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Work on developing a thermal shooting target

Abstract

The paper presents work on the development of a thermal target providing for shooting with the use of night-vision and thermovision sights in night conditions as well as during the day, without changing the target. The image of the target in the night sight is visible by illuminating it through an IR lamp. The target is designed so that the reflected IR stream is directed towards the objective lens. Compared to existing solutions, the new thermal target has a number of advantages, such as it does not require long-time heating and is immediately ready to operate after thermal lamp lighting, significantly reducing energy consumption. The project is currently at the stage of prototype target testing.

Keywords: thermal target, infrared, emissivity, shooting.

1. Introduction

Basic training for every soldier includes firearms training, during which soldiers learn to master the principles of firearm operation, proper posture, and correct use of weapons including constructing and servicing the weapon. The main objective of this training is to improve their skills with small arms using different targets in different weather conditions. A particularly difficult part of this training is shooting at night. During night shooting carried out for lit targets, flashes are exposed, however the soldiers must not expose themselves [1].

At present, two basic types of targets are used in Poland for shooting at night: lighted with reflectors to visible light (Fig. 1a) and heated by means of resistance wire (Fig. 1b).

a) b)

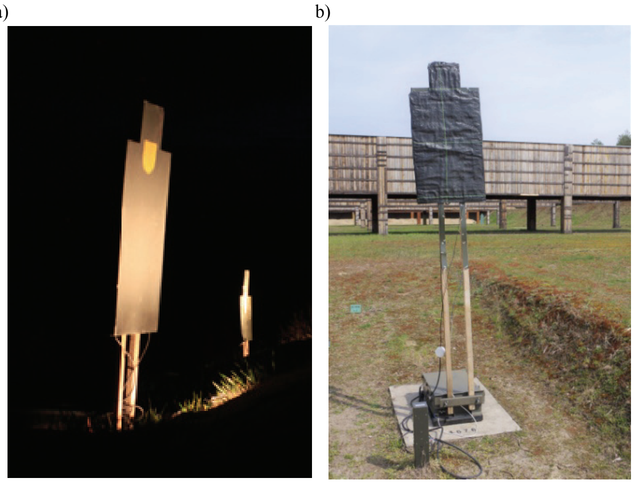

Fig. 1. Targets currently used for shooting at night

After analysis of global technology solutions for targets for shooting at night with the use of thermal and night vision sights [2-8], undertaken in the Military Institute of Armament Technology, and in cooperation with OPTIMUM company, we developed the concept of a new solution of target technology for night shooting. The concept for this target has been patented [9].

2. The novel concept of the thermal target

The essence of the concept is repetitive, three-dimensional surface structures reflecting and scattering infrared radiation on the target which includes convex spherical mirrors. The symmetry axes of the spherical mirrors are parallel to each other and are inclined towards the vertical and deviated from it towards the source of infrared radiation. In addition, the spherical mirrors are covered with a greenish-colored alumina layer of thickness not exceeding 6 μm. Illuminated by infrared radiation, the three-dimensional surface pattern of the firing target, containing primarily spherical mirrors, provides almost complete reflection of the incident beam. It also causes a corresponding pattern of reflected infrared radiation beam arriving at the observation and sighting devices, comprised of a solid angle of less than one steradian. The reflected infrared beam in a small solid angle has a significant energy density, providing effective irradiation of observation and sighting devices. The colored green layer covering the spherical mirror allows adequate visibility of the target as it is illuminating in the visible range. Thanks to the almost complete reflection of the incident infrared radiation beam through the spherical mirror of the target, an infrared radiation source of relatively low power can be used to irradiate it. This system allows efficient observation and optimally effective target shooting, both night and day, with low power requirements for infrared radiation which is particularly important when powering the battery source. Power must be provided from batteries due to safety requirements at the shooting range.

The developed solution is illustrated in Figures 2 and 3. Figure 2 shows a side view of a vertical shooting target with an infrared source illuminating the target.

