Design features of the glossmeter system

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Abstract. The paper discusses the stages of development of the glossmeter device. Possible options are analysed and the choice of the optical scheme is justified, as well as the choice and matching of the source and detector. The issues of ensuring the linearity of the device characteristics are considered. The results of the device testing are given.

1. Introduction
This device is necessary in industry, both in the fabrication and in the inspection of coatings, for example, in cars painting. The geometry of the optical system of the glossmeter varies; the most common angles for inspecting the gloss are 20/20, 45/45, 60/60, 85/85, and a gloss meter with the geometry of 75/75 is sometimes used to inspect paper materials. The choice of angle depends on the degree of glossiness of the coating, for high-gloss coatings an angle of 20/20 is used, for medium-gloss ones – 60/60, for matte ones – 85/85. This device can be used not only to inspect the glossiness of coatings, but also to determine the brightness of coatings and products in there is a special geometry in the device 45/0 [1].

The glossiness of coatings is measured in gloss units. The reflection of black velvet is taken as 0 gloss units, the gloss of a black glass plate with a refractive index of 1.567 is taken as 100 gloss units; the height of irregularities should not exceed 2 interference fringes. The device has been designed and tested at the base of K-M LLC. The device has been developed in accordance with the following regulatory documents: Russian State Standard 31975-2017 [1], Russian State Standard 896-69 [2], Russian State Standard 16143 [3], ISO 7668 [4], ASTM C346 [5], ASTM D523 [6], ASTM D2457 [7], ASTM D4039 [8], ASTM E430 [9], DIN EN 14086 [10].

In accordance with the considered documents, the beam incidence on the inspected surface shall be parallel, the surface irradiance shall be uniform, the source shall have a spectrum corresponding to a source of A or C type [11]. International standards offer the Keller system as a standard optical system (figure 1 (a)). Russian State Standards do not offer a specific optical system, and as a principle of operation they offer a schematic diagram of the device (figure 1 (b)).

2. Optical system of the device
In the first version of the device “Constanta BF”, a single-lens optical system has been used as a lighting system, the lens material is an optical polymer, the light source is the LED KPT-1608YC from Kingbright, and the photodetector is the Photodiode BPW34S from Vishay. Calibration in VNIIOFI has shown that the device has errors of up to 19 units. The calibration results are printed in figure 2.
Figure 1. Schematic optical diagrams in the gloss measurement device: (a) according to ASTM E 430, (b) according to Russian State Standards 31975-2017. 1 – light source; 2, 3 – lighting channel lens; 4 – collector lens; 5 – inspected surface; 6 – field aperture; 7 – field diaphragm of the detector; 8 – detector.

Figure 2. The results of calibration of the first version of the gloss meter "Constant".

The errors can be caused by the following reasons:
- characteristic of the lighting channel (non-parallel light beam, non-uniformity of the energy distribution over the surface).
- inconsistency between source and detector, and the detector is sensitive to the IR radiation.

The LED 16-led of XD series from CREE has been chosen as a new light source. The advantages of this LED are that it has small dimensions (1.6x1.6 mm²) and the luminous flux is about 150 Lm at 350 mA (the maximum operating current of the LED is 2 A), the LED in the device will operate at the current of 100 mA (the luminous flux is 43 Lm). The color temperature of the chosen LED is 5000 K. The detector channel uses the photodiode from Blue Enhanced Photodiodes of the series VTB9413BH with the sensitive area of 1.6 mm², the spectral sensitivity range is within 330-720 nm, and the
maximum sensitivity corresponds to 580 nm. Since the sensitivity curve of the photodiode lies in the visible range, changes in the temperature of the surface under test does not affect the instrument readings.

The technical assignment has restricted the dimensions of the optical system. The lighting and detecting parts should be less than 50 mm in length. Taking into account the overall dimensions of the housing, the diameter of the optical system should not be greater than 10 mm. The diameter of the optical system for the geometry of 85/85 should not exceed 6 mm.

The following options for the optical lighting system have been considered:
- single lens system without aspherical surfaces;
- single lens optical system with aspherical surfaces;
- keller system;
- optical system of two plano-convex lenses.

Various options of a single-lens optical system have been designed. In case of using a system without aspherical surfaces, either a high energy concentration in the center of the illuminated area, or a large energy concentration in the ring has been observed (figure 3 (a)) [12]. This effect can be excluded by adding the asphericity coefficient, or by adding the optical elements. As can be seen from figure 3 (b), the use of the aspherical lens gives more uniform energy distribution, but the stock aspherical lenses cannot be used to achieve necessary characteristics, and manufacturing a small set of lenses of this type is expensive, therefore, it has been decided not to use such an optical system in the model.

As an alternative, the system proposed by international standards has been calculated using the Keller system (figure 4 (a)). As can be seen from figure 4 (b), the system gives a uniform distribution of energy and collimates the beam. The first lens in a system is flat-convex with a focal length of 24 mm, the lens diameter is 18 mm, the material is TF3; the second lens is also flat-convex with the focal length of 40 mm, the diameter is 24 mm, the material is K8; the overall length of the system is 159 mm.

However, the overall dimensions of this system exceed dimension of the ones, specified in the technical assignment, and it is impossible to reduce the dimensions of the system without complicating the components, therefore, this system cannot be implemented in the considered case [6].

