BRITISH STANDARD

BS 235:1987

Specification for

Gears for electric traction

UDC 621.833:[621.33 + 629.03-83]

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Machinery and Components Standards Committee (MCE/-) to Technical Committee MCE/5, upon which the following bodies were represented:

Advanced Manufacturing Technology Research Institute
Association of Consulting Engineers
British Clock and Watch Manufacturers' Association
British Coal
British Gear Association
British Horological Institute
British Railways Board
Engineering Equipment and Materials Users' Association
Federation of Manufacturers of Construction Equipment and Cranes
Gauge and Tool Makers' Association
Institution of Mechanical Engineers
Institution of Production Engineers
Lloyd's Register of Shipping
Milling Cutter Association
Ministry of Defence
Power Generation Association (BEAMA Ltd.)
Society of Motor Manufacturers and Traders Limited

The following bodies were also represented in the drafting of the standard through subcommittees and panels:

Brush Electrical Machines Ltd.
London Regional Transport
Railway Industry Association of Great Britain

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Contents

Foreword

This revision of this British Standard has been prepared under the direction of the Machinery and Components Standards Committee. The main changes incorporated are the inclusion of metric module gears and the deletion of diametral pitch gears, the relating of gear accuracy grades to pitch surface velocity, reference to a method of calculating gear loading and the addition of a list of ordering instructions.

This revision of BS 235 supersedes BS 235:1972, which is withdrawn.

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

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 10, 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.

1 Scope

This British Standard specifies requirements for spur and helical gears in accuracy grades 5, 6, 7 and 8 of BS 436-2, for the drive between the electric motors and the axles of vehicles running on rails. It also specifies requirements for the permissible deviations and tolerances of tooth form and dimensions, hardness and the fitting surfaces, keys and keyways of wheels and pinions.

NOTE 1 Appendix A lists the instructions that should be supplied by the customer to the gear designer. Guidance is given in Appendix B on the materials for the manufacture of gears. Appendix C recommends a method for determining the bedding surface of taper bored pinions. Appendix D gives guidance on the choice of gear tooth accuracy grades.

NOTE 2 The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this British Standard the definitions given in BS 2519-1 apply, together with the following.

case depth of a surface hardened gear

the depth measured normal to the surface of the gear at which the hardness is 550 HV 1 for carburized and hardened gears and 80 % of surface hardness HV 1 for all other surface hardened gears

3 Gear tooth accuracy grades

Gears for electric traction shall belong to accuracy grades 5, 6, 7 or 8 of BS 436-2.

4 Symbols

For the purposes of this British Standard the symbols shown in BS 2519-2 apply. For convenience the list of symbols used in this standard is as follows:

a	Centre distance
b	Face width
b_1	Face width, pinion
b_2	Face width, wheel
d	Reference circle diameter
d_1	Reference diameter, pinion
d_2	Reference diameter, wheel
d_a	Tip diameter
d_{a1}	Tip diameter, pinion
d_{a2}	Tip diameter, wheel
d_b	Base diameter
h_a	Addendum
K_A	Application factor
k	Number of teeth over which base tangent span is measured
l	Length of arc
m_n	Normal module
s	Arc tooth thickness
W_k	Base tangent span
x	Addendum modification coefficient
x_1	Addendum modification coefficient, pinion
x_2	Addendum modification coefficient, wheel
y	Centre distance modification coefficient
z	Number of teeth
z_1	Number of teeth, pinion
z_2	Number of teeth, wheel
α_n	Normal pressure angle at reference cylinder
α_t	Transverse pressure angle at reference cylinder
α_{tw}	Transverse pressure angle, working
β	Helix angle at reference cylinder
β_b	Base helix angle
ϕ_f	Tolerance factor for tooth profile deviation
ϕ_p	Tolerance factor for total composite deviation

5 Normal modules

Normal modules, m_n, for traction gears shall be within the following range:

4, 4.5, **5**, 5.5, **6**, 7, **8**, 9, **10**, 11, **12**, 14 mm.

