# PRELIMINARY THEOTRETICAL AND EXPERIMENTAL STUDIES AT THE RECOIL AND WEAPON'S JUMP OF THE AUTOMATIC FIREARMS

Łukasz SZMIT [1] – Zbigniew LECIEJEWSKI [1]* – Jacek KIJEWSKI [1]

[1]*Military University of Technolog, Kaliskiego 2, 01 925, Warsaw, Poland*
*Corresponding author: lszmit@wat.edu.pl

Received 16.10.2013; accepted 17.12.2013

**Abstract**
Paper presents results of the preliminary studies at the recoil and weapon's jump of the automatic firearms. Studies include theoretical and experimental examination of that phenomenon. Theoretical part of the studies is based on the recoil and weapon's jump simulations of the chosen models of automatic firearms (MSBS-5,56). Experimental part of the studies includes shooting tests on the test stand – designed and constructed specially for this purpose. This allowed verification of the simulation results. Gained data proved also that both the recoil and weapon jump are strongly affected by the moving parts of the automatic weapon. Further works will focus on comparing different design schemes in order to find an optimal design with the lowest recoil and weapon jump.

**Keywords:** ballistics, weapon design, firearms tests, mechanics, firearm, rifle.

## 1 Introduction

Since the 2007 Military University of Technology from Warsaw in cooperation with the "Archer" – Radom Arms Factory LLC has been working at the 5,56 mm Modular Weapon System (MSBS-5,56) which may become future armament of the Polish Armed Forces. System consists of several rifles and carbines built both in the classical layout and as a bull-pup. One of the tasks of this project were versatile tests of the prototypes. A need of optimizing rifle's recoil and weapon's jump characteristics appeared during that work. However analysis showed that the ballistic pendulum – the equipment currently used to examine the recoil – doesn't meet the requirements, mainly because it gives only a total value of the recoil velocity with no information about the influence of the moving parts inside the weapon on the recoil. It is also impossible to measure the weapon's jump on the ballistic pendulum. Common used mathematical model also appeared to be inappropriate, they are describing the recoil of a single shoot firearm. All of that gave the impulse to start studies at the automatic weapon reaction for the shoot.

## 2 Early stage theoretical studies

Theoretical studies started with the designing physical and mathematical models of the automatic weapon reaction to the shoot. Reaction was divided into three components: recoil [3], weapon's jump [4], and weapon's turn [1]. Then there were created physical (Fig. 1 to 3) and mathematical models of each component.

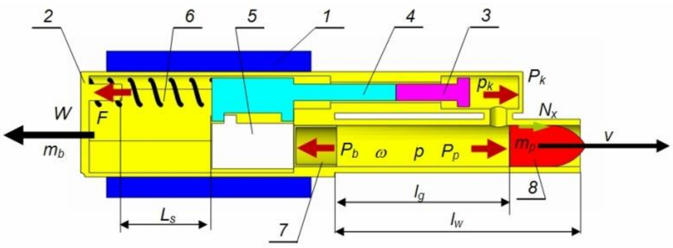


***Fig. 1*** *Physical model of the recoil: 1 – guides, 2 – the weapon, 3 – gas piston, 4 – slide, 5 – bolt, 6 – recoil spring, 7 – case, 8 – bullet, F – recoil spring force, $l_g$ – distance from the chamber to the gas port, $L_s$ – slide position, $l_w$ – rifling bore length, $m_b$ – recoiled mass, $m_p$ – bullet mass, $N_x$ – force on the groves, p – pressure in the barrel, $P_b$ – force at the case bottom, $p_k$ – pressure in the gas chamber, $P_k$ – force at the front wall of the gas chamber, $P_p$ – force at the bullet bottom, v – bullet velocity, W – recoil velocity.*

Models are describing the cycle of operation of gas operated weapon with the short stroke piston because this is one of the most popular principal of operation among modern rifles and carbines. It is also the principal of operation used in the MSBS-5,56 weapon system. It is also the most complicated example of gas operated weapon, and the models can be easily reduced to the long stroke piston case.

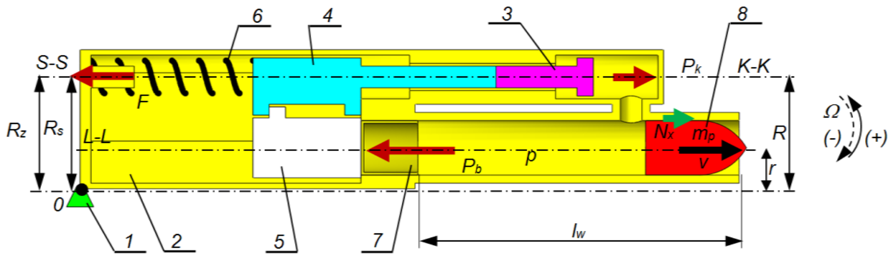


***Fig. 2*** *Physical model of the weapon's jump: 1 – support, 2 – the weapon, 3 – gas piston, 4 – slide, 5 – bolt, 6 – recoil spring, 7 – case, 8 – bullet, 0 – fulcrum, F – recoil spring force, K-K – gas chamber axis, L-L – barrel axis,* $l_w$ *– rifling bore length,* $m_b$ *– recoiled mass,* $m_p$ *– bullet mass,* $N_x$ *– force on the groves, p – pressure in the barrel,* $P_b$ *– force at the case bottom,* $P_k$ *– force at the front wall of the gas chamber, R – distance from the fulcrum to the gas chamber axis, r – distance from the fulcrum to the barrel axis,* $R_s$ *– distance from the fulcrum to the recoil spring axis* $R_z$ *– distance from the fulcrum to the slide bumper axis, S-S – recoil spring axis, Ω – weapon's jump angular velocity.*

