DYNAMICAL ANALYSIS OF THE GAS POWERED IMPULSE GENERATOR

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Abstract: *The paper presents the 3D design, results of the theoretical calculation of the force generated by the experimental carbon dioxide powered recoil force and impulse generator and comparison with the experimental measurement on the manufactured origin. The approximate calculation of the resultant generated force was performed with the kinetic energy loses method. The comparison with the measured real firearm recoil force and impulse is also presented.*

Keywords: *recoil simulation, assault rifle, impulse, force diagram*

1. INTRODUCTION

Presented experimental, carbon dioxide powered, impulse generator was designed to provide an experimental data for the purpose of the research and development of the device for the gun's recoil simulation. The main idea for the design and development is to acquire the force and impulse diagrams and compare them with the earlier obtained diagrams of the commercial carbon dioxide training recoil adapters. The generator was designed in the CAD environment of the SolidWorks 2015 and subsequently manufactured. The part of design was an approximate calculation of the impact speed of the piston on the buffer and the generated force size. At the end the experimental measurement was also performed.

2. 3D DESIGN

The origin of the carbon dioxide powered recoil force generator was designed in the CAD environment of the SolidWorks 2015. The mechanical drawings of the components were exported after the design completion and next the functional origin was manufactured.

2.1 Design description. Whole mechanism is located in the cylinder with the inner diameter of 30 mm. The cylinder allows the moving of the movable piston from the front to the rear position. The piston is forced to move by the expansion of the injected pressurized carbon dioxide. The dimension tolerance between the cylinder inner diameter and the piston diameter is minimal and with the lubricant provides the sufficient tightness. For the purpose of the measurement, two pistons with different masses were manufactured. The weight of the heavier piston is 309 g and in the case of the lighter piston it is 240 g. The aperture in the rear part of the cylinder provides the discharge of the air in front of the piston and the aperture in the middle of the cylinder provides the discharge of the pressurized carbon dioxide after the acceleration of the piston.

The threads on the both ends of the cylinder are for the closing nuts. In the rear of the cylinder a case with the buffer is inserted and it's directly connected with a firearm stock.

A bronze was chosen as a material for the slip edges, due its better slip properties. The recoil spring provides the piston transfer back to the front position. The spring stiffness is 550 $N.m^{-1}$. The view of the mechanical part arrangement of the generator is shown in Fig. 1.

