

DIAMONDS COLOUR MEASUREMENTS

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ABSTRACT

As a rule, evaluation of diamond colour is carrying out visually, because creation of the measuring devices is a complex problem due to influence of defects in diamonds (irregularity of coloration, cracks and graphite inclusions). And elimination of this influence is a very difficult task. In this work, an analysis of visual diamond colour evaluation methods and assessment of known devices for objective diamond colour measurements is carried out. As a result, an installation for measuring diamond colour is offered, which as much as possible meets the visual evaluation conditions.

Keywords: diamond, colour, colour evaluation, colorimetry, devices for measurement of diamond colour

1. INTRODUCTION

The visual evaluation of diamond colour is carrying out at a white paper bookmark. The diamond is installed on it with the plane part down, and observation is carried out perpendicular to the diamond spike surface (Fig. 1). Traditionally colour is estimating when illuminating with light of the sky northern part not containing direct solar rays. Therefore, the room for diamond colour evaluation is usually placed in the building northern part. Spectrum of such natural light is characterised by colour temperature and can be classified as *D* type source. CIE [1] recommendation is to use *D*₆₅ source in most cases.

There are several evaluation systems of diamond colour, of which the GIA system proposed by the

Gemmological Institute of America is most widespread. In this system, every diamond colour is designating by a letter of Latin alphabet from *D* (completely colourless diamonds) to *Z* (diamonds with a pale yellow or brown shade). Each letter is followed by the colour description.

In Russia, diamond colour is designating by figures from 1 (colourless highest diamonds) to 9 (dark-brown and black diamonds). Each figure is followed by the colour description, Fig.2, [2].

Small diamonds are divided by colour groups according to Table 1, whereas middle and large diamonds are divided according to Table 2. A comparative analysis of diamond colour groups is presented in Table 3.

At present, diamond colour is estimated under artificial illumination conditions with application of standard light sources *D*₆₅ against the background of white paper (photo – base is a substrate in accordance with GOST 30113) [2]. A working room intended for this purpose should have general illumination of 200 lx illuminance and a local illumination increasing the illumination to (1000–1200) lx [3]. In order to exclude influence of outside co-

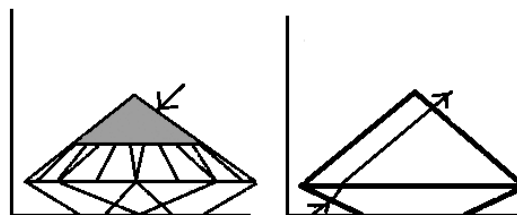


Fig. 1. A diagram of radiation travel through diamond in case of visual colour evaluation

Table 1. Colour Groups of Small Diamonds (to 0.29 carat)

Characteristic	Colour group
Colourless highest, colourless	1
With an insignificant shade	2
With a small yellowish, lilac, grey or scarcely perceptible brown shade	3
With an obviously visible yellow, lemon, grey or scarcely perceptible brown shade	4
Yellow with yellow or lemon colour in the whole diamond, as well as yellow with an insignificant brown shade	5
With a visible brown shade and grey diamonds	6
Brown, yellow-brown and black	7

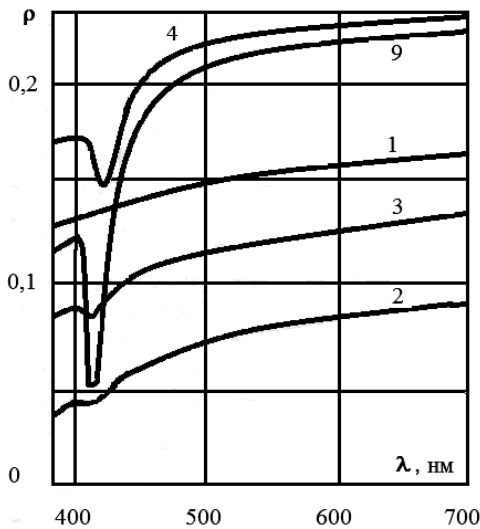


Fig. 2. Spectral reflection factors of diamonds (curve figures designate colour diamond group according to the Russian classification)

four flare spots on the evaluation results, the room should be painted using an achromatic light paint, and estimators should work in the special white gowns.