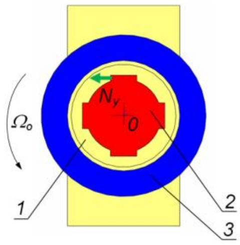


***Fig. 3*** *Physical model of the weapon's turn: 1 – the weapon, 2 – bullet, 3 – guides, 0 – barrel axis,* $N_y$ *– force on the groves,* $Ω_o$ *– weapon's turn angular velocity.*

Equations of the mathematical models were used to make three simulation programs [5], one for each component of the weapon's reaction. Programs are written in the Borland-Pascal environment and able to calculate parameters of the recoil, weapon's jump, and weapon's turn. Initial data for the programs are weapon's dimensional and mass characteristics and ballistic data for the pressures and slide velocity calculations.

First stage simulations [5] were using predicted parameters of the MSBS-5,56 prototypes. They were used mainly to prepare requirements for the laboratory test stand able to measure recoil and weapon's jump parameters during the shoot. Those simulations confirmed that the moving parts of the weapon are affecting both recoil and weapon's jump. Results showed also that the weapon's turn has only minimal share in the weapon's reaction to the shoot and there is no need of experimental examination of this phenomenon. In the contrary the results proved that the automatic firearms recoil and the weapon's jump needs further examination, also experimental.

## 3 Laboratory test stand

Designing the laboratory test stand begun with the compiling the requirements [6]. It was decided that the test stand should be capable to test MSBS-5,56 modular rifles built both in the classical layout and as a bull-pup. The test stand should also allow to test other firearms similar with the dimensions to the MSBS-5,56. In particular the test stand should be able to measure:

- recoil distance – no less than 100 mm,
- weapon acceleration – in the range of ±3000g,
- recoil force – in the range of 3 kN,
- weapon jump angle – in the range of 30°.

Weapon mounted on the test stand is placed on its side. This makes operating the weapon easier. This also allows making the construction of the test stand less complicated. Shoot is initiated by an electric trigger. According to the design the test stand can be set in three configurations enabling measuring:

- recoil distance and accelerations of the weapon (Fig. 4),
- weapon's angle and speed (Fig.5),
- for measuring recoil force (Fig.6).

During measuring the recoil distance (Fig. 4) weapon mounted in the carts can move along the guides of the test stand. Shoot pushes the weapon and the position sensor measures to the rear cart – the recoil distance.

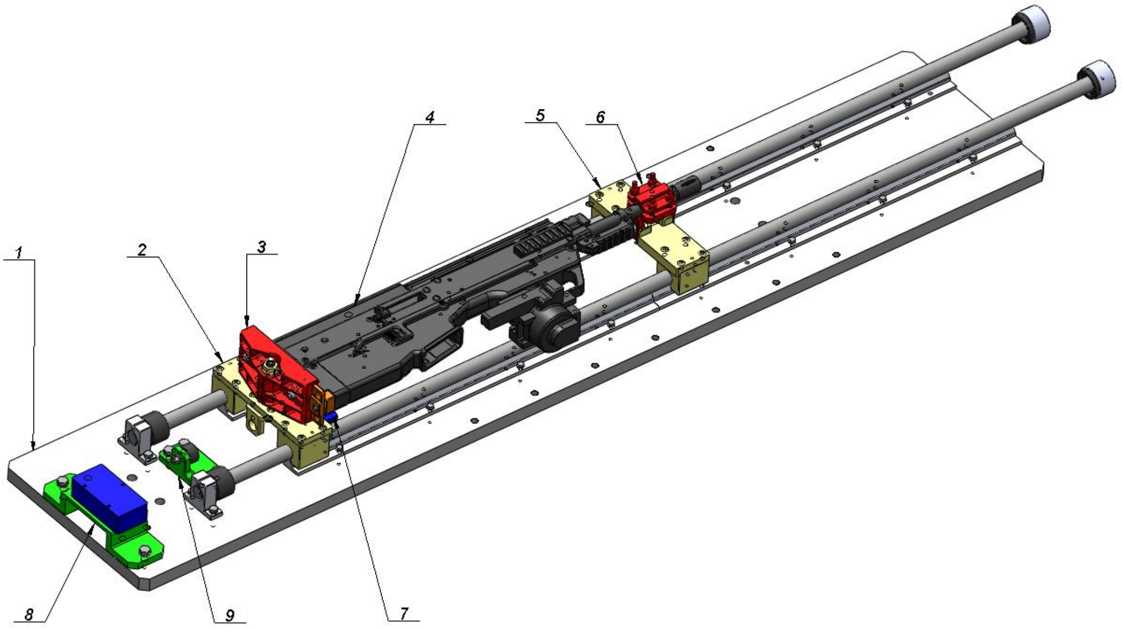


***Fig. 4*** *Test stand set for measuring the recoil distance and the weapon's acceleration: 1 – base, 2 – rear cart, 3 – butt holder, 4 – examined weapon, 5 – front cart, 6 – barrel holder, 7 – acceleration sensor, 8 – position sensor base with the sensor, 9 – force sensor base with the shock-absorber.*

