DYNAMICAL ANALYSIS OF SEMI-AUTOMATIC SNIPER RIFLE

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Introduction

The paper presents dynamical model of semi-automatic sniper rifle firing the 0.5 inch (12.7 x 99 mm) cartridge. The rifle is currently under construction.

The simulational model was built in order to learn about mechanical properties prior to manufacturing the rifle prototype. As the designing process has not been finished yet, the constructor may take into consideration information gained from the model. Many aspects of the simulation results may be utilised in the design process. This paper is focused on the recoil forces.

Reduction of recoil forces applied to a human body is a crucial issue during the design of large calibre rifles. These forces are strongly influenced by the dynamics of motion of rifle parts upon firing. Springs employed in the rifle mechanism play a very important role in the reduction of recoil forces. Changing the spring characteristics is the easiest way to change recoil forces acting on a human body. The objective of presented study was to choose spring stiffnesses and preloads for which recoil forces applied to the human body are minimal.

The *ADAMS 11* package was used for the modelling and simulation.

The rifle description

The schematic view of the rifle is presented in Fig. 1.

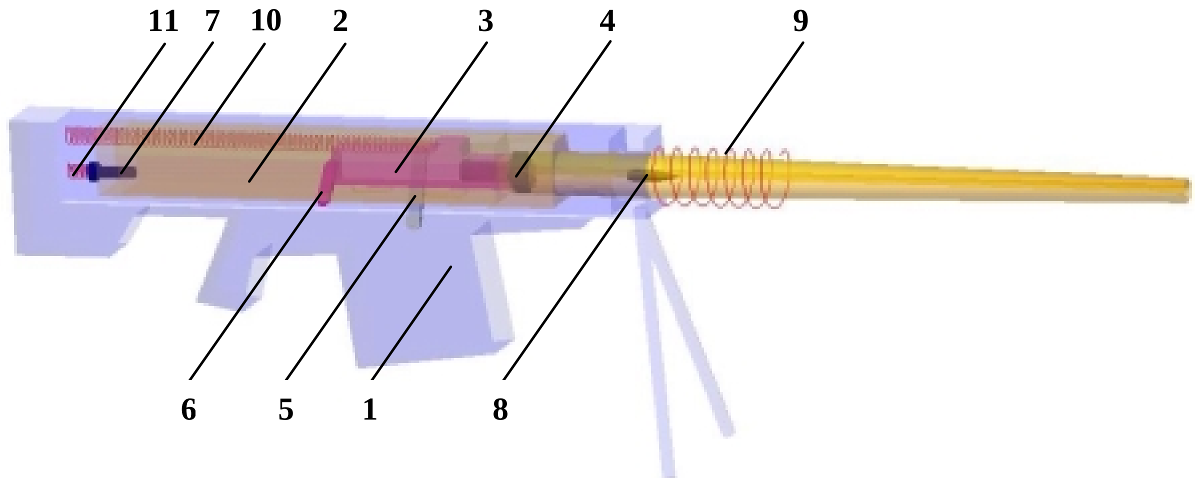

Fig. 1. Schematic view of the rifle.
1 - rifle body with bipod, 2 - barrel with barrel extension, 3 - bolt carrier, 4 – bolt, 5 - accelerator arm, 6 - cocking lever, 7 – recoil buffer, 8- bullet, 9- barrel spring, 10 - main return spring, 11- recoil buffer spring.

The rifle operates on short recoil principles. Upon firing, the bullet is forced through the barrel and case-head thrust is delivered to the bolt face. This thrust transfers through bolt lugs to the barrel extension. The barrel recoils. At the beginning of recoil the bolt is engaged with the barrel. The barrel, bolt and bolt carrier are moving together. Then, the barrel extension pushes the accelerator arm, which forces the bolt carrier to move faster than the barrel. This action serves to rotate the bolt out of engagement with the barrel extension and to transfer energy from the barrel to the bolt carrier. The pin-in-slot joint between the bolt carrier and bolt causes the bolt to rotate 45 deg during the separation of the carrier and the barrel extension, thus moving the bolt locking lugs out of engagement with the barrel. Then the bolt carrier and the bolt continue to move under their own momentum. As the carrier pulls the bolt to the rear, the cocking lever recocks the firing pin and the ejector withdraws the fired cartridge case from the weapon. After separation with the bolt the barrel extension strikes the rear part of the rifle body and then the barrel spring restores the barrel to the forward position. The bolt carrier strikes the recoil buffer and then the main return spring forces the bolt carrier forward, stripping a new cartridge from the magazine and chambering it. Then, the bolt meets the barrel and rotates, locking the lugs into engagement with the barrel.

