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Preliminary Studies of a Propellant System for the Counterprojectile of an Active Protection System

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Abstract. This paper presents a selection of the deliverables for a research project intended to develop a technology demonstrator for a smart counterprojectile forming part of an active protection system. Given the required activation of the active protection system within a distance of ten or so metres from the protected facility, a solid-propellant rocket engine was used, which has the characteristics of a booster rocket. For the determined configuration of the rocket engine, the elements of the counterprojectile and missile launcher were designed, based on homogeneous rocket propellant of Polish origin. To confirm the validity of the adopted concept for the propulsion system solution, preliminary testing of the rocket engine was conducted using an engine test bed, and included the measurement of gas pressure and engine thrust for different masses of ignition charge.

This work has been compiled from the paper presented during the 11th International Armament Conference on Scientific Aspects of Armament and Safety Technology, Ryn, Poland, September 19-22, 2016.

To ultimately verify the operation of the design, field testing of the counterprojectile propulsion system was carried out, based on which the parameters of projectile motion inside the missile launcher and along the initial flight path length were determined.
Keywords: mechanics, active protection system, rocket engine, solid rocket propellant

1. INTRODUCTION

The Military University of Technology (Warsaw, Poland) is implementing a research project intended to develop an active protection system involving a smart counterprojectile. Given the short duration of propulsion, a solid-propellant rocket engine with the characteristics of a booster rocket was used. The design characteristics of the rocket engine [1, 2], presented in Table 2, were determined on the basis of the specific requirements adopted for the counterprojectile (Table 1) and the energy and ballistic properties of Bazalt 2a homogeneous rocket propellant of Polish origin.

Table 1. Specific requirements for the counterprojectile

Mass of counterprojectile head	[kg]	2.50
Mass of rocket engine (without propellant)	[kg]	2.00
Outer diameter of rocket engine and counterprojectile	[m]	0.081
Projectile velocity upon propulsion end	[m/s]	min. 150
Maximum distance from the protected facility, when the rocket engine stops its operation	X [m]	15
Maximum time of propulsion (rocket engine operation)	[s]	0.2

Table 2. Parameters of the rocket motor

Minimum nozzle diameter	d_m [mm]	25.0
Number of propellant charge grains	N [pcs]	7
Inner diameter of propellant grain	d_0 [mm]	16.4
Outer diameter of propellant grain	D_0 [mm]	22.8
Length of propellant grain	L_0 [mm]	170
Thickness of the combustible layer of propellant grain	e_1 [mm]	1.6
Mass of propellant charge	m_p [kg]	0.380

The elements of the projectile and missile launcher were then designed and manufactured to suit the determined configuration of the rocket propulsion system. Tests were then carried out to verify the concept of the solution. The first tests were conducted on an engine test bed under stationary (laboratory) conditions.

The objective of these tests was to determine, among other things, pressure *p* of the gasses in the combustion chamber, thrust *R* of the engine and its duration. Further tests conducted at a proving ground constituted a basis for evaluating the performance of the rocket propulsion system and analysing the counterprojectile motion (flight) parameters along the projectile trajectory.

2. DESIGN OF THE ROCKET PROPULSION SYSTEM

The elements of the projectile and missile launcher were designed and then manufactured at ZM „DEZAMET" Joint Stock Company in Nowa Dęba (Poland), for the determined configuration of the counterprojectile rocket propulsion system. Figures 1-3 show the counterprojectile, the dummy head and the missile launcher.

