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SAFETY OF LASER PRODUCTS –

Part 1: Equipment classification and requirements

INTERPRETATION SHEET 1

This interpretation sheet has been prepared by IEC technical committee 76: Optical radiation safety and laser equipment.

The text of this interpretation sheet is based on the following documents:

FDIS	Report on voting
76/587/FDIS	76/593/RVD

Full information on the voting for the approval of this interpretation sheet can be found in the report on voting indicated in the above table.

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Subclause 4.3 Classification rules

This subclause is clarified by the following:

Introduction

For some complex extended sources or irregular temporal emissions, the application of the rules of subclause 4.3 may require clarification because of changes from IEC 60825-1:2007.

NOTE 1 For the purpose of this interpretation sheet, the abbreviation “AE” is used for “accessible emission”.

NOTE 2 The clarifications also apply in an equivalent way to MPE analysis, i.e. for Annex A.

IEC 60825-1:2014-05/ISH1:2017-12(en-fr)

ICS 13.110; 31.260

1 Subclause 4.3 b) Radiation of multiple wavelengths

See IEC 60825-1:2014/ISH2.

2 Subclause 4.3 c) Radiation from extended sources

When using the default (simplified) evaluation method (subclause 5.4.2) for wavelengths ≥ 400 nm and < 1 400 nm, the angle of acceptance may be limited to 100 mrad for determining the accessible emission to be compared against the accessible emission limit, except in the wavelength range 400 nm to 600 nm for durations longer than 100 s where the circular-cone angle of acceptance is not limited. When evaluating the emissions for comparison to the Class 3B AELs, the angle of acceptance is not limited.

3 Subclause 4.3 d) Non-uniform, non-circular or multiple apparent sources

In subclause 4.3 d), for comparison with the thermal retinal limits, the requirement to vary the angle of acceptance in each dimension might appear to contradict the labelling in Figure 1 and Figure 2 of subclause 5.4.3 where the field stop is labelled as circular.

Interpretation

A circular field stop is applicable for circularly symmetric images of the apparent source and for this case is consistent with the procedure given in subclause 4.3 d). For images of the apparent source that are not circularly symmetric, the simple example below clarifies the application of subclause 4.3 d).

A circular field stop with an angular subtense equal to $\alpha_{\max}$ is, however, applicable for non-circularly symmetric profiles if the analysis performed according to subclause 4.3 d), following variation of the angle of acceptance in each dimension, results in a solution which is equal to $\alpha_{\max}$ in both dimensions.

As a general principle, for whatever emission duration t the AEL is determined (such as the pulse duration, the pulse group duration or the time base for averaging of the power), the same emission duration t is also used to calculate $\alpha_{\max}(t)$.

The following example demonstrates the method described in subclause 4.3 d) to analyse irregular or complex images of a source. It is noted that the example is equivalent to the second part of the example (“Additional Remarks”; 6 mrad spacing instead of 3 mrad) B.9.1 of IEC TR 60825-14:2004 (however, for 6 mrad element spacing, the result in terms of which grouping is critical was not correct). The source is a diode array (Figure 1). The task is to determine the applicable AEL that limits the AE for Class 2. Each diode contributes a partial accessible emission AE of 1 mW that passes through a 7 mm aperture stop at the distance where the analysis is performed (i.e. a total power of 20 mW passes through the aperture stop), and the emission is continuous wave. The analysis requires determination of the most restrictive (maximum) ratio of AE over AEL by variation of the angle of acceptance in position and size to achieve different fields of view.