NOTE Preferred values are given in bold type face.

6 Form of gear tooth

6.1 Basic rack profile

Any modifications to the basic rack tooth profile as specified in BS 436-2 and shown in Figure 1 shall be within the following limits:

a) variation of the total depth within the limits 2.25 to 2.40, permitting an increase in root clearance within the limits 0.25 to 0.40 to allow for different manufacturing processes;

b) variation of the root radius within the limits 0.25 to 0.39;

c) variation of the pressure angle.

NOTE 1 The basic rack tooth profile has a pressure angle of 20°.

NOTE 2 Protuberance cutters should be used to ensure that root fillets are free from grinding or other mechanical damage post-heat treatment operations.

6.2 Tooth dimensions

The teeth of wheels and pinions shall have the dimensions calculated from the formulae given in Table 1.

NOTE Unless precluded by design considerations, pinion helix angles should be right hand.

Table 1 — Nominal tooth dimensions of wheels and pinions[a]

Dimensions	Symbol	Formula
Reference circle diameter	d	$\frac{m_n z}{\cos\beta}$
Centre distance[b]	a	$\frac{d_1 + d_2}{2} + m_n y$ (1) $\qquad$ $\frac{d_1 + d_2}{2} + m_n (x_1 + x_2)$ (2)
Addendum[c]	h_a	$m_n (1 + x)$
Total tooth depth (addendum and dedendum)[d]	—	$2.25\ m_n$
Arc tooth thickness on reference circle	s	$m_n \left(\frac{\pi}{2} + 2x \tan\alpha_n\right)$
Tip diameter	d_a	$m_n \left[\frac{z}{\cos\beta} + 2\,(1 + x)\right]$
Transverse pressure angle	α_t	$\tan^{-1}(\tan\alpha_n \sec\beta)$
Base diameter	d_b	$d \cos\alpha_t$
Base helix angle	β_b	$\sin\beta_b = \sin\beta \cos\alpha_n$
Number of teeth over which base tangent span is measured[ef]	k	$\frac{1}{\pi}\left\{z \tan\left[\cos^{-1}\left(\frac{d_b}{d\,(1 + \frac{2x}{z})}\right)\right] \sec^2\beta_b - z\ \text{inv}\,\alpha_t - 2x \tan\alpha_n + z\ \text{inv}\,\alpha_t + \frac{\pi}{2}\right\} + \frac{x}{8}$
Base tangent span	W_k	$m_n \cos\alpha_n [\ \pi\,(k - 0.5) + 2x \tan\alpha_n + z\ \text{inv}\,\alpha_t]$

[a] Numbers appropriate for pinion dimensions and wheel dimensions to be entered, i.e. z_1 and x_1, and z_2 and x_2 respectively.

[b] Gears designed for (1) will engage with minimum backlash, gears designed to (2) may have additional backlash to any envisaged by cutting details.

[c] Guidance is given on the addendum modification coefficient x in PD 6457.

[d] This may have any value from $2.25\ m_n$ to $2.40\ m_n$ [see **6.1** a)].

[e] The value of k should be rounded to the nearest integer. The term $x/8$ is an empirical value which ensures that the rounding is to the most practical value.

[f] A check should be made to ensure that the face width of helical gears enables the measurement to be made over the base tangent span.

