acceleration of slide and firing pin in stage II
a. Displacement; b. Velocity; c. Acceleration

4 CONCLUSION

Through analysis of operating characteristics, building mathematical model for analysing the dynamic of dynamic of firing mechanism of underwater pistol and application with the SPP-1M underwater pistol, we see that the calculation results was suitable for the fact. Therefore, the theoretical model of the article has been presented is model have high accuracy and can be applied to design the underwater piston and underwater firearm and amphibious assault rifle. The research results of this paper have been used in the state-level project "*Design and manufacture underwater pistol and projectile to serve the water commando forces"* code: KC.03.TN08/11-15.

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Phân tích động lực học cơ cấu phát hỏa của súng ngắn bắn dưới nước

Nguyễn Thái Dũng, Nguyễn Văn Hưng

***Tóm tắt* - Tính toán và phân tích động lực học của cơ cấu phát hỏa là một vấn đề rất quan trọng trong tính toán thiết kế súng ngắn bắn dưới nước. Trên cơ sở phân tích hoạt động của súng ngắn dưới nước, bài báo trình bày một mô hình lý thuyết để phân tích động lực cơ cấu phát hỏa súng ngắn bắn dưới nước có kể đến ảnh hưởng do lực cản của nước tác động lên khóa nòng và kim hỏa. Kết quả nghiên cứu của bài báo có thể ứng dụng trong tính toán thiết kế súng ngắn và súng tiểu liên bắn dưới nước.**

***Từ khóa* - Động lực học, Cơ cấu phát hỏa, Lực cản của nước, Súng ngắn bắn dưới nước.**