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BSI Standards Publication

Railway rolling stock materials

Part 7: Specification for product and technical approval requirements for cast wheels

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Contents

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 54, an inside back cover and a back cover.

Foreword

Publishing information

This part of BS 5892 is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 30 November 2014. It was prepared by Panel RAE/3/-/1, *Wheels and Wheelsets*, under the authority of Technical Committee RAE/3, *Railway rolling stock materials.* A list of organizations represented on this committee can be obtained on request to its secretary.

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Relationship with other publications

BS 5892 is published in the following parts:

- BS 5892-1, *Railway rolling stock materials – Part 1: Specification for axles for traction and trailing stock*;
- BS 5892-2, *Railway rolling stock materials – Part 2: Specification for forged and rolled wheel centres*;
- BS 5892-3, *Railway rolling stock materials – Part 3: Specification for monobloc wheels for traction and trailing stock*;
- BS 5892-4, *Railway rolling stock materials – Part 4: Specification for forged and rolled tyres*;
- BS 5892-5, *Railway rolling stock material (metric) – Part 5: Specification for steel bars for retaining rings for tyred wheels*;
- BS 5892-6, *Railway rolling stock materials – Part 6: Specification for wheelsets for traction and rolling stock*;
- BS 5892-7, *Railway rolling stock materials – Part 7: Specification for product and technical approval requirements for cast wheels*;
- BS 5892-8, *Railway rolling stock materials – Part 8: Railway applications – Wheelsets and bogies – Powered and non-powered wheelsets with inboard bearings – Product requirements*.

Presentational conventions

The provisions of this standard are presented in roman (i.e. upright) type. Its requirements are expressed in sentences in which the principal auxiliary verb is “shall”.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

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Introduction

Before the publication of this part of BS 5892, the only standards available to define quality and technical approval requirements for monobloc wheels were BS 5892-3, BS EN 13262 and BS EN 13979-1, which apply only to forged and rolled wheels, and DD CEN/TS 13979-2 and DD CEN/TS 15718, which were published as reference documents for cast wheels.

Cast wheels are commonly used by railways applying the Association of American Railroads (AAR) standards and have been introduced into Europe on some applications for freight wagons. The product and technical approval requirements of this British Standard are derived from BS 5892-3, BS EN 13262 and BS EN 13979-1.

This British Standard provides a complete definition of the product and delivery procedures for cast wheels by:

a) defining all the wheel characteristics;

*NOTE 1 These are either verified during the qualification procedures or for the delivery of the product (see Clause **4**).*

b) defining qualification procedures (see Annex A); and

c) defining delivery conditions (see Annex B).

NOTE 2 A choice is given to the supplier, of either:

*1) a traditional delivery procedure with a control by batch sampling as in existing documents (see **B.4**); or*

*2) a delivery procedure using quality assurance concepts (see **B.4.6**).*

This British Standard also describes how to assess the wheel design, following the principles of BS EN 13979-1 as set out for cast wheels in DD CEN/TS 13979-2. To be able to apply the specifications, the use of the wheel needs to be defined; this standard also states how to define this use.

At least four aspects are described with different purposes:

- a geometric aspect – to allow interchangeability of different solutions for the same application;
- a thermomechanical aspect for tread braked wheels – to manage wheel deformations and to ensure that braking does not cause wheels to break;
- a mechanical aspect – to ensure that no fatigue cracks occur in the web; and
- an acoustic aspect – to ensure that the solution chosen is as good as the reference wheel, for the use in question.

For each of these three latter aspects, the rules tend to limit the procedure; thus, the easier the objectives are to attain by the wheel under study.

The main content of the technical approval clauses of this standard is derived from BS EN 13979-1 with differences linked to the needs of the cast process for the product as proposed in DD CEN/TS 13979-2.

1 Scope

This British Standard specifies the characteristics of, and technical approval requirements for, cast railway wheels for conventional rail operation. It can be applied in conjunction with BS or BS EN standards for axles and wheelsets. This standard is not applicable to urban rail.

Three steel grades, C48, C56 and C64, are defined in this standard.

NOTE 1 For the purpose of this British Standard, the steels referred to as C48, C56 and C64 are based on those defined as AAR Class L, A and B respectively.

This British Standard is applicable to cast wheels which are rim-chilled and have their wheel webs shot peened.

NOTE 2 'Rim-chilled' is a heat treatment of the rim, the aim of which is to harden the rim and to create compressive residual stresses in the rim.

NOTE 3 Cast wheels are shot peened to improve the web fatigue strength.

The wheels defined in this British Standard are for applications up to 120 km/h (i.e. 75 mph).

It only applies to wheels of new design or new application.

These requirements are intended to be used to assess the validity of the design choice for the proposed use and constitute the technical approval procedure.

This British Standard does not cover assessment of the hub nor of the static mechanical dimensioning of the wheel.

2 Normative references

Standards publications

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ASTM E399-90:1997, *Test method for plane-strain fracture toughness of metallic materials*

ASTM E1245, *Standard practice for determining the inclusion or second-phase constituent content of metals by automatic image analysis*

BS EN 13103, *Railway applications – Wheelsets and bogies – Non-powered axles – Design method*

BS EN 13104, *Railway applications – Wheelsets and bogies – Powered axles – Design method*

BS EN 13979-1:2003+A2:2011, *Railway applications – Wheelsets and bogies – Monobloc wheels – Technical approval procedure – Part 1: Forged and rolled wheels*

BS EN ISO 148-1, *Metallic materials – Charpy pendulum impact test – Part 1: Test method*

BS EN ISO 6506-1, *Metallic materials – Brinell hardness test – Part 1: Test method*

BS EN ISO 6506-2, *Metallic materials – Brinell hardness test – Part 2: Verification and calibration of testing machines*

BS EN ISO 6506-3, *Metallic materials – Brinell hardness test – Part 3: Calibration of reference blocks*

BS EN ISO 6892-1:2009, *Metallic materials – Tensile testing – Part 1: Method of test at ambient temperature*

BS EN ISO 9712, *Non-destructive testing – Qualification and certification of NDT personnel (ISO 9712:2012)*

ISO 5948:1994, *Railway rolling stock material – Ultrasonic acceptance testing*

ISO 6933:1986, *Railway rolling stock material – Magnetic particle acceptance testing*

ISO/TR 9769, *Steel and iron – Review of available methods of analysis*

Other publications

[N1] SOCIETY OF AUTOMOTIVE ENGINEERS. *SAE J827, High-carbon cast-steel shot.* Warrendale, PA: SAE International, 2013.

[N2] SOCIETY OF AUTOMOTIVE ENGINEERS. *SAE J444, Cast shot and grit size specifications for peening and cleaning.* Warrendale, PA: SAE International, 2012.

[N3] SOCIETY OF AUTOMOTIVE ENGINEERS. *SAE J442, Test strip, holder and gage for shot peening.* Warrendale, PA: SAE International, 2013.

[N4] SOCIETY OF AUTOMOTIVE ENGINEERS. *SAE J443, Procedures for using standard shot peening Almen strip.* Warrendale, PA: SAE International, 2013.

[N5] ASSOCIATION OF AMERICAN RAILROADS. *AAR Manual of standards and recommended practices: Section G – Wheels and axles – Specification M 107 M 208.* AAR, 2011. [1)]

[N6] ERRI report B169/RP12. *Production of a universal matrix representative of damage to a railway component with a view to performing fatigue tests.* October 1997.

[N7] ERRI report B169 RP10. *Definition of a specification for solid axisymmetrical wheels – Verification of mechanical design: fatigue strength – Towards a better shape for the wheel centre.* January 1999.

3 Terms and definitions

For the purposes of this part of BS 5892, the following terms and definitions apply.

3.1 Heat
identification of all the wheels produced from a single furnace load of liquid steel

3.2 technical specification
document describing the specific parameter/product requirements in addition to the requirements of this standard

4 Product definition

4.1 General

The application for which the wheel is to be approved shall be defined by the parameters in accordance with this British Standard and the additional requirements defined in the technical specification.

1) Available from <http://www.ttci.aar.com/standards/publications.php> [last viewed 10 November 2014].

The product sample shall be taken from the locations as indicated in this British Standard. Where the characteristics of the wheel vary due to the nature of the steel casting process, the test shall be taken from a worst case location as defined in the technical specification.

For any process change the locations shall be reviewed and, if necessary, defined again.

4.2 Chemical composition

4.2.1 Requirements

The defined chemical composition shall be within the ranges defined in Table 1 and Table 2.

To safeguard against hydrogen cracking the minimum sulfur content shall not be less than 0.005%; greater values may be defined in the technical specification.