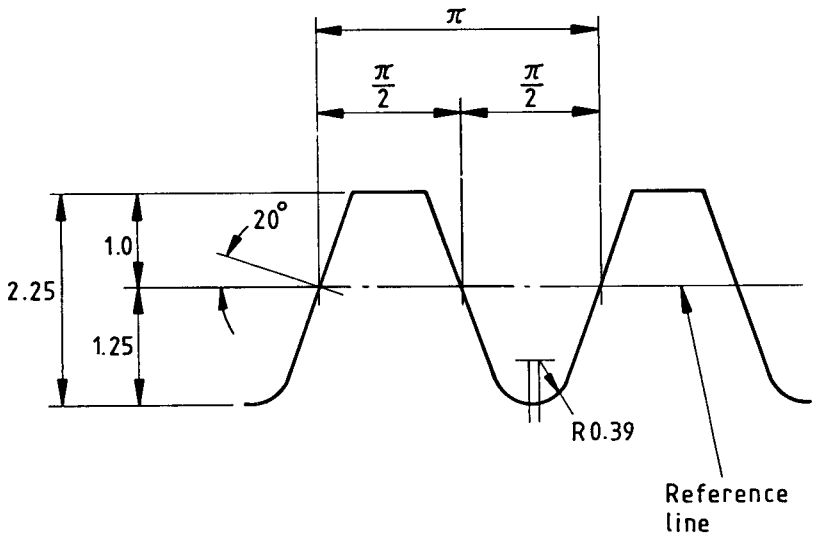


Figure 1 — Basic rack tooth profile for unit normal metric module

7 Gear tooth accuracy

NOTE The data in clause **7** are taken from BS 436-2 and are included in this standard for convenience.

7.1 Limits of tolerance on pitch

Limits of tolerance on gearwheel and pinion tooth profiles shall comply with Table 2 as appropriate.

Measurement of the transverse pitch deviation shall be made on a circle which is concentric with the axis of rotation.

Table 2 — Tolerance on pitch

Accuracy grade	Limits of tolerance
	μm
5	$1.6\sqrt{l} + 4.0$
6	$2.5\sqrt{l} + 6.3$
7	$3.55\sqrt{l} + 9.0$
8	$5.0\sqrt{l} + 12.5$
NOTE l is any selected length of an arc less than $\pi d/2$ (in mm).	

7.2 Limits of tolerance of tooth profile deviation

Limits of tolerance of tooth profile deviation shall comply with Table 3, as appropriate.

Where gear teeth are profile ground the surface roughness on the tooth flank, measured in accordance with BS 1134-1, shall not exceed 0.8 μm R_a.

NOTE 1 The tolerance values are based on a tolerance factor ϕ_f, given by the following equation:

$$\phi_f = m_n + 0.1\sqrt{d}$$

where

m_n is the normal module (in mm);

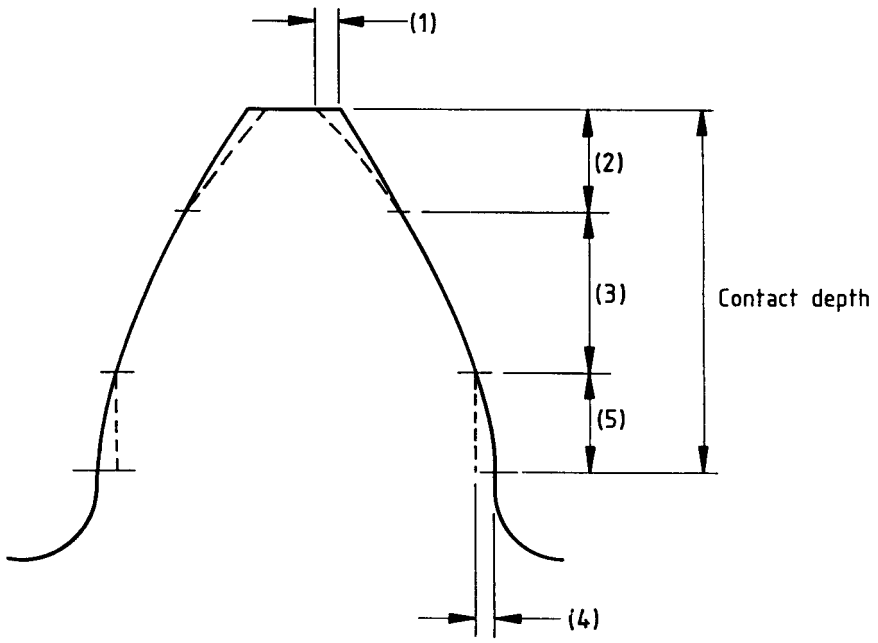
d is the reference circle diameter (in mm).

