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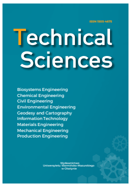

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MODELLING AND SIMULATION OF FUNCTIONING OF THE GSH-23 AVIATION AUTOCANNON MECHANISMS

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Abstract

Article presents the simulation model and the study of the basic mechanisms of the GSh-23 aviation autocannon. The research made use of Solid Edge ST9 software and the multibody systems method implemented in it. Simulation of functioning cannon mechanisms was carried out for two variants of forcing a piston mechanism movement by the gunpowder gases. The results obtained are time courses of a bolt and a cartridge belt drive mechanism elements movement. Assumed variants of a piston mechanism movement and elaborated simulation model will be verified in the next (planned) stage of studies basing on the results of the measurements of the experimental kinematic parameters utilising high-speed camera (Phantom) and TEMA software.

Introduction

In the process of designing and developing the rules of operation of aviation weaponry assumptions regarding the period of device reliable operation and range of services are made, which is reflected in device expected lifespan provided by the producer (or prescribed way of tracking its current technical

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condition). However, in the result of a long-term exploitation of the aviation armament there is sometimes a necessity to use equipment after the lifespan given by the manufacturer. In that scenario the need to define a new lifespan value or to change the way of exploitation to exploitation by technical condition arises (JASZTAL et al. 2007). Introduction of any changes in that aspect requires conducting range of studies related to the cognition of physical phenomena determining loss of durability of individual components, as well as identification of diagnostic parameters which allow tracking of device current technical condition. Unfortunately, there is often no possibility to use manufacturers full technical and test documentation, while only chosen statistical information from exploiting the device is available. Therefore there is a need to conduct such studies, of which inevitable is carrying out expensive and time-consuming experimental investigation. However, the number of planned experiments can be minimalised by usage of modern modelling, calculation and simulation environment CAD/CAE (JASZTAL 2006, 2017). It is possible to simulate functioning of a selected mechanism or a whole device for different conditions of its work in such environments, registering values of selected parameters. Modelling wide range of exploiting situations makes identification of diagnostic parameters, determining device reliability condition, same as development of weapon malfunctions or mechanical failures models possible.

Following work discusses modelling and simulation of functioning mechanisms of the 23-mm twin-barreled GSh-23 aviation autocannon (Fig. 1), intended for being fired from the aircraft at both aerial and ground targets (*23 mm DZIAŁKO LOTNICZE GSz-23Ł* 1990). A GSh-23 cannon was an integral cannon armament of MiG-21 and MiG-23 fighters. It has also found its application in a SPPU-22-01 suspended gun pod, carried by Su-15TM, Su-17TM, Su-22M, Yak-28PM and Yak-38 aircraft. It was also mounted in tail gunner turret of bombers: Tu-95, Tu-22, transport aircraft: Il-78, Il-76 and patrol aircraft: Tu-142. Mi-24D/M attack helicopters carried UPK-23-250 gun pods armed with GSh-23 cannon. Another version, Mi-24VP had fixed NPPU-23 movable mounting with GSh-23 cannon (GRUSZCZYŃSKI 1993).