Table 1 **Maximum content of main elements within cast wheels**

Steel grade	**Maximum content %**				
	C	**Si**	**Mn**	**P**	**S** (see Note)
C48	0.45–0.52	0.60	0.90	0.025	0.025
C56	0.52–0.60	0.60	0.90	0.025	0.025
C64	0.60–0.67	0.60	0.90	0.025	0.025

NOTE For special applications, variations within the maximum limit of these values may be defined in the technical specification.

Table 2 **Maximum content of residual elements within cast wheels**

Steel grade	**Maximum content %**								
	Cr	**Cu**	**Mo**	**Ni**	**V**	**Al**	**Ti**	**Nb**	**Cr + M + Ni**
C48	0.25	0.35	0.10	0.25	0.06	0.06	0.03	0.05	0.50
C56	0.25	0.35	0.10	0.25	0.06	0.06	0.03	0.05	0.50
C64	0.25	0.35	0.10	0.25	0.06	0.06	0.03	0.05	0.50

NOTE For special applications, variations within the maximum limit of these values may be defined in the technical specification.

4.2.2 Location of the sample

The sample for determining the chemical composition shall either be taken from the molten steel during the casting process or from a position 15 mm below the tread at its nominal diameter.

For product approval, both samples shall be taken.

4.2.3 Chemical analysis

The chemical composition analysis shall be performed in accordance with ISO/TR 9769.

4.2.4 Hydrogen analysis

The hydrogen content shall be determined for each Heat. The Heat shall conform to a maximum hydrogen percentage limit of 2.5 ppm.

4.3 Mechanical characteristics

4.3.1 Tensile test characteristics

4.3.1.1 Requirements

The rim and web characteristics of the cast wheels shall be, as a minimum, the values given in Table 3.

Table 3 **Rim and web characteristics of the wheels**

Steel grade	Rim			Web	
	R_{eH} A) N/mm²	R_m N/mm²	A_5 %	R_m reduction B) N/mm²	A_5 %
C48	≥460	760/940	≥6	≥100	≥4
C56	≥520	860/1 050	≥5	≥70	≥4
C64	≥570	940/1 140	≥4	≥50	≥4

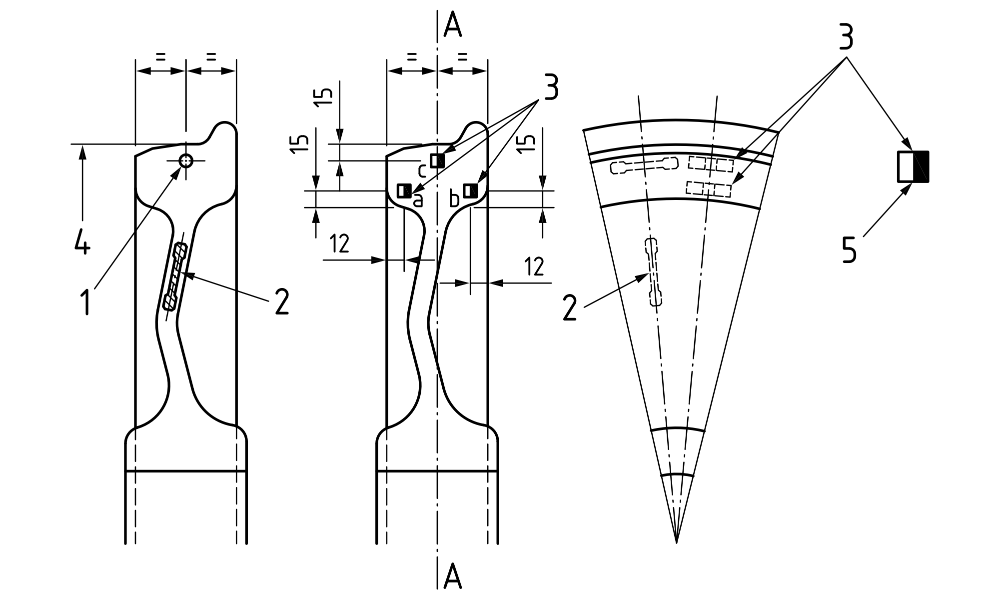
A) If no distinctive yield strength is present, the proof stress $R_{p0.2}$ is determined.

B) Reduction of tensile strength is relative to that of the rim on the same wheel.

4.3.1.2 Location of test pieces

Test pieces shall be taken from the rim and the web of the wheel, as shown in Figure 1.

Figure 1 **Location of test pieces**



Key

1 Tensile test piece (rim)
2 Tensile test piece (web)
3 Impact test piece
4 Nominal diameter
5 Notch

4.3.1.3 Test method

The test shall be carried out in accordance with BS EN ISO 6892-1:2009, Method B. The diameter of the test piece shall be at least 10 mm in the parallel length and the gauge length shall be five times the diameter.

NOTE Where the wheel design prevents a sample of the stated size from being taken, a smaller sized sample may be taken if agreed in the technical specification.

4.3.2 Hardness characteristics in the rim

4.3.2.1 Requirements

The minimum values of Brinell hardness given in Table 4 and defined by B, C and D in Figure 2 shall be applicable up to a maximum wear depth of 35 mm under the tread.

If the wear depth is greater than 35 mm, the values shall be defined in the technical specification.

The hardness values in the rim-web transition (point A in Figure 2) shall be at least ten points lower than the wear limit values.

Table 4 **Minimum hardness values**

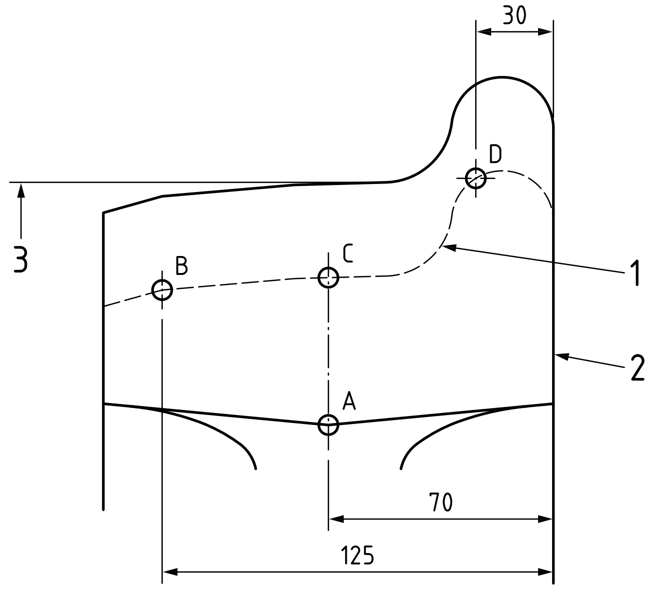
Steel grade	Minimum value for Brinell hardness
C48	235
C56	255
C64	277

4.3.2.2 Location of readings

Four readings shall be carried out on a radial section of the rim as shown in Figure 2. Where the microstructure of the wheel varies due to the casting process, e.g. between risers, the test positions shall occur in the worst-case locations, circumferentially around the wheel.

Figure 2 **Readings taken on a radial section of the rim**

Dimensions in millimetres



Key

1 Limit of wear or last turning diameter

2 Inside surface of finished wheel

3 Nominal diameter

4.3.2.3 Test method

The test shall be carried out in accordance with BS EN ISO 6506-1. The ball diameter shall be 5 mm.

4.3.3 Impact test characteristics

4.3.3.1 Values to be achieved

The average and minimum impact test values for cast wheels shall be as given in Table 5.

NOTE The values represent the average and minimum values for the three test specimens defined in ***4.3.3.2****.*

At +20 °C, U-notch specimens (KU) shall be used. At –20 °C, V-notch specimens (KV) shall be used.

Table 5 **Average and minimum impact test values**

Steel grade	KU(J) at +20 °C		KV(J) at –20 °C	
	Average values	Minimum values	Average values	Minimum values
C48	≥8	≥6	≥4	≥3
C56	≥8	≥6	≥4	≥3
C64	≥8	≥6	≥4	≥3

4.3.3.2 Location of the test pieces

Test pieces shall be taken from the rim of the wheel, as shown in Figure 1.

The bottom notch axis shall be parallel to the A–A axis of Figure 1.

4.3.3.3 Test method

The test shall be carried out in accordance with BS EN ISO 148-1.

4.3.4 Fatigue test characteristics

4.3.4.1 Requirements

For all steel grades, the web shall withstand the stress variation, $\triangle\sigma$, given in Table 6 during 10^7 cycles without any crack initiation, with a probability of 99.7%.

Table 6 **Minimum fatigue characteristics**

State of delivery of the web	$\triangle\sigma$ N/mm²
Partially machined or as cast and shot peened	315

NOTE 1 The aim of this characteristic is to ensure that product characteristics are higher than those used for the definition of permissible stresses for the fatigue design of the web.

