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A Review on Illuminance Measuring Technique for Hassles Free Operation in Underground Mines

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Abstract

Lighting plays an important role in underground mining operations. Underground mines are completely dependent on artificial sources of illumination. Without proper and effective lighting, there is much probability of accidents and less productivity. In order to maintain effective lighting in underground mines, measuring of illuminance and luminous energy is very much necessary. Because, humans receive the bulk of their information visual, the quantity and quality of illumination is critical to the safe and efficient operation. This paper explains the making of illumination and luminous energy measurements, photometer and factors which effect on accuracy of photometer. It also deals with the photocell characteristics and the probability of errors takes place while measuring.

Keywords: Illuminance, Luminaire, Nystagmus, Photopic vision and Scotopic vision.

Introduction

Underground mining operations are carried out in very hazardous environments. The environment of underground mines is not comparable with any other surface oriented industries. It is a dynamic one that includes dust, confined spaces, low reflective surfaces and low visual contrasts. These are dependent on the moisture condition of underground atmosphere. To recognize underground mining hazards Miners are very much dependent on visual cues [1]. Consequently, illumination greatly affects miner's ability to perform their jobs safely. Mining is a hazardous calling requiring a continual state of awareness and an ability to recognize danger from many sources, which is impossible without adequate illumination [2 & 3]. Lighting has a serious effect upon morale and plays an important part in improving operating conditions below ground. In this respect good lighting underground can have a marked effect. One adverse effect of insufficient lighting in mines is the incidence of the eye disease of miners' Nystagmus [4, 5, 6 & 7]. This is usually evidenced by oscillations of the eyeballs, slow adaptation of the eyes to both light and dark and other neurotic effects. The sufferers also have a marked dislike for bright light [3]. Since, the reflection factor in mines is so poor, a minimum illumination of 0-4 lm/ft should be provided [8 & 9]. The design of good lighting systems for underground mines is not so much easy because of the different and dangerous environment and work procedures situated in underground mines [2 & 3]. If they are carefully designed and implemented, lighting systems provide mine workers improved visibility and contribute to improved safety and productivity. Effectively designed lighting systems can prove to be a very cost-effective investment in underground mines. Instruments are required to evaluate lighting systems and components in order find out the illumination depreciation over time. The field of light measurement is called photometry, and the instruments used to measure lighting are called photometers [30 & 31]. All objects are seen by contrast, either dark against a light background or light against dark. Our ability to see them depends on this contrast, and we need more of it at lower lighting levels and when we need to see small detail. Unless the objects are self-luminous their contrast with the background comes from the amount of light directed at them which is returned to the eye [10].

LUMEN – THE POWER OF LIGHT

The radiation or "luminous flux", which comes from a lamp, is measured in lumens (lm). This quantity allows for the fact that the sensation of "light" experienced by the human eye/brain system depends on the wavelength of the radiation entering the eye [10]. The same amount of energy at the opposite ends of the spectrum - red and blue - produces less sensation than in the middle (yellow/green). At the peak of sensitivity one watt of radiated electromagnetic power is equivalent to 683 lumens.

EFFICACY

This is defined as the number of lumens produced by a lamp for each watt of electrical power it consumes. The unit is lumens per watt [10 & 11]. A low pressure sodium lamp emits nearly all its radiation near the yellow "peak" and has a high efficacy of 200 lumens / watt, whereas a tungsten lamp emits most of its radiation in the infrared part of the spectrum to which the eye is "blind", and has a low efficacy of around 14 lumens / watt. The efficacy of LEDs is constantly improving: "white" LED sources are becoming available with efficacies approaching 100 lumens / watt.

INTENSITY - THE CANDELA

A lamp emits light in all directions. The flux emitted in a given direction within a very small solid angle "surrounding" the direction, divided by the solid angle, is the intensity in that direction. The unit of measurement, lumens per steradian, is called the candela (cd).

