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LEDs Lighting Arrangements for Underground Mines

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Abstract

Lighting condition is very critical to mine workers, since they completely depend upon visual indication. Effective lighting systems provide better visibility and contribute to improved safety, production, productivity and efficiency of equipments. This paper intended to present a simulation study of configurations for the uniform illumination over a rectangular-target surface (underground mine 26X4.8 m gallery) using power LEDs. This cost effective lighting involved different sets of arrangements of LEDs that provide a close uniform light level for given optimized parameters. The optimized values of the variables in the arrangements were obtained by the using of MATLAB functions for optimization toolbox.

Keywords: *power LED, uniform illumination, objective function, optimization.*

1. Introduction

Lighting is very important in mines especially in underground mines. The environment of underground mines is not comparable with any other surface industries. It is an industry where work is full of dust, limited spaces, very low reflective surfaces and low visual contrasts [1-3]. These are dependent on the moisture condition of underground atmosphere. Countries with a well-established underground mining industry are usually quite specific in their requirements regarding what constitutes a safe mine lighting system [4-6].

The lighting industry today is in a major state of transition. For more than a century incandescent bulbs have dominated the landscape of general illumination. With depleting non-renewable sources and threat of global warming, there has been an increasing awareness and need for energy efficiency together with conservation [6, 7]. Measures have been taken by several countries for the phased withdrawal of incandescent lamps. The incandescent lamps are being replaced by Compact Fluorescent Lamps (CFL) which possess longer life and better efficiency. Certain problems though exist in CFLs including flicker, presence of mercury and slow start among others. Solid-state lighting, primarily LEDs have come a long way in terms of light output and range of colors [1], [8-10]. They have already occupied some niche areas like traffic lamps and billboard lighting and are increasingly becoming competitive for home lighting also. With advantages ranging from higher energy efficiency, modularity, long life, no toxic mercury, no flickering, instant start and many more when compared to traditional lighting sources [11, 12]. LEDs are positioned to become the choice of lighting in the coming days. But in mining field especially underground mine, LEDs lighting is very less. As LED has longer life and better efficiency, it will reduce accident factor, the energy cost, improve the working efficiency and lighting system also [13].

There are different types of mining methods for extracting ore. In underground coal mining, the “Bord and Pillar” is one of the coal extracting method. In this method of mining coal seams involves the dynamic of a series of narrow headings in the seam all of them parallel to each other and connected by cross headings to form pillars. It has to be either partial or should be square but they are sometimes rectangular or of rhombus shape. The galleries surrounding the pillars are invariably of square cross-section. The Bord and Pillar method of mining is suited to work flat coal seams of average thickness and at low depths. For this method the coal seams of 1.8 to 3m thickness are best suitable, though the method has been successful in thinner seams also down to a thickness of 1.2m and in thicker seams up to 4.8m in thickness. According to “Indian Coal Mining Regulations, (Reg. 99(2), 1957)” width and height of a gallery should be restricted to 4.8m and 3m. And the length of pillar varies from 12m to 45m, it

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dependents upon the depth (60m to 360m) of the mine. Generally in lower seam coal mining, the pillar's length 26m, width 4.8m and the height is 3m. And here also in all the cases the dimension of a pillar is 26X4.8m and height is 3m [14-16]. Underground mines are completely dependent on artificial sources of illumination. Lack of proper and adequate lighting, there is much possibility of accidents. Especially underground mining operations are carried out in very hazardous environments. These are dependent on the moisture condition of underground atmosphere. This is particularly true for mines which have methane gas given off from the workings, usually coal mines. The provision of lighting in coal mines and other mines have always presented a problem due to the danger of inflammable gas. The need for general lighting in underground mines as well as in open cast mines is desirable [6].

One of the desirable features in task-lighting is the uniform illumination over an underground mine roadway gallery. This has to do with the user's perception of the target-surface, as well as, reducing power consumption by ensuring that there is no excess illumination. A generally accepted measure of uniformity of illumination is - ratio of the minimum illumination on the target-surface to the mean illumination over the target-surface. An interesting application of obtaining the uniform illumination over a target surface, is the illumination of underground mine roadway gallery. According to "the coal mines regulation 1957, these standards are summarized below [14-16].