NOTE 2 It is not realistic to distinguish between the steel grades due to the many approximations in a fatigue calculation.

4.3.4.2 Specimens for fatigue test

Specimens shall consist of wheels as delivered. Their surface appearance shall be in accordance with **4.7.1**.

4.3.4.3 Test method

The test shall:

- allow bending stresses in a web section;
- be carried out such that results can be statistically evaluated; and
- be monitored by measuring the radial stresses, which exist in the crack initiation area.

NOTE For an example of this test method, see Annex C.

4.3.5 Fracture toughness characteristics of the rim

4.3.5.1 General

Fracture toughness shall only be verified for wheels where tread braking is the sole means of service braking.

4.3.5.2 Values to be achieved

For steel grade C48, the average value obtained from six test pieces shall be greater than or equal to 65 N/mm² $\sqrt{m}$ and any single value shall not be below a minimum of 50 N/mm² $\sqrt{m}$.

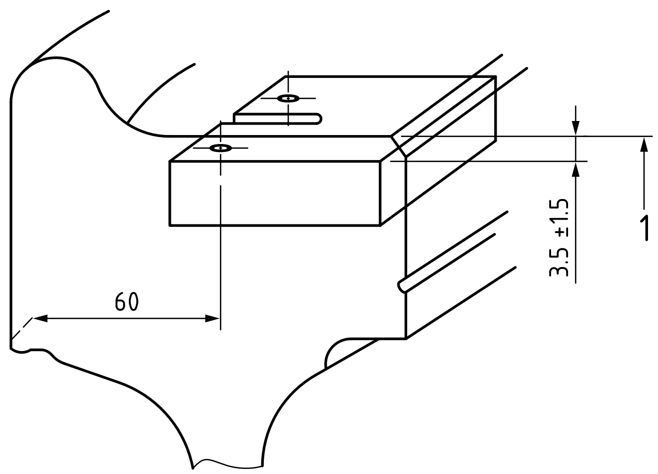
For steel grades C56 and C64, the technical specification shall state the applicable values.

4.3.5.3 Location of test pieces

Six test pieces shall be taken from the rim as shown in Figure 3. Where the microstructure of the wheel varies because of the casting process, the test positions shall be in the worst-case locations of the wheel.

Figure 3 **Test pieces taken from the rim**

Dimensions in millimetres



Key

1 Nominal diameter

4.3.5.4 Test method

The test shall be carried out in accordance with ASTM E399-90.

The test conditions shall be:

a) The compact specimen shall have a CT thickness of 30 mm (CT 30 specimen), with chevron notch having an aperture angle of 90° (see ASTM E399-90:1997, Figure 4).

b) The temperature during the test shall be between +15 °C and +25 °C.

c) The measurement of the crack displacement of the specimen shall be in accordance with ASTM E399-90:1997, Figure 3.

d) The rate of increase of stress intensity, $\triangle K/s$ (stress intensity per second), shall be within the range 0.55 $N/mm^2 \sqrt{m/s}$ to 1 $N/mm^2 \sqrt{m/s}$ (see ASTM E399-90).

e) The value of the toughness to be considered shall be the value K_Q, which is calculated from the value of the load F_Q from the load-displacement record.

4.4 Metallurgical structure

The wheel shall have a pearlitic structure, but the presence of bainite in addition to pearlite within areas that are subject to rim quenching shall be acceptable.

4.5 Material cleanliness

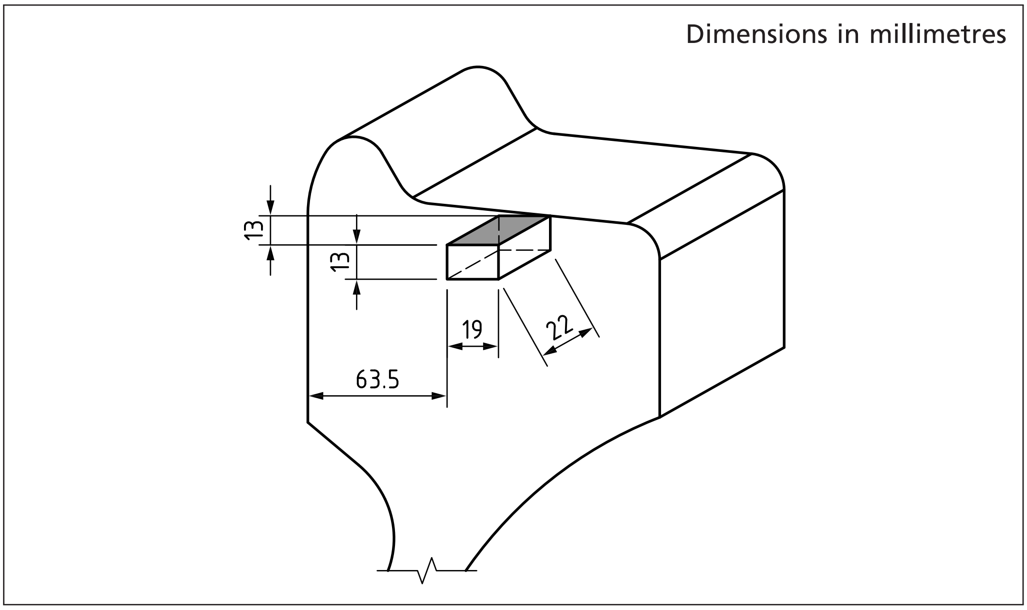
4.5.1 Micrographic cleanliness

4.5.1.1 Sample size and location

A minimum of six samples shall be taken from each wheel tested; these shall be approximately equidistant around the circumference of the wheel.

NOTE Figure 4 shows the location and size of each sample.

Figure 4 **Location of sample for the micrographic examination**



4.5.1.2 Sample preparation

Each 22 mm × 19 mm × 13 mm sample shall be prepared and evaluated in accordance with ASTM E1245. The flicker method shall be used to establish the correct setting of the grey-level threshold limits.

The total area evaluated for each sample shall be not less than 161 mm^2. All inclusions greater than 2.5 µm shall be counted.

4.5.1.3 Level to be achieved

The average and worst field area percentage of inclusions and voids shall be recorded.

The maximum permissible values for the six samples shall be:

- 0.1% for the average oxide inclusions plus voids; and
- 0.75% for the worst field sulphides and also 0.75% of oxides plus voids.

NOTE Demonstration that there is no fatigue crack propagation beneath the tread is subject to confirmation by in-service experience of wheels.

4.5.2 Internal integrity

4.5.2.1 General

Internal integrity shall be determined from ultrasonic examination.
The examination shall be carried out before shot peening.

NOTE Standard flat bottom holes for ultrasonic testing have different diameters for different types of ultrasonic testing.

4.5.2.2 Requirements

4.5.2.2.1 Rim

The rim shall have no internal defects that give echo magnitudes larger than or equal to 25% of that obtained for a standard defect situated at the same depth. The diameter of this standard defect shall be 3.12 mm (1/8 in), unless otherwise defined in the technical specification.

There shall be no attenuation of the back echo signal higher than 4 dB during the axial examination.

4.5.2.2.2 Web

The web shall not have:

a) more than ten echoes with magnitudes greater than or equal to those obtained for standard defects of 3.12 mm (1/8 in) diameter, unless otherwise defined in the technical specification; and

b) echoes of magnitude greater than or equal to those obtained for a standard defect of 5 mm diameter.

The distance between two acceptable defects shall be at least 50 mm.

4.5.2.2.3 Hub

The hub shall not have:

a) more than three echoes of magnitude greater than or equal to those obtained for standard defects of 3.12 mm (1/8 in) diameter, unless otherwise defined in the technical specification; and

b) echoes of magnitude greater than or equal to those obtained for a standard defect of 5 mm diameter.

The distance between two acceptable defects shall be at least 50 mm.

For one circumferential examination, there shall be no attenuation of the back echo signal equal to or greater than 6 dB.

4.5.2.3 Test piece

The complete wheel shall be examined after heat treatment, before shot peening and before any corrosion protection is applied.

4.5.2.4 Method of examination

4.5.2.4.1 General

Ultrasonic examination shall be carried out on samples in accordance with ISO 5948 and the requirements of **4.5.2.4.2**, **4.5.2.4.3** and **4.5.2.4.4**, with particular reference to the casting process and the inspection methods appropriate for that process.

The test method shall be documented in the technical specification, including any additional test methods specified by the manufacturer.

NOTE An alternative method for axial testing using the loss of back reflection may be agreed in the technical specification.

4.5.2.4.2 Rim

Unless otherwise specified in the technical specification, the following shall apply.

a) The rim examination shall be in accordance with ISO 5948:1994, Table 1, Method D1 and Method D2.

b) Defect estimation shall be made by comparison to artificial defects in the standard rim in accordance with ISO 5948:1994, Figure 1 and Figure 2.

c) Ultrasonic examination shall be carried out to cover the rim to web transition.

