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Tutorial

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A practical tutorial for generating ISO 10110 drawings

Abstract: This tutorial provides a brief introduction to the ISO 10110 optical drawing standard. The indications included on an ISO 10110 optical drawing are defined, and an example drawing is provided to illustrate how the information is commonly presented. To aid the designer who may not be familiar with the capabilities of optical shops, a set of specification values are provided, which illustrate easy, typical, and difficult values to achieve in fabrication. The same type of information is presented for lens dimensions. Finally, a set of design best practices are presented to aid in reducing fabrication difficulty and cost.

Keywords: ISO 10110 guide; ISO 10110 tutorial; lens drawings; lens specifications; optical drawings.

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1 Introduction

The ISO 10110 standard is an optical drawing standard used to explicitly describe an optical part based on the principle of geometric dimensioning and tolerancing (GD&T). Although the ISO 10110 optical drawing standard has begun to see widespread use in the optical industry, an optical shop will often receive an ISO 10110 drawing that is incomplete or incorrectly implemented. In talking to vendors and fellow designers about the issue, it became obvious to me that most errors arise from a designer's or a design team's unfamiliarity with the standard and how to implement it. This is not particularly the designer's fault. The real problem seems to be the lack of a 'simple, practical' guide for generating an ISO drawing. In particular, a guide is written for designers who may want to use ISO 10110 but are unsure of where to begin or for anybody who may need a lens fabricated but is not necessarily familiar with the details of optical fabrication.

The goal of this tutorial is to fulfill this role as an aid to the designer or the drafter in adequately and correctly completing an ISO 10110 drawing.

2 Geometric dimensioning and tolerancing

ISO 10110 fundamentally relies on the principles of GD&T to describe a mechanical part. GD&T was devised as a method to explicitly describe nominal geometry and allowed variation for use in engineering drawings. In the United States, the use of ANSI Y14.5-2009 is almost universal, although many machine shops may still rely on ANSI Y14.5M-1994 because the current version is relatively new. Under the ISO system, geometrical product specifications (GPS) are governed by the Technical Committee (TC) 213 and include ISO 286-1 and -2:2010, ISO 1101:2012, ISO 5458:1998, ISO 5459:2011, and many other standards. GD&T standards for data exchange and integration are governed by ISO 10303. It would be a good idea for the designer to verify what revision of standard the fabricator uses when submitting drawing packages to avoid any possible misinterpretations [1].

This tutorial assumes that the reader is familiar with basic GD&T/GPS practices, so we can focus on the unique practices associated with describing optical components. As a mechanical part, an optical component can be described to some extent under the standards listed above [2]. However, the unique aspects of optical components require additional standards to accurately describe the part to be made.

3 ISO system for specifying optical components

ISO TC 172, Optics and Optical Instruments, writes and maintains the majority of standards for specifying optical components. Under their cognizance, ISO 10110, Optics and Optical Instruments – Preparation of Optical Drawings for Optical Elements and Systems, is the primary reference for the preparation of drawings for optical elements and systems. ISO 9211, Optical Coatings, is also very important. In addition to these, there are many ancillary standards that contribute to the specification and testing of optical components. A complete list of ISO standards under the purview of TC 172 is available from the ISO website at **http://www.iso.org**.

4 ISO 10110 standard summary

ISO 10110 is a multipart standard describing the preparation of drawings for optical elements and systems. Table 1 lists the part numbers and the aspects that the parts cover.

Each part describes very well how to place each indication on the drawing and what the values mean. There are also a few examples to show what the indications should look like. I highly recommend that if you design lenses as a career, you obtain and maintain a set of the ISO 10110 standards and keep them near your desk as a reference. This is especially true if you work with optical shops in countries where the standard is widely adopted or if – as an optical shop – you receive bids that include ISO 10110 drawings in the bid package.

