564. The Dynamics of the One-Way Pneumatic Drive for Training Weapons

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Abstract: Riflemen's trainers are efficiently applied for the training of the armed forces, police and shooting athletes. However, the training quality directly depends on the perfection of trainers as well as their functional facilities. Trainers should qualitatively develop the skills of correct levelling of a gun to target, represent probable combat situations and reproduce the process of single and shot series. The work presents the theoretical and experimental investigation of the pneumatic drive for recoil imitation of the weapon.

Keywords: shot, recoil, imitation, pneumatic, mechanisms, dynamics.

Introduction

Lately laser trainers have been effectively used for riflemen and sportsmen training. However, the majority of trainers have neither real recoil nor sound imitation systems. For this reason the objective of this work is to investigate the recoil of the automatic rifle under single and serial shooting regimes and their interaction with a shot so that training weapons could be created with a complete recoil imitation.

Recoil is a backward movement of a rifle when it fired is. It seems to as that there is quite a difference between "recoil" and "kick". The gun recoiled, and we got a kick on the shoulder. The recoil is mechanical, while the kick, or at least the effect of it, is mostly physical and psychological. The amount of kick resulting from the recoil force applied by the gun is largely dependent on the weight and conformation of the shooter, whether he holds the gun tightly or loosely. The location and shape of the shooter's bones and the texture of his flesh seems to have a big effect in some cases. The recoil consists of three parts [1]. The first is the reaction, which accompanies the acceleration of the bullet from a state of rest to the velocity it possesses when it leaves the gun, that is, to its muzzle velocity. The second is the reaction, which accompanies the acceleration of the powder charge in the form of gas to a velocity in the order of half the muzzle velocity of the bullet. The third is reaction due to the muzzle blast, which occurs when the bullet leaves and releases the gas, which rushes out and gives the same kind of reaction or push that propels a rocket or a jet plane. The effect of the secondary recoil is minimized by making grooves at the end of the gun barrel. Outgoing gas dispersed and it has no great impact on the gun motion when it fired is. Therefore, the gun recoil will be in further analyzed without taking into account the impact of gas.

Several pneumatic drives for recoil imitation created by the authors we successfully applied in laser trainers [2, 3, 4]. In this paper the dynamics research of the one way operation pneumatic drive for the training weapon is presented.

One way operation pneumatic drive for gun recoil imitation

Pneumatic drive of one way operation very effectively can be used for all shooting regimes recoil imitation in laser training weapons for riflemen (Fig. 1). In this case pneumatic drive of one way operation consists of a lock mechanism the operation of which is ensured by pressure pulses of compressed air supplied though the main pipeline. As it is shown in Fig. 1, the compressed air from the main pipeline flows to the chamber of pneumatic cylinder 2. Under the action compressed air on piston 3 the latter moves to the right thus compressing spring 4. After switching the valve the cylinder chamber is connected to the atmosphere and pressure it starts dropping and the piston under the spring action is shifted to the other side position.

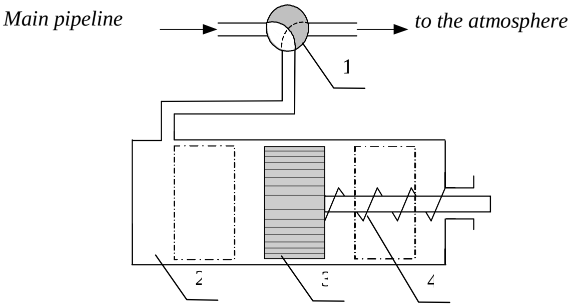


Fig. 1. One way operation pneumatic drive scheme: 1) – valve, 2) - pneumatic cylinder, 3) – piston, 4) - spring

The operation of one way drive is expressed by the following equation [6]:

$$m\ddot{x} = (p - p_a)F - c_1 x - c_2 \dot{x} - P \tag{1}$$

here c_1, c_2 - coefficients of proportionality. The resultant of all acting forces with the only exception air pressure force is

$$P = \pm P_0 + P_1 \pm P_2 \tag{2}$$

here P_0 - the force due to initial compression of the spring, P_1 - friction force, P_2 - the force of resistance to motion. The methodical calculation of one way operation pneumatic drive is presented in [6, 7].

In the case under investigation the dynamics of training weapon when its lock is affected by the pulses of compressed air was analyzed. Dynamical model of the investigation case is shown in Fig. 2.

The plane motion of the training weapon at the moment of a shot imitation is described by the mathematical model where the influence of the movement of the gunlock imitation mechanism during firing is evaluated. The force $F(t)$ (air pressure) initiating recoil in a training gun first of all makes the lock move when the influence of recoil is transferred to the gun's body. The gunlock imitation mechanism moving inside the gun influences the movement of the gun during firing. In order to adjust the mathematical model in question the forces acting on the gunlock imitation mechanism and the training weapon have to be determined.

