Specifying Optical Components

- Lenses, Mirrors, Prisms,…
- Must include tolerances
  - Allowable errors in radius, thickness, refractive index
- Must consider
  - Surface defects
  - Material defects
  - Mounting features

Dimensional tolerances for lenses

Diameter tolerance of 25 ± 0.1 mm means that the lens must have diameter between 24.9 and 25.1 mm

Lens thickness is almost always defined as the center thickness

Typical tolerances for small (10 - 50 mm) optics:

Diameter +0/-0.1 mm

Thickness ± 0.2 mm

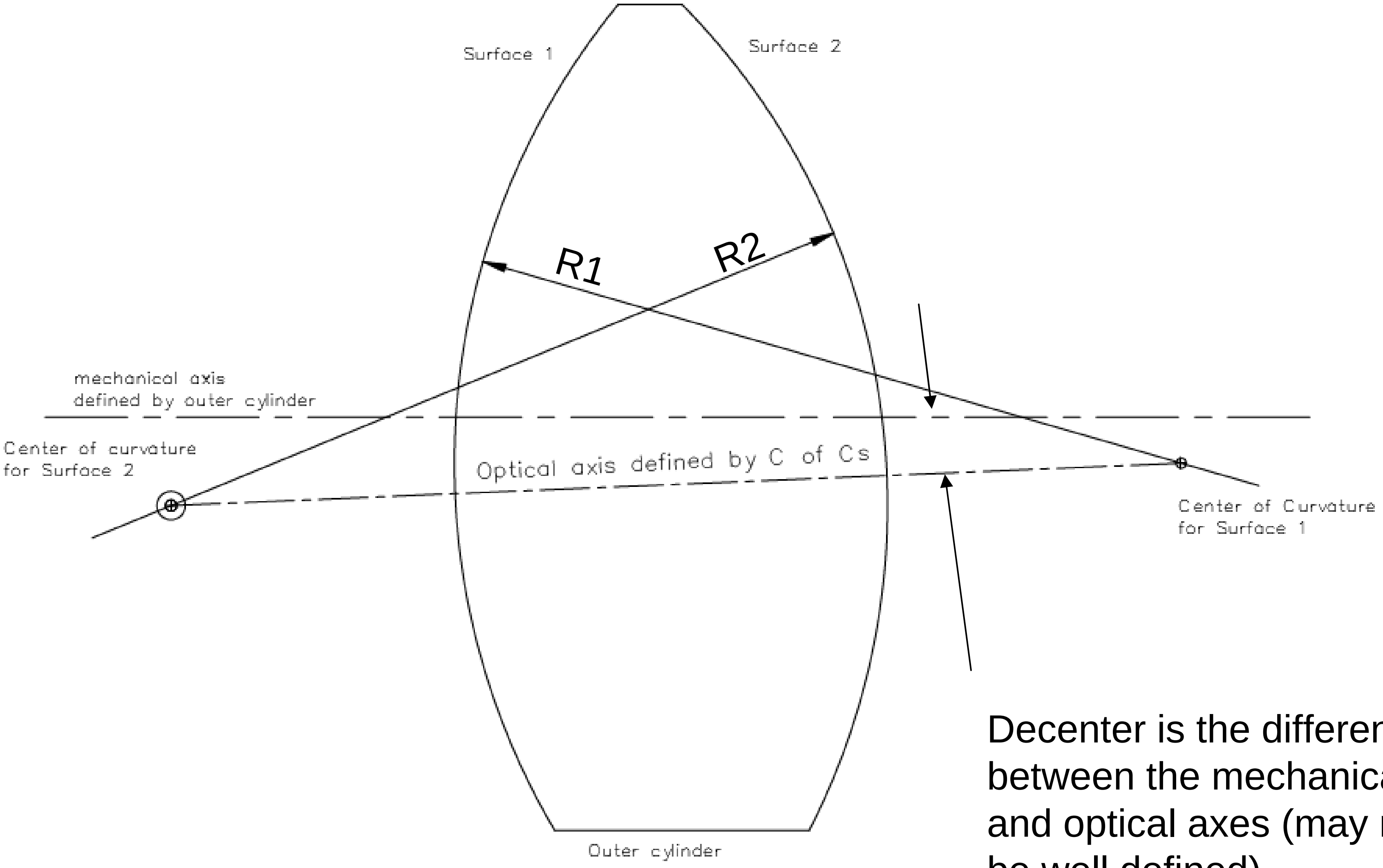
Clear aperture is defined as the area of the surface that must meet the specifications. For small optics, this is usually 90% of the diameter.

Understanding wedge in a lens

- “wedge” in a lens refers to an asymmetry between
  - The “mechanical axis”, defined by the outer edge.
  - And the “optical axis” defined by the optical surfaces

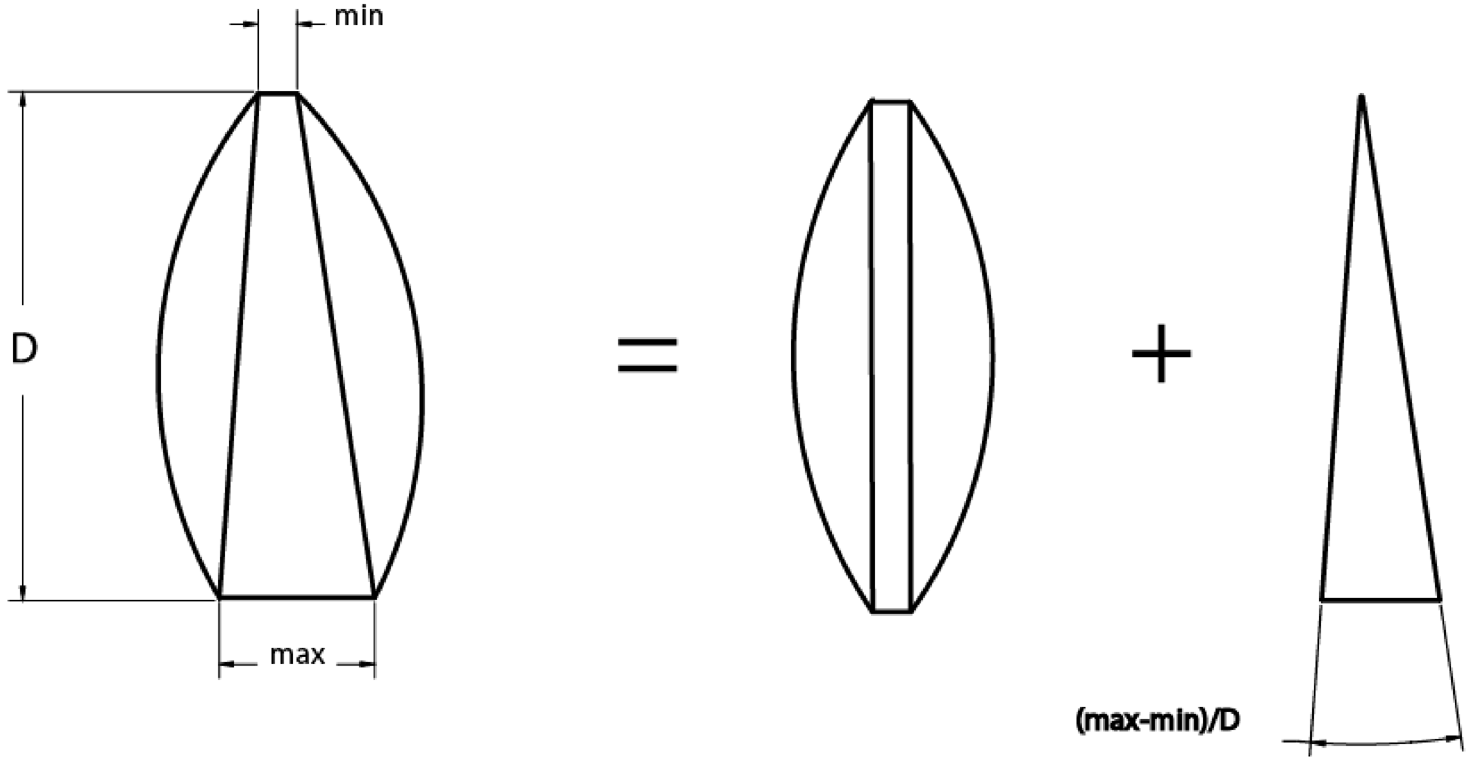
Lens wedge deviates the light, which can cause aberrations in the system

Optical vs. Mechanical Axis



Decenter is the difference between the mechanical and optical axes (may not be well defined)

Effect of lens wedge



$\alpha = ETD / D$

$\delta = \alpha(n - 1)$

Tilt and decenter of lens elements

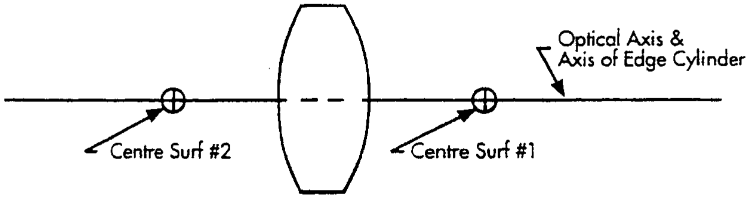


FIG. 6.3a. Centered element.