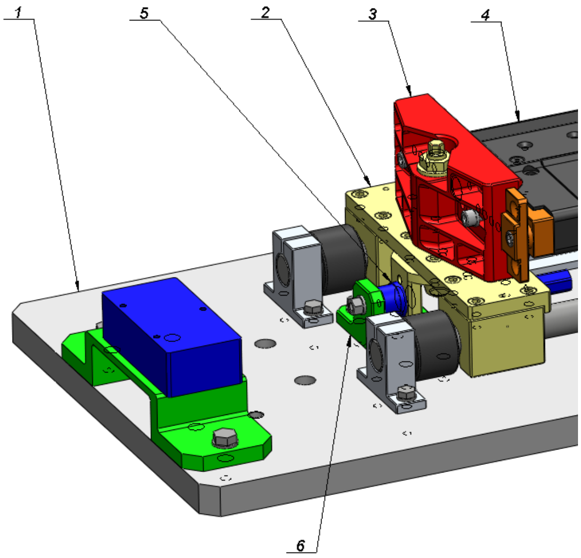


***Fig. 5*** *Test stand set for measuring the recoil force: 1 – base, 2 – rear cart, 3 – butt holder, 4 – examined weapon, 5 – force sensor, 6 – force sensor base.*

For measuring the recoil force (Fig. 5) rear cart is fixed to the test stand base by the force sensor. In this configuration weapon doesn't move during the shoot.

To measure the weapon's jump (Fig. 6) the test stand needs some rearrangement. The table and the turn axis base are mounted on the test base. And the weapon is mounted on the transverse cart and the turn axis. During the shoot weapon can turn around the turn axis.

The laboratory test stand was made by the „Archer" - Radom Arms Factory LLC with usage of blueprints made by the Department of Special Design from Military University of Technology. Fitting of the main parts and mobility of carts and the turn axis was checked during the stand assembly.

The test stand was checked in all configurations during live fire test with MSBS-5,56 rifles. Tests confirmed that the test stand is working correctly.

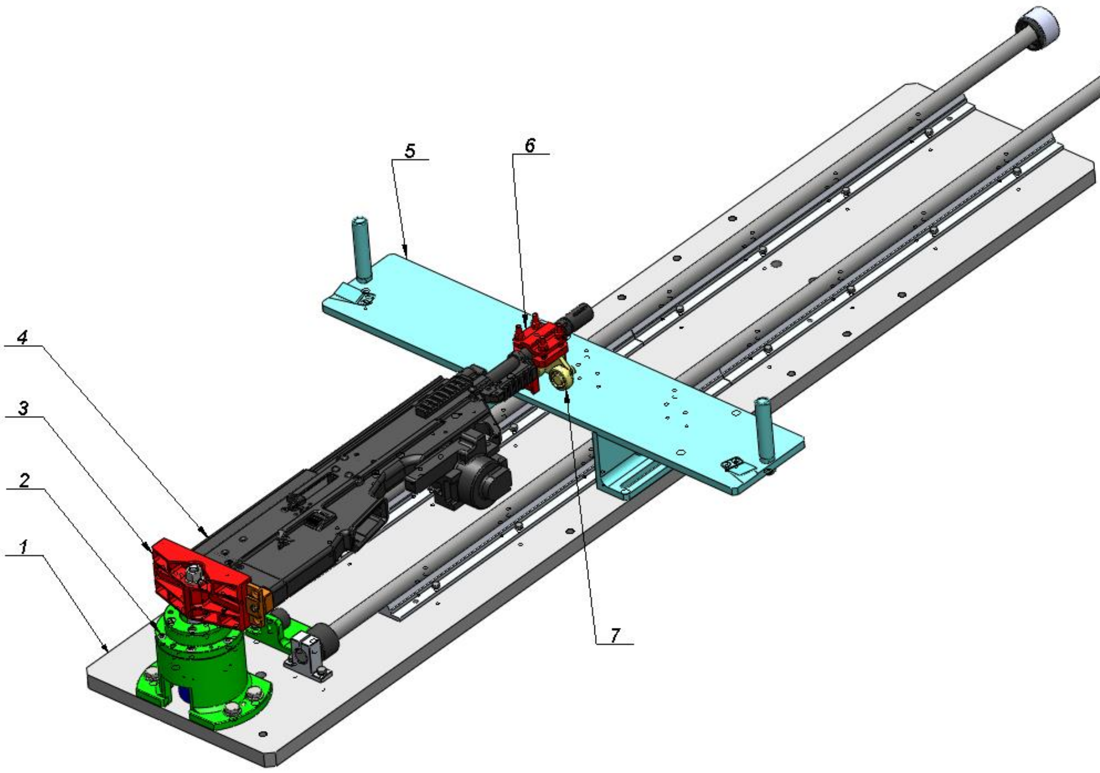


***Fig. 6*** *Test stand set for measuring the weapon's jump angle: 1 – base, 2 – turn axis base with the encoder, 3 – butt holder, 4 – tested weapon, 5 – table, 6 – barrel holder, 7 – transverse cart.*

## 4 Preliminary theoretical and experimental studies at the recoil and weapon's jump

The main aim of the preliminary studies at the recoil and weapon's jump was verification of the mathematical models and simulation programs. During the theoretical part, parameters of the recoil and weapon's jump of the rifles were calculated by the simulation programs. Then the same parameters were measured during live fire test on the laboratory test stand.

