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NUMERICAL SIMULATION OF SUBMACHINE GUN OPERATION CYCLE

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***Abstract**: Results of numerical simulations of the submachine gun operation cycle using a simplified model were presented in the paper. The investigations of gun kinematic parameters were conducted by making use of the multi-body analysis (MBA) approach. Boundary conditions for the considered problem were stated using theoretical interior ballistics models. Comparison of obtained results with experimental data confirmed applicability of the utilized methods, which are characterized by a relatively low computational cost.*

***Keywords**: submachine gun simulations, gun dynamics modelling, small arm numerical simulations, experimental gun operation cycle investigation*

Introduction

Numerical simulations of gun operation is one of the most important stage of the armament design process. Results of these analyses provide set of crucial data allowing appriopriate modifications of gun construction, ensuring desired operation parameters and safety for an operator.

Available literature provides many raports on gun operation modelling. In papers [1, 2] authors focused their attention on simulations of gas-operated rifle. Presented model was seriously simplified but ensured relatively reliable results. What is very important, these data were obtained with extremely low computational cost due to application of a lumped-parameters model, which resulted in very short computation time. Authors of [3, 4] applied much more complex approach to model the gas-operated rifle operation. In this case, the multibody analysis (MBA) and the finite element analysis (FEA) provided dynamic and kinematic parameters of under-consideration system. The presented approach ensured direct influence of model geometry on gun operation parameters. During investigations authors applied measured propellant gases pressure course for the boundary conditions, which allowed for more accurate comparison of results with experimental data and model validation.

Due to the lack of similar raports on investigations of the blowback gun system, the aim of this paper, is to present results of 9 mm submachine gun operation cycle modelling and validation of applied approach considered in [5, 6, 7].

Interior ballistics calculations

In this work, the interior ballistics model described in details in [5, 6, 7] was applied. In order, to obtained propellant gas pressure course, which was applied in operation cycle simulations, the following set of fundamental equations was solved:

$$\frac{dl_{proj}}{dt}=v_{proj} \quad , \tag{1}$$

$$\frac{dv_{poc}(t)}{dt}=\frac{s_{barrel}\,p_{p\,g\,proj}(t)-F_{br}-F_{air}-F_{case}}{m_{proj}} \quad , \tag{2}$$

$$\frac{d\psi(t)}{dt}=\Gamma(\psi)\cdot f\left(p_{p\,g}\right) \ , \tag{3}$$

$$f(p)=p_{atm}\,x_p{}^{\alpha}\ ;\ x_p=\frac{p_{pg}}{p_{atm}} \quad , \tag{4}$$

$$\frac{dT_{pg}}{dt}=\frac{m_{pow}\dfrac{d\psi}{dt}\left(q_{pow}-c_{vpg}T_{pg}\right)+\left(c_{vpg}m_{pow}+c_{vair}m_{air}\right)T_{pg}\dfrac{d\xi}{dt}-\dfrac{dW_{sum}}{dt}-\dfrac{dI_{out}}{dt}}{c_{vpg}m_{pow}\left(\psi-\xi\right)+c_{vair}m_{air}\left(1-\xi\right)} \ , \tag{5}$$

$$\frac{dI_{out}}{dt}=\left(c_{ppg}m_{pow}+c_{pair}m_{air}\right)T_{pg}\frac{d\xi}{dt} \ , \tag{6}$$

$$\frac{dW_{br}}{dt}=F_{br}\,v_{proj} \ , \tag{7}$$

$$\frac{dW_{air}}{dt}=F_{air}v_{proj} \ , \tag{8}$$

$$\frac{dW_{kin}}{dt}=\left(I_{proj}\frac{4\pi^2}{\eta^2}+m_{proj}+\frac{m_{pow}}{3}\right)v_{proj}\frac{dv_{proj}}{dt} \ , \tag{9}$$

$$\frac{d\xi(t)}{dt}=\frac{s_{barrel}}{m_{pow}+m_{air}}\left(\frac{2}{\gamma_{pg}+1}\right)^{\frac{1}{\gamma_{pg}-1}}\sqrt{\frac{2\gamma_{pg}}{\gamma_{pg}+1}}\,\frac{p_{pg}}{\sqrt{R_{pg}T_{pg}}} \ , \tag{10}$$

