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Design, Research and Practical Implementation of the Laser Shooting Simulation System for 5.56 mm G-36, 7.62 mm FN MAG and 84 mm Carl Gustaf

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Abstract. Riflemen's trainers are efficiently applied for the training of the armed forces, police, and shooting sportsmen. However, the training quality directly depends on the perfection of trainers as well as on their functional facilities. One of them is the shooting possibility by using various weapons. The new modification of a practise range is created: it's included three types of weapons imitators for 5.56 mm G-36 assault rifle, 7.62 mm FN MAG machine gun and, 84 mm CARL GUSTAF recoilless gun. The work presents the universal dynamical and mathematical models of the one way operation pneumatic drive for recoil imitation, results of its investigation and description of the new modification of laser range for riflemen.
Keywords: mechanics, armed forces, weapons, dynamical models, practise range

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1. INTRODUCTION

It is known that the well-developed countries are widely using laser riflemen training equipment for the riflemen and sportsmen training. Usage of the training equipment in the process of teaching enables not only to reduce the ammunition – related economical costs used for rifle shooting experts preparation but to shorten significantly the time of their training as well as to improve the training quality.

It is clear that the training equipment of the riflemen must reproduce the process of single shots and burst as precisely as possible, in good quality develop skills of correct targeting, and to model possible fighting situations. This way, the efficiency of the training equipment is determined by the maximum reproduction of physical and psychological influence characteristics on a rifleman of the real fighting guns (shot and burst, recoil and sound, imitation of real fighting situation etc.). Also rendering of additional information to the shooting instructor and the rifleman through the additional informational systems (e.g. position of the sight at the moment of a shot, the process of trigger pressing, the correctness of butt pressing to the rifleman's shoulder, the trajectory of gun targeting etc.).

It is clear that the maximum reproduction of recoil and sound during shot and burst is very important factor for the 5.56 mm G-36 assault rifle and 7.62 mm FN MAG machine gun and only sound imitation for 84 mm CARL GUSTAF recoilless gun.

In practice, the hydraulic, pneumatic and electric impulse systems are most widely spread and these systems could be used for the solution of the formulated problem [1, 2]. However, the results of the preliminary analysis show that the pneumatic power impulse systems with external control are the most perspective for the imitation of single shots and burst. This is predetermined by the weight-size limitations, shooting velocity capacity and other technical – maintenance characteristics of the recoil imitation mechanism being designed.

For this reason, the objective of this work is to investigate the recoil of the automatic rifle under single shooting regime and burst and their interaction with a shooter so that, to design a new modification of laser training equipment for the rifleman having three types of weapons imitators: 5.56 mm G-36 assault rifle, 7.62 mm FN MAG machine gun and 84 mm CARL GUSTAF recoilless gun.

2. DYNAMICS RESEARCH OF THE RECOIL IMITATION

Recoil is a backward movement of a rifle when it is fired. It seems 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 5.56 mm G-36 and 7.62 mm FN MAG (automatic guns – AG) 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 body seems to have a big effect in some cases. The recoil consists of three parts [3]. 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 barrel muzzle, that is, to its muzzle velocity. The second is the reaction, which accompanies the acceleration of the powder charge in the form of powder 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 powder 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 third recoil at the end of the AG barrel is minimised by compensators with various ports. Outgoing powder gas dispersed and it has no great impact on the gun motion when it is fired. Therefore, the AG recoil will be in further analysed without taking into account the impact of powder gas.

Several pneumatic drives for recoil imitation are created by the authors and successfully applied in laser trainers. But pneumatic drive of one way operation very effectively can be used for all shooting regimes of recoil imitation in laser training AG for riflemen [4].

In the case under investigation, the dynamics of training AG when its lock is affected by the pulses of compressed air was analysed. Dynamical model of the investigation case is shown in Fig. 1.