4.5.2.4.3 Web

The web examination shall be carried out from both front and back surfaces of the web. The direction of the examination shall be perpendicular to the surface.

Defect estimation shall be made by comparison to artificial defects in a standard web.

The web shall be defined as the part of the wheel between the two diameters at *m* and *n* (see **4.8**).

The thickness, *e*, of the web shall be designated by the minimum thickness of the cross-section.

The artificial defects shall be positioned mid way between the transition radius from the underside of the rim and the transition radius of the hub. These shall be at least 100 mm apart in a circumferential orientation.

The depth of the artificial defects shall be given as a function of *e* and shall be:

a) Three flat bottom holes of 3.12 mm (1/8 in) diameter, located the first at 5 mm, the second at (e/2) mm and the third at (e – 5) mm below the back surface of the web.

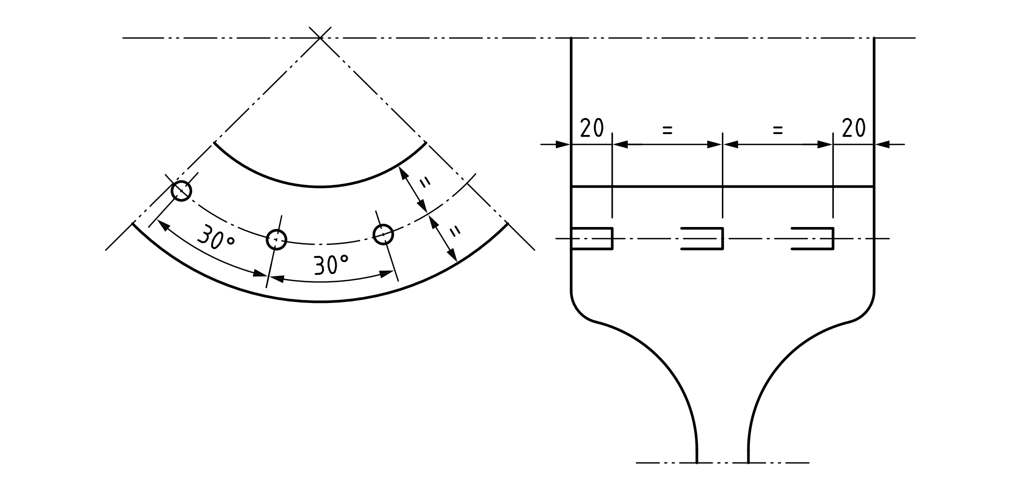
b) Three flat bottom holes of 5 mm diameter, located the first at 5 mm, the second at (e/2) mm and the third at (e – 5) mm below the back surface of the web.

4.5.2.4.4 Hub

The hub examination shall be carried out from both front and back surfaces of the hub. The direction of the examination shall be perpendicular to the surface.

Defect estimation shall be made by comparison to artificial defects in the standard hub shown in Figure 5.

Figure 5 **Standard hub for ultrasonic examination**



The artificial defects shall be spaced and have the depths as shown in Figure 5. These shall be:

- three flat bottom holes of 3.12 mm (1/8 in) diameter;
- three flat bottom holes of 5 mm diameter.

4.6 Residual stresses

4.6.1 General

A compressive circumferential residual stress field inside the rim shall be induced by wheel heat treatment.

4.6.2 Requirements

The circumferential residual stresses σ_{crs} at the surface of the tread of the finished wheel shall be in a compressive state with $-200\ N/mm^2 \leq \sigma_{crs} \leq -80\ N/mm^2$. If the magnitude of the circumferential residual stresses at the surface of the tread of the finished wheel is beyond $-200\ N/mm^2$, it shall be proved that the level of radial residual stresses in the web is acceptable regarding fatigue limit and notch sensitivity considering the applicable operating conditions.

NOTE The proof can be based on return of experience, calculation, fatigue test of the web.

The circumferential stresses shall be compressive to a depth of 35 mm. If the wear depth is greater than 35 mm, the value of the depth where the circumferential stresses are no longer compressive shall be defined in the technical specification.

4.6.3 Test piece

The test piece shall be the complete wheel after heat treatment.

4.6.4 Measurement methods

The variation of circumferential stresses located deep under the tread shall be estimated.

This method shall be stated in the technical specification.

NOTE Annex D gives an example method that can be used for this measurement.

4.7 Surface characteristics

4.7.1 Surface appearance

4.7.1.1 Characteristics to be achieved

The wheel surface shall not show any marks other than those at the positions required in this British Standard.

NOTE According to their use, wheels may be fully or part machined.

All "as cast" surfaces of the web shall be shot peened unless defined otherwise in the technical specification.

Average surface roughness, R_a, area values of "finished" or "ready for assembly" wheels shall be as given in Table 7.

Table 7 **Average surface roughness**

Area of the wheel	State of delivery	Roughness, R_a µm
Bore	Finished	≤12.5
	Ready for assembly A)	0.8 to 3.2
Web and hub	As cast B)	≤12.5
Rim tread	Finished B)	≤6.3
Rim faces	Finished B)	≤6.3

A) If the wheel is to be fitted on a hollow axle, other values might be required for in-service ultrasonic inspection.

B) If defined in the technical specification, this area of the wheel can remain unmachined, provided the fatigue characteristics indicated in Table 6 are achieved.

4.7.1.2 Measurement method

The roughness of the wheel surfaces, R_a, at the delivery stage given in Table 7 shall be inspected by comparison with the roughness specimen described or measured.

4.7.2 Surface integrity

4.7.2.1 General

To determine surface integrity, a magnetic particle test of the web shall be carried out in accordance with **4.7.2.4** and a visual inspection of the entire wheel shall be carried out to check for other visible defects, e.g. sand inclusions, shrinkage and/or shrinkage cracks, porosity, etc.

4.7.2.2 Level to be achieved

The maximum indicated length of permissible surface breaking defects on a finished wheel shall be 2 mm.

4.7.2.3 Test piece

The wheel shall be examined after heat treatment and after shot or other cleaning, but before shot peening and before the application of any temporary corrosion protection.

4.7.2.4 Methods of inspection

General requirements for the magnetic particle test shall be defined in accordance with ISO 6933 with the following exceptions:

a) the level of surface magnetic induction shall be greater than 4 mT; and

b) the level of ultra-violet light energy shall be greater than 15 W/m^2.

The magnetization method shall be carried out in accordance with ISO 6933:1986, Figure 2c. The apparatus used shall scan the required web surface and shall be able to detect the defects whatever their orientation.

4.8 Geometric tolerances

The geometry and dimensions of the wheels shall be defined by a drawing as part of the technical specification.

The geometric tolerances shall conform to those given in Table 8 as defined in Figure 6.

4.9 Static imbalance

The maximum static imbalance of a finished wheel in the delivery condition shall be ≤125 g.m (see **B.3**).

The means and methods of measurement shall be defined in the technical specification.