Table 3 — Limits of tolerance on tooth profile

Accuracy grade	Profile tolerance
	μm
5	$0.40\,\phi_f + 5.0$
6	$0.63\,\phi_f + 6.5$
7	$1.00\,\phi_f + 8.0$
8	$1.60\,\phi_f + 10.0$

NOTE 2 The limits of tolerance apply to the unmodified (true involute) section of the tooth profile. In most applications part of the gear tooth profile will be modified from true involute form. This will normally take the form of "tip" or "root" relief, as shown in Figure 2, and known as profile modification. Such profile modifications are designed to accommodate the effects of tooth deflection under load and small pitch variations. They are specified by the gear designer when required and may be applied to the pinion, the wheel or both.

NOTE 3 Checking of gear tooth profiles is normally performed using a generative involute profile measuring machine, which measures variation from true involute, It is usual for such machines to show a true involute as a straight line on the record sheet, with departures from true involute being shown as a deviation from a straight line. For this reason, profile tolerances are shown in the form of a profile diagram. An illustration of this type of diagram is shown in Figure 3, and Figure 4 shows a sample profile diagram with typical dimensions.



Key
1 Tip relief
2 Radial length of tip relief
3 True involute portion
4 Root relief
5 Radial length of root relief

NOTE This figure is for guidance only and does not form part of this standard.

Figure 2 — Typical tooth profile modification

7.3 Limits of tolerance of total composite deviation

Limits of tolerance of total composite deviation shall comply with Table 4, as appropriate.

NOTE The tolerance values are based on the factor ϕ_p, given by the following equation:

$$\phi_p = m_n 0.25 \sqrt{d}$$

where

m_n is the normal module (in mm);

d is the reference circle diameter (in mm).

Table 4 — Limits of tolerance on total composite error

Accuracy grade	Total composite tolerance
	μm
5	$2.00\ \phi_p + 25.0$
6	$3.15\ \phi_p + 40.0$
7	$4.50\ \phi_p + 56.0$
8	$5.60\ \phi_p + 71.0$

7.4 Backlash

Backlash shall be not less than

$(20\ m_n + 40)$ μm

or greater than

$(50\ m_n + 100)$ μm

i.e. maximum backlash = 2.5 × minimum backlash.

NOTE 1 Tooth thicknesses of wheels and pinions should be adjusted as necessary to provide this specified range of backlash. It is essential that adjustments to tooth thickness are compatible with tooth strength requirements.

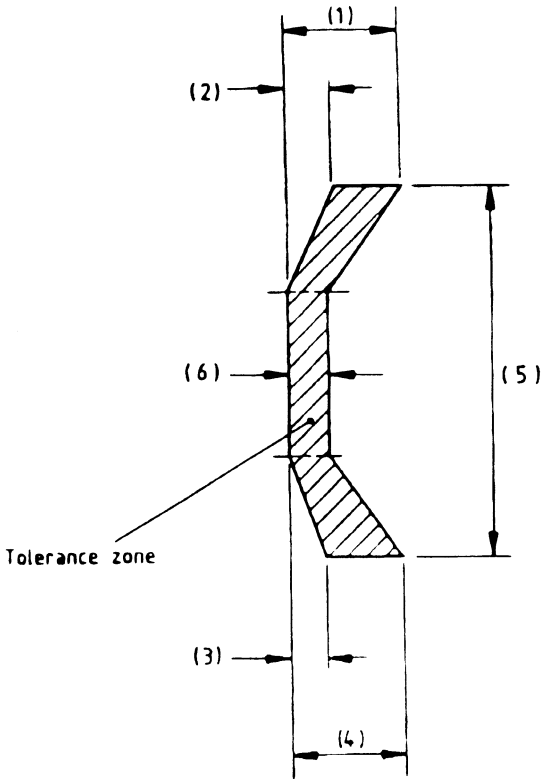
NOTE 2 Backlash should be measured at nominal (minimum) centre distances (i.e. the centre distances given in Table 1).