2. DEVICES FOR MEASUREMENT OF DIAMOND COLOUR

For an objective diamond colour evaluation, devices not measure colour parameters (colour co-ordinates, colour purity, etc.) but are generally using for correlated values (statistical connected with colour) measuring. Most of such devices measure a relation of direct transmission factors in blue and yellow-green spectrum parts, which is statistically connected with the colour gradations characteris-

ing colour saturation of yellow tonality. Transmission factors are usually measured with illumination through the subject plane with a subsequent integration of the rays outgoing through top edges in the integrating sphere. Sometimes, when illuminating through the subject plane, integrating sphere is not applying. In this case, scattered radiation outgoing through bottom edges is measured.

A reason of such measurement method (according to the transmission factor relation) is a specific nature of spectral distribution of diamond transmission factor.

Among foreign devices operating by the principle of measuring a colour correlated value, one can

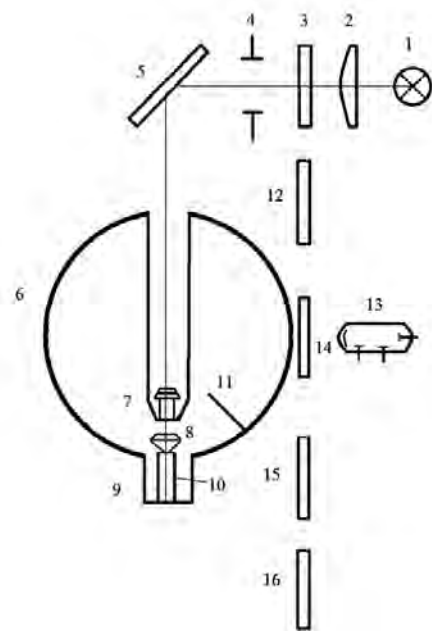


Fig. 3. Optical circuit of the Brilliant-1 device

Table 2. Colour Groups of Middle and Large Diamonds (from 0.30 carat)

Characteristic	Colour group
Colourless highest, as well as with a bluish shade	1
Colourless	2
With a scarcely perceptible shade	3
With an insignificant shade	4
With a small yellowish, lilac or grey shade, as well as with an insignificant brown shade	5
With visible yellow or grey shade	6
With visible brown shade	6-1
With clearly visible yellow, lemon or grey shade	7
Very light-coloured yellow	8-1
Slightly light-coloured yellow	8-2
Little-coloured yellow	8-3
Light-yellow	8-4
Yellow	8-5
Light-coloured brown	9-1
Little-coloured brown	9-2
Brown	9-3
Dark brown and black	9-4

name *Electronic Colorimeter* [5], in which spectral ranges are selected by filters, and the relation is calculated by a computer built in the device. Another device based on interference filters, which name is *Diamond Photometer*, has an indicator, which indications are used to calculate transmission factors, and according to their relation transmission coefficient is calculated.

In Russia, based on such method, the Brilliant-1 device was developed, which layout is given in Fig. 3 [6]. The device basis is integrating sphere 6, in which diamond 8 is installed on support 10 with the plane up. A light beam focused

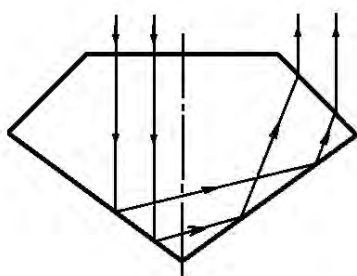


Fig. 4. Travel of light rays in round diamonds

by micro lens 7 is directed to the plane. The micro lens is fixed in the draw-tube and operates in the illuminator circuit with incandescent lamp 1 located in condenser 2 focus, with aperture diaphragm 4 and mirror 5. The radiation outgoing through the top faces is integrating by the sphere and partly passes to radiation receiver (photo multiplier) 13, and the radiation outgoing down falls in nielloed light trap 9. Two pairs of interference filters 3 and 14 or 12 and 15 collect radiation with wave length of 550 nm or 390 nm providing double monochromatization and excluding influence of a possible fluorescence on the measurement results. Gate 16 is used to shut-off light when checking the device “zero”. The sphere has screen 11 excluding incidence of direct rays from a specimen to the receiver.