$$p_{pg}=R_{pg}T_{pg}\rho_{pg}\left(1+\beta_{pg}\rho_{pg}\right) \ , \tag{11}$$

where l_{proj} denotes the distance travelled by the projectile, t is the time, v_{proj} is the projectile velocity, s_{barrel} denotes the barrel cross-section area, $p_{\mathrm{pg\ proj}}$ is the pressure acting on the projectile bottom, F_{br} is the barrel resistance force, F_{air} is the resistance of air in front of the projectile, F_{case} is the interaction force between the projectile and the case, m_{proj} is the mass of the projectile, p_{atm} is the atmospheric pressure, γ denotes the specific heat ratio, T_{pg} means the propellant gases temperature, m_{pow} is the propellant charge mass, q_{pow} is the isochoric heat of combustion, c_{vpg} is the specific heat of propellant gases at constant volume, W_{sum} is the total work made by gases, ξ is the relative mass of outflowed gases, m_{air} is the mass of air initially present in the case, c_{vair} is the air specific heat at constant volume, I_{out} is the enthalpy of outflowing gases. Closing relations for above-presented equations were described in [5, 6, 7].

As the result of differential equations solution, the propellant gas pressure course was obtained (Fig. 1). Calculated data are compliant with experimental courses shown in [5, 6].

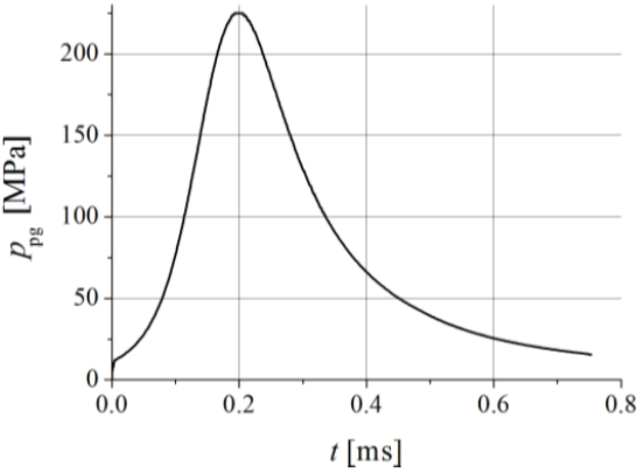


Fig. 1. Propellant gases pressure course as the function of time

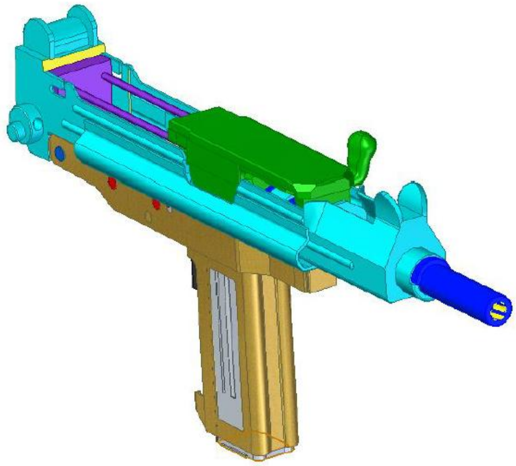
Parts motion simulation model

In order to simulate motion of parts system, the multibody analysis (MBA) approach was applied [8]. This method is based on the assumption of rigidity of all parts (except springs). Solving the equations of motion (transational and rotational) of every part and taking into account closing relations of contact definition between bodies and loading boundary conditions, the kinematic and dynamic parameters of system are obtained. In under-consideration problem, the penalty-based contact formulation between bodies was applied [8]. Additionally, in order to reduce numerical oscillations, the viscous damping terms was added.

In presented considerations, the model shown in Fig. 2 was investigated. The reconstruction of the submachine gun geometry was conducted by making use of 3D scanning [9]. Mass values of system elements were additionally verified by weighting.

Motion of the slide was forced by gas pressure presented in Fig. 1. The pressure force was denoted by F_p. F_{sp1}, F_{sp2}, F_{sp3}, F_{sp4} and F_{sp5} denote force of springs of recoil system, hammer, delay system lever, magazine and delay system weight, respectively.

The spring forces were assumed to be linear functions of deformation and their properties were determined experimentally using material testing machine.



