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BRITISH STANDARD

BS 3693:1992
Incorporating Amendment No. 1

Recommendations for

Design of scales and indexes on analogue indicating instruments

Confirmed January 2011

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Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Power Engineering Standards Policy Committee (PEL/-) to Technical Committee PEL/13, upon which the following bodies were represented:

Department of Energy (Electricity Division)

Department of Trade and Industry (National Measurement Accreditation Service)

Department of Trade and Industry (National Physical Laboratory)

Electricity Industry in United Kingdom

GAMBICA (BEAMA Ltd.)

General Electric Company Ltd.

Institution of Electrical Engineers

Institution of Incorporated Executive Engineers

This British Standard, having been prepared under the direction of the Power Engineering Standards Policy Committee, was published under the authority of the Standards Board and comes into effect on
31 January 1992

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BS 3693-1 first published February 1964
BS 3693-2 first published November 1969
First combined edition February 1986
Second edition January 1992

The following BSI references relate to the work on this standard:
Committee reference PEL/13
Draft announced in *BSI News,* November 1991

ISBN 0 580 20252 6

Amendments issued since publication

Amd. No.	Date	Comments
7448	February 1993	Indicated by a sideline in the margin

Contents

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Foreword

This British Standard has been prepared under the direction of the Power Electrical Engineering Standards Policy Committee. It supersedes BS 3693:1986, which is withdrawn.

This edition introduces technical changes to bring the standard up-to-date but it does not reflect a full review of the standard, which will be undertaken in due course. However, the Committee has agreed that geometric construction and form of digits should not be subject to standardization. Therefore BS 3693A:1964 and BS 3693B:1964 are now withdrawn.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 16, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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1 Scope

This British Standard gives recommendations for the design of scales and indexes of analogue indicating instruments in which an index moves in relation to a fixed array of scale marks to display the value of a measured quantity, or in which the scale moves in relation to a fixed index. Basic designs are given for scales for single, dual and multi-range fixed or portable instruments.

This British Standard is applicable to scales with:

a) black or dark coloured scale marks on a white or light coloured background;

b) white or light coloured scale marks on black or dark dials;

c) transilluminated scales.

BS 3693 can be applied in the design of both linear and non-linear scales.

No recommendations are given for the design of scales displayed on cathode ray tubes.

This British Standard can apply to non-electrical instruments.

NOTE The title of the publication referred to in this standard is given on the inside back cover.

2 Definitions

For the purposes of this British Standard the following definitions apply.

NOTE Figure 1 illustrates some of the defined terms.

2.1
scale

the ordered set of scale marks, together with any associated numbering, forming part of an indicating device

2.2
index

the fixed or movable part of an indicating device whose position with reference to scale marks enables an indicated value to be determined

NOTE Examples of an index include the following:
a) pointer;
b) luminous spot;
c) liquid surface;
d) recording pen.

2.3
dial

that part of an indicating device, fixed or moving, which carries the scale or scales

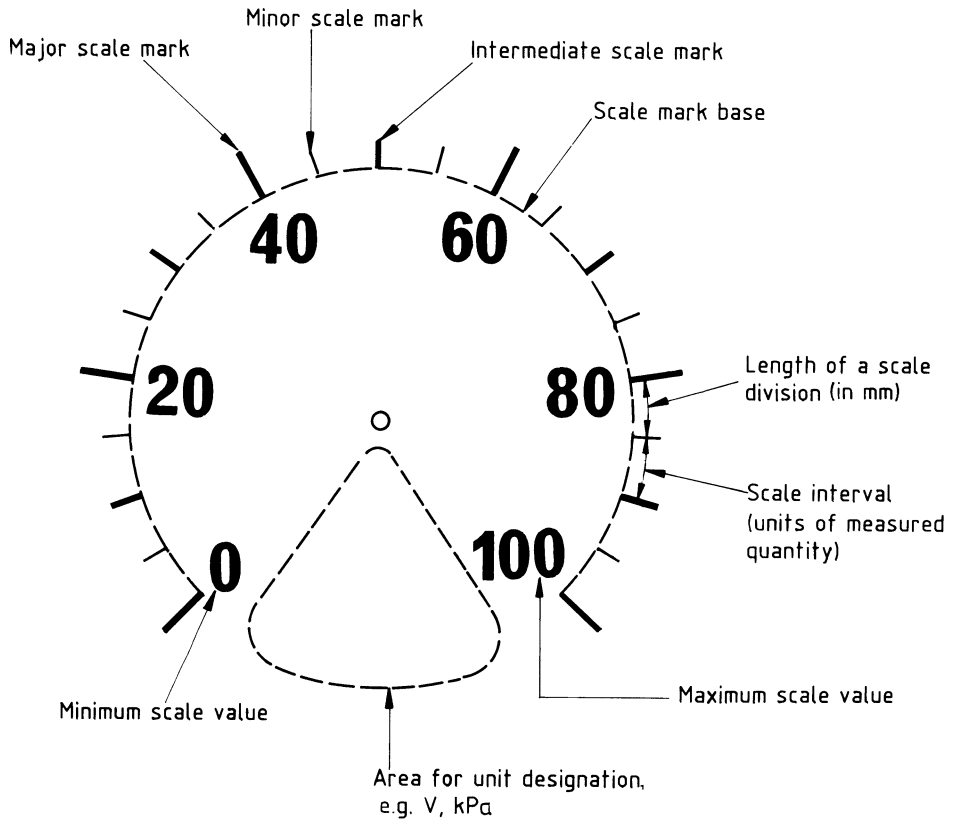

Figure 1 — Nomenclature for dials and scales

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2.4
graduation

the process of setting out a scale

NOTE The use of the word "graduation" in the sense of a "graduation mark" is deprecated, the term "scale mark" being the defined term.

