Implementation of ISO 10110 Optics Drawing Standards for the National Ignition Facility

D. Y. Wang, R. E. English Jr., D. M. Aikens
Lawrence Livermore National Laboratory
P. O. Box 808, L-495
Livermore, CA 94551

ABSTRACT

The National Ignition Facility (NIF) project elected to implement ISO 10110 standard for the specifications of NIF optics drawings in 1996. More than 7,000 NIF large optics and 20,000 NIF small optics will be manufactured based on ISO 10110 indications.

ISO 10110 standard meets many of the needs of the NIF optics specifications. It allows the optical engineer to quantify and clearly communicate the desired optical specifications. While no single drawing standard specifies all the requirements of high energy laser system, a combination of ISO 10110 standard with detailed notes make it possible to apply international drawing standards to the NIF laser system.

This paper will briefly describe LLNL's interpretation and implementation of the ISO 10110 drawing standard, present some examples of NIF optics drawings, and discuss pros and cons of the indications from the perspective of this application. Emphasis will be given to the surface imperfection specifications, known as 5/, for the NIF optics.

Keywords: Optics drawings, ISO 10110, National Ignition Facility (NIF)

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1. Introduction

In 1996, the ISO Technical Committee 172, Subcommittee SC 1 approved and published ISO 10110-1, Parts 1 to 13, under the general title "Optics and Optical Instruments – Preparation of drawings for optical elements and systems" [1]. The ISO 10110 standard specifies the presentation of design and functional requirements for optical elements in technical drawings used for manufacturing and inspection. The standard is widely recognized by the international optics vendor community. An increasing number of U. S. optics vendors are also cognizant of the standard.

The NIF optics procurement of 7,000 large optics with aperture sizes ≥ 40cm and over 20,000 small optics with aperture sizes ≤ 15cm [2] will peak over the next few years, in preparation for the initial activation of the facility. The U. S. optics industry will continue to supply refurbished and replacement parts to NIF over the program's thirty-year operation. We strive to buy optics that meet the NIF's aggressive technical, schedule, and cost requirements. To be successful, we seek the most appropriate specifications for each optics and to communicate our requirements to the optics vendors in an unambiguous fashion.

When we started determining the specifications for the NIF optics three and half years ago, we needed a standard for optics specifications and drawings. Three options were available. Option #1 was to continue with our existing approach, using an amalgamation of MIL-standards, vendor-specific call-outs and other miscellaneous U. S. standards. This approach, used successfully for the Nova Laser project, had disadvantages associated with outdated and in some cases obsolete MIL specs and inconsistencies, since there is no consensus of interpretation of the standards among U. S. optics vendors. Option #2 was to create LLNL's own standard. The final option was to implement an international standard to the extent possible and reasonable. The project elected the final option and began to specify all the optics drawings in accordance to the ISO 10110 standard by 1996.

There are a number of practical issues that we must address in the implementation of any new standard. The first is the knowledge and understanding of the standard itself, both by our staff and the optics vendors. We come to understand the standard and its implications, by means of in-house training, communicating with our vendors and practice. An equally important issue is the technical application of ISO 10110 specifications to actual parts. It is one thing to generate a drawing in accordance to ISO 10110. It is another to buy material and finished parts to the drawings. The project strongly encourages vendor feedback and incorporates vendor recommendations into the optics drawings whenever possible.

2. ISO 10110 and its implementation

The ISO 10110 standard is the normative standard for NIF optics drawings. The ISO 10110 standard covers nearly all of the traditional optical element and system specifications in optics drawings. Table 1 shows the structure of the ISO 10110-1 standard. The standard uses the metric system and all linear dimensions are in millimeters.

Part	Title	Indication
1	General	N/A
2	Material imperfections – Stress birefringence	0/
3	Material imperfections – Bubbles and inclusions	1/
4	Material imperfections – Inhomogeneity and Striae	2/
5	Surface form tolerances	3/
6	Centering tolerances	4/
7	Surface imperfection tolerances	5/
8	Surface texture	√
9	Surface treatment and coating	(λ)
10	Table representing data of a lens element	N/A
11	Non toleranced data	N/A
12	Aspheric surfaces	N/A
13	Laser irradiation damage threshold	6/

Table 1 – Structure of ISO 10110-1 standard.