Table 1. Lighting Standards

	A. Open cast mines	
Sl. no	Location	Minimum illumination (Lux)
1.	Operational area of draglines and shavels	5-10
2.	Operational area of drills	10
3.	Operator's cabin of shovel, dragline drill etc.	30
4.	Dumper haul road	0.5 to 3.0
5.	OB and Coal dumps	3
6.	Roadways & footpaths from bench to bench	3
7.	Coal Handling plant, workshop and service buildings	30-50-100
	B. Underground mines	
Sl. no	Place	Recommended minimum average illumination level (in lumens per sq. foot) for satisfactory light condition
1.	Pit bottom	1.5 to 3.0
2.	Main junctions	1.25
3.	Roadways	0.4
4.	Haulage engines, control gear and haulage drum	1.5

The light should ensure adequate illumination within the gallery dimensions. The problem of obtaining a suitable and uniform illumination is, to determine the best configuration with the corresponding parameters for different arrangements of the lamps. This is approached by a combination of optimization, and iteration. A configuration is chosen by intuition with the knowledge of source radiation pattern, geometry, and symmetry. Here the parameters for the configuration are identified and the problem is formulated. This is solved using MATLAB toolbox "optimization". There are many configurations possible. Thus based on physical, optometric, economical, and other application-specific considerations, the configurations are to be studied. In this paper, all of the configurations are studied through simulation [17, 18].

2. Methodology
2.1. Assumptions

The point source of light assumption for the LED source is not valid according to the standard CIE-127, as stated [11]. A good approximation would be considering it as an imperfect Lambertian emitter. For simulation purposes however, the LED is considered as an ideal point source of light (ideal Lambertian emitter). This is a simplistic model for small angles of illuminance, suitable as an approximation and for task lighting applications. Assuming the LED to be a point source of light entails it to follow the inverse square law and Lambert's Cosine Law [19-22].

2.2. Problem Specifications
1) The target-surface for illumination is a rectangular area of side unit length (26 X 4.8).
2) Each of the point source (LEDs) in the simulation is of unit luminous intensity (1 p.u).
3) Bounds for the height (h) at which the LEDs are placed: 0 < h < 1 unit.
4) The LEDs are always placed within different configuration in gallery dimension (26m X 4.8m).
5) The bounds are chosen from the perspective of lighting system design for underground roadway lighting.

2.3. Optimization
The optimization is carried out with the use of MATLAB functions for optimization in the Optimization Toolbox. The MATLAB function used is ‘fmincon’ which finds the minimum of a constrained nonlinear multivariable function. ‘fmincon’ is a gradient based method and uses Hessian to find the minimum [19, 20].

The objective function is vital for the optimization process [23, 24]. A good and suitable objective function helps in obtaining the desired results. ‘α’ is chosen as a measure of uniformity of illumination and defined as follows,

$$\propto = \frac{I(max)-I(min)}{I(mean)} * 100$$

Where, I(max) is the maximum illuminance, I(min) is the minimum illuminance and I(mean) is the average illuminance on the target-surface. The goal of the optimization process is to minimize ‘α’ by optimizing the values of the variable parameters.

2.4. Configurations
In all the configurations, the LEDs are placed perpendicular to the target-surface in a symmetrical fashion about the center of the mine roadway gallery.

