Lighting Systems Design, Inc.

Member since 1990, International Laser Display Association

Audience Scanning Displays and Safety Compliance

Introduction

Beam into the audience

At first, the mere idea of intentionally directing a Class IIIb or IV laser beam into an audience seems insane. Such a beam can easily cause permanent harm in milliseconds, and the audience is unable to protect itself against such a hazard. Numerous safety officials and safety reports commonly cite "beams in the audience" as the worst-case safety problem in a laser display application.

My first experience with audience scanning was from a rock show in 1977. Two 16 Watt Argon lasers were used, projecting scanning patterns onto large mirror balls suspended over the audience. The resulting effect, called "laser rain" was extremely dramatic, almost frightening. The audience roared in approval. Yet, in spite of numerous shows with audiences over 20,000, no injuries were reported. Similar shows in New York discos scanned multiwatt Krypton laser beams into the audience. These primitive beginnings have been greatly surpassed by modem shows, where raw power has been replaced by finesse, and brute-force effects have been replaced by complex and beautiful choreography.

Irradiance reduction by scanning

With audience scanning, the exposure is reduced dramatically by the rapid deflection of the laser beam. For example, a 1 watt beam scanned over a 3 meter path can reduce the average exposure to a level of 1 milliwatt/centimeter squared. A phasing circular lissajous will scan a pattern that approaches a lens-like dispersion of the beam, with the respective reduction in irradiance. However, a safe exposure is not just a function of average exposure. The individual pulse exposure must also be below the MPE.

Why audience scanning?

The most basic question is why anyone would want to produce such a display, with the potential risks involved. The answer is that scanning laser beams in a hazy environment can create vivid, beautiful and dramatic effects. These effects cannot be created with any other lighting instrument. Modem laser projectors and control software allow the creation of realtime visual effects that were previously available only to Hollywood special effects labs. These shows are nearly hypnotic in the fluid movement of colored light in space. Moreover, a properly designed show is not irritating to the eyes, and is within the permissible exposure limits.

4625 Winter Garden Road, A-2 • Orlando, Florida 32811 • Phone (407) 299-9504 • Fax (407) 299-3965

Scanfail Interlock

CDRH example

After the initial forays into audience scanning, the Center for Devices and Radiological Health (CDRH), then BRH, released an analysis of certain laser lightshow effects. Couched in terms of AEL, rather than MPE, this has provided a basis for calculating exposures to a scanning beam. Examples are given for linear scans of different waveforms (fan effects), a circular lissajous pattern (laser tunnel), and mirror ball scanning. The CDRH standard clearly spells out that any device that relies on scanning to meet compliance with the exposure limits must have a means of preventing exposure above the limits should a failure of the scanning occur. This device must react fast enough to prevent exposure above the limit, even if the scanner failure is essentially instantaneous. An informal example from CDRH, cited a 1 watt beam, scanning rapidly enough to meet Class I exposure. If the beam were to stop, it would exceed the Class I limit in 200 nanoseconds. This extreme example has been widely touted in the U.S., and I believe is the basis for the lack of audience scanning in this country.

Scanning systems do fail, however, whether this is caused by a blown fuse or a mistake by an operator. With the exception of lasers that are Class Illa or below, it is not possible for an operator to protect the audience with his/her reaction time. An automated mechanism is needed for this scan-fail detection.

Velocity threshold interlock

The common galvanometer scanners used for laser displays are the General Scanning G120D and the Cambridge Technologies 6800HP. Both of these devices have integral position detectors that are used to enhance the positional accuracy and scanning bandwidth. The servo amplifiers that drive the scanners use the first derivative of the position signal, velocity, to optimize the performance. The magnitude of the velocity signal represents the angular velocity of the deflected beam.

The simplest scanfail interlock derives the vector velocity as the sum of the squares of the X and Y velocity signals, comparing this against a threshold voltage. When the vector velocity is below the threshold, the beam is shuttered. While this is sufficient to make sure the beam is moving faster than a certain angular velocity, it does not ensure compliance with the MPE. Moreover, the speed of a mechanical shutter is often less than the settling time of the galvos, and therefore insufficient to preclude exposure to a static beam.

AOMs as fast shutters

The development of the PCAOM has changed the design of most laser projectors. This modified AOTF allows both intensity and color control of a multi-wavelength laser beam, with traditional AO speed and extinction. A single, easy to use device has replaced the older galvanometer blanking and actuator color control mechanisms. Response time is about 3 to 5 microseconds, depending on beam diameter, and extinction is -50 dB, taking a 5 watt beam down to 50 microwatts. Moreover, the PCAOM allows variable intensity control over a 1000:1 range, so that a 5 watt beam may be attenuated to 5 milliwatts.

