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Recommendations for

Preparation of drawings for optical elements and systems

Préparation des dessins d'éléments et de
systèmes optiques – Recommandations

Technische Zeichnungen für optische Teile und
Systeme

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Foreword

This British Standard has been prepared under the direction of the Cinematography and Photography Standards Policy Committee. It supersedes BS 4301 : 1982, which is withdrawn.

This standard was first published in 1968 and was revised in 1982. This second revision has been prepared as a result of a request for improved methods of describing and quantifying surface defects. Technical changes in this edition have therefore been confined to clauses 14, 15, 26, 27 and 28, together with a minor addition to clause 32.

BS 308, particularly Part 3, provides ample scope for the definition of complex shapes on drawings and this standard contains only directions on matters not covered or inadequately covered in BS 308. In particular, and because of the common practice in the optical industry to use angular measurements when measuring and checking optical elements and subassemblies, this standard introduces the use of angular values and fringes in the tolerance frames. This special need for optical drawings is not covered in BS 308 : Part 3, and BS 4301 should be regarded as a supplement to that standard.

The preparation of international standards on related subjects is not sufficiently advanced to justify delaying the publication of this standard.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Section one. Introduction

1. Scope

These recommendations apply to the presentation, on drawings, of design and functional requirements for optical elements and systems. Sections five, eight and nine include information considered necessary for the correct appreciation and application of the recommendations.

The material included is that necessary to provide a standardized method of presenting information on drawings, and is not intended to impose restrictive practices upon designers.

2. References

The titles of the standards publications referred to in this standard are listed on the inside back cover.

3. Introductory notes

3.1 BS 308 methods should be used unless recommended otherwise in this standard.

3.2 The inclusion in these recommendations of the means of indicating various parameters of optical elements or systems does not imply a requirement that such information should be on a drawing. Therefore on a drawing the omission of any parameter should be taken as indicating that there is no requirement. The preferred method, however, relative to the use of defect codes (see table 1) is to follow the index figure and oblique line by a hyphen (e.g. 5/-) as this signifies that the lack of instruction is deliberate.

Additionally, the use of the instruction '(see note)' as an alternative to the hyphen can be used to indicate the presence of a note giving further information. In this case the note should be numbered to provide easy reference (see 7.5).

In some circumstances the individual defect rating of elements is not critical within the context of the performance of the complete assembly or subassembly. In such cases there is no reason to insist on the defect rating of each element when assembled being within a stated specification, and it is recommended that the defect rating should be enclosed in brackets, thus: 5/(a x b x c). This will indicate to the manufacturer of the total system that the rating is for guidance only, but should be applied to individual elements being provided as replacements in existing systems.

4. Definitions

For the purposes of this standard the definitions given below, and at the beginning of some later sections, apply.

NOTE. The definitions given below are of a general nature and are therefore not included in each section. Further definitions are given in the relevant sections.

4.1 element. An optical unit that cannot be subdivided into other optical units.

4.2 field stop. The aperture or any of its images limiting the extent of the object viewed.

4.3 pupil. The aperture or any of its images limiting the bundle of rays entering the system from an object point at the centre of the field.

NOTE 1. The entrance pupil is the pupil in the object space.

NOTE 2. The exit pupil is the pupil in the image space.

4.4 optical axis. The ray path passing through centres of pupils and field stops.

4.5 test region. An optically effective surface or space, or both, that is subject to testing to ascertain defects.

4.6 test field. The portion of a test region that is effective in the system at any one time.

Section two. General recommendations, methods of presentation and definition of materials for optical elements and systems

5. Types of drawing

Three types of drawing may be needed, as indicated in 5.1 to 5.3.

5.1 Optical arrangement. An optical arrangement drawing is only for reference and should show the relative positions of all the elements or subassemblies of a complete optical system and should specify, as appropriate, the following:

- (a) element or subassembly reference part numbers (or parts-list reference numbers);
- (b) separation distances;
- (c) magnification and/or system equivalent focal length;
- (d) magnification between consecutive image planes;
- (e) true field of view;
- (f) position and sizes of field stops;
- (g) position and sizes of pupils;
- (h) clear apertures at element or subassembly component surfaces;
- (i) details of light source;
- (j) special notes regarding assembly and test procedures;
- (k) movements required for magnification and focus adjustment;
- (l) mounting interface data.

An example is shown in figure 1.

5.2 Optical subassembly. An optical subassembly drawing should give, as appropriate, the following:

- (a) element part numbers (or parts-list reference numbers) and assemblies on which each is used;
- (b) details of cement or other method of fixing (see section eleven);
- (c) dimensions and tolerances that are additional to those given in the detail drawings;
- (d) equivalent focal length or test data;
- (e) special notes regarding assembly and test procedures.

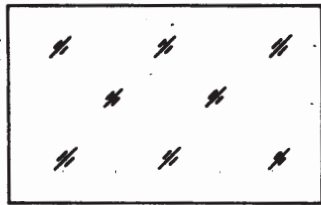
6. Orientation of drawings

Orientation of optical arrangement drawings should be such that the ultimate receptor (e.g. the eye, projection screen, photographic plate or photoelectric cell) should appear to be on the right-hand side, unless shown otherwise on the corresponding mechanical assembly drawing. In subassembly and detail drawings, elements may be oriented with optical axes horizontal or as they appear on the optical arrangement drawing.

