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INFLUENCE OF MAGNIFIERS ON OCULAR EXPOSURE LEVELS

Paper 503

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Abstract

From the beginning of laser safety standards it was taken into account that the ocular hazard may be increased when optical aided viewing is assumed. Especially, for highly divergent beams this kind of hazard was recognized when analyzing the potential hazard for inspecting optical fiber tips. Up to now different methods and measurement conditions were published in the IEC standard to cover all products that emit divergent laser beams. Each new version of the standard increased the effort on the measurement setup, which finally leads to the ongoing discussion about the current Condition 2 (loupe condition) in IEC 60825-1 (2007). On the basis of numerous measurements of different divergent sources this paper shows that Condition 2 is only relevant for small sources and could be simplified or even eliminated from part I of the standard series IEC 60825.

Introduction

Part 1 of the standard series IEC 60825 (and IEC 825 [1], respectively) considered the use of optical instruments (loupe, telescope) until 2001 by a specified test: the power (energy) should be measured with a 50 mm measurement aperture at a distance where the maximum power (energy) could be measured (a minimum distance of 100 mm should be used). The measured power (energy) was then compared with the corresponding accessible emission limit (AEL). This large measurement aperture was of particular importance for highly divergent beams as well as for good collimated beams with a large diameter (larger than 7 mm) since much more power (energy) could be collected compared to the power (energy) that would be collected through a 7 mm aperture, which was specified for the naked eye. Laser products emitting such beams were often assigned to Laser Class 3A whereas a second condition must have been fulfilled concerning the irradiance which was measured at the same position as for the power measurement. As this measurement configuration meets the real use of optical instruments poorly the measurement setup as well as the laser classes were changed and were published 2001 in edition 1.2 of IEC 60825-1 [2].

In this version of the standard two different measurement setups were defined, one for the telescope the other one for the loupe, called Condition 1 and Condition 2, respeclively (Table 10 of the standard). In case of the telescope condition the measurement distance was determined to be 2 m in front of the laser aperture, and the 50 mm measurement aperture was restricted to the wavelength range 400 to 1400 nm (25 mm for 302.5 to 400 nm and for 1400 to 4000 nm). On the other hand the measurement distance for the loupe condition was specified to be 14 mm referring to the position of the apparent source. In addition for wavelengths from 400 to 1400 nm this measurement distance was depending on the size of the apparent source and could vary from 14 to 100 mm. Finally, a measurement aperture of 7 mm for all wavelengths was defined in Condition 2.

In the last and current version of the standard IEC 60825-1, ed.2.0 (2007) [3] new considerations regarding the practical use of loupes were taken into account. For this reason a complete new measurement setup was defined as shown in figure 5 of the standard - see Figure 3.

In the same year ANSI [4] adopted the laser class schema of IEC and the measurement Condition I for telescopic viewing with some deviations but not Condition 2, (Note: Condition 2 in ANSI Z136. 1 is identical with Condition 3 in IEC 60825-1 ed. 2 (2007)).

A. Setup According To Figure 5

According 10 the previous standard versions just one single 7 mm aperture was used to measure energy or power at diverse distances from the laser source or reference point, respectively. In the current standard version (IEC 60825-1 ed. 2.0 (2007)) a more or less realistic situation is assumed. Consequently, the measurement setup was considerably upgraded and is illustrated in figure 5 of the standard IEC 60825-1 ed. 2.0 (2007). As four optical elements are used in this setup all parameters are shortly explained in the following.

Aperture 1: Provided the beam diameter is larger than the diameter d_L of aperture 1 in front of the loupe, this loupe aperture limits the energy that can pass as well as truncates the beam, thus reducing the image information of the source. The 7 mm loupe aperture was defined for practical reasons since such apertures were already commonly used.

Lens 1 (L1): Lens 1 represents the loupe. The angular magnification (Γ) of a magnifying glass (a simple biconvex lens with a short focal length f_L) is defined as the ratio of the angle (σ') subtended by the virtual image when the loupe is used to the angle (σ) subtended by the object when viewed with the naked eye. Commonly, 25 cm are chosen for the object distance b (distance eye to object) to calculate the magnification. If the ratio b/f_L is sufficient high, following equation is approximately valid:

$$\Gamma = \sigma'/\sigma = 25\ \text{cm}/\ f_L \quad (1)$$

This definition is normally used to specify the magnification power. The standard defines a focal length of 35 mm. Considering the commonly used reference distance of 25 cm the magnification can be derived from equation (1) by Γ = 25cm/3.5cm ≈ 7 (Note: also for the telescope condition a magnification of 7 is assumed).