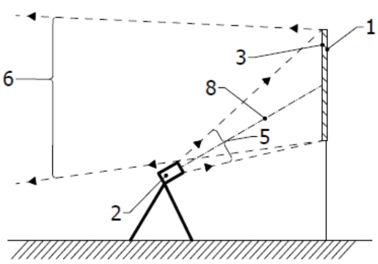

Fig.2. Vertical shooting system with infrared source illuminating the target

This system consists of a shooting target 1 positioned vertically and a source 2 for infrared illumination (Fig.2). The infrared radiation source 2 is below the lower edge of the target 1 and the axis 8 of the infrared radiation beam 5 is inclined at an angle of 30 degrees to the horizontal. The illuminated surface 3 of the target 1 consists of repetitive three-dimensional surface structures mainly for reflecting and, to a much lesser degree, infrared radiation diffraction, including equal, convex spherical mirrors 4 evenly distributed on the surface 3 (Figure 3). The spherical mirrors 4 are coated with an alumina layer of 6 μm thickness, colored green. The symmetry axes 7 of the convex spherical mirrors 4 are parallel to each other and deviate from the vertical by an angle of 105 degrees towards the infrared radiation source 2 (Figure 3).

The infrared radiation beam 5 emitted by the source 2, falling on the surface 3 of the target 1, is almost completely reflected by the convex spherical mirrors 4. The reflected beam 6 of infrared radiation is located at a solid angle of not more than one steradian, effectively illuminating the thermal sighting and sighting devices (not included in the drawing), so that in night conditions the target 1 is clearly visible as a target from the observation and sighting station.

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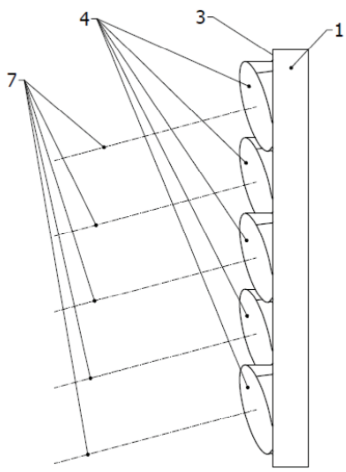


Fig. 3. Fragment of the target - side view

3. Study of target models

In order to determine the actual angle of reflection of infrared radiation by the target, the target model is made of aluminum (Fig. 4). Measuring the angle of reflection of infrared radiation conducted on the model of the target made of aluminum, on the surface of a milled convex mirror forming a spherical sector of the same solid angle of approx. 1 steradian, and the same inclination angle relative to the surface model of the target. To determine the angle of reflection, a test stand on which the model of the target was illuminated with an IR lamp was built at a distance of 2 m. The optical axis of the IR lamp was set so that a maximum flow of infrared radiation reflected from the lens was directed after being reflected towards the camera lens. The FLIR SC 7600 thermal imaging camera was 2 meters from the model of the target and its optical axis was perpendicular to the surface of the model (position "0"). During the measurement, the model was rotated in the elevation of the "0" position of 5° to an angle in the range ± 35°. The thermal imaging camera recorded "apparent" changes of the temperature field of the target from reflection of a beam of infrared radiation from the surface of the target, but not its real growth. The graph (Figure 5) shows the results of these measurements.

Fig. 4. Model of target to measuring the angle of reflection of infrared radiation

Measurements were made at ambient temperature $T_0 = 23.1$°C.

The next stage of the experimental work was to determine the emissivity of the material which was used to coat the target with a layer of aluminum oxide. The study was conducted on 6 samples of aluminum channel covered with anodized layers of different colors. Samples are shown in Fig. 6.

