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IMPROVEMENT OF MAJOLICA LIGHTING AT THE KOMSOMOLSKAYA-RADIAL METRO STATION

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ABSTRACT

The article describes solving of one of the most important problems of perception of architectural decoration of metro stations: removal of veiling reflections on glazed mosaics and majolica caused by lighting devices.

A number of lighting methods reducing luminance of the veiling reflections is analysed. Their efficiency is exemplified by lighting of the Mine Laying majolica (based on sketches by Eugene Lancer) at the Komsomolskaya station of Moscow Metro.

The content of the article relates not only to metro stations but to any areas with reflective or glazed surfaces.

Keywords: Moscow metro, Komsomolskaya station, lighting devices, light emitting diodes, majolica, glazed surface, veiling reflection, luminance, contrast

1. INTRODUCTION

Veiling reflections are rather common for stations of the Moscow Metro by virtue of rich decorations with various murals, mosaics and frescoes made of polished marble, majolica and smalt mosaic patterns, etc. A veiling reflection is a light spot on a highly illuminated convex or flat glazed surface. It appears as a result of regular reflection or combination of regular and diffuse reflection of radiation of a bright lighting device (LD).

It is well-known that it is virtually impossible to remove veiling reflections on large reflective surfaces illuminated by large number of LDs, which are often also used as decorative elements. Nevertheless, originally the luminance level of veiling reflections at metro stations was significantly less. The problem of veiling reflections is at least not mentioned in literature [1, 2], which is likely to be caused by generally low level of illumination of the early metro stations. It appeared after the first modernisation of lighting conducted in the 60s to increase energy efficiency and the lighting level of certainly dark stations by replacing incandescent lamps (IL) with fluorescent lamps (FL). With that, luminance of LDs largely increased and the veiling reflections appeared on glazed surfaces and began preventing authentic perception of a station and thus nullifying efforts of architects, artists and lighting engineers who had created it. Given that the current level of lighting of the majority of stations does not comply with applicable standards [3], negative effects of veiling reflections on comfortable perception of decorations keep rising.

Human eye is adaptive. Visual perception is influenced by luminance distribution over the field of view [4] and veiling reflections, with their luminance higher than that of surroundings, prevent this perception.

It is obvious that relative position of a spectator and an object and therefore LD illuminating it is one of most important factors of perception of a fresco, mosaic or majolica image, especially when it is illuminated by an artificial light source. With ideal lighting, a spectator's position is usually defined only by the composition of the image, however, LDs often "intervene" in this process creating glaring areas on the viewed surface, and the more

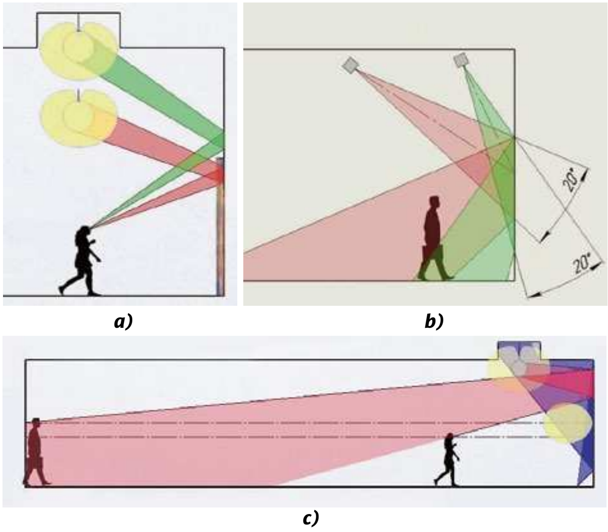


Fig. 1. LD location effect on formation of veiling reflections:
a – lighting at different angles; *b* – height; *c* – illumination from below

Fig. 2. Illumination of a mosaic at the Prospekt Mira station of Koltsevaya line

there are such areas the less the quality of lighting is. As a result, moving along an art object, a spectator defines the position at which the effect of LD on his/her perception is minimal. That is why it is very important to minimise their effect on perception, which especially applies to large art objects in the case of which it is virtually impossible to fully remove the veiling reflections in the conditions of a metro station. Therefore, alongside with spatial light distribution of LD, the most important characteristics of lighting installations (LI) "responsible" for veiling reflections are geometric relations defining relative position of LD and an object as well as characteristics of the surface of an object reflecting radiation of LD. It is necessary to remember that luminance does not depend on distance; therefore, for instance, if LD is moved at a larger distance from a mural it illuminates, the area of a veiling reflection will reduce but its luminance will remain the same [5].

