PROBLEMY MECHATRONIKI
UZBROJENIE, LOTNICTWO, INŻYNIERIA BEZPIECZEŃSTWA

ISSN 2081-5891 **9, 2 (32), 2018, 99-110**

PROBLEMS OF MECHATRONICS
ARMAMENT, AVIATION, SAFETY ENGINEERING

IR Detection of Impact Places of Projectiles in the Training System "ŚNIEŻNIK"

Waldemar ŚWIDERSKI[*], Tomasz GŁOGOWSKI, Paweł HŁOSTA, Sławomir STĘPNIAK

Military Institute of Armament Technology
7 Prymasa Stefana Wyszyńskiego Str. , 05-220 Zielonka, Poland
[*] *Corresponding author's e-mail address:waldemar.swiderski@wp.pl*

Received by the editorial staff on 2 June 2016.
Reviewed and verified version received on 8 June 2018.

DOI 10.5604/01.3001.0012.1104

Abstract. Multimedia laser-shooting training systems are more and more frequently used for trainings uniformed services and protective formations. One of the subsequent stages of the development of the "Śnieżnik" system is the possibility of training with weapon and combat ammunition, basing on dynamic scenarios and moving targets displayed on a screen. The paper presents application of IR for detection of the impact place of the projectile of combat or blank ammunition.

Keywords: electronics, multimedia shooting range, infrared radiation, projectile

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, 19-22 September 2016.

1. INTRODUCTION

The “ŚNIEŻNIK” (Fig. 1) it is an advanced multimedia training system that has been designed and performed by the Autocomp Management Ltd. firm and the Military Institute of Armament Technology for the Polish MoD.

“ŚNIEŻNIK” is a stationary device dedicated for learning, checking, and estimation of accuracy of aiming from small arms and for preparing soldiers for:

- shooting with combat ammunition at „open” shooting ranges to shields and combat figures, detection, recognition, and destruction of real targets in various terrain (urban terrain, open terrain), various time of a day and night, and various atmospheric conditions (fog, snow, rain, wind),
- cooperation in the fight with application of various types of weapon and ammunition,
- reaction of soldiers to abnormal situations [1].

Fig. 1. The “Śnieżnik” system

Training set can be installed in any room and consists of:

- a projecting system, generating on the screen, plane imaging of a 3D-model computer of terrain – battlefield (e.g., of combat shooting range),
- a system for tracking the points of gun aiming,
- sound equipment, ensuring realistic representation of acoustic environment,
- operator’s position for carrying-out and supervision of trainings,

- central unit, based on PC computers, equipped with special software fulfilling particular functions of the system,
- specimens of smart weapon, equipped with modules of radio communication, laser diodes, and pneumatic reloading systems.

Next stage of the system development was elaboration of an electronic system for detection of the impact places of gun projectile, intermediate and rifle bullet, at a closed shooting range, equipped with a training device for generation of virtual pictures of training situations displayed on screens. Because precision of localisation of projectiles impacting the screen, within the range of visible radiation, was insufficient, for this goal IR radiation was used. The results, selected from this stage of the system's development, are presented in this paper.

2. DETERMINATION OF THERMOPHYSICAL PARAMETERS OF MATERIALS USED FOR SCREENS OF COMBAT AMMUNITION SHOOTING

Walls, floor, and ceiling of the closed shooting range for shooting with combat ammunition are covered with rubber-polyurethanes plates (blocks) that are anti-ricochet shields. In the "Śnieżnik" system, the shields covering the shooting range walls fulfil also a role of a screen, on which a virtual training situation is generated. To estimate the possibility of detection of "heat traces" of the projectiles impacting a screen by means of a thermal camera, numerical calculations were performed using the special software ThermoCalc6L [2]. For calculations, thermophysical parameters of materials used for anti-ricochet shields have to be determined. To do it, experimental methods were used.

Fig. 2. Rubber-poliurethane sample designed to tests with TPMU method

Investigations consisted in determination of thermal conductivity and thermal diffusivity of homogeneous solid-state material in normal conditions (at temperature of +20^{o}C). For investigations, the material sample of dimensions (30 × 32) mm and thickness of 10.2 mm (Fig. 2) was taken from anti-ricochet rubber-polyurethane shield's plate.

The producer ensures that the shield has high ability to absorb kinetic energy and to keep ricochets from uncontrolled reflection.

The applied TPMU–*a* λ–20 hardware consists of a heating unit and a controller (Fig. 3). The obtained results are not so precise as these obtained by means of the method of periodically pulsed excitation [3] but their precision is sufficient to perform computer simulations [4].