2.5
scale mark

a line or other mark on an indicating device corresponding to one or more defined values of a measurand

2.6
major scale mark

a scale mark which is a primary divider of the scale. Major scale marks are emphasized generally by elongation relative to the minor marks, or by thickening all or part of the mark

2.7
minor scale mark

a scale mark which is a secondary divider of the scale. Minor scale marks divide the distance between major scale marks into scale divisions (see **2.13**)

2.8
intermediate scale mark

a minor scale mark which is emphasized in order to assist reading the scale between a pair of adjacent major scale marks

2.9
scale mark base

the actual or implied line, part circle or straight, between the extreme end scale marks, from which one end of all the scale marks emanate

2.10
index path

the line of travel, relative to the scale, of that place on the index, or on the geometric prolongation of the index, which is effective in indicating the value of the measurand

NOTE In some instruments, the place on the index which is thus effective may vary with the position of the index.

2.11
boundary line

a line, perpendicular to the scale marks, bounding the scale. The boundary line may be coincident with the scale mark base or it may be arranged on the opposite side of the scale

2.12
scale length

the length of the line (curved or straight) which passes through the centres of all the shortest scale marks contained between the first and the last scale marks

NOTE The scale length is expressed in units of length.

2.13
scale division

the part of a scale between any two successive scale marks

2.14
length of a scale division

the distance between any two successive scale marks, measured along the scale mark base

NOTE The length of a scale division is expressed in units of length.

2.15
major scale division

the part of a scale between any two successive major scale marks

2.16
intermediate scale division

the part of a scale between any two successive intermediate scale marks or between an intermediate scale mark and an adjacent major scale mark

2.17
minor scale division

the part of a scale between any two successive scale marks, one of which is a minor scale mark

2.18
scale range

for a given scale, the set of values between the extreme scale marks

NOTE The scale range is expressed in the units marked on the scale, regardless of the units of the measurand. It is normally stated in terms of its lower and upper limits, e.g. 100 °C to 200 °C.

2.19
measuring range

the range defined by two values of the measurand within which the limits of error of a measuring instrument are specified

2.20
minimum scale value

the smallest value of the measurand displayed by the scale

2.21
maximum scale value

the greatest value of the measurand displayed by the scale

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2.22
scale interval

the difference between the scale values corresponding to two consecutive scale marks

NOTE Scale interval is expressed in the units marked on the scale, regardless of the units of the measurand.

2.23
linear scale

a scale in which the divisions between successive scale marks denoting similar increments of the measurand are intended to have the same length

2.24
non-linear scale

a scale in which the length of a scale division is not constant throughout the scale

NOTE Examples of a non-linear scale include the following:
a) logarithmic scale;
b) square-law scale.

2.25
multiple scale (multi-scale)

a dial having more than one series of scale marks, etc. with different scale mark bases and a common index

2.26
dual scale

two scales associated with a common index and a common scale mark base, the scale marks being drawn in opposite directions on the scale mark base

2.27
multiple zone scale

a scale in which the value of the scale interval varies in steps from one region to another

2.28
superimposed scale

a scale provided throughout its effective length with two resolutions, one intended for close reading and fine resolution, the other being of coarser resolution and intended for reading at a distance or at a glance

2.29
interpolation

the process of dividing a scale division by eye without the aid of scale marks

2.30
interpolated division

one of the parts into which a minor scale division is divided by eye

2.31
scale factor

the number, often one, by which the indication is multiplied to obtain the value of the measurand

2.32
accuracy

the quality which characterizes the closeness of the indicated value of the measurand to the true value (conventional true value)

2.33
observation error

the error made by the observer when reading the indication of an instrument

NOTE The term "reading error" is deprecated.

2.34
parallax

when applied to a scale and index, the effect of the apparent change in the position of the index, relative to the scale marks, when the observer views the scale and index perpendicularly and obliquely

2.35
resolution

the smallest change in the value of the measurand which can be meaningfully determined

2.36
interpolated resolution

the smallest change in the value of the measurand to which a numerical value can be assigned by interpolation, i.e. by estimating the distance between the index and the nearest scale mark

NOTE 1 For the purposes of this standard, the interpolated resolution is expressed as a percentage of the scale range.
NOTE 2 Unless otherwise stated, interpolation to fifths of a scale division is assumed.

2.37
resolution factor

a number, designated r, having the same numerical value as the interpolated resolution expressed as a percentage, e.g. interpolated resolution 0.5 %:

$r = 0.5$

2.38
moving element

the moving part of an instrument, the deflection of which is observed

3 Factors influencing scale design

3.1 General

3.1.1 *Interpolation to the required interpolated resolution*

It should be possible for a practised observer to interpolate a scale division to the required interpolated resolution. This resolution should be related to the accuracy class of the instrument of which the scale and index form part. The resolution factor should be equal to or less than the class index of the instrument.

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The statistical basis adopted for this standard is that, in at least 95 observations out of every 100 taken by practised observers positioned directly in front of the scale, an observation should not depart from the indicated value by more than the interpolated resolution of the scale when the illuminance (intensity of illumination) of the dial has a minimum value of 130 lx.