Distance 100 mm: It was assumed that a distance of 100 mm between lens L1 (loupe) and lens L2 (eye) is a typical usage and was an arbitrary choice.

Aperture 2: The 3.5 mm aperture in front of lens L2 (eye) represents the pupil diameter d_{Pupil}. As good ambient lightning is necessary for precise work (e.g. examination of surfaces) the pupil diameter cannot be in the dilated state. Therefore, the diameter of the aperture that is usually 7 mm was reduced to 3.5 mm.

Lens L2: the function of lens L2 is equivalent to the human eye lens and creates an image of the object on the CCD-Chip.

B. Considerations Regarding Figure 5

Position of source (reference point) Using eye loupes or hand magnifiers the object is normally located at the focal plane or slightly closer to the lens. An object in the focal point of the lens creates an image at infinity. This is the setup of a projector [5,6] and is the preferred configuration as the eye relaxes to accommodate viewing. For an ideal point source that is placed in the focal plane of the lens, the size of the apparent source α_{AS} does not depend on the distance to the loupe (within the flash distance) as well as the power through a 3.5 mm aperture does not vary within the flash distance. Unfortunately, there are never ideal point sources that are given to test labs and α_{AS} varies with distance, if the tested product represents a large source.

Magnification Regarding the magnification Γ of loupes three different kind of magnifying glasses can be distinguished roughly:

- handheld magnifiers: $\Gamma \leq 12$x
- eye loupes: Γ = 10x - 20x
- fiber microscopes: Γ = 200x – 400x
  (used for telecommunication services)

Although the concerns about using a loupe were first recognized in the field of telecommunications (examination of fiber tips) just a magnification of 7 was specified in the standard.

Loupe aperture On the one hand the 7 mm loupe aperture limits the power that can pass on the other hand it truncates the beam, thus reducing the image information of the source.

Sensitivity Due to the small diameter of aperture 2 and the relatively short focal length of lens 2 the measurement setup is very sensitive regarding any deviation from the ideal alignment of all four optical elements. In order to ensure a minimum reliability each measurement is very time consuming.

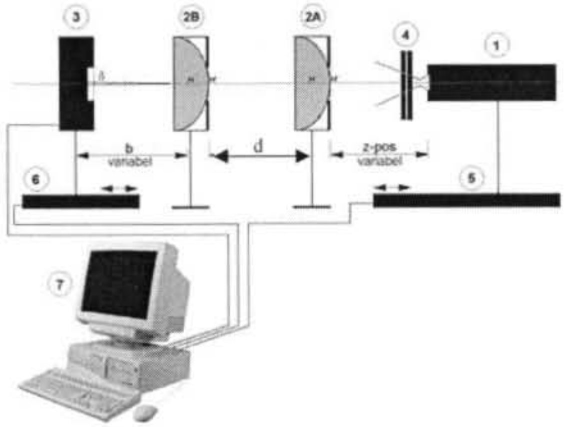
Evaluation Of The Loupe Condition

A. Investigated Sources

A number of divergent sources such as fibers with different diameters, diode lasers (using collimating or diffuser optics) and laser line generators were investigated – see Table 2. According to IEC 60825-1, ed. 2.0 (2007) two measurement setups regarding Condition 2 were applied: the simplified setup and the setup according to figure 5 of the standard. For the simplified evaluation (used for point sources) the power was measured with a 7 mm aperture at a fixed distance of 7 cm from the specified reference points. On the other hand all relevant parameters were varied for the extended evaluation (used for extended sources).

B. Measurement Analysis

As all measurements are based on the setup according to figure 5 of the standard IEC 60825-1 ed. 2.0 (2007). Since the distances between source and loupe (lens 1) as well as between eye (lens 2) and CCD-camera (simulating the eye's accommodation) have been varied, the measurement setup according to figure 5 of the standard was automated with the help of two linear stages and was controlled by a computer – see Figure 2. For each position of the source the full accommodation range of the eye (CCD-camera) was passed in steps of few tenths of a millimeter. At the end of one single measurement 1500-2000 images were taken and stored for the subsequent analysis.



1 ... laser source
2a ... lens 1, loupe
2b lens 2, artificial eye
3 ... CCD-camera
4 ... absorbing filters
5 ... linear stage for laser source
6 ... linear stage for simulating the accommodation
7 ... controlling unit

Figure 1: Experimental set-up.