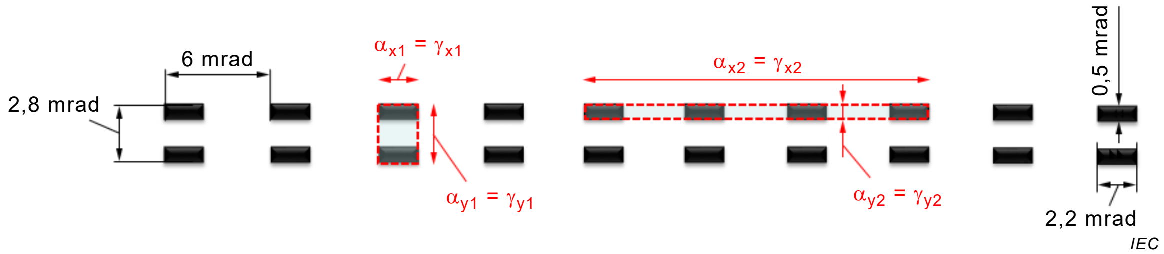

Figure 1 – Image of a source pattern for the example of 20 emitters. Two possible groupings are defined by the respective angle of acceptance γ_x and γ_y

The analysis of a sub-group of sources is associated with a certain value of α for that group, and a certain accessible emission associated with that sub-group. For instance α of a single element equals (1,5 mrad + 2,2 mrad)/2 = 1,85 mrad so that the AEL = 1,23 mW. The applicable AE = 1 mW and AE/AEL = 1 mW/1,23 mW = 0,8. For a vertical two-element group, as shown in the figure with γ_{x1} and γ_{y1}, α = (2,8 + 2,2)/2 = 2,5 mrad so that AEL = 1,66 mW; AE = 2 × 1 mW = 2 mW and AE/AEL = 1,2, which is more restrictive than AE/AEL for only one element. For one row of 10 diodes α = (1,5 + 56,2)/2 = 28,9 mrad, AEL = 19,2 mW, the AE = 10 × 1 mW = 10 mW and AE/AEL = 0,5. Analysis of all possible groupings shows that the vertical two-element group has the maximum AE/AEL and therefore is the solution of the analysis. This means that the AEL of Class 2 is exceeded by a factor 1,2. Note that only a portion of the power of 20 mW that passes through the 7 mm aperture stop is considered as the AE (2 mW; as partial power within the angle of acceptance that is associated to the part of the image with the maximum ratio of AE/AEL) that is compared against the AEL. The entire array represents the highest ratio of AE/AEL in cases where the element spacing is sufficiently close, e.g. when the contributions of extra elements to the AE are not dominated by the increased AEL due to the larger subtended angle.

For pulsed emission, for the determination of α according to the above method (4.3 d)) where the ratio of AE to AEL is maximized, requirement 3) of 4.3 f) is not applied, i.e. the $\text{AEL}_{\text{single}}$ is not reduced by C_5. Due to the dependence of α_{max} on emission duration t, the analysis of the image of the apparent source may result in different values of α and of the partial accessible emission, depending which emission duration is analysed for the requirements of 4.3 f). For example, for emission durations shorter than 625 µs (α_{max} = 5 mrad), the maximum partial array to consider in the image analysis is a vertical two element group.

Ref.: Classification of extended source products according to IEC 60825-1, K. Schulmeister, ILSC 2015 Proceedings Paper, p 271 – 280; *Download: https://www.filesanywhere.com/fs/v.aspx?v=8b70698a595e75bcaa69*

4 Subclause 4.3 f) 3) determination of α

For an analysis of pulsed emission, α_{max}, which is a function of time α_{max} (t), limits both the value of α for the determination of $C_6(\alpha)$ as well as the angle of acceptance γ for the determination of the accessible emission (see 4.3 c) and d)) and Clause 3 of this interpretation sheet; in this process, α_{max} (t) is determined for the same emission duration t that is used to determine AEL(t) (i.e. the pulse duration or the pulse group duration for 4.3 f) 3) and the averaging duration for 4.3 f) 2), respectively). However, the parameter α is also used in subclause 4.3 f) 3) in the criteria which C_5 is applied. For these criteria, the parameter α is not limited in the same way as for the determination of C_6 according to 4.3 d).