3.1.2 ***Speed of observation***

Where quickness of observation is a factor to be considered, interpolation to the required resolution is important. For general applications, as the speed of observation becomes more important, so the required resolution factor increases, and vice versa. For instance, it is important that an automobile speedometer which would normally have a resolution factor of the order of 1 be read quickly without a gross observation error, while quickness of observation is of much less importance when reading laboratory test instruments.

3.2 Interpolation

3.2.1 Research into human performance has shown that the fundamental principles in scale design given in **3.2.2** to **3.2.7** govern observation error resulting from interpolation.

3.2.2 The proportion of observation errors depends upon the angle subtended at the observer's eye by the interpolated division. Best performance is achieved when this angle is 7×10^{-4} rad. This is equivalent to an angle of 2.5 ′ of arc, or a width of 0.2 mm at a reading distance of 300 mm. When the angle is larger then this, the number of observation errors increases and when the angle is less than 2.5 ′ of arc the observation errors increase rapidly.

3.2.3 Where quickness of observation plays no important part in the reading process there may be some additional advantage in the reduction of observation errors by choosing the minor division such that interpolating into halves achieves the required resolution factor. In practice this advantage has significance only with finely divided scales.

3.2.4 The method of scale division is important. For best performance it is recommended that scale divisions related to 1, 2 or 5 units of the measurand should be used. This reduces mental calculation and thus minimizes observation errors.

3.2.5 There should not be more than four successive minor marks between any two other marks. Also, there should be not more than four intermediate marks between two successive major marks.

3.2.6 There should be not more than four unfigured major marks between figured major marks.

3.2.7 There should not be two unfigured marks between adjacent figured marks.

4 Determination of scale length and reading distance

4.1 Basis for setting out scales

The basis for setting out all scales should be the scale length, and this basis applies equally whether the scale is full circle, part circle or straight. The dimensions of the scale should be related to the intended distance at which the scale is to be read with the minimum number of observation errors.

4.2 Minimum acceptable scale length

The minimum acceptable scale length should be determined in accordance with the following.

From **3.2.2** it may be determined that:

$$L = 0.0007\ Dn \qquad (1)$$

where:

L is the scale length (in mm);

D is the reading distance (in mm);

n is the total number of interpolated divisions.

By definition,

$$n = \frac{100}{r} \qquad (2)$$

where:

r is the resolution factor.

Therefore,

$$L = \frac{0.07D}{r} \qquad (3)$$

Equation (3) results in the minimum acceptable scale length. This scale length may, with advantage, be increased by a factor of up to 2 especially when the application of the equation results in a scale length inappropriate to the instrument moving element or, for instance, in the interests of uniformity with other adjacent instruments. The scale length should be determined by the intended reading distance. The scales of instruments intended for close reading should be designed for a reading distance of 300 mm. For panel mounted instruments, a reading distance of 1 000 mm may be appropriate.

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4.3 Examples of scale lengths for reading at distances of 300 mm and 1 000 mm

Based on the equations given in **4.2**, examples of typical scale lengths for two reading distances of 300 mm and 1 000 mm are given in Table 1 for resolution factors of 0.2, 0.5 and 1. The method of designing scales for all resolutions, ranges and reading distances is given in clause **6** and Figure 2.

Table 1 — Examples of scale lengths for reading at distances of 300 mm and 1 000 mm

Reading distance,D	r = 0.2	r = 0.5	r = 1.0
	Minimum scale length,L		
mm	mm	mm	mm
300	105	42	21
1 000	350	140	70

NOTE The relationship between D, L and r is explained in **4.2**.

5 Basic scales

5.1 Linear scales

Linear scales should be divided in accordance with one of the examples in Figure 3.

NOTE The scales shown are designed to cover the majority of needs.

Where other scale divisions are justified they should be constructed to meet the recommendations of clause **3**.

5.2 Non-linear scales

The system of dividing a non-linear scale should be based on the smallest scale division within the measuring range.

As far as is practicable, the values of the measurand corresponding to the major, intermediate and minor divisions should be constant throughout the measuring range.

Where an instrument has a different accuracy class over some part of the scale, it may be necessary to construct this part of the scale based on another resolution factor(s).

If, outside the measuring range, it is impractical to include all the major scale marks, those that are shown should be figured with half-size or less-emphasized figures.

5.3 Dual scales

Where two separate measurands can be read using the same index, both scales may be linear, one may be linear and the other non-linear, or both may be non-linear, and they may or may not have a common zero or a common resolution factor.

The procedure for design of dual scales either linear or non-linear is exactly the same as for single scales but with additional factors of compromise on differing resolution factors.

6 Method of design of scales

The approach to the method of designing a scale is conditioned by the initial requirements. A recommended generalized approach for all resolution ranges and reading distances is shown in Figure 2 (see also **4.3** but where certain factors are pre-determined, e.g. by the constraint of fixed case sizes and the qualities of the measuring element, shortened procedures may be adopted. Thus a manufacturer may wish to establish scales for a pre-determined case size, measuring element and type of application, in which the relationship between the measuring element and the proposed resolution factor of the scale should be determined, bearing in mind the maximum scale length which the proposed case will accommodate.

NOTE The resolution factor of the scale depends largely on the proposed application.

7 Index

7.1 Pointer tip

NOTE The accuracy of location of the index is of paramount importance.