ILLUMINANCE

The flux from a luminaire travels in various directions through space until it strikes a surface. The amount of light falling per unit area of the surface is called the illuminance, and is measured in lumens per square meter or lux (lx). If the luminaire is at reasonable distance from the surface it can be regarded as a point source and the illuminance (lx) on a surface perpendicular to the intensity direction is simply the intensity I (cd) divided by the square of the distance r (m) as shown in Fig.1. This is sufficiently accurate to calculate the illuminance of vertical objects lit by headlamps.

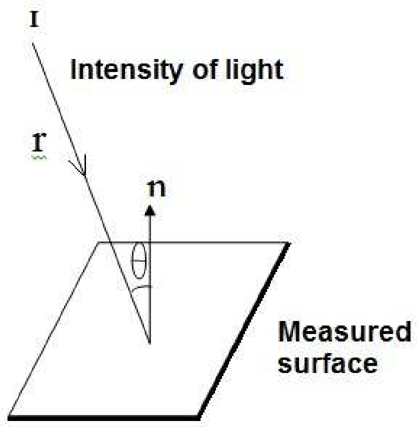

Fig.1 : Basic principle of illumination

Finally, for an object to be seen, some of the light striking it has to be scattered in the direction of the observer's eyes. The measured intensity of this reflected light per unit area of illuminated surface is called the luminance of the surface, and is measured in candelas per square meter. It is the differences in luminance between various objects and their backgrounds which basically determine how visible they are. The concept of luminance is used also to describe the characteristics of extended light sources, such as internally illuminated road signs [11, 12 & 13].

The relationship between the illuminance of a surface and its consequent luminance is quite complicated, as it depends on the direction from which the incident light strikes the surface, the direction from which it is viewed, and the inherent qualities of the surface itself - its reflection characteristics.

LUMINANCE

The amount of light (luminous intensity) per unit area leaving a surface is called luminance. Luminance is used to quantify the density of luminous flux emitted by an area of a light source in a particular direction toward a light receiver, such as an eye. Luminance is defined in terms of lumens (luminous flux per steradian) per square foot, or foot-lambert.

REFLECTION CHARACTERISTICS

There are basically three types of reflection. In specular reflection the light is not scattered but leaves the surface in one direction only, directly opposite to its direction of arrival, as in a mirror [14-20]. A very wet road surface behaves in this way. In Specular Reflection light bounces off the surface as shown in Fig.2

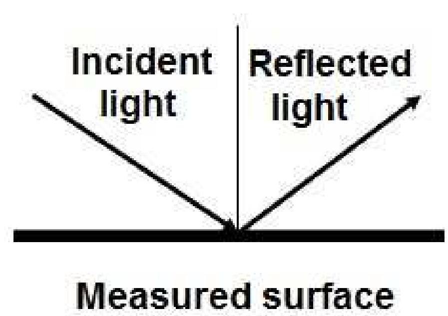

Fig.2 : Specular reflection of light on measured surface

In contrast, a perfectly diffuse reflector scatters light in all directions, in such a way that the luminance is the same for all angles of viewing as shown in Fig.3.and if the surface is dark like underground coal mines more light will be absorbed in to the surface as shown in Fig.4.

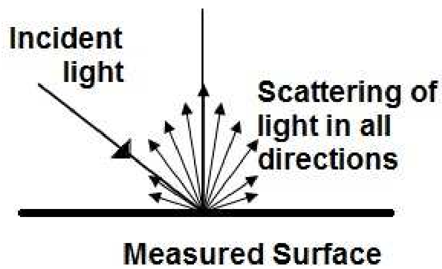

Fig.3 : Diffuse reflection of light on measured surface

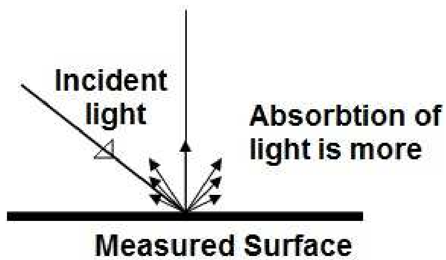

Fig.4 : Diffuse reflection of light at a dark surface

RETROREFLECTION

A retro-reflecting object returns a significant amount of the light falling on it back in the direction from which it came. Its effectiveness in night-time safety relies on the fact that an observer's eyes are very close (spatially) to his vehicle's headlights, particularly when the retro-reflecting object is some distance away. A retro-reflectorised object is considerably less bright for others viewing from wider angles.