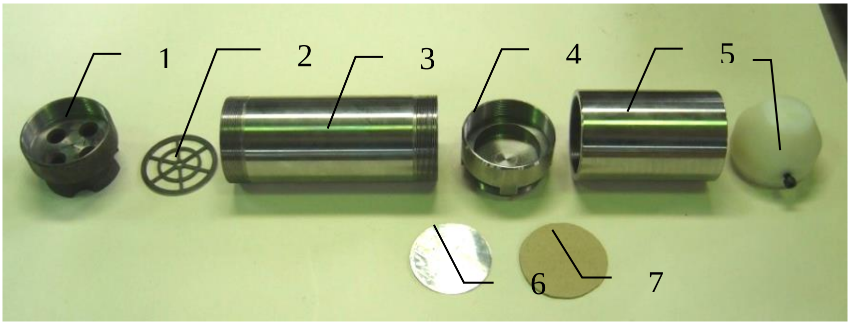

Fig. 1. Components of the counterprojectile:
1 – nozzle set, 2 – grate, 3 – rocket engine body, 4 – bottom,
5 – dummy head,6 – igniter cover, 7 – membrane

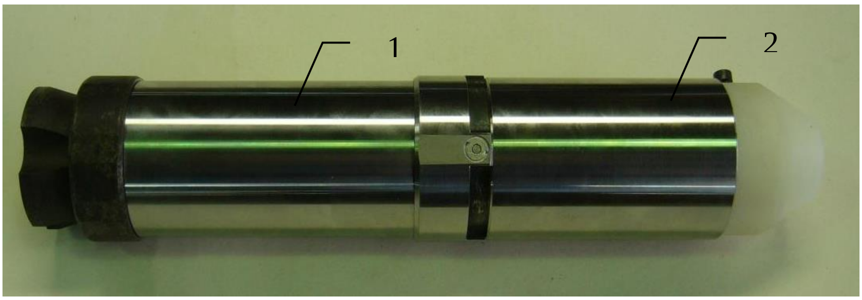

Fig. 2. Counterprojectile: 1 – rocket propulsion system, 2 – dummy head

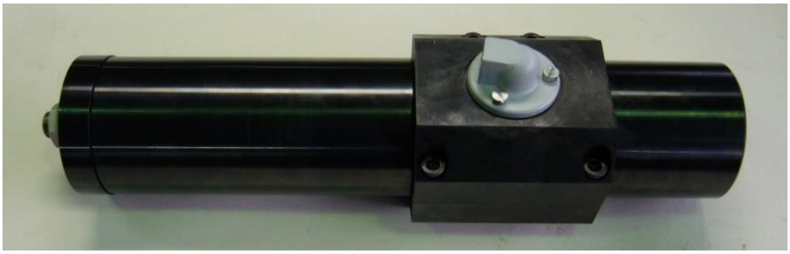

Fig. 3. Launcher for the counterprojectile

Charges based on the Bazalt 2a rocket propellant (Fig. 4) were produced by Special Production Plant „GAMRAT" Ltd. in Jasło (Poland).

Fig. 4. Seven single grain Bazalt 2a propellant charges

3. TESTING

3.1. Stationary tests on an engine test bed

The objective of the stationary tests was to measure pressure p of the gasses in the combustion chamber, thrust R of the engine and the duration of the propulsion system. The propulsion charges used in the tests were based on Bazalt 2a propellant, and the average values of the grains used for the propellant are shown Table 3.

Table 3. Mean parameters of the grains for the Bazalt 2a propellant

Mass	m [g]	54.70
Inner diameter	d_0 [mm]	16.42
Outer diameter	D_0 [mm]	22.84
Length	L_0 [mm]	170

Fig. 5 presents a filled combustion chamber. The combustion chamber for the engine test bed is shown in Fig. 6. The stationary tests were conducted at a standard temperature (+21°C), using igniters of mass m_z: 5.5; 6.0; 6.5 and 7.0 g.