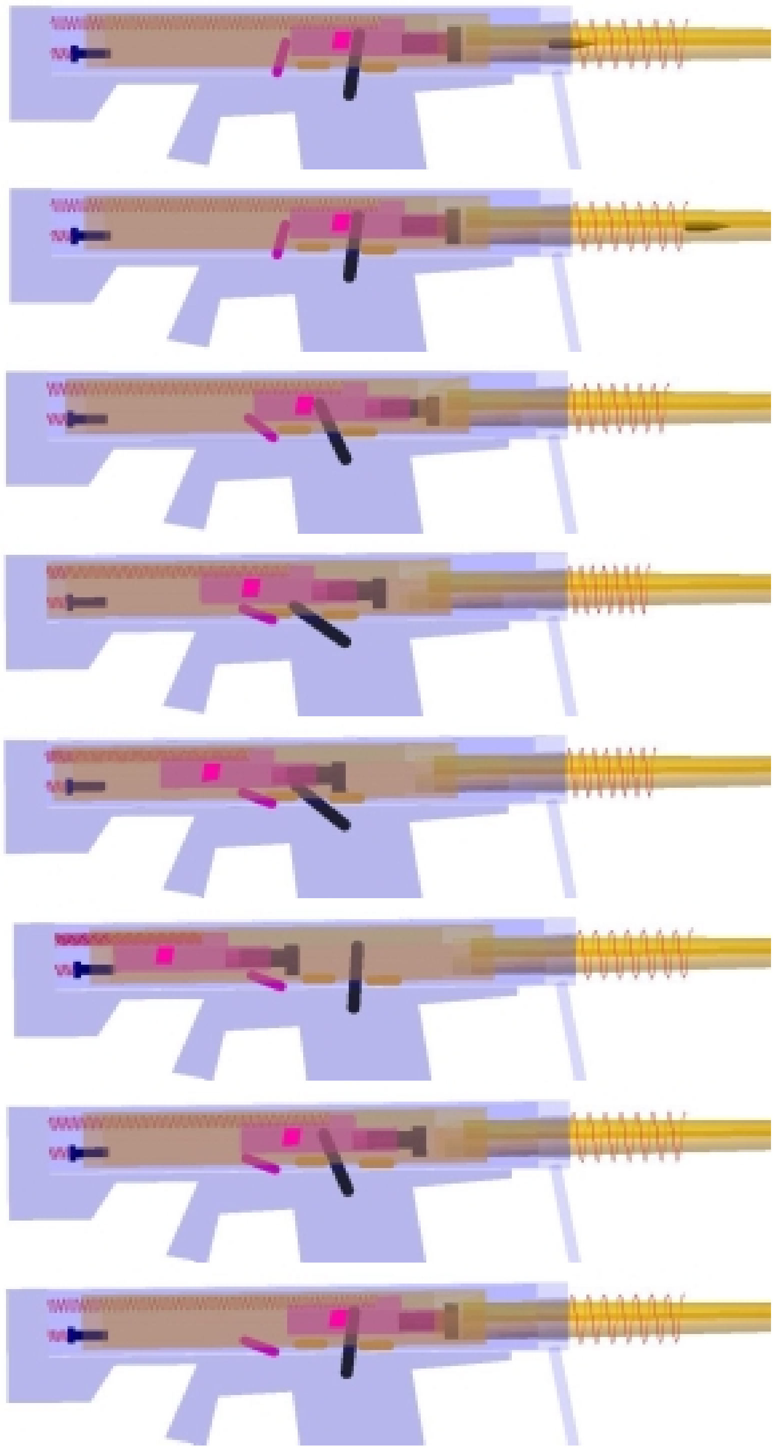

Fig. 2. The sequence of rifle parts motion.

The dynamics of recoil

The bullet (mass 45 *g*) leaves the barrel in approximately 1.5 milisecond, with a muzzle velocity of approximately 900 *m/s*. According to Newton's second law, an average force acting on the bullet during its' motion inside the barrel is equal to:

$$\frac{0.045kg \cdot 900\frac{m}{s}}{0.0015s} = 27000N$$

If the barrel was rigidly supported (fixed to the ground), those 27000 *N* would be exactly the average recoil force applied to the support. This simple calculation gives an impression of how big the forces are acting on the rifle parts and why reduction of recoil forces acting on a human body is such an important issue.

