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Testing coatings of reflecting infrared radiation for a target for night shooting

Abstract

The paper presents the principle of operation of a new night-shooting target. Because this target requires a covering that reflects the infrared radiation flux generated by the reflector from its surface, testing of different variants of the cover and the shape of the target surface has been carried out. Emissivity is a physical parameter characterizing the radiant properties of real bodies. The emissivity coefficient of extruded aluminum sheet samples covered with a layer of green colored aluminum oxide was determined. The aluminum oxide layer was applied using two different technologies being galvanic and anodizing.

Keywords: thermal target, infrared, emissivity, shooting.

1. Introduction

During a night of shooting carried out for the purposes of the study, flashes were either exposed or not exposed. For the purposes of lit and unmasked firing shots, this is carried out using backlighting of the sight scale (self-lighting caps). For non-unmasking purposes, this is carried out using optoelectronic sights, with the targets exposed by infrared and heat radiators [1]. When shooting with optoelectronic sighting, targets visible in infrared are used.

Due to the strict safety conditions at the shooting ranges, infrared radiation sources used to illuminate targets during night shooting must be supplied with DC current from accumulators. This limits the density of the infrared radiation stream to which the target is illuminated. In order for the target to be clearly visible with a thermal imaging sight, there must be an appropriate thermal contrast between the target and the background on which the target is visible. The temperature difference between the target and the background should be at least 5 ° C. There is a simple relationship between the temperature of the object and the radiation emitted by it, referred to as the law of Stefan-Boltzmann [2]:

$$W_b = \sigma T^4 \quad (1)$$

where: W_b - total black-body emittance (power per unit area emitted from a black body), σ - Stefan-Boltzmann's constant = 5.67×10^{-8}, W / m^{2}K^4, T - absolute temperature of the black body, K.

However, such a relationship is right only for the theoretical object - a black body. For real objects, it has the following form:

$$W = \varepsilon\sigma T^4 \quad (2)$$

where: ε - emissivity.

Emissivity is a measure of the intensity of radiation from the test object in relation to the intensity of the radiation of the blackbody surface at the same temperature. The emissivity value of an object also depends on the temperature of the object. Taking the above into account during the observation of the target by the thermal imaging sight, its good imaging will be influenced by the spectral range in which the viewfinder works and the emissivity value of the target surface.

2. Target for night shooting

The concept of a new night-shooting target is described in detail in the patent [3]. The works on developing the target model are described in papers [4-6]. The developed system of the shooting target with its source of infrared radiation is intended for conducting day and night exercises on shooting ranges and training grounds, also in conditions of limited visibility. It can also be used in the field of learning to recognize targets, aim, and fire from weapons using observation and sighting devices working in the visible and infrared radiation.

The idea of this system is that the repetitive three-dimensional surface structures reflecting and scattering the infrared radiation of the target contain convex spherical mirrors. The symmetry axes of the spherical mirrors are parallel to each other and inclined to the vertical as well as inclined away towards the source of infrared radiation. In addition, the spherical mirrors are covered with a layer of aluminum oxide colored green with a thickness not exceeding 6 µm.

The three-dimensional surface pattern of the target, containing spherical mirrors and illuminated by infrared radiation, provides almost complete reflection of the incident beam. It also causes the appropriate shape of the reflected beam of infrared radiation reaching the observation and sighting devices, located at a solid angle below one steradian. A reflected beam of infrared radiation located at a small solid angle has a considerable energy density which provides sufficient thermal contrast between the target and the background in observation and sighting devices. A green layer covering the spherical mirrors enables proper visibility of the target when illuminated with visible rays. Due to the almost complete reflection of the incident beam of infrared radiation by the spherical mirrors of the target, a source of infrared radiation of relatively low power may be used for irradiating it. This system enables effective observation and optional effective shooting of the target visible both in night and day conditions, with low requirements in the range of the power of the infrared radiation source, something which is particularly important when powering the source from accumulators.

The developed solution is illustrated in Figures 1 ÷ 3. Figure 1 shows a side view of the arrangement of a vertical shooting target with a source of infrared radiation illuminating the target. Figure 2 shows an isometric view of a target fragment with a visible three-dimensional surface pattern irradiated with infrared radiation. Figure 3 shows a fragment of the target shown in Figure 2, in a side view from one side of the target fragment.

