PROBLEMY MECHATRONIKI
UZBROJENIE, LOTNICTWO, INŻYNIERIA BEZPIECZEŃSTWA

PROBLEMS OF MECHATRONICS
ARMAMENT, AVIATION, SAFETY ENGINEERING

ISSN 2081-5891; E-ISSN 2720-5266 **https://promechjournal.pl/**

Modelling and Testing the Dynamic Properties in a Submachine Gun-Man System

Zbigniew J. DZIOPA[1*] (zdziopa@tu.kielce.pl)
Andrzej LENARCIK[1] (andrzej.lenarcik@gmail.com)
Krzysztof ZDEB[2] (krzysztofzdeb@gmail.com)

[*]Corresponding author
ORCID: https://orcid.org/0000-0002-9135-6306

[1]*Kielce University of Technology*
7 Tysiąclecia Państwa Polskiego Ave., 25-314 Kielce, Poland
[2] *Forensic Laboratory of the Regional Police Headquarters*
109 Mogilska Str., 31-571 Cracow, Poland

Received: July 7, 2022 / Revised: September 5, 2022 / Accepted: September 6, 2022 / Published: September 30, 2023.

2023, 14 (3), 25-40; https://doi.org/10.5604/01.3001.0053.8818

Cite: Chicago Style

Dziopa, J. Zbigniew, Andrzej Lenarcik, and Krzysztof Zdeb. 2023. "Modelling and Testing the Dynamic Properties in a Submachine Gun-Man System". *Probl. Mechatronics. Armament Aviat. Saf. Eng.* 14 (3) : 25-40. https://doi.org/10.5604/01.3001.0053.8818

Abstract. This work was an attempt at an analysis of the interaction between a firearm and a human, exemplified by a cal. 9 mm submachine gun (SMG), PM-98 GLAUBERYT and a trained, professional shooter - a Police special team operator. The results of the analysis made it possible to develop several guidelines aimed at designing the dynamic performance of SMGs to improve their aiming accuracy. In connection with this work, experimental tests were performed at a firing range, where the process of firearm discharge was recorded using a Phantom slow-motion digital camera. What followed was the analysis of the video record using the Tema dedicated computer software. The SMG's dynamic performance was adjusted to reduce the hit scatter. Based on the results of the empirical tests at the firing range, physical and mathematical models of the SMG-operator system were formulated. The SMG-operator system was simulated in the Scilab software, which provided time-based variation trends of the kinematic quantities that characterised the movements of individual modelled objects. The variation trends determined included displacement, velocity and acceleration of the SMG, its bolt assembly, and the human operator as a function of time. The results of the theoretical analysis were compared to the empirical test results from the firing range. It was found that in the virtual modelling space, the SMG model had a performance similar to that of its real counterpart. With the theoretical model verified, several performance parameters of the SMG were modified and guidelines were developed that could improve the aim.
Keywords: mechanical engineering, submachine gun, shooter, empirical testing, theoretical analysis

1. INTRODUCTION

The test object was an SMG-operator system, as shown in Photo 1. The operator was a trained Police anti-terrorist operative shooting with a PM-98 GLAUBERYT, a Polish cal. 9 mm submachine gun (manufactured by Fabryka Broni "Łucznik"- Radom Sp. z o.o. in Poland), loaded with 9 × 19 mm Luger (Parabellum) FMJ (*Full Metal Jacket*) cartridges (manufactured in 2017 by Sellier & Bellot, Czech Republic).

The primary objective of this work was to develop guidelines for the design of SMG dynamic performance to reduce the projectile scatter. The dynamic performance of the SMG-operator system is construed as a set of its defining physical parameters that affect the form of a modal matrix and the response of the SMG-operator system to external inputs. To achieve the objective of this work:

- video images of the process of discharging rounds from the SMG by the operator, recorded using a Phantom v.9.1 slow-motion digital camera, were analysed in the Tema [1] dedicated software suite, which enabled:
  - plotting the trends of displacement, velocity and acceleration vs. time which characterised the motion of individual objects in the SMG-operator system;
  - evaluation of the impact of the SMG bolt reversing movement, clearing of the muzzle by the projectile, ejection of the spent casing out of the SMG, the bolt reaching the dead reverse position, SMG bolt forward movement,

and the bolt reaching the dead forward position on the response of the SMG-operator system [2], [3];
- determination of the initial performance characteristics, including the position, velocity and acceleration of flight of each discharged projectile;
- determination of the projectile scatter [4];