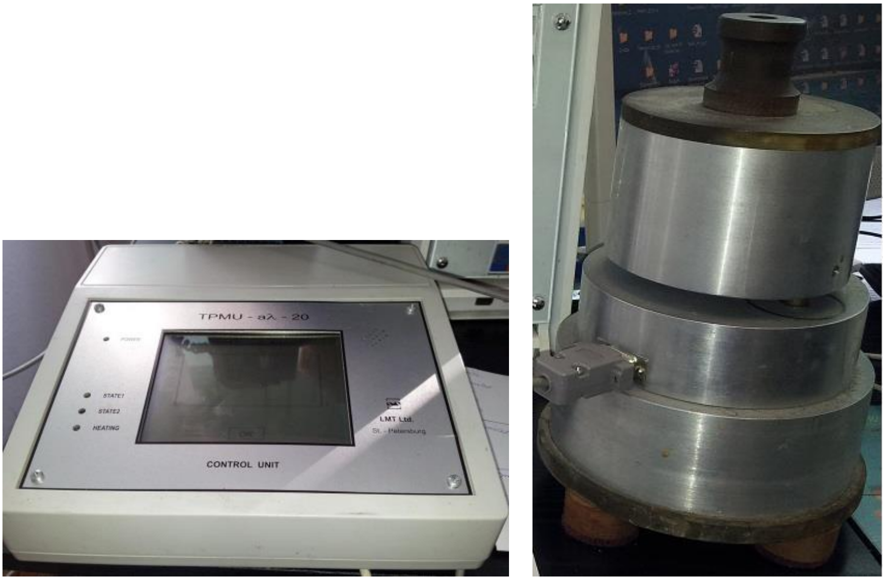

Fig. 3. TPMU–*aλ*–20 hardware for determination of thermal conductivity and diffusivity of non-metal solid materials, controller (left), heating unit (right)

The lower part of the TPMU–*aλ*–20 hardware constituted the base. The base and the upper part of hardware (upper block) form together an isothermal metallic rod of the hardware. In the central part of the hardware, there is a hole in which an electric heater is located with a built-in temperature sensor. The heater and the upper block are thermally isolated from each other due to the separating pad.

During the investigations, at the initial stage, the upper block was in close contact with the front surface of the base, to ensure isothermal metallic conditions in a metallic rod of hardware. The empty space was between the upper block and the heater.

Before the test, the upper block was deviated and the sample was situated at the heater. During the tests, the upper block pushed the sample to the heater with its own mass. During investigations, both heater and sample were heated after heat delivery. An initial test was carried out at the room temperature.

During investigations, both the heater and sample were heated for strictly determined time. The changes of temperatures of the heater and the sample's surface, with which the heater was in contact, were measured by means of temperature sensors with previously determined time interval.

To determine thermal conductivity and thermal diffusivity of the sample, regular heating conditions were applied. The above parameters were determined on the basis of the defined values of various temperature signals between the sample and the base-upper block system. The system's temperature was relatively constant as well as the heating rate was stable. In calculations, a lot of parameters were considered such as calibration parameters of the hardware related to, among others, thermal capacity of the heater, heat losses through thermal isolation and side surfaces of the sample. Calibration constants have been determined by the hardware producer during the calibration tests on the samples consisting of reference materials. The following results have been obtained:

– thermal conductivity:

$$\lambda = (0{,}1479 \pm 0.001109)\ \mathrm{W/(m\cdot K)}; \qquad \varepsilon_\lambda = 0.75\%; \qquad \alpha = 0.95$$

– thermal diffusivity:

$$\alpha = (0{,}9306 \pm 0.0449)\cdot 10^{-7}\ \mathrm{m^2/s}; \quad \varepsilon_\lambda = 4.82\%; \qquad \alpha = 0.95$$

where:

ε_λ – relative error, $\alpha =$ 0.95 – confidence interval.

The measurement of the density (ρ) was performed at the Laboratory of Testing Combat Means of the Military Institute of Armament Technology using a pycnometric method (by means of a gas pycnometer). The sample density was 1.38 g/cm^3 = 1380 kg/m^3.

The specific heat (c_p) of the investigated sample of material, that will be needed for numerical calculations, has been determined from the known relation [5]:

$$\alpha = \lambda/(c_p\rho) \tag{1}$$

and it was $c_p = 1152$ J/kg·K.

3. NUMERICAL CALCULATIONS

The algorithm applied for numerical calculations with the finite elements method in ThermoCalc6L$^{\mathrm{TM}}$ program is in detail described in papers [6, 7].