Figure 6 **Symbols**

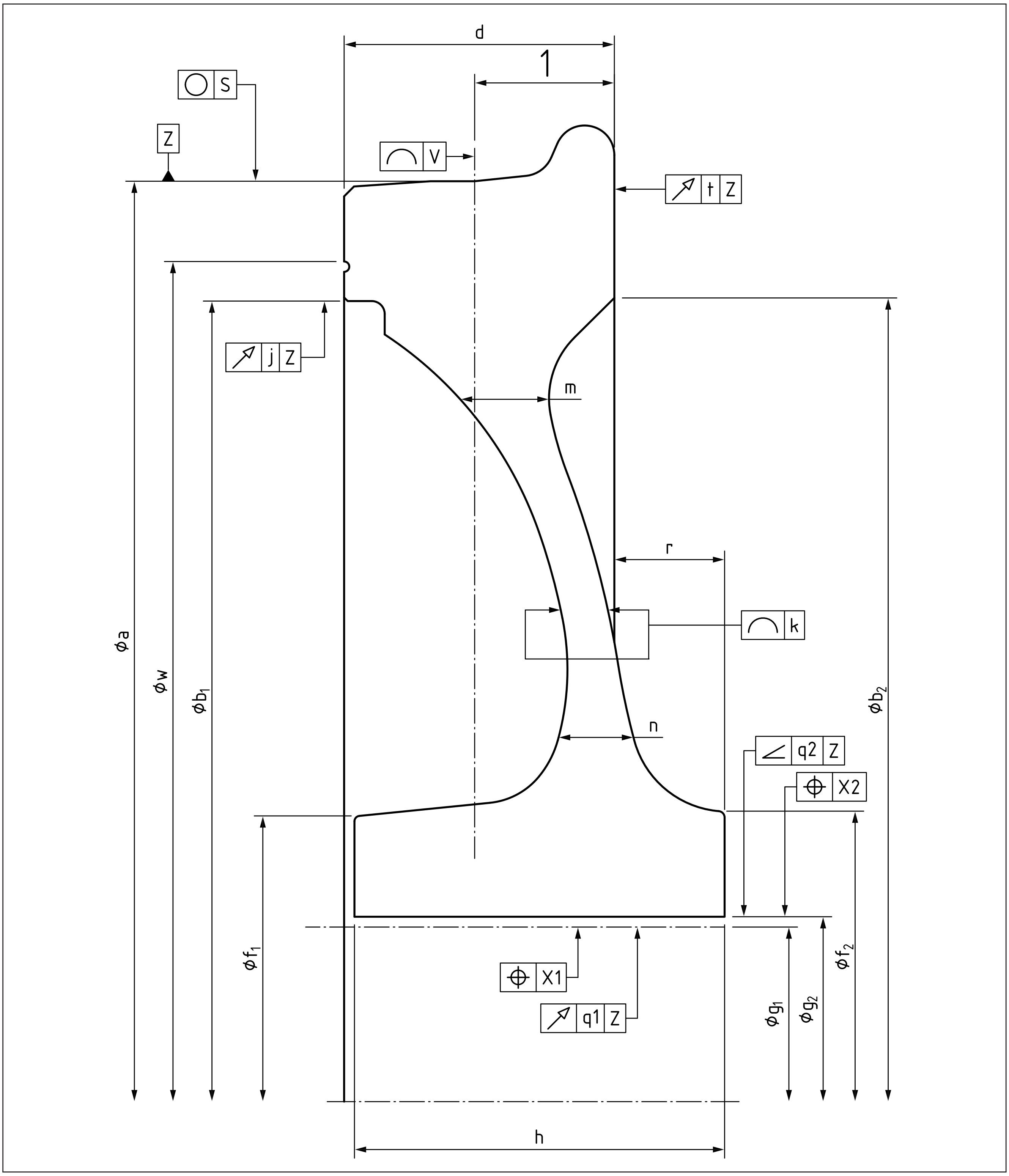


Table 8 **Geometric tolerances**

Designation		**Symbols** A)		**Values (mm)**	
		Dimensions	**Geometric** B)	**Unmachined**	**Finished**
Rim	External diameter	a			0/+4 C)
	Internal diameter (outer)	b_1			0/–4
	Internal diameter (inner)	b_2			0/–4
	Width	d		±1 D)	±1 D)
	Tread profile E)		V		≤0.5
	Circularity of the tread		S		≤0.2
	Total run out in axial direction		T		≤0.3
	Total run out in radial direction of the jaw hold		J		≤0.2
	External diameter of the groove (i.e. wear line)	w			0/+2
Hub	External diameter (outer)	f_1		0/+10 F)	0/+5 F)
	External diameter (inner)	f_2		0/+10 F)	0/+5 F)
	Internal diameter of the bore:				
	"Finished"	g_1			0/–2
	"Finished ready for assembly"	g_2		In accordance with the drawing or the assembly standard to ensure the interference fit	
	Cylindricity of internal diameter of the bore:				
	"Finished"	x_1			≤0.2
	"Finished ready for assembly"	x_2			≤0.02 G)
	Length	h			0/+2 H)
	Hub to wheel flange back overhang	r			0/+2 D)
	Total run out of the diameter of the bore:				
	"Finished"		Q1		≤0.2 I)
	"Finished ready for assembly"		Q2		≤0.1
Web	Position for the web at the connection with the rim and the hub		K J)	≤8	≤8
	Thickness at the connection with the rim	m		+8/0	+5/0
	Thickness at the connection with the hub	n		+10/0	+5/0

A) See Figure 6.

B) See BS EN ISO 1101.

C) In accordance with the technical specification.

D) For vehicles not subject to the Interoperability Directive, ±4 may be agreed in accordance with the technical specification.

E) From the top of the flange as far as the external chamfer.

F) For vehicles not subject to the Interoperability Directive, 0/+26 may be agreed in accordance with the technical specification.

G) Any slight taper within the permitted tolerance shall be such as the "larger" diameter is at the axle entry end of the bore on assembly of the wheel on the axle.

H) For vehicles not subject to the Interoperability Directive, ±7 may be agreed in accordance with the technical specification.

I) For vehicles not subject to the Interoperability Directive, ±2 may be agreed in accordance with the technical specification.

J) With respect to each specific design drawing.

4.10 Shot peening – requirements

4.10.1 General

The shot shall be made of a hardened steel (SAE 550 shot or larger), in accordance with the Society of Automotive Engineers (SAE) technical standards SAE J827 [N1] and SAE J444 [N2].

Wheels shall be subjected to shot peening after any rectification to the wheel surface. The permitted rectification process applied to the wheel surface shall be defined in the technical specification.

Fixed peening machines shall be equipped with a separator for continuously removing broken shot. Sufficient new shot shall be added to ensure that a minimum of 85% shot is maintained in the machines at all times.

NOTE A portable peening device may be used to re-peen small reconditioned areas no larger than approximately 50 mm × 75 mm on wheel web surfaces excluding the critical fillet areas (front hub and back rim).

The peening time of wheel webs shall be at least as long as the time required to produce the 0.008 in (0.20 mm) Almen C2 arc height. The equipment shall be re-tested on an Almen C strip after no more than 8 h of use. A record of the Almen C test results shall be maintained.

4.10.2 Values to be achieved

Measurement of the shot peening intensity shall be undertaken at the most critical areas of the wheel design.

The peening intensity shall be sufficient to produce an average arc height of not less than 0.008 in (0.20 mm) Almen C2 within the zones defined in **4.7.1.1**.

4.10.3 Measurement method

Measurements of arc height shall be made in accordance with SAE J442 [N3] and SAE J443 [N4].

The minimum peening time shall ensure full coverage is attained on the Almen C strip as defined in SAE J443 [N4].

4.11 Protection against corrosion

Protection against corrosion shall be provided on all fully machined surfaces with the exception of the surface of the rims.

NOTE See the technical specification for any further requirements for protection against corrosion.

4.12 Manufacturer's markings

For the purpose of traceability, each wheel shall be marked, as a minimum, with the following marks:

a) manufacturer's mark;

b) serial number traceable to Heat number;

c) steel grade;

d) month and two last figures of the year of production; and

e) position of residual imbalance and its symbol (see **4.9**).

The markings shall be applied to the back hub face at the hub-web fillet. These markings shall not be put on the transition between hub and web.

These markings shall be stamped or cast in, except for imbalance marks which may be made by other means. Stamps with sharp edges shall not be used.

The manufacturer's mark shall be applied at the final process stage prior to delivery.

NOTE The manufacturer's mark identifies the unique reference for quality and characteristics of the component.

5 Technical approval

The technical specification for the wheel to be approved shall include documentation comprising the following:

a) a description of the manufacturing process (casting, heat treatment, shot peening, machining condition);

b) the definition of the wheel geometry (drawing);

c) the following manufacturing parameters:

   1) steel grade;

   2) geometric tolerances;

   3) surface finishes;

d) the parameters for defining the duty of the wheel for which approval is requested.

NOTE Qualification in accordance with Annex A may be undertaken concurrent with Technical Approval using the same wheels.

6 Parameters for the technical approval process

6.1 General

The duty for which the wheel is to be approved shall be defined by the parameters in **6.2** to **6.5**.

If the parameters are changed for an already approved wheel, there shall be a review of the original approval to assess what further approvals will be made necessary by the changes.

The wheel shall be approved when the following assessment requirements have been met:

- assessment of the geometric parameters;
- assessment of the thermomechanical behaviour (tread braked wheels only);
- assessment of the mechanical behaviour;
- assessment of the acoustic behaviour;
- compilation of a file for the whole technical approval procedure as it progresses.

6.2 Geometric parameters

*COMMENTARY ON **6.2***

The geometric parameters are defined according to functional, assembly or maintenance requirements.

6.2.1 Functional requirements

The functional requirements for the geometric parameters shall be:

- nominal tread diameter (that influences the buffer height and the loading gauge);

- maximum rim width (linked to track geometry, e.g. points, crossings, track brakes, etc.);
- tread profile (outside the conical part of the tread);
- position of the rim internal surface relative to the corresponding surface of the hub.

6.2.2 Assembly requirements

The assembly requirements for the geometric parameters shall be:

- bore diameter;
- hub length to ensure correct position of the hub on the wheel seat.

6.2.3 Maintenance requirements

The maintenance requirements for the geometric parameters shall be:

- wear limit diameter or the last reprofiling diameter;
- geometry of the area on the wheel for clamping on reprofiling machines;
- position and shape of the hole and groove for displacement of the wheel from the axle using oil pressure (where required);
- a rim shape that permits ultrasonic measurement of residual stresses in tread braked wheels (where required).