In retro-reflection the incident light is returned back in the direction of the source, with a very small spread in the light around this particular direction as shown in Fig.5. Although one of the earliest retro-reflective road markings was inspired by nature - the cat's eye practical retro-reflectors are manmade, and produced as either discrete items or in the form of sheets and panels [21 & 22]. Most surfaces display a combination of specular and diffuse behaviour, with the specular becoming increasingly noticeable for large angles of incidence and observation as shown in Fig.6.

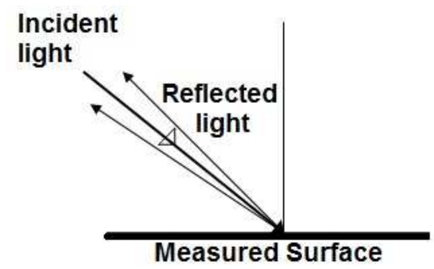

Fig.5 : Retro Reflection of light on measured surface

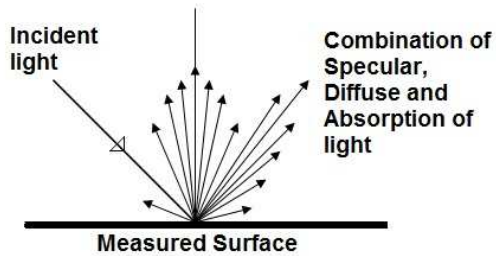

Fig.6 : Real Reflection – Combination of Specular, Diffuse and Absorption of light

CONTRAST

It is a crucial concept for determining visibility. If an object has no contrast with its background, it will not be seen, regardless of how much illuminance is applied [23 & 24].

Luminous contrast is measured by the following formula :

$$\text{contrast} = \frac{\text{object luminance} - \text{background luminance}}{\text{back ground luminance}}$$

Illuminance Measurements

The purpose of illuminance measurements is to determine the incident luminous energy (foot candles) on a surface and the light output characteristics of a luminaire.

Specific uses for underground mine illumination system measurements are :

- Measuring illumination depreciation over time
- Checking light distribution
- Evaluation of discomfort and disability glare
- Verification of illumination compliance and luminance specifications in the regulations
- Calculation of reflectance of mine and mine simulator surfaces
- Evaluation of illumination system design options.

The photocell is designed to generate an output signal that is proportional to all the light impinging on it and passing through an imagined hemisphere below which the photocell is placed with the lens facing directly up [25]. Therefore, if a measure of illuminance impinging on a surface is required, the photocell should be placed flat against the surface, as shown in Fig.7.

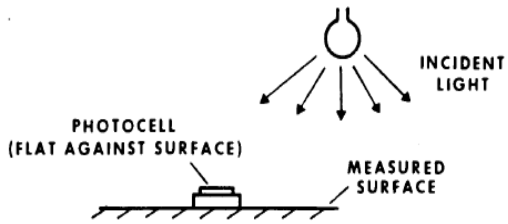

Fig.7 : Measurement of surface illuminance

To determine the candlepower distribution of a luminaire, the photocell should be placed directly at the luminaire, as show in Fig.8. The candlepower curve can then be computed using the inverse square law, $E = I/D^2$ where E is the measured illuminance; D is the distance to the luminaire and I is the luminous intensity. This method becomes inaccurate when the distance from the photometer to the luminaire is less than five times the maximum luminaire dimension [26 & 27].

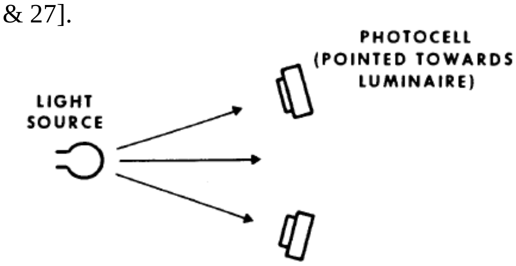

Fig.8 : Measurement of candle power.