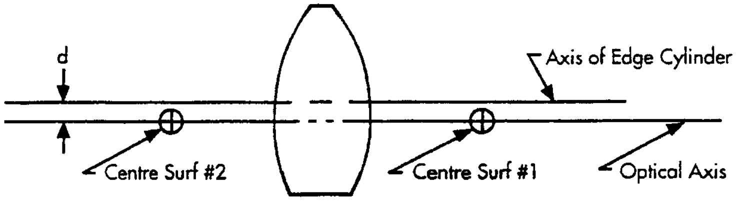


FIG. 6.3b. Displaced (decentered) element.

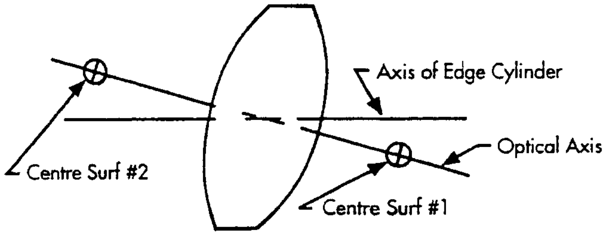


FIG. 6.3c. Tilted element.

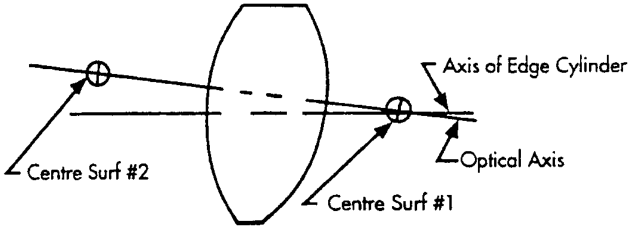


FIG. 6.3d. Element with tilted surface.

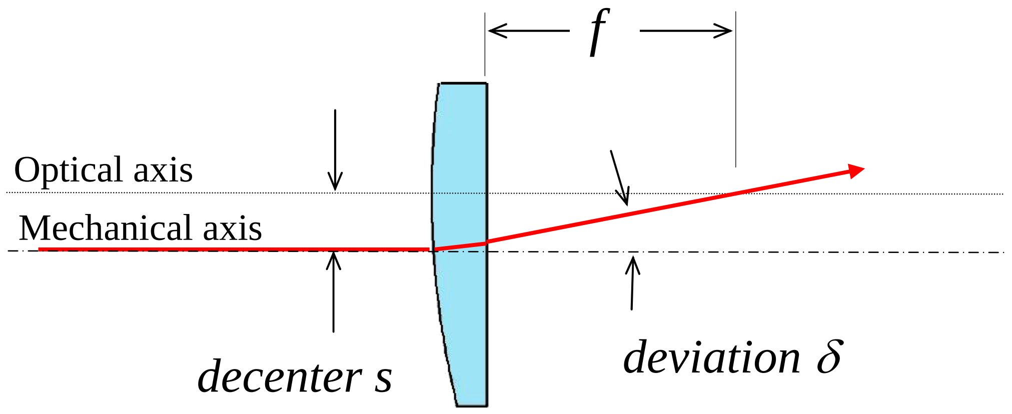
Parks

Specifying wedge in a lens

- The optical axis of a lens defined by line connecting centers of curvature of the optical surfaces
- The mechanical axis defined by outer edge, used for mounting.
- Wedge angle α = Edge Thickness Difference (ETD)/Diameter (often converted to minutes of arc)
- Deviation $\delta = (n-1)*\alpha$
- Lenses are typically made by polishing both surfaces, then edging. The lens is held on a good chuck and the optical axis is aligned to the axis of rotation. Then a grinding wheel cuts the outer edge.
- The wedge specification dictates the required quality of the equipment and the level of alignment required on the edging spindle.
- Typical tolerances are
  - 5 arcmin is easy without any special effort
  - 1 arcmin is readily achievable
  - 15 arcsec requires very special care

Lens element centration

- Lens wedge can also be describe as centration. This is defined as the difference between the mechanical and optical axes.

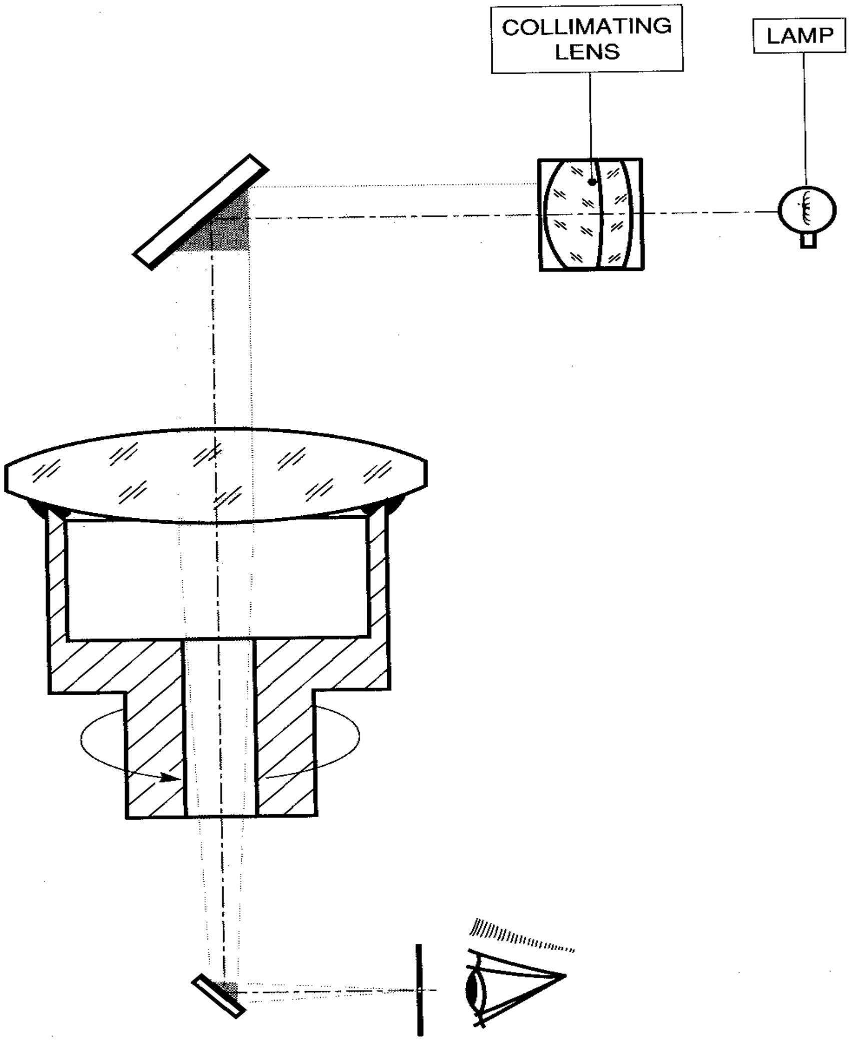


$$\delta = \frac{s}{f}$$

$$\text{Wedge } \alpha = \frac{\delta}{n-1} = \frac{s}{f\left(n-1\right)}$$

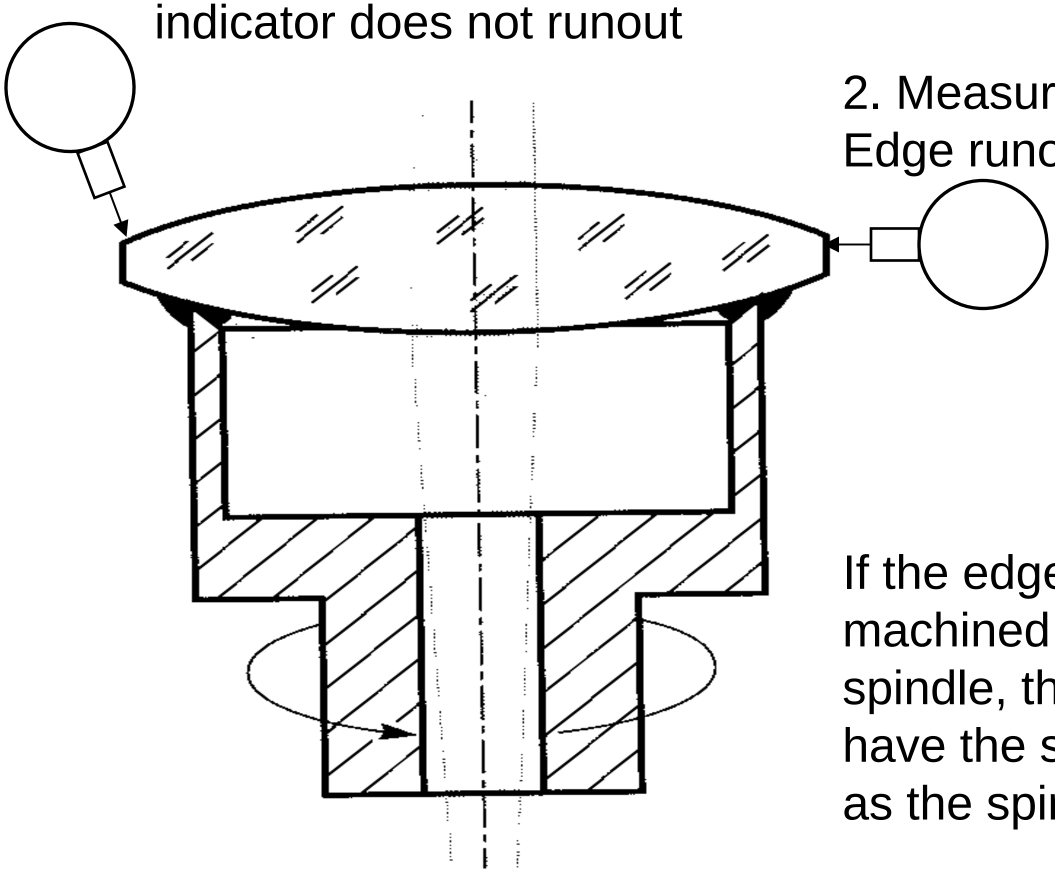
Centering a lens

1. Use optical measurement



Centering a lens

- Use mechanical measurement



1. Move lens until dial indicator does not runout

2. Measure Edge runout

If the edge is machined on this spindle, then it will have the same axis as the spindle.