The evaluation of each image that was projected onto the CCD-Chip is based on the analysis of the power to limit ratio (PLR) that is defined by the proportionate power within a rectangular area (somewhere on the image) to the circumference of this rectangle. If PLR is above the AEL the image may cause a thermal injury. To find the maximum $PLR_i(z)$ for one single image each possible rectangular area within the image is evaluated regarding the power to limit ratio. The arithmetic mean of length and width of the corresponding rectangle $((\delta_x+\delta_y)/2)$ describes the "diameter" of the image that is used for all subsequent calculation. When this arithmetic mean is divided by the image distance b the corresponding angular size δ of the rectangle can be derived: $\delta = (\delta_x+\delta_y)/(2\cdot b)$.

As for each position z the full accommodation range of the eye is considered up to 80 images must be evaluated for one single z-position. The maximum of all $PLR_i(z)$ regarding this z-position is named PLR(z) in the following. The related rectangle characterizes the size of the apparent source α_{AS} $(= \delta(z))$ at the position z. This procedure is done for every position along the beam axis in order to find the maximum PRL(z) by comparison of all PRL(z). The resulting position is called most-restrictive-position MRP. At this position the measured power (within the evaluated rectangle and for a certain accommodation) exceeds the limit mostly or is closest to the limit. In the following this final result is named PLR_{MR} $(= PLR(z = MRP))$ and the corresponding size of the apparent source α_{MR} $(= \alpha_{AS}(z{=}MRP))$.

- $PLR_{MR,NE}$ = Proportionate $Power_{NE}$ / AEL_{NE} (if viewed with the naked eye)
- $PLR_{MR,L}$ = Proportionate $Power_L$ / AEL_L (if viewed with the loupe)

In the literature often the term "correct" or "real" image is used. But independent of the configuration (source position or accommodation state) there will always be an image on the CCD-camera. To each position an apparent source can be assigned and therewith a factor C_6. Criteria such as smallest diameter according to commonly used diameter definitions (e.g. 1/e or second moment) cannot be used for PLR analysis in case of complex beam profile structures (e.g. laser line generator that projects five parallel lines). Besides, the smallest diameter does not always represent the worst case.

The results are presented in terms of the relative increase-factor that is derived from the power to limit ratios (PLR). The ratio of the $PLR_{MR,L}$ to the $PLR_{MR,NE}$ of the naked eye defines the increase-factor when using a loupe:

$$\text{Increase-factor} = PLR_{MR,L} / PLR_{MR,NE} \quad (2)$$

The potential hazard was measured for three different methods (Note: the abbreviations are used in the following tables):

- (S.E.): Simplified evaluation of Condition 2 (7 mm @ 70 mm)
- (E.E.): Extended evaluation of Condition 2 (Figure 5 of the standard).
- (E.E.+ MRP_L): Extended evaluation of Condition 2 considering the most restrictive position of the eye.

C. Evaluation According To IEC 60825-1 (2007)

Condition 2 according to the standard defines the parameters as shown in Table 1. In addition an appropriate focal length of the eye-lens was chosen to ensure that even a 100 mrad image is completely projected onto the CCD-Chip of the camera. The distance from the reference point of the laser sources to the principal plane of lens 1 was fixed to 70 mm for the simplified method and to 35 mm for the extended evaluation, respectively. A time base of 100 s was used for the determination of the AELs.

Table 1: Measurement parameters according to IEC 60825-1, ed. 2.0 (2007) relevant for an extended evaluation.

d [mm]	d_L [mm]	f_L [mm]	d_{Pupil} [mm]
100	7	35	3.5

The increase-factors are shown in Table 3. For the given measurement parameters (Table 1) only "small sources" show an increase of hazard when using a loupe. (Note: the 50/125 fiber is not a "small source" in the sense of the standard as $\alpha_{MR,NE}$ is equal to 1.62 mrad, nevertheless the increase factor is higher than 1. Measurements to evaluate the upper limit for $\alpha_{MR,NE}$ for which this statement is still correct have not been made). In all other cases the use of a loupe reduces the potential risk compared to the naked eye viewing.

The simplified method is valid only for "small sources" as the results of the increase factor correlate more or less with the results of the other methods. For all other sources the simplified method overestimates the potential hazard. Two special results should be underlined: in case of the extended evaluation just in one single case (50/125 fiber) the most restrictive position MRP_L equals 35 mm. The second special source was a line generator (Nr. 9) that emits an asymmetric line since for this source the maximum for the most restrictive position MRP_{NE} was found at 370 mm for the naked eye viewing and MRP_L = 105 mm for using a loupe. Correspondingly, the increase-factor was doubled for the optical aided viewing, but was still smaller than 1.

D. Parameter Variations

Beside the measurements according to the current standard, the following parameters were varied in order to see their influence on the increase-factor:

1) distance loupe - eye
2) diameter of pupil aperture
3) focal length (magnification)
4) diameter of loupe aperture
5) distance loupe – source

(Note: there is no source for which all measurement constellations were investigated. For this reason there might be other parameter combinations that would give a higher increase-factor than shown in the tables.)