7. Methods of representation

7.1 Where there is a particular need to indicate optical axes they should be shown as thin chain double-dash lines, thus:

7.2 Optical materials when shown in section should use the following representation:



7.3 Field stops and pupils in optical arrangement drawings should be indicated as follows.

(a) Position of field stop is indicated by a cross (i.e. X) on the optical axis (see figure 2).

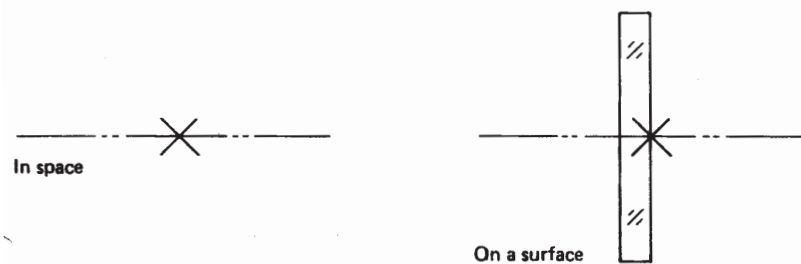


Figure 2. Field stop position

(b) Position of pupil is indicated by a short line across the optical axis (see figure 3).

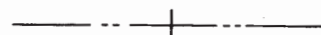


Figure 3. Pupil position

(c) Physical apertures should be drawn in thick continuous lines defining position; sizes should be indicated by short cross lines. Other apertures should be drawn in a similar manner, but in thick dashed lines. When required, field stops should be marked FS₁, FS₂ etc., following the path of the incident light (see figure 4).

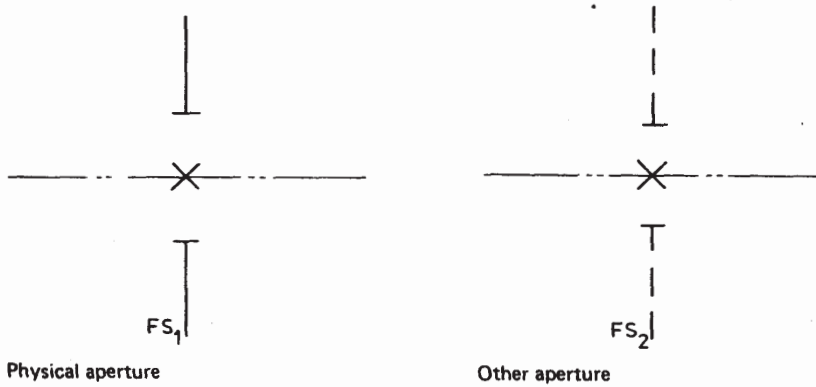


Figure 4. Physical aperture

(d) When required, pupils should be marked EP₁, EP₂, etc., following the path of the incident light (see figure 5).

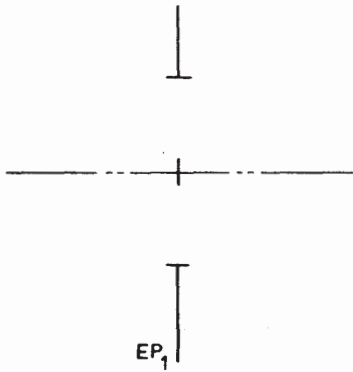


Figure 5. Pupil marking

(e) Dimensions of field stops and pupils should be shown adjacent to the stop or pupil (see figure 6).

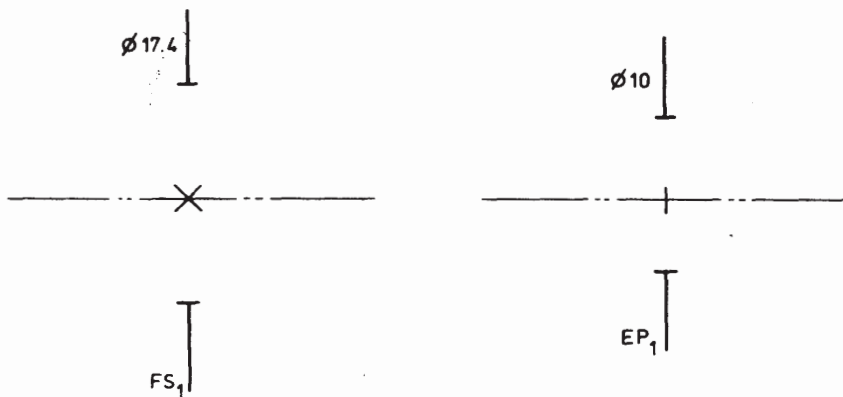


Figure 6. Dimensions of field stops and pupils

7.4 General notes and notes relative to defect classifications should be always grouped together at one edge of the drawing. Each separate note should have a number for ease of reference against dimensional or defect classification data on the main part of the drawing.

Such notes should refer, when appropriate, to the following:

- (a) magnification(s);
- (b) true field of view;
- (c) equivalent focal length;
- (d) assembly and testing procedure;
- (e) performance specification;
- (f) detail of light source or principal wavelength or both;
- (g) notes applicable to defect classifications qualified by the instruction: (see note);
- (h) coating description or performance specification (see section ten);
- (i) description of paint or other treatments (see section ten);
- (j) cement or joining specification (see section eleven).

7.5 In optical arrangements where the positions of elements or subassemblies can be varied by the user so as to adjust focus, magnification, etc., the elements or subassemblies should be shown in the nominal position and dimensions given for the extreme positions. Adjustments that are to be made during assembly may be indicated by a note (see figure 1).