7.5 Tolerance of tooth alignment

The limits of tolerance of tooth alignment deviation shall be in accordance with the formulae given in Table 5.

NOTE 1 Tolerances are related to a proportion or to the whole of the face width b (in mm) of the gear and apply up to a maximum value of 150 mm.

NOTE 2 In specifying the accuracy of gear helices and gear mounting arrangements, tolerances should be chosen which will enable mesh misalignment to be kept within the required limits.



Key
1 Maximum tip relief
2 Minimum tip relief
3 Minimum root relief
4 Maximum root relief
5 Trace length
6 Profile tolerance

NOTE This figure is for guidance only and does not from part of this standard.

Figure 3 — Typical tooth profile tolerance chart

Table 5 — Limits of tolerance on tooth alignment

Accuracy grade	Tolerance on alignment
	μm
5	$0.80\sqrt{b} + 4.00$
6	$\sqrt{b} + 5$
7	$1.25\sqrt{b} + 6.3$
8	$2\sqrt{b} + 10$

NOTE The tolerances derived from the formulae do not indicate the range of deviation of tooth alignment permitted for the teeth of an individual gear.

7.6 Crowning or taper relief

When the gear teeth have been modified by crowning or by taper relief so as to mitigate the effects of mesh misalignment resulting from shaft deflection bearing clearances etc., backlash shall be determined at the unmodified part of the teeth.

NOTE Some guidance of this subject is given in Appendix C of BS 436-3:1986.

8 Hardness and case depth of finished, surface hardened gears

8.1 Hardness tests

Hardness tests, appropriate to the gear being tested, shall be carried out on finished, surface hardened gears in accordance with BS 240, BS 427-1, BS 891-1, BS 6479 or BS 6481.

In cases where it is necessary to convert hardness numbers, such conversions shall be in accordance with BS 860.

8.2 Position and number of hardness tests

When measurements on a sufficient number of gears show the relationship between hardness at the chosen position and tooth flank hardness to be consistent, hardness tests shall be carried out on both flanks of two teeth approximately 180° apart or on crests, roots or ends of teeth.

8.3 Carburized and hardened gears

The surface hardness of carburized and hardened gears shall be not less than 650 HV 30 (58.0 HRC). Maximum hardness, appropriate to the materials being used, shall be specified on the manufacturer's drawings.