A part of the kinetic energy which is lost by the projectile during anti-ricochet shield is changed into thermal energy and as a result on the shield's surface there occurs "heat trace" at the place of projectile's impact.

To simulate this phenomenon, the thermal pulse of the maximum density $Q = 10^6$ W/m^2 and the heating period $\tau_h = 0.01$ s were applied. The initial temperature of the sample and the room temperature was 20°C.

Distribution of the heat flux density is described by the Gauss function. The surface, onto which falls the heat flux, is comparable with a cross-section of the 9 - mm projectile. The thickness of anti-ricochet shield was 50 mm. The thermophysical parameters of the shield, necessary for computer simulation, were determined experimentally. Figure 4 shows temperature distribution on the sample's surface, at the place heated by a thermal impulse. For comparison, the results obtained directly after the heating termination and 30 s after the heating completion in the phase of cooling the sample's surface are given.

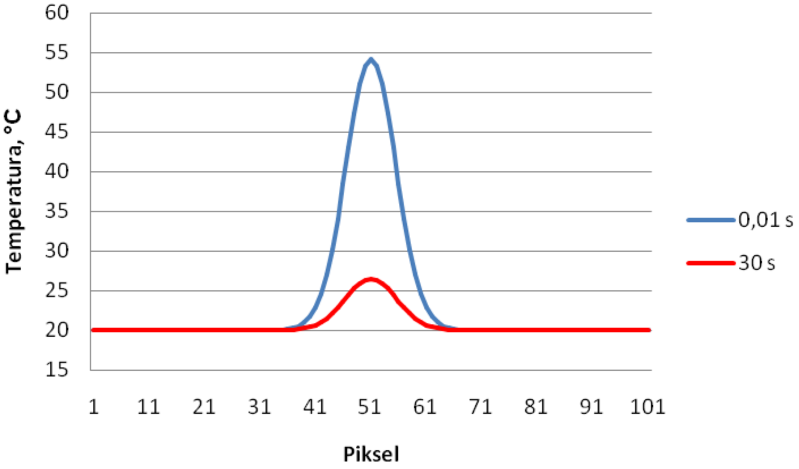

Fig. 4. Temperature distribution on the sample surface, directly after heating completion and 30 s after heating finish

4. EXPERIMENTAL INVESTIGATIONS

Experimental investigations were performed at the set-up shown in Fig. 5. For recording the changes of the temperature field of the anti-ricochet shield, the FLIR A655 thermal camera was used. Shootings were made with the combat ammunition 9 × 19 mm NATO and 5.56 × 45 mm NATO and blank ammunition 9 mm MMR, 5.56 mm MMR, 9 mm TBR, and 5.56 mm TBR (Fig. 6).

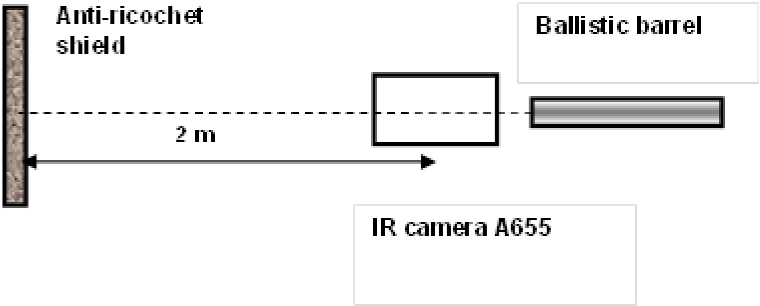

Fig. 5. Experimental set up


a) b) c) d) e) f)

Fig. 6. Combat ammunition a) 9 × 19 mm NATO, b) 5,56 × 45 mm NATO, blank ammunition: c) 9 mm TBR, d) 5,56 mm TBR, e) 9 mm MMR, f) 5,56 mm MMR

5. RESULTS

The carried-out experimental investigations showed that as a result of shooting with combat projectile ammunition (Fig. 6 a-b), as well as with blank projectile (Fig. 6 c-d) to the anti-ricochet shield made of rubber-polyreuthane composite, well visible, in IR, a "heat trace" (Figs. 7 and 8) appeared. The impact places of the projectiles of combat ammunition, that penetrate the tested shield (of a thickness of 5 cm) do not leave "heat traces" on the shield's surface that can be well seen in a visible range. The projectiles of blank ammunition are reflected from the shield and it is not possible to localise the places of their impact in a visible range [7].

