INTERNATIONAL STANDARD

ISO 12721

First edition
2000-04-15

Non-destructive testing — Thermal neutron radiographic testing — Determination of beam L/D ratio

Essais non destructifs — Essais de neutronographie thermique — Détermination du rapport L/D du faisceau

Reference number
ISO 12721:2000(E)

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 12721 was prepared by Technical Committee ISO/TC 135, *Non-destructive testing*, Subcommittee SC 5, *Radiation methods*.

Annex A of this International Standard is for information only.

Non-destructive testing — Thermal neutron radiographic testing — Determination of beam L/D ratio

1 Scope

This International Standard defines an empirical technique for the measurement of the effective collimation ratio and effective L/D of thermal neutron radiography beams for values between 20 and 1 000. The technique is based upon analysis of a neutron radiographic image and is independent of measurements and calculations based on physical dimensions of the collimator system. The device described in this International Standard has been developed and tested using Gd foil converters with a single emulsion, high resolution film in vacuum cassettes.

2 Terms and definitions

For the purposes of this International Standard, the following terms and definitions apply.

2.1
effective L/D ratio
one measure of the resolution capability of a neutron radiographic system; the ratio of the effective distance between the entrance aperture and the image plane (L) to the effective diameter of the entrance aperture (D)

NOTE The value measured may differ from the ratio obtained using physical dimensions.

2.2
umbra
the portion of the shadow image where the total primary beam has been intercepted by the object (as in total eclipse)

See Figure 1.

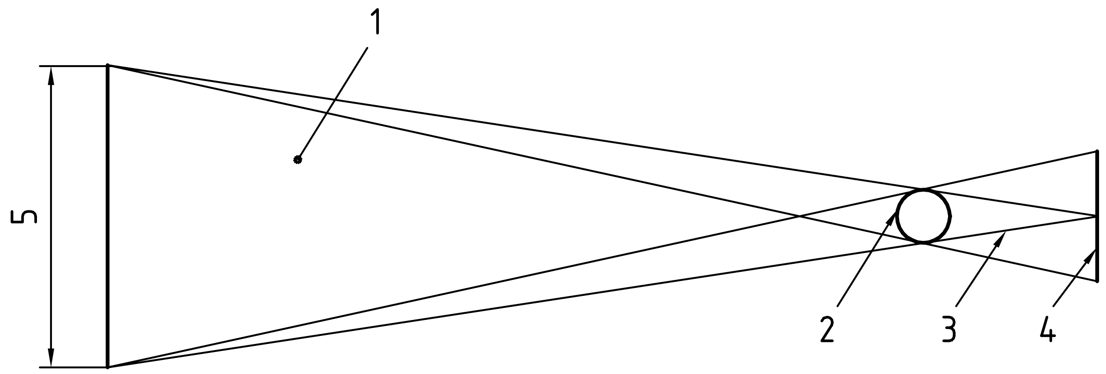
2.3
penumbra
the portion of the shadow image where only a part of the primary beam has been intercepted by the object (defines the unsharpness of the shadow)

See Figure 1.

2.4
primary beam
the beam of neutrons originating at the source and remaining essentially unscattered until it interacts with the object/detection system

3 Principle

Determination of neutron beam effective L/D ratio using the zero umbra technique is accomplished by radiographing the zero umbra device with the neutron beam to be measured and subsequently analysing the radiograph by one of three methods. Each of the three methods is based upon the determination of that point at which the umbra shadow width reaches zero.



Key

1 Radiation beam

2 Object

3 Umbra

4 Penumbra

5 Source

Figure 1 — Diagram of zero umbra configuration

4 Significance and use

The quality of a neutron radiographic image is dependent upon many factors. The L/D ratio is one of those factors. The effective L/D ratio required for specific neutron radiographic test is dependent upon the thickness of the specimen and the physical characteristics of the particular element of interest. Use of this method allows the radiographer and the user to determine and periodically check the effective collimation ratio.

