# Optical specifications

Optics can be found virtually everywhere, from fiber optic couplings to machine vision imaging devices to cutting-edge biometric iris identification systems. Despite the many applications that depend on optics, most of our customers are not optical engineers. As a result, they require aid in specifying the correct optical components for the mechanical, electrical, and various other existing applications.

After a design is successfully completed, we can determine the characteristics of each optical surface in the system and tolerance them according to manufacturing capabilities. This is done with an emphasis on the value and uniformity of the shape, as well as on the cosmetics of each surface. The maximum allowable deviation of an optical surface from a perfect surface is described by Surface Accuracy. There are several terms associated with Accuracy, as follows:

## (1) Surface Quality

Cosmetic surface quality describes the level of defects that can be visually noted on the surface of an optical component. Specifically, it defines state of polish, freedom from scratches and digs, and edge treatment of components. These factors are important, not only because they affect the appearance of the component, but also because they scatter light, which adversely affects performance. Scattering can be particularly important in laser applications because of the intensity of the incident illumination. Unwanted diffraction patterns caused by scratches can lead to degraded system performance, and scattering of high-energy laser radiation can cause component damage. Over specifying cosmetic surface quality, on the other hand, can be costly. The most common and widely accepted convention for specifying surface quality is the U.S. Military Surface Quality Specification, MIL-0-13830A, Amendment 3.

As stated above, all optics in this catalog are referenced to MIL-0-13830A standards. These standards include scratches, digs, grayness, edge chips, and cemented interfaces. It is important to note that inspection of polished optical surfaces for scratches is accomplished by visual comparison to scratch standards. Thus, it is not the actual width of the scratch that is ascertained, but the appearance of the scratch as compared to these standards. A part is rejected if any scratches exceed the maximum size allowed. Digs, on the other hand, specified by actual defect size, can be measured quantitatively. Because of the subjective nature of this examination, it is critical to use trained inspectors who operate under standardized conditions in order to achieve consistent results.

The scratch-and-dig designation for a component or assembly is specified by two numbers. The first defines allowable maximum scratch visibility, and the second refers to allowable maximum dig diameter, separated by a hyphen; for example, 80–50 represents a commonly acceptable cosmetic standard. 60–40 represents an acceptable standard for most scientific research and commercial applications. 10–5 represents a precise standard for very demanding laser applications.

### (2) Scratches:

A scratch is defined as any marking or tearing of a polished optical surface. In principle, scratch numbers refer to the width of the reference scratch in ten thousandths of a millimeter. For example, an 80 scratch is equivalent to an 8-μm standard scratch. However, this equivalence is determined strictly by visual comparison, and the appearance of a scratch can depend upon the component material and the presence of any coatings. Therefore, a scratch on the test optic that appears equivalent to the 80 standard scratch is not necessarily 8 μm wide. If maximum visibility scratches are present (e.g., several 60 scratches on a 60–40 lens), their combined lengths cannot exceed half of the part diameter. Even with some maximum visibility scratches present, MIL-0-13830A still allows many combinations of smaller scratch sizes and lengths on the polished surface.

### (3) Digs:

A dig is a pit or small crater on the polished optical surface. Digs are defined by their diameters, which are the actual sizes of the digs in hundredths of a millimeter. The diameter of an irregularly shaped dig is 1/2#(length plus width): 50 dig = 0.5mm in diameter 40 dig = 0.4mm in diameter 30 dig = 0.3mm in diameter 20 dig = 0.2mm in diameter 10 dig = 0.1mm in diameter. The permissible number of maximum-size digs shall be one per each 20mm of diameter (or fraction thereof) on any single surface. The sum of the diameters of all digs, as estimated by the inspector, shall not exceed twice the diameter of the maximum size specified per any 20-mm diameter. Digs less than 25 micrometers are ignored.

### (4) Edge Chips:

Lens edge chips are allowed only outside the clear aperture of the lens. The clear aperture is 90% of the lens diameter unless otherwise specified. Chips smaller than 0.5mm are ignored, and those larger than 0.5mm are ground so that there is no shine to the chip. The sum of the widths of chips larger than 0.5mm cannot exceed 30% of the lens perimeter. Prism edge chips outside the clear aperture are allowed. If the prism leg dimension is 25.4mm or less, chips may extend inward 1.0mm from the edge. If the leg dimension is larger than 25.4mm , chips may extend inward 2.0mm from the edge. Chips smaller than 0.5mm are ignored, and those larger than 0.5mm must be stoned or ground, leaving no shine to the chip. The sum of the widths of chips larger than 0.5mm cannot exceed 30% of the length of the edge on which they occur.

### (5) Cemented Interfaes:

Because a cemented interface is considered a lens surface, specified surface quality standards apply. Edge separation at a cemented interface cannot extend into the element more than half the distance to the element clear aperture up to a maximum of 1.0mm . The sum of edge separations deeper than 0.5mm cannot exceed 10% of the element perimeter.