<u>1) Distance eye – loupe d = 50/100/120 mm:</u> Three different distances were chosen for d. All other parameters were not changed. The distance d between the magnifying glass and the eye has little effect on the results, as expected for a "projected" source. Deviating from Table 1 some additional measurements were made with a 7 mm pupil diameter d_{Pupil} for Nr. 1 of the laser line generators. Also in this case the increase-factor does not vary significantly.

<u>2) Diameter of pupil d_{Pupil} = 3.5/7 mm:</u> A special source, a laser line generator that projects five parallel lines with a fan angle of 10°, was chosen for this comparison. Just two diameters of the pupil were evaluated, all other parameters were kept constant (Table 1), also the most restrictive position – see Table 5. As one could expect the size of the apparent source α_L as well as the collected power increased, if the pupil diameter is changed from 3.5 to 7 mm, thus resulting - in this case – in an increase-factor that is four times higher. The increase of α_L is much less than the increase of the measured power.

<u>3) Focal length f_L = 12.5/15/35 mm:</u> Three different focal lengths for the loupe (lens L1) were used for this comparison. The focal lengths correspond to the magnifications 20, 17, and 7 (e.g. 12.5 mm focal length corresponds to 20 x standard magnification). All other parameters were not changed except for the loupe aperture d_L. For some measurements the diameter of the loupe aperture was altered from 7 mm to 17 mm – see Table 6. For shorter focal lengths the value of increase-factor becomes always higher which was already shown by Marshall [7]. Even large sources may become more hazardous, if the magnification is increased (e.g. 600/660 fiber: the increase-factor was doubled). Sources that appear as "small" for the naked eye at 10 cm have an increased risk of up to a factor of 3 for large magnification cases. Besides it turned out that the simplified evaluation is a good estimation for small sources like the 50/125-fiber for 7x magnifications (the simplified evaluation still results in a higher increase-factor). If a 20x magnification is used, the simplified evaluation

method underestimates the potential hazard by factor of 1.5-1.8.

4) Diameter of loupe aperture d_L = 7/17 mm: Table 7 shows the results, if the diameter of the loupe aperture is varied. All other defined measurement parameters were not changed (Table 1). Beside the 7 mm aperture a 17 mm loupe aperture was used (whereas the 17 mm aperture was arbitrarily chosen and is not based on special considerations).

The use of an aperture with a 17mm diameter instead of a 7 mm aperture results in a hazard increase just for extended sources (diode laser with optic and diffuser as well as 600/660 fiber), due to the accessible power. Although the increase-factor was doubled in case of the diode laser this ratio was still below 1, i.e. even if the aperture equals 17 mm the naked eye condition is still more restrictive. As the diode laser with diffuser is the largest investigated source, the simplified evaluation method overestimates the potential hazard by a factor of more than an order of magnitude. The hazard increase of about 20% for the 600/600 fiber is caused by considering the most restrictive position of the loupe. The same fiber evaluated according to standard (extended source) would result in a decreasing hazard by a factor of 2. In all other cases no significant influence was noticed.

5) Focal length + diameter of loupe aperture are changed: The results if the focal length f_L and the diameter of the loupe aperture d_L are changed are given in Table 8. Following focal lengths were used: f_L = 12.5/15/25.6/35 mm. The corresponding magnifications are 20x/17x/10x/ and 7x. For the loupe aperture three different diameters were used: 7, 17, and 35 mm. Tabel 6, Table 7, and Table 8 indicate that the influence of the focal length f_L (magnification) on the increase-factor is much higher than the aperture diameter d_L – for large as well as for small sources. Table 8 shows that also large sources can be become hazardous (increase-factor > 1), if an appropriate combination of measurement parameters is used.

E. Sensitivity Of The Measurement Setup

Deviating from the measurement setup according to figure 5 in the standard a shorter focal length was used to point out in principal the sensitivity of the setup. The diagram in Figure **2** shows the change of the PLR for small shifts of the loupe and therewith the sensitivity of the setup. A lateral shift of the loupe of just 10 µm relative to the optical axis could result in an underestimation of 20-30% of the real PLR, a shift of 20 µm would cause a 50% deviation from the maximum PLR. In addition, the angle of the beam axis to ideal optical axis has a wide influence on the evaluated value of the PLR. On account of these influences a lot of time must be spent on the alignment to ensure that the maximum PLR will be found. Especially the combination of non-visible radiation and high divergence aggravates the problem as the determination of the optical axis is difficult. If the laser beam profile is additionally inhomogeneous, the optical axis can just roughly be estimated, thus increasing the uncertainty of the measurement.