Specification of lens tilt

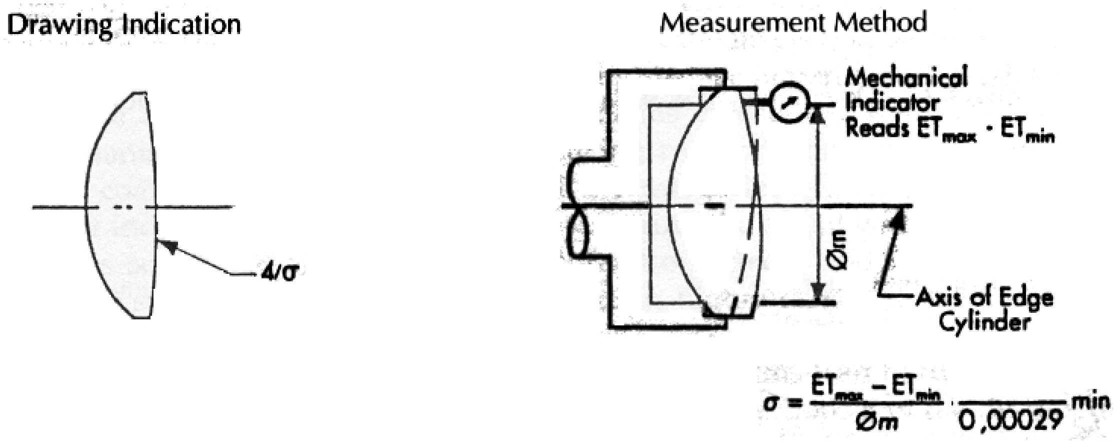


FIG. 6.4. Measurement of surface tilt using mechanical metrology.

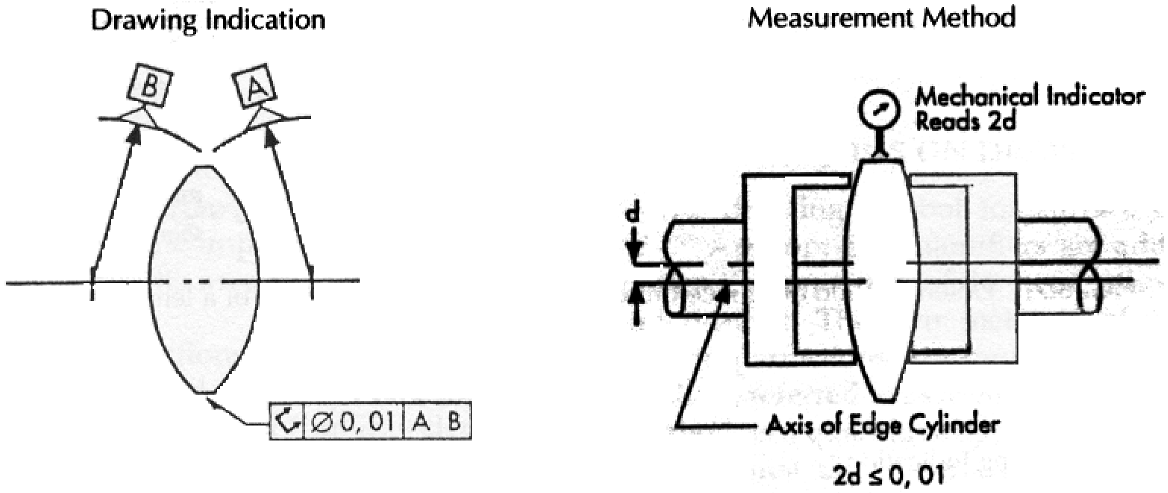
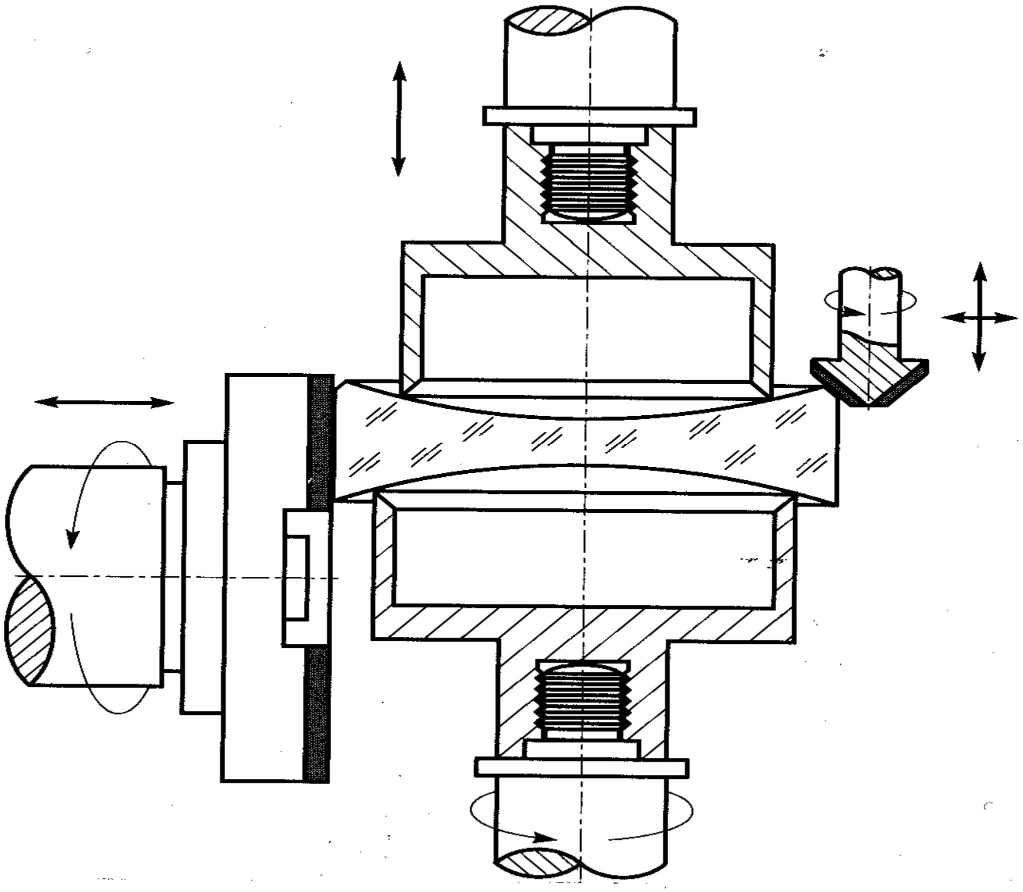


FIG. 6.5. Measurement of run-out of edge cylinder.

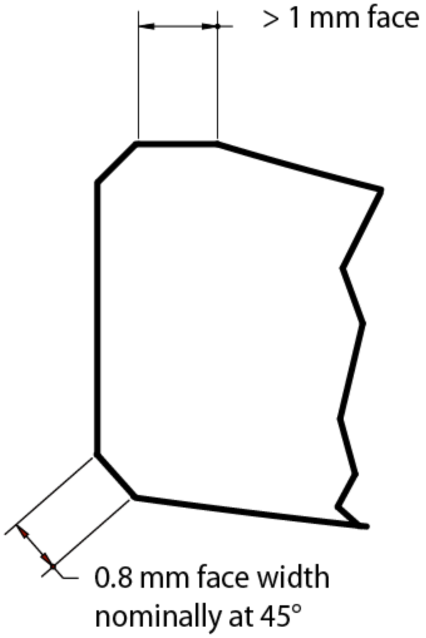
Automatic edging

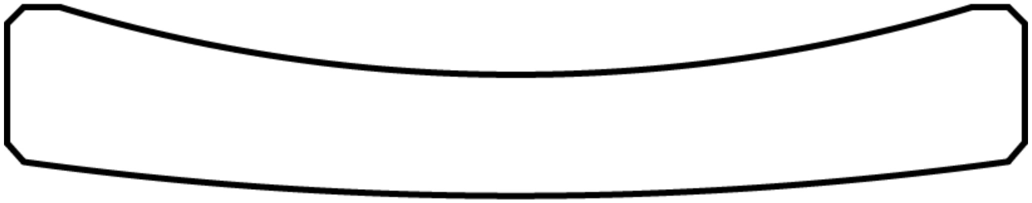
Clamped between two chucks with common axis,
then outer edge is ground concentric.



Edge bevels

- Glass corners are fragile. Always use a bevel unless the sharp corner is needed (like a roof). If so, protect it.