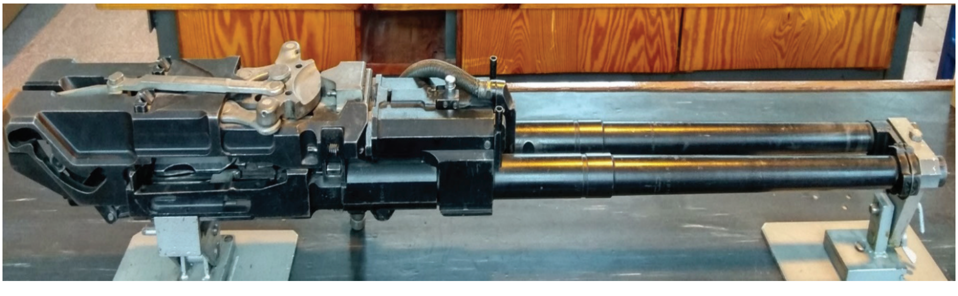
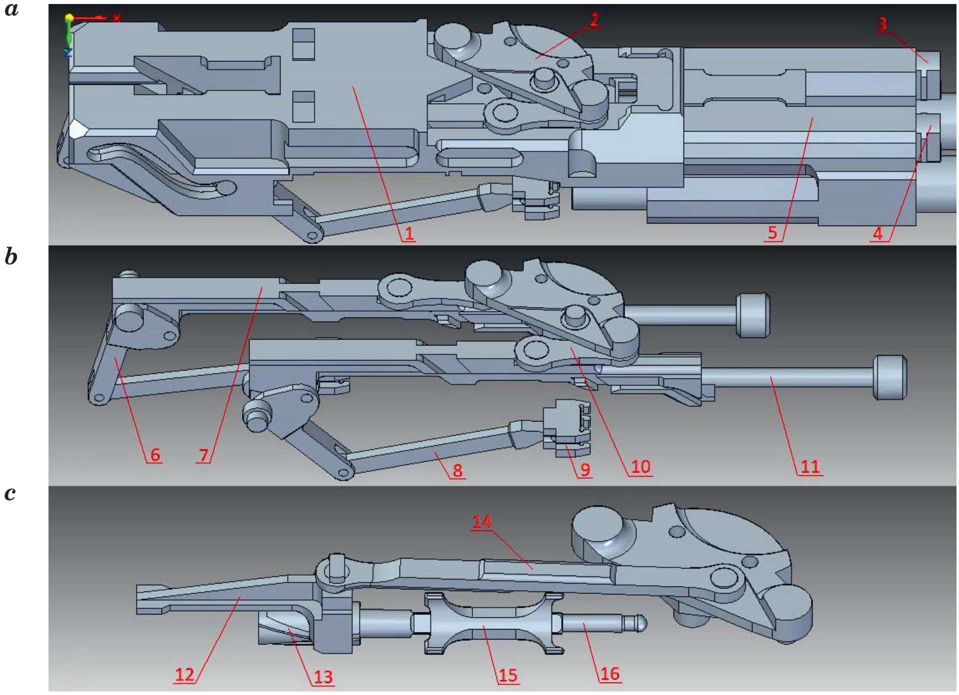


Fig. 1. GSh-23 autocannon
Source: own elaboration.

The mechanism of the twin-barreled GSh-23 autocannon works on the principle of using gunpowder gases energy. The gases are discharged from barrels to the gas distributor. Reloading action of one of the cannon barrel is operated by the energy of expanding gases released by firing the other barrel. Driving link of the mechanism are sliders with gas shafts. Figure 2 presents a sliders scheme of operation. A cannon has two sliders (*7*, Fig. 2), kinematically joined with connectors (*10*, Fig. 2) and connecting lever (*2*, Fig. 2). During one full cycle of operation, every slider moves only in one direction (backward or forward). When the projectile passes the gas discharge holes in the barrel tube, the gunpowder gases are fed simultaneously into space in front of the piston of the retreating stem with slider and space behind the piston of the returning stem and slider. Due to the gunpowder gases, the stems begin to move: one backwards and the other forwards. When the movement of the stems with the slide occurs, the acceleration mechanisms, the so-called cam mechanisms, begin to work. One of them, by means of the bolt, feeds the cartridge into the



1 – base of the lift, *2* – connecting lever, *3* – left front plug, *4* – right front plug, *5* – gas distributor, *6* – accelerator, *7* – slider, *8* – connecting rod, *9* – bolt, *10* – connector, *11* – gas stem, *12* – feeder collector, *13* – feeder drum, *14* – feeder connecting rod, *15* – feeder star, *16* – multi-spline shaft

Fig. 2. Diagram of the basic mechanism of the autocannon: *a* – body connecting the mechanisms, *b* – acceleration mechanism, *c* – feeding mechanism

Source: own elaboration.