We start each optics drawing with the ISO 10110 template. We made two exceptions to ISO 10110, based on vendor feedback. First, we use decimal point to indicate decimal dimensions instead of comma (e. g., 3.45 not 3,45). Second, we permit tabular entries to minimize the total number of optical drawings.

We augment each optics drawings with detailed notes. The notes discuss specific items at length, cover any requirements beyond the scope of ISO 10110 standard and help mitigate ambiguity between LLNL and our vendors. The notes template has five sections. Section #1 covers general requirements for all optics (e. g., wavelength for fringe & wavefront measurements, part & serial number, etc.). Section #2 addresses material specifications. Section #3 discusses surface characteristics not fully covered by ISO 10110 (e. g., transmitted wavefront error, RMS wavefront error, RMS wavefront gradient and power spectral density, etc.) [3]. Section #4 covers coating requirement [4]. The final section addresses packaging and handling of optics [5].

We use ASME Y14.5M-1994 as the mechanical drafting standard for all optics drawings. The use of this drafting method help us better describe the physical part we need. Geometrical dimensioning and tolerancing allows us to optimize the tolerance specifications, lower manufacturing cost and ensure the opto-mechanical performance.

3. Translation examples

This section reviews three examples to illustrate how typical optical specifications translate into the ISO 10110 format. Reference 6 lists additional examples. One common thread is that the ISO 10110 standard is a powerful tool to quantify the optical requirements of the finished part.

3.1 Material imperfections - Stress birefringence

Stress within optical materials generates an isotropic index of refraction. The effect of stress is most pronounced in transmissive optics, where it can severely impact functional performance. The stress birefringence is typically specified by the maximum permissible optical path difference per cm of glass path, in the units of nm/cm.

At present, major glass vendors subscribe to different indications for specifying stress birefringence. The ISO 10110 indication is 0/A. The '0/' is the header for stress birefringence. A is the permissible OPD in nm/cm. Table 2 compares LLNL's interpretation of the Schott glass designation [7] and LLNL's interpretation of the ISO 10110 standard. For this example, the Schott glass designation applies to all glass types up to dimensions of 160 mm x 160 mm x 100 mm. This paper uses Schott designation for example purposes. Similar tables can be developed for other glass supplier birefringence specifications.

Permissible OPD Per cm glass path	ISO 10110	Schott glass designations*	Typical applications	NIF applications
[nm/cm]				
≤ 2	0/2		Polarization instruments Interferemetric instruments	Injection laser system • Laser rods • Faraday rotator glasses
4	0/4	NSSK, PSSK (≤4)	Precision optics	
5	0/5	NSK (≤6)	Precision optics Astronomical optics	Injection laser system • Telescopes • Polarizers Main laser system • Spatial filter lenses • Amplifier slabs Alignment & diagnostic systems • Telescopes • Beam splitters
10	0/10	Normal quality after fine annealing	Photographic optics Microscope optics	Alignment light sources • Collimators
20	0/20		Magnifying glass View finder optics	
Without requirement	0/-		Illumination optics	Alignment light sources • Condenser optics

Table 2 – Stress birefringence indications – Schott designation vs. ISO 10110.

* NSK is normal quality after special annealing or precision quality.
NSSK is normal quality after extra special annealing.
PSSK is precision quality after extra special annealing.

3.2 Material imperfections - Bubbles and inclusions

Optical specifications generally treat bubbles and inclusions as equivalent material imperfections. Material imperfections induce scatter losses and beam intensity fluctuations. The inclusion sites typically have lower laser damage threshold than the bulk material and are more susceptible to laser damage. Two parameters typically specify inclusion specs.

- The total cross sectional area obscured by all the inclusions.
- The maximum permissible size of any single inclusion.