Where the index is a pointer, it should have either a pointed tip or the tip should be a narrow blade. Where the tip is pointed, the penetration of the tip over the scale should be between one-third and two-thirds of the length of the minor scale mark. Illustrations of recommended shapes of pointer tip are given in Figure 4.

7.2 Direction of movement

The direction of movement of the index to show increasing magnitude of the measurand should be as shown in Table 2. Illustrations of the types of scale are given in Figure 5.

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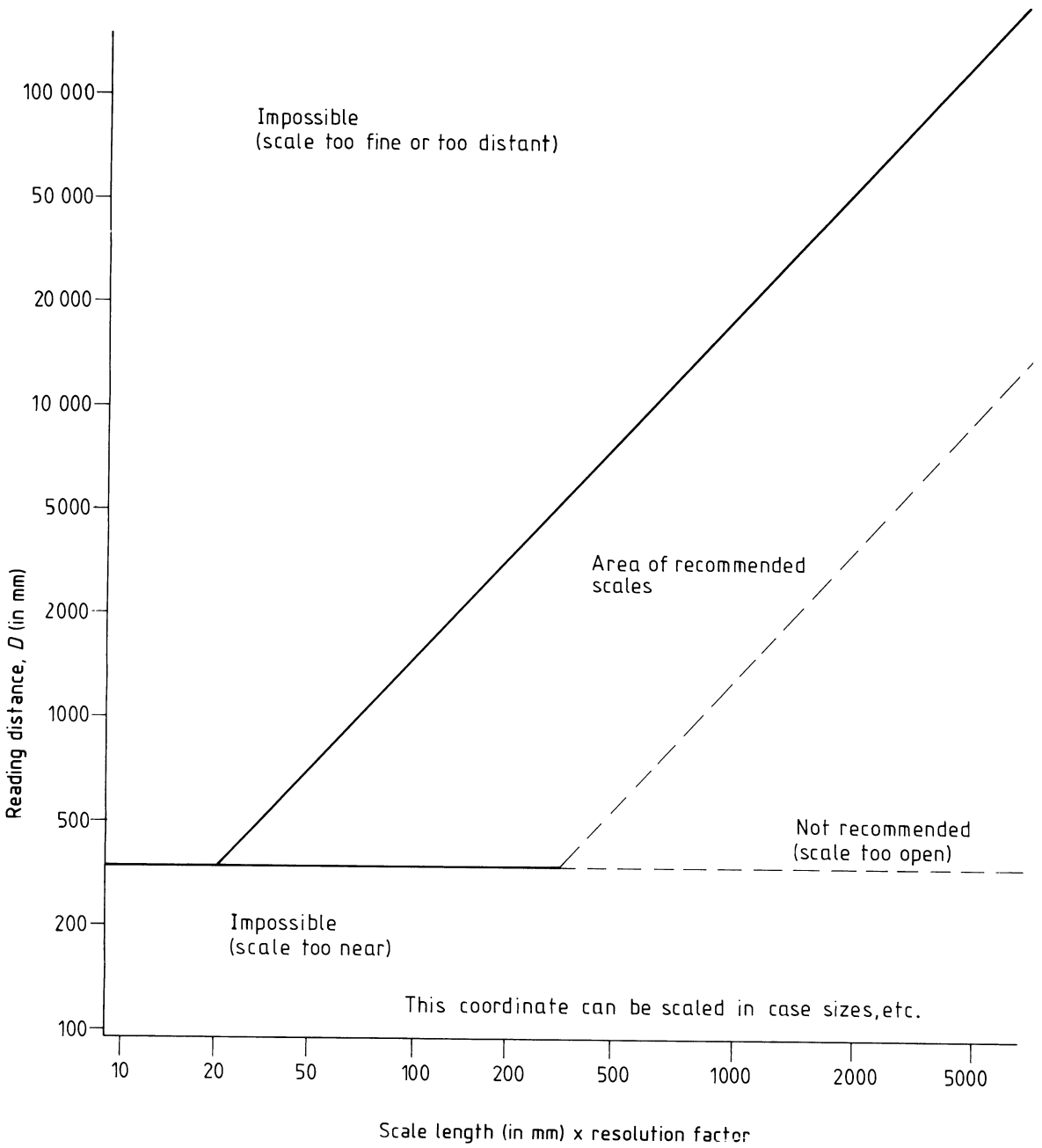

NOTE The right hand limit has been arbitrarily chosen and represents an interpolated division 10 times as large as the minimum recommended. It may be readjusted to suit manufacturing requirements.

Figure 2 — Relations between reading distance and scale length with respect to resolution factor