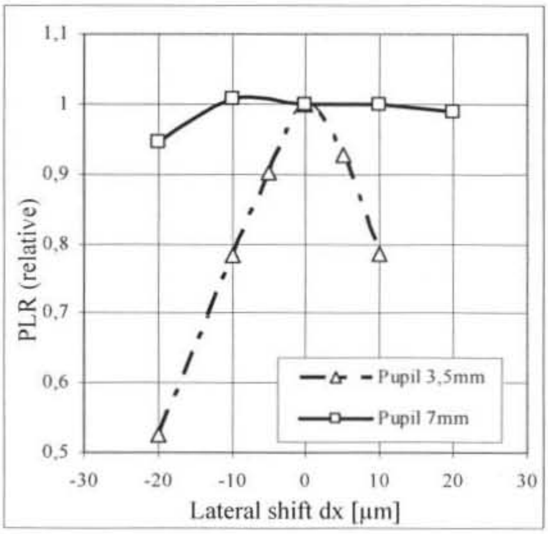


Figure 2: PLR (relative) as a function of the lateral shift dx of the loupe for two pupil diameters. Light source: diode laser, λ=660 nm, fiber 125/50, measurement set up according to figure 5 but the focal length was changed: f_L=15 mm (magnification 17), distance fiber end to loupe = 13 mm.

Table 9 underlines the problem of alignment. In order to test the reliability of the measurement setup two measurements have been done with different loupes for a small source (e.g. fiber 50/125). Between the measurements the fiber was taken off the alignment fixture and fixed again. In case of the standardized focal length of 35 mm (Γ = 7x) the size of the apparent source ($\alpha_{MR,L}$) was enhanced by a factor of 1.13 whereas for the loupe with a focal length of 12.5 (Γ = 20) the apparent source size ($\alpha_{MR,L}$) was decreased by a factor of 1.57. In contrast to the apparent source the increase-factor was higher than before in both cases by a factor of 1.29 and 1.72, respectively. Not only the increase-factor is affected by small misalignments but also the measured size of the apparent source (factor C_6) which is one of the most important factors for manufacturers. In an exaggerated way it could be stated that in case of an appropriate beam profile a lateral shift of about 20 µm of lens 1 could eventually cause a switch to another laser class even if the specified focal length of 35 mm is used.

In order to reduce the influence of an accurate alignment which is very time-consuming a larger pupil (e.g. 7 mm or even 50 mm) would be an advantage for practical reasons. If the measurement conditions are not changed it is open to question whether different laboratories will have comparable results.

F. Summary

1) Distance eye-loupe d: has marginal influence on the increase-factor.
2) Diameter of pupil d_{Pupil}: has one of the greatest effects of all parameters. The potential hazard is increased significantly with a larger pupil diameter.
3) Focal length of loupe f_L (magnification): in addition to the pupil diameter the focal length has great influence on the increase-factor. The higher the magnification the higher becomes the increase-factor. Recessed sources limit the practical use of highly magnifying loupes. Therefore, the limitation is reasonable for practical measurement reasons. Besides, the results of the extended evaluation show that the most restrictive position MRP is rarely identical with the default value of 35 mm.
4) Diameter of loupe aperture d_L: the larger the source the higher the influence of the loupe aperture since power as well as image information is lost. Especially for complex beam profile structures the limitation to 7 mm has significant impact on the results regarding the size of the apparent source or the calculated diameter of the image.
5) Sensitivity of measurement setup: especially for small sources the alignment is of particular importance. A little shift of the test object along the optical axis or a lateral shift of the loupe of just a few tenths of a millimeter could change the image considerably. Quite apart from the fact, that it is practically very difficult to determine the distance from a reference point somewhere inside (recessed source) or outside of the product to the principal plane of lens 1. To ensure reproducible results the test personnel must be highly qualified.

CONCLUSIONS

The main result is that for the investigated extended sources the hazard potential was lower for a configuration shown in figure 5 of the current standard than for the naked eye condition. The main reason for this result is the 3.5 mm aperture stop in combination with the 7x magnification. In contrast to a 7 mm aperture for the naked eye, significantly less power is measured with a 3.5 mm aperture. Additionally, due to the truncation of the beam by the aperture information of the image is lost.

The study provides a basis for the following conclusions: when the results from the analyzed sources are generalized, the conclusion would be that Condition 2 is only relevant for small sources ($\alpha_{AS} \leq$ 1.5 mrad at a distance of 10 cm from the reference point). For small sources (such as 50/125 glass fibers) the PLR is increased by a factor of about 1.7 when the extended evaluation is used. The simplified method yields a factor of 2 and is therefore a good representation of the increased hazard. If other magnifications were to be considered, the simplified method would have to be adapted since for higher magnifications, the current simple evaluation would underestimate the hazard increase.