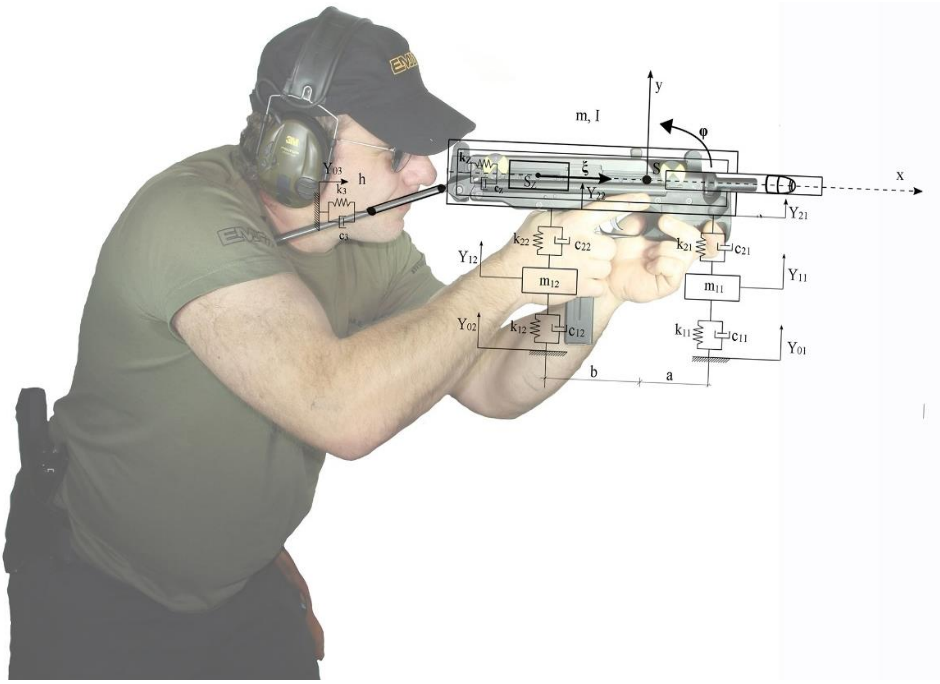

Photo 1. Police anti-terrorist operative discharging rounds from the PM-98 GLAUBERYT SMG (composite of the physical model adopted for the SMG-operator system)

- physical and mathematical models were formulated for the movement in the SMG-operator system, which should behave in the virtual modelling space like the real-life object [5]. For this task:
  - three models of the SMG-operator system were developed;
  - the basic dynamic performance characteristics of the SMG-operator system were determined;
  - a reverse method was applied to determine the trend of time-based variations of the loads applied to the SMG-operator system;
  - the trends of the kinematic quantities that characterised the movements of individual modelled objects in the SMG-operator system were compared to the real-life SMG-operator system;

- a theoretical model was developed for the projectile flight and the simulation results were compared to the results from the experimental tests [6];
- guidelines were developed for the design of SMG dynamic performance to reduce the projectile scatter.

Given the limited volume of publications, this work only includes a selection of the produced results.

2. EXPERIMENTAL TESTS

The experimental tests were performed at an indoor, certified firing range of the company EMJOT of Chorzów, Poland. It was assumed that the meteorological and ballistic conditions at the indoor location were stable and would not introduce random interference. One hundred rounds were discharged from the SMG in semi-automatic fire to a target located 25 m from the muzzle. Photo 2 shows the operator during the experimental test, with the SMG and the test stand equipment.

The video images recorded during the tests using a Phantom v.9.1 slow-motion digital camera were analysed in the Tema dedicated software suite. This provided reliable variation trends of kinematic quantities as a function of time, where the trends characterised the motion of the SMG. A representative example of angular displacement during the pitching of the SMG, as well as the angular velocity and angular acceleration of the SMG, are shown in Figs. 1, 2, and 3, respectively. The charts refer to a single shot discharged from the PM-98 GLAUBERYT.

The trend vs. time charts of angular velocity and acceleration produced in Tema were found to be imprecise and a different method of plotting the charts was used. The method involved the calculation of a differential coefficient based on a larger number of data points. The first and the second differential coefficients were determined using, respectively, a linear regression straight line $x(t) = at + b$ and a regression parabola $x(\mathrm{t}) = at^2 + bt + c$, as well as the least squares method.

For a single discharge (shot) (with the SMG fed from a box magazine with two cartridges), two consecutive characteristic moments of time were isolated (Figs. 1, 2, and 3):

	t = 0.0000 [s]	– slow, smooth pressure is applied to the trigger;
(0)	t = 0.0320 [s]	– the trigger is fully depressed and the cartridge is discharged;
(1)	t = 0.0327 [s]	– the projectile clears the muzzle and the bolt blowback action begins;
(2)	t = 0.0453 [s]	– the spent case is ejected from the ejection port;
(3)	t = 0.0507 [s]	– the bolt meets the rear stop and is momentarily stopped;
(4)	t = 0.0520 [s]	– the bolt begins to move forward;

(5) t = 0.0573 [s] – the bolt is stopped by the delayer, which is its function;
(6) t = 0.0733 [s] – the delayer stops and the bolt begins to move forward;
(7) t = 0.1167 [s] – the bolt is stopped by the barrel head and remains stationary.

Photo 2. (from top to bottom): Operator in the firing stance, shown with the SMG and the test stand equipment

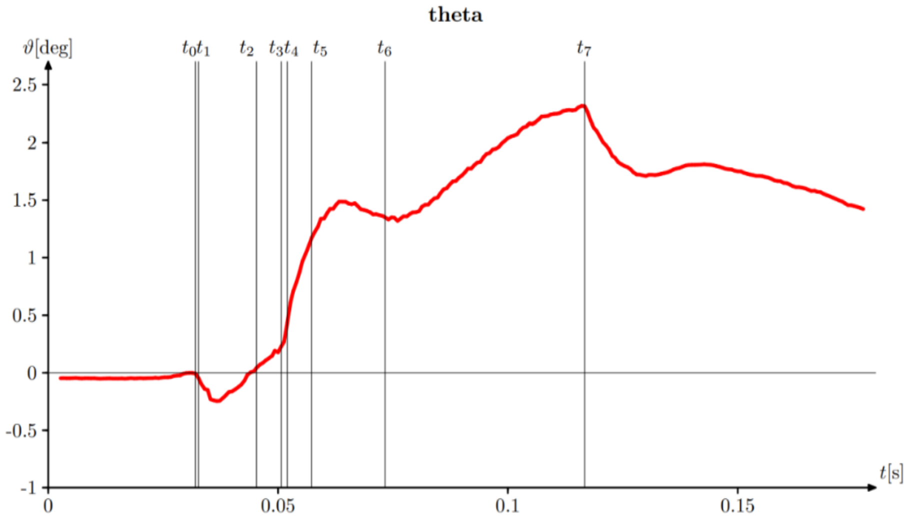

Fig. 1. Trend chart of the SMG angular displacement during pitching,
with t_0, t_1,…, t_7 being the characteristic moments during a single shot