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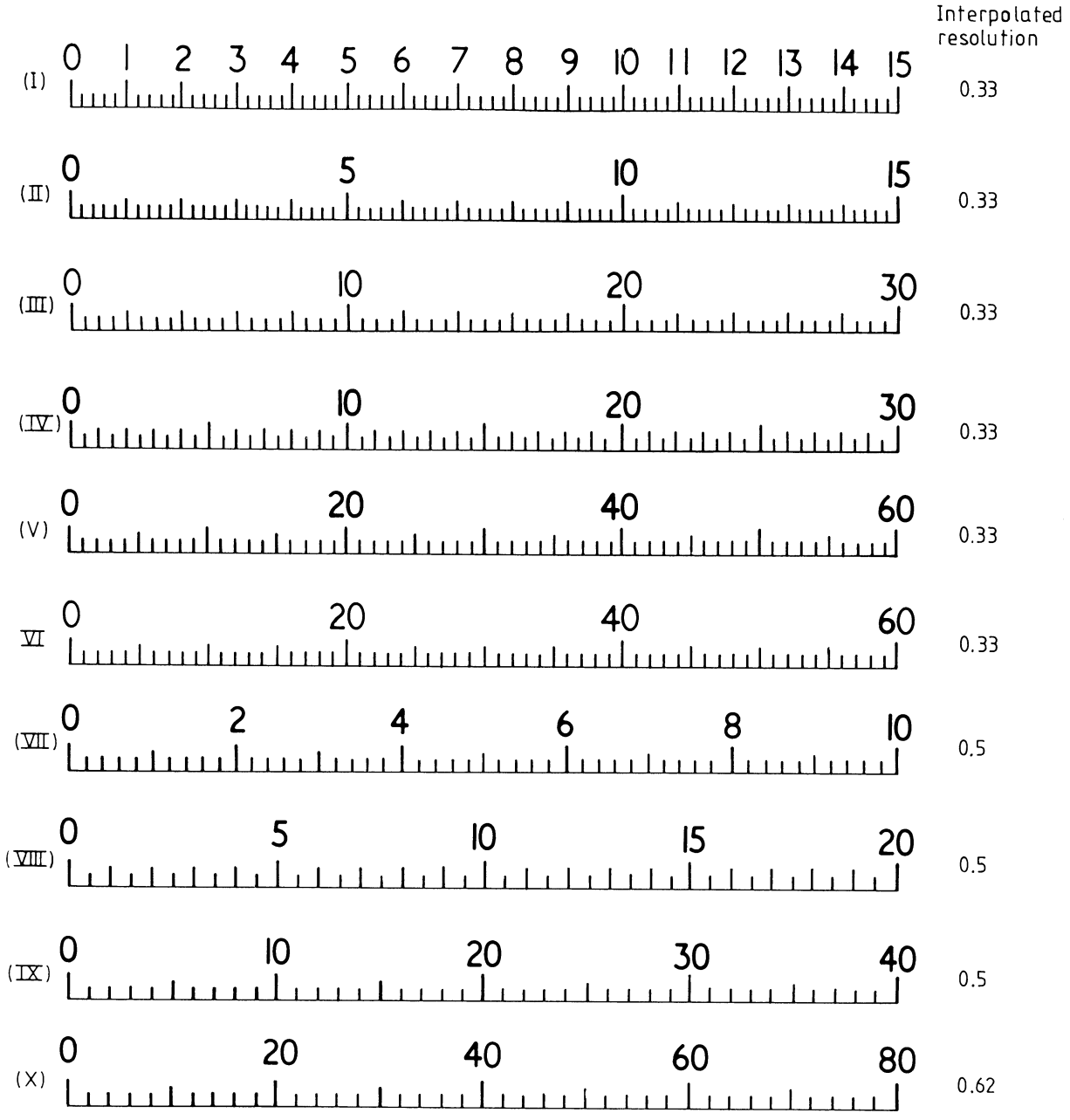

Figure 3 — Examples of recommended scale marks

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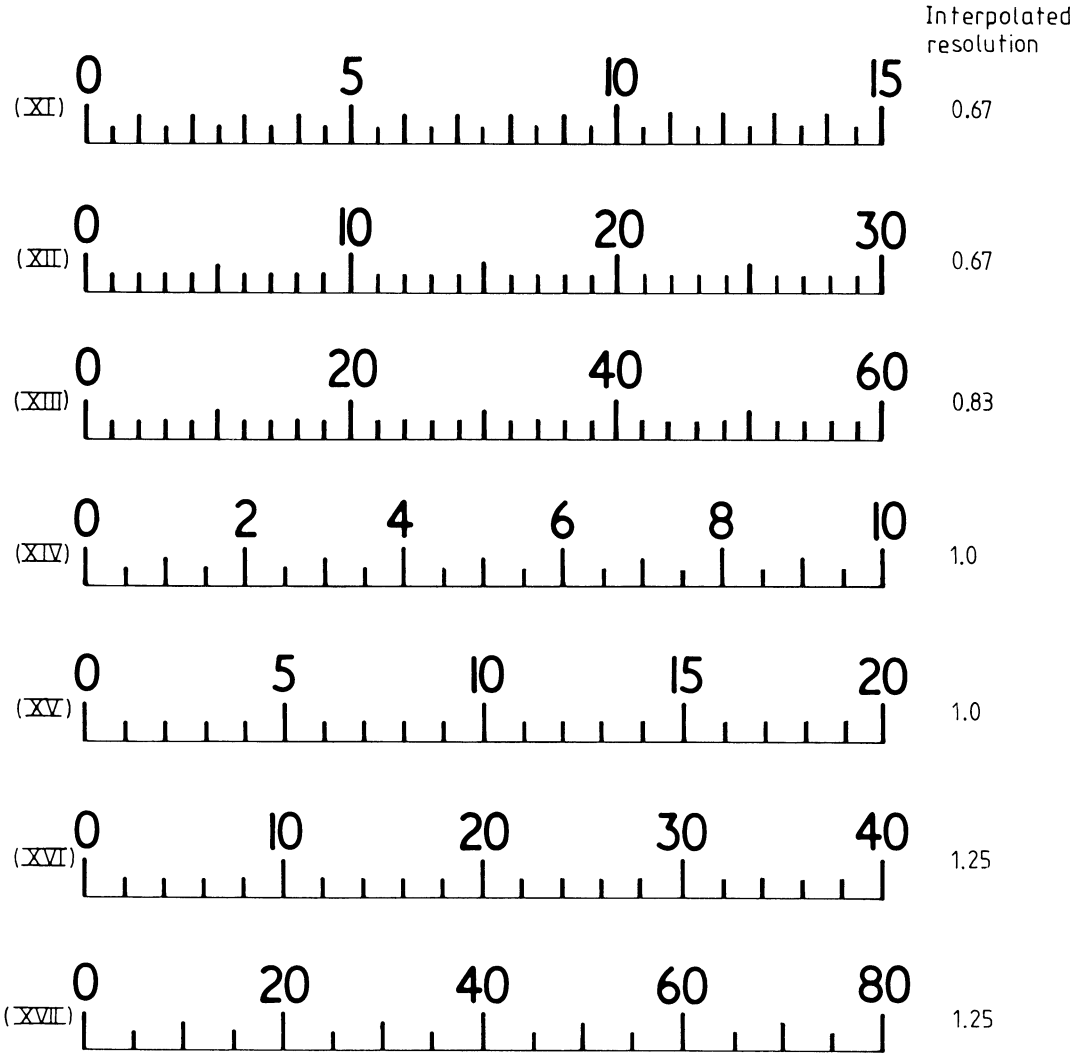