Rules of thumb for edge bevels

Nominally at 45°

Lens diameter	Nominal facewidth of bevel
25 mm	> 0.3 mm
50 mm	> 0.5 mm
150 mm	> 1 mm
400 mm	> 2 mm

Tolerancing of optical surfaces

- Radius of curvature
  - Tolerance on R (0.2% is typical)
  - Tolerance on sag (maybe 3 µm = 10 rings)

$$\Delta sag = -\frac{D^2}{8R^2}\Delta R$$

- Conic constant (or aspheric terms)
- Surface form irregularity (figure)
- Surface texture (finish)

} PSD = A/f ^{B}

- Surface imperfections (cosmetics, scratch/dig)
- Surface treatment and coating

Get nominal tolerances from fabricator

Tolerance for radius of curvature

Surface can be made spherical with the wrong radius.
Tolerance this several ways:

1. Tolerance on R (in mm or %)
2. Tolerance on focal length (combines surfaces and refractive index)
3. Tolerance on surface sag (in µm or rings)

$$sag \cong \frac{\left({D}/{2}\right)^2}{2R}$$

$$\Delta sag = -\frac{D^2}{8R^2}\Delta R$$

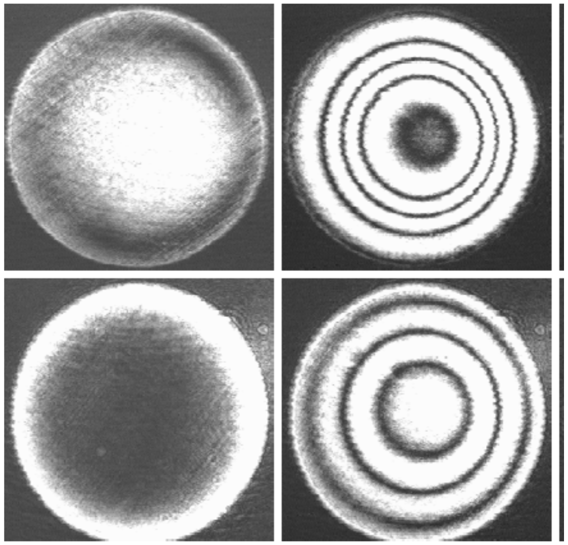
1 ring = λ/2 sag difference between part and test glass

Test plates

- Most optical surfaces are measured against a reference surface called a test plate
    - The radius tolerance typically applies to the test plate
    - The surface departure from this will then be specified
      i.e. 4 fringes (or rings) power, 1 fringe irregularity
- The optics shops maintain a large number of test plates. It is economical to use the available radii.
- Optical design programs have these radii in a data base to help make it easy to optimize the system design to use them. Your design can then use as-built radii.
- If you really need a new radius, it will cost ~$1000 and 2 – 3 weeks for new test plates. You may also need to relax the radius tolerance for the test plates.

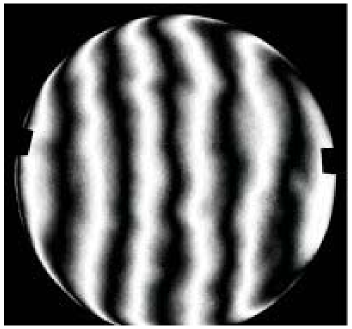
Test plate measurement

Power looks like rings

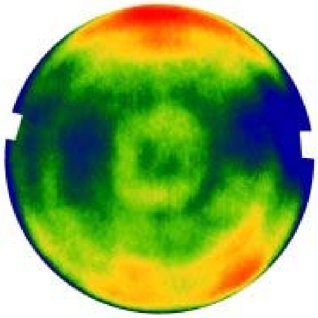


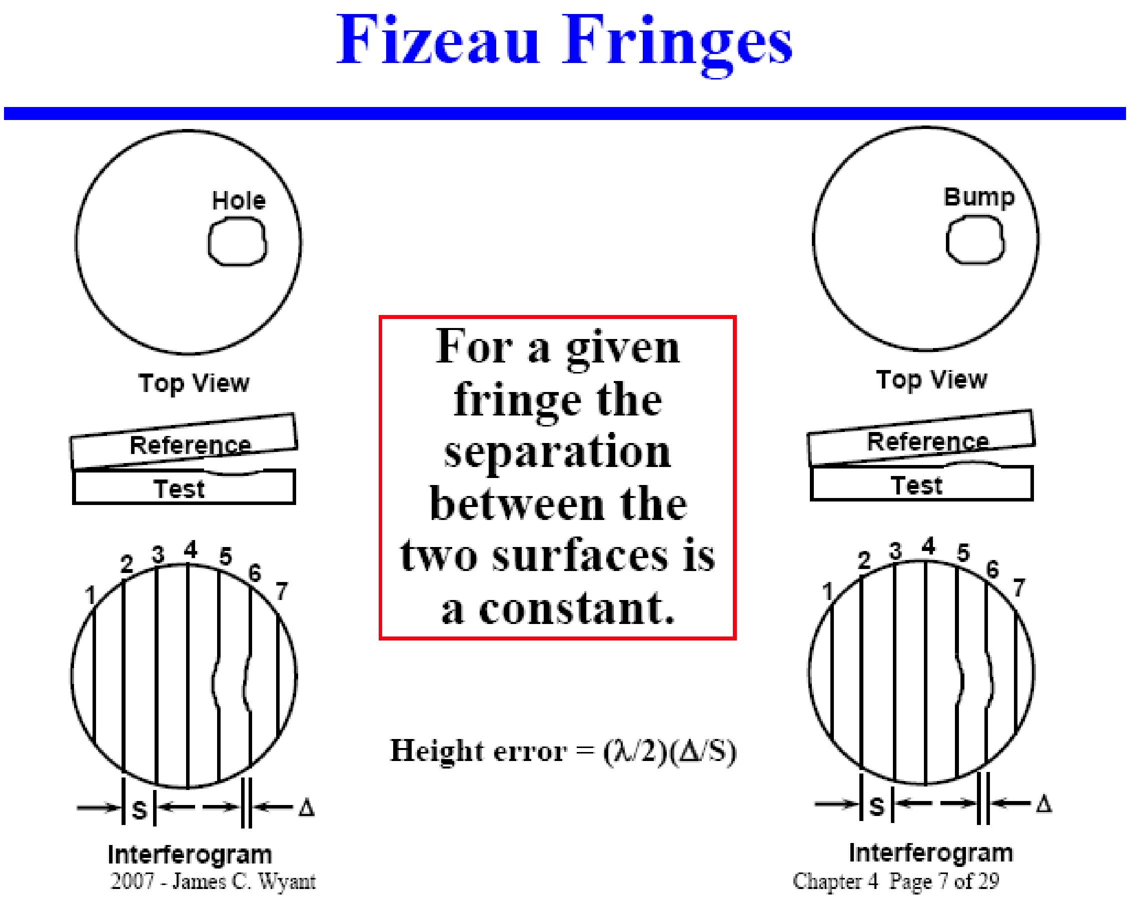
Irregularity

Interferogram



Phase map





Fizeau Fringes

For a given fringe the separation between the two surfaces is a constant.

Height error = (λ/2)(Δ/S)

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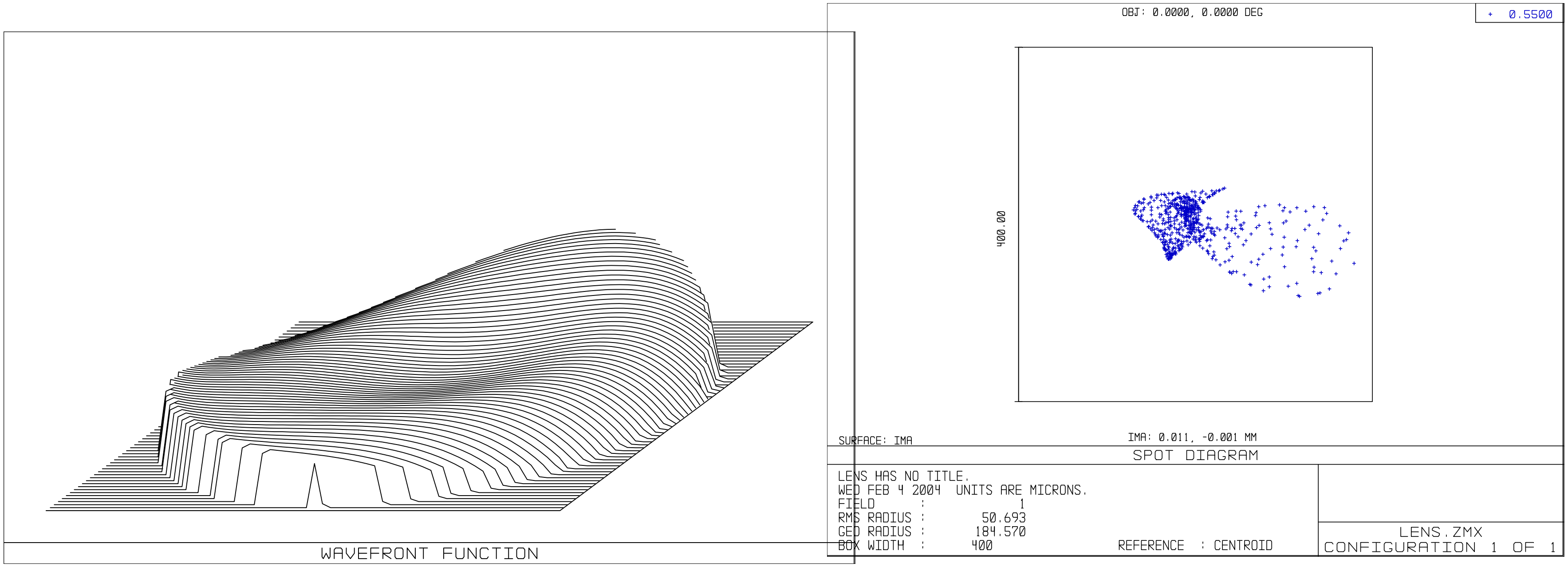
Surface figure specification