2. METHODS FOR REMOVAL OF VEILING REFLECTIONS

Reflection diagram of such diffused and glazed surfaces as mosaics and majolica frescos has diffuse and regular components. When lighting such surfaces, it is necessary that a spectator see only the diffuse component. For this purpose, possible specta-

Fig. 3. The northern hall of the Komsomolskaya metro station

Fig. 4. Appearance of the majolica:
a – the left part with reflections; *b* – the left part without reflections; *c* – the right part with reflections; *d* – the right part without reflections

tor's positions and conditions of his/her perception of a picture or a mosaic, i.e. angle of view at which veiling reflections of a given area and their luminance level, should be defined.

If light distribution curve of LD is narrow, specific for a reflective spotlight LD, the angle of incidence of radiation should be as high as possible; with such method, the reflective component of reflected radiation is directed to the floor and not to a spectator's eyes (Fig. 1, *a*). If LD light distribution curve is wide, specific for diffuse-reflecting optical elements (e.g. frosted diffuser), the height of LD should be increased as much as possible, so that its light is not reflected on a mosaic (Fig. 1, *b*).

As a result of analysis of situations forming veiling reflections, several major methods of their prevention were formulated: 1) the most radical one which completely makes their alignment impossible is changing of beam path by illuminating an object from below; 2) reduction of luminance of veiling reflections; 3) increase of adaptation luminance; 4) changing of position of a veiling reflection relative to an image; 5) reduction of size of a veiling reflection.

The first approach implemented by means of additional luminaires installed underneath [6] (Fig. 1, *c*) provides incidence of the reflective component of a beam on a ceiling whereas the diffuse component reflected by a mural increases its luminance and, subsequently, luminance of adaptation thus making a veiling reflection less visible or completely removing it. Naturally, this method assumes application of LDs with high degree of protection from mechanical damage. Moreover, such allocation of LDs significantly refuses the useful area of a station. Unfortunately, the listed factors do not allow us to use this method (one of the most efficient ones) at metro stations.

The second method may be implemented when light distribution curve of LD illuminating, for instance, a mural is asymmetric, therefore, such LD is a corner reflector [7] or when its luminance at the mural side is lowered.

The third approach may be applied by moving the accent of lighting, for instance, by installing LD inside a column like it is done for lighting of a mosaic at the Prospekt Mira station of the Koltsevaya line (Fig. 2).

The fourth method usually requires changing position of LD relative to a lighted object, which is rather reasonable in some cases.

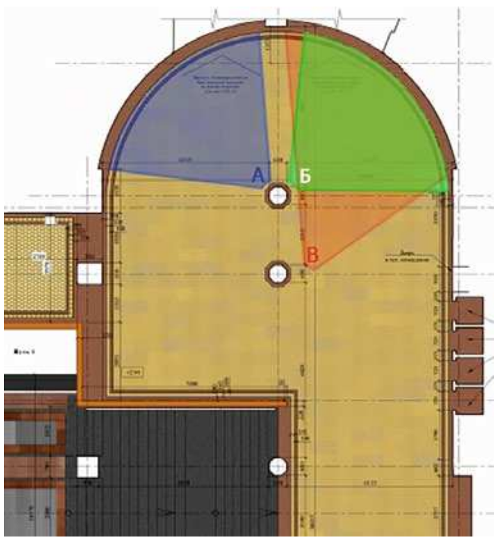
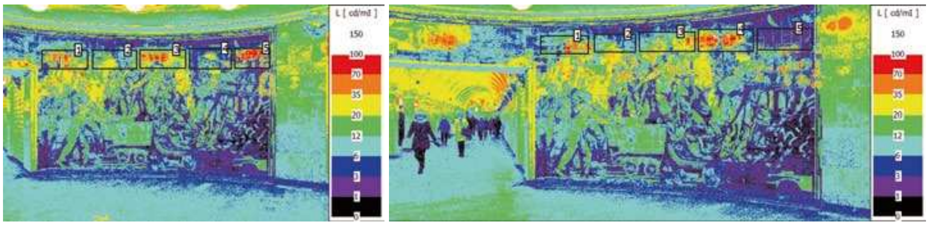
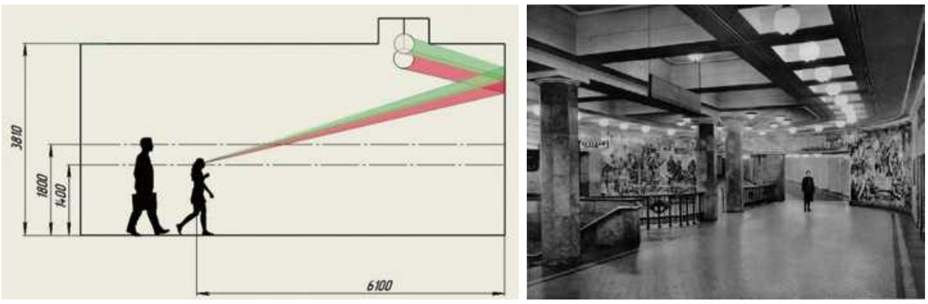