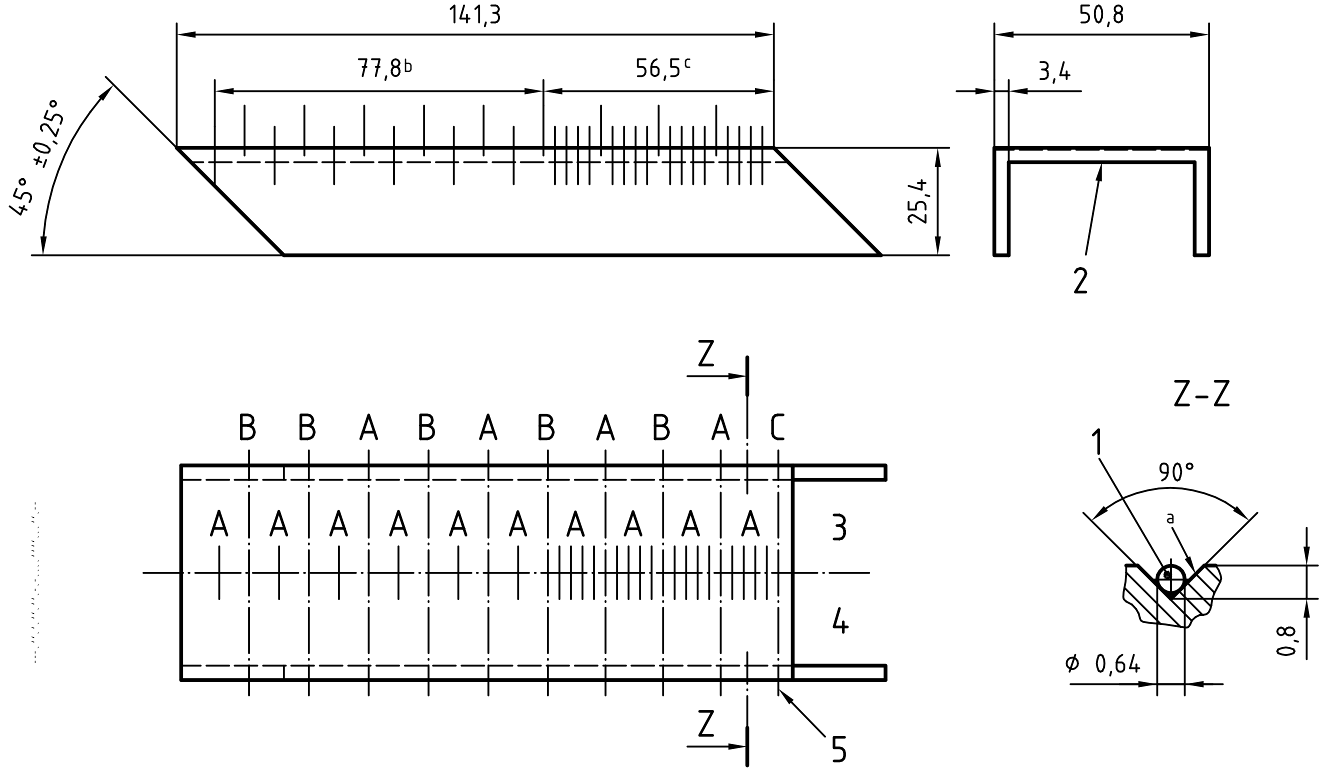
5 Apparatus

5.1 Zero umbra device, (see Figures 2 and 3) employing neutron absorbing rods positioned at various distances from the image plane.

In practice this device consists of cadmium rods located in V-grooves accurately machined in the surface of an aluminium channel section set at an angle of 45° ± 0,25° to the side support plate. Near the image plane end the V-grooves are typically machined on 2,8 mm centres. After 21 V-grooves (counting one on the end), the grooves are machined on 7,1 mm centres to the source end. The rods of diameter d, typically 0,64 mm diameter cadmium rods, are laid in the V-grooves and secured with neutron transparent adhesive tape. The aluminium channel is supported by side plates to maintain the 45° ± 0,25° angle relative to the image plane. For determination of L/D ratios greater than 150, additional offsets may be used to extend the scale as shown in Figure 4 (B unit).

If rods of diameter 0,64 mm are not available, rods of a similar but carefully measured diameter may be used, provided appropriate adjustments are made for the 0,64 mm factor in the formulae of clause 7. The "as-built" dimensions should be used in all calculations.