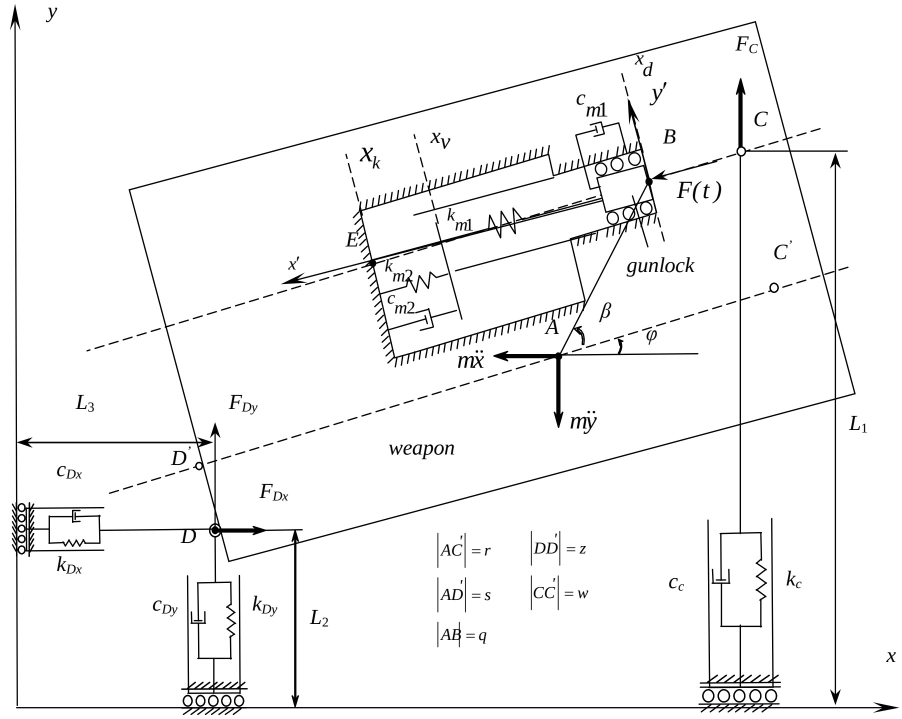


Fig. 2. Dynamical model of the training weapon

The piston of the gunlock imitation mechanism moves along axis *x'*. The equation describing piston's movement will depend on its position in this axis. The piston's coordinates are $(x',0)$. The following four cases will be researched:

1) when $x_v < x_{m1} < x_d$, then the equation describing piston's movement:

$$m\ddot{x}_{m1} + c_{m1}sign(\dot{x}_{m1}) + k_{m1}x_{m1} = F(t) \tag{3}$$

$$\text{here } sign(\dot{x}_{m1}) = \begin{cases} 1, & \text{when } \dot{x}_{m1} > 0 \\ -1, & \text{when } \dot{x}_{m1} < 0 \\ 0, & \text{when } \dot{x}_{m1} = 0 \end{cases}$$

At point *B* the gun will be impacted by force $c_{m1}sign(\dot{x}_{m1})$, and at point *E* the gun will be impacted by force $k_{m1}x_{m1}$. When making the equation describing training weapon's movement, the *Coriolis* and centrifugal forces are not evaluated because the training weapon's angular velocity in the previously researched model is <2 *rad/s* (when 3 shots in a row are simulated).
The equations describing the training weapon's movement are as follows:

$$\begin{cases} m_1\ddot{x}_{m1} + c_{m1}\,sign(\dot{x}_{m1}) + k_{m1}x_{m1} = F(t) \\ m\ddot{x} = F_{Dx} + c_{m1}\,sign(\dot{x}_{m1})\cos\varphi + k_{m1}x_{m1}\cos\varphi \\ m\ddot{y} = F_{Dy} + F_C + c_{m1}\,sign(\dot{x}_{m1})\sin\varphi + k_{m1}x_{m1}\sin\varphi \\ I\,\ddot{\varphi} = F_{Dx}\,(s\sin\varphi + z\cos\varphi) - F_{Dy}\,(s\cos\varphi - z\sin\varphi) + \\ \qquad + F_C\; r(\cos\varphi - w\sin\varphi) - c_{m1}\,sign(\dot{x}_{m1})w - k_{m1}x_{m1}w \end{cases} \tag{4}$$

2) when $x_k < x_{m1} < x_v$

$$m\ddot{x}_{m1} + (c_{m1} + c_{m2})sign(\dot{x}_{m1}) + (k_{m1} + k_{m2})x_{m1} = F(t) \tag{5}$$