Figure 3 — Examples of recommended scale marks *(concluded)*

8 Proportions of scale marks

The thickness of scale marks should be approximately one-tenth of the length of a minor division, this latter distance being determined in the manner described in clause 4. These dimensions, expressed as a ratio of the scale length, are given in Table 3. For dual scales, the values for the lengths of scale marks should be 70 % of the values given in Table 3. The same tolerances are applicable. The marks may be emphasized by an increase in length but should not be increased in thickness over the main part of the scale as it is essential for all marks to be of the same thickness in the region of the index path, so that the lengths of all the scale divisions are the same. Where appropriate, further emphasis can be obtained by thickening a portion of each major scale mark opposite the scale mark base; an increase of up to three times the thickness of the main mark is recommended.

For scales in which the major scale marks are numbered using even numbers only, the intermediate scale mark between figured major scale marks may be replaced by an unfigured major scale mark.

9 Parallax

From consideration of the geometry of the diagram shown in Figure 6 it is clear that the error introduced by parallax can be reduced by making the fraction d/D small, where

d is the distance of the index from the dial;

D is the reading distance.

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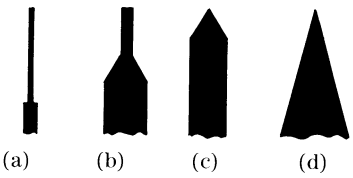
The error due to parallax is likely to be larger for shorter reading distances, as there is the practical difficulty of reducing the distance of the index from the dial below a certain amount.

In general, these recommendations are based on the ability to read scales to one-fifth of a division. If the distance between the index and the scale is equal to one-fifth of a division and the value indicated is read at an angle of 45° to the normal, an observation error equal in magnitude to the resolution is introduced. Furthermore, the scale division appears smaller to the observer; thus the probability of making an observation error is increased.

Where scales have to be viewed from a fixed position, care should be taken in so arranging the instruments that they are viewed normally as far as is practicable, i.e. from a position at right angles to the plane of the dial at the relevant scale mark. This suggests an instrument layout on a curved or angled plane where several instruments are to be viewed from a single position.

One type of construction is that known as a platform dial, in which the dial is stepped immediately adjacent to the ends of the scale marks to accommodate the index. Index and scale marks are thus in the same plane, and errors solely due to parallax will be reduced. Nevertheless, the divisions will appear smaller where viewed at an angle, and further, as the index tip will necessarily stop short of the ends of the scale marks, an observation error may be introduced due to the necessity of visually projecting the index tip on to the scale.



Key

(a) Recommended for resolutions up to 0.5 and multiple scales;

(b) Recommended for resolutions from 0.5 up to, but not including, 1.0;

(c) and (d) Recommended for resolutions of 1.0 and above.

Figure 4 — Recommended shapes of pointer tip

Where scales are to be read at short distances, an anti-parallax mirror may be provided. This mirror enables an observer to align the position of the eye in relation to the index so that it bisects the reflection of the pupil of the eye. Thus the scale is viewed at right angles in the region of the index, thereby reducing the total observation error. This form of construction also assists if scales are read at short distances, where parallax errors can result from binocular vision. The index should be thin and parallel-sided for a length which exceeds the width of the mirror. For scales having a small resolution factor one eye only should be used. It is also helpful if the underside (adjacent to the mirror) of the index is of a colour which contrasts with its sides and the outer side as the correct viewing position is then indicated when the contrasting colour disappears.

10 Other considerations

10.1 Boundary lines

The scales should preferably be without boundary lines but, if a boundary line is desired, not more than one should be used and its edge adjacent to the scale marks should coincide with the scale mark base. The thickness of the boundary line, if used, should never exceed the thickness of a minor scale mark.

10.2 Circular and part circular scales

For circular and part circular scales, it is desirable to place the figures on the outside of the scale arc so that the index will not obscure any of the figures. However, to achieve the maximum scale length, the figures may have to be placed inside the scale mark base.

10.3 Straight, sector and quadrant scales

For straight, sector and quadrant scales, whether horizontal or vertical, the figures should preferably be on that side of the scale marks which is opposite the index.