7.6 The boundaries of test regions should be drawn in thin continuous lines and the regions themselves should be hatched. They may be subdivided into zones to which different tolerances apply if required. In such cases the zones should be numbered 1, 2, 3, etc., starting from the centre, to clarify the relationship of notes defining the specifications for the zones. The zone number should be indicated by a leader to the appropriate area (see figure 7).

Where necessary, special views entitled 'test regions' may be added showing optically effective regions and provided with appropriate dimensional data. If symmetrical elements or subassemblies present dissimilar test regions (e.g. due to the path of the rays being divergent or convergent), the regions in question should be suitably identified to prevent wrong assembly. The method of identification should be explained on the drawing (see figure 8).

If the test regions of optical elements or subassemblies are not shown, the optically effective surfaces and spaces should count in their full extent as test regions.

7.7 A test field may be shown in any position within the test region as a dimensioned area bounded by a thin continuous line. Appropriate requirements indicated by a leader to this test field will apply to any area within the test region (see figure 9).

8. Dimensions and tolerances

NOTE: The method of dimensioning drawings detailed in BS 308 : Parts 1, 2 and 3 should be used throughout. The following notes detail specialized information that may be required to complete drawings of optical elements and systems.

8.1 When a chamfer needs a special tolerance, this should be dimensioned in accordance with BS 308 : Part 2.

When it is not permissible for an edge to be chamfered, this fact should be indicated with a leader drawn to the edge concerned.

When other chamfers are permitted (e.g. for protection against damage, or for removal of local chips) these should not be drawn, and they should be disregarded when indicating element dimensions, but their width should be stated in a note. According to need either minimum and maximum width should be stated, or only maximum width.

8.2 The diameter of a lens should be shown with a tolerance. The minimum size of the clear aperture should be specified (in brackets) together with the descriptor 'clear' and where this differs between one side and the other the values concerned should be stated separately (see figure 10).

8.3 Spherical surfaces should be defined by stating the radius dimension. When curves are shallow, radii should be drawn out of scale to exaggerate the curvature. The radius should always be given with a tolerance (see figure 11).

NOTE: Test plate fitting references on drawings for spherical surfaces are not recommended as these can be misleading.

8.4 Plane surfaces may be indicated by the word PLANE together with a sphericity tolerance in fringes to indicate permissible spherical departure from flatness (see figure 11).

8.5 The use of terms such as 'pyramidal error' and 'skew error' should not be used on prism drawings. Geometrical tolerancing should be used instead. An example is shown in figure 12 and the interpretation is as follows. Datum planes A and B are specified and the surfaces of the prism are required to be parallel to the line of intersection of the two datum planes, within the tolerances given.

8.6 When two surfaces are to be joined, the radius dimension on the surface of each element to be joined should be annotated CEMENT TO PART XYZ. Only one radius should be tolerated; the other should be identified '(ref)'; see figure 13.

8.7 An aspheric surface should be identified by a leader to the surface stating: 'NON SPHERICAL SURFACE (see note)'. The note should be located with other notes (see 7.5) and should contain all data necessary for the definition of the surface shape. Where special test requirements exist these should be included in the note.

8.8 Where a dimension needs adjustment (e.g. for assembly), to account for variations in the properties of the material the nominal values (without a tolerance) should be given and reference to a note added indicating how the correct working value is determined (e.g. by reference to an explanatory table).

