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# MODERNISATION OF LIGHTING SYSTEMS OF A CASTING AND EXTRUSION PLANT IN KRASNOYARSK

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## ABSTRACT

The article describes modernisation of the lighting systems of Segal Casting and Extrusion Plant LLC in Krasnoyarsk and technical solutions of its implementation. The parameters of the new lighting system based on *Diora Craft* LED luminaires are presented and it is shown that replacement of luminaires based on high pressure mercury lamps (HPML) with LED luminaires allows saving 73.5 % of power consumed by lighting with high quality of the light environment established in the shops of the plant. Payback period of such modernisation is 1 year.

**Keywords:** light emitting diode (LED), lighting devices (LD), industrial lighting, lighting systems, lighting installation, LED luminaires, modernisation of lighting systems, energy saving

## 1. INTRODUCTION

Numerous studies have found significant impact of artificial lighting of industrial facilities on visual performance, physical and mental states of workers and, subsequently, labour efficiency, quality of products and work place injuries. Correct lighting of work places is the key factor of safeguarding and health protection of workers [1].

The informational field regarding developments and innovations in the area of industrial lighting has reduced dramatically over the previous 30 years; publications in scientific and technical journals are nearly non-existent and are replaced by news websites. The requirements to installation and operation of lighting installations (LI) for different production facilities are specified in federal regulatory documents [2–4], unfortunately, the applicable industry regulatory documents are compiled back in the Soviet period (1970–1990). After Perestroika, the industry regulatory documents virtually were not developed; therefore the obsolete regulations do not reflect the current level of development of technical means and technologies of lighting.

At the current stage of development of artificial lighting, due to well-known reasons, LED lighting holds the leading position (the main reasons include energy saving requirements in lighting [5] and international treaties aiming at solving of global environmental problems [6–8]).

With consideration of the above-mentioned circumstances, lighting of industrial facilities, being the most energy-consuming, must be transferred to application of LEDs on a first-priority basis.

This article describes the results of modernisation of lighting systems of Segal casting and extrusion plant (CEP) in Krasnoyarsk which included replacement of HPML-based luminaires with LED-based luminaires for increase of both quality of the light environment in shops and energy efficiency of LIs. The related programme of modernisation of lighting systems comprises three main stages: the first one (2015) – design of modernisation; the second one (2016) – implementation of the modernisation project (the said replacement of luminaires); the third and final one (2018–2019) – painting of vertical structures, ceiling and metal structures of

floors white (as an indirect method of increase of quality of light environment). At all stages of modernisation, the characteristics of LIs were measured, and the results of these measurements are presented in Table 1.

Segal Casting and Extrusion Plant LLC (a branch of GC SIAL) produces aluminium cast alloys, extruded aluminium profiles and products made of the same. The annual capacity of the plant is 32,000 tons and current volume of output is 26,000 tons per annum.

The structure of the facility includes cast, extrusion and painting workshops, anodic treatment section, production of suspended facades, formworks and products of aluminium profiles, analytical laboratory and packaging section.

Aluminium profiles are manufactured by means of automated extrusion systems based on presses with workload of 2,750; 2,500; 2,100; 1,200; 2,750 and 1,460 tf (1tf = 9.807 kN). For painting of aluminium alloy products, the facility employs *Trevisan* (Italy) and *TNE* (Singapore) vertical automatic painting sections and a *NEWLAC* (Spain) horizontal automatic powder painting section.

## 2. MODERNISATION OF LIGHTING SYSTEMS OF CEP WORKSHOPS

The aspects of industrial facilities lighting are defined by the sphere of production activities, lighting standards, category and characteristics of visual performance, nature and distinctions of process equipment, natural lighting conditions and workplace assessment requirements. It is implied that the workplaces are illuminated with standardised natural lighting and quality artificial lighting compliant with labour safeguarding and health protection requirements. An optimal LI solution complies in a compromising way with requirements of visual comfort ability and high energy efficiency which may be assessed by standard values of maximum acceptable specific installed capacity (SIC) of the system of production premises artificial lighting.