Fig. 5. Propellant charge grains inside the combustion chamber

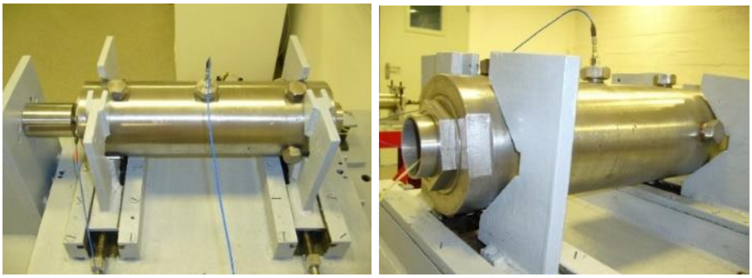

Fig. 6. Stationary stand for the solid propellant rocket motor tests

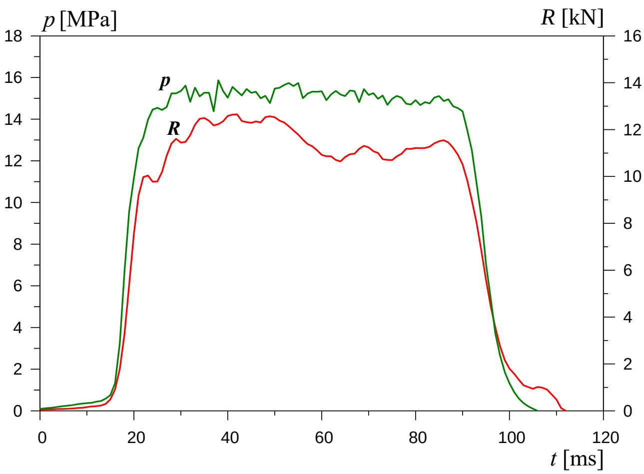

Fig. 7. Results for pressure $p(t)$ and thrust $R(t)$; igniter mass: 5.5 g

The results for pressure $p(t)$ and thrust $R(t)$ using igniters with a mass of 5.5 g and 7.0 g are presented in Figures 7 and 8.

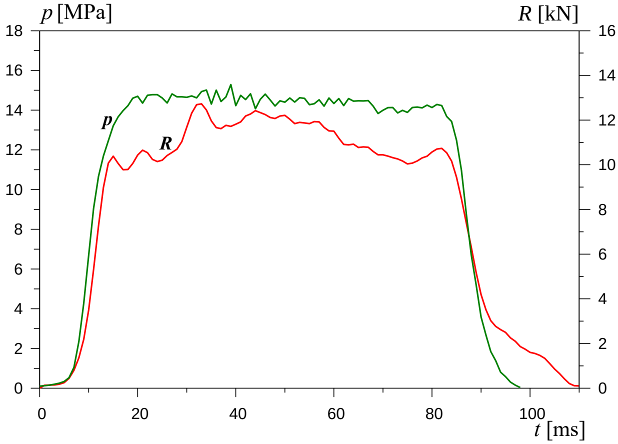

Fig. 8. Results of pressure $p(t)$ and thrust $R(t)$; igniter mass 7.0 g

The maximum (p_{max}, R_{max}) and mean ($\bar{p}$, $\bar{R}$) values of pressure p and thrust R, the duration of the rocket engine test t_p, and total impulse I_c, are shown in Table 4.

Table 4. Tested parameters of the solid rocket motor

m_z [g]	p_{max}	$\bar{p}$	R_{max}	$\bar{R}$	t_p	I_c
	[MPa]	[MPa]	[kN]	[kN]	[s]	[N·s]
5.5	15.9	10.9	12.65	7.90	0.112	885
6.0	17.5	9.3	13.74	6.98	0.118	824
6.5	15.0	11.1	11.99	8.31	0.105	873
7.0	15.3	11.2	12.73	7.84	0.114	894

The stationary tests demonstrated that the duration of engine operation was approx. 110 ms, less than the anticipated 0.2 s. One important parameter of engine operation is the duration of ignition charge operation, the value of which was determined based on the recorded changes in the pressure of the gasses in the laboratory rocket engine combustion chamber (Figures 9 and 10). The pressure line between the blue and red vertical lines give the pressure results during the combustion of the ignition charge within the combustion chamber.