With such illumination and measurement version, the radiation passes a distance within a diamond, which is approximately equal to $1.5 D$ (where D is diameter of the diamond along the girdle¹), Fig. 4. This is surpassing radiation distance in case

¹ Girdle is a narrow band determining a diamond configuration, which plane separates the stone bottom from top

Table 3. Comparative Analysis of Diamond Colour Groups

Russian classification		GIA	Characteristic
To 0.30 carat	From 0,30 carat		
1	1 2	<i>D</i> <i>E</i>	Bluish-white
2	3	<i>F</i>	With a scarcely perceptible shade
3	4 5	<i>G</i> <i>H</i>	Grayish-white, yellowish-white. With a scarcely perceptible yellowness shade
4	6 7	<i>I</i> <i>J</i>	White with a scarcely perceptible colour shade
5	8 (1–5)	<i>K-L</i>	Pale-yellowish shade
6	6 (1)	<i>M-N</i>	Yellowish shade
7	9 (1–4)	<i>O-R</i> <i>S-Z</i>	Yellowish shade. Yellow

of a visual evaluation almost twice. As a result, colour of the measured stone will be more saturated and more yellow than with a visual evaluation. Besides, this installation is intended to measure defectless diamonds. Radiation reflection at cracks, graphite points and smoky inclusions significantly affects the measured diamond colour.

In another correlation method, diamond colouration of yellow tonality caused by reflection factor reduction general for all diamonds in the blue spectrum part is connected with the observed local cavity near wavelength of 415 nm (see Fig. 2). Depth of this cavity is quantitatively characterised by so-called *F*-number (farb-index)

$$F = \frac{\rho_{412}\rho_{420}}{\rho_{415}^2},$$

where ρ_{412} , ρ_{415} and ρ_{420} are reflection factors at the correspondent wavelengths.

Of objective colorimeters adapted to measure classical cut diamond colour, one can name electronic comparator ЭКЦ –1 [7] upgraded in the Scientific Research Institute of Introscopy (SRIIN), Fig. 5.

An initial device is intended to measure colour co-ordinates of diffusely reflecting specimens by the comparison method. In this case, colour co-ordinates differences of the specimen under test and of the compared specimen are measured. The second specimen colour co-ordinates are known in advance. The comparator works in the XYZ system.

The upgraded device is constructed according to a dual-beam principle, which allows alternately illuminating two compared specimens 8 and 10 by means of modulator disc 4 and of one incandescent lamp 1. Light from the lamp being source *A* is directed to the specimens (diamond plane) using a symmetric system containing lenses 2 and 6, prisms 3 and flexible multifiber light guides 7. Output end faces of the light guides are covered with plates of opal glass, which provides illumination of diamond plane part with scattered light, and plate size in this case do not exceed plane size. The radiation passed through specimens is integrated by the integrating sphere. A part of the integrated radiation passes to the radiation receiver (not shown in the figure) through output light guide of polished organic glass, which input end face 9 is at the centre of the sphere and, therefore, a direct incidence of the integrated radiation to the receiver is excluding. Between the output light guide and the radiation receiver replaceable filters are placed. They are intended to correct the receiver according to the colour mixture curves.

The measurements are reduced to an alignment of the radiation fluxes falling on the radiation receiver by both channels using nielloed meshed filters 5 adjusting the radiation flux without change of its spectral composition. An electronic circuit selects signals of both channels, and after luminous fluxes are aligned with an introduced correcting filter, an analogue circuit makes it possible to find the relation of colour co-ordinates.