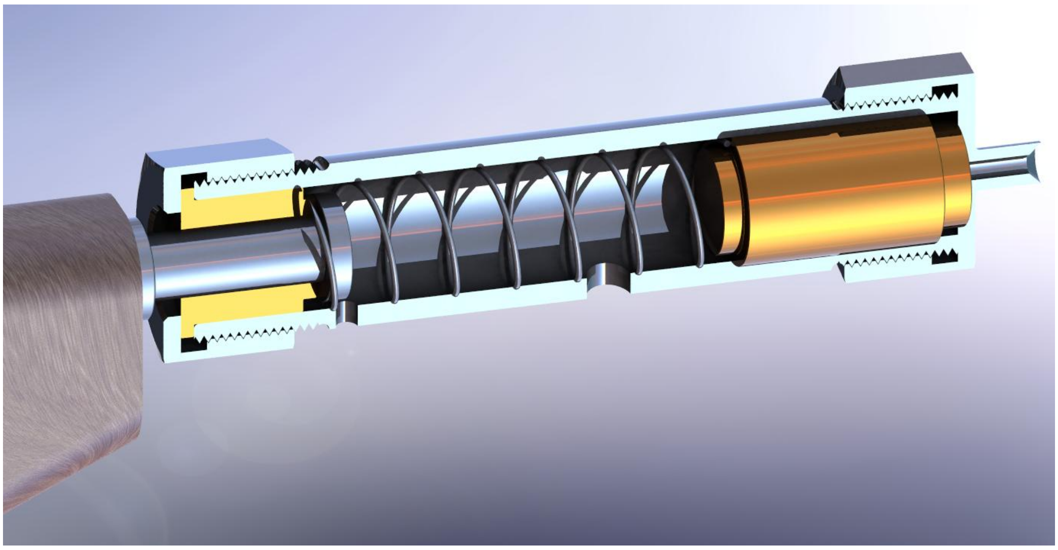

FIG. 1 Inner arrangement of mechanical parts

2.2 Function principle. The pressurized carbon dioxide is injected under the piston in the cylinder. The mass of the injected carbon dioxide is controlled by the electromagnetic valve GSR Type 46, driven by the time relay ElkoEP PDR-2. The parameters are closely presented in [1]. The carbon dioxide begins to expand and force the piston to move. The piston begins to move immediately after the pressure rises to the sufficient level. The recoil spring is also pressed by the piston during its move in to the rear position and when the rear edge of the piston get through the aperture in the cylinder, the discharge of the carbon dioxide from the cylinder begins. After that the piston moves freely to the rear position, where impacts the buffer. This way a recoil force is generated and transferred through the stock to the ballistic mount or the shooter's arm. When the carbon dioxide is fully discharged, the recoil spring forces the piston to move to the initial position.

Fig. 2. shows the view of the designed and manufactured generator system.

FIG. 2 View of the system

3. CALCULATION OF THE IMPACT SPEED

The input data for the calculation are given in the Tab. 1. The maximum pressure in the cylinder depends on the pressure loses in the valve, inlet port cross-section, initial volume and the mass of the injected carbon dioxide and substantially differs from the pressure in carbon dioxide tank. The approximate initial value of the pressure around 2 MPa was obtained from the Matlab calculation model, see [2]. The calculation was realized on the basis of the kinetic energy loses in the each phase.

Table 1. Input data

Mass of the piston	0.309 kg
Mass of the recoil parts	0.314 kg
Stiffness of the recoil spring	550 $N.m^{-1}$
Initial force of the recoil spring	2 N
Maximal force of the recoil spring	48.37 N
Pressure	1,5 MPa
Total stroke of the piston	84.3 mm
Section lengths	67.5; 10; 3.5 mm

3.1 Calculation of the phases of motion. In the first phase, the initial energy is given to the piston by the pressurized carbon dioxide. The piston starts to move before the pressure rises to the maximum magnitude and then the maximal pressure is smaller. During the motion in this phase, the small amount of the energy is spent by the recoil spring. The length of the first phase is 67.5 mm. The second phase length is 10 mm and due to the simplicity, the calculation in this phase expects the immediately depressurization, so in this section, the piston moves freely with the initial velocity and energy.

Cross-section of the piston:

$$S_p = \frac{\pi \cdot d^2}{4} = \frac{\pi \cdot 0.03^2}{4} = 0.0007065 \text{ m}^2$$

Where S_p – cross-section of the piston,
d – diameter of the piston.

Maximal force provided by the carbon dioxide on the piston:

$$F_{HP} = p \cdot S_p = 1500000 \cdot 0.0007065 = 1060 \text{ N}$$

Where F_{HP} – maximal force acting to the piston,
p – acting pressure.

Recoil spring force on the end of the phase:

$$F_{675} = F_{p1} + \left(c_{pp} \cdot x_1\right) = 2 + \left(0.55 \cdot 67.5\right) = 39.125 \text{ N}$$

Where F_{675} – force at the end of the phase,
F_{p1} – initial force of the recoil spring,
c_{pp} – stiffness of the recoil spring,
x_1 – length of the phase.

The force acting on the piston at the end of the phase:

$$F_{res} = F_{HP} - F_{675} = 1060 - 39.125 = 1020.875 \text{ N}$$

Where F_{res} – resulting force at the end of the phase.

Piston acceleration:

$$a_p = \frac{F_{res}}{m_{rp}} = \frac{1020.875}{0.31} = 3285.27 \text{ m.s}^{-2}$$

Where a_p – acceleration of the piston.

Time of the movement in the phase:

$$t_{675} = \sqrt{\frac{2 \cdot x_1}{a_p}} = \sqrt{\frac{2 \cdot 0.0675}{3285.27}} = 0.0064 \text{ s}$$

Where t_{675} – whole time of the motion in the phase.

The piston velocity at the end of the phase:

$$v_{p1} = a_p \cdot t_{675} = 3285.27 \cdot 0{,}0064 = 21.06 \text{ m.s}^{-1}$$

Where v_{p1} – resulting velocity of the piston at the end of the phase.

Energy spent by the recoil spring:

$$A = \frac{F_{p1} + F_{675}}{2} \cdot x_1 = \frac{2 + 39.125}{2} \cdot 0.0675 = 1.388 \text{ J}$$

Where A – Energy spent by the recoil spring during the pressing.