Dimensions in millimetres



Key

1 Rod

2 6061 T 6 aluminium

3 Nylon rods

4 Cadmium rods

5 Base line

NOTE 1 Rods at "A" positions are 10 mm each side of centreline (22 ea.).

NOTE 2 Rods at "B" positions are 20 mm each side of centreline (9 ea.).

NOTE 3 Rods at "C" positions are 25 mm each side of centreline (1 ea.).

NOTE 4 All dimensions are taken from the base line in order to reduce accumulative errors.

NOTE 5 The rod arrangement shown is for a single system device. For an add-on device, to form a double system, extend the 11 spaces for 77,8 mm to 19 spaces for 134,3 mm and eliminate the close spacing (20 spaces for 56,5 mm).

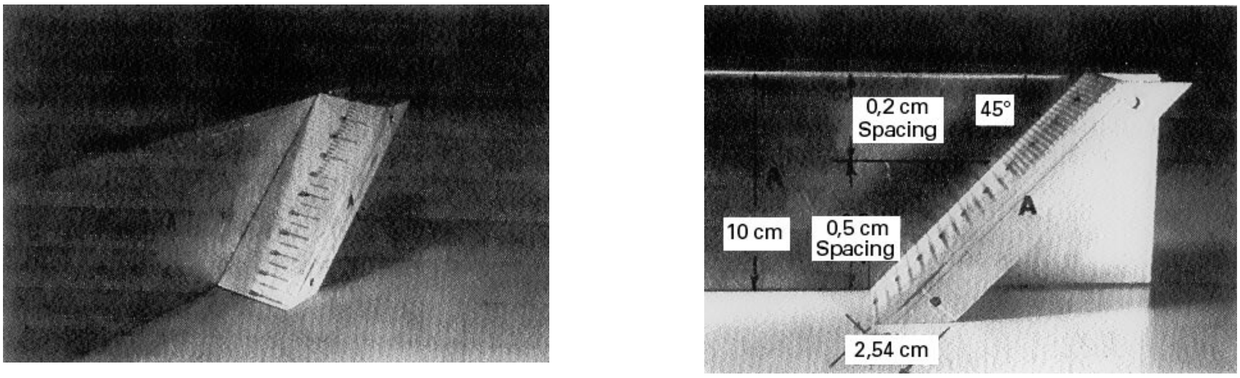
NOTE 6 Rods are held tightly in position with one layer of transparent tape.

[a] milled across entire face.

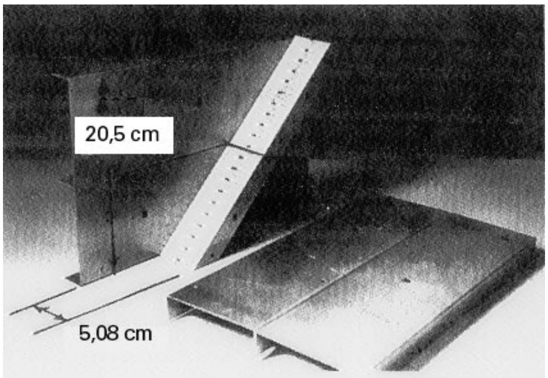
[b] 11 equal spaces (see NOTES 4 and 5).

[c] 20 equal spaces (see NOTES 4 and 5).

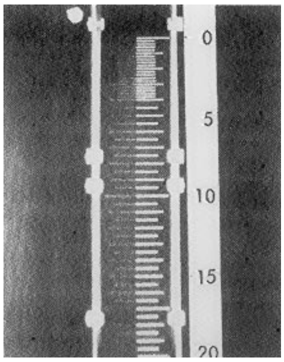
Figure 2 — Support channel subassembly with rod spacing



a) Single system image device (one side plate removed)