6.3 Parameters for thermomechanical assessment (tread braked wheels only)

The following parameters shall be applied for the thermomechanical assessment:

- the maximum braking energy created by the friction of the brake shoes on the tread surface;

  NOTE 1 This energy may be defined by a power, P_a, a time, t_a, and a train speed, V_a, during drag braking. If it is defined by other parameters (for braking to a stop, for example), these parameters are defined in the technical specification. Required values of P_a for European interoperability and GB domestic only applications are given in Annex E.

- the type of brake shoes applied to the wheel (nature, dimensions and number).

NOTE 2 For freight rolling stock subject to the Interoperability Directive, the thermomechanical behaviour does not need to be verified when braking to a stop, but only when drag braking, because of the lower energy generated when braking to a single stop.

6.4 Parameters for mechanical assessment

The following parameters shall be applied for the mechanical assessment:

a) the maximum vertical static force per wheelset;

b) the type of service to be provided by the vehicles fitted with the wheels to be approved:

   1) description of routes, including geometric quality of the tracks, curve parameters, maximum speeds, etc;

   2) duty cycle;

c) the distance operated by the wheelset for its calculated service life.

6.5 Parameters for acoustic assessment

The application shall state all the parameters influencing the noise emitted by the wheel and not directly related to the design of the wheel to be approved.

NOTE These parameters could include:

- *the reference track on which the wheel is to be assessed;*
- *the reference wheel to which the design is compared;*
- *the reference rolling stock and one or more reference speeds;*
- *one or two surface roughness spectra representative of the range of operational values of the wheel under test.*

7 Assessment of the geometric parameters

The wheel design shall conform to the requirements of **6.2**.

8 Assessment of the thermomechanical behaviour (tread braked wheels only)

8.1 General procedure

*COMMENTARY ON **8.1***

*Assessment of the thermomechanical behaviour may comprise three stages. The progression from one stage to the next depends on the results obtained. The first and second stages (**8.2** and **8.3**) can be undertaken in any order as they are both mandatory for cast wheels. The order given here reflects that used in BS EN 13979-1; this might be preferable in practice.*

The assessment shall be carried out in accordance with Annex F.

For each of the three stages, the test shall be carried out on a new rim (nominal tread diameter) and a worn rim (wear limit tread diameter).

For both new rim and worn rim, the web geometry of wheels to be tested shall be the worst case for thermomechanical behaviour within the geometric tolerance ranges. It shall be proved by numeric simulation that the tested wheels represent the worst case. If worst case conditions are not confirmed, the numeric simulation shall allow correction of the results to correspond with those that would be obtained on wheels in the worst case geometric conditions.

NOTE For the moment, the calculation codes and thermomechanical parameters are too imprecise and not well known enough to be used as assessment parameters in a standard. In future, if this situation develops, a thermomechanical calculation should be made as the first stage of the assessment.

8.2 First stage – Braking bench test

8.2.1 Test procedure

The test procedure and the measurements to be made shall be carried out in accordance with **F.2**.

The power to be applied during this test shall be equal to 1.2 P_a (see **6.3** for a definition of P_a). The duration of each drag braking period and the train speed are those defined in **6.3** (t_a and V_a) and Annex E.

8.2.2 Decision criteria

The criteria shall be met for the wheel with the new rim and the wheel with the worn rim.

a) Wheel with new rim:

1) maximum lateral displacement of the rim during braking: +3/–3 mm;

2) level of residual stress in the rim after cooling:

- $\sigma_{rn} \leq + \Sigma_r$ N/mm² as the average of three measurements;
- $\sigma_{in} \leq + (\Sigma_r + 50)$ N/mm² for each measurement;
- maximum lateral displacement of the rim after cooling: +1.5/–1.5 mm.

b) Wheel with worn rim:

1) maximum lateral displacement of the rim during braking: +3/–3 mm;

2) level of residual stress in the rim after cooling:

- $\sigma_{rw} \leq + (\Sigma_r + 75)$ N/mm² as the average of three measurements;
- $\sigma_{iw} \leq + (\Sigma_r + 100)$ N/mm² for each measurement;

3) maximum lateral displacement of the rim after cooling: +1.5/–1.5 mm.

The lateral displacement shall be deemed positive if the distance between the two back faces of the wheels of the wheelset increases.

8.3 Second stage – Wheel fracture bench test

8.3.1 Test procedure

The test procedure shall be carried out in accordance with **F.3**.

8.3.2 Decision criterion

The wheels tested shall be deemed to have passed the test if they do not fracture, as defined in Annex F.

8.4 Third stage – Field braking test

8.4.1 General

In order to secure technical approval, if any of the criteria in the first stage are not achieved, then subject to having achieved the criterion in the second stage, this third stage shall be undertaken.

If all the criteria in the first and second stages are achieved, then this third stage shall be deemed to be optional.

8.4.2 Test procedure

The test procedure and the measurements to be made shall be carried out in accordance with **F.4**.

The power 1.2 P_a (P_a is defined in **6.3**) shall be taken into account for this test. The duration of each drag braking and the running speed of the train shall be those defined in **6.3** (t_a and V_a).

8.4.3 Decision criteria

Three criteria shall be met simultaneously for the wheel with the new rim and the wheel with the worn rim.

a) Wheel with new rim:

1) maximum lateral displacement of the rim during braking: +3/–3 mm;

2) level of residual stress in the rim after the tests and after cooling:

- $\sigma_{rn} \leq + (\Sigma_r - 50)$ N/mm² as the average of three measurements;
- $\sigma_{in} \leq + \Sigma_r$ N/mm² for each measurement;
- maximum lateral displacement of the rim after cooling: +1.5/–1.5 mm.

b) Wheel with worn rim:

1) maximum lateral displacement of the rim during braking: +3/–3 mm;

2) level of residual stress in the rim after the tests and after cooling:

- $\sigma_{rw} \leq + \Sigma_r$ N/mm² as the average of three measurements;
- $\sigma_{iw} \leq + (\Sigma_r + 50)$ N/mm² for each measurement;

3) maximum lateral displacement of the rim after cooling: +1.5/–1.5 mm;

The lateral displacement shall be deemed to be positive if the distance between the two back faces of the wheels of the wheelset increases.

9 Assessment of the mechanical behaviour

9.1 General procedure

The assessment of the mechanical behaviour shall comprise two stages: calculation and test, so as to ensure that there is no risk of fatigue cracking either in the wheel web or in its connections with the hub or the rim during the service life of the wheel (e.g. new rim [nominal tread diameter], fully worn rim [wear limit tread diameter]).

Both for the calculation and the test, the wheel geometry shall be the worst case within its tolerance range, with regard to the mechanical behaviour.

If the wheel geometry is not the worst case, the test parameters shall be corrected as necessary by an assessment against the calculation.

The assessment shall be carried out in accordance with Annex G.

9.2 First stage – Calculation

9.2.1 Applied forces

The force convention used shall be as specified in BS EN 13103 and BS EN 13104.

NOTE The forces are calculated from the value of load P. Load P is defined in BS EN 13103 and BS EN 13104.

From the parameters necessary for the mechanical assessment defined in **6.4,** additional forces shall be used if these parameters generate greater forces (for example, curve parameters, frozen track, etc.).

Three defined load cases shall be used (see Figure 7):

a) Case 1: straight track (centred wheelset):

1) $F_z = 1.25\ P$;

2) $F_{y1} = 0$.

b) Case 2: curve (flange pressed against the rail):

   1) $F_z = 1.25\ P$;

   2) $F_{y2} = 0.6\ P$ for non-guiding wheelsets.

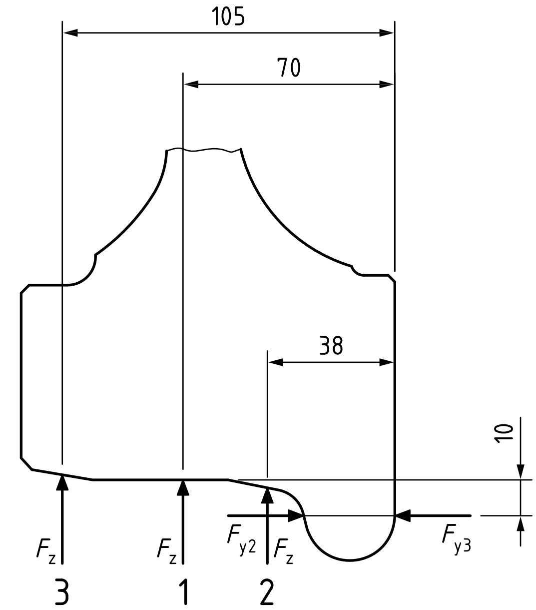
c) Case 3: negotiation of points and crossings (inside face of flange applied to the rail):

   1) $F_z = 1.25\ P$;

   2) $F_{y3} = 0.6\ F_{y2} = 0.36\ P$ for non-guiding wheelsets.