Apart from special considerations, such as the association of two instruments on a panel where for ease of taking comparative readings it may be desirable for the instruments to be of opposite hand, it is recommended that the figures should appear on the left of vertical straight scales and, where practicable, above horizontal straight scales.

10.4 Figures on scales

It is recommended that for figures on scales (other than those of the maximum scale values) the number of digits should not exceed three.

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Table 2 — Direction of movement of the index for increasing magnitude of the measurand

Type of scale	Direction of movement
Circular and part circular	Clockwise
Horizontal sector (top)	From left to right
Horizontal sector (bottom)	
Vertical sector (left hand)	Upwards (i.e. clockwise)
Vertical sector (right hand)	Upwards (i.e. anticlockwise)
Quadrant (upper left)	Upwards (i.e. clockwise)
Vertical (straight or edgewise)	Upwards
Horizontal (straight or edgewise)	From left to right

NOTE Increasing magnitude includes a transition from a negative value towards zero.

Table 3 — Dimensions of scale marks expressed as a ratio of scale length

Scale mark	Resolution factor, r		
	r = 0.1 to 0.25	r = 0.33 to 0.62	r = 0.67 to 1.25
	Dimension of scale mark expressed as a ratio of scale length		
Minor scale mark:			
Thickness[a]	0.001	0.00225	0.0045
Length[a]	0.01	0.016	0.024
Intermediate scale mark:			
Thickness	0.001	0.00225	0.0045
Length	0.01 × 1.5	0.016 × 1.5	0.024 × 1.5
Major scale mark:			
Thickness	0.001	0.00225	0.0045
Length	0.01 × 2	0.016 × 2	0.024 × 2
Figures:			
Height[a]	0.02	0.03	0.04

NOTE The dimensions of scale marks are obtained by multiplying the scale length by the values shown in this table.
[a] These dimensions should be within ± 20 % of these values.
The ratio of the sizes of major and intermediate scale marks to minor scale marks should remain as given in this table.

Where the unit of the measurand is such that it would result in the use of four or more digits, consideration should be given to the use of an appropriate SI prefix. For example, numbers such as 12 000 V or 0.005 bar[1)] should be avoided by the use of kV and mbar respectively as the units.

10.5 Limits of the measuring range

10.5.1 If the measuring range does not occupy the whole scale length, the limits of the measuring range should be clearly identified.

10.5.2 When the value of the scale division or the nature of the scale mark enable the measuring range to be identified without ambiguity, no marking of the measuring range limits is necessary. An example is shown in Figure 7.

10.5.3 When there is only one scale and marking of the limits of the measuring range is necessary, these may be identified by means of dots as shown in Figure 8.

10.5.4 When there is more than one scale and marking of the limits of the measuring range is necessary, the limits of these may be identified either by dots as in **10.5.3**, or by means of widened scale mark bases as shown in Figure 9.

10.6 Unit designation

It is recommended that the size of the unit symbol or scale caption is not less than the size of the figures on the scales. Suitable symbols may be found in BS 5775.

[1)] 1 bar = $10^5 N/m^2$ = 10^5 Pa.

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11 Form of digits

Digits and unit designations on dials should conform to ergonomic standards for legibility. The heights of the characters should be related to the intended reading distance; the height should subtend an angle of not less than 16 ′ of arc at the user's eye. Examples of typical character heights are given in Table 4.

Table 4 — Examples of character heights for reading at distances of 300 mm, 600 mm and 1 000 mm

Reading distance	Character height
mm	mm
300	1.4
600	2.8
1 000	4.65

The aspect ratio of the character set (width/height) should be between 55 % and 80 %. The character stroke width should be between 10 % and 20 % of character height. Italic forms should not be used.

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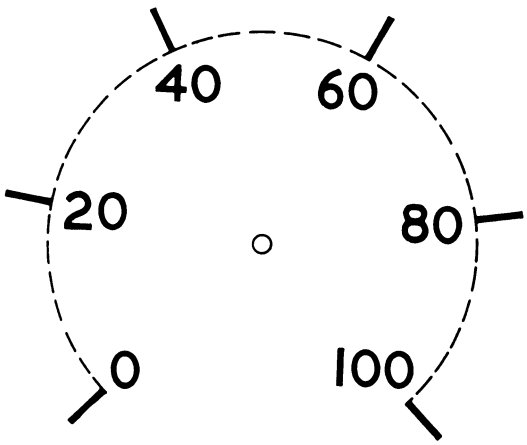
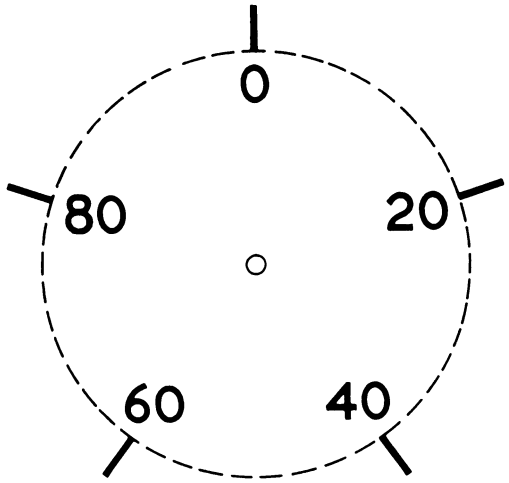
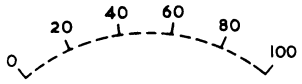