Kinetic energy at the end of the phase:

$$E_{p1} = \frac{1}{2} m_{pč} \cdot v_{p1}^2 - A = \frac{1}{2} \cdot 0.31 \cdot 21.06^2 - 1.388 = 67.5 \text{ J}$$

Where E_{p1} – resulting energy of the piston after the first phase.

Analogicaly the next two phases were calculated and the maximum final calculated recoil force, transferred to the arm, was 4 363 N.

4. VERIFICATION MEASUREMENT

The measurement was realized for the both used pistons in the firing rest STZA 12 equipped by the Kistler 9051A annular force-sensor. As a ballistic computer, the Dewetron DEWE 5000 was used. Several free runs were realized before the measurement due to the device stabilization in the firing rest. The impact speed of the piston on the buffer was evaluated from the hi-speed camera record.

After the initial stabilization, the 5 cycles were performed, the data from the ballistic computer were processed and the obtained force diagram for the five runs with the heavier piston is shown in Fig. 3.

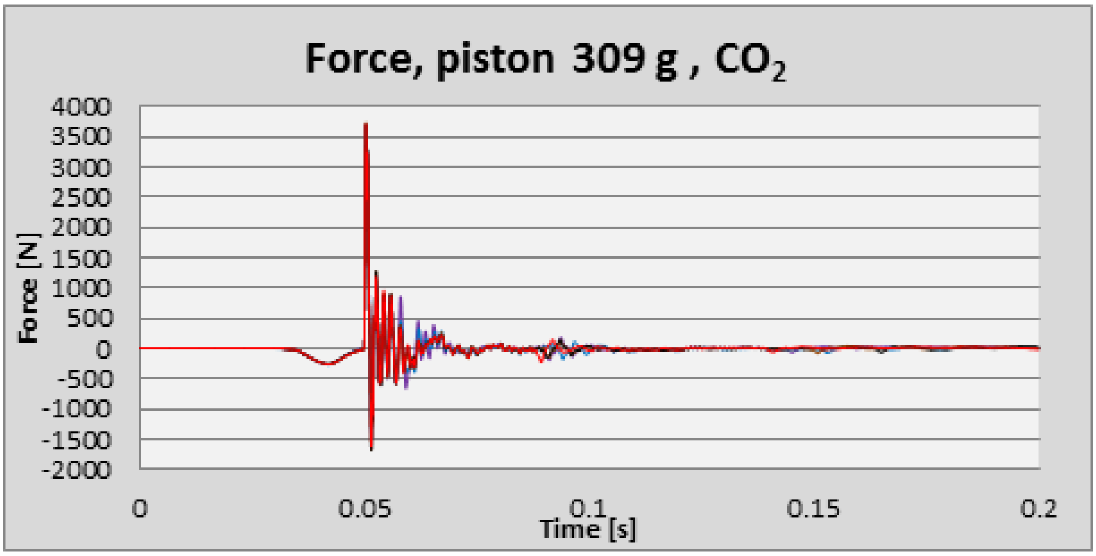

FIG. 3 Force diagram for the 309g piston

The small negative spike at the motion beginning is caused by the acceleration of the the piston after its release. During the forced motion of the piston to the rear position, the whole device is forced by the pressurized gas to move in the opposite direction.

The main force peak is caused by the piston impact and it's in the range from 3 600 to 3 750 N. This is around the 70% of the real maximum recoil force peak. This is caused by a non-absolute stiffness of the firing rest recoil system and the previous measurements in this firing rest configuration shows that it's around 70%. The real recoil force peak is then in the range between 5 100 and 5 400 N.

Impulse diagram was obtained by the numerical integration from the measured data in the table processor. The impulse courses for the each measurement are shown in Fig. 4.