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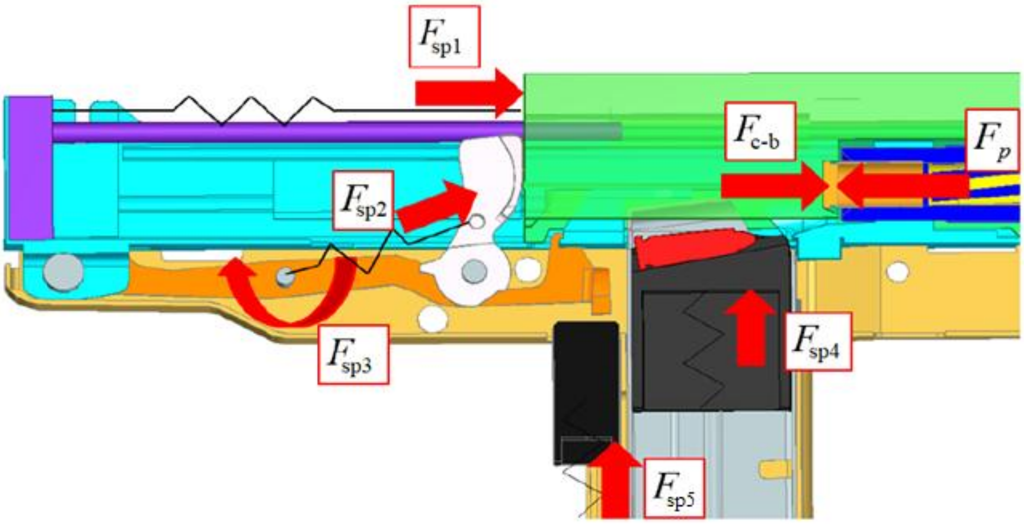

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Fig. 2. The geometry of under-investigation submachine gun model [9]

Experimental stand

Experiments were conducted using the set-up presented in Fig. 3 and consisted of the following elements [10]:

- submachine gun;
- high speed camera Phantom v12;
- ballistic mount;
- precision light screen B-470 for velocity measurement;
- personal computer with appropriate software – TEMA motion.

Fig. 3. Experimental set – up (A – investigated pistol, B – ballistic mount, C – high speed camera, D – precision light screen B-470)

Results

As the results of investigations, experimental and numerical slide velocity courses as the function of time were obtained. For the numerical simulations, two cases were taken into account – first one was the case, in which the loading of next round was considered. The course of the slide velocity was presented in Fig. 4. The loading of the next round is noticable in the stage denoted by VIII.

The second case did not include loading of the next round. For this conditions, due to safety conditions, the experimental measurements were carried out. In order to obtain data concerning the dispersion of experimental results, seven tests were done and the velocity courses were presented in Fig. 5. Results of numerical and experimental studies were shown in Fig. 6. Comparison of these data was made for one representative experimentally obtained course. In this case, these is no visible slide velocity jump in the region of magazine, which is the result of lack of next round on the slide path.

Comparing the results of numerical and experimental data, the acceptable convergence can be observed. It can be concluded, that all of slide motion stages were reproduced in the simulation, which suggests that every crucial part of under-investigation gun was correctly modelled and the boundary conditions were stated appropriately.