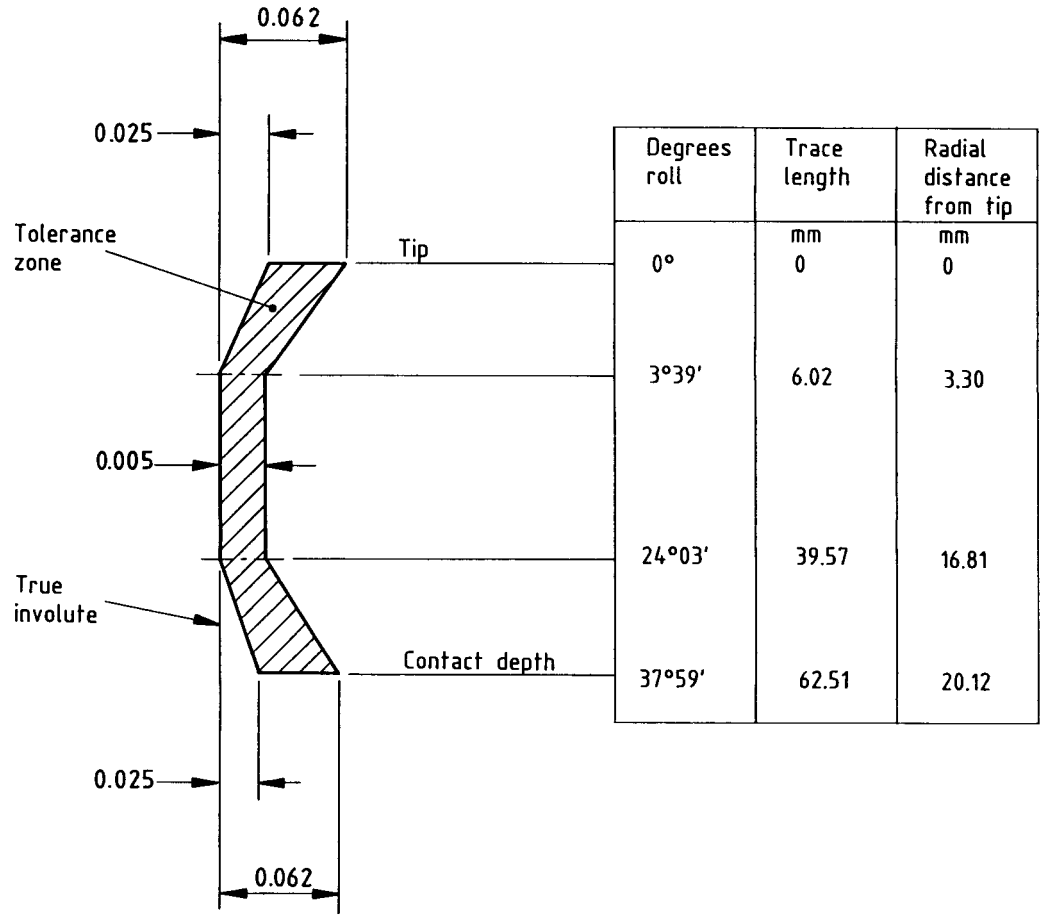
8.4 Other case hardened gears

The surface hardness of other case hardened gears shall be not less than 550 HV 30 (53.1 HRC). Maximum hardness, appropriate to the material being used and the production process, shall be specified on the manufacturer's drawings.

8.5 Case depth

8.5.1 *General.* The effective case depth shall be determined in accordance with BS 6481 for induction hardening and BS 6479 for carburizing.

8.5.2 *Carburized and hardened gears.* The case depth of carburized and hardened gears shall comply with Table 6, as appropriate. For checking the case depth each container shall have one "spy piece" when box carburizing, and at least one, but preferably two (towards top and bottom of furnace), when gas carburizing. The "spy piece" shall have a cross section which simulates that of the teeth which it represents, and shall be placed near to, but not on, the teeth of the gear. To verify hardness depth, as specified in Table 6, a traverse shall be made over a section of this "spy piece".



Degrees roll	Trace length	Radial distance from tip
	mm	mm
0°	0	0
3°39′	6.02	3.30
24°03′	39.57	16.81
37°59′	62.51	20.12

NOTE This figure is for guidance only and does not form part of this standard.

Figure 4 — Example of a typical tooth profile tolerance chart

8.5.3 *Other surface hardened gears.* Before each batch of gears is hardened, the process shall be proved by hardening a number of consecutive teeth of a representative test piece. The hardened teeth shall be sectioned and, when tested, their case depth and hardness shall comply with Table 6, as appropriate.

NOTE Variations in case depth can occur between the tooth flanks, tooth roots and any test pieces. The extent of this variation depends upon the hardening process used, the gear design and the material. When considered necessary, the extent of the permitted variation should be agreed between the purchaser and the gear manufacturer, taking into account the effect on gear rating as calculated by BS 436-3.