Fig. 5. Characteristic points of view



a) b)

Fig. 6. Luminance distribution over the right part of the majolica as seen from point B (*a*) and C (*b*)



a) b)

Fig. 7. The diagram of changing the position and size of a reflection: *a* – dimensions; *b* – the northern hall of the Komsomolskaya station (1935)

Fig. 8. Requirements to position of reflections on the majolica: green and red areas are areas where reflections are acceptable and not acceptable respectively

At last, the fifth approach is implemented by replacing an applied LD with another one of other design or by significantly changing the distance from a lighted object, which is not allowed at cultural heritage objects.

3. GLARE REFLECTIONS REMOVAL OF AT KOMSOMOLSKAYA-RADIAL

Komsomolskaya metro station was the first station where a work of art with a complete composition was used for architectural decoration: the mural about participation of Komsomol in construction of the Metro system based on sketches by Eugene Lancer [8] (four murals had been planned but only one was actually made). The mural is installed on the semi-cylindrical wall of the northern hall. Coloured majolica tiles painted with glaze paint and covered with a layer of transparent glaze, which makes a colour composition glazing and bright after firing, were selected as a material.

Since the surface of majolica is glazed (average reflectance of 0.2, regular reflectance of 0.05), it reflects the light of LDs located in vicinity which forms rather bright veiling reflections on fragments of figures, which makes it impossible to perceive the composition as a whole. Basically removal of these reflections or at least reduction of their effect on perception of majolica (Fig. 3) was the main goal of this work.

Fig. 4 shows the majolica with and without veiling reflections.

At the same time, it is worth noting that current appearance of the station is different from the original one in terms of floor illuminance: illuminance was about 50 lx while currently it is about 150 lx, which still does not comply with applicable requirements (200 lx) [1], just as colour rendering quality does not (R_a < 80), which is caused by use of FL[1]. This is where the main conflict arises: the applicable sanitary standards require higher illumination of the hall floor but it will increase luminance of veiling reflections. Moreover, according to requirements of the metro system, reconstruction should be performed within the framework of heritage preserva-

[1] Besides, the condition of LI requires its new reconstruction at a contemporary level.

Table 1. Specifications of the Luminance Meter

Name	LMK Mobile Advanced
Appearance	
Resolution (effective pixels)	2136×1424
Luminance measurement range, cd/m^2	0.1–10,000
Acceptable relative measurement error, %	± 5
Luminance meter number in National Measuring Equipment Register	55241–13

Table 2. Luminance Measured in Different Areas of the Majolica from Points B and C

Area/Figure		Luminance, cd/m^2		
		minimum	maximum	average
1	Fig. 6, *a*	0.1	131.6	22.6
2		1.1	67.3	13
3		1.1	94.5	26.2
4		0.2	93.6	8.7
5		0	112.8	29.8
1	Fig. 6, *b*	0.2	108.3	19.2
2		0.8	86.5	10.5
3		0.5	93.0	17.7
4		0.2	129.5	28.9
5		0.1	66.8	5.6

tion which means that the station may be illuminated only by LDs similar to original 1935 LDs [10], therefore, only light sources (LS) may be replaced whereas diffusers of LDs should remain the same.