- Wavefront error = Surface error $\times(n-1)\cos\theta_{incident}$
- Specifications are based on measurement
  - Inspection with test plate.
    Typical spec: 0.5 fringe = $\lambda/4$ P-V surface
  - Measurement with phase shift interferometer.
    Typical spec: 0.05 λ rms
- For most diffraction limited systems, rms surface gives good figure of merit
- Special systems require Power Spectral Density spec
  PSF is of form A/f^B
- Geometric systems really need a slope spec, but this is uncommon. Typically, you assume the surface irregularities follow low order forms and simulate them using Zernike polynomials – rules of thumb to follow…

Wavefront error vs Image shape



For each ray:

$$\varepsilon_x = -\frac{\partial W}{\partial x} \cdot B_i F_n$$

$$\varepsilon_y = -\frac{\partial W}{\partial y} \cdot B_i F_n$$

ε_x, ε_y are errors in ray position at focal plane

W_i is wavefront error from surface i

$\frac{\partial W}{\partial x}, \frac{\partial W}{\partial y}$ are wavefront slope errors (dimensionless)

B_i is diameter of beam footprint from single field point
(< diameter of the element)

F_N is system focal ratio

Surface irregularity

For 1 µm P-V surface irregularity:

Surface Error	RMS surface error ΔS (µm)	Normalized RMS surface slope Θ_S (µm/radius)
Focus	0.29	1.43
Astigmatism	0.20	0.72
Coma	0.18	1.24
4th order spherical aberration	0.30	3.35
Trefoil	0.18	0.89
4th order astigmatism	0.16	1.58
5th order coma	0.14	2.04
6th order spherical aberration	0.19	3.50
Sinusoidal ripples, frequency of N cycles across the diameter	0.35	1.11 N
Rule of thumb for small spherical optics	**0.25**	1 for < 2” optics 2 for > 6” optics

Rules of thumb

Exact dependence is function
of the form of the error

Normalize slopes to µm/radius where the radius = half of the diameter.

Effect of surface irregularity – rms wavefront

ΔW, the wavefront error from surface error ΔS is

$$\Delta W = \Delta S(n-1)\cos(\phi)$$

Where n is the refractive index (use n = -1 for reflection)

ϕ is the angle of incidence

Define α_i = ratio of beam footprint from single field point to the diameter of optic = B/D

For spherical surfaces like lenses, wavefront errors for each field point will fall off roughly with α, so surface i would contribute a wavefront error of

$$\Delta W_i \approx \alpha_i \Delta S_i (n-1)\cos(\phi)$$

Effect on system wavefront due to surface irregularity from lenses

Using rules of thumb for 1 λ P-V glass surfaces,

λ = 0.5 µm, *n* = 1.5, cosϕ = 1:

evaluating

$$\Delta W_i \approx \alpha_i \Delta S_i (n-1)\cos(\phi)$$

Gives a wavefront contribution of **ΔW = 0.125α** waves rms per surface

For M lenses (2 surfaces per lens) with 1 wave P-V surfaces and average α of 0.7, the overall wavefront error will be roughly

$$\Delta W \approx 0.125 \times 0.7 \times \sqrt{2M}$$

$$\Delta W \approx \sqrt{M}/8$$

A lens with 4 elements will have wavefront errors of about 0.25 waves rms (~20% SR, NOT diffraction limited)

Effect of surface irregularity, rms spot size

1. Convert the normalized surface slope Θ to wavefront slope ∇W

$$\left(\nabla W\right)_{rms} \approx \Theta_{rms} \times (n-1)\cos(\phi) \div \frac{D}{2}$$

Surface slope (µm/radius)

Convert to wavefront

Convert slope to units of µm/mm by dividing by the lens radius

2. Relate rms wavefront slope to rms spot size (via Optical Invariant)

   $B_i = \alpha_i D_i$ = beam footprint from single field point

   F_n is system working focal ratio

$$\varepsilon_{rms} = \left(\nabla W\right)_{rms} B_i F_n$$

$$\varepsilon_{rms} = 2\Theta_{rms}(n-1)\cos(\phi)\alpha_i F_n$$

Where ε_{rms} gives the image degradation in terms of rms image radius.
D_i is the lens diameter, $B_i = \alpha_i D_i$ is the diameter of the beam from a single field point.

Effect on system spot size to surface irregularity from lenses

Using rules of thumb for 1 λ P-V glass surfaces for small lenses,
λ = 0.5 µm, n = 1.5, cosϕ = 1:

Θ_{rms}, rms surface slope error, is 1 waves/radius = 0.5 µm/radius rms

evaluating

$$\varepsilon_{rms} = 2\Theta_{rms}(n-1)\cos(\phi)\alpha_i F_n$$

$$\varepsilon_{rms} \approx \frac{\alpha F_n}{2} \quad (\mu m)$$

For M lenses (2 surfaces per lens) with 1 wave P-V surfaces and average α of 0.7, the overall wavefront error will be roughly

$$\varepsilon_{rms} \approx \frac{F_n \sqrt{M}}{2} \quad (\mu m)$$

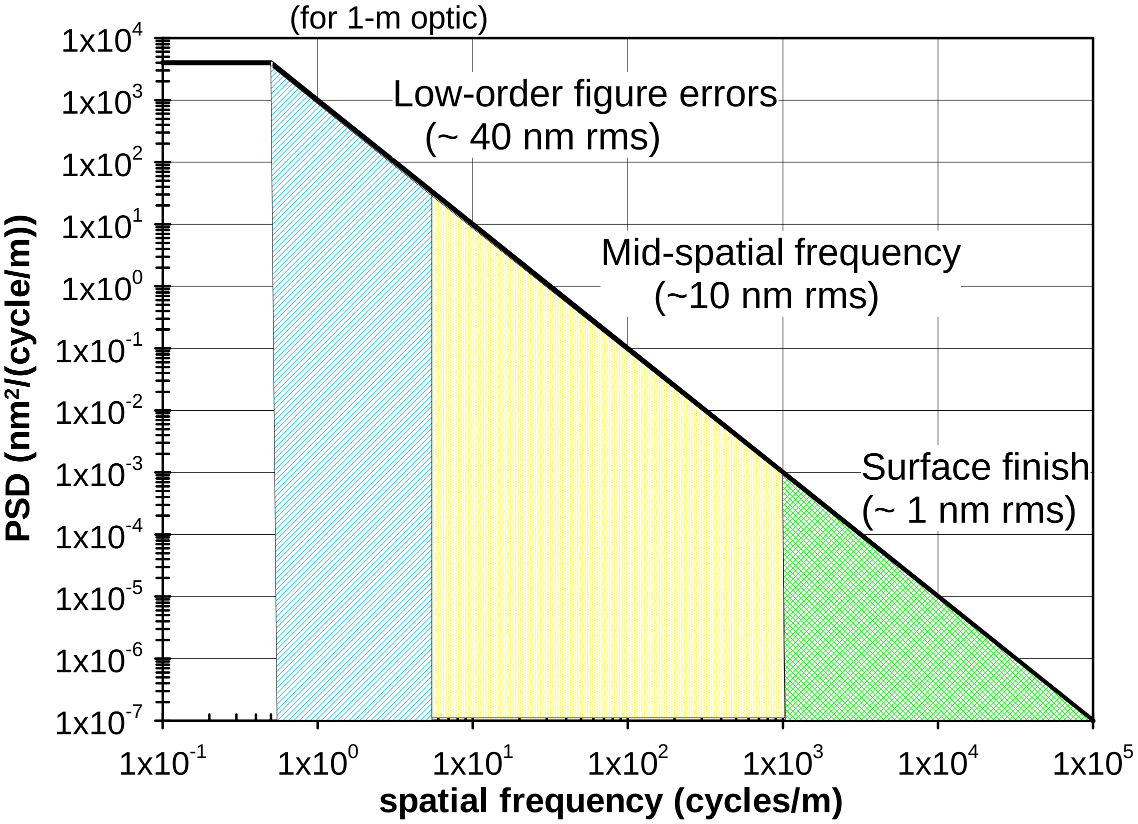
So the 1 λ P-V surfaces from an f/8 lens with 4 elements would cause 8 µm rms blur in the image. This is about 2 times larger than the effect of diffraction.