For the criterion "Unless α > 100 mrad", the angular subtense of the apparent source α is not restricted by α_{max}. For non-uniform (oblong, rectangular, or linear) sources, the inequality needs to be satisfied by both angular dimensions of the source in order for C_5 = 1 to apply.

To calculate $T_2(\alpha)$ and in the criteria "$\alpha \leq 5$ mrad", "5 mrad $< \alpha \leq \alpha_{\text{max}}$", and "$\alpha > \alpha_{\text{max}}$", the quantity α is limited to a maximum value of 100 mrad, equivalent to α_{max} that applies for 0,25 s emission duration and longer. For T_2 and these inequalities, α is not limited to a value of α_{max} (t) smaller than 100 mrad, and is therefore the same as the value that applies for the determination of C_6 for an emission duration of 0,25 s and longer. As is generally defined (see subclause 4.3 d)) the arithmetic mean is applied to determine α, i.e. it is not necessary that both dimensions satisfy the criterion "For $\alpha \leq 5$ mrad" independently.

For the determination of the applicable value of C_5 in 4.3. f) 3) in an analysis of moving apparent sources (originating from scanned emission when not accommodating to the pivot point or vertex) the value of α in the respective inequalities relating to the choice of C_5 in 4.3 f) 3) is determined for the *stationary* apparent source and the respective accommodation condition that is analysed (such as accommodation to infinity).

5 Subclause 4.3 f) 3) groups of pulses with group duration longer than T_i

For non-uniform repetitive pulse patterns, i.e. groups of pulses (see Figure 2 for an example), when $\alpha > 5$ mrad and the duration of the group of pulses is longer than T_i, it is not clearly stated how the thermal additivity expressed by requirement 3) of 4.3 f) is applied. For *uniform* (i.e. constant peak power, duration and period) repetitive pulse trains, it is not necessary to analyse the emission patterns in terms of groupings of pulses.

When individual pulses are close together, they are thermally grouped and thermally represent one "effective" pulse so that C_5 also (additionally to analysing the pulse train based on the actual pulses and the average power) applies to these "effective" pulses, where N is the number of pulse groups within T_2 or within the time base, whichever is shorter.

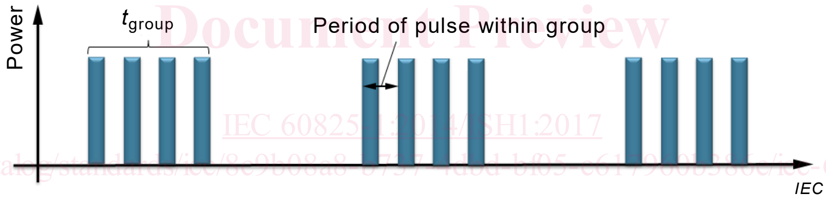

Figure 2 – Example of three groups of pulses (each group duration is longer than T_i) where each group is considered as one "effective" pulse and C_5 is applied to the AEL that applies to the group duration, where C_5 is determined with the number of pulse groups within the evaluation duration (in the example of the figure N = 3)

For the analysis of pulse groups, the value of $\text{AEL}_{\text{single}}$ is determined for the corresponding pulse group duration t_{group}. For the determination of C_5, N is the number of pulse groups within T_2 or the time base, whichever is smaller. The respective value of C_5 is applied to $\text{AEL}_{\text{single}}$ to obtain $\text{AEL}_{\text{s.p.train}}$ that limits the AE of the pulse groups, where AE is the sum of the energy of the pulses contained within the pulse group.