### (6) Bevels:

Although bevels are not specified in MIL-0-13830A, our standard shop practice specifies that element edges are beveled to a face width of 0.25 to 0.5mm at an angle of 45°±15°. Edges meeting at angles of 135° or larger are not beveled.

Bevels are clean ground edges used to prevent edge chips or simply as protective chamfers. Our bevels are defined as maximum face widths at 45°, with a standard tolerance of ±15°. For micro optics, we do not bevel the edges (since the attempt will likely cause chips). Also, we do not bevel the edges for small radii meeting the diameter edge at large angles. If the diameter = (0.85 x radius of curvature), then no bevel is used. The actual clear aperture (CA) value used will typically be smaller than that defined by the bevels with a maximum possible CA calculated as follows:

$$\mathrm{CA} = \mathrm{Dia.} - 2\sqrt{\mathrm{bevel}^2/2}$$

### (7) Coating Defects:

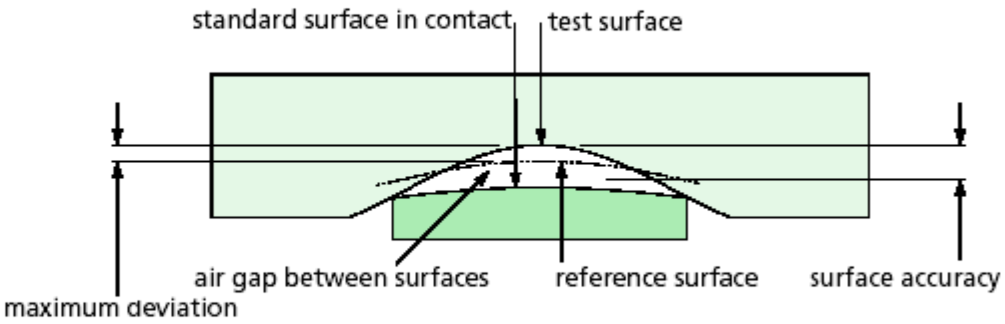
Defects caused by an optical element coating, such as scratches, voids, pinholes, dust, or stains, are considered with the scratch and-dig specification for that element. Coating defects are allowed if their size is within the stated scratch-and-dig tolerance. Coating defects are counted separately form substrate defects.

### (8) Surface Flatness:

Surface Flatness is the deviation for a plano surface such as a window or mirror. When a test plate (typically an optical flat, as shown below) is held in contact with the work piece (the part under inspection), a contour map is visible as light and dark bands. These dark bands are called Newton's rings or fringes. Due to the air gap between the surfaces, each ring corresponds to the vertical distance between the test plate and the surface under inspection. Since the test plate in this case is a clear, flat reference, the air gap is very small so the surface flatness is defined in terms of wavelength (very small unit of measure); i.e. 1/4 wave or λ/4. The spacing between rings is equal to one-half the wavelength of the illumination source; i.e. 1/4 wave = 1/2 ring. A monochromatic green light at the 546.1 nm mercury line or helium-neon red laser line at 632.8 nm is used for illumination. Typically, only values less than 1/4 wave are considered to be precision and values less than λ/10 to be high precision.

### (9) Surface Accuracy:

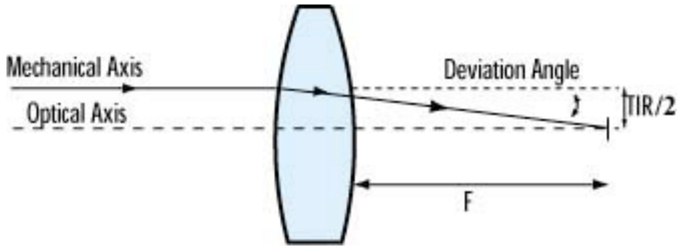
When attempting to specify how closely an optical surface conforms to its intended shape, a measure of surface accuracy is needed. Surface accuracy can be determined by interferometric techniques. Traditional techniques involve comparing the actual surface to a the test plate gage. In this approach, surface accuracy is measured by counting the number of rings or fringes and examining the regularity of the fringe. The accuracy of the fit between the lens and the test gage (as shown below) is described by the number of fringes seen when the gage is in contact with the lens. Test plates are made flat or spherical to within small fractions of a fringe. Modern techniques for measuring surface accuracy utilize phase measuring interferometry with advanced computer data analysis software. During manufacture, a precision component is frequently compared with a test plate that has an accurate polished surface that is the inverse of the surface under test. When the two surfaces are brought together and viewed in nearly monochromatic light, Newton's rings (interference fringes caused by the near-surface). The number of rings indicates the difference in radius between the surfaces. This is known as power or sometimes as figure. It is measured in rings that are equivalent to half wavelengths. Beyond their number, the rings may exhibit distortion that indicates non-uniform shape differences. The distortion may be local to one small area, or it may be in the form of noncircular fringes over the whole aperture. All such non-uniformities are known collectively as irregularity.



