Modern optics drawings update: translating from American MIL drawings to ISO 10110

Reference to interpret ISO 10110 drawings (2023 Update)

Full standard contains complete descriptions and explanations for proper use

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Surface Form Tolerances and Evaluation[5, 20]

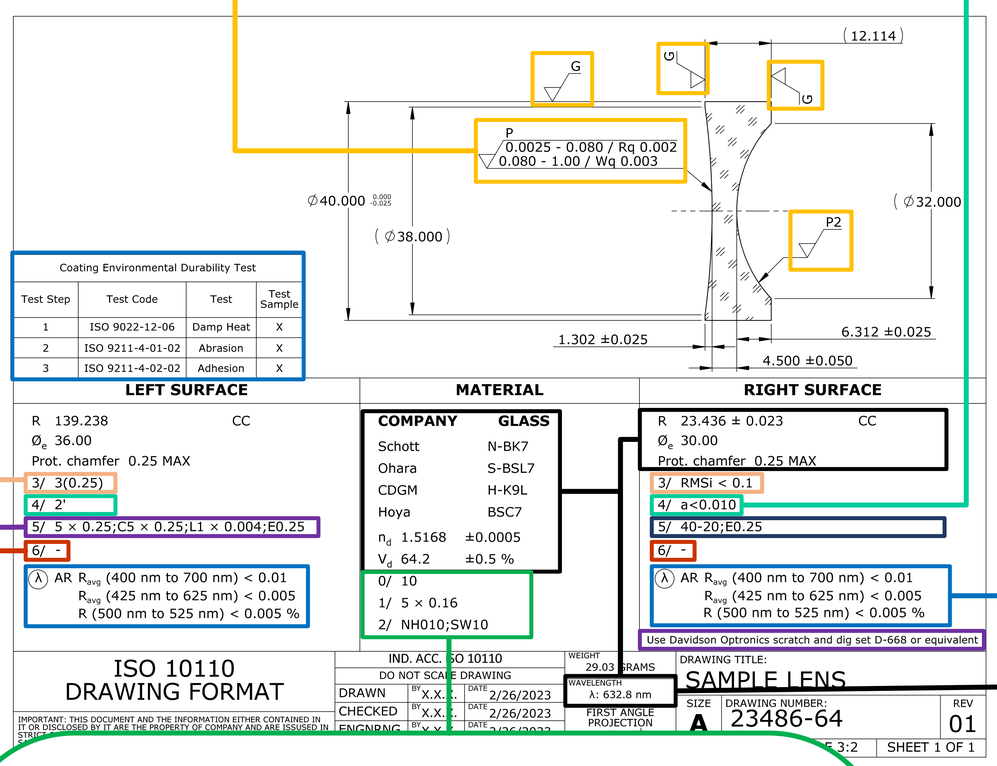
- Units are preferred to be in nm, but allowed in µm or fringes
  - If fringes are the unit specified, a wavelength needs to be defined either in the title block or for the tolerance
- Written as 3/ A(B/C) PV(D) RMSx < E; λ = W
  - A = power: PV approximation spherical wavefront
    - When a dash is listed no tolerance applies otherwise a default power tolerance is present
  - B = irregularity: PV wavefront irregularity
  - C = rotationally invariant irregularity: PV rotational invariant irregularity
  - D = total deviation: PV total wavefront deviation
  - E = rms deviation; where x is
    - t = total rms surface deviation
    - i = rms surface deviation with power removed
    - a = asymmetric variant rms surface irregularity
  - W = wavelength (λ) in nm
    - If wavelength is not indicated in the title block, it must be specified in the tolerance
- Other than power, when a dash or nothing is listed in place of one of the tolerances, that type of tolerance will not be applied
- Further forms of surface form tolerances can be applied, such as surface slope or Zernike coefficients
  - Slope is written as 3/ $\Delta S_{v,w}$(F/G/H)
    - v = number of dimensions (1 or 2)
    - w = orientation
    - F = Max slope deviation (ξ)
    - G = sampling length
    - H = spatial sampling interval
  - Zernike coefficients written specifically as 3/ Z(n, m) (PV < O; RMS < P)
    - Z(n, m) = Zernike radial polynomial
    - O = PV surface form deviation
    - P = rms surface form deviation

Surface Texture[8]

- Polish code above the texture symbol is either P (polished), G (ground) or P1-P4 (polish grades) which indicate a default specification of surface texture
  - Polish grades are standardized surface roughness values over a spatial band of 0.002 mm to 1.00 mm
- Texture requirements written as follows
  - Each requirement on its own line, showing a spatial wavelength band and a surface texture specification separated by a /
  - Spatial wavelengths are given in mm
  - Rq indicates rms surface roughness in microns
  - Wq indicates rms surface waviness in microns
  - Sq indicates the areal rms surface texture in microns
  - RΔq indicates rms surface slope in microradians
  - PSD indicates the maximum value of the power spectrum over the specified spatial wavelength band, given as a power coefficient and an intercept in nm^2 mm
- When upper and lower limits are provided they are indicated with a U or an L
- When the lay of the measurement is provided it is indicated as R (radial), C (circumferential), ⊥ (vertical) or = (horizontal).