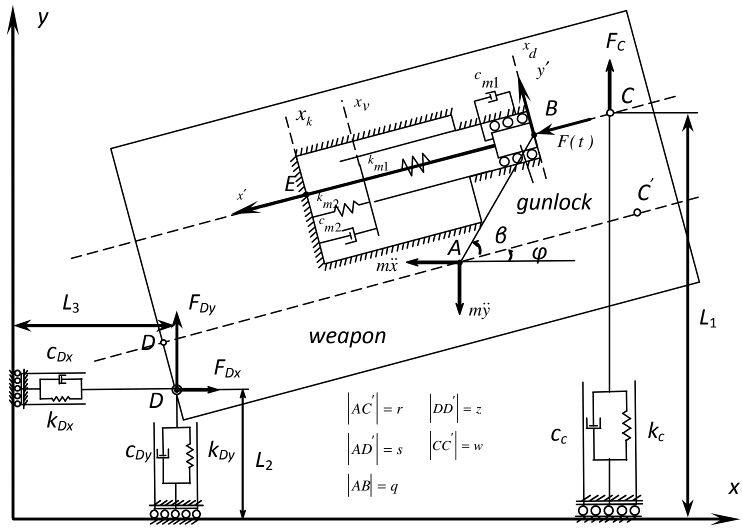


Fig. 1. Dynamical model of the training weapon AG

The plane motion of the training weapon AG 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 AG 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 AG 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.

The gun's centre of gravity is point $A(x, y)$. During a shot, stiffness and the damping forces F_C, F_{Dx}, F_{Dy} act at the points C and D. The ranges $L_1, L_2, L_3, AB, AC', AD', DD', CC'$ and the angles φ, β describe the status of equilibrium. Dashed line, passing through the points B and C, is called a shot line, and the line $C'AD'$ parallel to it – the line of centre of gravity.

The piston of the gunlock imitation mechanism moves along the 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:

$$m_1\ddot{x}_{m1} + c_{m1}sign(\dot{x}_{m1}) + k_{m1}x_{m1} = F(t) \tag{1}$$

where: m_1 – mass of piston's;

k_{m1}, c_{m1} – coefficients of stiffness and damping;

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

At the point B the gun will be impacted by the force $c_{m1}sign(\dot{x}_{m1})$, and at the point E the gun will be impacted by the 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 burst are simulated).

The equations describing the training weapon's movement are as follows:

$$\begin{cases} m_1\ddot{x}_{m1} + c_{m1}sign(\dot{x}_{m1}) + k_{m1}x_{m1} = F(t) \\ \mathrm{m}\ddot{\mathrm{x}} = \mathrm{F_{Dx}} + c_{m1}sign(\dot{x}_{m1})\cos\varphi + k_{m1}x_{m1}\cos\varphi \\ \mathrm{m}\ddot{\mathrm{y}} = \mathrm{F_{Dy}} + \mathrm{F_C} + c_{m1}sign(\dot{x}_{m1})\sin\varphi + k_{m1}x_{m1}\sin\varphi \\ \mathrm{I}\ddot{\varphi} = \mathrm{F_{Dx}}\,(\mathrm{s}\sin\varphi + z\cos\varphi) - \mathrm{F_{Dy}}\,(\mathrm{s}\cos\varphi - z\sin\varphi) + \\ \qquad + \mathrm{F_C}\,\mathrm{r}(\cos\varphi - w\sin\varphi) - c_{m1}sign(\dot{x}_{m1})w - k_{m1}x_{m1}w \end{cases} \tag{2}$$

where: I – the moment of inertia of weapon.
2) when $x_k < x_{m1} < x_v$

$$m_1\ddot{x}_{m1} + (c_{m1} + c_{m2})sign(\dot{x}_{m1}) + (k_{m1} + k_{m2})x_{m1} = F(t) \tag{3}$$

where: k_{m2}, c_{m2} – coefficients of stiffness and damping.