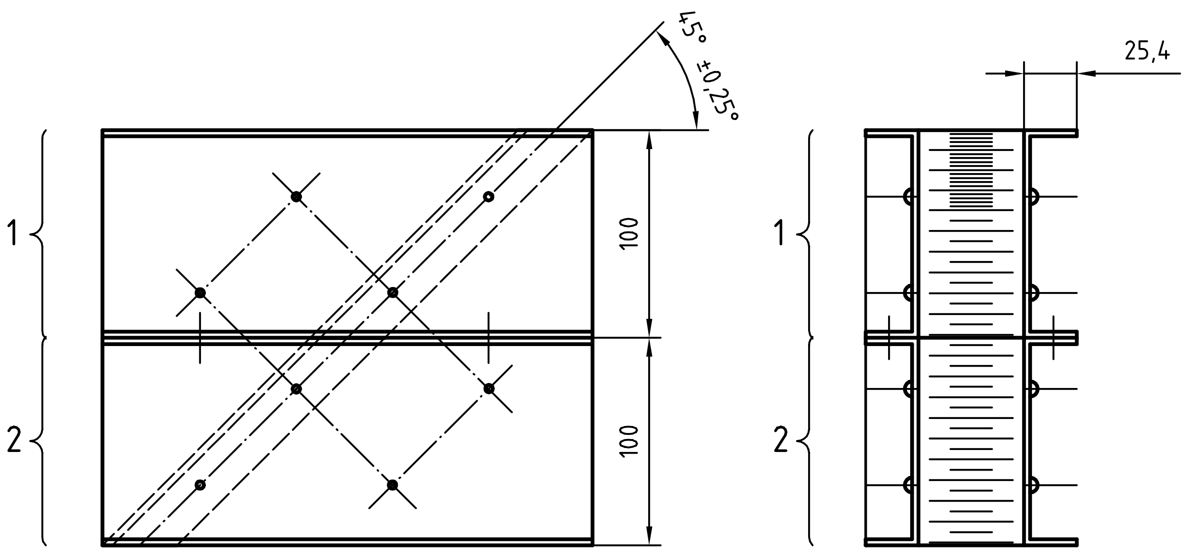
b) Double system image device (one side plate removed)



c) neutron radiograph of double system image device

Figure 3 — Zero umbra device pictorials (schematic)

Dimensions in millimetres



Key

1 A unit – single system for L/D less than 150

2 B unit – double system for L/D 150 to 300

Figure 4 — L/D apparatus assembly

6 Procedure

6.1 Place the zero umbra device against the cassette with the finely spaced rods nearest the cassette.

6.2 Align the plane of the cassette perpendicular to the axis of the neutron beam.

6.3 Expose the single-emulsion film and zero umbra device for a time span that will produce a nominal background film density of 2,5 ± 0,4.

6.4 Process the exposed film in accordance with the manufacturer's recommendations.

6.5 Analyse the resultant image in accordance with one or more of the three methods described in clause 7.

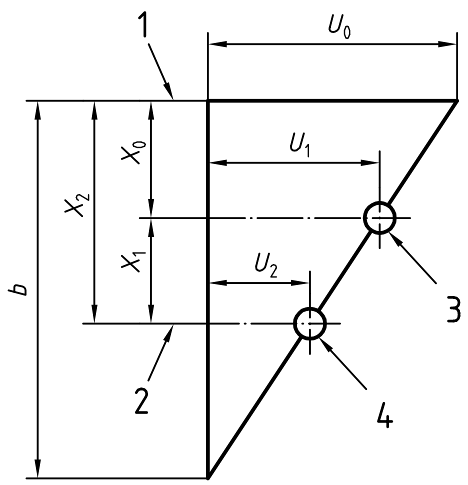
7 Data Analysis

7.1 Visual analysis

A visual determination of the effective L/D ratio shall be made directly from the neutron radiograph. When observing the individual rod images, the umbral line can be recognized as the "white" line along the centre of the rod image. This umbral line will decrease in width as the rods are located farther and farther from the film. At some point the umbral lines will disappear. Beyond this point a less intense line will appear and increase in width with increasing rod distance. Use of a 5 × to 10 × magnifier will aid in determining the point at which the umbral line disappears and then increases in width with decreased intensity. Based on this visual observation, the distance, b, between the first rod with no umbral shadow and the cassette shall be determined. The L/D ratio is as follows:

$$L / D = (b / d) \tag{1}$$

where b (Figure 5) and the rod diameter d are in the same units. This analysis method is valid up to an L/D ratio of 100. Above this value a microdensitometric analysis method shall be used.