### 4.1 Theoretical studies

Initial data for the simulation includes weapon's dimensional and mass characteristics (mass of the weapon ant the moving parts, bore length, gas port characteristics, cycle of operation parameters) and ballistic parameters related with the cartridge [7]. Results of the simulations are graphs presenting recoil distance versus time (Fig. 7) and weapon's jump angle versus time (Fig 8). Weapon's jump angle was calculated for three cases: with the fulcrum 29 mm below the barrel axis, with the fulcrum in the barrel axis and with the fulcrum 29 mm above the barrel axis.

Recoil simulation results are presented on the Fig. 7. Curve describing the recoil of the K-01 rifle can be divided onto two characteristic fragments. First one (from 0 to the band) corresponds with the time when the slide is moving backward and the second is corresponding with the time when the slide is moving forward. Collision of the slide and the receiver refers to the band of the curve. Program ends calculations when the slide returns to the forward position. Curve describing the recoil of the B-01 rifle is very similar due to the similar characteristics of both rifles.

Weapon's jump simulations results (Fig. 8.) show the weapon's jump angle versus time in three cases: when the fulcrum is above the barrel axis (r=-29mm), when the fulcrum is in the barrel axis (r=0) and when the fulcrum is below the barrel axis (r=29mm).

The Graph shows large similarities between the weapon's jump characteristics of both rifles due to their similar construction. Just like during the recoil - two characteristic periods can be easily found. Weapon's jump of the K-01 rifle is notably lower due to its higher momentum of inertia. Graph also shows that in specific situations – fulcrum above the barrel axis – weapon's jump has negative values. The results showed also that fulcrum located close to the barrel axis results with the most favourable weapon's jump angle. Also placing the slide bumper in the barrel axis helps to reduce the effect of collision between the slide and the receiver.

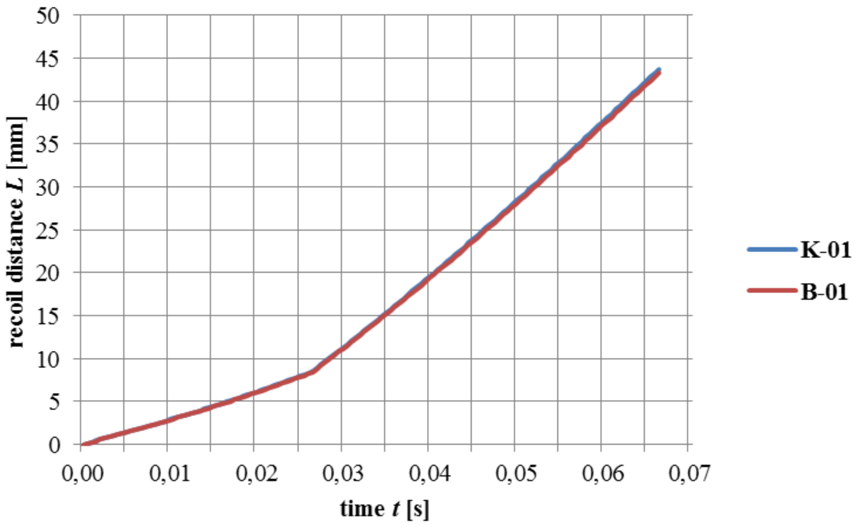


***Fig. 7*** *Simulated recoil distance L versus time t.*

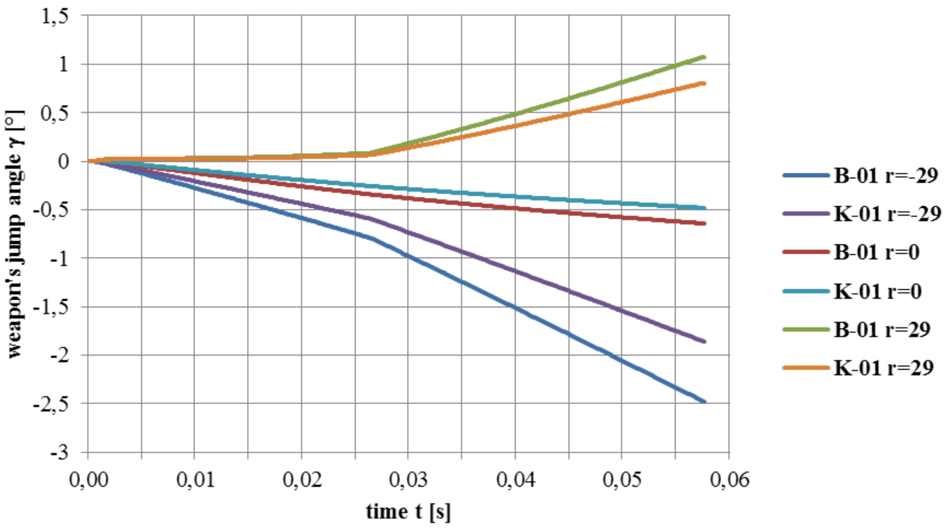


***Fig. 8*** *Simulated weapon's jump angle $\gamma$ versus time t.*

## 4.2 Experimental studies

The experimental studies included shooting in three configurations: for measuring the recoil distance, for measuring the recoil force, and for measuring the weapon's jump angle. Tested weapon were the technology demonstrators of the MSBS-5,56 weapon system. Before the shooting - weapon was prepared to installation on the test stand by replacing the butt stock with the montage element and the hand grip with the electric trigger (Fig 9). Then tested weapon was placed on the test stand as shown on the Fig. 10.