Part	Title	Indication
ISO 10110-1	General	N/A
ISO 10110-2	Material imperfections – stress birefringence	0/
ISO 10110-3	Material imperfections – bubbles and inclusions	1/
ISO 10110-4	Material imperfections – inhomogeneity and striae	2/
ISO 10110-5	Surface form tolerances	3/
ISO 10110-6	Centering tolerances	4/
ISO 10110-7	Surface imperfection tolerances	5/ and 15/
ISO 10110-8	Surface texture	$\sqrt{}$
ISO 10110-9	Surface treatment and coating	(λ)
ISO 10110-10	Table representing data of a lens element	N/A
ISO 10110-11	Nontolerance data	N/A
ISO 10110-12	Aspheric surfaces	N/A
ISO 10110-17	Laser irradiation damage threshold	6/

Table 1 Structure of the ISO 10110 standard.
The ISO 10110 standard consists of 13 parts, each describing a separate component of a complete ISO 10110 drawing [3, 4].

But let us be honest. Like any standard, ISO 10110 makes a great short-term cure for insomnia, and the learning curve is steep when, as a designer, you are unfamiliar with generating optical drawings or how an optical shop fabricates a lens. Additionally, an optical shop encountering an ISO 10110 drawing for the first time (such as what happens quite often in the United States) will be lost trying to interpret the drawing. Some optical design programs, such as ZEMAX or CODE V, include the option to generate ISO drawings and will even dimension the part. However, you still need to provide a large amount of information to correctly specify the lens. The first question you probably ask is this: What numbers do I put in?

5 Specification examples

One of the worst mistakes that a designer can make is to submit an incomplete drawing to a fabrication shop and 'hope for the best'. You may get lucky the first time you try this approach, but at some point you will get a lens back that was not what you wanted. Of course, this will usually happen when you are behind schedule and your project manager is asking you for daily status updates. In other words, your part will fail at the worst possible time.

The second worst mistake you can make is to provide a drawing to the fabricator with tolerances and specifications so tight that it will be unnecessarily costly and threaten the schedule. You do not want to go back to the optical shop a few months later and find your drawing framed on their wall with the caption: 'Our most difficult fabrication job yet!' I am going to help you avoid this embarrassment.

Let us examine two useful tables that will aid in completing an ISO 10110 drawing [5, 6].

Table 2 is a set of specifications that I have developed to illustrate ISO 10110 indications. The table includes three sets of specifications that correlate to low-quality, typical, and high-quality lenses. Much of these specifications control the quality of the glass that the lens is made out of and thus are of immediate importance to the glass manufacturers. However, it is important to note that the indications apply to the finished lens.

Table 3 is a list of tolerances for fabrication and mounting of lenses. The 'Easy' column is a list of tolerances that, if loosened further, do not provide any significant reduction in the cost of the lens. The 'Typical' column is about what a typical shop expects to see, and tightening these tolerances much further will begin to significantly raise

Parameter	Indication	Low quality	Typical	High quality
Stress birefringence	0/A	20 nm/cm	10 nm/cm	4 nm/cm
Bubbles/Inclusions	1/N×A	1/10×0.3	1/4×0.1	1/2×0.075
Inhomogeneity/Striae	2/A;B	2/1;2	2/3;3	2/5;5
Surface irregularity (for spherical surfaces)	3/A(B)	3/-(2) (radius tolerance is a dimension)	3/3(0.5)	3/1(0.2)
Centering tolerances (wedge, arc minutes)	4/σ	4/5′	4/2′	4/0.6′
Surface imperfection (scratch and dig per MIL-PRF-13830 in the USA)	5/N×A; 5/LN″ ×A″; 5/EA‴	5/5×0.5; 5/L1×0.008; 5/E1.0 (80–50 in the USA)	5/5×0.4; 5/L1×0.006; 5/E0.5 (60–40 in the USA)	5/5×0.05; 5/L1×0.001; 5/E0.5 (10–5 in the USA)
Laser irradiation damage threshold	6/H_{TH}; λ; pdg	6/10; 1064; 2 (group 2 per ISO 11254-1)	6/20; 1064; 2 (group 2 per ISO 11254-1)	6/40; 1064; 2 (group 2 per ISO 11254-1)

Table 2 Examples of low-quality, typical, and high-quality ISO 10110 indications.
Although these values should serve as guidelines, the optical performance requirements of the lens or system should determine the specific values.