**(10) Centration:**

Centration is defined as the maximum allowable deviation between the optical and mechanical axes for a spherical lens. The optical axis is defined as the line connecting the centers of curvatures of both lens surfaces (as shown below). The mechanical axis is the centerline of the outer cylindrical edge of the lens or simply its geometrical axis. The mechanical axis coincides with the rotating axis of the centering machine that edges the lens to its final diameter. This centering process also, in turn, defines the diameter tolerance, which is typically +0, given mounting considerations.

If a ray of light is coincident with the mechanical axis, then a lens will deviate the ray so that it passes the optical axis at the focal plane (as shown below). The separation of the two axes at the focal plane is then defined as the decentration, or axial displacement centering error. The centering accuracy value used in optical fabrication is actually twice this value and is often called the Total Indicator Run-out or TIR. The deviation is then the angle equal to the decentration divided by the focal length of the lens. The concentricity or centration of a lens is typically specified by the deviation angle, however it is typically tested at double the value while the lens is rotated. An angular deviation of 1 to 3 arc minutes is common for precision components.



## (11) Prism Angle Accuracy

Typically, the relative angle between the reflecting surfaces (as in a roof) needs to have a critical tolerance in order to maintain a maximum allowable angular deviation. However, depending on placement in a system, the other angle(s) could be toleranced to limit aberration effects. Angle tolerances for prisms are inspected using an autocollimator with the prism oriented as a retro-reflector. This is only suitable for testing 90° and 45° angles; i.e. as in a right angle prism. Note that although this specification relates to the physical edge of two reflecting surfaces, it is typically tested as beam deviation.

## (12) Thickness

The importance of an element's axial thickness depends greatly on its role in a system and can vary dramatically. Thickness refers specifically to the center thickness of a lens or spacing between elements. For curved surfaces, a reasonable operating tolerance runs ±0.1mm. For flat surfaces, however, the production of large sheets of non-polished glass yields larger variances in thickness. Thickness will vary greatly depending on sheet size and where on the sheet the measurement is made. In order to accommodate this fact a nominal tolerance value is used meaning that no specific thickness tolerance is defined. Over time, nominal thickness tolerance has generally been accepted to be ±0.015" to 0.020". Again, this refers to glass that is not polished after fabrication.

If a specific thickness or precision surface accuracy is needed then polishing is clearly required and higher orders of tolerancing can be maintained. Typically, a 6:1 diameter to thickness ratio is used as a rule of thumb for high accuracy plano surfaces in order to prevent warping in fabrication or in the final mounting. Higher ratios may be used for lenses depending on radii and diameter values.

**Edge thickness** is used as a "reference" for lenses meaning that it is not a manufacturing limit. Edge thickness is actually a calculated value which depends on radii, diameter, and center thickness. It is thus used as a reference to indicate physical limitations for mounting considerations.

### (13) Edge Treatment:

There are several terms associated with the treatment of edges. The most basic is a cut edge; this is literally what it means. A large sheet of glass is either "cut" using a scribe and break technique or cored for circular pieces. The edges are left as is which can leave sharp edges. The next edge type is swiped or seamed edges which means that all the sharp edges are removed. The final type is a ground edge which provides an even mounting surface and gives a uniform cosmetic appearance to the perimeter of the optic. The better the treatment of the edge, the less likely it may become chipped in handling. Edge chips are not permitted within the optics' stated clear aperture. Edge chips are typically defined for optical windows and first surface mirrors to have maximum values of 0.25 to 0.5mm.

### (14) Glass Index

**Glass Index** and **Abbé Number** values are the most important criteria in comparing one material to the next. The index of refraction is actually a ratio of the speed of light in a vacuum to that of light in a medium (i.e., a specific type of glass). Since the speed of light in any glass varies with the wavelength of light, the index of refraction also changes with wavelength. Typically, a glass is defined at nd, which is the index at yellow helium or 587.6nm.

Dispersion, or spectral variations in index of refraction, results in differences of focal distances for light of different wavelengths. This means that even though a lens will transmit a particular wavelength, if it was not designed at that wavelength then the performance will not be the same as that stated for the design wavelength. The Abbé number (vd) quantifies the amount of dispersion for a particular frequency range. This defines how much index changes with wavelength and the smaller the value means the quicker the change; vd=(nd-1)/(nF-nC), where nF=486.1nm and nC=656.3nm. Glasses are typically defined as either crowns or flints. Crown glasses have the following combination of values: nd<1.6 and vd>55 or nd>1.6 and vd>50. Flints define the rest and are typically referred to as high index glass.