Power Spectral Density

High performance systems use PSD to specify allowable surface errors at all spatial frequencies

PSD typically shows mean square surface error as function of spatial frequency. Get rms in a band by integrated and taking the square root

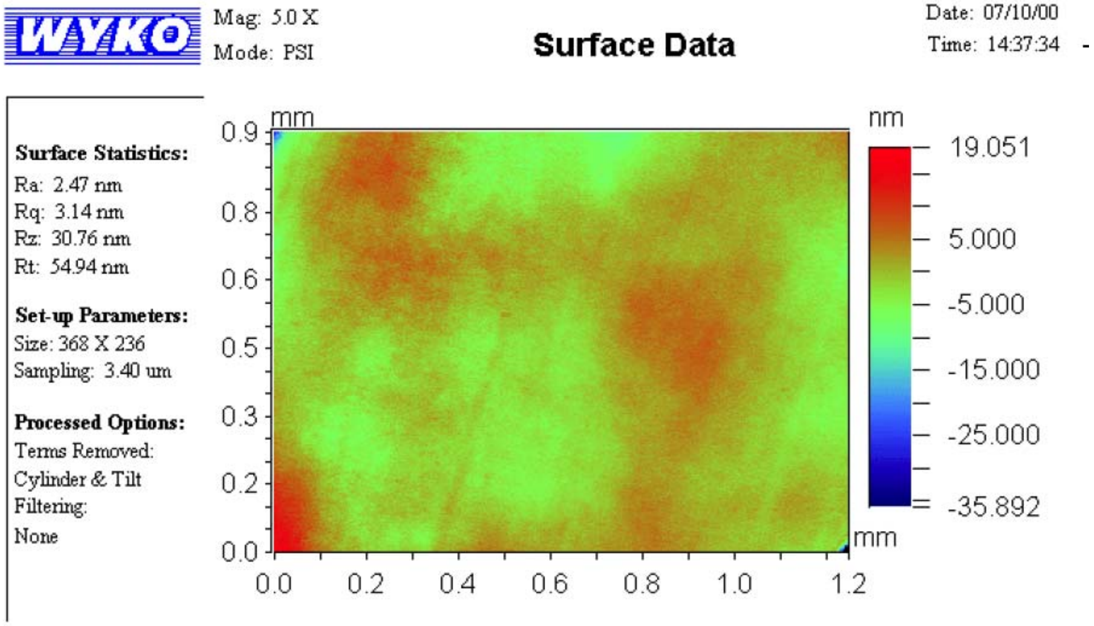
Typical from polishing: PSD = A * f^{-2} *(not valid for diamond turned optics)*



Surface roughness

- Small scale irregularity (sometimes called micro-roughness) in the surface, comes from the polishing process.
- Pitch polished glass, 20 Å rms is typical
- Causes wide angle scatter. Total scatter is σ^2, where σ is rms wavefront in radians.
- Example: for a 20 Å lens surface -> 10 Å wavefront, for 0.5 µm light, σ is 0.0126 rad. Each surface scatters 0.016% into a wide angle

Typical data for a pitch polished surface


Mag: 5.0 X
Mode: PSI

Surface Data

Date: 07/10/00
Time: 14:37:34

Surface Statistics:
Ra: 2.47 nm
Rq: 3.14 nm
Rz: 30.76 nm
Rt: 54.94 nm

Set-up Parameters:
Size: 368 X 236
Sampling: 3.40 um

Processed Options:
Terms Removed:
Cylinder & Tilt
Filtering:
None

Effect of small scale errors

Consider figure errors of ΔS nm rms with spatial period L

Convert to wavefront, and to radians

$$\Delta W = \Delta S(n-1)\cos(\phi)$$

$$\sigma = 2\pi\Delta W_{rms} = 2\pi\Delta S(n-1)\cos(\phi)$$

σ^2 of the energy is diffracted out of central core of point spread function

Diffraction angle θ is $\pm\lambda/L$ (where λ is wavelength)

<u>For L<<D</u>

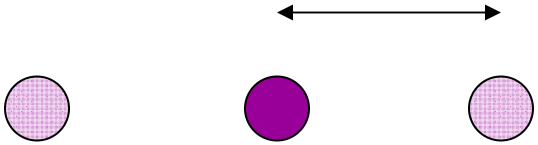
Optical Invariant analysis tells us that the effect in the image plane will be energy at

$$\varepsilon = \pm\theta\,(\alpha D_i)F_n$$

$$= \pm\frac{\lambda\alpha D_i F_n}{L}$$

αD_i is the beam diameter from a single field point on surface i under consideration

F_n is the system focal ratio



Each satellite image due to wavefront ripples has energy $\sigma^2/2$ of the main image

Surface Imperfections

Surface defects are always present at some level in optical surfaces. These consist of scratches, digs (little pits), sleeks (tiny scratches), edge chips, and coating blemishes. In most cases these defects are small and they do not affect system performance. Hence they are often called “beauty specifications”. They indicate the level of workmanship in the part and face it, nobody wants their expensive optics to looks like hell, even if appearance does not impact performance.

In most cases surface defects only cause a tiny loss in the system throughput and cause a slight increase in scattered light. In almost all cases, these effects do not matter. There are several cases that the surface imperfections are more important –

- **Surfaces at image planes**. The defects show up directly.
- **Surfaces that must see high power levels**. Defects here can absorb light and destroy the optic.
- **Systems that require extreme rejection of scattered light**, such as would be required to image dim objects next to bright sources.
- **Surfaces that must have extremely high reflectance**, like Fabry-Perot mirrors.

Scratch Dig spec

The specification of surface imperfections is complex. The most common spec is the scratch/dig specification from MIL-O-13830A. Few people actually understand this spec, but it has become somewhat of a standard for small optics in the United States. A related spec is MIL-C-48497 which was written for reflective optics, but in most cases, MIL-O-13830 is used.

Mil-O-13830A is technically obsolete and has been replaced by Mil-PRF-13830B.

A typical scratch/dig would be 60/40, which means the scratch designation is 60 and the dig designation is 40

The ISO 10110 standard makes more sense, but it has not yet been widely adopted in the US.

Scratch spec per Mil-O-13830A

Specification of surface defects per MIL-O-13830A Scratch/Dig

Scratch designation N : measured by comparing appearance with standard scratches under controlled lighting

Calculated as indicated --

For scratches designated as n_1, n_2 , ... length l_1, l_2, ...

Part diameter (or effective diameter) D

1. Combined length of scratches of type N must not exceed D/4
2. If a scratch designated N is present, sum(n_i * l_i)/D must be not exceed N/2
3. If no scratch designated N is present, sum(n_i * l_i)/D must be not exceed N

Example:

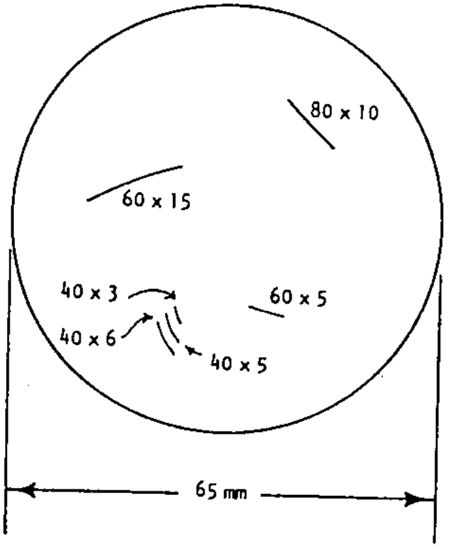


Figure 9. Interpretation of paragraphs 3.5.2.1 and 3.5.2.1.1 of MIL-O-13830A. Surface specified as 80-50.

80 x 10/65 = 12.3
60 x 15/65 = 13.8
60 x 5/65 = 4.6
40 x 14/65 = 8.6
39.3

Less than ½ of 80.
Lens meets specification

(from Parks 1980.)

Dig spec per Mil-O-13830A / Mil-PRF-13830B

A dig is a small pit in the surface. Originates from defect in the material or from the grinding process.

Dig designation M = actual diameters in µm / 10

1. Number of maximum digs shall be one per each 20 mm diameter on the optical surface.

2. The sum of the diameters of all digs shall not exceed 2*M (Digs less than 2.5 µm are ignored).

3. For surfaces whose dig quality is 10 or less, digs must be separated by at least 1 mm.

Rules of thumb for lenses

Optical element tolerances

Parameter	**Base**	**Precision**	**High precision**
Lens diameter	100 µm	25 µm	6 µm
Lens thickness	200 µm	50 µm	10 µm
Radius of curvature Surface sag Value of R	 20 µm 1%	 1.3 µm 0.1%	 0.5 µm 0.02%
Wedge (light deviation)	6 arc min	1 arc min	15 arc sec
Surface irregularity	1 wave	λ/4	λ/20
Surface finish	50 Å rms	20 Å rms	5 Å rms
Scratch/dig	80/50	60/40	20/10
Dimension tolerances for complex elements	200 µm	50 µm	10 µm
Angular tolerances for complex elements	6 arc min	1 arc min	15 arc sec
Bevels (0.2 to 0.5 mm typical)	0.2 mm	0.1 mm	0.02 mm

Base: Typical, no cost impact for reducing tolerances beyond this.

Precision: Requires special attention, but easily achievable in most shops, may cost 25% more

High precision: Requires special equipment or personnel, may cost 100% more

Tolerancing for optical materials

- Refractive index value
- Dispersion
- Refractive index inhomogeneity
- Straie
- Stress birefringence
- Bubbles, inclusions

Get nominal tolerances from glass catalogs

Some glasses and sizes come in limited grades.

Refractive index tolerance

- The actual glass will depart from the design value by some amount. Use melt sheet from the actual batch of glass for improved accuracy.
- The effect of refractive index errors is determined by perturbation analysis.
- From Schott:

Tolerances of Optical Properties consist of deviations of refractive index for a melt from values stated in the catalog. Normal tolerance is ±0.001 for most glass types. Glasses with n_d greater than 1.83 may vary by as much as ±0.002 from catalog values. Tolerances for n_d are ±0.0002 for Grade 1, ±0.0003 for Grade 2 and ±0.0005 for Grade 3.

The dispersion of a melt may vary from catalog values by ±0.8%. Tolerances for v_d are ±0.2% for Grade 1, ±0.3% for Grade 2 and ±0.5% for Grade 3.