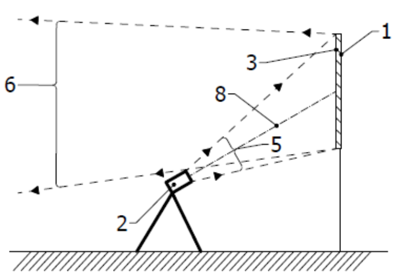

Fig. 1. The arrangement of a vertical shooting target with a source of infrared radiation illuminating the target [3]

This system consists of the shooting target 1 set vertically, and a source 2 of infrared radiation illuminating it (Fig.1). The infrared radiation source 2 is located below the lower edge of the target 1, while the axis 8 of the incident beam 5 of infrared radiation is inclined to the horizontal at an angle of 30 degrees. The illuminated surface 3 of the target 1 consists of repetitive, three-dimensional surface structures, mainly reflecting and, to a much lesser extent, infrared scattering, containing identical convex spherical mirrors 4 uniformly distributed on the surface 3 (Fig. 2).

The spherical mirrors 4 are covered with a layer of aluminum oxide 6 μm thick, colored green. The symmetry axes 7 of convex spherical mirrors 4 are parallel to each other and deviated from the vertical by an angle of 105 degrees towards the source 2 of infrared radiation (Fig. 3).

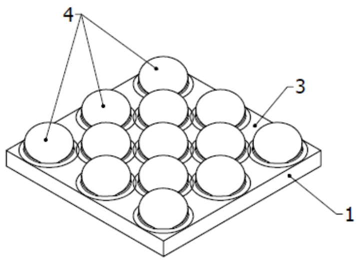

Fig. 2. Fragment of the target [3]

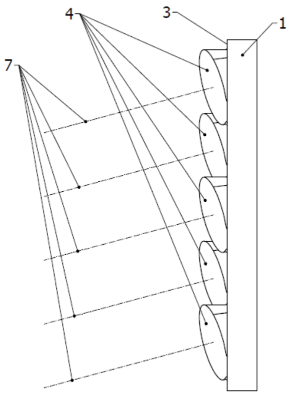

Fig. 3. Fragment of the target - side view [3]

The beam of infrared radiation emitted by the source 2, falling on the surface 3 of the target 1, almost completely reflects due to the convex spherical mirror 4. The reflected beam 6 of infrared radiation is located at a solid angle of no more than one steradian, effectively illuminating thermal observation and sighting devices (not included in the figure), so that in night conditions the target 1 is clearly visible as a target from the observation and sighting station. In daylight conditions, due to the effective reflection of the visible green color through the spherical mirror layer 4, the target 1 is clearly seen by the optical observation and sighting devices as the target with a green surface 3.

In the course of further work related to enabling the automatic detection of the impact of the projectile on the target, the target concept was expanded to include a short-circuit and impact system. The short-circuit system is based on the fact that the target is made of two sheet metal layers between which there is an insulating layer which does not conduct electricity. A DC voltage is applied to the metal layers. The projectile breaking the target causes a short- circuit, which is information about the hit of the projectile on the target. The principle of operation of the impact system is that an inertial sensor is mounted to the surface of the target. The inertial sensor detects vibrations caused by the impact of the projectile on the target. These new solutions also forced a change in the technology of pressing the aluminum sheet covering the target. The extrusion of micro lenses (Fig.4) is only possible for very thin aluminum sheets up to 0.4 mm thick. At the target, with the signaling of hits (impact and short-circuit), a thicker sheet is required. Therefore, the next step was to develop such technology as to create a three-dimensional target structure that would provide infrared radiation reflection as in the case of micro lenses. In the new solution (Figure 5), the three-dimensional structure of the reflective surface of the target is shaped as non-symmetrical waves whose longer sides are directed downwards. From the side illuminated by infrared radiation, the shield is covered with a layer of aluminum oxide of a green color.