chamber and ejects the previous cartridge case forward. The second, by means of the recoil, the bolt and the projections in the breech chamber, draws the cartridge case from the cartridge chamber and lowers it. This happens so that the case is ejected forward during the next cycle. The cartridge of the cannon is locked in the cartridge chamber by lateral displacement of the bolt (*9*, Fig. 2), which at the same time serves as a feeding element. The cannon has two bolts. Each of them is connected to its slider by a connecting rod (*8*, Fig. 2) and an accelerator (*6*, Fig. 2). The cam device is responsible for smooth acceleration and deceleration of the bolt (*23 mm DZIAŁKO LOTNICZE GSz-23Ł* 1990).To charge the cannon with cartridges one ammunition belt is used. The feeding mechanism is used here. The belt is moved by the feeder star (*15*, Fig. 2) which is connected kinematically through a connecting lever (*2*, Fig. 2) with the driving link of the mechanism (*23 mm DZIAŁKO LOTNICZE GSz-23Ł* 1990). During one cycle of the mechanism, the feeding unit moves the belt one stroke. Each cartridge is lowered by means of front and rear feeders to the feed line (i.e. to the bolt clamps). The feeders are kinematically connected to the sliders. Cartridges are inserted sequentially into each of the barrels by means of the bolts.

The accelerating and feeding mechanisms presented above are the basic mechanisms of the weapon and thus became the object of research within the framework of this work.

Simulation model

The complex character of interactions of the elements of the weapon mechanism causes difficulties in description and analysis using the classical mathematical relationships. Hence, numerical simulations are commonly used in this type of applications (FLORIO 2011, HUAI-KU et al. 2007, 2009, SHIPLEY et al. 2006, PATHAK et al. 2006, URRIOLAGOITIA-SOSA et al. 2011, WEI WU et al. 2013). The use of computer methods for the analysis of kinematics and dynamics of weapon mechanisms is realised by two methods: the method of multibody systems (SCHABANA 2005, SCHIEHLEN 1997, TOMULIK et al. 2011) and the finite element method (ZIENKIEWICZ et al. 2005, LOGAN 2007). However, it should be noted that in the case of modelling various types of mechanisms, the method of multibody systems is more useful, as it assumes that all elements of the mechanism are rigid bodies connected to each other by means of various types of elements defining the degrees of freedom of a given connection (e.g. connections: linear, cylindrical, spherical, rotational etc.). Literature analysis of utilization of the multibody system indicates that it is successfully applied to solve the problem that is being researched in this work (SHIPLEY et al. 2006, HUAI-KU et al. 2007, 2009, NI et al. 2011, PLATEK et al. 2015).

The first phase of building a simulation model of analysed mechanisms was to create CAD geometric model of those mechanisms parts and creation of an assembly model of the researched gun. For this purpose, Solid Edge ST9 software was used. Dimensions needed to create models of this gun were obtained from own measurements of that gun parts located in Aircraft Armaments Laboratory at the Military University of Technology, Warsaw, Poland. An assembly model prepared in this way was checked for geometric correctness using an automatic collision detection procedure and is shown in the Figure 3.

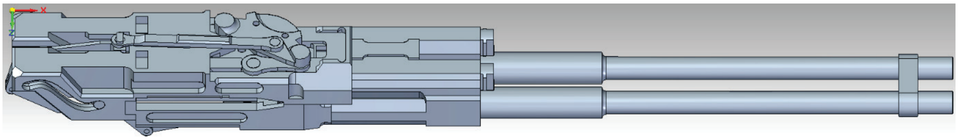


Fig. 3. CAD assembly model of the GSh-23 autocannon
Source: own elaboration.

To prepare and simulate the movement of the researched mechanisms, DST (Design Simulation Technologies) module implemented in Solid Edge ST9 software was used. At this stage of preparation of the simulation a necessary relationships between particular CAD models of the cannon elements were introduced. The following relationships were used: revolute joint, planar joint, translational joint and cylindrical joint. Moreover, it was assumed that the value of the friction coefficient between individual elements of the mechanism is zero. After introduction of the necessary relationships for particular kinematic pairs, a model ready for analysing basic kinematic sequence was obtained.