Surface Centering Error Due to Tilt[6]

- Implicit datums exist for typical, centered, spherical elements. If datum features are unclear, one must be specified
- Written as follows:
  - Spherical Surface: 4/σ
    - σ = maximum tilt relative to either the cylindrical surface (lens edge) or datum axis (optical axis)
  - Aspheric Surfaces or Rotationally Non-Variant Subassemblies: 4/σ(L)
    - σ = maximum tilt
    - L = maximum lateral displacement
  - Beam deviation can be specified for the entire lens element: 14/ρ
    - ρ = maximum transmitted beam deviation
  - Surface tilt can alternatively be specified by runout (e.g. lens edge measurement):
    - 4/a < A or 4/c < B
      - A = axial runout at the clear aperture
      - B = circular runout at the surface edge
- Tolerances can be applied as both angular and linear dimensions at single element or assembly level
- When a dash or nothing is listed in place of one of the tolerances, that type of tolerance will not be applied



Surface Treatment and Optical Coatings[9, 22-26]

- Functional coatings are indicated by a λ inside a circle
- As defined in ISO 9211-2 descriptions and applications of an optical coating must precede the specifications for spectral characteristics (e.g. Antireflecting [AR] or Filtering [FI])
  - Coatings specifications can primarily be broken down into three designations
    - τ(λ) or T(λ) = transmission for a waveband
    - ρ(λ) or R(λ) = reflectance for a waveband
    - α(λ) or A(λ) = absorptance for a waveband
  - Additional methods are possible to describe an optical coating past the waveband
    - Angle of incidence (AOI)
    - Aperture size
    - Polarization orientation
    - Phase
- Coating durability can be specified on a drawing using a test code, test sequence, and number of samples
  - List of possible test codes and sequences are in ISO 9211-3
  - Test codes are based on ISO 9022, environmental testing series, and ISO 9211-4, coating specific durability tests
- Surface treatments
  - Indicated on the optic by a thick chain line adjacent to the treated region
  - Specifications are written in a box with a leader line to the treated region
  - Surface treatment applications
    - mitigate damage to the optic (e.g. handling)
    - Provide functional uses outside main use of the optic (e.g. stray light control)

Surface Imperfection Tolerances and Evaluation[7, 21]

- Imperfections can be described by two methods
  - Visibility imperfections (MIL historical standard): 5/ S-D; CS’-D’; EA_e
    - Each group represents different types of imperfections
      - S-D = general surface scratch and dig designation
      - CS’-D’ = coated aperture scratch and dig designation
      - EA_e = edge chips
    - A drawing note stating the make and model of the comparison standard to be used is necessary
    - Accumulation and concentration rules apply
  - Dimensional imperfections (DIN historical standard): N_g x A_g; CN_c x A_c; LN_l x A_l; EA_e
    - Each group with a different prefix designation classifies types of imperfections
      - No Prefix = general surface imperfections
      - C = coated aperture imperfection designation
      - L = long scratches outside of general surface grades
      - E = edge chips
    - Each designation is listed in two methods
      - N_y x A_y
        - N = Number of imperfections within a grade class
        - A = Grade class to characterize imperfections
    - Accumulation and concentration rules apply

Materials[18, 27]

- The following optical material information needs to be listed; either
  - Manufacturer and optical material type
    - Multiple manufacturers may be listed for a given element
  - International glass code
  - The index and Abbe information
    - Material specifications occur at wavelength specific index and Abbe (e.g. n_d and V_d or n_e and V_e)
  - However the glass is specified, tolerance on the index and dispersion must be indicated
- Tolerances for optical materials are determined by three main groups
  - Stress birefringence: 0/A
    - A = maximum allowable optical path difference (OPD) in units of nm/cm
    - Value of stress birefringence is based on quality of annealing and optic size
  - Bubbles and inclusions: 1/N x A
    - A = grade of the bubbles determined by the square root of the projected area
    - N = number of allowable bubbles through a method of accumulation
  - Homogeneity and striae: 2/A;B
    - A = homogeneity: Maximum permissible PV variation of the refractive index preceded by an “NH” indicator
      - Homogeneity was previously specified by a class indicator
    - B = striae: amount of wavefront deviation tolerance limit per 50 mm path length in nm, preceded by an “SW” indicator
      - Striae was previously specified by a class indicator or the more common shadowgraph class
- Raw material is specified with the same tolerance property, except preceded by zero (“0X/”)
  - Tolerance notation is similar to indicators used for homogeneity (“NH”) and striae (“SW”)