Figure 7 **Application points for each load**

Dimensions in millimetres



Key

1 Straight track – load case 1

2 Curve – load case 2

3 Negotiation of points and crossings – load case 3

9.2.2 Calculation procedure

A finite element calculation code shall be used to determine the stresses. The validity of the code shall be proven and the choice of parameters having a critical influence on the results shall be justified.

NOTE ***G.2*** *gives one method of demonstrating this justification.*

The stresses shall be analyzed as follows.

a) The principal stresses at all points in the mesh (nodes) for each of the three load cases shall be determined.

b) For each node, the maximum principal stress for the three load cases (σ_{max}) and the direction of this principal stress shall be assessed.

c) For each node, the minimum stress equal to the lowest normal stress in the direction of σ_{max}, for the three load cases (σ_{min}) shall be assessed.

d) For each node $\triangle\sigma = \sigma_{max} - \sigma_{min}$ shall be calculated.

9.2.3 Preliminary assessment criterion

The range of dynamic stress $\triangle\sigma$ shall be less than the permissible stresses at all points of the web.

For the permissible range of dynamic stresses, a value (in the shot-peened condition) A = 290 N/mm^2 shall be adopted.

9.3 Second stage – Bench test

9.3.1 General

The second stage shall be carried out irrespective of the results of the first stage.

9.3.2 Definition of bench loading and of the test procedure

The bench loading and the test procedure shall be defined in the technical specification.

The bench loading and the test procedure shall reproduce in the web the stresses that are representative (direction, level and number of cycles) of those the wheel will be subject to throughout its entire life.

NOTE Annex G gives one method of achieving this criterion.

9.3.3 Decision criteria

Four wheels shall be tested. The wheel(s) shall be deemed to have passed the test if no fatigue cracks are identified once the test is completed.

NOTE Any new surface breaking defect is considered to be a fatigue crack if its length is equal to or greater than 1 mm. Any existing permissible surface breaking defect is considered to be a fatigue crack if its length increases by 1 mm or more.

10 Assessment of the acoustic behaviour

10.1 General procedure

The assessment procedure for the acoustic behaviour of wheels given in BS EN 13979-1 shall be followed.

10.2 Decision criteria

The acoustic decision criteria for cast wheels given in BS EN 13979-1 shall be applied.

11 Technical approval documents

The following technical approval documents shall be gathered:

a) identification of the wheel: drawing, material, etc.;

b) definition of the application covered by the approval;

c) geometric assessment documents;

d) thermomechanical assessment documents;

e) mechanical assessment documents;

f) acoustic assessment documents.

12 Qualification

At the end of the technical approval process and before being put into service, a wheel shall be subjected to product qualification.

NOTE A typical product qualification process is defined in Annex A.

Annex A (normative) Product qualification

A.1 General

*COMMENTARY ON **A.1***

This Annex specifies the requirements and procedures to be applied for product qualification.

*Qualification of a wheel is directly linked to the manufacturer and a wheel may only be deemed qualified if the manufacturer meets the requirements specified in **A.2**.*

The requirements and procedures of this Annex shall be applied only to wheels for which the design has been approved by the technical approval procedure in Clause **5**.

Qualification may be undertaken concurrent with the technical approval using the same wheels. The wheels used shall be produced from a minimum of four different Heats. The data resulting from the testing of wheels from these Heats shall be recorded and checked against Clause **4**.

The requirements shall be applied in the following cases:

a) any wheel from a new manufacturer;

b) any non-qualified wheel from a manufacturer, when its geometry is appreciably different to qualified wheels from this manufacturer (e.g. shape and thickness of the web, diameter, etc.);

c) any change in the manufacturing process of a manufacturer for an already qualified wheel.

A.2 Requirements

A.2.1 Requirements for the manufacturer

A.2.1.1 General

When the manufacture of a wheel involves more than one manufacturer, the following requirements shall be satisfied by all concerned.

A.2.1.2 Quality organization

Wheelset manufacture and testing shall be controlled within a recognized quality assurance system.

NOTE BS EN ISO 9001 represents an appropriate means of assuring conformity of a range of products to this standard. Other appropriate and equivalent quality systems may be applied.

A.2.1.3 Qualification of personnel

Staff carrying out non-destructive testing shall be qualified in accordance with BS EN ISO 9712.

A.2.1.4 Equipment

The equipment used by the manufacturer for production, control and monitoring shall allow the requirements of this standard to be met. An automatic process shall be used for ultrasonic examination of the rim for internal defects during manufacture.

A.2.2 Requirements for the product

The product shall conform to the product requirements in Clause **4**.

Each wheel shall be traceable throughout the manufacturing process.

A.3 Qualification procedure

A.3.1 General

The qualification procedure for the product shall comprise four successive stages:

a) provision of technical documents by the manufacturer;

b) evaluation of the manufacturing equipment and production processes;

c) laboratory tests;

d) operational monitoring of wheels.

After the third stage, a temporary qualification certification shall be given to allow in-service experience of the wheels to be gained.

*NOTE A competent body (or bodies) scrutinizes each of the elements of the data and results from the qualification procedure and signifies whether acceptable or not. Following these assessments, a competent body then reviews and, subject to acceptable results, issues the qualification certificate (see **A.4**).*

A.3.2 Documentation required

At the time of a qualification request, the manufacturer shall provide a document that comprises:

a) a description of the products which are the subject of the request;

b) a description of the company stating:

  1) company size (number of people employed, defining the proportion between fabrication, control and quality assurance);

  2) production per year of all products;

  3) a list of all the means of manufacture and control;

c) data about the company organization with the appropriate organization charts;

d) a description of manufacturing processes with descriptions of the different stages of manufacturing;

e) data about raw materials with the list of suppliers;

f) results of tests on products which are the subject of the request;

g) qualification certificates, if the product has been previously qualified.

NOTE If documents have already been provided by a manufacturer for the qualification of another wheel, the documents to be provided by this manufacturer for the qualification of a new wheel have only to be those with new information about the company or this specific wheel.

A.3.3 Evaluation of manufacturing equipment and of the production processes

Evaluation shall comprise:

a) an inspection of the manufacturing plant and examination of the production process;

b) a review of the raw material used for the ladle furnace and an examination of the methods of production;

c) auditing of the manufacturing organization against the requirements of **A.2.1**;

d) auditing of the information provided in the documents referred to in **A.3.2**.

At the end of this stage, a report shall be produced that identifies all the production processes, including those of the raw material, which are needed for product quality.

The report shall give an assurance that manufacturing equipment and the production processes satisfy the requirements of **A.2.1** for the qualification procedure to continue.

A.3.4 Laboratory tests

All characteristics defined in Clause **4** shall be proven for two wheels produced by the manufacturer's standard processes, except for fatigue and circumferential residual stress where other requirements are stated.

The fatigue characteristics shall be verified irrespective of the level of stress calculated in accordance with Clause **9**.

The fatigue characteristics shall also be verified:

a) if the surface roughness of the web of the production wheel is coarser than that adopted in a previous qualification for that wheel; or

b) if the manufacturing processes are different from those used for wheels which are qualified in comparable service.

To be sure that the fatigue characteristics defined in **4.3.4.1** are achieved, two wheels shall be tested using the method described in **4.3.4.3**, but without statistical evaluation. Radial stress levels shall be equal to those given in Table A.1 and there shall be no fatigue crack initiation after 10^7 cycles.

Table A.1 **Radial stress levels**

Symmetrical loading	**Partially machined or as cast and shot peened web** N/mm²	**Fully machined web** N/mm²
Value of radial stress for verification	±168	±240

*NOTE For a better understanding of the characteristics of the product to be qualified, there might be a need for further tests (e.g. microstructure and macrostructure, etc.) to be conducted at this stage in addition to those mentioned in Clause **4**. The results of such tests have no influence on the final decision to be made on qualification.*

A report shall be drawn up at the end of this stage, describing the test pieces, the test carried out and the test results. It shall specify whether the wheels tested conform to the requirements.

If the outcome is satisfactory, a provisional qualification certificate may be issued.

A.3.5 Testing of wheels

A.3.5.1 Extended production inspection

After provisional qualification, the first production batch of wheels to be qualified shall be subjected to extended inspection in accordance with the "qualification" column of Table B.1. Each batch shall comprise wheels of the same Heat and shall have been heat-treated under the same conditions.

The first batch shall comprise at least 24 wheels.