1) Configuration 1 (5 LEDs): In this configuration, five LEDs are placed along the length of the pillar

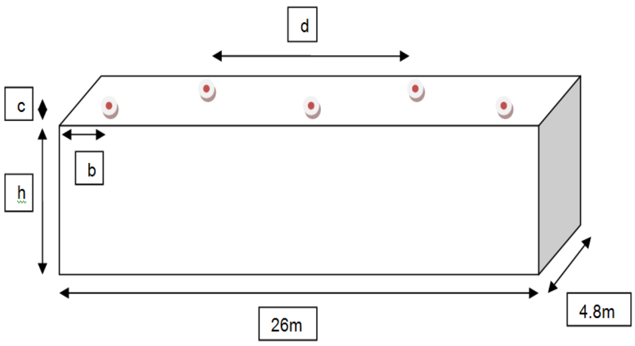

Figure 1. Configuration *of* five LEDs placed along the length of the pillar

Where, ‘h’ is height of the roadway gallery, ‘b’ is distance of a lamp from corner of the gallery, ‘c’ is distance of a lamp from edge of the pillar and ‘d’ is distance between two lamps. The variables considered for optimization are ‘b’, ‘c’, ‘d’ and ‘h’.

2) Configuration 2 (6 LEDs): In this configuration, six LEDs are placed along the length of the pillar in the above same pattern.
3) Configuration 3 (7 LEDs): In this configuration, seven LEDs are placed along the length of the pillar in the above same pattern.
4) Configuration 4 (8 LEDs): In this configuration, eight LEDs are placed along the length of the pillar in the above same pattern.
5) Configuration 4 (9 LEDs): In this configuration, nine LEDs are placed along the length of the pillar in the above same pattern.

6) Configuration 4 (10 LEDs): In this configuration, ten LEDs are placed along the length of the pillar in the above same pattern.
7) Configuration 4 (11 LEDs): In this configuration, eleven LEDs are placed along the length of the pillar in the above same pattern.
8) Configuration 4 (12 LEDs): In this configuration, twelve LEDs are placed along the length of the pillar in the above same pattern.

2.5. Simulation

For each of the configurations, the optimization of defined variable parameters is carried out. Table 2 is a comparison of the statistical results, of the illumination levels obtained on the target-surface, from the eight set of LEDs configurations. From Table 2, it is observed that among the configurations, the best possible uniformity is obtained in the case of configuration-8 comprising of 12 LEDs. All of the results were calculated with optimized variables value. This difference can be attributed to the difference in the heights at which the LEDs are placed, to minimize the stated objective function.

Table 2. Compairson among different set of LEDs

Sl no	Configuration	Illumination (in Lux)			'α'
		Maximum	Minimum	Mean	
1.	5 set of LEDs	0.157	0.027	0.090	144.7
2.	6 set of LEDs	0.144	0.048	0.089	106.9
3.	7 set of LEDs	0.178	0.043	0.124	109.6
4.	8 set of LEDs	0.153	0.082	0.113	62.55
5.	9 set of LEDs	0.209	0.056	0.161	94.80
6.	10 set of LEDs	0.172	0.114	0.140	40.90
7.	11 set of LEDs	0.237	0.079	0.195	80.80
8.	12 set of LEDs	0.194	0.143	0.169	30.28

1W LED from ProLight Opto Technology Corporations considered for the physical arrangement. The rated current of the LED is 350 mA, and the constant current drive is provided by the appropriate LED drivers. In flux characteristics of Lambertain type (Radiation pattern) white "PM2B-1LWE" (part number emitter). The average luminous flux of each LED is estimated to be 131 lm and viewing angle is 130^0 [25]. So, the light intensity is around 36.11cd [26]. By using the same intensity, some configuration can fulfill the illumination requirement of given standards. Here three different configurations with 8 sets of LEDs shown in Figure 2. The simulation results have been discussed in Table no 3. And Figure 3 shows the illumination plot of all three configurations.