In this work the functioning of the acceleration mechanism basic kinematic sequence was analysed: gas stem – slider – accelerator – connecting rod – bolt as well as ammunition belt pulling mechanism: gas stem – slider – connecting lever – feeder collector – feeder drum – feeder star. To predefine the forcing motion to simulate the movement of the mechanism, the tactical- technical information of the GSh-23 autocannon given by the producer were used. Rate of fire of 3000 rounds per minute was adopted, which translates to the time needed to fire one round being $t = 0.02$ s. Dislocation of the gas stems due to the usage of part of the gunpowder gases energy is 110 mm, however during firing one shot the feeder drum rotates 90 degrees.

Considering the fact that on the realised stage of the research there was no available information regarding the time course of gunpowder gases pressure affecting the gas piston during the shot, in these tests it was assumed to conduct a simulation of the movement of the mechanisms for two adopted variants. In defining the first one preset displacement of the gas piston was used (eng. Displacement) and in the second one preset velocity of the gas piston was introduced (eng. Velocity).

First variant conventionally referred to as “Displacement” (*D*) assumed that both slider and feeder drum move in uniformly accelerated motion in a timestamp from 0 to $t = 0.01$ s and then uniformly decelerated motion from $t = 0.01$ s to $t = 0.02$ s. This variant assumption was made that the gunpower gases pressure during the shot first increases in the gas cylinder and then decreases with the simultaneous action of the resistance forces of the cannon mechanism. Thus, the motion of the gas stem changes from uniformly accelerated to the half of its displacement, to uniformly decelerated to the end of its motion.

The second variant of calculations, conventionally referred to as ”Velocity” (*V*), assumed uniformly accelerated motion of the gas stem in the whole range of its displacement. This variant assumes that the gas stem is accelerated from the beginning to the end of the movement by the increasing pressure of the gunpowder gases. The assumed displacement and velocity of the gas stem as a function of time are shown in Figure 4.

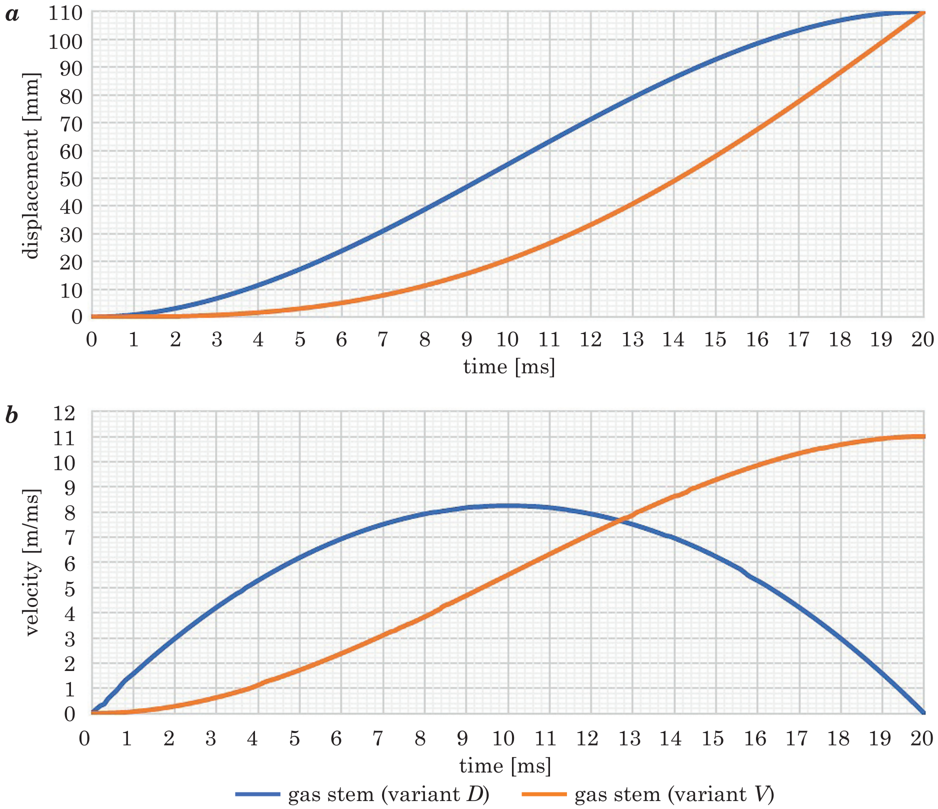


Fig. 4. The dependence of: *a* – displacement and *b* – velocity of the gas stem as a function of time for two forcing variants – Displacement (*D*) and Velocity (*V*)
Source: own elaboration.