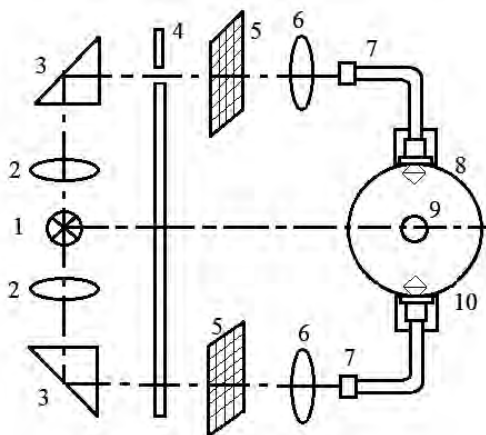


Fig. 5. Optical circuit of the ЭКЛ-1 device

In [7] is specified that this device provides a satisfactory reproducibility of diamond measurements but has a low sensitivity. According to the accepted comparison method, this device is used to measure colour difference of measured and standard (reference) specimens, which is providing maximum measurement accuracy. However, this requires a preliminary selection of a suitable comparison specimen, reduces measurement productivity and allows only comparing diamonds of yellow shades with specimens of yellow tonality.

In this installation, a disadvantage of diamond colour measurement connected with increase of radiation path length, which in this case is identical for reference and measured radiation, is eliminated. But deficiency of a diamond will still influence the stone colour, and as a result, its colour group will be determined incorrectly. It will be overestimated if a white smoky inclusion or reflection from a crack take place and it will be underestimated if graphite inclusions take place.

Great opportunities to measure diamond colour are provided by devices based on spectrophotometers. Among such devices, a spectrophotometer should be mentioned, which measures spectral distribution of diamond direct transmission factor when illuminating through the plane [5]. It is noticed in [5] that using this dependence, one can unambiguously and objectively determine colour of all gemstones.

In the SRIIN, a spectrophotometer based on the СИП-1 spectrometer was developed [8]. The СИП-1 spectrometer was earlier designed at the same place. An optical spectrophotometer circuit (Fig. 6) contains illuminator (1 – incandescent lamp, 2 – condenser), monochromator (3 – input

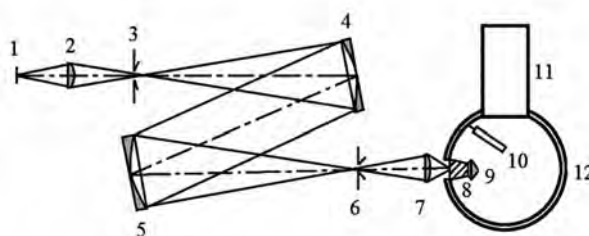


Fig. 6. A spectrophotometer developed by the NIIN

slit, 4 – collimating mirror, 5 – diffractive grating, 6 – output slit) and an attachment for diamond measurement. The attachment contains microlens 7 by which radiation outgoing through the monochromator slit is directed to the photometric unit. In its turn, the photometric unit contains integrating sphere 10, focon (conic light guide) 8, to which diamond plane 9 is pressed, and radiation receiver 11 with a circuit to measure photocurrent. Diameter of the focon output end face is much less than diameter of the diamond plane. In the sphere, white screen 12, which is excluding radiation fall on the receiver directly from the specimen, is placed.

This device has the same disadvantages of diamond colour measurement, as the Brilliant-1: the radiation passes path within a diamond twice exceeding the path in case of a visual evaluation, and the device is also intended to measure colour of defectless diamonds.

To measure diamond colour, *Adamas Gemmological Laboratory Company*, USA, manufactures a specialised laboratory spectrophotometric system SAS2000 (*Spectrometer Analysis System*) [9]. This is a two-channel fibre-optic spectrophotometer, which reference channel allows monitoring changes in radiation source spectrum. The device is intended to measure diamond spectral transmission factors with subsequent calculation by a computer built-in in the device and colorimetric parameters in the XYZ and CIELAB systems. Previously the device is calibrated according to *GIA* standards or to others at the request of the customer.