Fig. 2. Trend chart of the SMG angular velocity during pitching,
with t_0, t_1,…, t_7 being the characteristic moments during a single shot

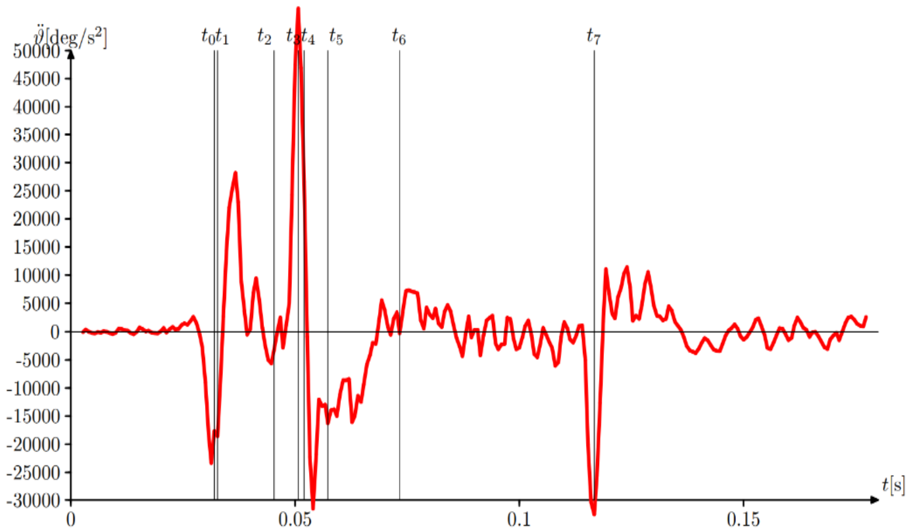

Fig. 3. Trend chart of the SMG angular acceleration during pitching, with t_0, t_1,…, t_7 being the characteristic moments during a single shot

3. THEORETICAL ANALYSIS

3.1. SMG-operator system model #1

At the outset of the theoretical analysis, a physical and mathematical model numbered 1 was formulated, which could be used to estimate the dynamic performance of the SMG; see Fig. 4 and Eq. (1). The vibration natural frequencies and mode shape of the SMG-operator system were determined.

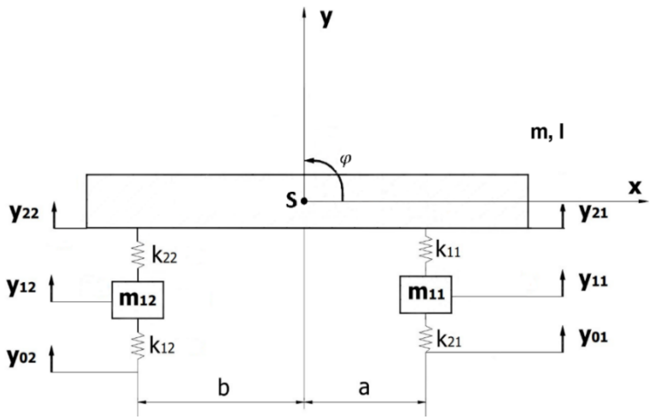

Fig. 4. SMG-operator system model #1

The summation equations of the SMG-operator system had the following form:

$$
\begin{aligned}
& m\ddot{y} + (k_{21} + k_{22})y + (k_{21}a - k_{22}b)\varphi - k_{21}y_{11} - k_{22}y_{12} = 0 \\
& I\ddot{\varphi} + (k_{21}a - k_{22}b)y + (k_{21}a^2 + k_{22}b^2)\varphi - k_{21}ay_{11} + k_{22}by_{12} = 0 \\
& m_{11}\ddot{y}_{11} - k_{21}y - k_{21}a\varphi + (k_{11} + k_{21})y_{11} = 0 \\
& m_{12}\ddot{y}_{12} + k_{22}y + k_{22}b\varphi + (k_{12} + k_{22})y_{12} = 0
\end{aligned}
\tag{1}
$$

The first mode of eigen vibrations is

$$\omega_{01} = 62.52\ [\frac{rad}{s}] = 9.95\ [Hz]$$

$$\mu_{11} = 1;\ \mu_{21} = -13.155;\ \mu_{31} = -0.578;\ \mu_{41} = 1.189$$

The second mode of eigen vibrations is

$$\omega_{02} = 89.57\ [\frac{rad}{s}] = 14.26\ [Hz]$$

$$\mu_{12} = 1;\ \mu_{22} = 6.156;\ \mu_{32} = 1.684;\ \mu_{42} = 0.863$$

The third mode of eigen vibrations is

$$\omega_{03} = 374.11\ [\frac{rad}{s}] = 59.54\ [Hz]$$

$$\mu_{13} = 1;\ \mu_{23} = -34.242;\ \mu_{33} = 3.299;\ \mu_{43} = -3.598$$

The fourth mode of eigen vibrations is

$$\omega_{04} = 543,25\ [\frac{rad}{s}] = 86,46[Hz]$$

$$\mu_{14} = 1;\ \mu_{24} = 2.8900;\ \mu_{34} = -0.400;\ \mu_{44} = -0.426$$

3.2. SMG-operator system model #2

Next, a physical and mathematical model numbered ‘2’ was developed and used to determine the functions representative of the loads imposed on the SMG as a function of time. Figure 5 shows the physical model analysed. The physical model was used to determine the mathematical model, described with Eq. (2) and (3), using an energy method. Figures 6, 7 and 8 show the functions representative of the loads imposed on the SMG as a function of time.