LDs for lighting of industrial facilities are selected with consideration of light-engineering and economic parameters of LDs including light distribution and luminous efficacy. Optimal selection of LD based on light distribution (with light distribution curve (LDC) and LD allocation scheme optimal for the given mounting height) allows power consumption for lighting to reduce by (30–35) %. For production premises with higher mounting height of LD (exceeding 6 m), LED-based narrow angle luminaires are efficient with their uniform allocation over the area of the production section. Necessity of use of LDs with concentrated light distribution increases with increase of ceiling height.

In workshops of cast plants, general lighting systems are primarily applied. The norms and quality indicators of lighting of cast plants production sections with visual performance category of Vb are well-known [2, 4]. As the production sections of case workshops are usually located in buildings with high ceilings (more than 8 m), general lighting LIs are equipped with LDs of high single capacity. In terms of the state of air environment, the premises of cast workshops are usually categorised as “dusty”, which determines the recommendations to use partially or fully dust-protected LDs (with protection class of at least *IP53*). But it is worth noting that contemporary mechanised and automated technologies promote enhancement of production practices and improvement of sanitary and hygienic conditions of workshops, which, in fact, makes conventional classification of air environment of modern industrial production facilities as “dusty” not necessary. Such situation fully relates to highly-automated workshops of CEP with their ceilings and walls being painted white at the final stage of modernisation. By content of dust, smoke and soot in the air environment, the production premises of Segal CEP are categorised as 1c [2, Table 4.3]. According to the calculations, painting of vertical surfaces, ceiling, and metal structures white increases average illuminance by (25–30)%, which has defined painting of enclosing structures of the workshop at the final stage of modernisation of the plant LIs. The efficiency of the effect of painting of the enclosing surfaces is demonstrated by increase of illuminance by 30 % in the workshop with the 2500 tf press (building No.2), from 267 lx to 348 lx, after painting the walls and the ceiling white (Table 1). This fact confirms efficiency of comprehensive approach by which high quality of the light environment is formed not only by correctly selected LDs but also by the state of the surrounding area.

Modernisation of LIs of the workshops of Segal CEP should serve as an example of progressive approach to modernisation of lighting of an industrial facility with its design comprehensively solving the issues of increase of energy efficiency, integrity of light environment in different operation

Fig. 1. *Diora Craft* 110/13000 luminaire (capacity of 110 W, luminous flux of 13,000 lm, $T_{cp}$=5000K, *IP65*): *a* and *b* – general view of the luminaire; *c* – LDC

Fig. 2. Lighting of CEP workshops after modernisation of LIs:
*a* and *b* – building No. 4, bay No. 5, automatic packaging line of painted profiles; *c* – building No. 2, workshop (2500 tf press)

modes of process equipment (in particular, blocking by gantry cranes), optimisation of the operation conditions of lighting equipment, convenience of installation and maintenance of LDs, comfort-ability of light environment. Modernisation was related to general lighting of workshops as part of the combined lighting system. Almost all production lines are automated; local workplaces are defined by location of equipment and are most frequently located in the beginning of a bay. Most commonly, these are the workplaces of production process operators made in the form of transparent unit of transparent protective glass.

Local lighting at workplaces is part of process equipment and is based on fluorescent lamps (FL) with *T5* bulb, which is specified by manufacturer of this equipment. Average illuminance at workplaces in the system of combined lighting is about 500 lx with the level of general lighting exceeding 200 lx [2]. The other part of the workshop is represented by automated lines providing general monitoring of the course of production process. Hereinafter the results of modernisation of the general internal lighting of Segal CEP will be described.