It is obvious that, to solve the said conflicts, it is necessary to develop a brand new LI, which would require conducting experimental studies necessary for calculation of relations between luminance of veiling reflections on majolica and luminance of majolica itself they are aligned on.

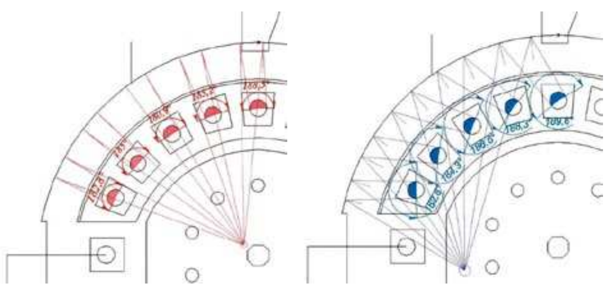
4. EXPERIMENTAL STUDIES

The relations between luminance of veiling reflections on majolica and luminance of majolica itself were determined by means of *LMK Mobile Advance* luminance meter [9] based on a *Canon* camera (Table 1). This device also allows us to obtain a graphic image of luminance distribution over the field of view and its software allows the measurement results to process (to determine luminance at a specific point or average luminance of a specific area, to output a pseudo-colour image, etc.). Therefore, just a few pictures may provide all information that we need.

The measurements were performed at characteristic points A, B, and C located near the columns (Fig. 5). The results of the measurements (Fig. 6 and Table 2) demonstrate that luminance of a veiling reflection is 3 to 10 times higher than that of the neighbouring area.

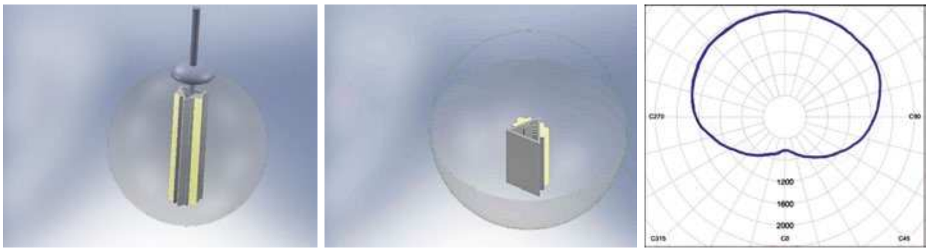
4.1. Removal of Veiling Reflections

Geometric calculations show that increasing of LD height provides positive results (Fig. 7, *a*). It is possible since originally the LDs were installed



a) b)

Fig. 9. Geometric calculations for determination of the luminaire segment forming the veiling reflection: *a* – view point 1; *b* – view point 2



a) b) c)

Fig. 10. Modernised LD:
a – structural scheme;
b – horizontal section;
c – horizontal section of the relative photometric body

higher than now (in 1935 [6, 8], LDs were partly located inside the caissons (Fig. 7, *b*)) and their upper parts were obscured by caissons. As a result, the veiling reflection will be reduced by 4 cm and relocated higher by 20 cm and the contours of the caissons will become clearly seen. Relocation of the veiling reflection area has positive effect on perception of the majolica since it is relocated from the narrative area with the metro constructors shown to the less important background area (Figs. 7, *a* and 8, *a*, *b*).