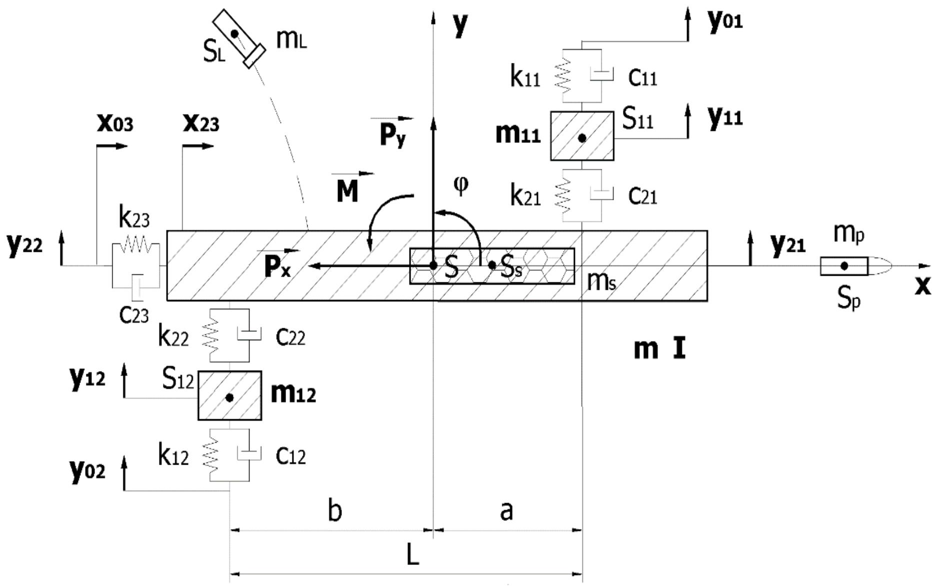

Fig. 5. SMG-operator system model #2

The equations of motion for the SMG-operator system had the following form:

$$m\ddot{x} + c_3\dot{x} + \mathrm{k}_3 x = \mathrm{c}_3\dot{x}_{03} + k_3 x_{03} - P_{\mathrm{x}}$$

$$m\ddot{y} - c_{21}\dot{\lambda}_{21} - k_{21}\lambda_{21} + c_{22}\dot{\lambda}_{22} + k_{22}\lambda_{22} = P_{\mathrm{y}} - mg$$

$$I\ddot{\varphi} - \mathrm{c}_{21}a\dot{\lambda}_{21} - k_{21}a\lambda_{21} - c_{22}b\dot{\lambda}_{22} - k_{22}b\lambda_{22} = M \qquad (2)$$

$$m_{11}\ddot{y}_{11} + c_{11}\dot{y}_{11} + k_{11}y_{11} + c_{21}\dot{\lambda}_{21} + k_{21}\lambda_{21} = c_{11}\dot{y}_{01} + k_{11}y_{01} - m_{11}\mathrm{g}$$

$$m_{12}\ddot{y}_{12} + c_{12}\dot{y}_{12} + k_{12}y_{12} + c_{22}\dot{\lambda}_{22} + k_{22}\lambda_{22} = c_{12}\dot{y}_{02} + k_{12}y_{02} - m_{12}g$$

where:

$$\lambda_{21} = y_{11} + y_{11\mathrm{st}} - y - y_{\mathrm{st}} - a(\varphi + \varphi_{\mathrm{st}})$$

$$\lambda_{22} = y + y_{\mathrm{st}} - b(\varphi + \varphi_{\mathrm{st}}) - y_{12} - y_{12\mathrm{st}}$$

$$\dot{\lambda}_{21} = \dot{y}_{11} - \dot{y} - a\dot{\varphi}$$

$$\dot{\lambda}_{22} = \dot{y} - b\dot{\varphi} - \dot{y}_{12}$$

The equations of balance for the SMG-operator system had the following form:

$$
\begin{aligned}
& k_{23} x_{\mathrm{st}} = 0 \\
& -k_{21}(y_{11\mathrm{st}} - y_{\mathrm{st}} - a\varphi_{\mathrm{st}}) + k_{22}(y_{\mathrm{st}} - b\varphi_{\mathrm{st}} - y_{12\mathrm{st}}) + mg = 0 \\
& -k_{21}a(y_{11\mathrm{st}} - y_{\mathrm{st}} - a\varphi_{\mathrm{st}}) - k_{22}b(y_{\mathrm{st}} - b\varphi_{\mathrm{st}} - y_{12\mathrm{st}}) = 0 \\
& k_{11}y_{11\mathrm{st}} + k_{21}(y_{11\mathrm{st}} - y_{\mathrm{st}} - a\varphi_{\mathrm{st}}) + m_{11}g = 0 \\
& k_{12}y_{12\mathrm{st}} - k_{22}(y_{\mathrm{st}} - b\varphi_{\mathrm{st}} - y_{12\mathrm{st}}) + m_{12}g = 0
\end{aligned} \tag{3}
$$

The force equation, P_x, had the following form:

$$P_x = -(m\ddot{x} + c_3\dot{x} + k_3 x)$$

The functions of $x, \dot{x}, \ddot{x}$ were produced from the experimental tests by recording the process of firing the SMG using a slow-motion digital camera and processing the results of the acquired video images. The chart of force, P_x vs. time is shown in Fig. 6.