For the application of C_5 to groups of pulses, the $\text{AEL}(t_{\text{group}})$ applicable to the group needs to be determined, as well as the energy per group (AE_{group}). For groups of pulses where the peak power of the pulses within the group varies, the group duration is not well defined. In order to simplify the evaluation, t_{group} can be set equal to the integration duration for which the energy per group (i.e. AE_{group}) was determined; it is not necessary to determine the group duration based on the FWHM criterion, which for groups of pulses with varying peak power is not well defined. By setting t_{group} equal to the integration duration that is used to determine AE_{group} (expressed as energy), the application of C_5 to groups of pulses is a simple extension of requirement 2) of 4.3 f) where the average power per group (equal to the energy within the averaging duration t_{average} divided by the averaging duration) needs to be below the $\text{AEL}(t_{\text{average}})$ determined for the duration over which the power was averaged (AE_{group} and $\text{AEL}(t_{\text{group}})$ expressed as power). As is common for the average power requirement, for irregular pulse trains, the averaging duration window (when expressed as energy: the integration duration window) has to be varied in temporal position and duration (for instance, if there are pulses with relatively low energy per pulse at the beginning or the end of the group of pulses, integration durations that exclude those low-energy pulses need to be considered also, not only the total group).

If individual pulses have sufficient temporal spacing (period larger than T_{crit}, see below), as a simplified analysis, they need not be considered for an analysis as a pulse group under 4.3 f) 3). The temporal spacing that is necessary for pulses to only be considered separate (and not analysed additionally as a group) depends on the angular subtense of the apparent source and the duration of the pulses t_{pulse} within the group. Note that there can be several levels of grouping, so that individual elements (with pulse duration t) within the group could themselves be “effective pulses”, i.e. subgroups.

When the

- pulse group (t_{group}) durations are between T_{i} and 0,25 s, and
- the angular subtense of the apparent source is larger than 5 mrad, and
- the period of the pulses (see Figure 2) is shorter than a critical period T_{crit} (if $t_{\text{pulse}} < T_{\text{i}}$, the value of t_{pulse} is set equal to T_{i}; further, for the determination of T_{crit}, $\alpha_{\max}$ is determined for t_{pulse}, not the group duration) where:

  for $\alpha \leq \alpha_{\max}$: $T_{\text{crit}} = 2 \cdot t_{\text{pulse}}$ where t_{pulse} is in seconds

  for $\alpha > \alpha_{\max}$: $T_{\text{crit}} = 0{,}01\ \alpha\ t_{\text{pulse}}^{0{,}5}$ where t_{pulse} is in seconds, and α is in mrad, not being limited to $\alpha_{\max}$,

then these pulses constitute a pulse group which is treated as effective pulses and C_5 (where N is the number of groups within the time base or T_2, whichever is shorter) is applied to the AEL applicable to the pulse group. For the determination of AE, $\alpha_{\max}$ is determined using the duration of the evaluated pulse group, t_{group}. If above conditions are not fulfilled, then the pulses within the group of pulses that is considered to be analysed as “effective pulse” need not be grouped, i.e. the group of pulses does not need to be analysed as one “effective” pulse.

Note that if multiple pulses occur within T_{i}, the rule as stated in 4.3 f) 3) applies in parallel, i.e. they are counted as a single pulse to determine N and the energies of the individual pulses that occur within T_{i} are added to be compared to the $\text{AEL}_{\text{s.p.train}}$ of T_{i} where the corresponding C_5 for emission durations $t \leq T_{\text{i}}$ is applied.

6 Subclause 4.3 f) simplifications

a) Constant peak power but shorter pulses

Depending on the angular subtense of the apparent source, it can be the case that the value of C_5 is more restrictive for pulses with pulse durations less than T_{i} than for pulses with durations longer than T_{i} which is against general biophysical principles for cases where the peak power is the same.

Interpretation

For the case of varying pulse duration within a pulse train, if the accessible emission for pulses longer than T_{i} is below the applicable AEL, then it can be assumed for the analysis that pulses with durations less than T_{i} but with the same (or lower) peak power as the longer pulses, are less critical. The rationale for this interpretation follows the principle that when pulses have the same peak power, the shorter pulse cannot be more restrictive than the longer one.