For extended sources, the naked eye condition (Condition 3) would always be more critical. As a consequence, the classification procedure can be simplified. If a manufacturer can prove that the source of the laser product is extended, he will not have to consider Condition 2 of the current standard. Only for small sources is the simplified measurement setup for Condition 2 to be applied. The setup shown in figure 5 of the standard would no longer have to be used.

If Condition 2 is removed from the standard, the level of safety that is lost is, based on the sources evaluated here, less than 2. This decrease of the safety level for the assumption of a 7x magnification must be considered in comparison to the naked eye condition, if small sources are viewed with a loupe which has a magnification of 7x or higher. If Condition 2 is not removed from the standard, the measurement conditions could be simplified and the applicability of Condition 2 could be reduced to the case of non-extended (i.e. small) sources only.

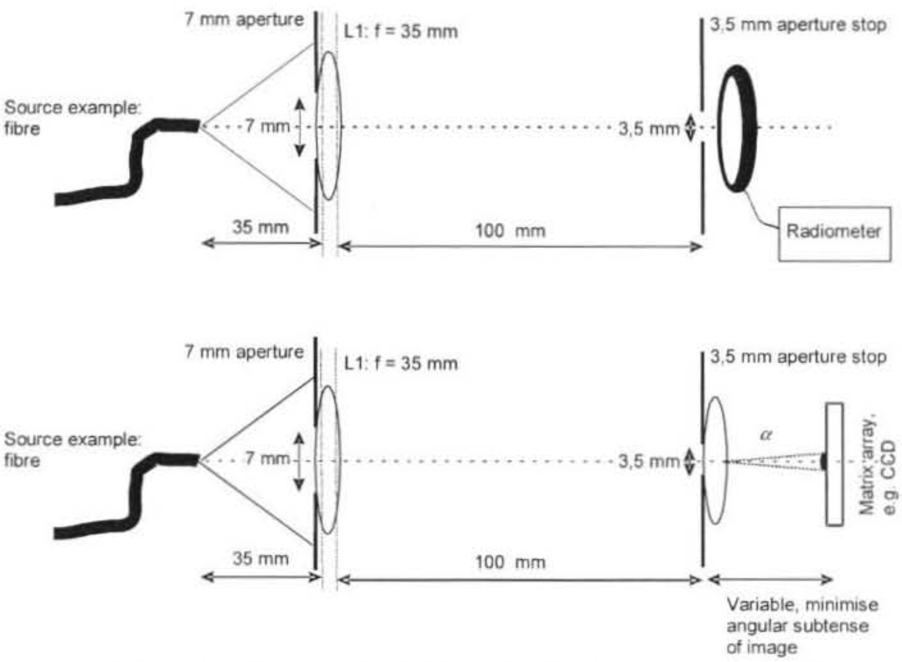


Figure 3: Set-up for Condition 2 according to IEC 60825-1, ed.2 (2007).

Table 2: Investigated sources

Source	Type	λ [nm]	Comments
Optical Fibers	600/660 *)	660	*) core diameter/ cladding diameter
	200/220	810	
	50/125	660	
	9/125	650	
Diode lasers	Without optic	670	Without any optical element
	With optic	670	Combination of collimating optic and diffuser
LEDs	SFH 485	885	Osram, half angle ±20°
	LXHL-BD01	640	Philips, Luxeon, Batwing
	LXHL-BL01	594	Philips, Luxeon, Batwing
	LT W5SM	528	Osram, Golden Dragon, lambertian emitter
	LW W5SG	white	Osram, Golden Dragon, lambertian emitter
Laser line generators	No. 1 fan-angle ≈ 70°	637	Generates 1 line
	No. 2 fan-angel ≈ 45°	637	Generates 1 line
	No. 3 fan-angle ≈ 10°	660	Generates 5 lines, alignment distance 5m
	No. 4 fan-angle ≈ 10°	660	Generates 5 lines, alignment distance 8cm
	No. 5 fan-angel ≈ 10°	660	Generates 5 lines, alignment distance 5m
	No. 6 fan-angel ≈ 15°	660	Generates 3 lines, alignment distance 8cm
	No. 7 fan-angel ≈ 5°	660	Generates 1 line, alignment distance 8cm
	No. 8 fan-angle ≈ 60°	532	Generates 1 line
	No. 9 fan-angle ≈ 45°	636	Generates 1 line; asymmetric line

Table 3: Increase-factor: ratio of the particular PLR to PLR_{NE}.