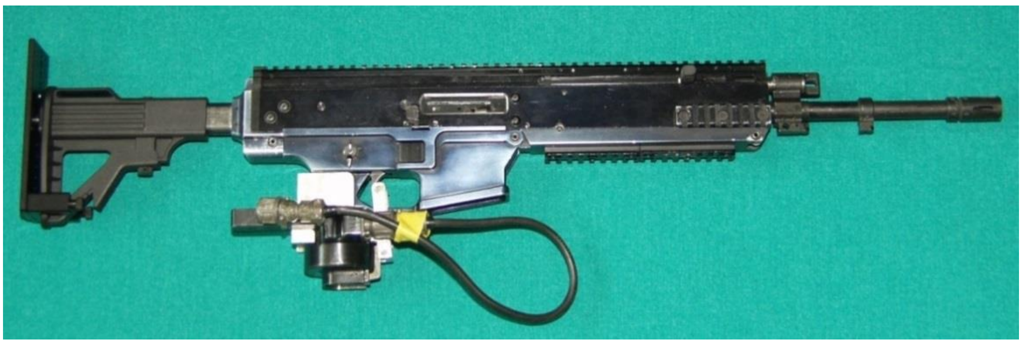

***Fig. 9*** *MSBS-5,56 K-01 rifle prepared to the installation on the test stand*

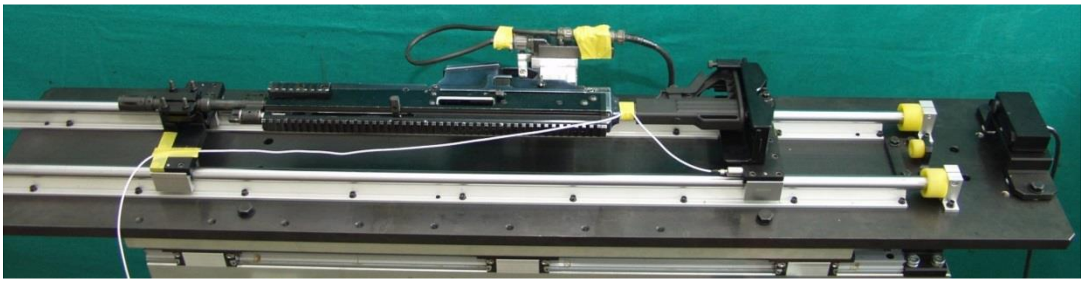

***Fig. 10*** *MSBS-5,56 K-01 during the recoil distance measurement.*

Recoil distance tests took 11 shots for each rifle. The result of the test is the average recoil distance *L* versus time *t* characteristics shown on the figure 11.

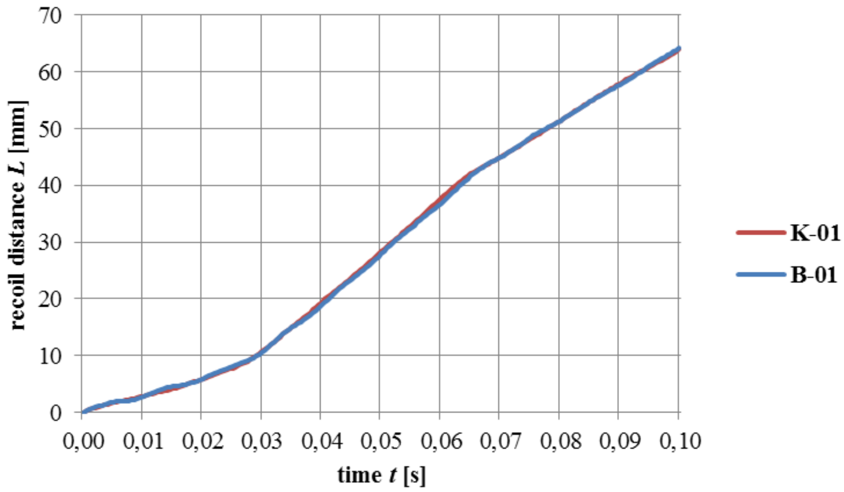


***Fig. 11*** *Experimental recoil distance L versus time t.*

K-01 rifle characteristic shows three periods. First one (from 0 to the first band) refers to the backward movement of the slide, second period (between the bands) refers to the forward movement of the slide, and the third (from the second band to the end) refers to the weapon's movement after the end of the cycle of operation. Bands of the curves refer to the slides collision with the receiver. The experiment confirmed that the moving parts of the weapon are affecting the recoil.

Second stage of the experimental tests was measuring the recoil force. The test stand was rearranged to the proper configuration, by replacing the bumper with the force sensor, and then the tests begun. Tests took 11 shots from each rifle. The result is recoil force *F* versus times *t* characteristic shown on the figure 12.