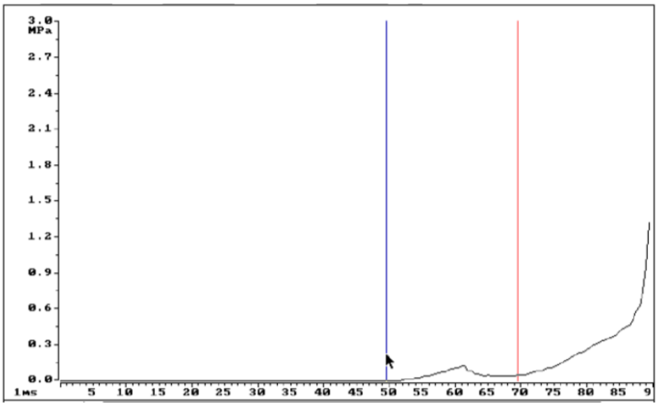

Fig. 9. Results for pressure $p(t)$ during the ignition period;
igniter mass: 5.5 g

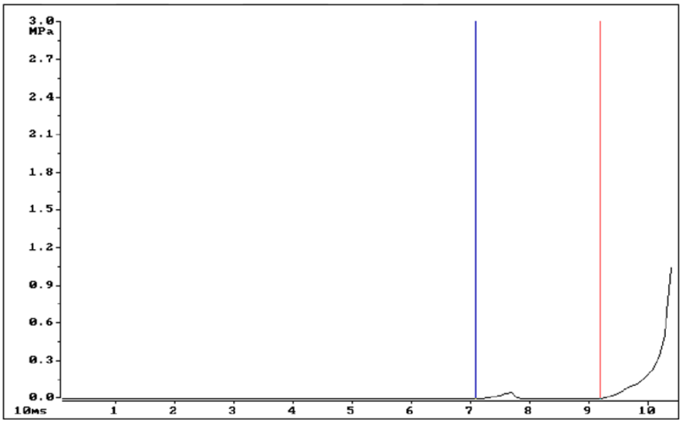

Fig. 10. Results for pressure $p(t)$ during the ignition period;
igniter mass 7.0 g

For both masses of ignition charge, the start time of the electric signal to the igniter until the start of combustion of the propellant charge (the distance between the vertical lines) is approx. 20 ms.

3.2. Field tests

The objective of the field tests was to verify the operation of the designed propulsion system and analyse the behaviour of the projectile along its trajectory. A view of the test bed (projectile) is presented in Fig. 11 and a view of the counterprojectile after the test is presented in Fig. 12.

Fig. 11. Launcher for the counterprojectile

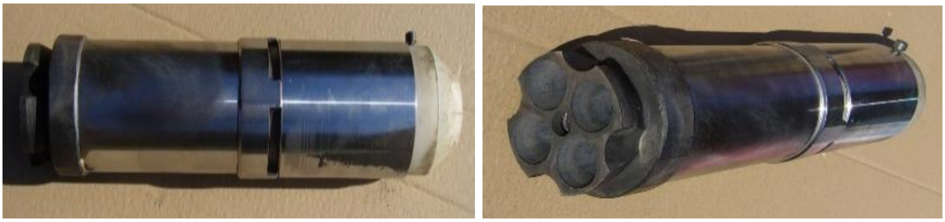

Fig. 12. Counterprojectile after the test

Recordings made using a Phantom v12 high speed camera constituted the basis for verifying the correct performance of the propulsion system, determining and analysing the motion properties of the counterprojectile inside the missile launcher and along the initial flight path (after leaving the launcher). The counterprojectile motion parameters, as recorded with the high speed camera, were determined using TEMA Motion v. 3.5 specialist software. Figures 13 and 14 present the forward speed charts of the counterprojectile vs. time and distance.