Table 6 — Case depth of finished, surface hardened gears

Material treatment	Hardness at effective depth	Recommended depth
		mm
Carburized and hardened	550 HV 1	(0.15 m_n + 0.2) to (0.2 m_n + 0.4)
Contour induction hardened	80 % of surface hardness HV 1	(0.08 m_n + 1.4) minimum
Spin and single shot induction hardened		(0.2 m_n + 1.4) minimum

8.6 Crack detection

After heat treatment all gears shall be inspected for cracks.

NOTE While the magnetic method is generally used (see BS 6072), the use of other methods, e.g. dye penetrant (see BS 6443), is not precluded.

9 Gear load capacity

The load capacity of the gears shall be assessed in accordance with BS 436-3.

NOTE It is emphasized that it is the responsibility of the gear designer in collaboration with the customer or his agent, to provide an application factor K_A which needs to take into account load increments deriving from condition of the track and any other source, e.g. coupling snatch, high starting-torques.

10 Features of the wheels and pinions

10.1 Fitting surfaces

10.1.1 If tapered, the fitting surface shall have a taper on diameter of either 1 in 10 or 1 in 20.

NOTE The latter is usually used for plug-in pinions.

10.1.2 When the pinion is fitted with its corresponding taper gauge there shall be bedding over not less than 90 % of the fitting surface.

NOTE Appendix C gives a recommended method for determining the bedding area of taper bores.

10.1.3 The fitting surface of all taper bores shall have a surface texture not coarser than 0.6 μm R_a when measured in accordance with BS 1134-1.

10.1.4 The fitting surface of parallel head gear wheels shall have a surface texture not coarser than 0.8 μm R_a when measured in accordance with BS 1134-1.

10.1.5 Where oil injection holes and grooves are provided, sharp corners shall be blended out.

10.2 Keys, keyways and shaft ends

10.2.1 *General*. Keys, keyways and shaft ends shall comply with BS 4235-1 and BS 4506.

10.2.2 *Alignment of keyways*. The alignment of keyways shall be checked. The tangent of the maximum deviation of the radial plane of symmetry of a keyway, from an axial plane of a bore or shaft, shall not exceed 0.0005 units per unit length.

NOTE 1 The relative positions of keyway and tooth spaces should be such as to reduce the possibility of fracture between root fillet and keyway.

NOTE 2 A suitable means for checking the alignment is a plug gauge with a dummy key.

10.3 Profile grinding of hardened gears

When the teeth of hardened gears are ground, the tooth flanks of the wheels and pinions shall be fully cleaned up over the usable tooth surface.

11 Marking

Each gear wheel and pinion shall be plainly marked with the manufacturer's identification and serial number.

NOTE Any other information required by the purchaser may also be marked.

Marking shall not result in stress raisers in highly stressed areas.

Appendix A Ordering instructions

The following information should be prepared by the customer and supplied to the gear designer to enable suitable gears to be designed:

a) the power and application factor (see clause **9**);

b) the pinion speed;

c) the centre distance;

d) any constraining dimensions;

e) the required ratio;

f) the wheel bore diameter with tolerance;

g) the pinion fitting surface dimension.

NOTE The lubrication system and the lubricant may be left to the discretion of the designer.

The following optional information may also be supplied:

h) the gearing accuracy grade;

i) a drawing with above information;

j) a drawing showing intended mounting arrangement, including bearing clearances;

k) the gear material;

l) the heat treatment etc.;

m) any other information required to determine gear design.

Appendix B Guidance on materials for the manufacture of traction gears

The materials given in Table 7 have proved successful in the past for the manufacture of traction gears. This list is for guidance only and is not intended to limit the gear designer in his choice of materials.

Table 7 — Materials for traction gears complying with BS 970-1

Type of gear	Grade	Size
Direct hardened alloy steel gears	709 M 40	S and T
	817 M 40	T
Contour induction hardened gears	709 M 40	S and T
	817 M 40	T
Case carburized and hardened gears (see note)	655 M 13	—
	665 M 17	—
	832 M 13	—

NOTE Forgings for case carburized and hardened gears need to be of inherent fine grain quality. Fine grain may be defined as that shown by the standard grain size numbers 5 to 8 in BS 4490.

