Is Audience Scanning at Laser Light Shows Ever Acceptable?

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ABSTRACT

Scanning laser beams across the faces of the audience at a laser light show is an accepted practice in many countries. Guidance generally requires the exposure levels to be below the internationally agreed maximum permissible exposure (MPE) levels. Laser shows consist of a large number of sophisticated scan patterns that appear to require considerable time and effort to analyse and therefore demonstrate that exposure levels are below the MPE. In short, the risk assessment is complex.

An analysis of some scan patterns used in a laser light show is presented which shows that the practice, as currently carried out, will invariably exceed the MPE. Some laser light show installations include scan failure detection systems but these may not be making the correct assumptions about the applicable MPE.

A simplified risk assessment approach is presented which leads to proposals for audience scanning which is below the MPE. A full understanding of the MPE boundaries for audience scanning allows the laser light show designer to develop shows which should stand up to the risk assessment process, including reasonably foreseeable failure modes.

INTRODUCTION

Lasers have been used in entertainment since the early 1960s. Modern laser shows use computer controlled scanning systems to generate two main effects: graphical images on a screen; and beam effects in the air made visible by the use of vapour or smoke. Laser beam effects are a unique artistic medium and can be used to engulf the audience - so-called audience scanning.

Internationally agreed values are published[1] for the maximum amount of laser radiation that should be permitted to enter the eye in order to minimise the risk of permanent eye injury. Therefore, any laser display that includes audience scanning needs to be assessed to ensure that the audience are not at risk.

NATIONAL APPROACHES TO AUDIENCE SCANNING

Few countries have specific legislation covering the use of lasers in entertainment. However, there are a number of national guidance documents and standards. There is also an international guidance document[2] although it is believed that it has not been adopted as good practice by any country yet.

National approaches are either based on considering the laser show as a product, and requiring that the areas in which the public are located should be designed such that the accessible emission limit (AEL) does not exceed that defined for Class I or 1 laser products, or they specify that the maximum permissible exposure

(MPE) should not be exceeded. The approaches used by a number of countries are summarised in table 1.

Table 1 - Summary of National Laser Entertainment Standards and Guidance

Country	Document	Control	Status
Australia	Radiation Health Series No. 37	Class 1	Guidance
Germany	DIN 56912	MPE	Guidance, but an insurance requirement
Sweden	SSI FS 1993:1	Location of beams	Mandatory
UK	HS(G)95	MPE	Guidance
USA	CDRH 21CFR Part 1040	Class I	Mandatory

In the USA, laser show companies are required to obtain a variance from full requirements of 21CFR Part 1040. Some States also have legislation requiring laser display operators to be licensed. Audience scanning is permitted provided it can be demonstrated that the AEL of Class I is not exceeded. It should be noted that Roman numerals are used for products classified under 21CFR Part 1040, whereas other national, and international, standards use Arabic numerals.

Legislation in Sweden requires laser companies to obtain a licence. Beams are not permitted within a volume bounded by a height 3 m above the floor and 2.5 m horizontally from any point accessible to the audience, ie audience scanning is not permitted.

COMPARISON OF MPE AND CLASS 1 AEL

The laser classification scheme provides and indication of the laser radiation hazard and, through the published safety standards, the control measures a manufacturer will be expected to provide and a user should consider. The classes are based on MPE values using assumptions.

Class I AEL limits published in 21CFR Part 1040 are expressed in terms of radiant energy or radiant power. MPE levels are expressed in terms of radiant exposure or irradiance. AEL and MPE are related by considering the energy or power entering a 7 mm aperture for laser beams in the wavelength region 400 to 700 nm for a given exposure duration.

For the remainder of the analysis in this paper MPE will be used.

DETERMINATION OF APPLICABLE MPE FOR AUDIENCE SCANNING

Unlike many non-entertainment laser applications, many of the lasers used for audience scanning will emit a number of wavelengths. A typical ëwhite lightí krypton-argon laser may produce eight specific wavelengths. Since the predominant emission is generally at 514.5 nm, it is general practice to assume that all of the emission is at about 500 nm. The MPE is presented as a function of wavelength and exposure duration in the international laser safety standard[1], table 6. Assuming the wavelength is 500 nm then a decision needs to be taken on the exposure duration. The worst case would be to assume that the same person was exposed to the scanned laser beam for the duration of the show. However, ten seconds is a more realistic exposure duration before the person would either move to avoid the exposure or the effect will change to expose other persons.