Most glass vendors specify the aforementioned parameters per 100 cm^3 of glass. The glass vendor's call out is convenient when fabrication shops order glasses but may limit competition in some cases. The ISO 10110 indication is 1/N x A. The '1/' is the header for bubbles and inclusions. A is the measure of maximum permissible inclusion size in mm and N is the total number of allowable inclusions at the maximum size. The ISO 10110 is intuitive and easy to understand, when we need to quantify the area obscured by inclusions over the optical clear aperture.

Table 3 compares LLNL's interpretation of the Corning indications for fused silica inclusion classes 0 to 2 [8] and ISO 10110 indications for an optic with 100 cm^3 of glass. For this example, any inclusion with a cross section $\leq$ 0.08mm is disregarded. This paper uses Corning designation for example purposes. Similar tables can be developed for other glass supplier bubbles and inclusions specifications.

Inclusion class number	Total inclusion cross section per 100 cm^3 of fused silica	Maximum inclusion size per 100 cm^3 of fused silica	ISO 10110 (Assuming vol. = 100 cm^3)
	[mm^2]	[mm]	
0	0.00 – 0.03	0.10	1/3 x 0.1
1	0.03 – 0.10	0.25	1/2 x 0.25
2	0.10 – 0.25	0.50	1/1 x 0.5

Table 3 – Bubbles and inclusions indications – Corning designation.

Table 4 shows LLNL interpretation of the ISO 10110 standard.

Maximum inclusion size	Each part can have 1 inclusion at the maximum inclusion size	Each part can have 5 inclusions at the maximum inclusion size
[mm]		
0.05	1/1 x 0.05	1/5 x 0.05
0.10	1/1 x 0.10	1/5 x 0.10
0.25	1/1 x 0.25	1/5 x 0.25

Table 4 – Bubble and inclusion indications -- ISO 10110.

3.3 Surface imperfections

Surface imperfections are localized blemishes, such as scratches and digs, on the surface of an optical element. Surface imperfections cause cosmetic and functional concerns. The cosmetic requirement addresses the visibility of scratches and digs on the optical surfaces. This is a genuine concern among manufacturers of consumer optics, since the average consumer interprets cosmetic flaws as indicators of poor workmanship. The functional requirement addresses performance degradation caused by light scattered from scratches and digs. First, light is scattered out of the image, in proportion to the area of the imperfection relative to the area of optical clear aperture. Surface imperfection affects Strehl ratio, since Strehl ratio is the illumination at the center of the Airy disk expressed as a fraction of the corresponding illumination for the perfect system. Second, the scattered light is thrown in to the outer zones of the Airy disk, further reducing system contrast.

At present, most U. S. vendors subscribe to some forms of the MIL-O-13830A standard or its successor MIL-PRF-13830B standard for the inspection of scratches and digs. MIL-O-13830A, section 3.5 discusses surface imperfections and is commonly referred to as the scratch and dig specs. The U. S. military drawing C7641866 governs the dimensions of the glass scratch comparison samples. Unfortunately, this reticle drawing has undergone numerous revisions, resulting in confusion regarding physical sizes of scratches and digs of a given number.

The dig is often interpreted in linear dimension by its diameter with unit of 1/100 mm. The scratch is defined by visibility not by linear dimension. Our experience shows that there is no consensus interpretation among U. S. optics vendors for the scratch spec, since visibility is subject to the inspector's interpretation, vintage of the comparison samples, light source characteristics and viewing conditions.

The ISO 10110 offers two methods to specify scratch and dig. Method 1 is the affected area method, which addresses the functional requirements. The ISO 10110 indication is 5/N x A;LN' x A'';EA'''. The '5/' is the header for surface imperfection. N is the number of digs at the maximum size. A is the maximum size of each dig in mm. 'L' is the header for scratch. N' is the number of scratches. A'' is the maximal width of each scratch in mm. E is the header for edge chip. A''' is the maximum chip size from the physical edge of the surface in mm. Method 2 is a Go / No Go test based on the visibility of surface imperfections, which addresses the cosmetic requirements.