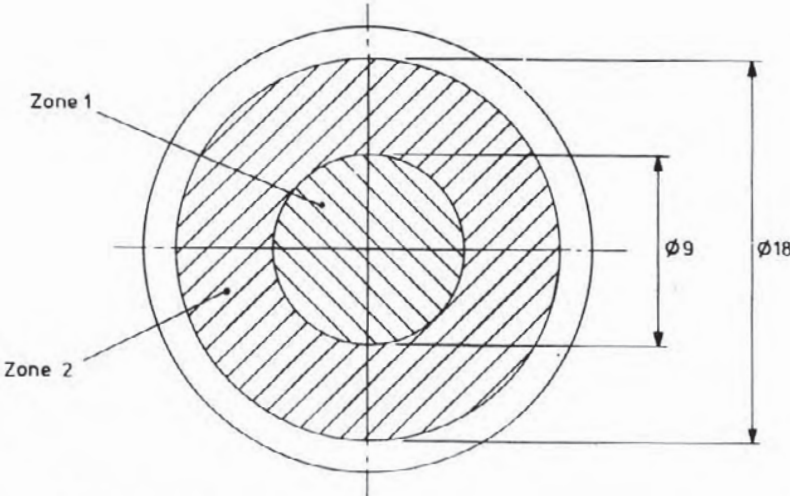


Figure 7. View showing test region

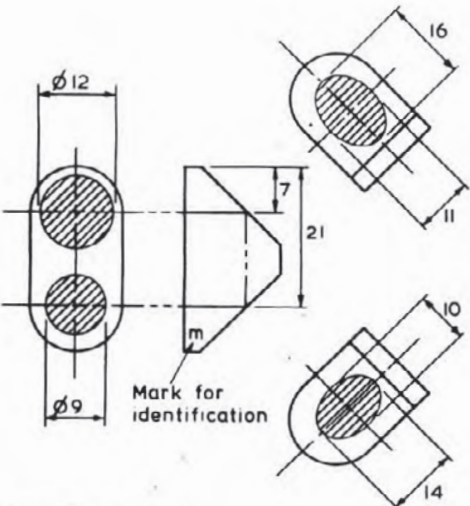


Figure 8. Test regions

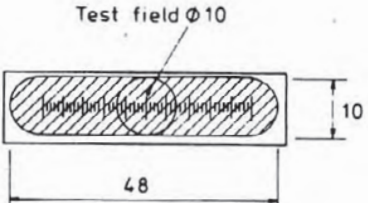


Figure 9. View showing test field within a test region

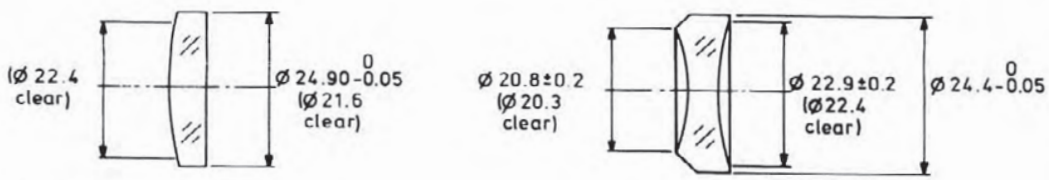


Figure 10. Diameters and tolerances

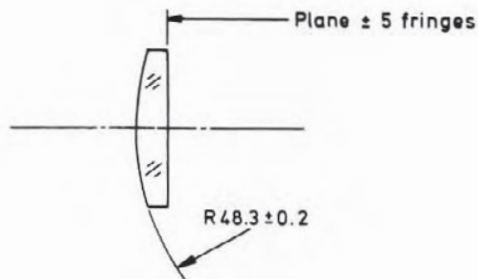


Figure 11. Spherical and plane surfaces

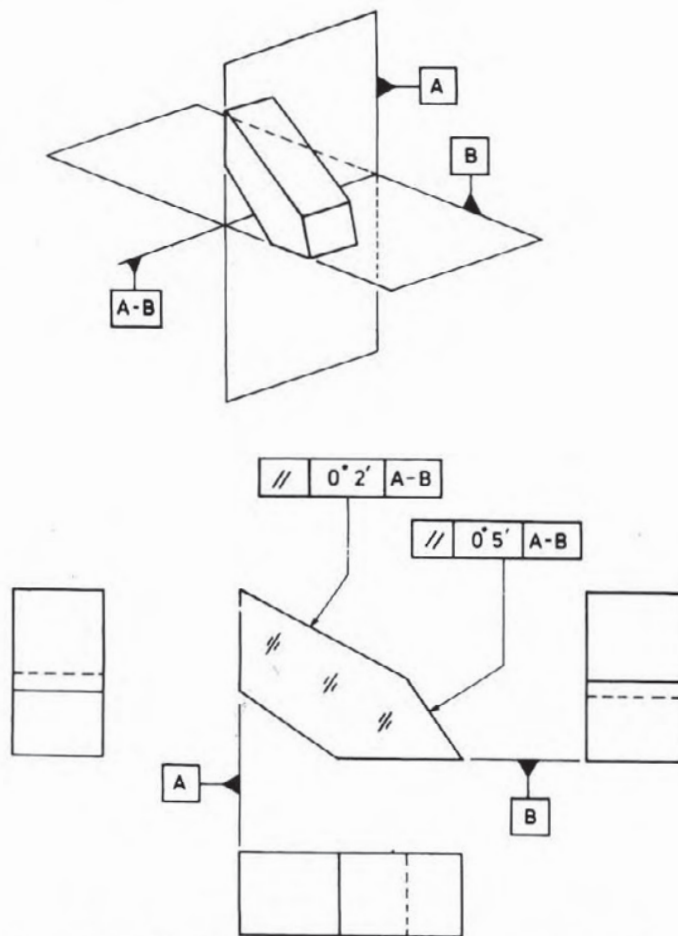


Figure 12. Example of geometrical tolerancing for prismatic component

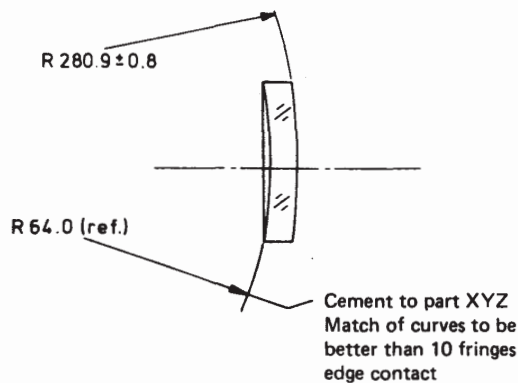


Figure 13. Cemented spherical surface

9. Materials

9.1 Requirements for the element material should be entered into a special panel giving, as appropriate, information such as:

- (a) description of material (e.g. glass, fused silica, fluorite etc.);
- (b) manufacturer's name and catalogue type;
- (c) other parameters, including tolerances essential to procurement.

9.2 Permissible material defects in finished glass elements when viewed in the direction of the optical axis, should be defined as specified in sections three, four and five of this standard.

Section three. Optical elements: strain-birefringence

10. Definitions

10.1 **birefringence.** The variation of refractive properties of an optical material with the direction of propagation and state of polarization of light within the material.

NOTE. Birefringence is measured as the maximum difference in the optical path length per unit length for light polarized in two mutually perpendicular directions. The unit of measurement is nanometres per centimetre (nm/cm).

10.2 **strain-birefringence.** Birefringence resulting from the process used for manufacture of the optical material or blank.

NOTE. Birefringence may also be an inherent characteristic of the material or may result from mounting or assembly of one or more elements. (Such cases should be dealt with by 'see note'.)

11. Defect rating code

Permissible strain-birefringence should be expressed by a code consisting of the index number 0/ followed by a value chosen from table 2.