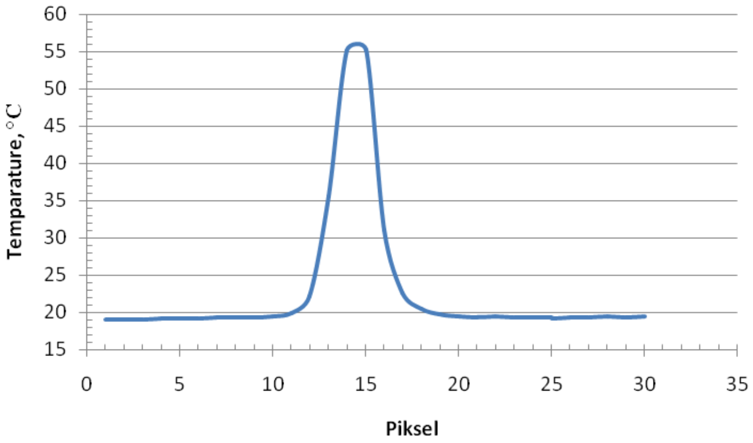

Fig. 7. Temperature distribution on the surface of anti-ricochet shield at the place of the projectile impact from 9 × 19 mm NATO cartridge

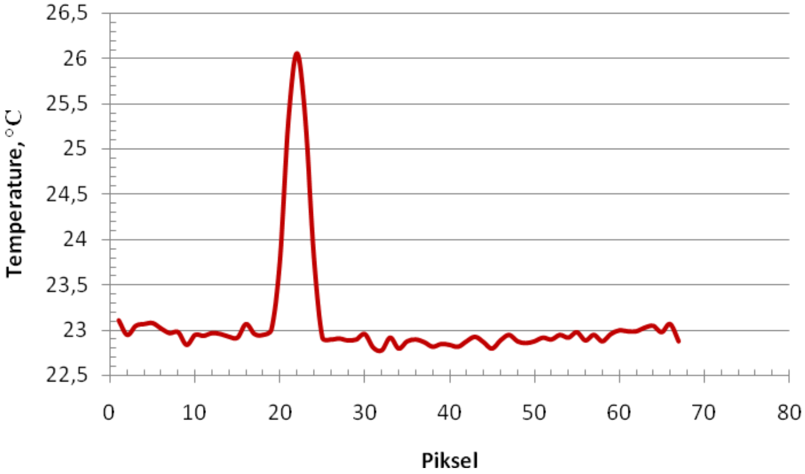

Fig. 8. Distribution of temperature on the surface of anti-ricochet shield at the place of the impact of 9 - mm projectile from TBR cartridge, blank ammunition

Thermophysical properties of materials of anti-ricochet shields, cause that the process of heat conduction occurs relatively slowly and a “heat trace” of the projectile’s impact can be seen for several tens’ seconds to a few minutes (Fig. 9). It additionally makes more difficult to record the places of next projectiles impact that are near the places of previous impacts.

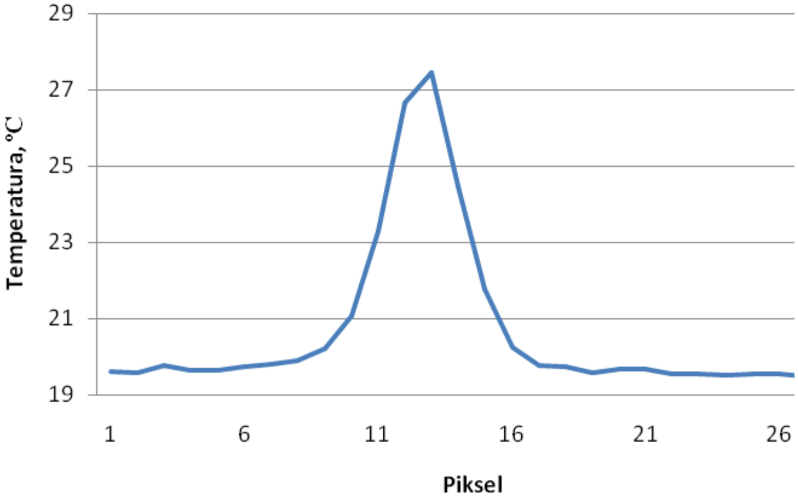

Fig. 9. Distribution of temperature on the surface of ani-ricochet shield at the place of impact of projectile from a cartridge of 9 × 19 mm NATO – 25 s after the impact

6. SUMMARY

The results of numerical calculations and experimental investigations showed that at the place of hitting the anti-ricochet shield by projectiles, from ammunition used in the investigations, the elevated temperature for at least several dozens of seconds is observed. In order to eliminate a disadvantageous phenomenon of too long visibility in IR of the "heat trace" of the place of the projectile's impact, two algorithms were proposed [8].