The *Diora Craft* industrial luminaires were specified by the modernisation project. General view of one of them is presented in Fig. 1 *a, b*. Light distribution of these narrow angle luminaires corresponds with Deep LDC (Fig. 1 *c*). Luminous efficacy (at least 120 lm/W), directed luminous flux (deep LDC with large mounting height) and rational allocation of luminaires in the premises provided high energy efficiency of LIs with maximum value of SIC of LIs of the plant workshops and sections not exceeding 3W/m$^2$ at average illuminance exceeding 200 lx (average value of SIC is 1.25 W/m$^2$ at 100 lx). Capacity of LED-based luminaires selected by calculation provides standardised illuminance (Table 1). According to the customer's design specification, the category of visual performance in the

**Table 1. Characteristics of LIs of Production Areas of Segal Cast and Extrusion Plant LLC after Modernisation**

| Area | $U_o$, per unit | | $E_{h\,av}$, lx | | | $K_f$,% | | $P_{sp\,max}$, W/m$^2$ | | UGR | | $R_a$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | standard | after* | standard | before** | after* | stan-dard | after* | stan-dard | after* | stan-dard | after* (*max*) design | stan-dard | after* |
| Formworks (the area is not shown in the photographs) | 0.40 | 0.90 | 200 | 152 | 253 | 20 | 0.2 | 5 | ≤ 3 | 25 | 20 | 80 | 80 |
| Building No. 4, bay No. 5, automatic painted profile packaging line, thermal processing section | | 0.70 | | 231 | 276 | | | | | | | | |
| Building No. 3B, workshop (with 2750 tf press) | | 0.80 | | 204 | 269 | | | | | | | | |
| building No. 2, workshop (with 2500 tf press) | | 0.60 | | 212 | 348 | | | | | | | | |

*Notes:*
– *standard* – standard values of parameters in accordance with [2, 4];
– after* – characteristics of LI after modernisation and after two years of operation (measurements of 2018);
– before** – characteristics of LI before modernisation (measurements of 2016).

*Legend:*
– $U_o$ – uniformity of illuminance distribution: $U_o = E_{min}/E_{av}$;
– $E_{h\,av}$ – average horizontal illuminance on work surface in the workshops;
– $K_f$ – flickering index;
– $P_{sp\,max}$ – maximum acceptable value of specific installed capacity;
– *UGR* – unified glare rating;
– $R_a$ – general colour rendering index.

**Table 2. Example of Print out of the Calculation results: Summary Results of Average Illuminance $E_{av}$ calculation for building No. 4**

| № | Обозначение | Тип | Растр | $E_{cp}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | $E_{min}/E_{cp}$ | $E_{min}/E_{max}$ |
|---|---|---|---|---|---|---|---|---|
| 1 | Пролет 1,2 | по горизонтали | 128×32 | 201 | 128 | 217 | 0,640 | 0,592 |
| 2 | Пролет 3,4 | по горизонтали | 128×32 | 202 | 131 | 216 | 0,651 | 0,609 |
| 3 | Пролет 5 | по горизонтали | 128×32 | 250 | 154 | 275 | 0,615 | 0,558 |
| 4 | Пролет 6 | по горизонтали | 128×32 | 254 | 157 | 282 | 0,615 | 0,556 |

modernised workshop is Vb and the standard value of illuminance is 200 lx [2]. All local workplaces with higher category of visual performance are equipped with local lighting.

For minimisation of costs of modernisation of the plant LIs according to the customer's design specification, *Diora Craft* luminaires (analogues of RSP-400, GSP-250, ZhSP-250 luminaires) are installed at existing light positions instead of obsolete luminaires with HPML 400 lamps (RSP-400). In each workshop, there are two components of LIs: stationary, with luminaires installed on floor frame work (Fig. 2, *a*), and mobile, with luminaires installed on the cross beam of gantry crane (Fig. 2, *b*). In the course of the production process, the mobile cranes are active in the workshops and their movement may cause blocking of stationary luminaires, impair stability of light environment and create discomfort for workers. To eliminate this unnecessary effect, the luminaires are installed on the crane beam and act as stationary ones at moments of blocking by the crane. Under-crane lighting is higher than general lighting by 15 %, which accentuates monitoring of crane work and increases safety of the works. Therefore, comfortable stability of workplace lighting during operation of mobile cranes is maintained in the workshop.

The progressive design and technical solution of LIs is supported by audacious design of the luminaires with their bell-shaped body of anodised aluminium serving as a reflector (integrated reflectance of 85 %) and a radiator at the same time. The protecting diffusing glass is made of optical polycarbonate and fixed to the body of the luminaire by means of an elastic silicone rim acting as a sealing. Integrated transmittance of the diffuser material is 0.91.