$\alpha_{MR, NE}$ … Size of apparent source measured for the naked eye at MRP_{NE}.

$\alpha_{MR, L}$ … Size of apparent source measured for the loupe at MRP_L.

MRP_{NE} ... Most restrictive position for naked eye.

MRP_L ... Most restrictive position of the loupe relative to the source.

S.E. … Simple Evaluation.

E.E. ... Extended Evaluation.

E.E.+ MRP_L … Extended Source and distance loupe-source is varied.

Source	Type	$\alpha_{MR,NE}$ (mrad)	MRP_{NE} (mm)	$\alpha_{MR,L}$ (mrad)	MRP_L (mm)	Increase-factor		
						E.E.+ MRP_L	E.E.	S.E.
Optical Fibers	600/660	5.23	100	19.3	39	0.80	0.67	7.76
	50/125	1.62	100	1.51	35	1.73	1.73	2.00
Diode laser	Without optic	1,5	92	2.1	21	1.25	1.25	2.34
	With optic + diffuser	100	30	64.9	46	0.31	0.27	19.25
LEDs	LXHL-BD01	100	30	59.5	43	0.49	---	---
	LT W5SM	100	35	34.3	40	0.62	---	---
	LW W5SG	100	35	61.8	48	0.57	---	---
Laser line generators	Nr. 2	4.2	80	7.1	15	0.53	---	---
	Nr. 3	2.6	105	2.1	34	0.63	---	---
	Nr. 4	2.6	105	3.9	32	1.01	---	---
	Nr. 5	1.9	25	7.1	32	0.45	---	---
	Nr. 6	2.6	100	4.5	20	0.62	---	----
	Nr. 7	2.1	155	3.0	38	0.71	---	---
	Nr. 8	4.0	95	4.0	16	0.64	0.63	6.24
	Nr. 9	2.1	370	6.6	105	0.38	0.19	2.12

Table 4: Increase-factor: ratio of the particular PLR to PLR_{NE}; parameter d

Source	Type	d (mm)	$\alpha_{MR,NE}$ (mrad)	MRP_{NE} (mm)	$\alpha_{MR,L}$ (mrad)	MRP_L (mm)	Increase-factor		
							E.E.+ MRP_L	E.E.	S.E.
Optical Fibers	600/660	50	5.23	100	15.5	37	0.74	0.69	7.76
		100	5.23	100	19.3	39	0.80	0.67	7.76
		120	5.23	100	26.6	41	0.90	0.71	7.76
	50/125	50	1.62	100	1.5	34.8	1.93	1.93	2.00
		100	1.62	100	1.5	35	1.73	1.73	2.00
		120	1.62	100	1.5	35	1.84	1.84	2.00
Laser line generator	Nr. 8	50	4.0	95	5.1	14	0.71	0.66	6.29
		100	4.0	95	4.0	16	0.64	0.62	6.29
		120	4.0	95	4.9	24	0.65	0.65	6.29
	Nr. 1	80	4.3	101	6.1	22	0.89	---	---
		100	4.3	101	5.6	20	0.94	---	---
		120	4.3	101	5.3	24	0.84	---	---

Table 5: Increase-factor: ratio of the particular PLR to PLR_{NE}; parameter d_{Pupil}

Source	Type	d_{Pupil} (mm)	$\alpha_{MR,NE}$ (mrad)	MRP_{NE} (mm)	$\alpha_{MR,L}$ (mrad)	MRP_L (mm)	Increase-factor		
							E.E.+ MRP_L	E.E.	S.E.
Laser line generator	Nr. 5	3.5	1.9	25	7.1	32	0.45	---	---
		7	1.9	25	10.4	32	1.74	---	---

Table 6: Increase-factor: ratio of the particular PLR to PLR_{NE}; parameter f_L and two different d_L

Source	Type	f_L (mm)	d_L (mm)	$\alpha_{MR,\,NE}$ (mrad)	MRP_{NE} (mm)	$\alpha_{MR,\,L}$ (mrad)	MRP_L (mm)	Increase-factor		
								E.E.+ MRP_L	E.E.	S.E.
Optical Fibers	600/660	35	7	5.2	100	19.3	39	0.80	0.67	7.76
		15	7	5.2	100	38.2	17	1.77	---	7.76
		35	17	5.2	100	71.7	47	1.01	0.32	7.76
		12.5	17	5.2	100	34.8	15	1.62	---	7.76
	50/125	35	17	1.6	100	1.5	35	1.76	1.76	2.00
		12.5	17	1.6	100	3.0	12	3.01	---	2.00
	200/220	35	17	1.6	105	4.1	36	0.76	0.76	2.62
		12.5	17	1.6	110	7.4	14	2.16	---	4.86
Diode laser	Without optic	35	7	1.5	92	2.1	21	1.25	1.25	2.34
		15	7	1.5	92	3.2	0.5	2.56		2.34
Laser line generator	Nr.8	35	17	3.9	95	5.9	26	0.66	---	6.24
		12.5	17	3.9	95	8.9	4	0.72	---	6.24