Two technologies for covering the surface of the target with a layer of aluminum oxide, anodizing and galvanic, were also used.

a) b)

Fig. 4. Elements of target a) after anodizing, b) before anodizing

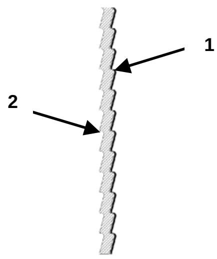

Fig. 5. Cross-section of the target structure: 1 - target, 2 - aluminum oxide layer

3. Testing covers

3.1. Test stand and samples

Since the decisive factor influencing the imaging of the target in the thermal imaging sight is the emissivity [7] of the target surface, the emissivity coefficient for 5 different samples intended to cover the target surface was experimentally determined in laboratory conditions on the measuring stand. On the surface of the target elements, reflective coatings were applied with two technologies: anodizing (samples 1, 4, and 5) and galvanic coatings (samples 2 and 3). The samples also differed in the thickness of the deposited layers as well as in the shape of a three-dimensional structure, which can be seen in the pictures in Figs. 6 and 7.

Fig. 6. The samples No. 1, 4 and 5

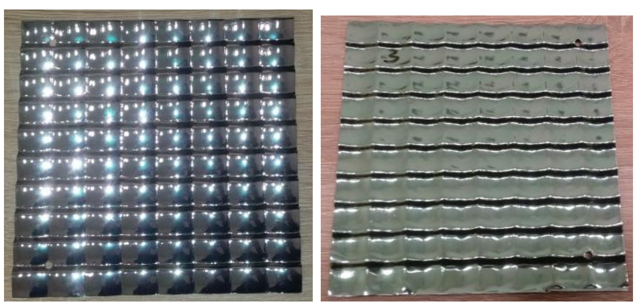

Fig. 7. The samples No. 2 and 3

Averaged emissivity was determined using a FLIR 655 thermal camera (measuring range (8...14) μm). Individual material samples were heated from an ambient temperature of 20°C to 55°C. The average emissivity coefficient was determined from the same area for all samples at 5°C. The temperature of the samples was measured directly by contact method using a thermocouple. In the camera's software, the emissivity factor was set so that the readings from the camera were the same as from the thermocouple measurement.

3.2. Results

The course of changes in the emissivity coefficient of the tested samples is shown graphically in Fig.8. Table 1 shows the average results of the emissivity coefficient measurement. Comparing the results for samples covered with a layer of aluminum oxide using different technologies, it can be seen that large differences in emissivity occur between coatings made with galvanic technology. The difference in the emissivity coefficient between the thin coating and the thicker layer is about 0.6. With coatings made using anodizing technology, this difference is about 0.3, and at a temperature range of 25°C … 40°C, approx. 0.15.

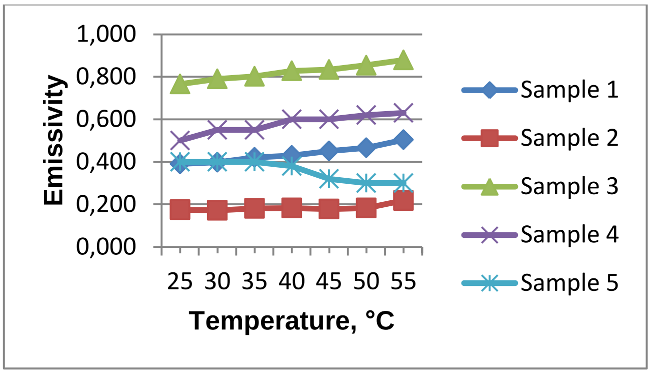

Fig. 8. Changes in the emissivity coefficient of the tested samples as a function of temperature

Tab. 1. Average values of the emissivity coefficient of the tested samples

Number of sample	1	2	3	4	5
Averange emissivity	0.437	0.184	0.822	0.579	0.357

4. Summary

The use of galvanic technologies for coating the plates reflecting the infrared radiation is economically justified since this technology is several times cheaper. The problem is to choose the thickness of the layer with the appropriate coefficient and such a color that the target can also be used for daylight shooting. The samples 2 and 3 are an example of such problems; the value of the emissivity coefficient of sample No. 2 ensures the best reflection of the infrared radiation stream, but its color in green is insufficient to use the dial in daylight conditions, whereas, sample no. 3 fulfills the conditions for conducting shooting during the day, but the emissivity coefficient of the coating applied to the sample does not provide the conditions for shooting at night.

The samples were covered with coatings made with the anodizing technology meet the requirements for shooting at night and during the day.

We would like to focus our further work on determining the thickness of the applied coating using galvanic technology so that the emissivity coefficient values are within the range provided by the anodizing technology with the coloring of the coating allowing shooting also during the day.

5. References

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