The Real World

Widespread practice

Outside of the U.S., audience scanning is a very common practice. From discotheques to concert halls, from corporate theater to special events, tens of thousands of people per day have access to the laser beam. Moreover, this is not a new practice; it has been going on for many years. Outside of the U.S., only Germany and the United Kingdom regulate the use of lasers for entertainment. The German DIN standard promotes an identical exposure limit to the ANSI Z136 standard, yet audience scanning shows are most common. Mexico, for example, has numerous nightclubs with laser installations, many of which perform audience scanning, and has virtually no regulation. Some of the companies that produce these displays make very reasonable efforts to assess the safety for the audience. Others take a more seat-of-the-pants method; the operator watches the show from the audience location. If the show is not obnoxious, it must be safe. Most of these shows are produced by multi-watt gas lasers, although the actual output may be far less. Some are direct beam systems, others are fiber optic coupled systems. Fiber optic based systems often have higher beam divergence (2-5 milliradians), offering some improvement in safety.

Live vs. Programmed shows

It is common practice in the U.S. for laser shows to be preprogrammed, either based on a computer playback or ADAT tape playback. In Europe, on the other hand, live performance, with either a bank of oscillators, or a computer keyboard, is more the norm. This leads to inconsistencies in show performance, and the possibility of an operator making an error. A laser tunnel effect may be safe to view when it is 3 meters in diameter. If the operator adjusts the size control down to 1 meter, this effect will suddenly be unsafe. Preprogrammed shows allow for greater and more accurate control of scanning speeds, laser beam intensity, and frequency of exposure. A preprogrammed show may not have the spontaneity of live performance, but the safety issues may not warrant the flexibility.

4625 Winter Garden Road, A-2 • Orlando, Florida 32811 • Phone (407) 299-9504 • Fax (407) 299-3965

Calculating the Hazard

Simple models

For numerical analysis of simple laser effects, the procedure outlined in David Royston's "Analysis of Some Laser Light Show Effects for Classification Purposes" provides a good basis. Unlike the AEL, and 7mm pupil used in this analysis, I find it more universal to use ANSI MPE values, in Watts or Joules per centimeter squared, which can be easily translated into the international standards of Watt per meter squared. ANSI also specifies the Multiple Pulse Reduction formula that is not present in the CDRH analysis. This approach works well to estimate the exposure from simple scanning patterns, such as a line, a circle, or a square.

Complex shows

Complex, computer generated waveforms, with dynamically changing power levels are difficult to model. In addition to the complexity of the scanning pattern, a large number of discrete effects may be contained in the show, rendering calculated analysis impractical. Even if you could model each effect, the time to perform each and every calculation becomes unreasonable.

Need for a better solution

The complexity of modem laser shows, and the growing volume of show producers indicates a need for a practical solution for safety assessment of these shows. An approach is needed that can be used by both safety people and show designers, one that does not require excessive knowledge of radiometry, yet can handle the variety of show situations.

How to Control the Hazard

Measurement in the audience area

The first approach is an "MPE Meter". This theoretical device can measure the light show from the audience area and provide a Go/No Go evaluation. A few devices have been made that approximate this function. CDRH has a special instrument made several years ago, incorporating a laser power meter and a portable computer. Lobo Electronic of Germany has the LMS-2, with a silicon detector and a laptop computer that can measure scanning beams, and determine both single pulse and cumulative exposure compliance. The latest entry is made by Precision Optical Engineering of the LTK, the "Laser MPE Meter", which also is a silicon detector/computer combination.

There are, however, several problems with field measuring devices. First, in an entertainment environment, there are often many non-laser light sources present, which may be moving or varying in intensity. This variable ambient light level is difficult to reject, particularly in that it may be many times the intensity of the laser signal.

Secondly, the measuring instrument is only sampling a single site. A complex laser show will rapidly vary the scanning field across the possible scan area, often creating a non-uniform exposure. A square "laser tunnel", rapidly moving back and forth, will provide a lower average exposure at the vertical segments than at the horizontal segments. The obvious response is to position the detector at the "worst case" location, but with a complex show design, this may be difficult or impossible to determine. Alternately, one might take a series of measurements at different locations. This can be time consuming, involving running the show program several times.