Internal glass variations

Striae are thread-like veins or cords which are visual indications of abruptly varying density. Striae can also be considered to be a lack of homogeneity caused by incomplete stirring of the molten glass. Some glasses contain components that evaporate during melting, causing layers of varying density, and therefore parallel striae appear.
Grade AA (P) is classified as “precision striae” and has no visible striae. Grade A only has striae that are light and scattered when viewed in the direction of maximum visibility. Grade B has only striae that are light when viewed in direction of maximum visibility and parallel to the face of the plate.

Birefringence is the amount of residual stress in the glass and depends on annealing conditions, type of glass, and dimensions. The birefringence is stated as nm/cm difference in optical path measured at a distance from the edge equaling 5% of the diameter or width of the blank. Normal quality is defined as (except for diameters larger than 600mm and thicker than 100mm):

i. Standard is less than or equal to 10 nm/cm
ii. Special Annealing (NSK) or Precision Annealing is less than or equal to 6 nm/cm
iii. Special Annealing (NSSK) or Precision Quality after Special Annealing (PSSK) is less than or equal to 4 nm/cm.

Homogeneity is the degree to which refractive index varies within a piece of glass. The smaller the variation, the better the homogeneity. Each block of glass is tested for homogeneity grade.

Normal Grade	$\pm 1 \times 10^{-4}$
H1 Grade	$\pm 2 \times 10^{-5}$
H2 Grade	$\pm 5 \times 10^{-6}$
H3 Grade	$\pm 2 \times 10^{-6}$
H4 Grade	$\pm 1 \times 10^{-6}$

Effects of index variations

- Straie are small scale. Small amounts of straie have similar effects as cosmetic surface errors
- Beware, unselected glass can have large amounts of straie
- Refractive index inhomogeneity happens on a larger scale. The wavefront errors from an optic with thickness t and index variation Δn are

$$\Delta W = t * \Delta n$$

- Use the same rules of thumb for surfaces to get rms and slopes.

Example: A 25-mm cube beamsplitter made from H1 quality glass.
Δn = ±2E-5, (4E-5 P-V, 1E-5 or 10 ppm rms).
ΔW = (25-mm)*(10 ppm rms) = 250 nm rms, this is
$\lambda/2$ rms for 500 nm wavelength.

Effects of birefringence

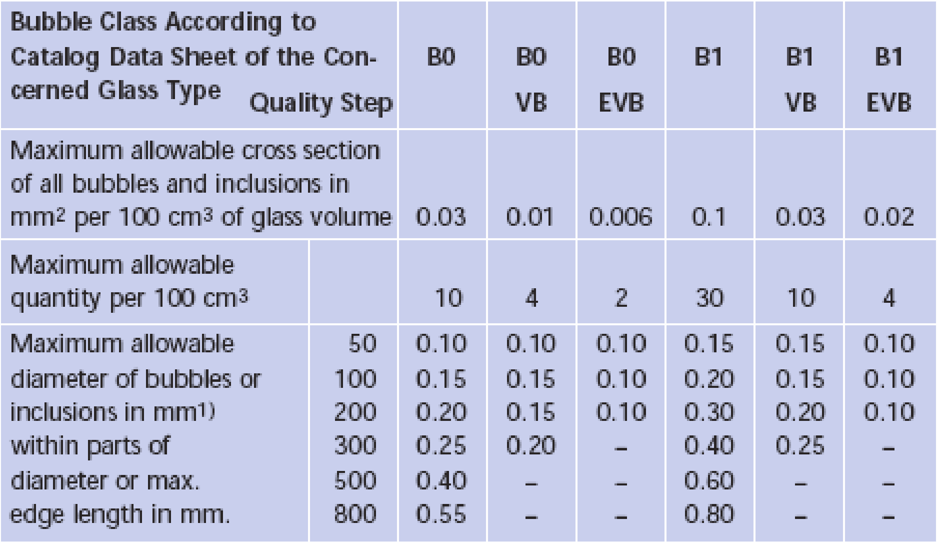
- Birefringence is a result of internal stress in the glass. This is minimized by fine annealing (slow cooling).
- Birefringence is observed in polarized light
- Large amounts of birefringence indicate large stress, which may cause the part to break
- The retardance due to the birefingence can be estimated as

  Retardance = birefringence * thickness/ wavelength

So the 25 mm cube beamsplitter with 10 nm/cm birefringence will cause 25 nm or about lambda/20 retardance

Bubbles and inclusions

The characterization of the bubble content of a glass is done by reporting the total cross section in mm^2 of a glass volume of 100 cm^3, calculated from the sum of the detected cross section of bubbles. Inclusions in glass, such as stones or crystals are treated like bubbles of the same cross section. The evaluation considers all bubbles and inclusions > 0.03 mm.



Bubble Class According to Catalog Data Sheet of the Concerned Glass Type **Quality Step**		**B0**	**B0 VB**	**B0 EVB**	**B1**	**B1 VB**	**B1 EVB**
Maximum allowable cross section of all bubbles and inclusions in mm^2 per 100 cm^3 of glass volume		0.03	0.01	0.006	0.1	0.03	0.02
Maximum allowable quantity per 100 cm^3		10	4	2	30	10	4
Maximum allowable diameter of bubbles or inclusions in mm$^{1)}$ within parts of diameter or max. edge length in mm.	50	0.10	0.10	0.10	0.15	0.15	0.10
	100	0.15	0.15	0.10	0.20	0.15	0.10
	200	0.20	0.15	0.10	0.30	0.20	0.10
	300	0.25	0.20	–	0.40	0.25	–
	500	0.40	–	–	0.60	–	–
	800	0.55	–	–	0.80	–	–

Bubbles have effects similar to surface digs. Usually they are not important.

(Ref. Schott catalog)

Rules of Thumb for glass properties

Parameter	**Base**	**Precision**	**High precision**
Refractive index departure from nominal	± 0.001 (Standard)	±0.0005 (Grade 3)	±0.0002 (Grade 1)
Refractive index measurement	± 3 x 10^{-5} (Standard)	±1 x 10^{-5} (Precision)	±0.5 x 10^{-5} (Extra Precision)
Dispersion departure from nominal	± 0.8% (Standard)	± 0.5% (Grade 3)	±0.2%% (Grade 1)
Refractive index homogeneity	± 1 x 10^{-4} (Standard)	± 5 x 10^{-6} (H2)	± 1 x 10^{-6} (H4)
Stress birefringence (depends strongly on glass)	20 nm/cm	10 nm/cm	4 nm/cm
Bubbles/inclusions (>50 µm) (Area of bubbles per 100 cm^3)	0.5 mm^2 (class B3)	0.1 mm^2 (class B1)	0.029 mm^2 (class B0)
Striae Based on shadow graph test	Normal quality (has fine striae)	Grade A (small striae in one direction)	Precision quality (no detectable striae)

(Ref. Schott catalog)

Chemical resistance of optical glasses

From Schott Glass:

Climate resistance (CR) is a test that evaluates the material's resistance to water vapor. Glasses are rated and segregated into classes, CR 1 to CR 4. The higher the class, the more likely the material will be affected by high relative humidity. In general, all optically polished surfaces should be properly protected before storing. Class 4 glasses should be processed and handled with extra care.

Resistance to acid (SR) is a test that measures the time taken to dissolve a 0.1µm layer in an aggressive acidic solution. Classes range from SR 1 to SR 53. Glasses of classes SR 51 to SR 53 are especially susceptible to staining during processing and require special consideration.

Resistance to alkali (AR) is similar to resistance to acid because it also measures the time taken to dissolve a 0.1µm layer, in this case, in an aggressive alkaline solution. Classes range from SR 1 to SR 4 with SR 4 being most susceptible to stain from exposure to alkalis. This is of particular interest to the optician because most grinding and polishing solutions become increasingly alkaline due to the chemical reaction between the water and the abraded glass particle. For this reason most optical shops monitor the pH of their slurries and adjust them to neutral as needed.

Resistance to staining (FR) is a test that measures the stain resistance to slightly acidic water. The classes range from FR 0 to FR 5 with the higher classes being less resistant. The resultant stain from this type of exposure is a bluish-brown discoloration of the polished surface. FR 5 class lenses need to be processed with particular care since the stain will form in less than 12 minutes of exposure. Hence, any perspiration or acid condensation must be removed from the polished surface immediately to avoid staining. The surface should be protected from the environment during processing and storage.

Conventions, standards,…

- There now exists international standards for specifying optical components. ISO-10110.
- The ISO standards provide a shortcut for simplifying drawings. When they are used correctly, they allow technical communication across cultures and languages
- Use *ISO 10110 --- Optics and Optical Instruments Preparation of drawings for optical elements and systems, A User's Guide 2nd Edition,* by Kimmel and Parks. Available from OSA.
- The ISO standards are not widely used in the US, and will not be emphasized in this class.