After defining the elements belonging to the basic kinematic sequence of the GSh-23 autocannon, assigning necessary relationships and introducing initial conditions, the simulation of the mechanism motion was carried out.

Research findings and their discussion

The final element of the work was to make the calculations of the kinematic parameters of the examined mechanism selected elements and to generate graphs showing the kinematic dependencies between individual elements of the GSh-23 autocannon mechanism model during single shot. For this purpose, the Solid Edge ST9 software functions were used, enabling the desired kinematic parameters to be plotted against time. For comparing the kinematic parameters of selected elements of the mechanism, it was necessary to use the function of exporting numerical values of measured parameters to the Excel programme. This allowed creating any graphs facilitating comparison and drawing conclusions about mutual displacement of the elements of examined kinematic sequence.

The basic kinematic sequence of the cannon is responsible inter alia for transfer of the movement from the gas stem to the bolt using the acceleration mechanism. Therefore, it seems interesting to present the portrayal of the gas stem and bolt displacement on one graph (Fig. 5), which shows that the acceleration mechanism causes a much larger range of motion of the bolt than the gas piston. Namely, the bolt travels more than 1.8 times longer distance than the gas stem, which allows insertion of the relatively big cartridge into the bolt clamps and feeding it to the chamber despite a much smaller range of motion of the gas stem. Furthermore, determination of the bolt velocity during its movement shows that the acceleration mechanism causes an increase in the bolt movement velocity, which the maximum value is approximately 3.7 times bigger than the maximum velocity of the gas stem.

Another function of the basic kinematic sequence of the cannon is realisation of sending the cartridges to the bolt clamps. It is done i.e. through transmission of power from the gas stems, through sliders to the connecting lever, which drives feeder collector, feeder drum and feeder star which pulls the ammunition belt. Hence the values of the angular deflection of the connecting lever, feeder collector and feeder star were determined for the two assumed variants of gas stem displacement considered in this work (Fig. 6).

On their basis it was found that the angular deflection of aforementioned parts is directly proportional to the displacement of the gas piston.