At point *B* the gun will be impacted by force $(c_{m1} + c_{m2})sign(\dot{x}_{m1})$, and at point *E* the weapon will be impacted by force $(k_{m1} + k_{m2})x_{m1}$. Now it is possible to write the differential equations of weapon's movement:

$$\begin{cases} m_1\ddot{x}_{m1} + (c_{m1} + c_{m2})sign(\dot{x}_{m1}) + (k_{m1} + k_{m2})x_{m1} = F(t) \\ m\ddot{x} = F_{Dx} + (c_{m1} + c_{m2})sign(\dot{x}_{m1})\cos\varphi + (k_{m1} + k_{m2})x_{m1}\cos\varphi \\ m\ddot{y} = F_{Dy} + F_C + (c_{m1} + c_{m2})sign(\dot{x}_{m1})\sin\varphi + (k_{m1} + k_{m2})x_{m1}\sin\varphi \\ I\,\ddot{\varphi} = F_{Dx}\,(s\sin\varphi + z\cos\varphi) - F_{Dy}\,(s\cos\varphi - z\sin\varphi) + \\ + F_C\,(r\cos\varphi - w\sin\varphi) - (c_{m1} + c_{m2})sign(\dot{x}_{m1})w - (k_{m1} + k_{m2})x_{m1}w \end{cases} \tag{6}$$

3) when the piston hits the left edge at point *E*, the gunlock imitation mechsnism's velocity before the impact is $\dot{x}_{m1}$, after the impact – $R_{sm}(-\dot{x}_{m1})$, here R_{sm} – coefficient of restoration, $0<R_{sm}<1$.

It is assumed that the coefficient of restoration equals 0.56 (steel-to-steel impact). The projections of change of weapon's velocity will be as follows:

$$\begin{aligned} \Delta\dot{x} &= -\frac{m_1(1 + R_a)\dot{x}_{m1}}{m}\cos(\varphi) \\ \Delta\dot{y} &= -\frac{m_1(1 + R_a)\dot{x}_{m1}}{m}\sin(\varphi) \end{aligned} \tag{7}$$

Now, the forces impacting the weapon at points *C* and *D* are evaluated:

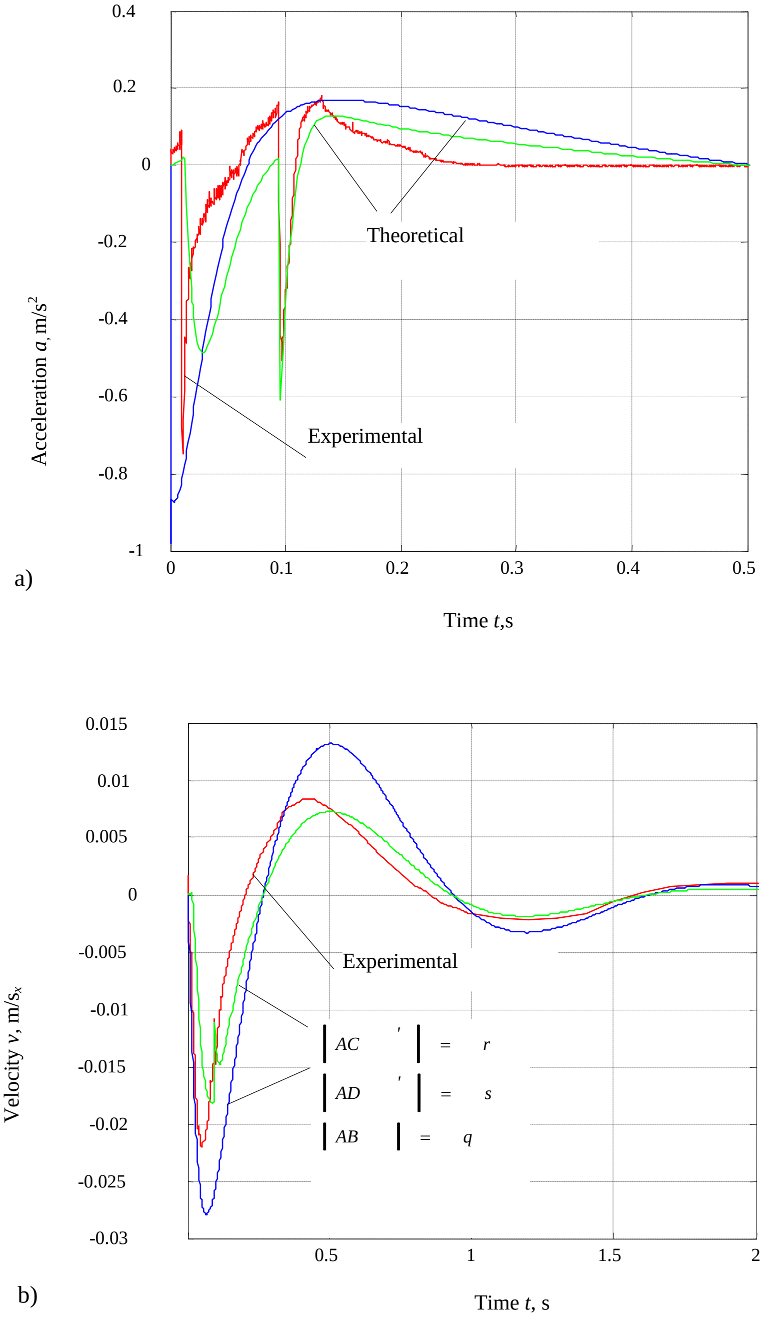
$$\begin{cases} F_C = -\,k_C\left(y + r\sin\varphi + w\cos\varphi - L_1\right) - c_C\left(\dot{y} + \Delta\dot{y} + r\cos\varphi\,\dot{\varphi} - w\sin\varphi\,\dot{\varphi}\right) \\ F_{Dx} = -\,k_{Dx}\left(x - s\cos\varphi + z\sin\varphi - L_3\right) - c_{Dx}\left(\dot{x} + \Delta\dot{x} + s\sin\varphi\,\dot{\varphi} + z\cos\varphi\,\dot{\varphi}\right) \\ F_{Dy} = -\,k_{Dy}\left(y - s\sin\varphi - z\cos\varphi - L_2\right) - c_{Dy}\left(\dot{y} + \Delta\dot{y} - s\cos\varphi\,\dot{\varphi} + z\sin\varphi\,\dot{\varphi}\right) \end{cases} \tag{8}$$