The adopted practical version of the system is a system consisting of two lenses (figure 5 (a)). It has suitable dimensions, provides uniform distribution of energy (figure 5 (b)). Due to the use in the system of flat convex lenses with spherical surfaces made of K8 glass, the cost of manufacturing of this system is optimum compared to others.
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**Figure 4.** Keller system (a) general view of the system, (b) surface irradiance.

In the lighting channel with the geometry of 85/85, the same optical system is used, but with a smaller diameter. The detecting channel with the geometry of 85/85 uses a system of a biconvex lens made of K8 material with the focal length of 7.4 mm. The other detecting channels use a flat-convex lens with the focal length of 18.9 mm.

**Figure 5.** System in use (a) general view of the system, (b) surface irradiance.

3. **Color Temperature Correction**

Since all regulatory documents require that the source have the color temperature of A type (2856 K) or C type (6774 K), in addition the system should include a light filter (a plane-parallel plate that does not affect the path of rays), the purpose of which is to correct the color temperature of the chosen LED.
in accordance with the requirements. To determine the parameters of the light filter, a series of measurements of spectral characteristics of the radiation in the optical system have been performed in order to take into account not only the spectral composition of the source, but also the spectral transmittances of the glasses, after that the values have been averaged and the light filter has been made according to them. The spectral transmission of the filter is illustrated in figure 6 [11].

\[ \text{Figure 6. Light filter transmittance to implement the spectral radiation of C type.} \]

To measure the color temperature, a series of spectrum measurements have been also performed in the system with the light filter. According to the results of measurement of the color temperature, and in particular of X and Y coordinates, the LEDs have been excluded, the total error margin of which, \( \Delta X \) and \( \Delta Y \), exceed \( \pm 0.015 \).

4. **Principle of operation of the electrical circuit of the device**

The device operates under the control of a microcontroller that uses embedded software. The microcontroller in the glossmeter controls the following processes:

- LED driver, LEDs operate in pulsed mode;
- analog-to-digital converter (ADC) in the receiving channel;
- SD card;
- temperature sensor;
- battery device;
- speakers;
- USB;
- display.

5. **Testing the components for physical characteristics**

To ensure the linearity of the device characteristics it is necessary to ensure the photodiode operation in the photodiode mode. In this circuit, a variable resistor of 10-100 KOhm is used.

The device has been tested for the following:

- to determine the photodiode’s signal dependence on gloss function;
• to define the photodiode signal shift as a temperature function. Finding of the deviation coefficient.

Figure 7 illustrates the photodiode signal vs the brightness curve, using a modified optical system. The results are the code from the analog-to-digital converter (ADC).

As it can be seen, the results have become more linear, however, the absolute measurement error satisfies the requirements only at the angles of 85/85 and 45/0.

![Figure 7. Results of the device testing using reference samples without diaphragm.](image-url)

In figure 7 the points mark the measurement results, also the trend lines are shown, which allow to evaluate the deviations of the obtained results from linearity.

To improve the linearity of results, it is necessary to bring the size of the source to a point one, that is, to add a diaphragm. Measurements have been performed with the following diaphragm diameters: 1 mm, 0.75 mm, 0.5 mm.

Figures 8, 9 show the results of tests with the diaphragms of 1 mm and 0.5 mm. As it can be seen, the smaller the diaphragm, the more linear the curve, but the diaphragm size is most critical at small angles: this is most noticeable if compare the angles of 20/20 and 60/60 (85/85). For the angle 20/20, the size of the source is most critical. For unification, it has been decided to add the diaphragm of 0.5 mm to the optical systems 20/20, 60/60, 45/0/45. In case of a system with the geometry of 85/85, no modifications have been made.

The tests for temperature deviation have been conducted in a thermobox with the temperature settings from 15 to 35 °C. The signal vs temperature function in the photodiode in the experiment has been found to be linear; therefore the ambient temperature will not introduce nonlinear distortions into the measurement results. If there is a temperature sensor, the appropriate correction can be introduced, therefore there is no need to wait until the device heats up to ambient temperature for starting measurements.
Figure 8. Results of the device testing using the diaphragm with the diameter of 1 mm.

6. General view of the device
A general view of the device with three angles in the section is shown in figure 10. This setup is the latest version at the moment.

Similarly, the device with the geometry of 45/0/45 (figure 11) has been simulated and set up. In the channel, the photodiode FDUK-2P is fixed at 0 degrees, no optical elements in this geometry are used.

Figure 9. Measurement results using the diaphragm with the diameter of 0.5 mm.
Figure 10. 3D model of the device with three angles in the section.

Figure 11. 3D model of the device 45/045 in the section.
7. Conclusion
The paper describes the developed device for measuring the gloss of surfaces. The developed device has passed through all stages of development – from the choice of the scheme to the design and assembly. The model of the device with the geometry 20/20, 45/45, 60/60, 85/85, 45/0 has been tested using the reference samples. The test results have demonstrated a decrease of the measurement error, the causes of deviations from the linearity of the results have been identified and taken into account; the best diaphragm size for the source has been selected based on the measurement results and their comparisons. In the future, it is planned to assemble the device and calibrate it with the aim of launching into mass production and for sale in the company “K-M” LLC, “Constant” Group of Companies.

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