Luminance Measurements

Luminance can be measured directly with photometers designed for this purpose. Typically, photometers have a luminance adapter as shown in Fig.9. The adapter has a lens system that allows light within a specific cone angle to be sensed by the photocell [8, 25 & 26].

Fig.9 : Photocell fitted with adapter

A method of checking an illumination system for compliance by measurement of luminance is the go, no-go, photometer [10]. This go, no-go, photometer provides a quick "go, no-go" indication to show whether the luminance of surfaces is below or above the 0.06-fL level required [11]. The instrument contains a red emitting diode lamp that is activated if the measured luminance is below 0.06 fL and a green diode lamp that is illuminated if the measured luminance is greater than 0.06 fL [11].

Luminance measurements specified in these regulations state that the photometer shall be held approximately perpendicular to the surface being measured. They also require that the sensing element be at a sufficient distance from the surface to allow the light sensing element to receive reflected light from a field not less than 3 ft^2 or more than 5 ft^2. In areas where a photometer cannot be held a sufficient distance from the surface to encompass at least 3 ft^2, the luminance can be computed by averaging four uniformly spaced readings taken at the corners and within a square field of approximately 4 ft^2. In the evaluation of large surface areas, the meter can be used in a scanning mode, which requires the meter be held 4 to 5 ft from the surface being measured and moved in a direction parallel to the surface [8]. In designing mine lighting systems, luminance measurements are often required to determine the reflectance of the simulated mine surfaces. For luminance measurements, meters with an available full-scale setting of approximately 0 to 0.1 fL are recommended.

Photometer

The photometer is one of the most important tools for illumination system design and evaluation. Many types of photometers are available to measure light energy and related quantities, including illumination, luminance, luminous intensity, luminous flux, contrast, color and visibility [30 & 31]. Before taking measurements with a photometer, care must be taken to insure that a luminaire or illumination system is in the proper condition to satisfy the purpose of the measurements. An adequate warm-up period should be allowed for fluorescent, sodium vapor, and mercury vapor luminaires. For instance, the light output of some types of fluorescent luminaires can be twice as great as initial levels after a 30-min warm-up period. The light output of some luminaires (especially incandescent) can vary widely with deviations in line voltage from nominal. Dirty luminaires, obstructions or deviations in luminaire mountings and orientations from specifications can significantly alter illumination levels [8 & 9]. The portable photoelectric photometer consists of a photocell that receives light and converts it into an electrical signal that is conditioned through an electrical circuit and is displayed on a visual meter.

The meter reading is proportional to the light energy level received by the photocell.

Even the more simple and durable photometers are delicate instruments that can give highly erroneous results when improperly used or calibrated. Proper instruction in the use and calibration of photometers cannot be overstressed [33]. Many factors can cause significant errors in the measurements in the very low light levels typical of underground mines. Photometers are available in a variety of models ranging from the low-cost, handheld units, which are very convenient but have limited accuracy and range, to more expensive and more accurate but less portable units. The photometer can be calibrated by periodically returning it to the manufacturer or with the use of a tritium illumination standard. This standard has a natural life of 5-6 yrs [8].

Principle of Operation

Precision operation amplifiers convert the photocurrent in nA resulting from the light sensation into a proportional voltage. The voltage is converted by a precision AD converter into a signal that is proportional to the expected illuminance in lux.

Factor Affecting The Accuracy OF Photometers

The major factors affecting the accuracy of photometers are as under.

Photo Cell Characteristics

Photocells used in portable photometers have been improved significantly in the past few years. New design photometers that utilize silicon photocell technology have distinct advantages when compared with selenium photocell photometers. Silicon photocells are more stable and exhibit a more uniform response in output with a change in light level. Selenium photocells are more prone to change in calibration with time and also can exhibit a hysteresis effect when measured light levels vary significantly. When exposed to illumination, the output of photocells decreases over a period of time because of fatigue. Therefore, the meter should be exposed to the light level being measured for as long an adaptation period as necessary; i.e., until the meter reading stabilizes [8 & 9].