Table 7: Increase-factor: ratio of the particular PLR to PLR_{NE}; parameter d_L

Source	Type	d_L (mm)	$\alpha_{MR,\,NE}$ (mrad)	MRP_{NE} (mm)	$\alpha_{MR,\,L}$ (mrad)	MRP_L (mm)	Increase-factor		
							E.E.+ MRP_L	E.E.	S.E.
Optical Fiber	600/660	7	5.2	100	19.3	39	0.80	0.67	7.76
		17	5.2	100	71.7	47	1.01	0.32	7.76
	50/125	7	1.6	100	1.5	35	1.73	1.73	2.00
		17	1.6	100	1.5	35	1.76	1.76	2.00
Diode Laser	With optic	7	100	30	64.9	46	0.31	0.27	19.25
		17	100	30	100	46	0.61	0.44	19.25
Laser line	Nr. 2	7	4.0	95	4.0	16	0.64	0.63	6.24
		17	4.0	95	5.9	26	0.66	---	6.24

Table 8: Increase-factor: ratio of the particular PLR to PLR_{NE}; parameter $f_L + d_L$

Source	Type	f_L (mm)	d_L (mm)	$\alpha_{MR,\,NE}$ (mrad)	MRP_{NE} (mm)	$\alpha_{MR,\,L}$ (mrad)	MRP_L (mm)	Increase-factor		
								E.E.+ MRP_L	E.E.	S.E.
Optical Fiber	600/660	35	7	5.2	100	19.3	39	0.80	0.67	7.76
		25.6	35	5.2	100	64.5	31	1.45	---	7.76
		15	7	5.2	100	38.2	17	1.77	---	7.76
	50/125	35	7	1.6	100	1.5	35	1.73	1.73	2.00
		35	17	1.6	100	1.5	35	1.76	1.76	2.00
		12.5	17	1.6	100	3.0	12	3.01	---	2.00
	9/125 (SM)	35	7	1.5	99	1.5	34	5.14	---	---
LED	LXHL-BD01	35	7	99.9	30	54.4	41	0.63	---	---
		25.6	35	99.9	30	99.9	36	1.41	---	---
Diode laser	Without optic	25.6	35	1.5	92	2.5	10	1.68 *)	---	2.34
		12.5	17	1.5	92	14.8	3	0.91 *)	---	2.34

*) Example of a "recessed source" that is not accessible with a focal length of 12.5 mm. Therefore, the hazard decreases in spite of a higher magnification.

Table 9: Measurement uncertainty (alignment)

Source	Measurement	f_L (mm)	d_L (mm)	$\alpha_{MR, NE}$ (mrad)	MRP_{NE} (mm)	$\alpha_{MR, L}$ (mrad)	MRP_L (mm)	Increase-factor		
								E.E.+ MRP_L	E.E.	S.E.
Optical Fiber	1 a	35	7	1.6	100	1.5	35	1.73	1.73	2.0
	1 b	12.5	17	1.6	102	3.0	12	3.0	---	2.0
50/125	2 a	35	7	1.6	102	1.7	35	2.24	2.24	2.84
	2 b	12.5	17	1.6	102	1.9	12	5.17	---	2.84

[1] International Electrotechnical Commission, IEC 825-1, ed.1.0 (1993-11), Safety of laser products – Part 1: Equipment classification, requirements and user's guide.

[2] International Electrotechnical Commission, IEC 60825-1, ed.1.2 (2001-08), Safety of laser products – Part 1: Equipment classification, requirements and user's guide, 1st edition with amendments 1 (1998) and amendment 2.

[3] International Electrotechnical Commission, IEC 60825-1, ed.2.0 (2007-03), Safety of laser products – Part 1: Equipment classification, requirements.

[4] American National Standard, ANSI Z136.1 – 2007, American National Standard for Safe Use of Lasers.

[5] Sliney D. & Wolbarsht M., "Safety with lasers and other optical sources", Plenum Press N.Y. (1980).

[6] R.Henderson, K. Schulmeister, "Laser Safety", Taylor & Francis, London (2004).

[7] W. J. Marschall, J. Bell, D.H. Sliney, "Methods for hazard assessment from viewing fiber optics with eye loupes", Journal of Laser Applications, Vol.16, No.3. (2004).