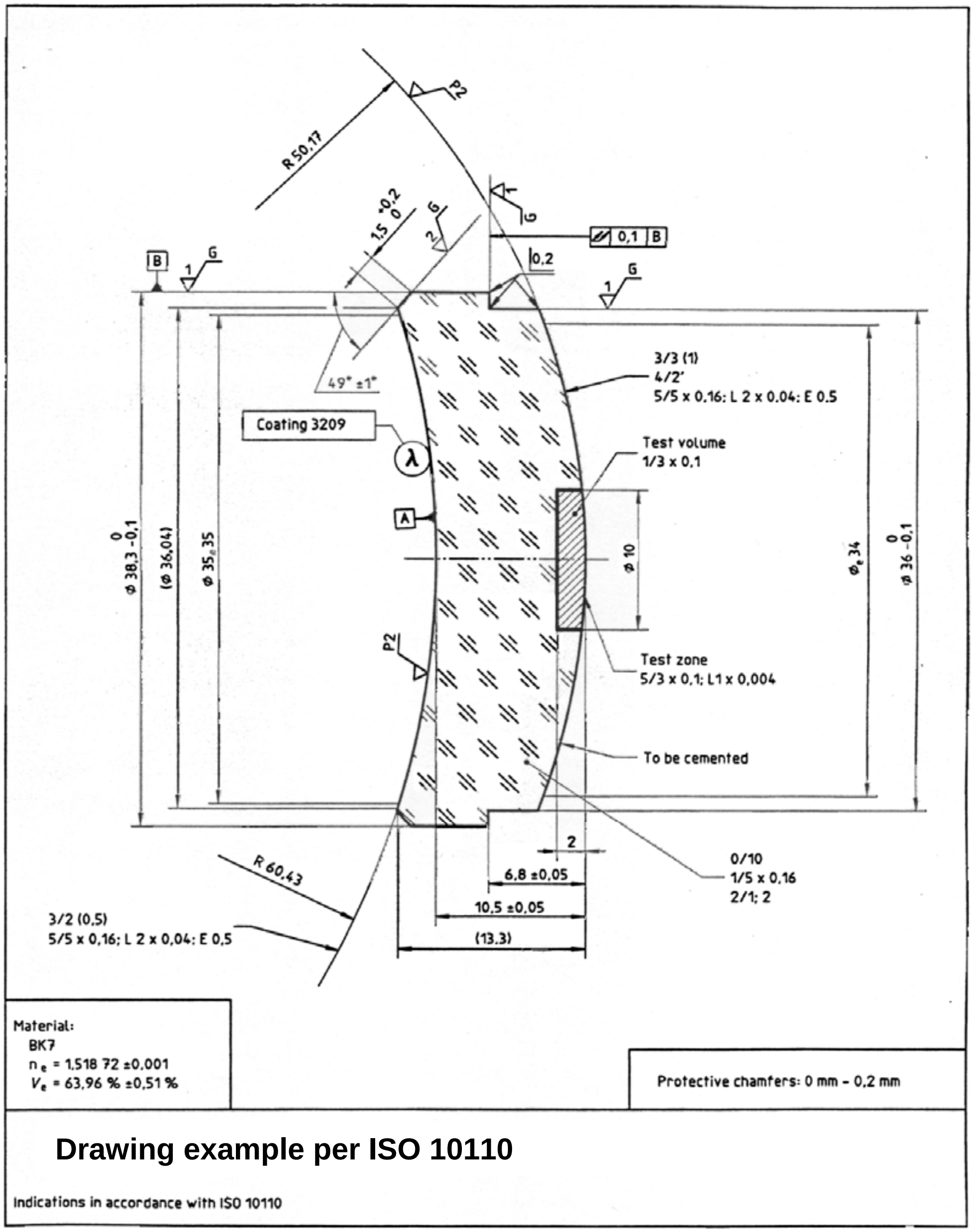
ISO 10110 --- Optics and Optical Instruments
Preparation of drawings for optical elements and systems

- 13 part standard
  - 1. General
  - 2. Material imperfections -- Stress birefringence
  - 3. Material imperfections -- Bubbles and inclusions
  - 4. Material imperfections -- Inhomogeneity and striae
  - 5. Surface form tolerances
  - 6. Centring tolerances
  - 7. Surface imperfection tolerances
  - 8. Surface texture
  - 9. Surface treatment and coating
  - 10. Tabular form
  - 11. Non-toleranced data
  - 12. Aspheric surfaces
  - 13. Laser irradiation damage threshold
- available from ANSI 212-642-4900
- Better yet, User's Guide is available from OSA

ISO 10110 --- Optics and Optical Instruments
Preparation of drawings for optical elements and systems

- <u>Codes for tolerancing</u>

0/A	Birefringence, A is max nm/cm OPD allowed
1/N x A	Bubbles and inclusions, allowing N bubbles with area A
2/A;B	Inhomogeneity class A, straie class B
3/A(B/C)	sagitta error A, P-V irregularity B, zonal errors C (all in fringes)
4/σ	σ is wedge angle in arc minutes
5/N x A	Surface imperfections, N imperfections of size A
CN x A	Coating imperfections, N imperfections of size A
LN x A	Long scratches, N scratches of width A µm
EA	Edge chips allowed to protrude distance A from edge
5/TV	Transmissive test, achieving visibility class V
5/RV	Reflective test, achieving visibility class V
6/H	Laser irradiation energy density threshold H



Drawing example per ISO 10110

Standards

General, physical dimensions

ISO-10110-1 Optics and optical instruments – Preparation of drawings for optical elements and systems – Part 1: General

ISO-10110-6 Optics and optical instruments – Preparation of drawings for optical elements and systems – Part 6: Centring tolerances

ISO-10110-10 Optics and optical instruments – Preparation of drawings for optical elements and systems – Part 10: Tabular form

ANSI Y14.5M Dimensioning and tolerancing

ISO 7944 Reference wavelength

ISO 128 Technical drawings – General principles of presentation

ISO 406, Technical drawings – Tolerancing of linear and angular dimensions

ISO 1101, Technical drawings – Geometrical tolerancing – form, orientation, run-out

ISO 5459, Technical drawings – Geometrical tolerancing – datums and datum systems

ISO 8015, Technical drawings – Geometrical tolerancing – fundamental tolerancing principle for linear and angular tolerances

DIN 3140 Optical components, drawing representation figuration, inscription, and material. German standard, basis of ISO 10110

MIL-STD-34 Preparation of drawings for optical elements and systems: General requirements, *obsolete*

ANSI Y14.18M Optical parts

Optical surfaces

ISO-10110-5 Optics and optical instruments – Preparation of drawings for optical elements and systems – Part 5: Surface form tolerances

ISO-10110-7 Optics and optical instruments – Preparation of drawings for optical elements and systems – Part 7: Surface imperfection tolerances

ISO-10110-8 Optics and optical instruments – Preparation of drawings for optical elements and systems – Part 8: Surface texture

ISO-10110-12 Optics and optical instruments – Preparation of drawings for optical elements and systems – Part 12: Aspheric surfaces

MIL-HDBK-141

MIL-STD-1241 Optical terms and definitions

Mil-O-13830A, Optical components for fire control instruments; General specification governing the manufacture, assembly, and inspection of.

ANSI PH3.617, Definitions, methods of testing, and specifications for appearance imperfections of optical elements and assemblies

ISO 4287 Surface roughness – Terminology

ISO 1302 Technical drawings – Method of indicating surface texture on drawings

ANSI Y14.36 Engineering drawing and related documentation practices, surface texture symbols

More Standards

Material imperfections

ISO-10110-2 Optics and optical instruments – Preparation of drawings for optical elements and systems – Part 2: Material imperfections – stress birefringence

ISO-10110-3 Optics and optical instruments – Preparation of drawings for optical elements and systems – Part 3: Material imperfections – bubbles and inclusions

ISO-10110-4 Optics and optical instruments – Preparation of drawings for optical elements and systems – Part 4: Material imperfections – inhomogeneity and striae

MIL-G-174 Military specification – Optical glass

Coatings

ISO-10110-9 Optics and optical instruments – Preparation of drawings for optical elements and systems – Part 9: Surface treatment and coating
ISO 9211-1, Optics and optical instruments – Optical coatings – Part 1: Definitions
ISO 9211-2, Optics and optical instruments – Optical coatings – Part 2: Optical properties
ISO 9211-3, Optics and optical instruments – Optical coatings – Part 3: Environmental durability
ISO 9211-4, Optics and optical instruments – Optical coatings – Part 4: Specific test methods
MIL-C-675 Coating of glass optical elements
MIL-M-13508 Mirror, front surface aluminized: for optical elements
MIL-C-14806 Coating, reflection reducing, for instrument cover glasses and lighting wedges
MIL-C-48497 Coating, single or multilayer, interference, durability requirements for
MIL-F-48616 Filter (coatings), infrared interference: general specification for

Even more standards

Measurement, inspection, and test

ISO 9022: Environmental test methods

ISO 9039: Determination of distortion

ISO 9211-4, Optics and optical instruments – Optical coatings – Part 4: Specific test methods

ISO 9335: OTF measurement principles and procedures

ISO 9336: OTF, camera, copier lenses, and telescopes

ISO 11455: OTF measurement accuracy

ISO 9358: Veiling glare, definition and measurement

ISO 9802: Raw optical glass, vocabulary

ISO 11455: Birefringence determination

ISO 12123: Bubbles, inclusions; test methods and classification

ISO 10109: Environmental test requirements

ISO 10934: Microscopes, terms

ISO 10935: Microscopes, interface connections

ISO 10936: Microscopes, operation

ISO 10937: Microscopes, eyepiece interfaces

ASTM F 529-80 Standard test method for interpretation of interferograms of nominally plane wavefronts

ASTM F 663-80 Standard practice for manual analysis of interferometric data by least-squares fitting to a plane reference surface

ASTM F 664-80 Standard practice for manual analysis of interferometric data by least-squares fitting to a spherical reference surface and for computer-aided analysis of interferometric data.

ASTM F 742-81 Standard practice for evaluating an interferometer

MIL-STD-810 Environmental test methods

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- Schott Glass
- Ohara Glass Catalog
- Hoya Glass Catalog