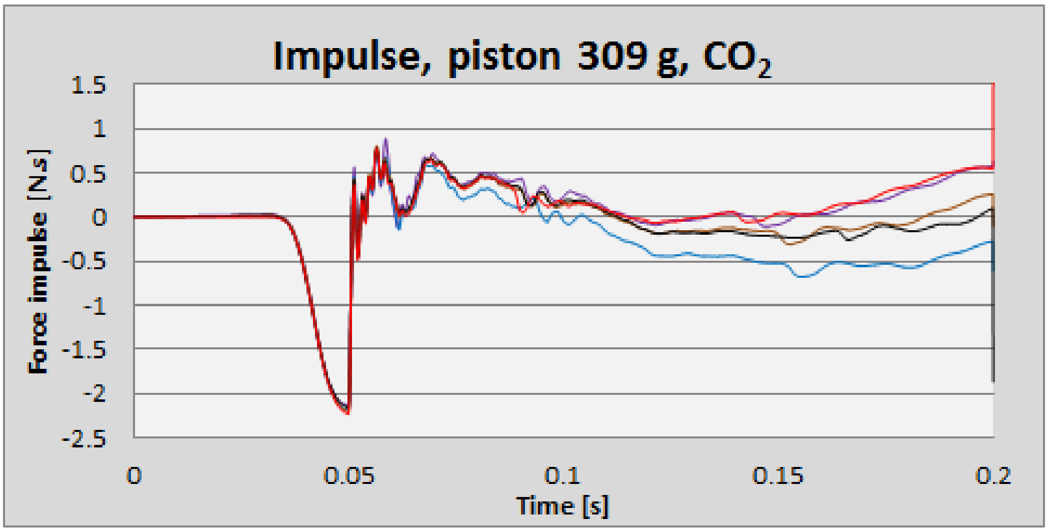

FIG. 4 Impulse diagram for the 309g piston

The obtained time courses of the force and impulse are almost identical, what makes this measurement representative and repeatable.

The next diagram in the Fig. 5 shows the force time courses in case of the lighter, 240g piston.

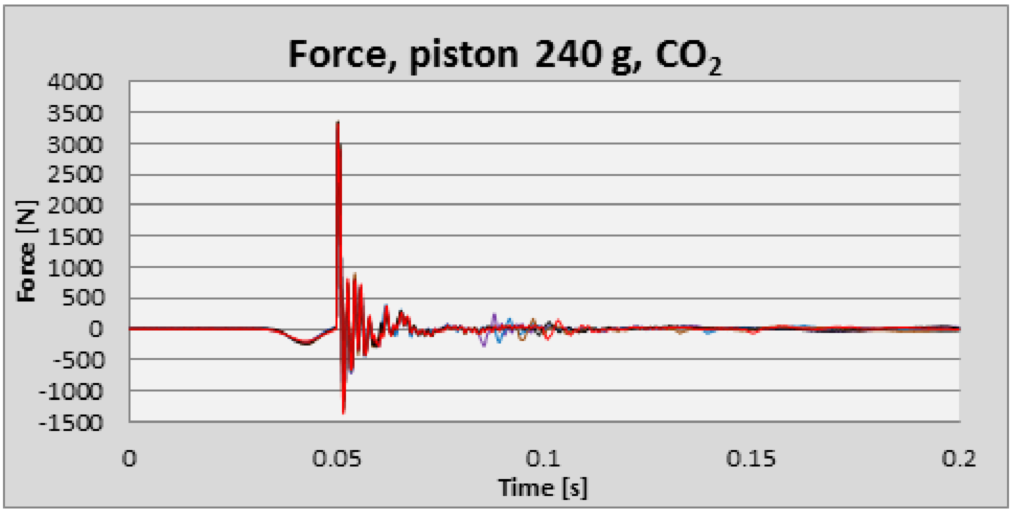

FIG. 5 Force diagram for the 240g piston

The time course is very similar and the measured main force peak is in the range between 4 300 and 5 000 N. It's evident, the piston with the smaller mass generates the smaller force and impulse at the impact in the rear position. The corresponding impulse diagram is shown in the Fig. 6.