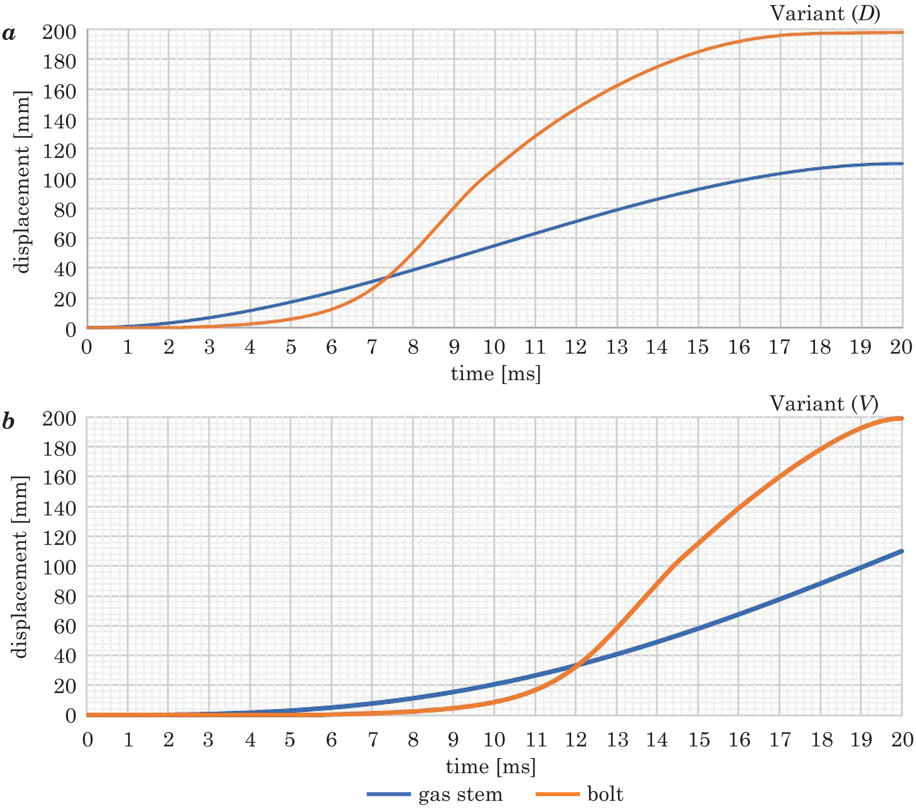


Fig. 5. The dependence of displacement of the gas stem and bolt as a function of time for two forcing variants: *a* – Displacement (*D*), *b* – Velocity (*V*)
Source: own elaboration.

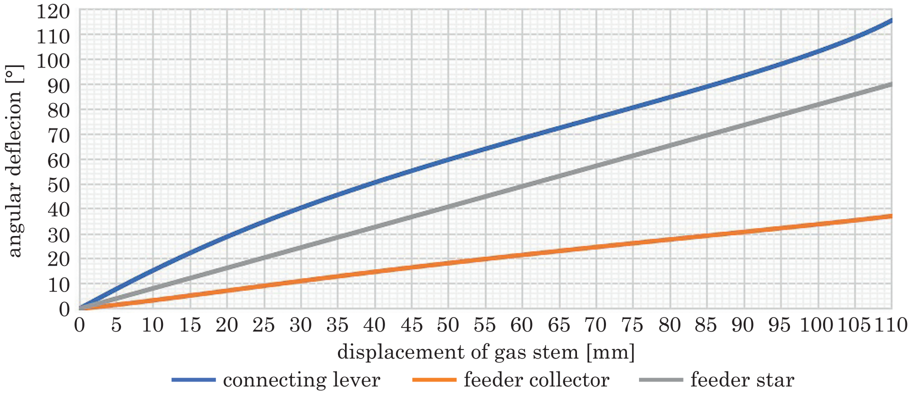


Fig. 6. Angular deflection of the connecting lever, feeder collector and feeder star as a function of the gas stem displacement
Source: own elaboration.

Conclusions

In this work graphs facilitating easier comparison of received parameters of the movement in two variants of forcing mechanism operation, called conventionally: Displacement (*D*) and Velocity (*V*) were presented. These variants can be treated as two limit means of displacement of the gas stem for various characteristics of the course of gunpowder gas pressure coming from the barrel tube. The differences in course of displacement and velocity for chosen variant of the simulation were plotted against the time for: gas stem, bolt, connecting lever, feeder collector and feeder star. The comparative graphs for two variants of forcing the movement were also developed as the graphs of displacement and velocity of the gas stem and the bolt plotted against the simulation time. On their basis, it can be seen that the "more beneficial" variant of the gunpowder-gases-based gas stem movement is the first variant called conventionally Displacement, because it allows more smooth joining the movement and decelerating of the cannon mechanisms parts, which achieve far lower speeds and hence the kinematic energy of said parts during collisions with other elements is lower, which results in slower wear of mechanisms. It should be noted that nevertheless, the first variant of driving the piston still provides a proper operation of the main kinematic sequence of the cannon. Assumed variants of the piston mechanism movement as well as elaborated simulation model will be verified in the next (planned) stage of studies basing on the results of the measurements of experimental kinetic parameters utilising high-speed camera (Phantom) and TEMA software.

It should also be noted that the created during the realisation 3D CAD models of the elements of the cannon paired with the assembly model and properly working simulation model have exceptional value as a didactic material for training of the Engineering and Aviation Service personnel operating this type of aviation weaponry.

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