Despite the low thickness of metal, original allocation of LED-modules on the inner surface of the body (Fig. 1) provides optimal heating mode for LED (temperature of the LED module does not exceed 80 °C) within the whole range of capacity of the *Diora Craft* luminaires line, from 55 W to 150 W, at operating temperatures varying from –60 °C to +60 °C. Operation of the body as a radiator makes an additional radiator which is usually massive and cast unnecessary. That is why the weight of a luminaire does not exceed 3.2 kg, which is significantly less than that of Russian analogues and provides significant advantages during height works and maintenance of LIs. Smooth bell-shaped body of the luminaires made using cold roll forming technology makes it free of ribs and angles (Fig. 1, *a*) on the outer surface, which virtually excepts accumulation of dust and other dirt on this surface and thus provides stability of LED heating mode, increases reliability and durability of luminaires and facilitates their cleaning. Allocation of LED modules in the upper part of the reflector provides the luminaires with additional useful features: high protective angle eliminating dazzling effect with mounting height of (6–15) m. The luminaires have high ingress protection rating (*IP65*), may be operated in areas with different air environment conditions, are categorised as the 4$^{th}$ operation group [2], comply with the requirements of [9], and their $T_{cp}$ = 5000K.

The LED modules are of petal shape and are allocated in the upper part of the body (Fig. 1, *b*); they are equipped with *LM561C* LEDs by *Samsung* with maximum single capacity of 0.6 W. The number of LEDs on a module board depends on capacity of a luminaire: 250 pcs. at 110 W and 420 pcs. at 130 W. LEDs are operated at lowered capacity in the luminaires, which, as it is known [10], increases their luminous efficacy. At the same time, in a *Diora Craft* 130 (130W) luminaire, single power of LED is 0.285 W (47 % of the maximum value) and in *Diora Craft* 110 (110 W), it is 0.405 W (67 % of the maximum value).

As a result, power allowance of 50 % and 30 % respectively provided luminous efficacy of the luminaires of at least 120 lm/W, increased their reliability and durability (due to facilitation of heating mode as compared to the maximum capacity mode of LED) and allowed the structure designing of luminaires using thin-wall body metal as a cooling radiator for the LED module.

It is obvious that reduction of single capacity of LED in LED modules increases their number to achieve optimal value of luminous flux, which principally makes the luminaires more expensive. A compromise in selection of single operating capacity and number of LEDs was defined by optimal quality-price ratio**.** The principle of design of a luminaire allowed to achieve high consumer characteristics and to set warranty period of 5 years with competitive price. In *Diora Craft* 110 and *Diora Craft* 130 luminaires, *PS130–700* power supply unit was used with minimum efficiency of 92 % at operating current of 700 mA and maximum power of 130 W.

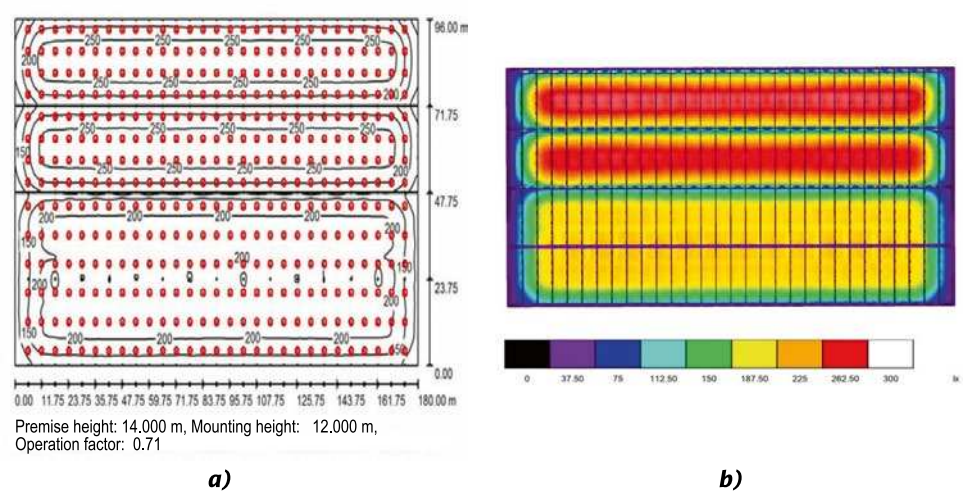


Fig. 3. Design fragments of the project of lighting of production areas of building No. 4. Design distribution of illuminance in iso-illuminance curves (*a*) and fictitious colours (*b*)