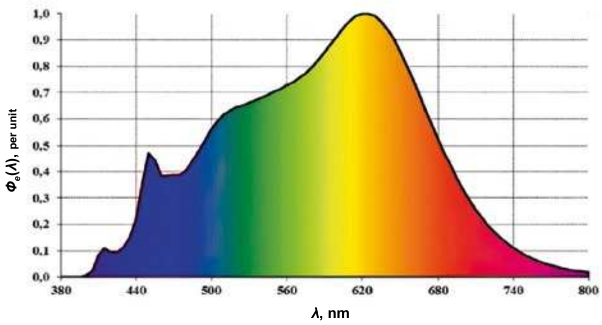
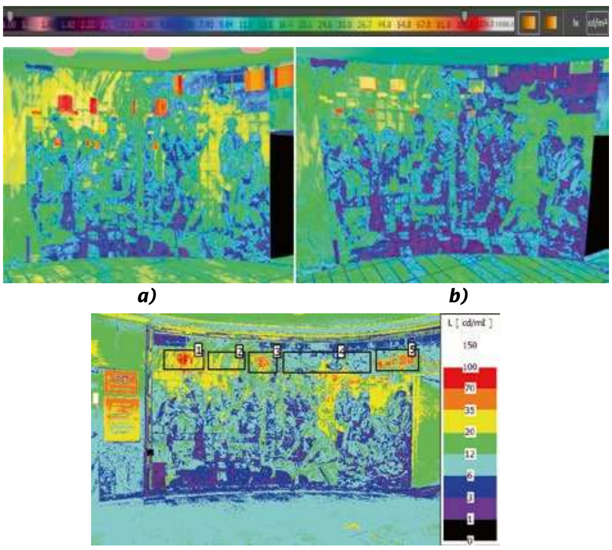


Fig. 11. Relative radiation spectrum of the applied LED models with remote phosphor



a) b)

c)

Fig. 12. LI modelling by means of *Dialux Evo 7*:
a – current LI; *b* – new LI; *c* – the results of luminance measurement at point A

4.2. Selection of View Points

As noted above, it is virtually impossible to remove the veiling reflections for all view points since they change their positions depending on a spectator's position, but it is possible to significantly reduce its luminance when viewed from a part of the hall (Fig. 5).

Geometric calculations (Fig. 9) demonstrate that, when watching the majolica at the shown points, reflection of radiation of a segment of LD with width of (180–190) ° can be seen. If we reduce luminance of this part of LD, luminance of the veiling reflection will be significantly lowered.

4.3. Structure of LD

The data obtained allows us to formulate the design principle of the structure of LD (Fig. 10): a triangular-prismatic emitter is installed into a frosted-glass diffuser and LED modules with remote phosphor are installed on two sides of the emitter. The qualitative and quantitative indicators of such modules are high (luminous efficacy of 111.5 lm/W, $Ra > 80$, cosine luminous distribution curve (LDC), no peak in the blue region of the spectrum specific for phosphor LEDs (Fig. 11) [11]). With that, one half of the ball diffuser is illuminated by the LED modules and the other one is illuminated only by multiple reflections inside it. The operating principle of such luminaire can be seen in Fig. 10, *a*.

The *Photopia* software [12] calculations demonstrate that LDC of LD with such design would be asymmetric. To test this hypothesis, a current and a modernised LI were simulated by means of *DiaLux Evo 7.* By means of the ray tracing method, luminance distribution over majolica was calculated for both models, which showed that application of LD with asymmetric LDC allows luminance of veil-

Table 3. Luminance Measured in Different Areas of the Majolica from Point A

Area	Luminance, cd/m^2		
	minimum	maximum	average
1	8.4	92.4	33.2
2	4.2	65	18.6
3	1.5	84.7	23.3
4	1.8	49.6	9.8
5	1.5	80	25

ing reflections to halve and "move" them upwards (by increasing the height of LDs) so that they do not prevent perception of composition.

The results of modelling and their comparison with the results of luminance measurement at point A are shown in Fig. 12 and in Table 3.

5. CONCLUSIONS

As a result of studying luminance distribution of majolica, the following was found:

• The sources of veiling reflections are diffusers of LDs which are reflected from the glazed surface of the majolica mural;

• Luminance of the reflections reaches 142 cd/m^2 with average luminance of majolica of (10–15) cd/m^2;

• Depending of the position of a spectator, the veiling reflections are located at height of 2 m to 3.5 m and obscure the narrative part of the composition.

Based on the analysis of the causes of the veiling reflections:

• Requirements to LI allocation and LD design were formulated;

• A model was developed and modelling of luminance distribution over the surface of majolica was performed by means of ray tracing using *Dialux Evo 7* software.

Despite the fact that it was not possible to remove the veiling reflections completely, the designed LI allows luminance and dimensions of the veiling reflections to halve and to move them from the narrative area to the background area, which positively affects perception of the composition.

The conclusion of the article is applicable not only to metro stations but to other areas with reflective or glazed surfaces.

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