Appendix C Recommended method for determining bedding area of taper bores

C.1 Check taper bores with a full form taper plug gauge which is compatible with the ring gauge used to check the corresponding taper shaft.

NOTE It is recommended that the purchaser supplies the manufacturer with the appropriate taper gauge.

C.2 Check every taper bore with the full form taper plug gauge.

Use either:

a) a suitable dye penetrant fluid viewed under ultra violet light; or

b) Prussian blue.

C.3 Coat the whole of the effective surface with a very thin film of the checking medium.

Carefully insert the plug gauge as far as possible into the taper bore without touching the sides, and complete the last stage in one clean linear movement. Do not rotate the gauge when inserting or removing it from the bore.

Inspect the pinion bore.

Reject any pinion:

a) not showing even distribution of the checking medium over 90 % of the bore; isolated unmarked areas should not be larger than 2 % of the total bore area;

b) which has circumferential or longitudinal waviness, as defined by the marking, with a pitch of 8 mm or more; where the pitch is 8 mm or less, the depth of the waviness should not exceed 0.005 mm.

Appendix D Guidance on the selection of the gear tooth accuracy grade

Major influences on the choice of accuracy grades are:

a) the dynamic stresses caused solely by the gear tooth errors;

b) the maximum noise levels which can be tolerated;

c) the maximum vehicle speed;

d) the condition of the track on which the vehicle is run;

e) the transmitted tractive and braking efforts.

All the above factors should be considered in making the final choice, but if further guidance is needed, recommended ranges for each quality grade are given in Table 8.

Table 8 — Gear tooth accuracy grades

Wheel and pinion accuracy grades	Recommended pitch surface velocity ranges	Approximate vehicle speed
	m/s	km/h
5	above 25	greater than 160
6	above 20 to 25	above 140 to 160
7	from 14 to 20	from 50 to 140
8	below 14	below 50

NOTE Pairing of mating gears of different grades, e.g. grades 7 and 8 for surface velocities from say 10 m/s to 16 m/s or grades 6 and 7 for surface velocities from 18 m/s to 22 m/s is a choice open to designers. If there is a choice it is recommended that the more accurate grade is chosen.

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Publications referred to

BS 240, *Method for Brinell hardness test and for verification of Brinell hardness testing machines.*

BS 427, *Method for Vickers hardness test.*

BS 427-1, *Testing of metals.*

BS 436, *Spur and helical gears.*

BS 436-2, *Basic rack form, modules and accuracy (1 to 50 metric module).*

BS 436-3, *Method for calculation of contact and root bending stress limitations for metallic involute gears.*

BS 860, *Tables for comparison of hardness scales.*

BS 891, *Method for Rockwell hardness test.*

BS 891-1, *Testing of metals.*

BS 970, *Specification for wrought steels for mechanical and allied engineering purposes.*

BS 970-1, *General inspection and testing procedures and specific requirements for carbon, carbon manganese, alloy and stainless steels.*

BS 1134, *Method for the assessment of surface texture.*

BS 1134-1, *Method and instrumentation.*

BS 2519, *Glossary for gears.*

BS 2519-1, *Geometric definitions.*

BS 2519-2, *Notation.*

BS 4235, *Metric keys and keyways.*

BS 4235-1, *Parallel and taper keys.*

BS 4490, *Methods for the determination of the austenitic grain size of steel.*

BS 4506, *Shaft ends.*

BS 6072, *Method for magnetic particle flaw detection.*

BS 6443, *Method for penetrant flaw detection.*

BS 6479, *Method for determination and verification of the effective depth of carburized and hardened cases in steels.*

BS 6481, *Method for determination of effective depth of hardening of steel after flame or induction hardening.*

PD 6457, *Guide to the application of addendum modification to involute spur and helical gears.*

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