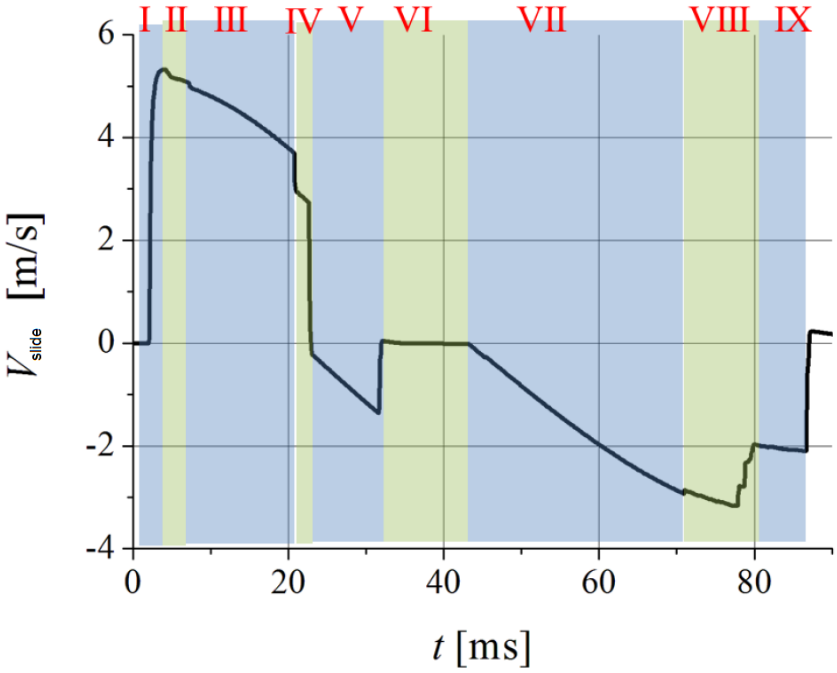

Fig. 4. Theoretically obtained slide velocity course as the function of time for the first case (with loading of next round)