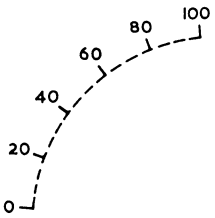
(a) Part circular scale



(b) Full circular scale

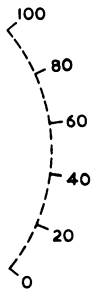


(c) Horizontal sector scale (top)



(d) Horizontal sector scale (bottom)

(e) Quadrant scale (upper left)



(f) Vertical sector scale (left hand)

(g) Vertical sector scale (right hand)

Figure 5 — Illustrations of types of scales

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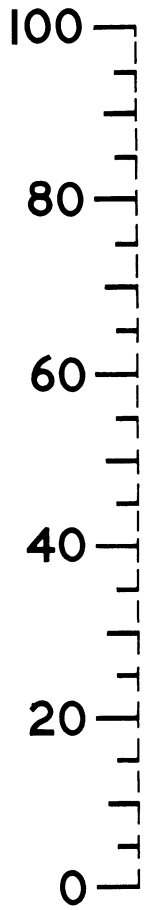
(h) Horizontal, straight or edgewise scale



(i) Vertical, straight or edgewise scale

Figure 5 — Illustrations of types of scales *(concluded)*

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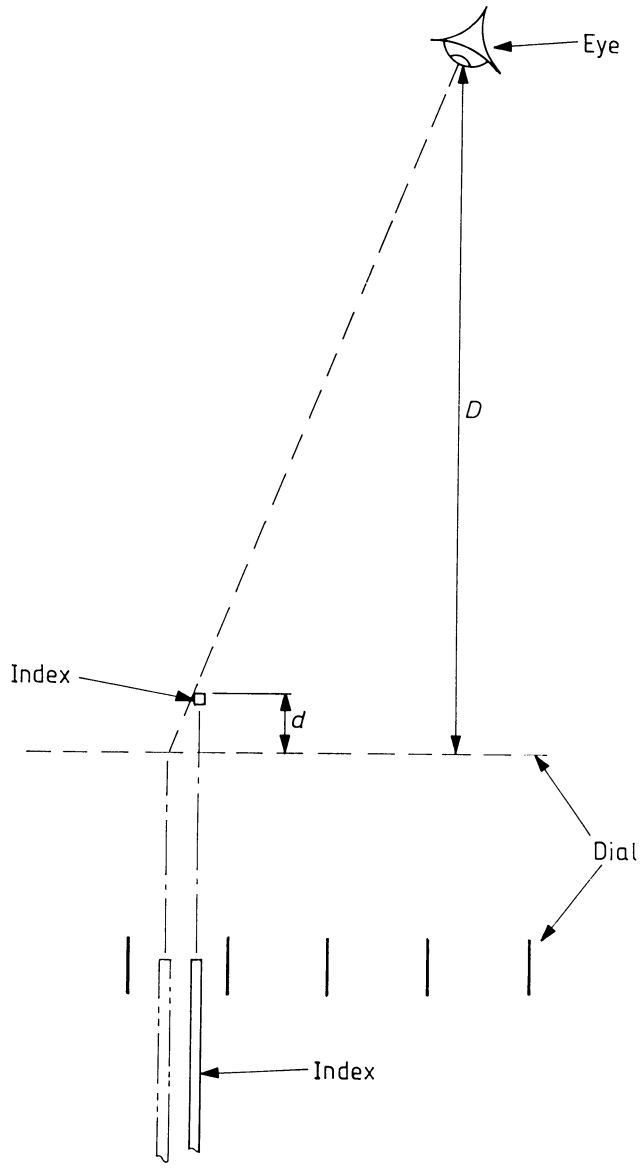

Figure 6 — Effect of parallax (see clause **9**)

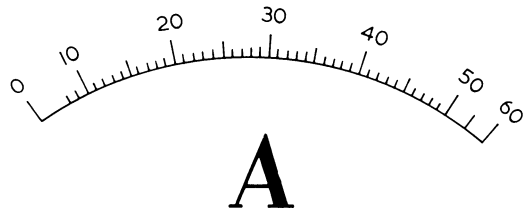

Figure 7 — Measuring range 8 A to 50 A, the subdivisions being omitted outside the measuring range

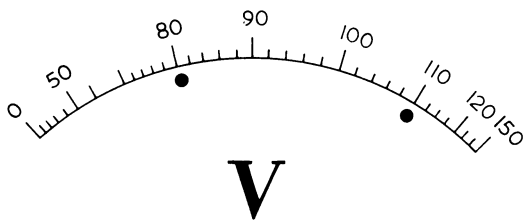

Figure 8 — Measuring range 80 V to 110 V, the measuring range being between the dots

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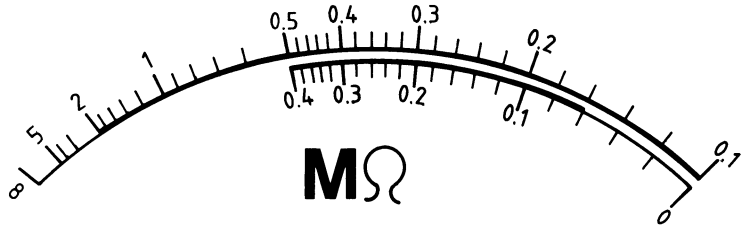

Figure 9 — Measuring ranges 0.06 MΩ to 0.4 MΩ and 0.1 MΩ to 2 MΩ, the scale mark bases of the measuring ranges being thickened

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