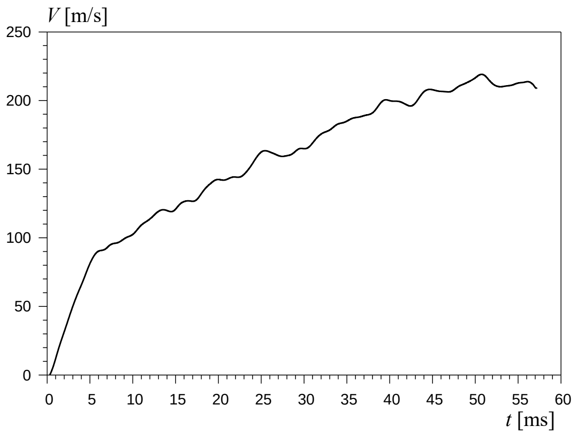

Fig. 13. Velocity of the counterprojectile as a function of time

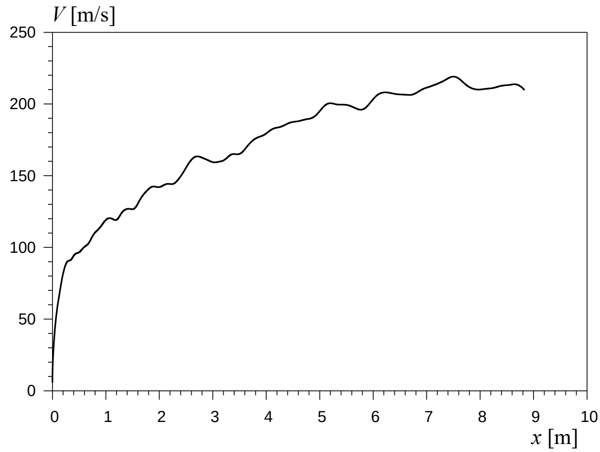

Fig. 14. Velocity of the counterprojectile as a function of distance

4. CONCLUSIONS

The testing corroborated the suitability of the design and operation of the rocket propulsion system for the counterprojectile. Based on these results, it was possible to draw the following conclusions:

a) the parameters of the rocket engine operation, such as gas pressure, thrust, and total thrust impulse confirm that the adopted assumptions and requirements were met,
b) the total duration of the rocket engine operation, including the time associated with operation of the electric igniter, combustion of the ignition charge, and combustion of the rocket propellant, was much less than 200 ms; which means that the assumed maximum action time of the rocket engine (0.2 s) was not exceeded,
c) the time needed for the counterprojectile to travel 10-15 m from the protected facility was 85-110 ms; this included the duration of the ignition charge (approx. 20 ms) and the motion (flight) time of the counterprojectile (approx. 65-90 ms),
d) the field tests demonstrated that the end of operation of the rocket engine (end of counterprojectile propulsion) occurred approx. 15 m from the launcher,
e) the designed rocket propulsion system met the requirements stated in the introduction, i.e. it achieved counterprojectile propulsion up to a velocity of approx. 200 m/s, for a duration not exceeding 0.2 s and a distance of up to 15 m from the protected facility,
f) for the next stage of project implementation it is planned to carry out tests with a warhead containing electronic detection (optoelectronic and radar) and resolution systems, as well as a destructor with a safety system.

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Badania wstępne układu napędowego antypocisku systemu ochrony aktywnej

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Streszczenie. Zaprezentowano wybrane wyniki realizacji projektu badawczego, którego celem jest opracowanie demonstratora technologii inteligentnego antypocisku systemu ochrony aktywnej. Jako układ napędowy pocisku zastosowano silnik rakietowy na paliwo stałe o cechach silnika startowego ze względu na wymagane działanie systemu ochrony aktywnej w odległości do kilkunastu metrów od ochranianego obiektu. Wykorzystując homogeniczne paliwo rakietowe produkcji polskiej zaprojektowano i wykonano elementy antypocisku i wyrzutni. Przeprowadzono wstępne badania silnika rakietowego na hamowni, w ramach których dokonano pomiaru ciśnienia gazów i ciągu silnika dla różnych mas ładunku zapłonowego oraz doświadczalne badania poligonowe napędu antypocisku, na podstawie których wyznaczono parametry ruchu pocisku w wyrzutni i na początkowym odcinku toru lotu.

Słowa kluczowe: mechanika, system ochrony aktywnej, silnik rakietowy, stałe paliwo rakietowe.