Parameter	Easy	Typical	Difficult
Center thickness	±0.10 mm (0.004″)	±0.025 mm (0.001″)	±0.005 mm (±0.00025″)
Diameter	+0.00/-0.10 mm	+0.00/-0.025 mm	+0.00/-0.025 mm
Clear aperture	90% of diameter	94% of diameter	98% of diameter
Mounting decenter	±0.10 mm (0.004″)	±0.025 mm (0.001″)	±0.005 mm (±0.00025″)
Radius of curvature	1%	0.3% to 0.1%	0.05%
Coating	Average transmission >96%	Average transmission >98%	Minimum transmission >98%
Protective chamfer (levels)	0.75–1 mm	0.1–0.3 mm	0.02–0.1 mm

Table 3 Glass lens manufacturing and mounting tolerances.
Begin your tolerance analysis using values in the 'Easy' column and tighten tolerances on specific dimensions only as needed to maintain performance. Remember, the performance of the system should be evaluated for as-built optics (i.e., Monte Carlo analysis) and not for the nominal design.

the cost of the lens. The 'Difficult' column really pushes the limits of what most optical shops can do, so expect tolerances such as these to result in significantly higher fabrication costs.

As they say in the United States, 'Your mileage may vary', so I encourage you to work with your vendor and/or glass manufacturers to determine their specific capabilities and ensure you obtain the part you need at the best possible price point.

One final note on tolerancing: If a specification has not been toleranced, ISO 10110-11 provides a set of 'default' tolerances that scale with the size of the part.

Property	Range of maximum (diagonal) dimension of the part (mm)			
	Up to 10	Over 10, up to 30	Over 30, up to 100	Over 100, up to 300
Edge length, diameter (mm)	±0.2	±0.5	±1	±1.5
Thickness (mm)	±0.1	±0.2	±0.4	±0.8
Angle deviation of prisms and plate	±30′	±30′	±30′	±30′
Width of protective chamfer (mm)	0.1–0.3	0.2–0.5	0.3–0.8	0.5–1.6
Stress birefringence according to ISO/DIS 10110-2 (nm/cm)	0/20	0/20	–	–
Bubbles and inclusions according to ISO/DIS 10110-3	1/3×0.16	1/5×0.25	1/5×0.4	1/5×0.63
Inhomogeneity and striae according to ISO/DIS 10110-4	2/1.1	2/1.1	–	–
Surface form tolerances according to ISO/DIS 10110-5	3/5(1)	3/10(2)	3/10(2) (all ø 30)	3/10(2) (all ø 60)
Centering tolerances according to ISO/DIS 10110-6	4/30′	4/20′	4/10′	4/10′
Surface imperfection tolerances according to ISO/DIS 10110-7	5/3×0.16	5/5×0.25	5/5×0.4	5/5×0.63

Table 4 Tolerance data from ISO 10110-11.
Care should be taken to understand the impact on performance when the drawing parameters are allowed to default to these values.