The recoil forces applied to the human body are much smaller than 27000 *N*, because the barrel is not rigidly fixed to the rifle body. The mass of the barrel with barrel extension is approximately 200 times bigger than the mass of the bullet and this big mass is travelling in the opposite direction to the bullet. During this motion the main return spring and the barrel spring are being compressed. Motion of the bolt and the bolt carrier as well as friction between all moving elements also influence the resultant recoil forces. As a result the impulse of the force transmitted to the rifle body is smaller, however it lasts longer.

Due to a complicated mechanism of force transmission between the fired bullet and human body it is not easy to assess recoil forces. A simulational model, reflecting all the major parts of the rifle is necessary.

The multibody model

The multibody model consists of 8 moving parts (rifle body with bipod, barrel with barrel extension, bolt carrier, bolt, accelerator arm, cocking lever, recoil buffer and bullet) and has 13 degrees of freedom. In the presented version of the model cartridge case ejection as well as new cartridge loading were neglected.

The gas pressure during bullet movement inside the barrel, as well as the pressure after leaving the barrel is known for Browning 0.5 in cartridge (it was calculated using Gau method and inner ballistic tables [1]). It was used as input data for the model.

Friction forces between bullet and barrel and those acting on the bolt were taken into consideration. The metal-to-metal contact forces between moving parts of the rifle were modelled using *IMPACT* function from *ADAMS* function builder [2].

The rifle is supported on the bipod and on a human arm. Two very simple models of a human body were used.

In the first model the human interaction with rifle is modelled as a spring-damper force acting between ground and rifle butt. The stiffness (500 *kN/m*) and damping (2700 *Ns/m*) used in the *ADAMS* model were assumed after [3].

In the second model of the support, the fact that actually some fragments of a human arm are moving together with the rifle body, is taken into account. In this model there is an additional mass between the rifle and the ground. This mass (0.7 *kg*) is connected to the ground and the rifle body via spring-damper forces. The stiffness and damping of the spring between the mass and the ground is the same as in the first model. The stiffness of the other spring is 5 times bigger. The mass and the stiffness and damping properties were assumed after [3].

Simulation results

The simulation was focused on finding rifle design parameters for which recoil forces applied to a human body are minimal. The simplest way to affect the recoil forces applied to a human body is to change the springs stiffnesses and preloads. Of course there are other possibilities, e.g. enlarging of masses of the rifle parts would decrease the recoil forces, but it is obviously a wrong idea. Other changes, like increasing the distance of barrel recoil would require redesigning of almost all elements. The optimisation presented in the paper was restricted to springs employed in the rifle mechanism, however other tests showed that the change of accelerator arm leverage significantly influences the recoil forces exerted on a human body.

The typical time history of the recoil force applied to a human body is shown in Fig. 3.

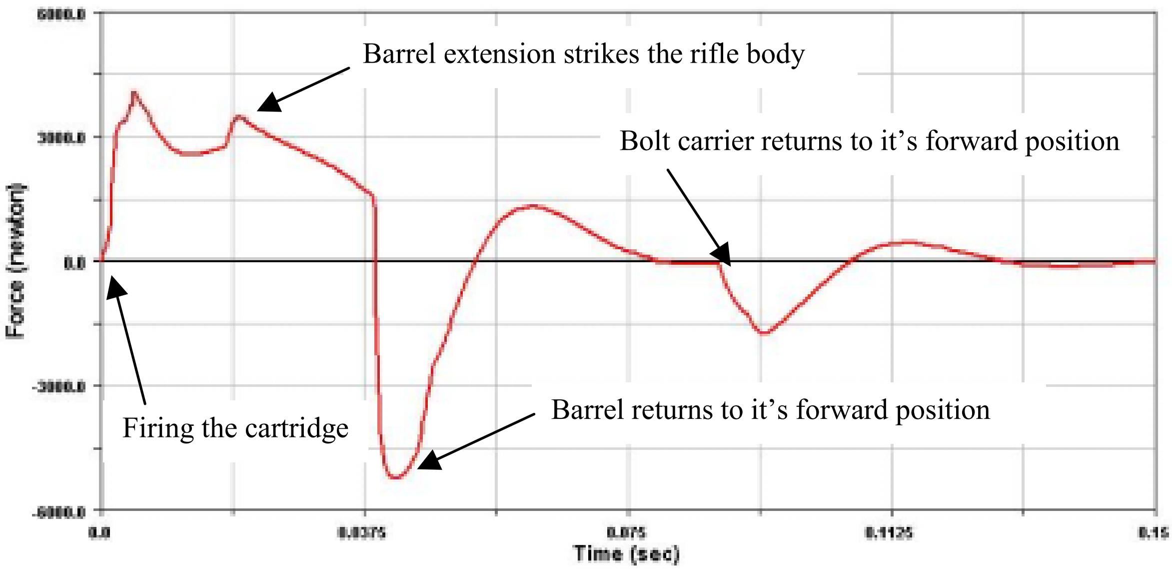

Fig. 3. Time history of recoil force applied to a human body.