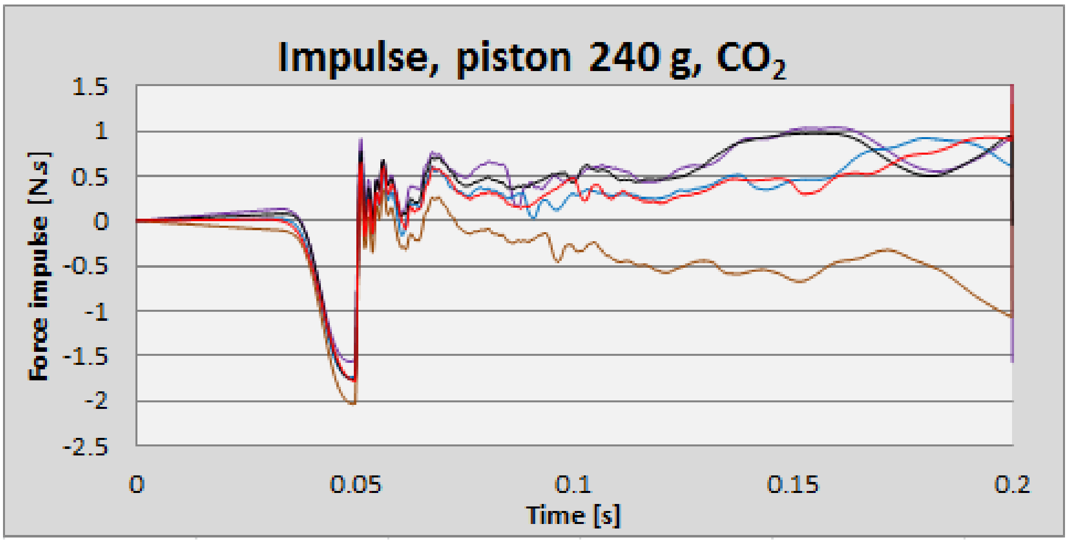

FIG. 6 Impulse diagram for the 240g piston

5. COMPARISON WITH COMMERCIAL RECOIL ADAPTER

The part of the research was also focused on the measurement of the force generated by the commercial recoil training adapters, provided by Eli Military Simulations, see [2]. Measurement of the recoil force and impulse of the automatic rifle vz.58, see[3]. The measurement was performed on the available adapters for the AK47 and AR-15 based rifles. The next table shows the results of the measurement and the comparison with the results of the measurement during the shooting with a live and blank ammunition.

Table 1. Comparison of measured parameters

	Force [N]			Impulse [N.s]		
	Live	Blank	Adapter	Live	Blank	Adapter
AK47	5 700	3 000	2 100	10-11	2.85-3.15	1.42
SA58	4 600	-	-	10-11	-	-
PAR Mk3	1 700-2 000	-	1 700	5.7-7	-	2.6
CO2 impulse generator	-	-	5 100 (4 300)	-	-	1.3 (1.1)

CONCLUSIONS

The presented impulse generator is the part of the the research and development of the device for gun’s recoil simulation. In this phase, the 3D model of the generator was created, subsequently was the generator manufactured. The verification of the calculated parameters was realized by an experimental measurement. The measurement shows that the generated force and impulse are comparable with force and impulse provided by a real firearm during the shooting with the live ammunition, and are higher than a force and impulse provided by an commercially used recoil adapters. In the next steps of the development, the reduction of the mass and eventually the dimensions will be realized.

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REFERENCES

[1] LUKÁČ, Tomáš; HORÁK, Vladimír; DO DUC, Linh; ROZEHNAL, Dalibor. Experimental Setup for Studying Properties of Power Gases. In: *The 17th INTERNATIONAL CONFERENCE AFASES 2015*. Brasov, Rumunsko: Publishing House of "Henri Coanda" Air Force Academy, 2015, p. 429-436. ISSN 2247-3173

[2] DO DUC, Linh; HORÁK, Vladimír; LUKÁČ, Tomáš; VÍTEK, Roman; MAI, Quang Huy. Dynamics of Knock-Open Valve for Gas Guns Powered by Carbon Dioxide. In: *Scientific Research and Education in the Air Force - AFASES 2016*. Brasov: Publishing House of "Henri Coanda" Air Force Academy, 2016, p. 323-330. ISSN 2247-3173

[2] LUKÁČ, Tomáš; DO DUC, Linh; HORÁK, Vladimír; PILCH, Ondrej. EXPERIMENTAL ANALYSIS OF THE RECOIL FORCE OF REAL FIREARM AND ITS RECOIL SIMULATION SYSTEM. In: *Armament and Technics of Land Forces 2016*. Liptovský Mikuláš: Akadémia ozbrojených síl generála M. R. Štefánika, 2016, p. 121-127. ISBN 978-80-8040-537-3

[4] LUKÁČ, Tomáš; VÍTEK, Roman; DO DUC, Linh; HORÁK, Vladimír. Experimental Mechanical Device for Recoil Simulation. In: *Scientific Research and Education in the Air Force - AFASES 2016*. Brasov: Publishing House of "Henri Coanda" Air Force Academy, 2016, p. 337-343. ISSN 2247-3173