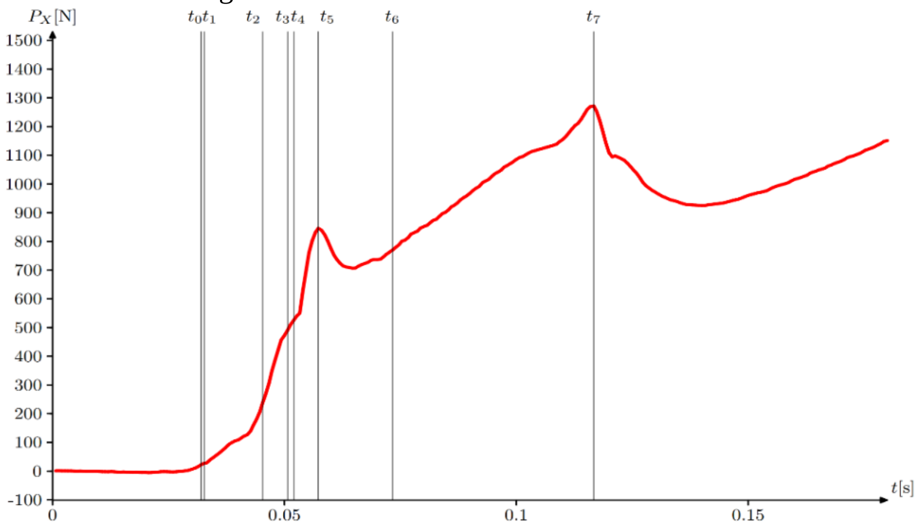

Fig. 6. Chart of force, P_x, vs. time

The force equation, P_y, had the following form:

$$P_y = m\ddot{y} - \mathrm{c}_{21}\dot{\lambda}_{21} - \mathrm{k}_{21}\lambda_{21} + \mathrm{c}_{22}\dot{\lambda}_{22} + \mathrm{k}_{22}\lambda_{22} + mg.$$

The functions of $y, \dot{y}, \ddot{y}$ were produced from the experimental tests by recording the process of firing the SMG using a slow-motion digital camera and processing the results of the acquired video images. The chart of force, P_y, vs. time is shown in Fig. 7.

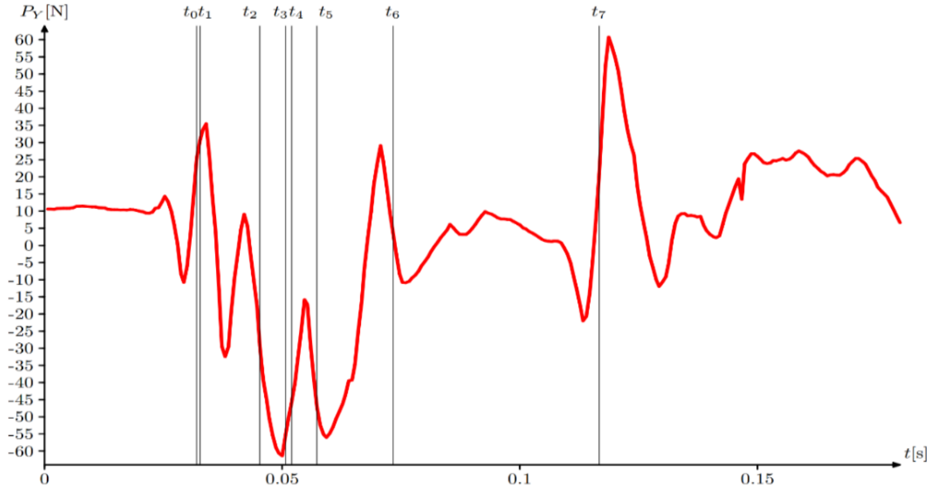

Fig. 7. Chart of force, P_y, vs. time

The moment equation, M, had the following form:

$$M = I\ddot{\varphi} - c_{21}a\dot{\lambda}_{21} - k_{21}a\lambda_{21} - c_{22}b\dot{\lambda}_{22} - k_{22}b\lambda_{22}$$

The functions of $\varphi, \dot{\varphi}, \ddot{\varphi}$ were produced from the experimental tests by recording the process of firing the SMG using a slow-motion digital camera and processing the results of the acquired video images.

The chart of moment, M, vs. time is shown in Fig. 8.

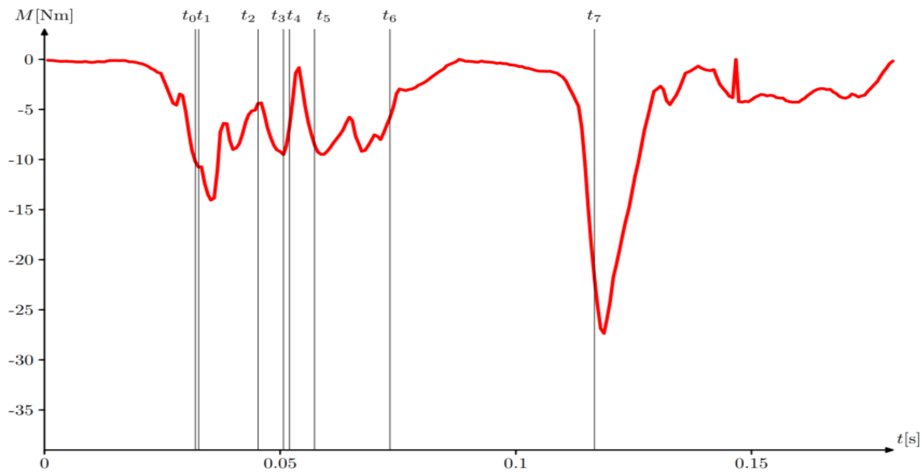

Fig. 8. Chart of moment, M vs. time

3.3. SMG-operator system model #3

Ultimately, to determine the kinematic quantities characterising the motion of the SMG, a physical and mathematical model numbered ‘3’ was formulated with six degrees of freedom, see Fig. 9 and Eq. (4) and (5). The produced results were compared to the results from the experimental tests (Fig. 10). Having achieved satisfactory accuracy, the acquired SMG-characteristic performance was verified (Fig. 11) [7].