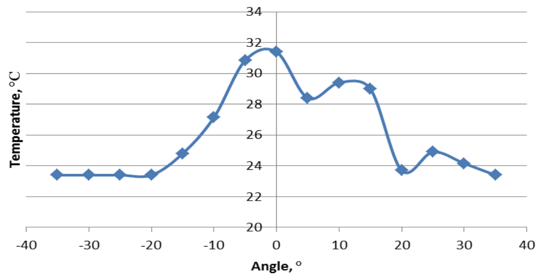


Fig. 5. The result of measurements the angle of reflection of infrared radiation

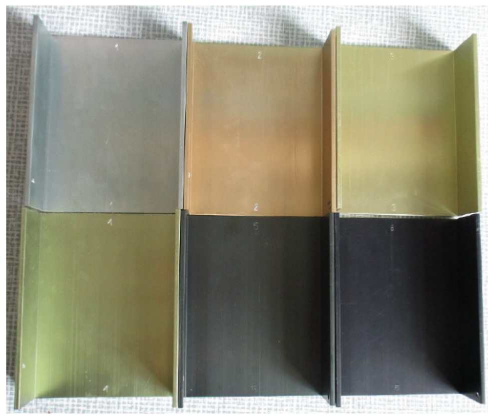


Fig. 6. The samples of aluminium channel covered with anodized layers of different colors

Measurements of the thickness of the anodized layer applied on samples made of aluminum (Fig. 6) were made at the Institute of Precision Mechanics. The measured values are presented in Tab. 1.

Tab. 1. The thickness of the anodized layer of samples

No. sample	1	2	3	4	5	6
Result of measurements, µm	6.13	3.8	4.11	3.47	10.63	15.99
	5.93	3.42	3.55	3.47	9.28	16.35
	6.24	3.72	3.51	3.3	9.53	15.53
	5.92	3.99	3.41	3.5	9.33	15.8
	5.67	3.94	3.04	3.5	9.73	16.35
Average value, µm	5.98	3.77	3.52	3.45	9.7	16

In order to assess the effect of thickness of the anodized layers and their coloration on the infrared radiation stream reflected from the target, the emissivity factor of the samples was determined experimentally in laboratory conditions (Figure 6). Emissivity is a physical parameter characterizing the radiant properties of real bodies [11].

The average emissivity was determined using a FLIR 7600 SC thermal camera (measuring range 3-5 µm). The individual samples of the material were heated from an ambient temperature of 20°C to 55°C. The average emissivity was determined from the same surface area for all samples at 5°C. The sample temperature was measured directly by contact method using a thermocouple. The camera software was adjusted to ensure emissivity measurement readings from the camera would be the same as the thermocouple measurement.

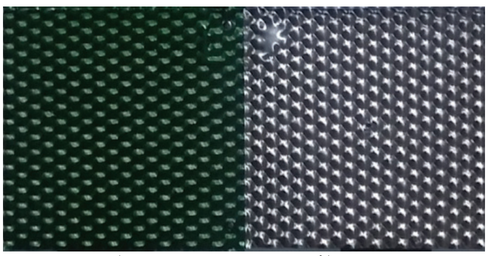
Table 2 shows the results of measuring the emissivity of the samples shown in Fig.6, made at Military Institute of Armament Technology.

Comparing the results of the measurement of emissivity in Table 2 with the results of measurement of the thickness of the applied anodized layer, it can be concluded that the flux density of the infrared radiation depends primarily on the thickness of the layer applied to the aluminum. The coloration of this layer visible in the range of visible radiation has little effect on the density of the reflected infrared radiation stream. An important role is therefore played by the material the samples are made of.