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

$$\begin{cases} m_1\ddot{x}_{m1} + (c_{m1} + c_{m2})sign(\dot{x}_{m1}) + (k_{m1} + k_{m2})x_{m1} = F(t) \\ \mathrm{m}\ddot{\mathrm{x}} = \mathrm{F_{Dx}} + (c_{m1} + c_{m2})sign(\dot{x}_{m1})\cos\varphi + (k_{m1} + k_{m2})x_{m1}\cos\varphi \\ \mathrm{m}\ddot{\mathrm{y}} = \mathrm{F_{Dy}} + \mathrm{F_C} + (c_{m1} + c_{m2})sign(\dot{x}_{m1})\sin\varphi + (k_{m1} + k_{m2})x_{m1}\sin\varphi \\ \mathrm{I}\,\ddot{\varphi} = \mathrm{F_{Dx}}\,(\mathrm{s}\sin\varphi + z\cos\varphi) - \mathrm{F_{Dy}}\,(\mathrm{s}\cos\varphi - z\sin\varphi) + \\ + \mathrm{F_C}\,(\mathrm{r}\cos\varphi - w\sin\varphi) - (c_{m1} + c_{m2})sign(\dot{x}_{m1})w - (k_{m1} + k_{m2})x_{m1}w\,. \end{cases} \tag{4}$$

3) when the piston hits the left edge at the point E, the gunlock imitation mechanism'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 the AG velocity will be as follows:

$$\begin{aligned} \Delta\dot{x} &= -\frac{m_1(1+R_a)\dot{x}_{m1}}{m}\cos(\varphi) \\ \Delta\dot{y} &= -\frac{m_1(1+R_a)\dot{x}_{m1}}{m}\sin(\varphi) \end{aligned} \tag{5}$$

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

$$\begin{cases} \mathrm{F_C} = -\,\mathrm{k_C}(\mathrm{y} + \mathrm{r}\sin\varphi + \mathrm{w}\cos\varphi - \mathrm{L_1}) - \mathrm{c_C}(\dot{\mathrm{y}} + \Delta\dot{y} + \mathrm{r}\cos\varphi\,\dot{\varphi} - \mathrm{w}\sin\varphi\,\dot{\varphi}) \\ \mathrm{F_{Dx}} = -\,\mathrm{k_{Dx}}(\mathrm{x} - \mathrm{s}\cos\varphi + \mathrm{z}\sin\varphi - \mathrm{L_3}) - \mathrm{c_{Dx}}(\dot{\mathrm{x}} + \Delta\dot{x} + \mathrm{s}\sin\varphi\,\dot{\varphi} + \mathrm{z}\cos\varphi\,\dot{\varphi}) \\ \mathrm{F_{Dy}} = -\,\mathrm{k_{Dy}}(\mathrm{y} - \mathrm{s}\sin\varphi - \mathrm{z}\cos\varphi - \mathrm{L_2}) - \mathrm{c_{Dy}}(\dot{\mathrm{y}} + \Delta\dot{y} - \mathrm{s}\cos\varphi\,\dot{\varphi} + \mathrm{z}\sin\varphi\,\dot{\varphi}) \end{cases} \tag{6}$$

In this case, the differential equations of AG movement will be the same as in Eq. (4).

4) when the piston hits the right edge at the point B, the change in training AG velocity, the forces acting on the weapon at the points C, D and the differential equations of training weapon's movement are written as Eqs. (2, 5 and 6).

Due to structural qualities of the weapon, it is assumed that the restoration coefficient R_{sm} equals 0.

The differential equations of AG training weapons planar motion by using Runge–Kutta algorithm [5, 6] and as well MATLAB software package were composed and investigated. The dependences of values describing the training weapons motion (acceleration, velocity, displacement) upon time were obtained.

Comparative analysis of theoretical and experimental research results of the developed training AG was performed. As it can be seen from dynamical characteristics of the training AG the results of theoretical and experimental research are in good agreement (Fig. 2).