The SMG was modelled as a rigid body with three degrees of freedom. Inside the upper receiver, the bolt was moving, modelled as a rigid body with one degree of freedom. It is a very complex problem to formulate a reliable firearm-operator model. To model the interactions between the operator and the SMG, the available, mature, anthropodynamic model with one degree of freedom developed by Vasiliev was used.

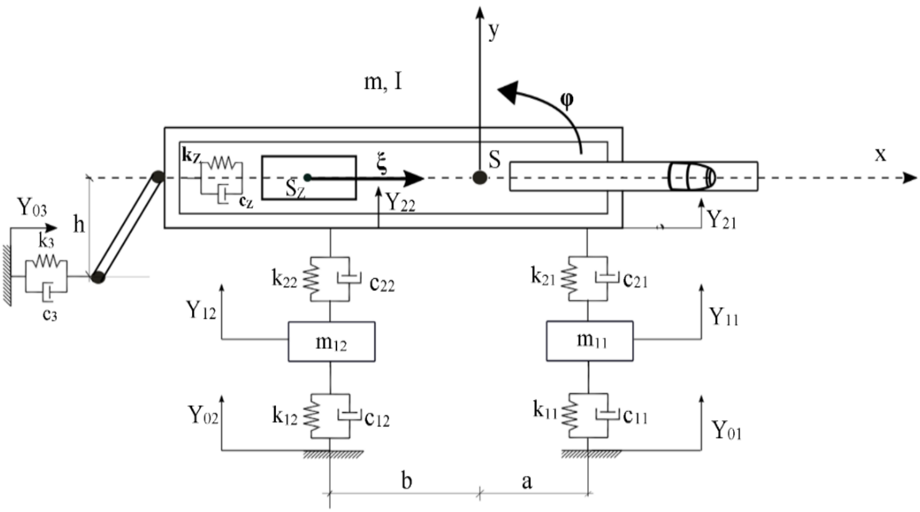

Fig. 9. SMG-operator system model #3

The equations of motion for the SMG-operator system had the following form:

$$(m+m_Z)\ddot{x} - m_Z\xi\ddot{\varphi}sin\varphi + m_Z\ddot{\xi}cos\varphi - 2m_Z\dot{\xi}\dot{\varphi}sin\varphi - m_Z\xi\dot{\varphi}^2cos\varphi$$
$$+c_{23}(\dot{x}+h\dot{\varphi}) + k_{23}(x+x_{\mathrm{st}}) + k_{23}h(\varphi+\varphi_{\mathrm{st}}) = c_{23}\dot{x}_{03} + k_{23}x_{03}$$

$$(m+m_Z)\ddot{y} + m_Z\xi\ddot{\varphi}cos\varphi + m_Z\ddot{\xi}sin\varphi + 2m_Z\dot{\xi}\dot{\varphi}cos\varphi - m_Z\xi\dot{\varphi}^2sin\varphi \quad (4)$$
$$+c_{21}(\dot{y}+a\dot{\varphi}-\dot{y}_{11}) + c_{22}(\dot{y}-b\dot{\varphi}-\dot{y}_{12}) + (k_{21}+k_{22})(y+y_{\mathrm{st}})$$
$$+(k_{21}a-k_{22}b)(\varphi+\varphi_{\mathrm{st}}) - k_{21}(y_{11}-y_{11\mathrm{st}}) - k_{22}(y_{12}+y_{12\mathrm{st}})$$
$$+(m+m_Z)g = 0$$

$$(I + I_Z + m_Z\xi^2)\ddot{\varphi} - m_Z\xi\ddot{x}sin\varphi + m_Z\xi\ddot{y}cos\varphi + 2m_Z\xi\dot{\xi}\dot{\varphi}$$
$$+c_{21}a(\dot{y} + a\dot{\varphi} - \dot{y}_{11}) - c_{22}b(\dot{y} - b\dot{\varphi} - \dot{y}_{12})$$
$$+c_{23}h\big(\dot{x} + h\dot{\varphi}\big)+k_{23}h(x + x_{st}) + \big(k_{21}a - k_{22}b\big)(y + y_{st})$$
$$+(k_{21}a^2 + k_{22}b^2 + k_{23}h^2)(\varphi + \varphi_{st}) - k_{21}a(y_{11} + y_{11st})$$
$$+k_{22}b(y_{12} + y_{12st}) + m_Z g\xi cos\varphi = c_{23}h\dot{x}_{03} + k_{23}hx_{03}$$

$$m_{11}\ddot{y}_{11} + c_{11}\dot{y}_{11} - c_{21}(\dot{y} + a\dot{\varphi} - \dot{y}_{11}) - k_{21}(y + y_{st}) - k_{21}a(\varphi + \varphi_{st}) \quad (4)$$
$$+(k_{11} + k_{21})(y_{11} + y_{st}) + m_{11}g = c_{11}\dot{y}_{01} + k_{11}y_{01}$$

$$m_{12}\ddot{y}_{12} + c_{12}\dot{y}_{12} - c_{22}(\dot{y} - b\dot{\varphi} - \dot{y}_{12}) - k_{22}(y + y_{st}) + k_{22}b(\varphi + \varphi_{st})$$
$$+(k_{21} + k_{22})(y_{12} + y_{12st}) + m_{12}g = c_{12}\dot{y}_{02} + k_{12}y_{02}$$

$$m_Z\ddot{\xi} + m_Z\ddot{x}cos\varphi + m_Z\ddot{y}sin\varphi + m_Z\xi\dot{\varphi}^2 + c_Z\dot{\xi} + k_Z(\xi + \xi_0) + m_Z g sin\varphi$$
$$= -P$$