12. Use of defect rating code

The values given in table 2 are preferred values and should meet most requirements. In special cases the strain-birefringence limit may be designated by a number other than those in the table, this number representing the maximum permissible strain-birefringence in nm/cm.

Table 2. Strain-birefringence defect rating

Strain-birefringence grade	Condition permitted
/3	Less than 3 nm/cm (normal polarization free)
/12	Less than 12 nm/cm (normal fine annealed)

Section four. Optical elements : inclusions and digs

13. Description

In optical materials (including cements) inclusions are in the form of bubbles or foreign matter that cause obscuration of light passing through the material. Digs on the surfaces of components are regarded as inclusions.

14. Defect rating code

Permissible inclusions and digs should be expressed by the code 1/ followed by two numbers and (where appropriate) a letter R or T, separated by 'X', e.g. 1/ a X b X R where :

- a* is the maximum permitted number of inclusions and digs in the test region;
- b* is the maximum permitted diameter of the inclusion or dig in micrometres taken from the preferred series ... 10, 16, 25, 40, 63, 100 ...
Extension of this series of numbers by multiples of 10 in both directions is permissible;
- c* is a letter indicating, for digs, whether the surface is viewed in reflection (R) or in transmission (T).

15. Use of defect rating code

15.1 Ignoring all defects less than 0.4 times the rated maximum value, or less than two steps in the series given in clause 14, it is permissible to accept a greater number of defects than the maximum indicated providing that the total area of all such defects is not greater than the sum of the areas of all indicated defects and that no one defect is greater than the maximum indicated size.

15.2 Inclusions and digs can be located by dark-field illumination with an arrangement similar to that shown in figure 19. Their diameter can be assessed by comparison, under bright-field illumination, if necessary by magnifier, with that of calibrated spot-equivalent standards (CSES) (see clause 28) of appropriate diameter. Inclusions within the component should be viewed in transmitted light but digs can be viewed in transmitted or reflected light as

appropriate; in each case the source should be distant to provide substantially parallel illumination. If a greater sensitivity of measurement is required, a microscope image comparator, calibrated using the CSES as described in 28.1, can be used.

15.3 It should be borne in mind that for optical reasons one inclusion may be repeated by reflection and may appear several times within the test region. The recommendations in clause 14 refer only to the actual inclusion. If any reflections occur they should be ignored when interpreting the defect rating.

Section five. Optical elements: homogeneity

16. Definition

optical homogeneity. Uniformity in optical properties throughout a material.

NOTE. The lack of uniformity may be either gradual, usually due to thermal history, or abrupt, usually due to lack of chemical uniformity. Sharply defined inclusions or bubbles that do not affect the refractive index of the glass in their immediate neighbourhood are excluded when inspecting homogeneity.

17. Defect rating code

17.1 Gradual homogeneity variations should be covered by a suitable material specification (see 9.1) and/or total form error requirements (see clause 21).

17.2 Permissible abrupt variations, striae, veins, cords, etc., that may be visible under certain conditions should be expressed by a code consisting of the index number 2/ followed by a grade number from table 3. Typical test methods for determining the grade number are described in 18.3.1 to 18.3.4.

Table 3. Homogeneity defect rating

Homogeneity grade	Condition permitted
0	No defect detected by test B (see 18.2) and not worse than approved vendor samples examined by test A (see 18.1)
i	No defect detected by test B
ii	No defect detected by test C (see 18.3), but defect detected by test B
iii	No defect detected by test D (see 18.4), but defect detected by test C

18. Use of defect rating code

18.1 The homogeneity grade for a component should be specified after giving proper consideration to the effective path length of the component in order that the grade relates to the homogeneity grades adopted by the manufacturers of raw optical material. Reference to raw material catalogues shows that standard test lengths, for example 100 mm, are used to grade homogeneity qualities. The longer an optical path, the higher is the degree of homogeneity necessary to maintain a detection threshold.

18.2 The detection thresholds denoted by table 3 have been established by the use of test procedures having different degrees of sensitivity so that visibility or non visibility of inhomogeneity determines the threshold. Further refinements of manufacturing experience and examination permit qualities better than the most sensitive of these thresholds to be defined by the use of a more critical test procedure and reference samples approved by user and vendor.

18.3 The four test conditions recommended are for operation in dark room conditions and typical test methods that have been found to be suitable are given, for information, in 18.3.1 to 18.3.4.

18.3.1 Test A. Condense light from a compact high-pressure mercury arc lamp on to a 1 mm pinhole aperture. Place the pinhole aperture on the focal plane, but slightly off the axis, of a 200 mm diameter first surface reflective coated concave mirror with focal length of approximately 1800 mm. Place a variable iris so that it can restrict the light from the pinhole source to the aperture of the mirror, and insert a filter in the light path to select the 546 nm wavelength.

Place for convenience, at approximately 3 m from the mirror, a white screen or light-sensitive paper so that it is illuminated by collimated light from the mirror. For assessment place the optical material having polished surfaces 500 mm in front of the screen or paper.

For material of which the refractive index is less than 1.62 or thereabout, the unpolished test specimen may be placed in a liquid cell that has two parallel glass plate windows and that contains a liquid whose refractive index is closely matched to that of the test specimen.

Under the same test conditions examine standard specimens. Determine the homogeneity quality of the test samples by comparison with the standard specimens.