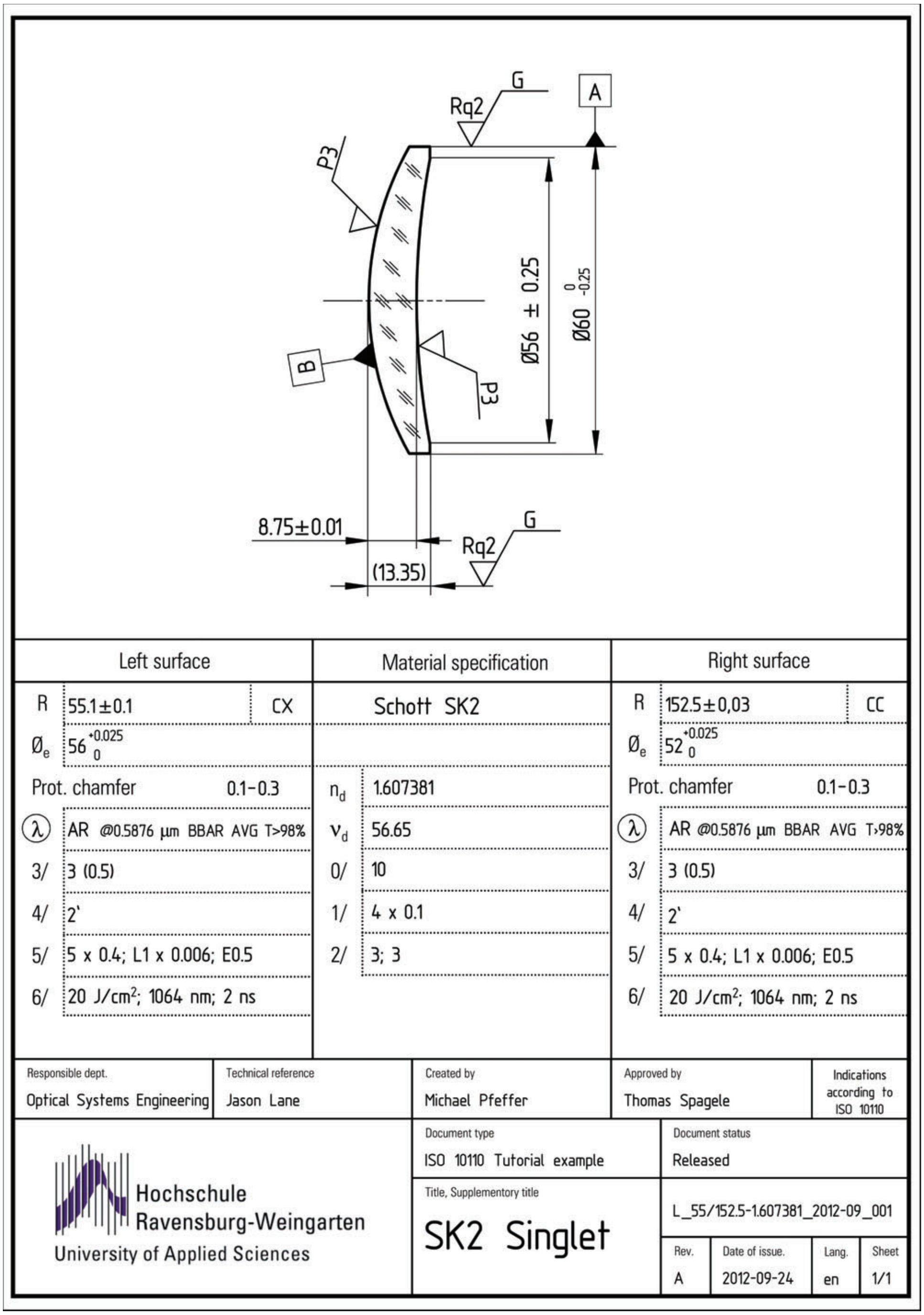

Figure 1 ISO 10110 drawing with typical indication values.
The values are taken from the 'Typical' columns in Tables 2 and 3. Drawing courtesy of Prof. Michael Pfeffer (Ravensburg-Weingarten University of Applied Sciences, Weingarten, Germany).

This is common in Europe but is a practice that opticians and engineers in the United States are not used to. Some of the default tolerances can be very loose and can lead to performance problems with the lens if a tolerance on the drawing is overlooked. I recommend that all specifications and dimensions be tolerance on the ISO 10110 drawing. If desired, a tolerance can be removed from the drawing if the ISO 10110-11 tolerances are acceptable. However, sending a drawing to a US optical shop without clearly defined tolerances may generate requests for clarification. The ISO 10110-11 default tolerances are provided in Table 4.

6 Generating the drawing

Figure 1 presents a sample ISO 10110 drawing to show you how the information should be included to fully specify the lens. The drawing layout is the tabular form described in ISO 10110-10, and I believe this is the easiest ISO 10110-compliant layout to interpret [7].

The specifications and tolerances are from the 'Typical' columns in the tables above. Also notice that the dimensions are all rounded values. This is purposeful in that optical shops can measure only to a certain level of accuracy and specifying significant digits beyond that ability is meaningless. Additionally, if the lens is to be fabricated with a CNC machine, less digits to enter into the program means less risk of entering the wrong value. When optimizing your design, you will find that the performance loss is almost negligible when moving a radius from, say, 50.248765–50.25 mm.

7 Best design practices to ensure a successful lens

Now that you have gained some insight on how to generate an ISO 10110 drawing and what specifications are achievable, you may still have a lens that is difficult to make. This can be one of the most frustrating aspects of lens design for the beginner. The design will perform, the tolerances look good, and the drawing is complete, but the optical shop returns a 'NO BID'.