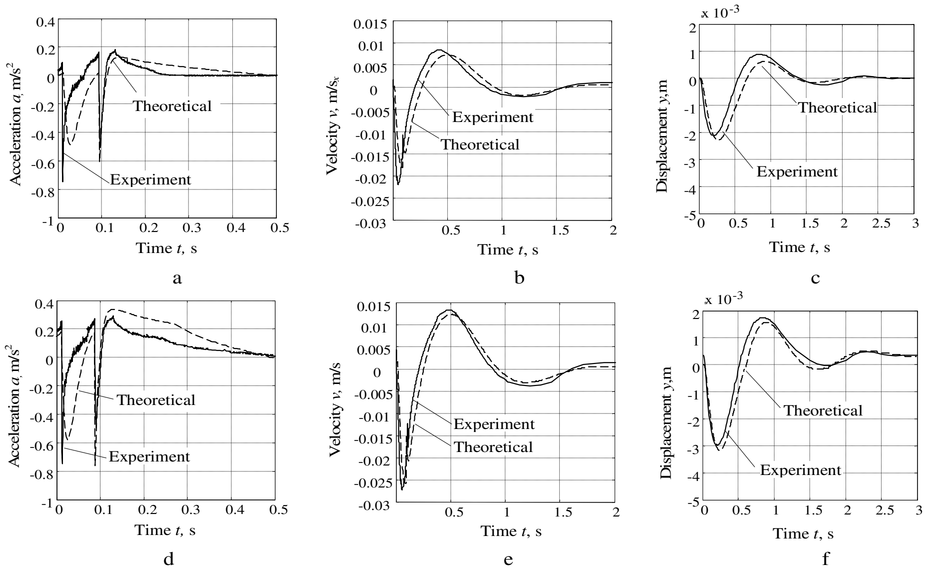


Fig. 2. Characteristics of AG on time:
5.56 mm G-36 – a) acceleration, b) velocity, c) displacement;
7.62 mm FN MAG – d) acceleration, e) velocity, f) displacement

3. EXPERIMENTAL RESEARCH OF THE RECOIL

For recoil imitation of weapon, pneumatic drive [7] installed into the training weapon was used. For the verification of its efficiency, the investigation of the recoil of real and imitated shots using 5.56 mm G-36 assault rifle and 7.62 mm FN MAG machine gun was performed. The scheme applied for experimental research of arm recoil at a shot is presented in Fig. 3 and general images of the test weapons are shown in Fig. 4 a, b.