In this case the differential equations of weapons's movement will be the same as in Equation (6).

4) when the piston hits the right edge at point *B*, the change in training weapon's velocity, the forces acting on the weapon at points *C*, *D* and the differential equations of training weapon's

movement are written as Equations (4, 7 and 8). Due to structural qualities of the weapon, it is assumed that the restoration coefficient R_{sm} equals 0.

Comparative analysis of theoretical and experimental research results of the developed training weapon was performed. As it is seen from dynamical characteristics of the training weapon the results of theoretical and experimental research are in good agreement (Fig. 3).



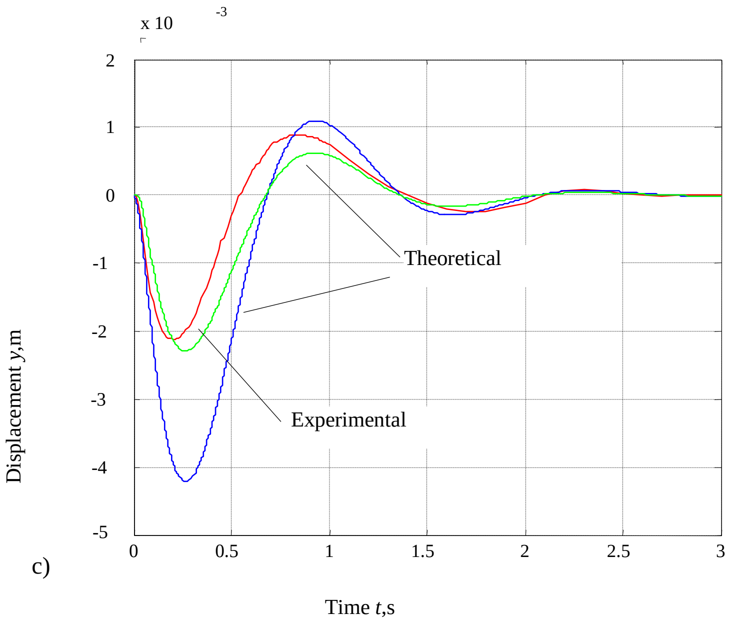


Fig. 3. Characteristics of training weapon on time: a) - acceleration, b) - velocity, c) – displacement

The obtained results were used for developing training weapon G36 general view of which and experimental measurement equipment are shown in Fig. 4, 5.

Fig. 4. G36 and measurement equipment

Fig. 5. Training weapon G36 with one way pneumatic drive

Conclusions

- The article presents a theoretical and experimental investigation of planar motion of recoil of the training weapon when it is fired in single shots and shot series. The dynamical model and differential equations of the training weapon were created.
- Differential equations of training weapon planar motion, by using *Runge – Kutta* algorithm [8, 9] and as well *MATLAB* software package, were composed and investigated. The dependencies of values describing the training weapon's motion (acceleration, velocity, displacement) upon time were obtained.

- The results of experimental investigation fully confirmed the data obtained during the solution of the mathematical model.
- It was determined that pneumatic pulse drives with forced control of operating conditions are the best to simulate recoil of small arms.
- The structural synthesis of the training weapon with full simulation of single shots and series of shots was accomplished, which resulted in creation of simulators that are successfully used in training riflemen for the defence institutions and sportsmen.

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