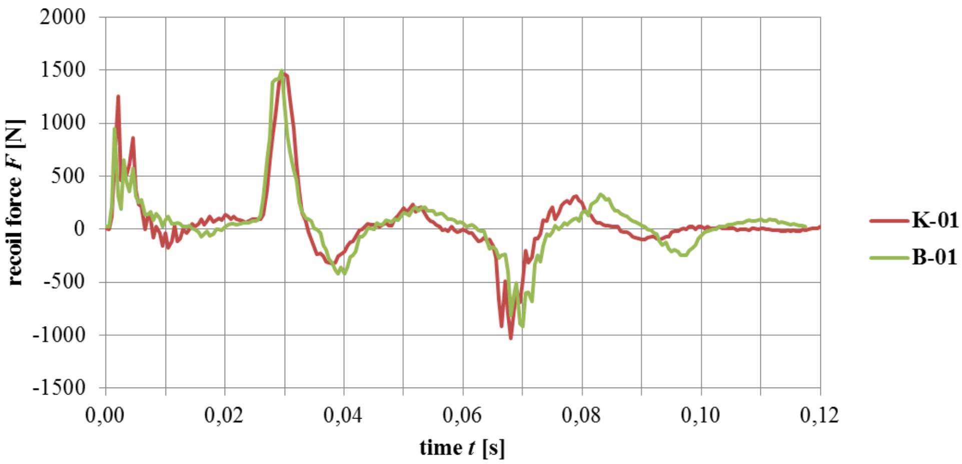


***Fig. 12*** *Recoil force F versus time t.*

Recoil force characteristics of both rifles are similar due to it similar parameters. The characteristics revile three extremes. First one (*F*=1200N) is the maximum recoil force when the bolt is locked. Second extreme (*F*=1500N) refers to the collision of the slide and the receiver when the slide reaches its rear position. Third extreme (*F*=-1000N) corresponds to the collision of the moving forward slide and receiver in the end of the cycle of operation. Interesting fact is that the highest recoil force was registered when the slide hit the receiver at the end of its movement. Unexpectedly it was even higher than the recoil force in the time when the bolt is closed and the pressure inside the bore is highest.

Weapon's jump tests started with the rearrangement of the test stand. The test stand was equipped with the turn axis base with the encoder and the table. Then the measurements started (Fig.12).

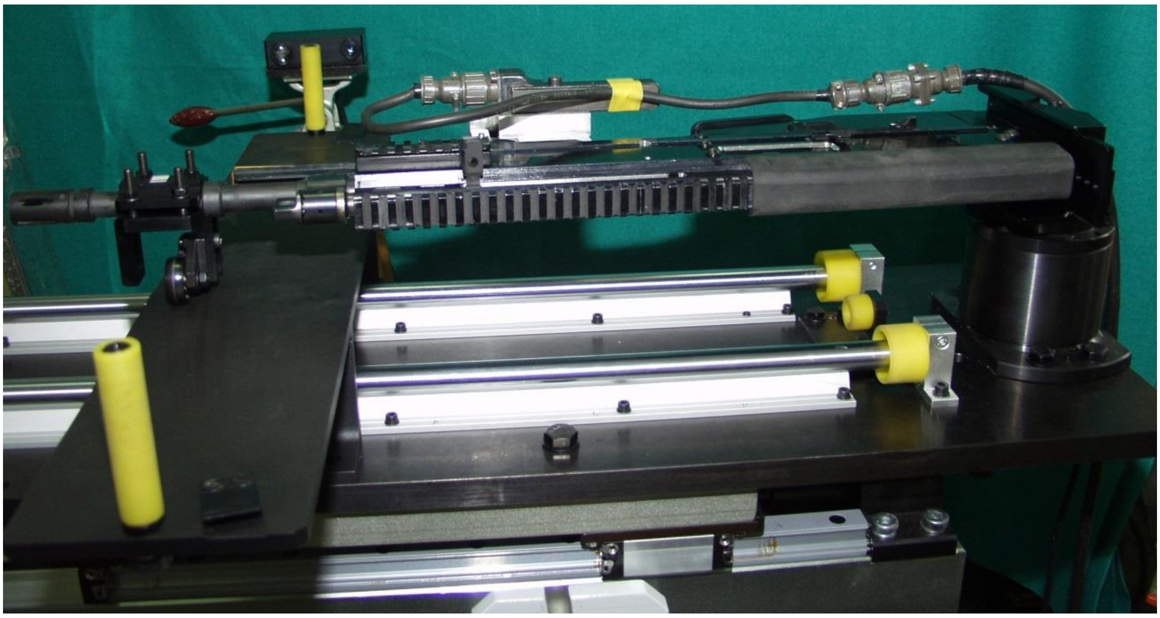

***Fig. 13*** *MSBS-5,56 rifle during the weapon's jump angle measurement*.

During the weapon's jump angle measurements each rifle was tested in three positions (11 shots in each one): with the fulcrum 29 mm above the barrel axis (r=-29), with the fulcrum in the barrel axis (r=0), and with the fulcrum 29 mm below the barrel axis (r=-29mm). The results of those tests are graphs presenting the weapon's jump angle $\gamma$ versus time *t* (Fig 14 and 15).