A person exposed to the scanned laser beam will be subject to a number of pulses of exposure as the effect is potentially scanned past their eyes. Calculation of the appropriate MPE is therefore a three-stage process requiring the calculation of the MPE for a single pulse, correcting this for the number of pulses and then calculating the average MPE. The applicable MPE is the most restrictive of the three. The MPE as a function of time is presented in table 2 (taken from reference 1).

Table 2 - Maximum Permissible Exposure Values for 500 nm

Exposure Time (s)	MPE
$<10^{-9}$	5×10^{6} W m^{-2}
10^{-9} to 1.8×10^{-5}	5×10^{-3} J m^{-2}
1.8×10^{-5} to 10	$18\ t^{0.75}$ J m^{-2}
10 to 10^{4}	10^{2} J m^{-2}
10^{4} to 3×10^{4}	10^{-2} W m^{-2}

An example would be the applicable MPE for a circularly scanned laser beam forming a tunnel of light. The scan rate would need to be at least 30 Hz to produce a flicker-free pattern. A typical scan rate would be between 30 and 100 Hz. At the closest position of interest, ie the closest position where a member of the audience is likely to be, the scan pattern diameter may be about 0.5 m. The speed of the scanning laser beam can be calculated from the circumference of the scan pattern and the scan rate. Assuming 100 Hz and a circumference of B x 0.5 m, the speed is 157 m s^{-1}. For a 3 mm diameter laser beam at this position, the exposure duration across a 7 mm effective eye aperture will be 44 µs, where the duration is defined as the full-width half-maximum of the exposure pulse. The MPE for a single pulse of 44 µs is 9.7 mJ m^{-2}. This is corrected for the number of pulses, N, in 10 s, ie 1000 pulses. The correction factor is $N^{-0.25}$. Therefore the MPE applicable to each pulse in a train of pulses becomes 1.7 mJ m^{-2}. The average MPE is calculated on the basis of the 10 s total exposure duration is is 100 J m^{-2}. This is allocated to each of the 1000 pulses to give an MPE per pulse of 0.1 J m^{-2}. It can be seen that the most restrictive MPE is the pulse train MPE. The maximum power through a 7 mm aperture can be calculated from this as 1.5 mW. Had the maximum power been calculated from the average MPE, then this would have given 87 mW or nearly 60 times greater.

Having calculated the maximum power permitted into a 7 mm aperture it is worth considering the effect of altering the scan speed. However, this makes no difference to the amount of power permitted since increasing the scan speed reduces the time the duration of each pulse as the laser is scanned past the eye but increases the number of pulses in the total exposure duration. The two cancel each other out[3]. The MPE for a static beam for 10 s would be 100 J m^{-2}. This represents about 0.4 mW into the 7 mm aperture. However, exposure to a static laser beam is likely to trigger the natural aversion response to the light within 0.25 s. Using the MPE appropriate to 0.25 s (6.36 J m^{-2}) the maximum power into 7 mm is 1 mW, demonstrating that measurement of the static beam will give a good idea of whether the MPE will be exceeded when the beam is scanned.

It is also obvious from the above analysis that the amount of laser radiation entering the 7 mm aperture is important. Therefore, if the beam diameter is increased such that the beam is greater than the 7 mm aperture, the maximum proportion of the beam that can enter the eye is reduced.

Many effects used for audience scanning are more complicated than simple circular scan patterns. The speed of the scan may not be constant and the same position in space may be visited more than once during a scan frame. Analysis of such effects in terms of MPE and the maximum power into the 7 mm aperture can be an extremely time-consuming process. However, if the analysis is confined to static beams then the process becomes practically achievable.

MEASUREMENT OF SCANNED BEAMS

** Problems with power meters/energy meters. Photodiode approach, LaserMPE and Logo LMS2.

ENGINEERING CONTROL MEASURES

** Describe use of multiple apertures, active attenuation, beam position monitoring.

SCAN FAIL MECHANISMS

** Describe philosophy (how flawed), part of allowable MPE already used up. Introduce concept of time between exposures - when do they become independent?

RISK ASSESSMENT

** Convincing the regulator, venue safety manager, etc.

CONCLUSIONS

** Audience scanning can be carried out by accepting some simple concepts. Check list (ie ILDA), can you look into the scan pattern without blinking?

REFERENCES

1. International Electrotechnical Commission. Safety of Laser Products. Part 1: Equipment classification, requirements and user's guide. IEC 60825-1: 1993. Geneva.

2. International Electrotechnical Commission. Safety of Laser Products. Part 3: Guidance for Laser Displays and Shows. IEC 60825-3: 1995. Geneva.
3. Corder, D. A., O'Hagan, J. B. and Tyrer, J. R. Safety Assessment of Visible Scanned Laser Beams. Journal of Radiological Protection, **17**, 4, 231-238, 1997.