The third problem is the ideal detector. Pyroelectric detectors have a very flat response across the visible spectrum, and are optimally suited for pulsed energy measurements. They have both the fast response time and sensitivity. Silicon detectors are generally accurate only at a known wavelength, although linearizing filters are available. Angle of acceptance and detector centering are also important issues.

Finally, a measuring instrument can only make the determination that the display is safe at the time the measurement is taken. It does not ensure that the display will be safe if there is either a failure of the equipment, or if a show parameter is changed, such as laser power, scanner velocity, or beam divergence.

Control at the projector

In approaching the problem of automatically insuring the laser display is safe, regardless of either equipment failure or parameter changes, an alternate technique involves making the projector more intelligent. If the projector can measure the velocity of the beam, it can dynamically adjust the intensity of the beam to stay within the safe exposure limit. Beam velocity may be calculated from the vector velocity and the range to the audience. This can be used to directly control the permitted intensity of the beam. As beam power can be measured before it is scanned, and inside a closed environment, accuracy and reliability are improved.

Preprocessing in software

An third approach is preprocessing the show material (program) in software. This assumes a standardized playback system such as computer or ADAT tape deck. In the show programming system, a secondary program examines the scanner and PCAOM commands, and varies the intensity according to the predicted velocity of the beam in an actual projector. This preprocessed show would then be sent out to standard projectors with a table describing maximum power as a function of range, spot size, and scan angle.

4625 Winter Garden Road, A-2 • Orlando, Florida 32811 • Phone (407) 299-9504 • Fax (407) 299-3965

Basic Guidelines

Show design standards

Several basic guidelines can be developed to enhance the safety of audience scanning shows in unregulated environments:

1 Always keep the beam moving.
2 Effects below zero volts on the Y axis should be audience safe. Effects above zero volts on the Y axis may not be.
3 The projector should be equipped with some form of scanfail interlock, even if the this is the most basic velocity threshold monitor.
4 Notice should be given to the audience that accessible scanning will occur during the show.
5 Basic tables to determine maximum laser power as a function of beam size, range to the audience, and scanfield size will allow operators to gauge how to run the laser show without laborious calculations.
6 Increased beam divergence and range serve to reduce hazard while increasing show effectiveness. Irradiance levels should be below 10 mW/cm^2 for a static beam.

None of these guidelines will ensure a safe show for the audience. However, they will serve to reduce the hazard potential of laser shows, and any improvement in safety in an uncontrolled environment is good.

The Ideal System

Operator interface

The ideal system for audience scanning should ensure safety, regardless of equipment failure, operator mishap or ignorance. It should be relatively easy to setup, calibrate, and confirm. It needs to react fast enough to ensure MPE compliance even in rapid failure mode.

A combination of the three approaches to audience safety provides redundancy, and overlapping areas of protection. First, the show programming software examines the intended show program against a model of the scanning system. The intensity commands are modified to represent 0 to 100% of the MPE, rather than 0 to 100% of the available intensity. This preprogrammed "safe" show ensures that no static beams are present, that the intensity commands correspond to the velocity of the scanner, and that the cumulative exposure at any audience location is within limits.

The second part is the intelligent projector. Basic setup controls include range to the audience, spot size at the audience, and scan field dimensions at the audience. The projector can then use the velocity signals to derive the linear velocity of the beam and hence the pulse width, using the result to control the intensity of the beam. This process I call Velocity Modulated Intensity. Additionally, the projector will have an internal laser power sensor that measures beam power after the PCAOM, closing the loop on intensity control. This sensor can accurately measure total laser power, regardless of spectral content. This process I call Color Modulated Intensity. If 500 milliwatts is the maximum safe power level, CMI will allow 500 mw of red light, magenta light or white light, automatically.

The last part is a measuring instrument that confirms that the preprocessed software and the intelligent projector are indeed providing a safe exposure. If the software is correct, the projector safety features have little to do, except in a failure mode. The measuring instrument can confirm that both in normal operation and in failure mode shutdown, the MPE is not exceeded.

Conclusion

Audience scanning is a dramatic visual effect that can be performed both effectively and safely. These new developments in measuring equipment, safety sensors, and show software will help ensure safety despite equipment failure or operator neglect. The simplified approach does not require the laserist or programmer to have extensive knowledge of laser safety, and needs only some basic inputs to operate correctly.

4625 Winter Garden Road, A-2 • Orlando, Florida 32811 • Phone (407) 299-9504 • Fax (407) 299-3965