18.3.2 Test B. Illuminate a translucent screen, approximately 150 mm to 200 mm square, at a distance of 1 m by a quartz halogen lamp whose filament area is 2 mm x 4 mm. To restrict the illumination to the effective area of the screen, place the lamp in a metal lamp house provided with a simple aperture. (The screens can be conveniently constructed from tracing paper sandwiched between glass sheets.) Polish, or immerse in matching liquid as defined for test A, the optical material to be assessed and place it approximately 100 mm in front of the screen. Make a visual examination of the shadow cast upon the screen, the observer being on the far side of the screen from the light source.

18.3.3 Test C. Prepare an illuminated black and white screen as follows.

Sandwich between glass plates tracing paper approximately 600 mm x 800 mm. Place 10 mm wide black tape across the screen in horizontal and vertical directions at a spacing of 200 mm. Illuminate the screen from behind by white fluorescent tubular lamps.

Samples for assessment should be polished. View the screen from a distance of 3 m to 4 m and hold the samples at arm's length in the line of sight.

Inhomogeneity in the test samples is detected by local deviation of the linear boundary between light and dark regions of the screen pattern.

18.3.4 Test D. Repeat test C but using a screen with no black tapes. Inhomogeneity in the test samples is detected by the presence of clearly visible patterns of light and dark regions, usually in curvilinear form, within the sample.

Section six. Optical elements: form errors

19. Definitions

19.1 surface form error. The extent to which an optical surface departs from its specified geometrical form.

19.2 total form error. The deviation in optical performance of a component from that intended, caused by manufacturing imperfections. It will, in general, be influenced by surface form errors, centring errors, material inhomogeneities, refractive indices and conditions of use.

20. Defect rating code

20.1 Permissible surface form error should be expressed by a code consisting of the BS 308 symbol for surface profile followed by a number representing in fringes (half wavelengths at 546 nm unless otherwise stated) the radial separation of concentric spheres between which the surface is required to be contained. This recommendation applies to plane and spherical surfaces (see figures 14 and 16).

NOTE. The index number 3/ (see figure 15) has in the past been used in place of the BS 308 symbol, but this method is not recommended by this standard.

20.2 Because aspherical surfaces present special difficulties, it is recommended that their permissible form tolerances should be specified by a special note.

20.3 The code, together with the surface defect code (see section eight), should be referred to the surface by means of a leader (see figure 16).

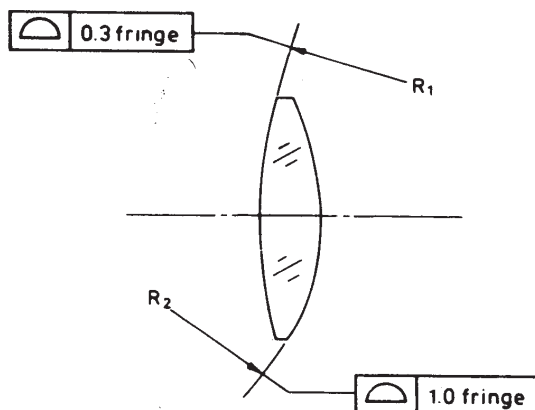


Figure 14. Surface form error using BS 308 symbol

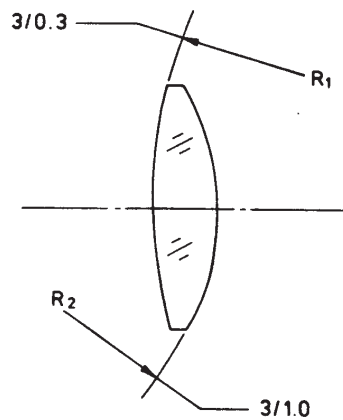


Figure 15. Surface form error (non-preferred alternative)

21. Total form error (transmitted wave error, cumulative error or effective form error)

Total form error should be expressed, as a special note, in one of the following ways:

- (a) lens action of the optical component in terms of the maximum permissible focal power change and astigmatic difference, in dioptres or millidioptres;
- (b) a maximum symmetrical and/or asymmetrical wavefront tolerance;
- (c) angular or photographic resolving power;
- (d) modulation transfer function.

Section seven. Optical elements: centring errors

22. Definition

centring error. The condition that exists due to manufacturing techniques when either

- (a) centres of curvature do not lie on the optical or mechanical axis, or
- (b) when a plane surface is not normal to the optical or mechanical axis.

23. Method of specifying centring error

23.1 Owing to the impracticability of relating tolerances to the optical axis, datum axes should be identified and centring error may be indicated as either surface tilt error (see 23.2) or lens centring error (see 23.3).

23.2 Surface tilt error is measured as the departure from squareness between the datum axis and the tangent to the surface at its intersection with the datum axis (see 24.2).

23.3 Lens centring error is measured as the angular deviation of a ray incident along the datum axis (see 24.3). Lens centring error is not applicable to reflecting surfaces.