Key

1 Film plane

2 Zero umbra

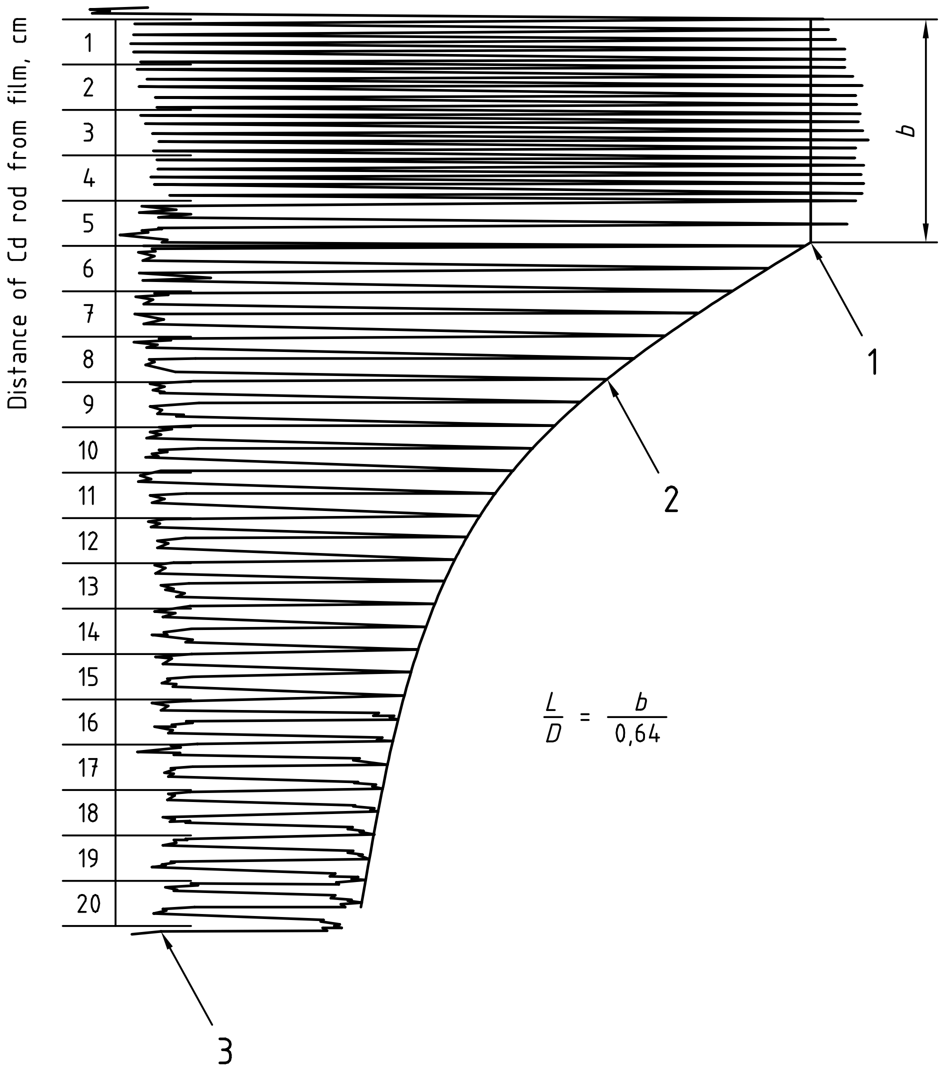
3 Rod 1

4 Rod 2

Figure 5 — Diagrammatic maths model

7.2 Microdensitometric analysis

The second data analysis method is based on a microdensitometric scan across the cadmium rod images beginning with the "0" position rod nearest the film. A typical scan is shown in Figure 6. A densitometer aperture of 20 µm × 300 µm and no horizontal expansion is suggested for this method. The value of b is obtained from the intersection of a straight line originating from the tip (low film density) of the scan of the "0" rod and curved line through the tips of the remaining wave forms as shown in Figure 6. This method gives the best results for L/D ratios up to a value of 300. Higher L/D ratios cannot be determined by this method due to the inability to obtain a stable wave from for large values of b.