General Notation[1, 11]

- Drawings can be prepared for an optical element or subassembly
- Default conditions unless stated otherwise:
  - Temperature = 20°C
  - Dimensional Units = mm
- Each tolerance property is applied for multiple cases:
  - X/ = element tolerance
  - 1X/ = subassembly tolerance
  - 0X/ = raw material tolerance
- Fundamental dimensions for a rotationally invariant optical element
  - Radius = dimensional value preceded by an R and the curvature orientation (CX or CC)
  - Thickness = dimensional value including tolerance unless specified otherwise
  - Diameter (Ø) = dimensional value including tolerance
    - Effective diameter ($Ø_e$) = sub-aperture where optical tolerances apply
  - Edge corners
    - Bevel = functional corner specified with a dimension, tolerance, and angle
    - Chamfer = nonfunctional corner specified as the maximum or minimum allowed face width
- Unless stated within each tolerance where a wavelength value is necessary, the title block must include reference wavelength
  - As of ISO 10110-1 2019 there is no default wavelength
- Values that do not have tolerances listed, or are meant to be ignored, have a default tolerance
  - Tolerances are based on the diameter of the lens

Laser Damage Threshold[17, 31, 32]

- Written as 6/ X_{th}; λ; τ_{th}
  - X can either be one of three conditions depending on the type of laser irradiation
  - Pulsed laser irradiation:
    - H_{th} = Threshold energy density in units of J/cm^2
    - E_{th} = Threshold power density in units of W/cm^2
  - Long pulse or CW laser irradiation
    - F_{th} = Threshold linear power density in units of W/cm
    - A pulse is considered long when the thermal transit distance, $(2\ D\ \tau_{eff})^{1/2}$, is on the order of the size of the test spot $d_{T,\ eff}$
      - D = Thermal diffusivity
  - In both cases, τ_{eff} = Effective pulse duration in units of s
- When a dash is present following 6/, or the 6/ is not included, the laser damage threshold is not defined and will not be tested

Wavefront Deformation from an Element or Assembly[14, 20]