The design study was performed for preloads and stiffnesses of the barrel spring, the main return spring and the recoil buffer spring. The maximum of the recoil force applied to human body (the force in spring-damper element between the ground and the rifle) was investigated. It was found that the recoil force shows the biggest sensitivity to changes of the barrel spring preload and stiffness and to the main return spring preload. For those three parameters an optimisation was performed. The goal was to minimize the maximal value of the recoil force applied to a human body.

The most important, initial part of time history of the recoil force applied to a human body before and after optimisation is shown in the Fig. 4.

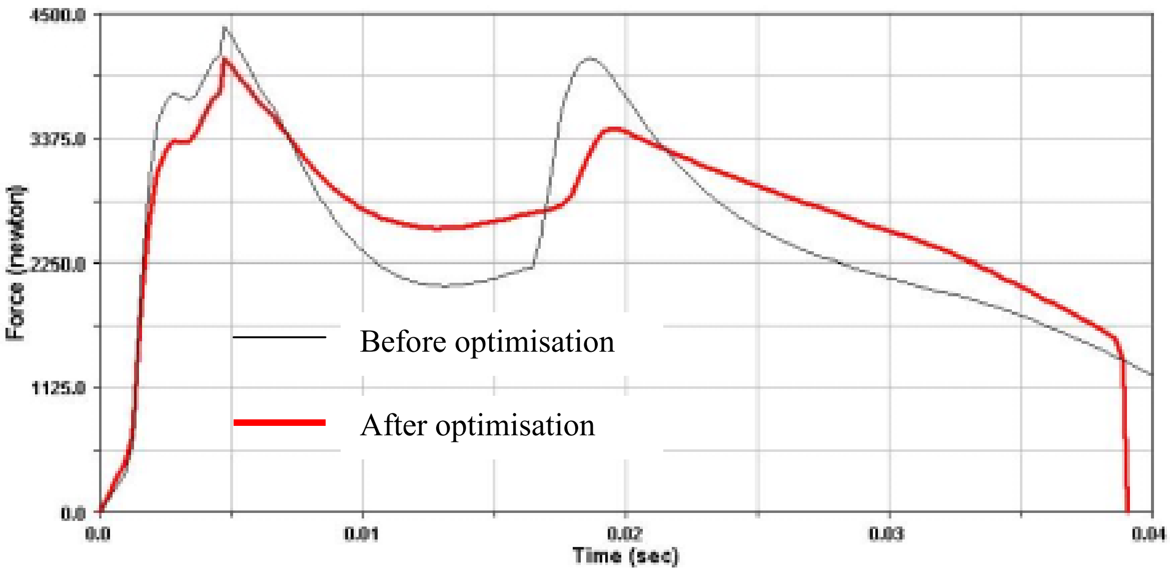

Fig. 4. The recoil force before and after optimisation.

The maximum recoil force was decreased approximately 10%. Results obtained for both the models of support were similar. The second model (with additional mass) showed recoil force values smaller by about 2%. It was also found that 20% changes of stiffness and damping of spring-damper element in the support model resulted in 5% changes in calculated recoil forces.

Conclusions

The 10% reduction of recoil forces is not a very big improvement. This result proves that initial design parameters were chosen reasonably. The results presented here are only preliminary, due to many unknowns in a newly designed rifle. It should be emphasised, that the rifle is going to be equipped with a muzzle brake, which is supposed to reduce the recoil forces up to 50%.

The model of support of the rifle was extremely simple. Building a better model of human - weapon interaction, which more accurately reflects the rheological properties of a human body, should be considered.

References

[1] *Inner ballistic tables, Part I and II* (in Polish). Military Technical Academy. Warsaw.
[2] *ADAMS 11 Manual*.
[3] St. Kochański. *Braked recoil of fire-arms* (in Polish). Warsaw University of Technology 1979.