There is no detailed description of the device optical circuit in [9] to measure spectral transmission factor. One can assume that it is similar to the comparator (see Fig. 5). A diamond is placed on the light guide with the plane down, and ray path within the diamond is similar to the one given in Fig. 4. Hence the radiation portion outgoing from the diamond depends on the configuration and cut quality, on diamond size and on defects as various

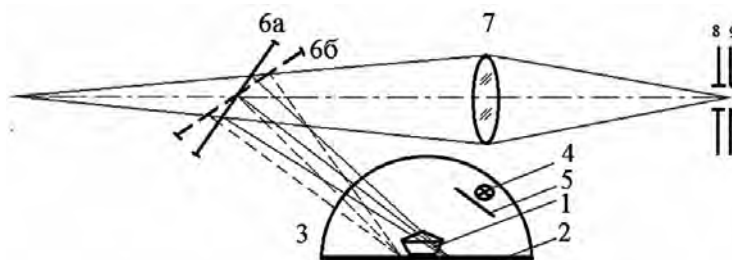


Fig. 7. Optical circuit of the recommended installation

inclusions and cracks. Therefore, the measurement results differ from the results of a visual evaluation. Diamond colour obtained in such a circuit is correlated, because radiation way length in a diamond surpass approximately twice the way length when visual diamond colour evaluating.

There are several common disadvantages inherent in all considered methods and devices using diamond illumination through the plane:

1. Radiation directed to the diamond plane comes back and in a greater degree falls into the illumination source, which leads to an incomplete radiation use;

2. Radiation portion outgoing from the diamond and falling to the light source is not constant and depends on the cut configuration and quality, as well as on presence of scattered light, defects and on diamond colouration irregularity, which can influence measurement results;

3. All devices using such illumination layout normally work with diamonds of a classical cut. Interpretation of the results of fancy cut diamond measurements, all the more of not cutted diamonds, is not obvious. It is not quite clear as well, what such devices measure in the event of the diamonds with internal defects;

4. The devices measure correlated colour since in each photometric layout, radiation way length within diamonds is different from the visual evaluation way length.

From this point of view, measurement layout corresponding to the visual evaluation conditions is most prospective. In this case, the diamond is placed with the plane down on a white substrate, and radiation falls on the receiver from the paper bookmark illuminated with scattered light. This radiation path length is equal to $0.65 D$, which corresponds to the light ray pass length in case of diamond colour visual evaluation. The receiver is placed at an angle of 45° in relation to the substrate [5].

Such a layout can be implemented in the installation (Fig. 7), in which studied diamond 1 is located on base 2 of hemisphere 3. In this case, diffused illumination of the diamond and background is provided with radiation source 4 and with protection screen 5 excluding direct radiation falling onto the diamond. Such illumination system excludes influence of outside objects (room walls, appraiser's clothes, etc.), which radiation can be scattered on diamonds and change their colour.

In such a layout, one can determine spectral coefficient of a diamond luminance as a relation of spectral luminance concentration of radiation passed through the diamond to spectral luminance concentration of the background, for example of the paper bookmark. In doing so, the radiation spectrum makes no difference.

In photometry, this method is named a replacement method, and its accomplishment in this installation is enabled by mirror 6 turn, which allows by means of lens 7 projecting image either of the diamond (mirror position 6a), or of the substrate (mirror position 6b) on the monochromator input slit 9.

Hartmann's aperture diaphragm 8 at the monochromator input slit is intended to select by height a site necessary for the measurements within the diamond image, for example of a round diamond spike, which corresponds to the conditions of diamond colour visual evaluation.

Unlike known layouts, in this one the following takes place:

1. It is possible to measure specimens of any configuration, including diamonds and pastes; the known installations are as a rule intended to measure plain specimens;

2. In the measurement process, the specimen remains immovable, which provides a photometric measurements of the same site (in the known devices, a diamond is entered into the light ray and brought out of it with each change of the spec-

tral device wavelength); and since various colour, smoky, graphite inclusions and cracks are possible in diamonds, an insignificant diamond movement can lead to a measurement result distortion;

3. A device is used that allows to photometric measuring any diamond area (if necessary), id est one can measure the parts without defects.

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