The first solution is application of the algorithm in the detection system, that makes possible to control the traces duration, in which they are exposed and read. The time of exposure of „heat traces" is controlled due to indication of the threshold of minimum value of the temperature reading, at which the exposure reading with application of a thermal camera is finished.

Application of the IR detection system allows for creation of an electronic system for detection the places of projectile's impact in form of the trace that can be thermally distinguished from a background (target surface/aim). Thus, the training people can make fire, using small and combat guns, to the goals visible in motion on the screen. Short exposure time of "heat traces" of the places of projectiles impacting the shields, in short time interval, makes it possible to record the consecutive projectiles hits at the same point or near this point. The algorithm considers also a calibre and a kind of the used ammunition what is significant for the value of increase in the temperature field at the place of projectile's impact.

Other solution is application of the algorithm that records the changes in the temperature field of above 2 × 2 pixels on the screen/shield and of the value increasing by 2°C the average screen/shield value.

The temperature change, appearing at the thermogram that can be seen on a computer screen, is automatically recorded by the software as a projectile's hit and it is electronically removed at the next picture (next thermogram) recorded by a thermal camera. In practice, the software records only one picture from the camera (thermogram) at which the first change in temperature field appears. The next changes of the temperature field are recorded as consecutive impact places of the projectiles on a single picture (thermogram). For the thermal camera that records with the frequency of 50 Hz, the records of hits from a single small arm are possible for every 0.02 s. Probability that the next projectile hits the same place, for shooting to the targets being observed in motion on the screen, in time shorter that 0.02 s, is practically equal to zero.

At the International Defence Industry Exhibition MSPO fair in 2015, that was held in Kielce (Poland), at MIAT's stand, the CQC trainer was presented, in which there was applied, the described in the paper, IR method of detection of impact points of blank projectiles on the screen.

REFERENCES

[1] www.witu.mil.pl

[2] ThermoCalc6L^{TM}

[3] Panas J. Andrzej, Mirosław Nowakowski, Zbigniew Jakielaszek, Przemysław Tkaczyk. 2011. „Badania dyfuzyjności cieplnej past termoprzewodzących metodą wymuszenia okresowego". *Modelowanie Inżynierskie* 41.

[4] Pracht Monika, Waldemar Świderski. 2016. „Eksperymentalne wyznaczanie parametrów termofizycznych kompozytu aramidowego stosowanego w indywidualnych osłonach balistycznych". *Problemy mechatroniki. Uzbrojenie, lotnictwo, inżynieria bezpieczeństwa – Problems of Mechatronic. Armament, Aviation, safety Engineering* 7 (2) : 89-104.

[5] Świderski Waldemar, Ryszard Chachurski. 2009. „Analiza porównawcza wybranych metod numerycznego modelowania zagadnień nieniszczących badań termicznych materiałów kompozytowych". *Biuletyn WAT* LVIII (4).

[6] Świderski Waldemar. 2010. *Metody termograficzne w nieniszczących badaniach materiałów kompozytowych do zastosowań specjalnych*. Monografia habilitacyjna. Zielonka: Wydawnictwo WITU.

[7] Świderski Waldemar, Tomasz Głogowski, Paweł Hłosta, Sławomir Stępniak. 2015. "The use of IR camera to detect the points of impact projectiles". *Measurement Automation Monitoring* 61 (6) : 271-274.

[8] Patent P.412063. *Sposób wykrywania i rejestracji miejsc uderzeń pocisków strzeleckich w cel za pomocą kamery termowizyjnej*.

Detekcja w podczerwieni miejsc uderzenia pocisków w systemie szkolno-treningowym „Śnieżnik"

Waldemar ŚWIDERSKI, Tomasz GŁOGOWSKI, Paweł HŁOSTA,
Sławomir STĘPNIAK

Wojskowy Instytut Techniczny Uzbrojenia,
ul. Prymasa St. Wyszyńskiego 7, 05-220 Zielonka

Streszczenie. Multimedialne laserowe strzeleckie systemy szkoleniowe coraz częściej są wykorzystywane w szkoleniu służb mundurowych i formacji ochronnych. Jednym z kolejnych etapów rozwoju systemu „Śnieżnik" jest umożliwienie treningu z użyciem broni i amunicji bojowej w oparciu o dynamiczne scenariusze oraz poruszające się cele wyświetlane na ekranie. W artykule przedstawiono zastosowanie podczerwieni do detekcji miejsca uderzenia pocisku amunicji bojowej i ćwiczebnej.

Słowa kluczowe: elektronika, strzelnica multimedialna, podczerwień, pocisk