Color Correction

The color response of a typical photocell differs from that of the human eye. This difference would cause a significant error in the measurement of visible light if the cell were not color corrected [8]. The photometers must be color corrected by filters to ensure accurate measurements. Color correction by using color gels or filters, is a process used in stage lighting, photography, television, cinematography. The intention of which is to alter the overall color of the light [9].

Cosine Correction

The response of a photocell changes as the angle of light impinging on its surface changes. At high angles of incidence, a greater portion of incoming light is reflected from the cell surface. This is because the reflectance of most surfaces increases as the angle of incidence increases. Also, the photocell support frame may prevent some light from reaching the photocell. Errors in light measurement caused by these factors alone may be as much as 25-30 pct. Cosine correction is provided by placement of a diffusing cover over the photocell .as shown in Fig.10. This cover adjusts the level of light received by the cell to the correct proportion for various angles of incidence [9]. A screening ring is also provided on some designs to reduce the light passing through the raised edge of the diffuser at very high angles of incidence [8].

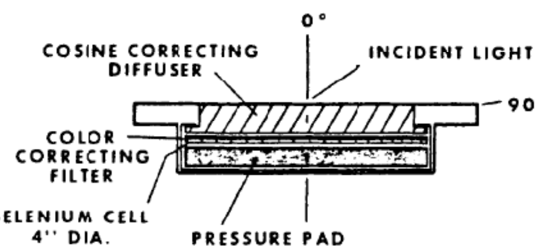

Fig.10 : Diffusion correction over photocell for cosine correction.

Photometer Zeroing

It is important to check photometer zeroing prior to taking measurements. If an analog meter is used, this requires setting the meter reading to zero with the photocell completely covered. It should be verified that the meter remains correctly zeroed, when the photometer scale selector is changed. A photometer that cannot be properly zeroed on all scale ranges should be repaired and recalibrated. Improper zeroing can be the source of significant error in the low-mine illumination levels [8 & 9].

Sensitivity

The sensitivity of a photo detector is the relationship between the light falling on the device and the resulting output signal. In the case of a photocell, one is dealing with the relationship between the incident light and the corresponding resistance of the cell as shown in Fig.11.

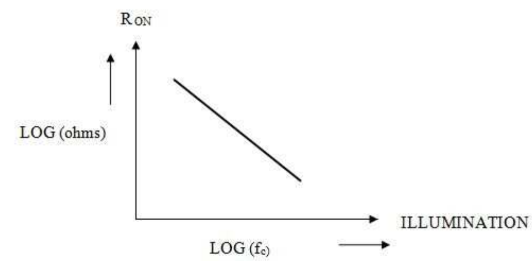

Fig.11 : Plot of incident light and resistance of cell in logarithmic scale

This is an important characteristic of photocells because in many applications not only is the absolute value of resistance at a given light level of concern but also the value of the resistance as the light source is varied. A meter with high sensitivity and accuracy permits the very necessary fine tuning of lighting systems needed to meet the stringent lighting regulations [8 & 9]. Illumination and luminance levels in underground mines are very low. Regulations call for an average luminance of 0.06 fL and incident illumination levels in the range of 2.0 fc. Photometers used for the design and evaluation of underground mine illumination systems should have full-scale ranges to accurately display levels in these ranges. For instance, when using a meter with a full-scale range of 30 fc to measure a level of only 2 fc, just the zero adjustment and error in reading the meter can be very significant. Overdesigning an underground mine illumination system to accommodate for poor instrumentation is an expensive alternative because of the relatively high cost of mine illumination system components [8 & 9].

Spectral Response

Like the human eye, the relative sensitivity of a photoconductive cell is dependent on the wavelength (color) of the incident light. Each photoconductor material type has its own unique spectral response curve or plot of the relative response of the photocell versus wavelength of light as shown in Fig.12.