NOTE This interpretation can also be used to smooth the step function at T_{i} for the classification of products, i.e. the classification of a product may be based on the assumption of pulse durations longer than T_{i} even if they are shorter than T_{i} provided that the longer pulses satisfy the applicable AEL and the shorter pulses have the same or lower peak power compared to the longer pulses.

b) **Larger image of apparent source**

For emission durations exceeding T_i, due to the step-function of C_5 at 5 mrad and at α_{max}, the AEL (as a function of C_5 and C_6) can be more restrictive for larger values of the angular subtense of the apparent source as compared to smaller ones, which is contrary to general biophysical principles.

Interpretation

When the class of a laser product is determined with the extended analysis (subclause 5.4.3) and the apparent source is larger than 5 mrad, the classification may be based on a value of the angular subtense of the apparent source less than 5 mrad (resulting in a smaller C_6 but also larger C_5). That is, when the AE is below the AEL for an assumed smaller apparent source, the resulting class is applicable even though the image of the apparent source is larger than 5 mrad. This also applies in an equivalent way to the step function of C_5 at α_{max}.

c) **Using a square aperture stop**

In some cases, such as 2D scanned laser beams, the use of a circular aperture stop to determine the accessible emission creates very complex pulse patterns.

Interpretation

Analysis performed with a square aperture stop with 7 mm side length (for determination of accessible emission and pulse duration) can be assumed to be equivalent to, or more restrictive than, a circular aperture stop and is therefore a valid analysis.

d) **Applicability of simplified default analysis**

For pulse durations longer than T_i, the value of C_5 is smaller (more restrictive) for angular subtense values α larger than 5 mrad compared to $\alpha \leq 5$ mrad. The assumption of $\alpha = 1{,}5$ mrad is the basis of the simplified (default) evaluation. It is therefore not obvious if the simplified (default) analysis still applies in terms of being a restrictive simplifying analysis even for the case that the angular subtense of the apparent source is actually larger than 5 mrad, where $C_5 < 1$.

Interpretation

It is acceptable to make use of the simplified restrictive assumption of $\alpha = 1{,}5$ mrad ($C_6 = 1$, $C_5 = 1$) even for the case that the angular subtense of the source is larger than 5 mrad. This means it is not necessary to show that $\alpha < 5$ mrad in order to apply $C_6 = 1$ and $C_5 = 1$ for the simplified (default) analysis, because overall this is a conservative simplification. Note that the simplified default analysis implies that the determination of the accessible emission is not limited by an angle of acceptance equal to α_{max}.

e) **Determination of the most restrictive position**

For the extended analysis, it is necessary to vary the position in the beam. For each position in the beam, the accommodation is varied and the most restrictive image is determined. For determining the most restrictive image (where the ratio AE/AEL is maximum) at a given position, requirement 3) of 4.3 f) is not applied. Otherwise a blurred (larger) image of the apparent source, resulting from variation of the accommodation, could appear more restrictive, which is contrary to general biophysical principles. Once the most restrictive image (and associated α) is identified for each position in the beam, all three requirements 4.3 f) are applied to determine the most restrictive position (identifying the position with the maximum ratio of AE/AEL).

f) **Application of total-on-time-pulse method**

For regular pulse trains, as well as for varying pulse durations and/or varying period of pulses (but excluding strongly varying peak powers; see below), the total-on-time pulse (TOTP) method (see also IEC 60825-1:2007, subclause 8.3 f) 3b)) may be used as alternative to requirement 3) of 4.3 f), i.e. as alternative to the application of C_5 to the single pulse AEL, provided that α_{max} is determined for the TOTP (or using the worst case value of 100 mrad). This is more restrictive than the rules of 4.3 f) because it is equivalent to an unlimited C_5 (C_5 not limited to 0,2 or 0,4), and because the value of α_{max} is typically larger for the TOTP as compared to the value applicable to the single pulse.