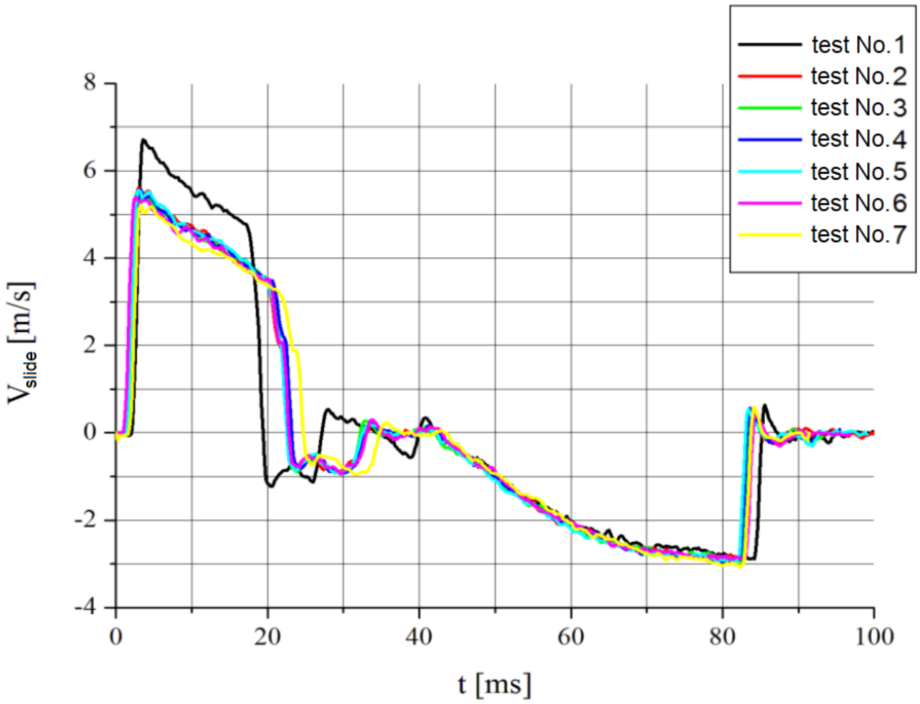

Fig. 5. Experimentally obtained slide velocity courses

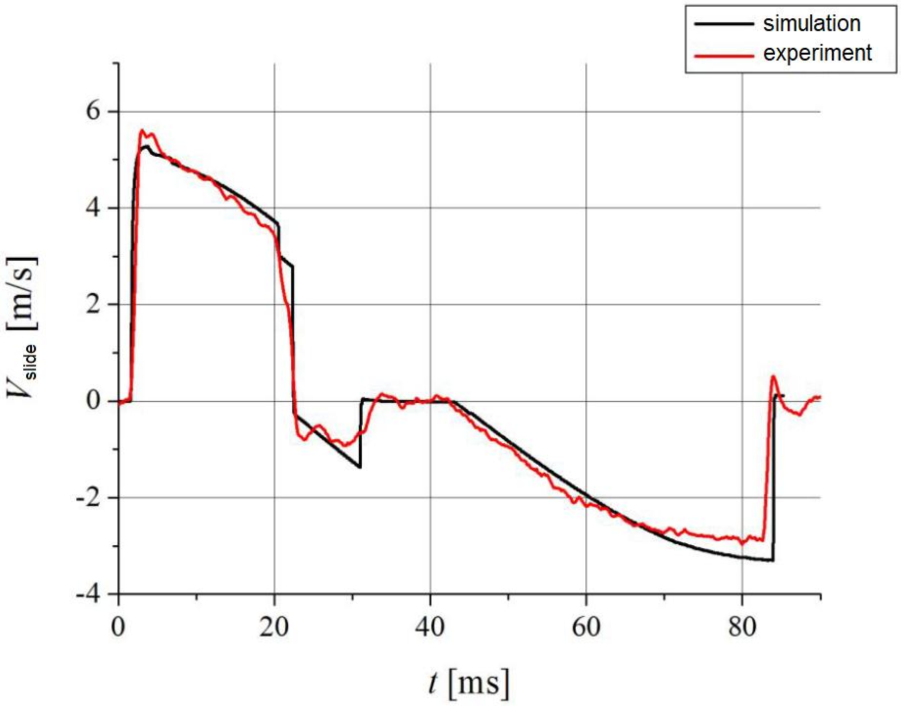

Fig. 6. Comparison of results of simulation with the experimental slide velocity course

Conclusions

Results of presented paper confirmed the possibility of submachine gun operation cycle simulations using multibody analysis method. Considered approach, due to application of lumped-parameters model (in the area of interior ballistics and parts' motion), was efficient from the computational cost point of view and provided acceptable convergence with experimental data. Further works will be focused on improvements of interior ballistics models.

References

1. Leśnik, G., Surma, Z., Torecki, S., & Woźniak, R. (2009). Thermodynamic model of work of gas operated weapon. *Bulletin of Military University of Technology, vol. 58* (3), p. 193-209.
2. Surma, Z., Szmit, Ł., Torecki, S., & Woźniak, R. (2010). Mathematical Model of Gas Operated Weapon Jump. *Problems of Mechatronics Armament Aviation Safety Engineering, vol. 1* (2), p. 51-63.
3. Małachowski, J., Płatek, P., Woźniak, R., & Zahor, M. (2011). Numerical Analysis of Operation Process of Gas Piston System with Slide for the Assault Rifle of Modular Small Arms System Cal. 5,56 mm. *Problems of Mechatronics Armament Aviation Safety Engineering, vol. 2*(4), p. 85-96.
4. Małachowski, J., Damaziak, K., Płatek, P., Sarzyński, M., Kupidura, P., Woźniak, R., & Zahor, M. (2016). Numerical and experimental failure analysis of rifle extractor. *Engineering Failure Analysis, vol. 62,* p. 112-127. DOI:10.1016/j.engfailanal.2016.01.004
5. Fikus, B. (2018). *Development and validation of blowback gun model (in Polish), PhD Thesis*. Warsaw: Military University of Technology.
6. Fikus, B., Surma, Z. & Trębiński, R. (2019). Preliminary Application Correctness Assessment of Physical Burning Law in Interior Ballistics Phenomena Modeling in Small-Caliber Guns. In Saraswat, V., K., Reddy, G., S., Woodley, C., (Eds.), *Proceedings of 31st International Symposium on Ballistics*. USA: Destech Pubns Inc.
7. Fikus, B., Płatek, P., Surma, Z., Sarzyński, M., & Trębiński, R. (2019). Preliminary Numerical and Experimental Investigations of 9 mm Pistol Bullet and Barrel Interaction. In Saraswat, V., K., Reddy, G., S., Woodley, C., (Eds.), *Proceedings of 31st International Symposium on Ballistics*. USA: Destech Pubns Inc.
8. Giesbers, J. (2012). *Contact mechanics in MSC Adams. A technical evaluation of the contact models in multibody dynamics software MSC Adams*. Twente: University of Twente.
9. Fikus, B., Paszkowski, R., & Płatek, P. (2018). Application of 3D Scanning Technology for Evaluation of Virtual Model of Gun Geometry. *Problems of Mechatronics Armament Aviation Safety Engineering, vol. 9*(1), p. 105-114.
10. Fikus, B., Koperski, W., Płatek, P., Surma, Z., & Trębiński, R. (2016). Experimental Investigations of Motion of Slide of Selected Pistol Types. *Problems of Mechatronics Armament Aviation Safety Engineering, vol. 7*(4), p. 23-32.