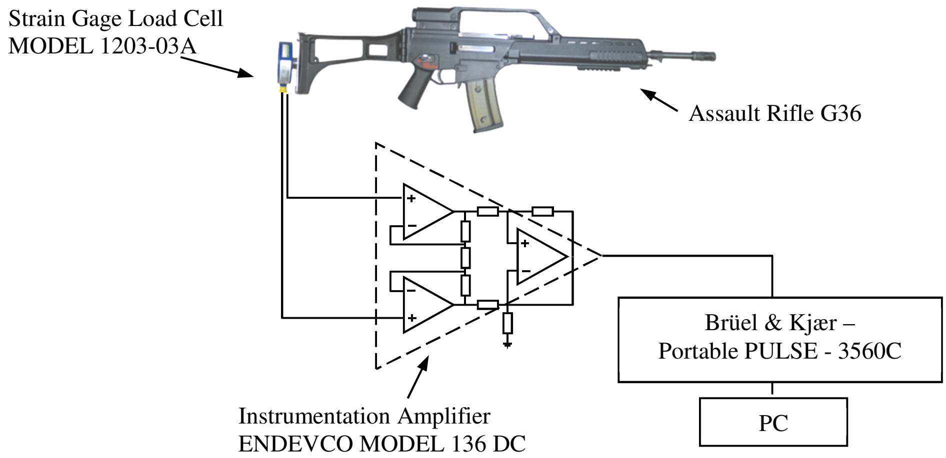


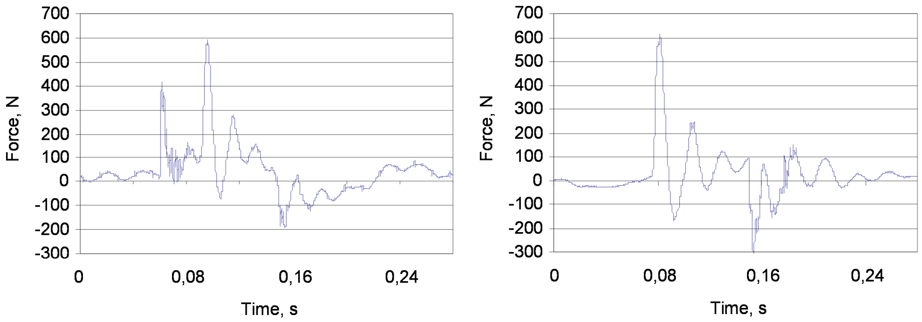
Fig. 3. Scheme applied for the experimental research of weapon recoil at a shot

a) b)

Fig. 4. General images of the test arms (weapons): a) assault rifle G-36 and measurement equipment; b) machine gun FN MAG

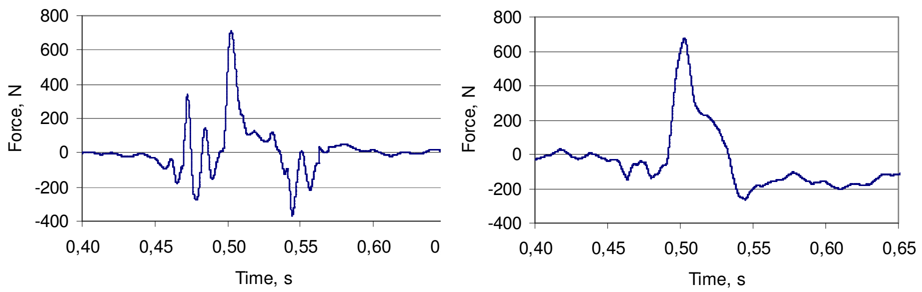
As it can be observed in Fig. 3, the scheme applied for experimental research of the recoil of automatic rifles includes the test weapon G-36 with the force sensor (model 1203-03A) attached to its butt stock and connected in series with the amplifier (Endevco model 136A), hardware of the company Brüel & Kjær PULSE – 3560C and personal computer on the monitor of which the graph of recoil force versus time during the shot process can be displayed and recorded.

The obtained dependences of the recoil force on time are presented in both Fig. 5 (assault rifle G-36) and Fig. 6 (machine gun FN MAG).



a) b)

Fig. 5. Dependences of recoil force on time for assault rifle 5.56 mm G-36:
a) real shot, b) simulation



a) b)

Fig. 6. Dependences of recoil force on time for machine gun 7.62 mm FN MAG:
a) real shot, b) simulation

As it can be seen from Fig. 5 and 6, the presented dependencies of recoil force on time, the magnitudes and durations of the recoil forces at real and simulated shots match sufficiently well. Therefore these training weapons can be effectively used in laser riflemen trainers.

4. DESIGN OF NEW MODIFICATION OF LASER RANGE FOR RIFLEMEN

Design of new modification of a practise range has been created and implemented in practice as a result of theoretical and experimental research, the function scheme of which is shown in Fig. 7.