In this case, there is just no substitute for experience. In Table 5, I have provided a few guidelines you can use to make sure fabrication of the part proceeds smoothly. Most of these I learned the hard way. A few thankfully were passed on by other designers. These are classic guidelines that you should always try to apply if you want to keep the cost down and reduce the difficulty of fabrication. Of course, some of these require a departure from the most optimal prescription. Do not get hypnotized by the merit function numbers: the optical designs can usually accommodate these guidelines with minimal impact on performance. They are by no means complete, nor do they apply to all cases. However, they will usually keep the beginning designer out of trouble.

8 Special consideration for American designers and optical shops

The ISO 10110 standard is very well thought out and is steadily gaining acceptance around the world. Contrary to Europe, however, outside of academia and drawings coming in from international business, the ISO 10110 standard has seen very little acceptance in

Nominal specification	Guide	Reason
Center thickness	Minimum 2 mm center thickness, particularly for concave lenses	Thin glass warps easier under pressure applied during polishing, with increased risk of surface-induced wavefront error
Ratio of center thickness to diameter	Less than 12:1	Same as above. Thin lenses are more likely to flex during the polishing process, with detrimental impact on performance
Edge thickness	Greater than 2 mm (radius)	Thinner edges are easier to break, both during handling and after installation, if the assembly experiences vibration or shock
Edge diameter clearance for mounting	Minimum 2 mm up to 100 mm, 5–10 mm for larger optics	Aids in keeping stresses from the mounting interface away from both the clear aperture and the edge
Air gaps	Maintain minimum of 1 mm at center and edge	Aids the optomechanical design
CTE match for doublets	Match the thermal expansion of both glass types that make up a doublet within ~1–2 μm/m/C or less	Avoids temperature-induced stress at the glass interface, which can deform the wavefront or even pop the cement in extreme cases
Keep your lenses from getting too thick	I like to keep my diameter to center thickness ratios between 3:1 and 12:1	Reduce cost of glass and keeps the weight of the system down. Usually, a thinner lens will optimize out just as well as thick one, but step the thickness down manually a little bit at a time
Mechanical dimensions (center thickness, diameter, radii of curvature)	Round to the nearest 0.05 mm if possible. Match radii to the shop's test plates and call out tolerances in fringes for large production runs	Reduces human error when copying values to CNC machines. Test plates reduce production cost

Table 5 A selection of guidelines for designing lenses.
Making use of these guidelines when designing imaging lenses will reduce cost and risk associated with fabrication.

North America. As large as the American market is, this fact of the current state of the optical industry cannot be ignored.

In preparing for this tutorial, I surveyed several American optical shops to gain insight into how often they handle ISO 10110 drawings. I found that 5–10% of incoming bid packages used ISO 10110 drawings. When I asked where the ISO 10110 drawings came from, I discovered that the overwhelming majority originated in Europe.

The United States currently has no optical drawing standard. Historically, MIL-STD-34 provided guidance for the generation of optical drawings in the United States [8]. This standard was cancelled in 1995 and superceded by ANSI Y14.18M-1986. Y14.18M was never updated and is also considered obsolete. ISO 10110 officially replaced these standards. However, it was never designed to accommodate the notes-based drawing standards that the American optical industry have used for decades. Engineers and opticians trained in the United States simply find ISO 10110 counterintuitive after having used MIL-STD-34 and its replacement ASME Y14.18M-1986 for several decades.

In spite of their obvious shortcomings, the preference is to generate drawings loosely based on these obsolete American standards and simply resolve ambiguous callouts during discussions between the fabricator and the customer. Sometimes a drawing is not even used, and the shop generates lenses off of the customer's original design file. An optical shop in the United States accommodates not only ISO 10110 drawings but also the obsolete American standards, drawings that are a mix of the standards, drawings that conform to no standard at all, and even design files where no drawings are generated at all. Needless to say, the American optical drawing system is very chaotic with no practical solution coming on the horizon.

9 Concluding remarks

The ISO 10110 standard is a serious effort to bring a standardization to a global market. As the drawing standard gains acceptance throughout the world, it is vital for the engineers and technicians in the optical industry to learn and understand how to interpret ISO 10110 drawings.

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