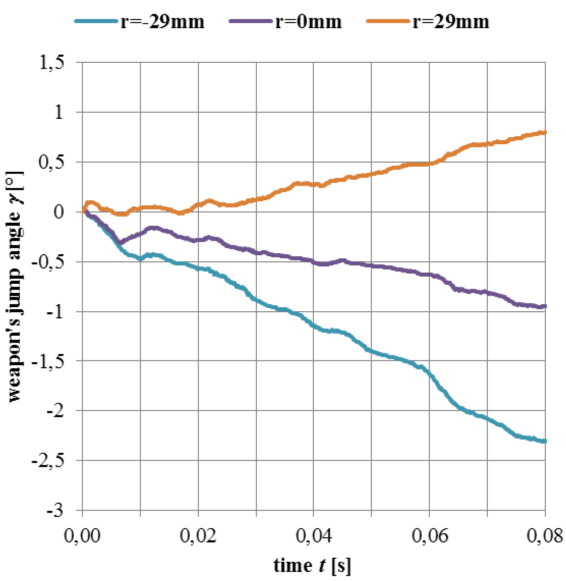


***Fig. 14*** *MSBS-5,56 K-01 rifle experimental weapon's jump angle $\gamma$ versus time t.*

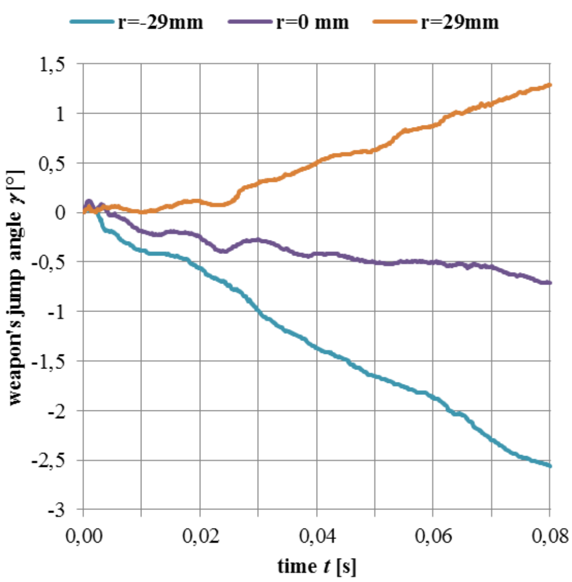


***Fig. 15*** *MSBS-5,56 B-01 rifle experimental weapon's jump angle $\gamma$ versus time t.*

The results confirmed that the weapon's jump is strongly depends on the distance from the fulcrum to the barrel axis. Weapon's jump angle of the rifle with larger momentum of inertia (K-01) reached lower values. Also collision of the slide and the receiver can be identified on the characteristics and the curve can be divided onto specific periods referred to the rearward and forward movement of the slide.

### 4.3 Comparison of the experimental and theoretical results.

In order to compare the theoretical and experimental results the experimental and theoretical graphs were placed in joint coordinates (Fig. 16 to 18).

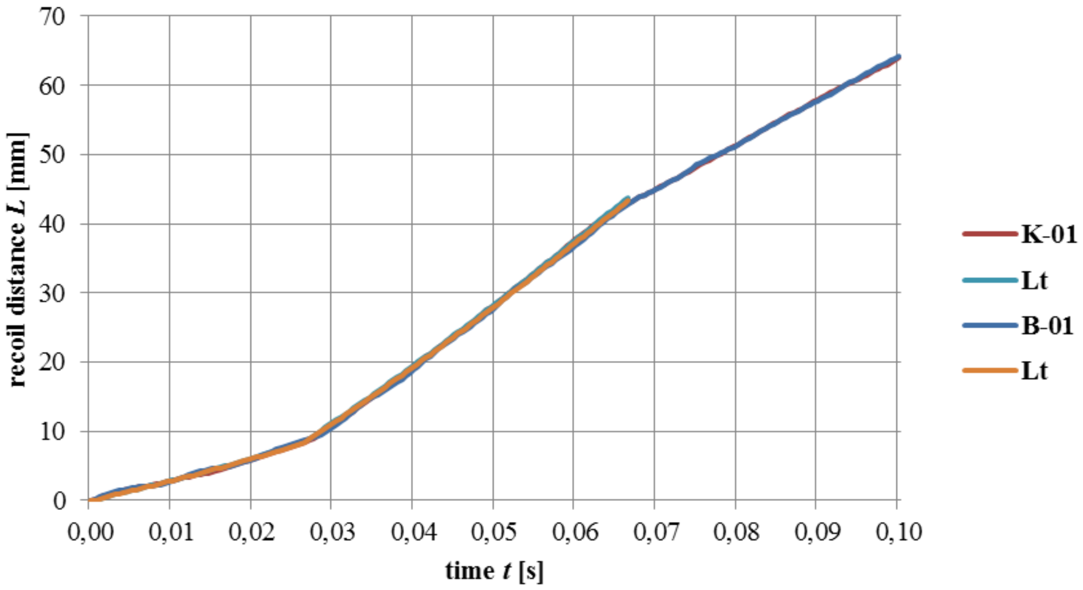


***Fig. 16*** *Comparison of the Recoil distance L versus time t gained by the simulation and experiment. Lt – theoretical graphs*

Theoretical and experimental plots of the recoil distance versus time shows large similarities. Curves show only minimal differences. They also have the same characters. Simulation results appear to be very accurate.

Compared plots of the weapon's jump angle versus time gained by the both methods also show large similarities. Weapon's jump angles gained by the simulations are notably higher. This can be caused by the specificity of the test stand. Nevertheless simulation results are quite accurate and are showing the character of the process.