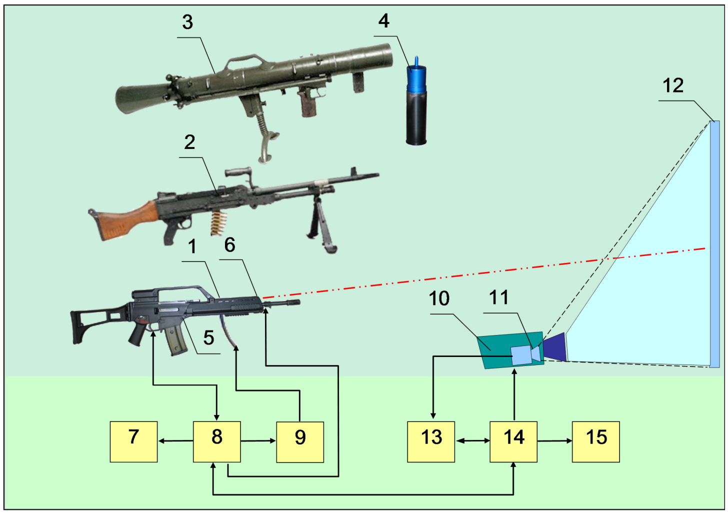


Fig. 7. Functional scheme of laser range for riflemen:
1 – training assault rifle G-36, 2 – training machine gun FN MAG,
3 – recoilless gun CARL GUSTAF, 4 – laser warhead, 5 – recoil imitation mechanism,
6 – IR (infrared) laser, 7 – sound imitation system, 8 – control block of recoil, sound and laser shot systems, 9 – compressed air supply system, 10 – projector,
11 – video camera, 12 – target screen, 13 – laser beam tracking system,
14 – computer, 15 – monitor

The created laser trainer for riflemen has 3 types of training weapons: automatic guns 5.56 mm G-36 (1) and 7.62 mm FN MAG (2) and recoilless gun CARL GUSTAF (3). Automatic guns G-36 (1) and FN MAG (2) imitate the recoil and sound of the corresponding shooting regimes. Recoilless gun CARL GUSTAF (3) imitates the shot sound and also it has a jet – pneumatic warhead (4) launch imitation system, The IR (infrared) laser with its electronic control system is mounted in the warhead (4), which imitates the shot. The one way pneumatic drive (5) is mounted within the automatic guns G-36 (1) and FN MAG (2), which imitates the gun recoil and the action of the gun lock during the shooting process. The IR lasers (6) that emit short light impulses are mounted in the gun barrels. They indicate the point of hit on the target which is projected on the screen (12). The firing sound of each weapon is simulated, by the shot imitation system (7). The control block (8) controls the compressed air supply system (9) and the sound imitation system (7). The projector (10) displays the views of the terrain with the targets and camera (11), registers the laser impulses on the target, which are projected on the screen (12). The camera (11) transmits the information about a hit to the shot detection systems (13), which is mounted in the computer (14). The software installed on the computer (14) processes the hit data, performs a statistic analysis, which is displayed on the monitor (15) in real time.

Trainer's software supplies not only information about hits and statistics, but also the weapon trajectory during aiming, and the position of the sights during each shot. It also lets the user to choose the type of the target, the shooting distance, the target display time etc. It should be noted that it is possible to perform all the exercises appraised by the Commander of the Lithuanian Army.

The view of the laser trainer is shown in Fig. 8.

Fig. 8. View of the laser trainer for riflemen

5. CONCLUSION

- The article presents theoretical and experimental investigations of planar motion of recoil of the training automatic gun when it is fired in single shots and burst. The dynamical model and differential equations of the training weapon were created.
- Differential equations of training weapon planar motion, by using Runge–Kutta algorithm [6] 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 performed experimental research on the recoil force of assault rifle 5.56 mm G-36 and machine gun 7.62 mm FN MAG at real and simulated shots revealed that their magnitudes and durations match sufficiently well, therefore these training weapons can be effectively used in laser range for riflemen.
- A new modification of laser range for riflemen was accomplished, which included three types of training weapons - automatic guns 5.56 mm G-36 and 7.62 mm FN MAG, recoilless gun 84 mm CARL GUSTAF and successfully used in training process for the defence institutions.

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