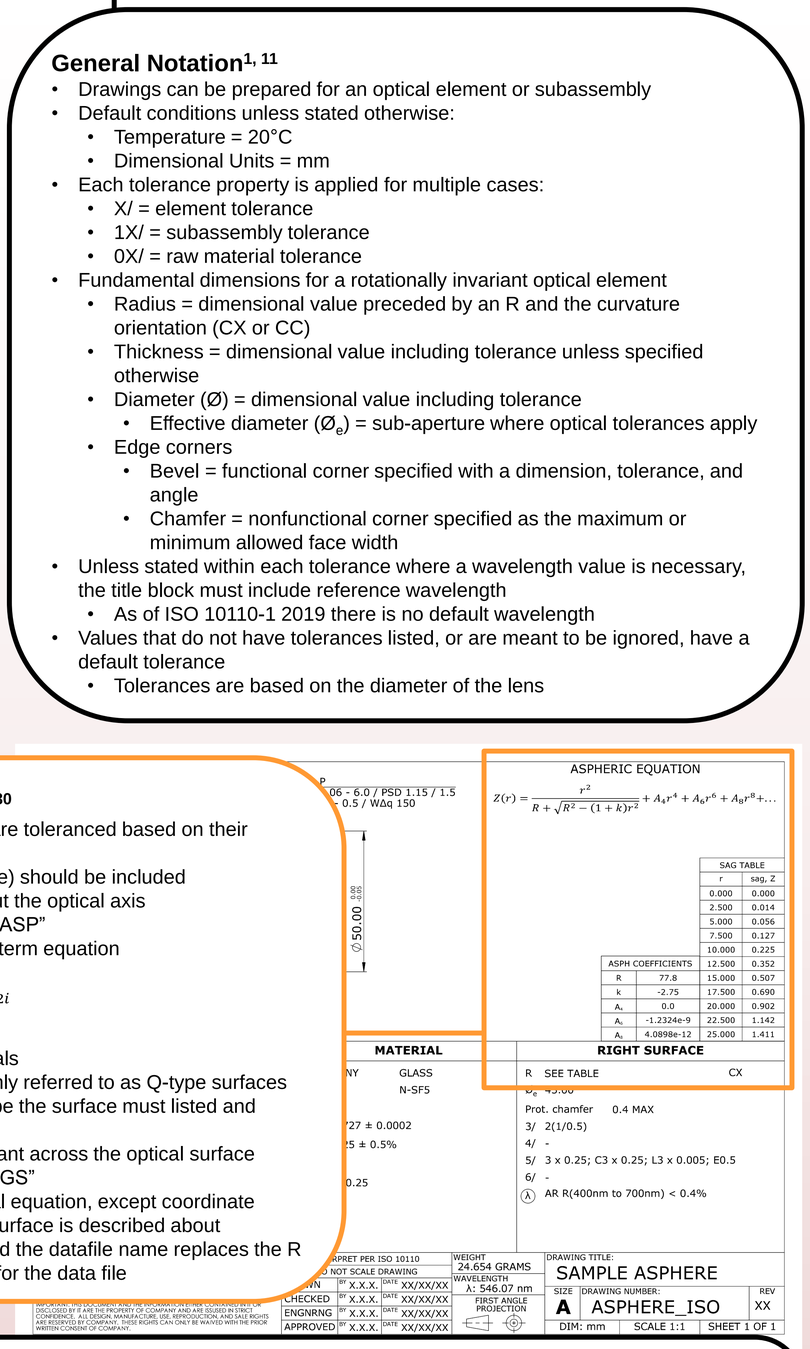
- Builds upon surface form tolerance specification where notation changes from 3/ to 13/
  - Written as 13/ A(B/C) RMSx < D; λ = E
  - Update: units of A, B, and C are waves instead of fringes
- Value specified is needs to be measurable using a single-pass metrology method, typically found to be an interferometer
- Specification would be shown on the drawing view or in a total system specification section of the table
- Assembly deformation example:
  - 13/ - RMSt < 0.04; λ = 632.8 nm
  - Example states that the measured total rms wavefront error needs to be less than 0.04 waves different from the theoretical total rms wavefront error when tested at 632.8 nm
- When a dash or nothing is listed in place of one of the tolerances, that type of tolerance will not be applied

Diffractive Surfaces[16]

- Diffractive surfaces are indicated by a # inside a circle
- Three properties of diffractive element must be specified, unless otherwise inferred from the type of grating (transmission grating for CGH)
  - Basic type of diffractive structure (e.g. LG = Linear grating)
  - Direction of diffracted light (e.g. RG = Reflection grating)
  - Type of structure (e.g. SR = Surface relief grating)
- Test region of diffractive structure needs to be shown in a face view with proper hatching to show applicable area (e.g. for a linear grating straight lines in the direction of the grating are shown)
  - Similar to effective aperture, you use $Ø_{\#}$
- Specification of type of grating is different for each basic type of diffractive structure
  - Linear grating: Diffractive parameters and direction of linear grating
  - Circular grating: Mathematical description and diffractive parameters
  - Computer generated hologram: Data set for processing and describing diffractive structure

Asphere and Freeform Surfaces[12, 19, 29, 30]

- Both aspheric and general (freeform) surfaces are toleranced based on their surface form (as per ISO 10110-5)
  - A sagitta table with Δz (sag) and/or Δs (slope) should be included
- Aspheric surfaces are rotationally invariant about the optical axis
  - Surface type in tabular field is indicated as “ASP”
  - Surface shape is described through a multi-term equation
    - Conic section and a power series
      - $z(h) = \frac{h^2}{R\left[1+\sqrt{1-(1+\kappa)\left(\frac{h}{R}\right)^2}\right]} + \sum_{i=2}^{n} A_{2i} h^{2i}$
    - Conic section and orthogonal polynomials
      - Multiple types of equations commonly referred to as Q-type surfaces
  - Coefficients and equation needed to describe the surface must listed and referred to in the surface radius designation
- General (freeform) surfaces are rotationally variant across the optical surface
  - Surface type in tabular field is indicated as “GS”
  - Surface shape is described by mathematical equation, except coordinate system is critical in determining where the surface is described about
  - For a cloud of points, the indication "GS" and the datafile name replaces the R for the surface, with a date and time stamp for the data file



Additional Information[28]

- All information covered here is expanded upon in the referenced citation

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