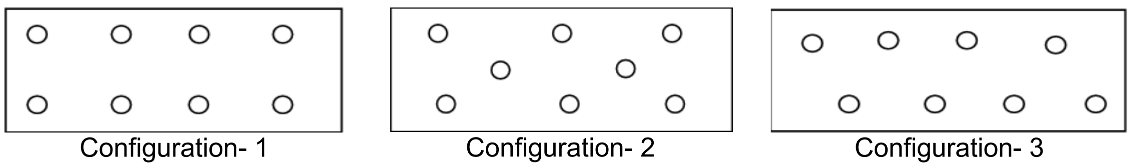

Figure 2. Top view of three different configurations with 8 sets of LEDs

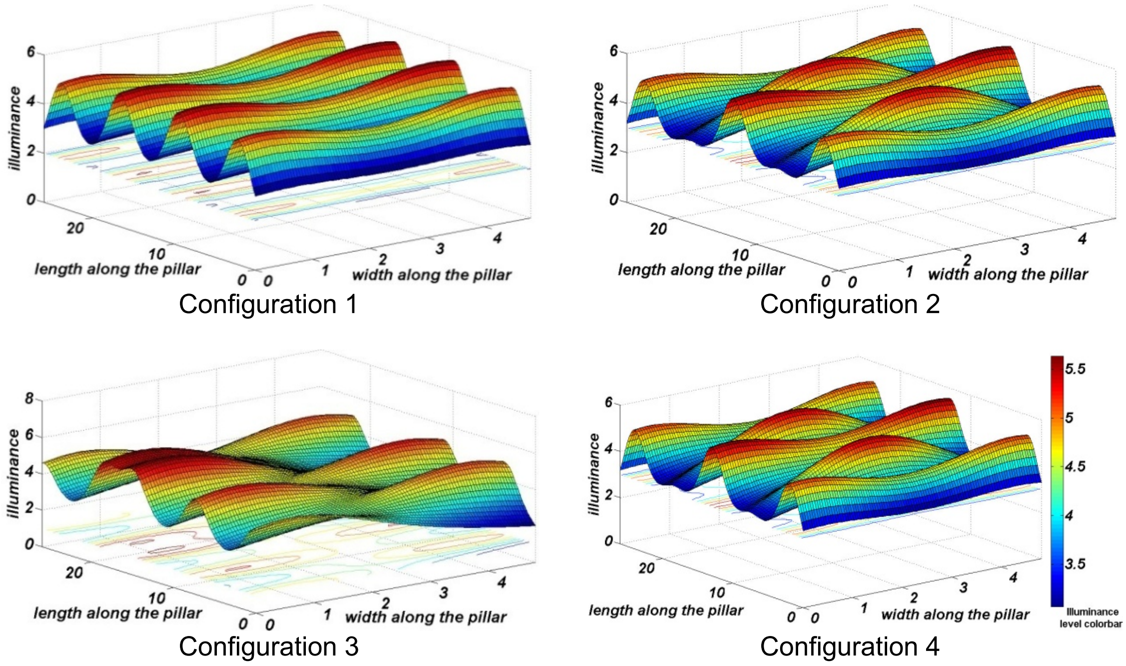

Figure 3. Illumination plot of a 26m long and 4.8m wide pillar by eight point lighting source placed at a height h with different configurations

Table 3. Comparison among different configuration with 8 sets of LEDs

Sl no	Configuration	Illumination (in Lux)			'α'
		Maximum	Minimum	Mean	
1.	Configuration- 1	5.51	2.97	4.07	62.55
2.	Configuration- 2	5.64	3.07	4.31	59.72
3.	Configuration- 3	6.07	1.99	4.23	96.18
4	Configuration- 4 (Illuminance level colorbar)	5.64	3.07	4.31	59.72

3. Conclusion

A near-uniform illumination level is possible with a suitable arrangement of LEDs. An arrangement of eight LEDs of three different configurations of 1 W (assuming an average luminous intensity of 36.11 cd for the 1 W LED), can provide close uniform illumination over a target-surface, for the optimal values of the variable parameters, as per the simulation results.

The proposed all three LED arrangements provide an average illumination more than 4 lx over the entire gallery that fulfills the required illumination level according to The Coal Mines Regulations 1957. Configuration- 2 (α = 59.72) gives the greatest uniform illumination over a gallery in comparison to configuration- 1 (α = 62.55) and configuration- 3 (α = 96.18). So for the LEDs lighting arrangement, configuration- 2 is suitable in every aspect and provide the most near uniform illumination. In term of cost benefit, initial installation of LED light fitting cost is little high but overall cost is very low in comparison to CFL, incandescent lamps and other lamps.

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