The equations of balance for the simulated SMG-operator system had the following form:

$$k_{23}x_{st} + k_{23}h\varphi_{st} = 0$$

$$(k_{21} + k_{22})y_{st} + (k_{21}a - k_{22}b)\varphi_{st} - k_{21}y_{11st} - k_{22}y_{12st}$$
$$= -(m + m_Z)g$$

$$k_{23}hx_{st} + (k_{21}a - k_{22}b)y_{st} + (k_{21}a^2 + k_{22}b^2 + k_{23}h^2)\varphi_{st} - k_{21}ay_{11st} \quad (5)$$
$$+k_{22}by_{12st} = 0$$

$$-k_{21}y_{st} - k_{21}a\varphi_{st} + (k_{11} + k_{21})y_{11st} = -m_{11}g$$

$$-k_{22}y_{st} + k_{22}b\varphi_{st} + (k_{12} + k_{22})y_{12st} = -m_{12}g$$

The chart in Fig. 10 shows the function of the SMG's angle of pitch in the domain of time, as recorded during the experimental tests and produced from a numerical simulation of motion of the developed theoretical model.

When investigating the produced functions, it was assumed that the SMG moving through the virtual space behaved similar to the actual SMG. Based on this, the effect of modifying the SMG-operator system parameters on improving the aim was studied [8-9]. The chart in Fig. 11 shows the function of the SMG's angle of pitch vs. time, produced from the numerical simulation of motion of the developed theoretical model for the initial and the preferably modified parameters of the SMG. The preferably modified parameters, which improved the behaviour of the SMG during firing, are discussed in the Conclusion section.

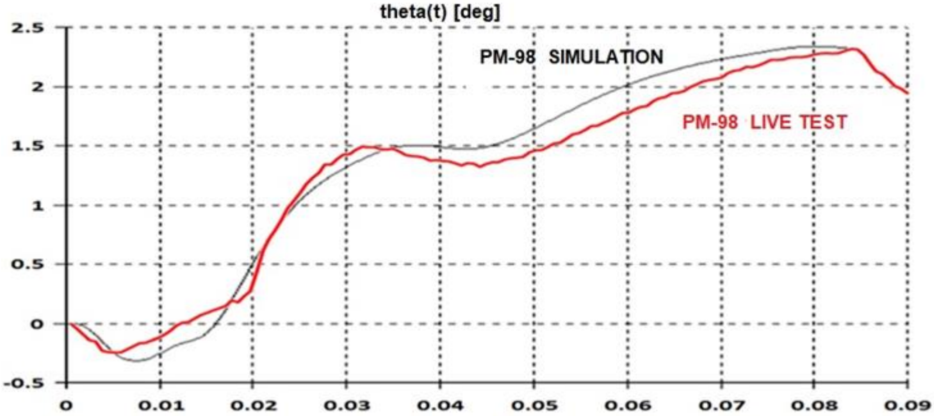

Fig.10. Graph of the function of the angle of inclination of the weapon in the time domain obtained from experimental research and numerical simulation

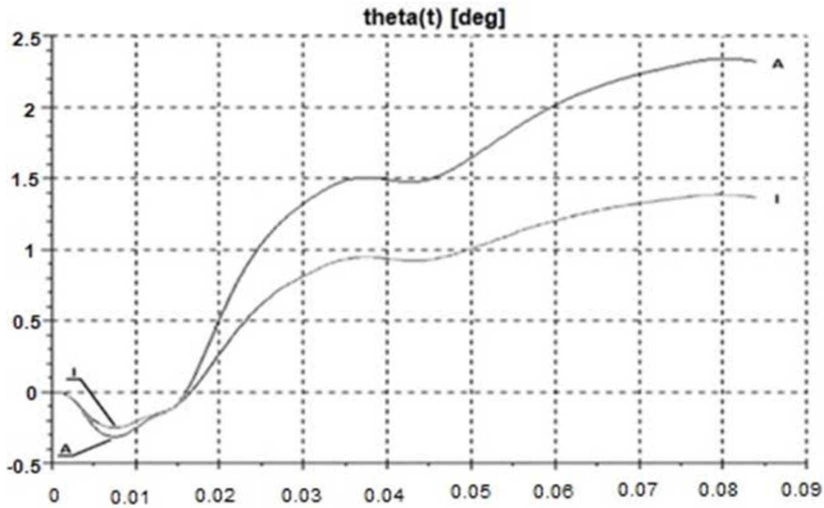

Fig. 11. Chart of the SMG angle of pitch vs. time,
produced from the numerical simulation for the initial parameters (see curve A)
and the preferably modified parameters (see curve I)

4. CONCLUSION

The testing and analysis of the dynamic phenomena occurring in a firearm-operator system are very complex, time-consuming, and interdisciplinary projects. This work was an attempt at an analysis of the interaction between a firearm and a human, exemplified by a PM-98 GLAUBERYT SMG and a trained shooter from a Police special team.