Tab. 2. Emissivity of samples for different temperature ranges

No. sample	25^0C	30^0C	35^0C	40^0C	45^0C	50^0C	55^0C
1	0.22	0.22	0.22	0.22	0.22	0.22	0.24
2	0.29	0.29	0.23	0.22	0.21	0.20	0.20
3	0.10	0.10	0.10	0.13	0.13	0.15	0.16
4	0.24	0.24	0.23	0.23	0.22	0.22	0.21
5	0.34	0.34	0.33	0.33	0.32	0.32	0.31
6	0.40	0.45	0.47	0.48	0.48	0.49	0.49

The next step was completed to better develop the technology of the target, which would ensure its performance at the lowest cost without compromising its parameters. 0.4 mm aluminum sheet coated with a green anodized layer was selected as a target. In daylight conditions, thanks to the effective reflection of green visible light through the spherical mirror layer 4, target 1 is clearly seen by optical sighting as a target with a green surface 3 (Fig. 2). Reflecting mirrors extrude from the surface of the target. The sheet metal elements are glued onto the wooden plywood. Fig. 7 shows elements from which a target designed for further investigation has been made.



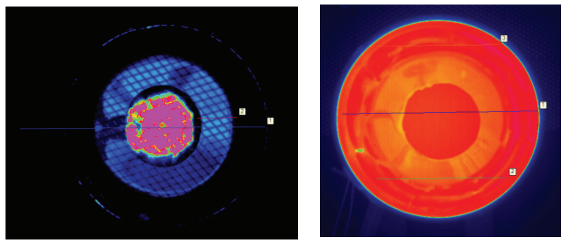
a) b)

Fig. 7. Elements of target a) after anodizing, b) before anodizing

Due to the regulations in force at military shooting facilities, the infrared lamp which illuminates the target must have power from direct current. For this reason, there were no commercially available IR lamps which met to our requirements. Therefore, an IR lamp was developed as shown in Fig. 8.

Fig. 8. IR lamp to illuminate the target

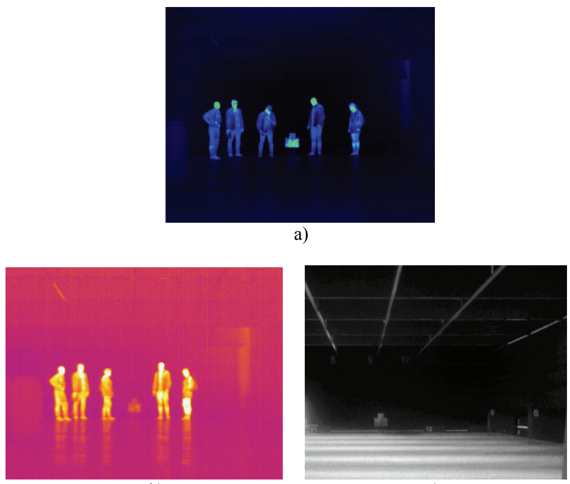
Fig. 9 shows the thermograms illustrating the reflected infrared stream from the IR lamp. The thermogram and Fig. 9a show a variant with a badly set filament (reflector not working properly) and thermogram Fig. 9 b shows the filament set correctly. In this case, the infra-red beam is directed toward the lens of the IR camera. The temperature of the filament measured by contact with the thermocouple was 270°C.



a) b)

Fig. 9. The thermograms illustrating the reflected infrared stream from the IR lamp: a) reflector not working properly, b) reflector working properly

The end result of this stage of the project was recording of the infrared images of the target made from elements before the anodized process. The recordings were performed on shooting at a closed distance of 50 m. Fig. 10 shows images recorded with a FLIR 7600 SC and FLIR 640 camera (8-12 µm range) and a night vision camera.



a)

b) c)

Fig. 10. Images of target a) 3-5µm range, b) 8-12µm range, c) night vision

4. Conclusions

The results of the research on target models confirmed assumptions of the novel concept of thermal target.

Future work will focus on:

- signaling hits system in thermal target,
- thermal target shooting projectiles of large calibers.

During the 3rd edition of the gala of the competition for Innovations for the Armed Forces of Poland, organized by the Inspectorate for Implementation of Innovative Defense Technologies, in the category of research and development projects for the Development of technology for thermal targets for night training and shooting, the WITU- OPTIMUM award was given to the consortium.

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