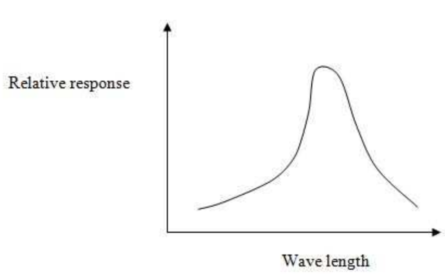

Fig.12 : Plot between Relative response of Photo cell and Wave length of light

Purkinje Shift

The Purkinje effect sometimes called the Purkinje shift or dark adaptation is the tendency for the peak luminance sensitivity of the human eye to shift toward the end of the color spectrum at low illumination levels. The relative sensibility of the retina varies for different colors with a change in brightness or it may be better to state that the relative sensation for various colors alters as the brightness values are reduced to a low intensity [12]. In general, the Purkinje effect may be described as an increasing sensibility of the retina for light of shorter wave-lengths (violet, blue, green) as the brightness decreases, or a corresponding decreasing sensibility for light of longer wave-lengths (yellow, orange, red). The effect may be seen on any colored surfaces at twilight illumination [13 & 30]. This effect introduces a difference in color contrast under different levels of illumination. Simply we can define as when luminance levels are below approximately 0.01 fL, the eye functions with only scotopic vision and the luminous sensitivity curve is shifted. This is called the Purkinje shift. Photometers used in underground mine illumination are calibrated for scotopic and photopic because the 0.06-fL regulation is in the photopic range. Photometers that automatically compensate for the Purkinje shift are not currently available [31]. For measurements below 0.01 fL, a photometer should be color corrected to match the scotopic luminous sensitivity curve.

Temperature and Humidity Effects

The performance of photocells is much dependent on Wide temperature. Prolonged exposure of selenium photocells at temperatures above 120^{O} F will permanently damage them. Silicon photocells are less susceptible to temperature variation when compared with selenium photocells. Exposure of a photometer to corrosive high-humidity conditions should be kept to a minimum. Photometers should certainly never be stored underground. Hermetically sealed cells provide sufficient protection from the effects of both temperature and humidity. It is recommended that desiccators be packed with meters taken underground [32].

Calibration

The most significant source of error in illumination measurements is inaccurate instrument calibration. Calibration is a method by which the response of a photometer is set to match a working standard. Photometers are sensitive instruments that are susceptible to loss of calibration. Meter calibration should always be checked both before and after any series of light measurements. The following are suggested methods of maintaining a standard for photometer calibration [33].

The meter can be calibrated with the use of a precision calibration incandescent lamp specifically manufactured for this purpose. This must be done with accurate control of lamp voltage and according to procedures recommended by the lamp manufacturer. These lamps have limited life and should be used only as recommended by the supplier. The working meter can be compared with a second reference meter that is periodically calibrated by the meter supplier. This reference meter would be used solely for calibration purposes. Use of the reference meter for other purposes would totally defeat its usefulness as a working standard.

The meter can be calibrated with a reference standard specifically designed by the manufacturer for the specific meter. These devices frequently employ nuclear standards.

Contamination

In underground mines, dust can rapidly accumulate on the photo detector surface and reduce measurement accuracy. Moisture and dust can enter photometer enclosures and cause component corrosion. These factors can easily affect the accuracy and useful life of an instrument. Photometers should be kept in a well sealed case and, to avoid contamination. The case should be removed only when they are to be used. The photo detector surface should be kept very clean, and care taken to use a cleaning method that will not scratch the surface [34, 35 & 36].

Stray Light

Miner cap lamps can be a significant source of error in underground mine illumination system measurements. Care must be taken to insure that cap lamps do not contribute to surface luminance on the photo detector surface. It is best to turn off all cap lamps in the area when taking lighting measurements [8 & 9].

Conclusion

This paper deals with the illumination & luminance measurements, measuring instruments which are used to identify the luminous levels and the factors which are highly effect on photocell characteristics. A well designed illumination system can provide important benefits to the miners and including improved safety. Hazards, especially in the mine worker's peripheral field of vision, can be more readily detected. By considering the characteristics one can minimize discomfort and disability glare. Based on the characteristics and intensity of luminance, efficient lighting system can be decided.

Acknowledgment

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