Key

1 Straight line

2 Curved line

3 Background film density

Figure 6 — Microdensitometer scan 1:1

7.3 Alternative microdensitometric analysis

7.3.1 General

This method also uses scanning microdensitometric traces for L/D ratio determinations and is applicable for both high and low L/D ratios. For this method the recommended microdensitometer settings are: 20 µm × 300 µm aperture and 50 × (or more) chart recording expansion. These settings will produce individual wave forms as shown in Figure 7. At least two wave forms shall be scanned, one near the film plane and one other near the point where the umbra disappears. Care shall be taken not to go beyond the point where the umbral image disappears. Microdensitometer settings shall remain the same for all scans. For L/D ratios above 100, the "0" centimetre rod image should not be used because the unsharpness due to the film/conversion screen combination overrides the unsharpness due to the L/D ratio. For the lower L/D ratios (under ~ 100), the simplified equation using X_2 and U_0, for the "0" rod image may be used with good results.

7.3.2 Calculating b

To determine the value of b it is necessary to measure the umbral image width for the two rods selected. This dimension is measured along a horizontal line (parallel to background) through the average of the low-density scan of the individual wave form. The desired dimension is the distance between the intersections of this horizontal line with lines drawn through the two sides of the wave form. The measurement need not be converted to the unmagnified value.

Using this dimension, determine the value of b as follows (see Figure 5):

$$b = (U_1 X_1)/(U_1 - U_2) + X_0 \qquad (2)$$

where:

U_1 is the umbral width of a rod near the image plane;

X_1 is the distance between the two rods chosen for analysis;

U_2 is the umbral image width of a rod near the distance where the umbra disappears;

X_0 is the distance from the film to the rod chosen for U_1.

Since

$$L/D = b/d \qquad (3)$$

it is possible to determine L/D directly as follows:

$$L/D = \left[\frac{U_1 X_1}{U_1 - U_2} + X_0\right] / 0{,}64 \qquad (4)$$

if cadmium rod diameters are 0,64 mm.

For low L/D ratios < 100 the following equation may be used:

$$L/D = \left[\frac{U_0 X_2}{U_0 - U_2} + X_0\right] / 0{,}64 \qquad (5)$$

where

U_0 is the umbral image of a rod adjacent to the cassette window;

X_2 is the distance from cassette to rod U_2.

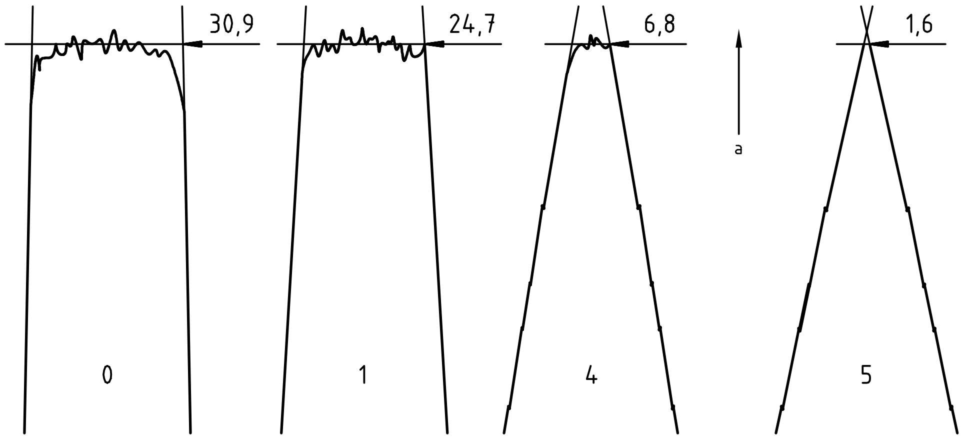
Since $U_0 \approx$ cadmium rod diameter = 0,64 mm

$$L/D = \frac{X_2}{0{,}64 - U_2} \tag{6}$$

7.3.3 Accuracy

The highest degree of accuracy can be obtained by measuring the umbral width of several rods. These measurements and their respective distances from the image plane are analysed by a linear regression technique (or alternatively by best-fit curve of the plotted data) to determine the x-axis intercept that is the value of b. The effective L/D ratio is simply b/d (rod diameter), e.g. 0,64 mm. This technique is recommended for L/D ratios above 200.