At the first stage of the plant LI modernisation, in 2016 (the first tenders were conducted in 2015), 632 *Diora Craft* 110/13000 and 33 *Diora Craft* 130/17000 luminaires were installed. As a result, even given the achieved enhancement of light-engineering parameters (Table 1), the power of LIs was lowered by 73.5 %, from 279.3 kW (before the modernisation) down to 73.8 kW (after the modernisation). With tariff equal to 4 roubles per kWh, annual saving of electric power costs was equal to 7.2 million roubles. Due to significant saving of energy for lighting, the investments in modernisation of the plant LI (with the cost of equipment procurement of 6.82 million roubles) were returned after a year of operation.

The programme of comprehensive modernisation of lighting of Segal CEP specifies stage-by-stage installation of LED luminaires in all workshops and painting the walls, ceiling and load-bearing metal structures white at the final stage of modernisation.

For all workshops of the first phase of modernisation, light engineering calculations and modelling were performed using *DIALux 4.13* software. Fig, 3 provides an example of calculations for production areas of building No.4. Building dimensions: area – 17,288 (180×96) m$^2$; mounting height of luminaires – 12 m; ceiling height – 14 m; spacing between rows of luminaires – 6 m; spacing between luminaires in a row – (6–8) m depending on the structure of floor slab in different bays. The operation ratio for *Diora Craft* luminaires categorised as the 4$^{th}$ operation group was taken equal to 0.71 [2, table 4.3 with consideration of note 4]. The values of reflectance of the ceilings, walls and floors taken for calculations are 0.70 (whitewash), 0.50 (grey plaster) and 0.20 (concrete). In Table 2, calculated values of illuminance are presented with consideration of the selected operation ratio of the luminaires.

Table 1 contains the results of implementation of the design solutions for production areas of the first phase (2016) of modernisation of the plant LIs and the results of measurements of illuminance conducted after the two years of operation of LIs (2018). Actual levels of illuminance are higher than the calculated values, which witnesses correctness of selection of the values of luminaire operation ratio and values of reflectance of the walls, ceilings and floors. Before the manuscript of this article was sent to the journal, as part of monitoring of LIs at section of thermal processing in building No. 4, additional measurements were conducted; they revealed reduction of illuminance over the third year of operation (July 2018 – August 2019) within the range of 3 %. (The operation mode of the plant is continuous.)

Fig. 2 shows the general view of the production areas in buildings numbers 2, 3B, 4 and the scheme of allocation of the luminaires after modernisation of LIs of Segal CEP. The LIs are distinctive with uniform allocation of the luminaires in rows parallel to the walls. The illuminated space of the workshop is saturated with light and is a comfortable light environment (Table 1) for performance of profile works.

Currently, Segal CEP is continuing the modernisation of lighting by stage-by-stage replacement of HPML-based luminaires with LED-based luminaires (*Diora Craft* series) and painting the vertical surfaces, ceiling and metal structures white.

## CONCLUSION

Introduction of LED-based luminaires in general industrial lighting installation is of great potential in terms of energy saving and quality of light environment in facilities. The example of comprehensive modernisation of CEP in Krasnoyarsk demonstrates such opportunities: the power of LIs was lowered by 73.5 %, from 279.3 kW (before the modernisation) down to 73.8 kW (after the modernisation) with high quality of light environment (Table 1). With annual reduction of energy costs by 7.2 million roubles, due to significant saving of energy for lighting, the investments in modernisation of the plant LI were returned after a year of operation.

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