The Influence of Solar Radiation on the Parameters of the Polymer Type Test Pattern, Designed to Adjust the Optical Aircraft Equipment

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Abstract. The flexible compound materials of test objects (type test patterns) to adjust the aviation optical equipment for the Earth remote sensing obtained by the method of ink-jet printing on banner fabric have been studied. The quantitative regularities of changes in the optical and mechanical properties have been determined, which allow predicting the maintenance of the operational characteristics of the type test pattern.

1. Introduction

Adjustment and determination of the spatial resolution of aviation electrooptical equipment is performed by shooting and subsequent recognition of line images applied to objects located in a certain way on the surface of the Earth [1].

Dismountable sets of fabrics made of polymer composite materials [2], which are flexible and resistant to weather factors, are proposed as carriers of line images (type test patterns): strength in dry and wet conditions, thermal and cold resistance. The most important property of the line image carriers is the stability of their optical characteristics. They include printing density or light reflection factor and contrast ratio of adjacent line images forming the type test pattern [3]. To determine the sensitivity limits of aviation electrooptical equipment, it is necessary to manufacture and study type test patterns with low-observable lines characterized by the contrast ratio of about 0.2.

As a result of short-term tests (radiation by mercury lamp with UV light in the laboratory for 100 hours) that have been conducted earlier [4] to assess the light resistance of the type test patterns printed by the ink-jet printer on banner fabric coated with polyvinyl chloride, no significant changes in optical density have been found. Determination of the contrast ratio of adjacent images of light and dark lines and changes in the contrast ratio influenced by UV radiation has not been performed. Therefore, in order to substantiate the reliability of light resistance prediction and ensure the multiple use of the type test patterns made of banner fabric, it is necessary to conduct longer tests with assessing the contrast ratio of the printed images and controlling the mechanical characteristics of the fabrics under conditions similar to operating conditions in areas with maximum solar radiation.

The paper objective is to determine the resistance to solar radiation of low contrast monochrome images of the type test patterns made by ink-jet printing on high-strength banner fabric.
Material: S-PRW334240B banner fabric made in the Republic of Korea from polyester thread grid coated with plastisol of polyvinyl chloride.
Ink for ink-jet printing (solvent ink): BIGINKT-900 BLACK.

The procedure for accelerated testing of the type test pattern corresponds to GOST 28202-89 (IEC 68-2-5-75) Part 2. Tests: Simulated solar radiation at the ground level. The test procedure on option A assumes an 8-hour radiation cycle. Radiation time is 60 days.

The UV source is a lamp of the brand DRT-1700 (SKTB "Xenon") with a capacity of 1700 W that provides a density of ultraviolet light power of 1120 W/m². The surface temperature of the polymer coating of the type test pattern is 60°C. It provides a specially designed and manufactured system of temperature control and water cooling of the underlying surface. The method for determining the mechanical characteristics is GOST R 55408-2013. The method of measuring the adhesive strength of the ink film [6].

Determination of optical density and reflection factor of the built-in light source D65 at the observation angle of 2 degrees has been performed using X-Rite Pantone e-Xact spectrophotometer with Gretag Macbeth Key Wizard V2.5 software. As a sample of white color, banner fabric without ink film has been used. Method for determining the contrast ratio by color coordinates [7]. Method for determining the contrast ratio by reflection factor [8].

2. Results and considerations

Type test pattern to adjust and determine electrooptical systems operating in the visible range of electromagnetic waves is repeating groups of light gray lines against a dark background of width 0.5 ÷ 2.0 m. The lines are printed on banner fabric with a mass of square meter 400 g. The thickness of the prints is 0.3 ± 0.04 mm. Conditional density of the compound material of the fabric is 0.132 g/cm³.

The optical density of the background and light lines of the type test pattern samples before UV radiation is given in the table. The type test pattern sample taken to test the light resistance is characterized by low contrast ratio [9]. The ink film adhesion on the areas of dark background and light lines exceeds the interlaminar strength of banner fabric (table) and is more than 120N/m². Large size of the parts of the dismountable type test pattern [2] cause large linear tensile stresses during their laying and aligning on the ground and stress concentration in the places where the fabrics are hooked for uneven stony ground or woody vegetation remainings. For this reason, after the exposure of the type test pattern to the UV radiation, the strength and tensile elongation have been determined.

If the time of the exposure of the type test pattern to the UV radiation increases, the change in the optical characteristics of the background and lines printed with jet inks on banner fabric is most intense during the initial period of time up to 2 days. The optical density of the light line and the optical density of the background are reduced by 14%. This change reduces the contrast ratio of the type test pattern and brings its image to the sensitivity limit of aviation electrooptical systems.

When calculating the contrast ratio \( K_1 \) by the formula (1), it changes by 11 % for 2 days

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K_1 = \frac{\rho_h - \rho_f}{\rho_h + \rho_f} \quad (1)
\]

Where \( \rho_h \)is the reflection factor of the standard source light of the D65 spectrophotometer by the line, \( \rho_f \) is the reflection factor of the standard source light of the D65 spectrophotometer by the background.

The change in the optical density of the type test pattern on the first day of radiation seems to be based on the removal of volatile organic substances from the ink film and the carbonization of components prone to damage by UV light. Further reduction of the optical density and increase in the factor of light reflection from the lines and background for 60 days is steady and is described by the logarithmic function \( \rho = kln(t) + b \) with a probability \( R^2= 0.93 ÷ 0.94 \). (Fig. 1)

Extrapolating the linear dependence of the reflection factor on time (Fig. 2) and the time dependence of the contrast ratio of the type test pattern (Fig. 3) for the period of solar radiation from
60 to 120 days, it is reasonable to assume that the contrast ratio of the type test pattern does not drop below the sensitivity limit of the electrooptical equipment of aircrafts during summertime.