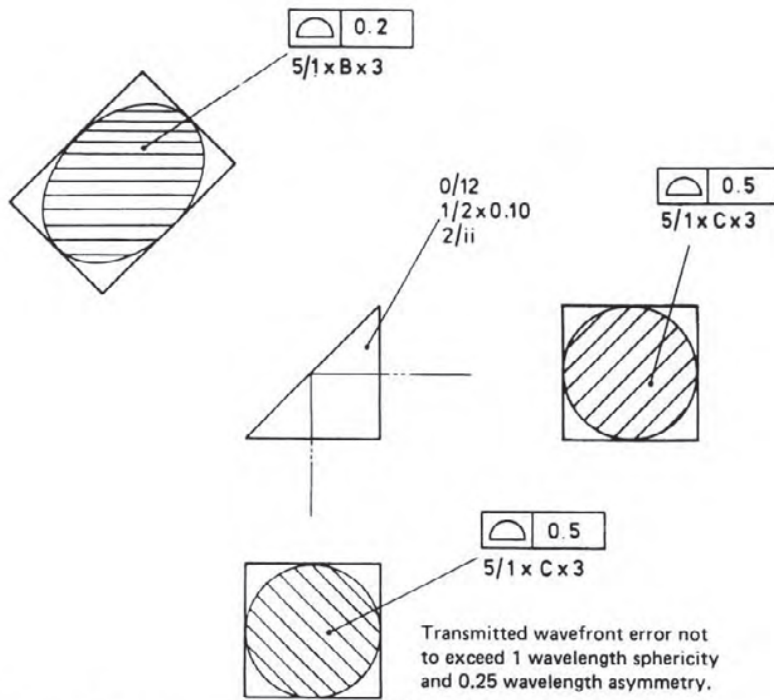


Figure 16. Drawing presentation of form error tolerances

24. Defect rating code

24.1 Datum features, when required, should be indicated in conformity with BS 308 : Part 3.

24.2 Surface tilt error should be indicated in conformity with BS 308 : Part 3 for tolerances of squareness, except that the tolerance value should be given as an angular measurement in minutes (see figure 17).

NOTE. In this example the datum axis A-B is defined as being concentric with datum B and square to the tangent to datum surface A at the point of intersection.

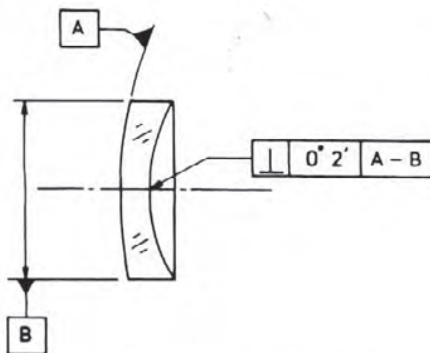


Figure 17. Surface tilt to mounting datum

24.3 Permissible lens centring error should be expressed by the index number 4/ followed by the numerical value denoting the permissible error in minutes. The code should be referred to the appropriate edge by means of a leader (see figure 18).

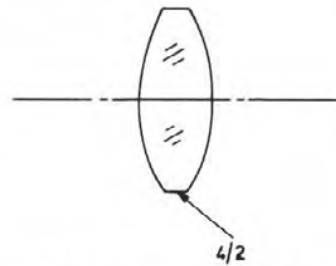


Figure 18. Lens centring error to edged surface

Section eight. Optical elements: surface defects

25. Definitions

25.1 surface defects. Marks on polished optical surfaces, including coated optical surfaces, in the form of digs, scratches or other blemishes.

NOTE. Surface defects fall into the two main categories defined in 25.2 and 25.3.

25.2 functional defects. Surface defects that are either situated in the immediate neighbourhood of an image plane (for example, on elements such as scales, graticules, masks and field lenses, which need explicit quality specifications) or that may contribute to a reduction in system performance (for example, by causing scatter).

25.3 cosmetic defects. Surface defects that are objectionable solely on aesthetic grounds.

26. Defect rating code

26.1 Digs are similar in effect to material inclusions on the surface and are covered in section four (see clause 14).

26.2 Permissible functional defects may be expressed either by the method given in 26.3 or by the code 5/ (see note). The note should be added to the drawing (see 7.4) to provide the following information, as applicable:

- (a) maximum line width or maximum line equivalent width, in the case of small scratches whose width cannot easily be measured by a standard microscope, in micrometres taken from the preferred series: 0.63, 1.00, 1.60, 2.5, 4.0, 6.3, 10.0, 16.0;
- (b) maximum length in millimetres;
- (c) maximum number (divided into zones if necessary);
- (d) relationship to other features or defects on the surface;
- (e) magnification to be used for identification of the location of defects;
- (f) illumination conditions to be used for identification and measurement of defects;
- (g) acceptance level of special requirements;
- (h) method of measurement;
- (i) whether measurement employed transmitted or reflected light.

26.3 Permissible cosmetic scratches should be expressed by the code 5/ followed by a number and two letters separated by 'X', e.g. 5/ a X b X c where :

- a is the permitted maximum accumulated length in millimetres of all scratches on the surface to which the leader refers and which conform to 27.2 and 27.3 below;
- b is the reference letter of the certified line equivalent width (LEW) (see clause 28) defining the maximum permitted visibility of the scratch (see 27.1);
- c is a letter indicating whether the surface is viewed in reflection (R) or in transmission (T).

26.4 The defect rating code, together with the surface form error code (see section six) should be referred to the surface by means of a leader.

27. Use of defect rating code

27.1 For the indication of maximum permitted cosmetic scratches a reference letter is defined by the thresholds in table 4.

Table 4. LEW threshold and reference letter

Reference letter of maximum line width	LEW greater than	LEW not greater than
	µm	µm
A	0	1.0
B	1.0	2.5
C	2.5	6.3
D	6.3	16.0

NOTE. See clause 28 for details of the LEWs shown and calibration requirements.

27.2 The use of a reference letter as defined in 27.1 indicates that the sum of the length of all scratches assessed as maximum does not exceed 25 % of the maximum permitted accumulated length (see 26.3).

27.3 The use of a reference letter as defined in 27.1 indicates the sum of the length of all scratches greater than 0.25 LEW (see clause 28) and not greater than the indicated maximum LEW does not exceed the maximum permitted accumulated length (see 26.3) provided that the conditions of 27.2 are also observed.