The ISO 10110 is clear and unambiguous, when we want to quantify the area obscured by surface imperfections over the optical clear aperture. Table 5 compares LLNL's interpretation of the dig specs between MIL-O-13830A and ISO 10110, method 1.

	MIL-O-13830A	ISO 10110, method 1	
Maximum dig size in mm		Each part can have 1 dig at the maximum dig size	Each part can have 5 digs at the maximum dig size
0.05	5	5/1 x 0.05	5/5 x 0.05
0.10	10	5/1 x 0.10	5/5 x 0.10
0.20	20	5/1 x 0.25	5/5 x 0.25

Table 5 – Dig spec per MIL-O-13830A vs. ISO 10110 indications.

Table 6 compares LLNL's interpretation of the scratch specs between MIL-O-13830A and ISO 10110, method 1. We have assumed the U. S. military drawing no. C7641866, Rev. L for discussion purposes [9].

	MIL-O-13830A	ISO 10110, method 1	
Maximum scratch width in mm	U. S. military drawing C7641866, Rev. L Scratch standard Visual comparison test	Each part can have 1 scratch at the maximum scratch width	Each part can have 5 scratches at the maximum scratch width
0.001	10	5/L1 x 0.001	5/L5 x 0.001
0.002	20	5/L1 x 0.002	5/L5 x 0.002
0.004	40	5/L1 x 0.004	5/L5 x 0.004

Table 6 – Scratch spec per MIL-O-13830A vs. ISO 10110 indications.

4. NIF specifications - Example

Other papers in this session discussed the origin and technical basis for the optical specifications for NIF. It is instructive to see how they are described in ISO 10110 form. Table 7 presents a partial listing of the specifications for a lens element. This lens is a part of the transport spatial filter (TSF) alignment relay system, which transports the signals from NIF alignment sources to the alignment telescope in the output sensor package. This lens is a typical example of NIF small optics with low laser damage threshold.

Specifications	Value	Notes
Radius R1	806.64 CX	LLNL will fit designs to vendor's test plate
Radius R2	-1440.75 CX	LLNL will fit designs to vendor's test plate
Center thickness	12 ± 0.5	
Edge thickness	10.8	Reference only
Material	BK7 or equivalent	
Lens diameter (∅)	70 +0/-0.1	Same as physical diameter.
Effective diameter (∅e)	62	Same as optical clear aperture.
Stress birefringence	0/5	Maximum OPD is 5 nm/cm.
Bubbles and inclusions	1/2x0.05	Allow up to 2 inclusions, each no larger than 50 µm in size, over the optical clear aperture.
Inhomogeneity and Striae	2/4;5	Homogeneity class 4 is Δn = +/- 2e-6. Striae class 5 is no visible striae (NVS).
Surface form error for both surfaces	3/0.5(0.2/0.125)	Fringe and optical path difference given for λ = 633 nm. 0.5 fringe of sag (power) error. 0.2 fringe of irregularity error. 0.125 fringe of symmetric irregularity error.
Centering error	4/0.3'	Element wedge is 0.3 arc minute.
Surface form error	5/5x0.05;L1x0.001;E0.5 Maximum scratch length is 4 mm. Maximum number of chip is 1.	Allow up to 5 digs, each no larger than 50µm in size, over the optical clear aperture. Allow 1 additional long scratch, no wider than 1 µm and longer than 4mm, over the optical clear aperture. This is a 10-5 Scratch/dig spec to most U. S. vendor. Allow 1 edge chip no larger than 0.5 mm. Polish out all edge chips.
Laser damage threshold	0.5 J/cm^2 λ = 1053 nm 3 ns FWHM Gaussian pulse	
AR coating	R < 0.25%	Hard dielectric AR coating on both surfaces. Minimum coating diameter is effective diameter + 2 mm.

5. Conclusions

This paper briefly describes LLNL's interpretation of the ISO 10110 drawing indications. Our experiences have shown that ISO 10110 allow the optical engineers to clearly communicate and quantify the optical requirements and tolerances. We are interested and willing to participate in the development of an optics drawing standard that is broadly adopted across the U. S. industry and around the world.

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