The results of the analysis made it possible to develop several guidelines aimed at designing the dynamic performance of SMGs to improve their aiming accuracy. The theoretical and empirical analysis made it possible to determine changes in the design and physical parameters of the SMG, which included:

- addition of a stock aligned in parallel to the barrel centreline;
- reduction of the bolt assembly weight to 37%;
- reduction of the stiffness of the bolt return springs to 29% [12];
- reduction of the distance from the centre of gravity to the foregrip to 28%.

FUNDING

The authors received no financial support for the research, authorship, and/or publication of this article.

REFERENCES

[1] Dziopa, Zbigniew, and Krzysztof Zdeb. 2017. "Empirical research of human-weapon system". *Technical Transactions* 10 (114) : 131-139.

[2] Kijewski, Jacek, and Łukasz Szmit. 2014. „Theoretical and Experimental Studies at the Weapon's Jump of the Automatic Small Arms" (in Polish). *Probl. Mechatronics. Armament Aviat. Saf. Eng.* 5 (4) : 83-100.

[3] Kijewski, Jacek, and Łukasz Szmit. 2013. „Theoretical and Experimental Studies at the Recoil of the Automatic Firearms" (in Polish). *Probl. Mechatronics. Armament Aviat. Saf. Eng.* 4 (3) : 49-66.

[4] Dziopa, Zbigniew, and Krzysztof Zdeb. 2019. „Analysis of the scatter of bullets fired from Glauberyt submachine gun" *Probl. Mechatronics. Armament Aviat. Saf. Eng.* 10 (1) : 121-134.

[5] Dziopa, Zbigniew, Krzysztof Zdeb. 2016. „Model teoretyczny układu człowiek-broń". *Zeszyty Naukowe Akademii Marynarki Wojennej*. LVII (2) : 53-64.

[6] Dziopa, Zbigniew, and Krzysztof Zdeb. 2017. "Effect of the Man-Weapon Kinematic System on the Trajectory of a Projectile Fired from a Machine Pistol". *Probl. Mechatronics. Armament Aviat. Saf. Eng.* 8 (1) (27) : 101-114.

[7] Fikus, Bartosz. 2018. *Opracowanie i walidacja modelu broni działającej na zasadzie odrzutu zamka swobodnego*. Rozprawa doktorska. Warszawa: Wojskowa Akademia Techniczna.

[8] Ejsmont, A. Jerzy. 2012. *Celność broni strzeleckiej. Praktyczny poradnik*. Warszawa: Wydawnictwa Komunikacji i Łączności.

[9] Taraszewski, Michał. 2018. *Analiza wpływu interakcji broń-strzelec na celność broni*. Rozprawa doktorska. Warszawa: Politechnika Warszawska.

[10] Ewertowski, Janusz., and Robert Piekarski. 2016. "The impact of selected sorts of rifles on shooter – comparative analysis" (in Polish). *Problemy Techniki Uzbrojenia* 138 (2) : 73-86.
[11] Ewertowski, Janusz. 2007. „Analiza siły oddziaływania broni ramiennej na strzelca w czasie strzału". *Biuletyn WAT* .LVI (1) : 207-221.
[12] Kijewski, Jacek, and Grzegorz Leśnik. 2014. „Theoretical and Experimental Tests of Influence of Recoil Springs Stiffness on Slide Velocity of Gas-Operated Weapon" (in Polish). *Probl. Mechatronics. Armament Aviat. Saf. Eng.* 5 (3) : 107-118.

Modelowanie i badanie dynamicznych właściwości układu strzelec-pistolet maszynowy

Zbigniew J. DZIOPA[1], Andrzej LENARCIK[1], Krzysztof ZDEB[2]

[1]*Politechnika Świętokrzyska*
Aleja Tysiąclecia Państwa Polskiego 7, 25-314 Kielce
[2] *Laboratorium Kryminalistyczne Komendy Wojewódzkiej Policji w Krakowie*
ul. Mogilska 109, 31-571 Kraków

Streszczenie. W pracy podjęto próbę analizy wzajemnego oddziaływania broni i człowieka na przykładzie 9 mm pistoletu maszynowego PM-98 GLAUBERYT i wyszkolonego, zawodowego strzelca, którym był funkcjonariusz jednostki specjalnej policji. Otrzymane wyniki pozwoliły na opracowanie kilku wytycznych zmierzających do takiego kształtowania charakterystyki dynamicznej pistoletów maszynowych, aby zwiększyć ich celność. W związku z tym przeprowadzono badania eksperymentalne na strzelnicy, rejestrując proces strzelania szybką kamerą cyfrową Phantom. Następnie wykonano analizę zarejestrowanych obrazów, wykorzystując specjalistyczne oprogramowanie Tema. W celu zmniejszenia rozrzutu broni dokonano korekty jej charakterystyki dynamicznej. Na podstawie wyników badań empirycznych sformułowano modele fizyczne i matematyczne układu strzelec-pistolet maszynowy oraz przeprowadzono badania symulacyjne układu w programie Scilab, otrzymując przebiegi zmienności w czasie wielkości kinematyczne charakteryzujące ruch poszczególnych obiektów modelu. Wyznaczone przebiegi zmienności obejmują przemieszczenia, prędkości i przyspieszenia broni, zamka i człowieka w funkcji czasu. Uzyskane z analizy teoretycznej wyniki porównano z wynikami otrzymanymi z badań empirycznych. Stwierdzono, że w warunkach przestrzeni wirtualnej broń zachowuje się podobnie jak obiekt rzeczywisty. Mając zweryfikowany model teoretyczny dokonano zmiany niektórych parametrów broni i uzyskano wytyczne umożliwiające poprawę jej celności.
Słowa kluczowe: inżynieria mechaniczna, pistolet maszynowy, strzelec, badania empiryczne, analiza teoretyczna.