27.4 Where a coating is shown on the drawing the defect rating code should apply to the surface after the application of the coating.

NOTE. The cosmetic significance of a scratch is substantially affected by coatings and by whether it is viewed in transmitted or reflected light.

27.5 It should be noted that it is possible to apply the visibility standards to the elements only during manufacture and that no comparison against the standards is possible when the elements are assembled into their optical system. When assembled with other elements the defect on any one element generally presents a changed appearance as a result of the effect of other elements.

Therefore this section does not make any recommendation on how the aesthetic qualities of complete systems can be specified on drawings, or assessed as products.

28. Design and use of calibrated line-equivalent width standards (CLEWS) and spot-equivalent standards (CSES)

28.1 For the purpose of this standard, defects such as inclusions, digs and scratches are quantified by the extent to which, under controlled conditions of illumination and viewing, they remove light from a beam in comparison with spots or lines of known dimensions. In this way a scratch viewed in transmission will be found to remove the same amount of light from a beam as an opaque line of a particular width. This value is termed the line-equivalent width of the scratch or LEW rating. If the scratch is viewed in reflection the quantity of light removed, and hence its severity, will be equated to the width of a transparent slit on a reflecting substrate. Inclusions and digs are measured, in transmission, by reference to opaque spots of

known diameter, and digs are measured, in reflection, by clear spots in a reflecting coating. This diameter is termed the spot-equivalent diameter or SED rating.

NOTE. The description of a typical design of instrument for quantifying defects in terms of their LEW or SED rating can be found in BAKER, L.R. Inspection of surface flaws by comparator microscopy. *Applied Optics*, Nov 15th 1988, 27, 4620-4625.

28.2 Calibrated line-equivalent width standards are produced on glass plates 1.0 mm to 2.0 mm thick with both surfaces polished to a surface grade of 3 (see clause 32) in the form of:

(a) black opaque lines of minimum length 2.5 mm and with widths given in 26.2 (a), with a tolerance of $\pm 0.1 \mu\text{m}$, on one surface for use when calibrating the instrument for measuring scratches in transmitted light;

(b) slits of minimum length 2.5 mm and with widths given in 26.2 (a), with a tolerance of $\pm 0.1 \mu\text{m}$, in a highly reflecting opaque coating on one surface of the glass plate for use when calibrating the instrument for measuring scratches in reflected light.

28.3 Calibrated spot-equivalent standards are produced on a similar substrate to that used in 28.2. The diameters of black opaque spots on a transmitting substrate and transmitted clear areas on an opaque reflecting coating are to be as shown in clause 14. A diameter tolerance of $\pm 0.1 \mu\text{m}$ applies to all the above spots and clear areas.

28.4 Scratches and digs can be located by dark-field illumination with an arrangement similar to that shown in figure 19. Their LEW or SED can be assessed in reflection or transmission as appropriate by comparing their visibility under bright-field illumination, if necessary by magnifier, with that of the calibrated lines and/or spots. The source of light should be distant to provide substantially parallel illumination.

If a greater sensitivity is required, a microscope image comparator as referenced in 28.1 and calibrated using the CLEWS and CSES can be used.

**Section nine. Optical elements:
surface texture**

29. Definitions

NOTE. In the context of this standard, surface texture is a term used to define the surface roughness requirement of optical components. The concept can be divided into the two categories defined in 29.1 and 29.2.

29.1 grey surfaces. Those surfaces of which the texture can conveniently be defined by standard roughness values (see clause 31).

29.2 polished surfaces. Those surfaces of which the texture is too smooth to be conveniently defined by standard roughness values (see clause 32).

30. Method of specifying surface texture

30.1 The basic surface texture symbol conforming to BS 308 : Part 2 should be used and should be supple-

mented by a roughness number or symbol indicating quality of surface texture. The basic symbols used to indicate optical working are shown in figure 20.

30.2 The quality of surface texture should be indicated by the method recommended in clause 31 for grey surfaces, or by the method recommended in clause 32 for polished surfaces.

30.3 Where these or BS 308 methods do not adequately cover a requirement an appropriate note (see 6.5) should be added.

31. Grey surfaces

The maximum permissible roughness, expressed by one of the N series of roughness numbers selected from table 5, should be placed above the surface texture symbol (see figure 21).

NOTE. For a full explanation of roughness numbers and their equivalence to micrometre values see BS 1134.

Table 5. Preferred maximum roughness values

Maximum roughness number	Maximum R_a value
	μm
N3	0.1
N6	0.8
N9	6.3
N12	50

32. Polished surfaces

The grade of polish, expressed by one of the symbols selected from table 6, should be placed above the surface texture symbol (see figure 22).

Table 6. Symbols and grades for polished surfaces

Symbol	Maximum number of defects per 10 mm of surface length (see note)	Grade
	400	Coarse
	80	Medium
	16	Fine
	3.2	Very fine

NOTE. The defects can be detected as discrete irregularities of amplitude $0.01 \mu\text{m}$ or greater in the trace obtained from an electromechanical stylus profile recording instrument with a stylus having a nominal tip radius of $2 \mu\text{m}$, when used with a vertical magnification of 50 000 to 100 000. An alternative non-contacting method of assessing the grade of polish is to count the residual digs over 10 mm of surface length. This may be done using a microscope. Measurement of the highest quality of surface polish with root mean square values less than 0.5 nm requires the use of some form of phase contrast microscope or micro-interferometer.