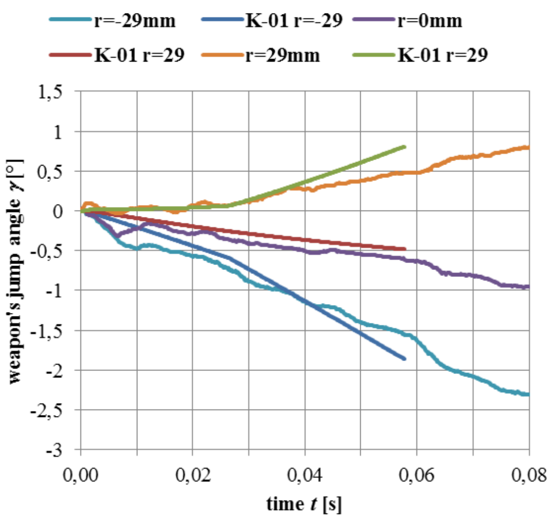


***Fig. 17*** *Comparison of the K-01 rifle weapon's jump with the simulation results.*

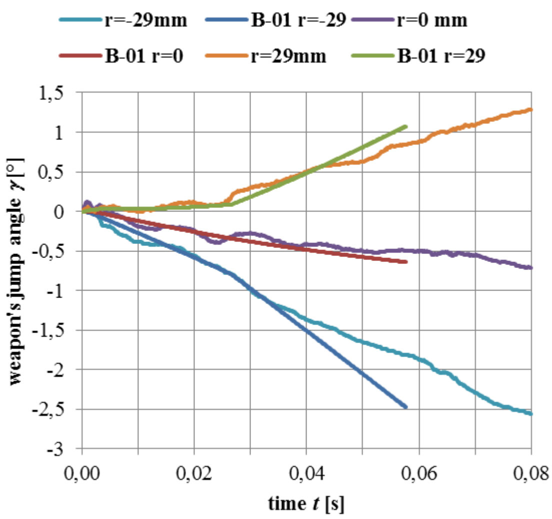


***Fig. 18*** *Comparison of the B-01 rifle weapon's jump with the simulation results.*

## 5 Conclusion

Preliminary studies confirmed suspects that the automatic weapon's reaction to the shoot is affected by the weapon's mechanisms, especially by the slide moving rearward and forward and hitting the receiver. Comparing the theoretical and the experimental results showed that the simulation programs give satisfactory accurate data. This shows that the simulation programs can be used to evaluate the recoil and weapon's jump characteristics during the designing new rifles even before building the prototypes. This can help to optimize construction and minimize the negative effects of the recoil and weapon's jump on the accuracy.

Further works will focus on comparing different design schemes and evaluation of the impact of different factors on the recoil ant weapon's jump. This will help to find an optimal design with the lowest recoil and weapon's jump and prepare practical tips for weapon's designers.

**Acknowledgements**

*Authors are grateful for the support of experimental works by project RMN/08-864/2013/WAT.*

**References**

[1] Z. Surma, Ł. Szmit, S. Torecki, R. Woźniak: Simulations of weapon turn by example 5,56 mm automatic carbine. Proceeding of the VIth International Symposium On Defence Technology (5-6.05.2010, Budapest) [CD-ROM] BJMTF, Budapest 2010. p. 921-932.

[2] Ł. Szmit, R, Woźniak: Usage Of CAD/CAM Software In The Firearms Test Stand Design Process (in Polish). Proceedings of the XV Międzynarodowa Szkoła Komputerowego Wspomagania Projektowania, Wytwarzania i Eksploatacji (9-13.-5.2011, Jurata), Vol. 2 p. 341-348. ISBN 978-83-61486-7, ISBN 978-83-61486-5, WAT, Jurata 2011.

[3] Ł. Szmit, S. Torecki: Mathematical Model of the Gas Operated Carbine Recoil (in Polish). Proceedings of the 8$^{th}$ International Armament Conference on Scientific aspects of armament & safety technology (6-8.10.2010 Pułtusk), [CD-ROM] WAT, Pułtusk 2010. p. 921-932.

[4] Z. Surma, Ł. Szmit, S. Torecki, R. Woźniak: Mathematical Model of Gas Operated Weapon Jump (in Polish). Problems of Mechatronics. Armament, Aviation and Safety Engineering No 2(2)2010, p. 51-63.

[5] Z. Surma, Ł. Szmit, S. Torecki, R. Woźniak: Chosen Results of the Simulations of Gas Operated Carbine Constructional Parameters Influence on the Recoil and the Jump of the Weapon (in Polish). Problems of Mechatronics. Armament, Aviation and Safety Engineering No 2(4)2011 p. 73-84.

[6] Ł. Szmit, R. Woźniak: Specificity of Design and Action of the Weapon's Jump and Recoil Laboratory Test Stand. Problems of Mechatronics. Armament, Aviation and Safety Engineering No 3(9)2012 p. 29-39.

[7] Ł. Szmit, J. Kijewski – Theotretical and Experimental Studies at the Recoil of the Automatic Firearms (in Polish) Proceeding of the 9$^{th}$ International Armament Conference on Scientific aspects of armament & safety technology (25-28.09.2012 Pułtusk), [CD-ROM] WAT, Pułtusk 2012, p. 395-410.

*Review: Ján Tvarožek*
*Harold Mäsiar*