**Figure. 1.** Dependence of the sunlight reflection factor on the printed lines (1) and dark background (2) of the type test pattern.

**Figure. 2.** Linear approximation of the dependence of the sunlight reflection factor on the printed lines (1) of the type test pattern.

**Figure. 3.** Linear approximation of changes in the contrast ratio of the type test pattern when radiated with UV light.
The regularities of change in the strength of the type test pattern when irradiated with UV light are different from the regularities of change in the optical properties. During the initial period of solar radiation (up to 15 days), the material strength of the type test pattern decreases slightly (2%). This change in strength is within the limit of errors of the breaking stress measurement by the standard method. In the next 15 days, i.e. after 30 days of radiation, the strength decreases by 20%, and after 45 days of radiation it decreases by 40%. Upon the completion of the test cycle, when the type test pattern is exposed to radiation for 60 days, residual strength of the parts is 24 mPa.

The loss or decrease in the adhesion of the ink film to the polymer coating is a certain danger to the stability of the photometric characteristics of the dismountable type test pattern on the printed banner fabric. When modules of the type test pattern are rolled and stored for a long time, ink that partially destroyed by solar radiation can glue to the back of the banner fabric. To predict and prevent such damage to modules of the type test patterns, the film ink adhesion strength on the printed coating is determined by the method of pull-off [6]. It is impossible to assess the adhesion of the ink film to the banner fabric before the exposure to solar radiation, since it exceeds the interlaminar strength of the fabric. An attempt to separate the ink film results in its delamination, so the table shows the value of the ink adhesion more than 1.2 MPa. When the type test pattern is radiated for 15 days, the ink film can be separated from the banner fabric with normal stress of more than 0.35 MPa. This value does not change significantly throughout the time of accelerated climatic tests and is more than 3 times higher than the standard interlaminar strength of printed products and laminated packaging materials [9].

Table 1. The value of the ink adhesion.

| Time of Radiation with UV light, day | Reflection factor ($\rho_{\text{comp}}$) | Contrast ratio ($K_2$) | Tensile strength, MPa | Ink film adhesion, MPa |
|-------------------------------------|--------------------------------------|------------------------|-----------------------|------------------------|
|                                     | line | background | line | background | line | Background |
| 0                                   | 0.087 | 0.06      | 0.31 |           | 40   | 43         | >1.2       | >1.2       |
| 2                                   | 0.123 | 0.089     | 0.28 |           | 40   | 43         | >1.2       | >1.2       |
| 15                                  | 0.129 | 0.097     | 0.25 |           | 39   | 42         | 53         | 0.57       |
| 30                                  | 0.135 | 0.104     | 0.23 |           | 32   | 33         | 0.35       | 0.50       |
| 45                                  | 0.147 | 0.107     | 0.27 |           | 29   | 31         | 0.30       | 0.45       |
| 60                                  | 0.151 | 0.114     | 0.25 |           | 24   | 25         | 0.25       | 0.35       |

3. Conclusion
The analysis of the accelerated testing results for the photochemical stability of a polymer type test pattern sample, designed to determine the spatial resolution of aviation and/or space electrooptical equipment, has established quantitative regularities of changes in optical and mechanical properties, allowing to predict the maintenance of the operational characteristics of the type test pattern at an adequate level.

References
[1] Goryl F and Burini A 2009 Calibration Test Sites and Cal/Val Portal Renovation. IVOS 21 (University of Lethbridge, Canada)
[2] Altukhov E V, Bablyuk E B, Veselov U G, Vlydychenko O V and Moroz V A 2017 Pat. 175973, RF, Dismountable test object, i.e. type test pattern to determine the parameters of
electrooptical systems IPC G01M 11/02, G03B 43/00, H04N 17/00, pubd. 25.12.2017, Report No.36 dated 17.04.2017.

[3] Ermakova I N, Kondratov A P and Nagornova I V 2015 Transparent polyolefin-based laminated materials with variable colouring, International Conference on Oil and Gas Engineering pp 101-103

[4] Bablyuk E B, Berlad Yu M, Letyago A G and Kondratov A P 2017 Materials for test objects to configure aviation optoelectronic earth remote sensing systems MATEC Web of Conferences 99 01001

[5] Zhuravleva G N, Nagornova I V, Kondratov A P, Bablyuk E B and Varepo L G 2017 Control of the operational properties of polymer materials with applied type test patterns Methods and technology of petrochemical and oil and gas production materials 7th International Scientific and Technical Conference pp 185

[6] Kondratov A P, Bozhko N N, Dryga M A and Bablyuk E B 2010 Pat. 2390004, RF, Method for assessing the connection strength of screen inks and coatings with printing materials IPC G01N19 / 04, pubd. 20.05.2010, Report No.14 dated 20.05.10

[7] Kondratov A P, Varepo I G, Nagornova I V and Ermakova I N 2015 Transparent layered materials based on variable color polyolefins Procedia Engineering, 113 423–428

[8] Aisenberg U B (Eds.) 2006 Reference book on lighting engineering (Moscow: Znak)

[9] Travnikova N P 1985 Efficiency of visual search (Moscow: Mashinostroeniye)