Dimensions in millimetres



[a] Decreasing density

Figure 7 — Film density scans of individual cadmium rods 50:1

Annex A
(informative)

Zero umbra method

A.1 Theory

A.1.1 The collimation ratio of a neutron radiography beam is defined as the distance between the source and the image plane (L) divided by the diameter of the source (D). Since the source diameter (D) is typically large (> 2 cm), and because materials with very high neutron attenuation coefficients are available, a unique approach to the effective L/D ratio determination is possible. If an opaque rod with a diameter much smaller than the source diameter is placed near the image plane, an umbral shadow will be cast as shown in Figure A.1.

A.1.2 For a given source diameter (D) and a given rod diameter (d), there will be a rod to image plane distance (b) where the width of the umbral shadow on the image plane will equal zero. For this particular distance a simple formula can be developed to determine the effective L/D ratio:

Triangle XYZ is similar to triangle STZ, therefore $L/D = b/d$

where

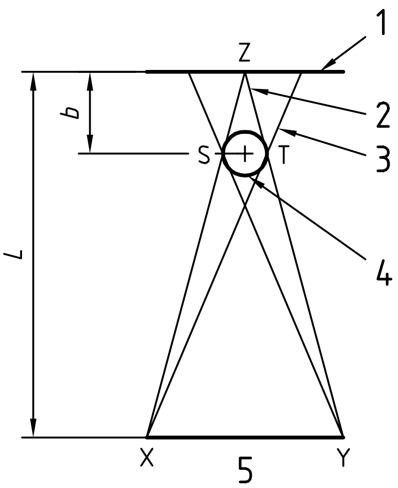
L is the source to film distance;

D is the source size;

b is the object to film distance;

d is the object size.

NOTE When $b << L$, $L \approx L - b$. Therefore, L may also be considered source-to-object distance. Thus, if the rod diameter is known, the effective L/D ratio can be calculated because the value of b can be determined from a neutron radiograph of a system of rods.



Key

1 Image

2 Umbral shadow

3 Penumbral shadow

4 Cd rod

5 Source

Figure A.1 — Zero umbra geometry

A.2 Accuracy

A.2.1 The zero umbra method for determining L/D ratios is particularly accurate in the normal range of L/D ratios used for neutron radiography, that is, 20 to 250. Major sources of inaccuracy are:

a) the variations in the cadmium rod diameter;

b) the variations of conversion screen to centreline of first rod distances;

c) the inherent unsharpness of the film/conversion screen system;

d) the effect of conversion screen gamma photons on the film density of the cadmium rods.

(d) applies primary to the L/D analysis method using a 1:1 microdensity scan of all rods.

A.2.2 Use of the linear regression analysis of individual rod umbral image measurements should provide accuracies of ~ 2 % to 3 % for L/D ratios up to 1 000 assuming the cadmium rod diameter is accurately known. Any of the analysis techniques using microdensitometer scans should provide an accuracy of ~ 5 % for L/D ratios up to 250 and the visual observation is equally accurate when interpreted by a trained film reader.

A.2.3 The visual determination has certain limitations fixed by rod spacing. For example, if the umbral image is observed at 4 cm but is not visible in 4,5 cm rod image, one can only say that the L/D lies between (4/0,064) and (4,5/0,064) or 62,5 and 70,3. The accuracy is therefore limited to 12,5 %. Similarly at an L/D of 20, because the cadmium rods are spaced at 0,2 cm, the best visual accuracy is limited to 16,7 % (between 18,75 and 21,87 L/D).

A.2.4 The accuracies noted above have been experimentally verified by analysis of neutron radiographic images produced with facilities having well-defined geometrical configurations. The most significant point to be considered in the use of the zero umbra method for determining L/D ratios is that the image is a true indicator. If the values of L/D determined by the zero umbra method disagree with the values determined by geometrical calculations based on alleged source size and source to film distance, it is most probable that the zero umbra method values are more accurate. One should proceed to analyse the source configuration with pinhole techniques to locate source leakage or other problems should the values differ widely. The technique has been found to be equally accurate for circular or square aperture configurations. In the case of a rectangular of oval shaped aperture, the zero umbra device will indicate the L/D ratio normal to the rod direction. At least two measurements are necessary to characterize a rectangular source.

ICS 19.100

Price based on 10 pages