A.3.5.2 Operational monitoring

The first wheels supplied with a provisional qualification shall be specially monitored in service. For this purpose, a programme shall be stated in the technical specification. It shall comprise:

- definition of the number of wheels to be monitored;
- description of the intermediate and final inspections;
- time period for the monitoring.

A.3.5.3 Results of operational monitoring

The product shall be deemed as qualified at the earliest two years after the first wheel has entered service subject to satisfactory service experience which meets the operational monitoring requirements set out in **A.3.5.2**.

A report shall be produced, containing as a minimum:

- the number of wheels and batches;
- the results of the operational monitoring;
- the number of wheels rejected during the operational monitoring and the reasons for the rejection;
- wheel applications, including axle load, etc.

A.4 Qualification certificate

A.4.1 Condition of the validity

The certificate of qualification shall define the limits of validity, at least for:

a) wheel diameters;

b) steel grades.

A.4.2 Modification and extension

At the manufacturer's request, the scope of the certification validity shall be modified or extended if:

a) other products are to be considered;

b) the main parameters have been modified (e.g. wheel design manufacturing processes, quality organization, etc.).

A.4.3 Transference

For a change of ownership, an existing qualification shall, when the request is made, be transferred to another company if the relevant content and the conditions before qualification have not been modified.

A.4.4 Lapsed certificate

If there has been no production for two years of qualified products that have been previously certified, the wheels of the first batch of the new production shall be delivered in accordance with the 'qualification' column of Table B.1.

A.4.5 Cancellation

If the customer identifies significant defects on the product, the relevant parts of the qualification procedure shall be repeated.

NOTE If the manufacturer has not complied with the important conditions of the qualification, it might be cancelled.

A.5 Qualification documents

For every qualified product, a qualification document shall be produced containing the following:

a) the application request of the manufacturer;

b) the documents supplied by the manufacturer (see **A.3.2**);

c) the evaluation reports (see **A.3.3**);

d) the laboratory test report (see **A.3.4**);

e) the utilization report (see **A.3.5**);

f) the qualification certificate (see **A.4**).

Annex B (normative) Product delivery

B.1 General

B.1.1 The technical specification shall define:

a) geometry and dimensions of the wheel (drawing);

b) maximum phosphorus content and other minimum and maximum contents if necessary (see Table 1);

c) the type of corrosion protection (see **4.11**);

d) the location of wheel markings (see **4.12**);

e) whether the marking of the nominal diameter of the tread is required;

f) the delivery condition (see **B.2**).

B.1.2 The technical specification shall define the quality control process to be applied during manufacturing, either:

a) by batch control, as described in **B.4**; or

b) a quality plan approved by the customer, as indicated in **B.4.6**.

The technical specification shall define the following points:

1) specimen test piece diameter (see **4.3.1.3**);

2) measurement methods (see **4.6.4**, **4.9** and **B.4.3**);

3) surface integrity inspection (see Table B.1);

4) imbalance (see **B.4**).

B.1.3 As an alternative to destructive testing of wheels as required during the product delivery process (see Table B.1) the data from the Heats (see **A.1**) and subsequent Heats shall be used to verify the properties of the steel and derive limits. These derived limits may then be used to confirm conformance during the product delivery testing for any subsequent production batches.

NOTE Batch control frequency and sampling conditions may be amended as defined in the technical specification.

B.2 Delivery condition

The wheels shall be delivered in one of the following conditions:

- **unmachined** (as-cast and shot-peened condition): where the wheel has not been machined except for what the manufacturer has to do to make the wheel compatible with the requirements of this standard;

- **rough-machined** (requested by the customer): where the wheel has been machined and requires subsequent machining;
- **semi-finished**: where the wheel, except for the bore, is finish machined in some parts, but other parts require final machining;
- **finished**: where the wheel has undergone final machining (all parts apart from the bore); or
- **finished, ready for assembly**: where all parts of the wheels including the bore are in the final machined state for assembly.

B.3 Controls on each wheel

Whether quality assurance during manufacture is controlled by batch sampling (see **B.4**), or with a quality plan (see **B.4.6**), controls shall be made on each delivered wheel to allow for the special characteristics defined in Clause **4**.

The following specific controls shall be made on each delivered wheel:

a) internal integrity of the rims (see **4.5.2**);

b) surface integrity (see **4.7.2** or **B.4.5**);

c) imbalance (see **4.9**);

d) tread diameter, bore diameter, rim profile (see **4.8**).

B.4 Batch control

B.4.1 Controls

The nature and number of controls shall be as defined in the 'delivery' column of Table B.1. Batches shall be made up of wheels from the same Heat and heat treated in the same conditions.

B.4.2 Uniformity of batches by measurement of rim hardness

The measurement of Brinell hardness (ball of diameter 10 mm) shall be checked on the rim of each wheel, after heat treatment.

The test shall be carried out in accordance with BS EN ISO 6506-1, BS EN ISO 6506-2 and BS EN ISO 6506-3 on the flat surface opposite to the flange. The impression shall be located as defined in Figure B.1.

The range of hardness values of the rims of wheels from the same batch shall not exceed 30 HB.

NOTE Brinell hardness impressions can be left on the surface. The test can be made before machining.

B.4.3 Orientation of residual stresses on rim chilled wheels

The existence of compressive stresses shall be verified by the measurement of the reduction in the distance between two marks, 100 mm apart, marked in the middle of the rim thickness, on the opposite side to the flange. A radial cut shall be made from the top of the flange to the bore, at a position half way between the two marks.

After the internal stresses are relieved, the distance between the two marks shall reduce by a value ≥1 mm.

NOTE Other methods may be used as specified in the technical specification.

Table B.1 **Type and number of controls to be carried out**

Characteristics to be verified	**Qualification (see A.3.5)**	**Product delivery**		**Clause reference**
		Quantity of wheels per Heat (see B.2)	**Quantity of wheels per batch when B.1.2 is applied (see B.2)**	
Maximum size of the batch	≤100	≤250	≤250	–
Chemical composition	4 Heats	each Heat	each Heat	**4.2**
Hydrogen content	4 Heats [A)]	each Heat [A)]	each Heat [A)]	**4.2.4**
Tensile characteristics:				
in the rim	4 Heats	1 per Heat	1 per batch	**4.3.1**
in the web	4 Heats	1 per Heat	1 per batch	**4.3.1**
Hardness on rim parts	4 Heats	1 per Heat	1 per batch	**4.3.2**
Hardness on rim (Batch uniformity)	100%	100%	100%	**B.4.2**
Impact tests	4 Heats	1 per Heat	1 per batch	**4.3.3**
Toughness [B)]	4 Heats	1 per Heat	1 per batch	**4.3.5**
Material cleanliness	4 Heats	1 per Heat	1 per batch	**4.5.1**
Internal integrity				
Rim	100%	100%	100%	**4.5.2**
Hub	100%	–	–	**4.5.2**
Web	20% [C)]	–	–	**4.5.2**
Residual stresses trends	4 Heats	1 per Heat	1 per batch	– [D)]
Surface appearance	100%	100%	100%	**4.7.1**
Surface integrity	100%	100% [E)]	100% [E)]	**4.7.2**
Geometric tolerances	100% [F)]	100% [F)]	100% [F)]	**4.8**
Static imbalance	100%	100%	100%	**4.9**
Shot peening				**4.10** and **B.4.4**
Laboratory tests	– [G)]	–	–	**A.3.4**

A) One analysis per Heat. The maximum hydrogen level reported is representative for the whole Heat.

B) Only tread-braked wheels.

C) The non-conformance of one wheel requires verification of the whole batch.

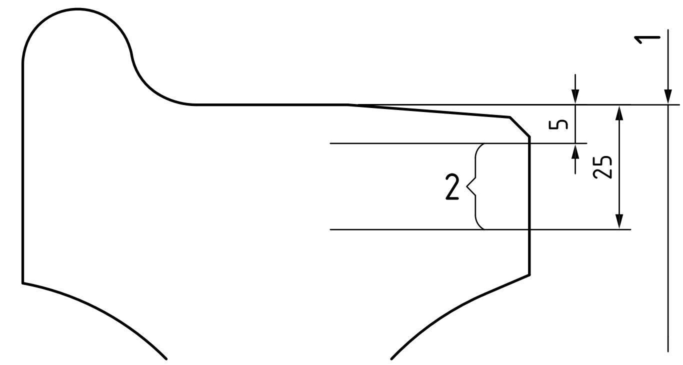
D) See **A.3.5** for qualification and **B.4.3** for delivery.

E) Magnetic particle inspection is mandated for the web (see **4.7.2.1**). The technical specification may specify magnetic particle inspection can be replaced by visual inspection for other parts of the wheel.

F) Tread diameter, bore diameter, rim profile.

G) To be defined according to test laboratory results.

Figure B.1 **Location of hardness measurements**



Key

1 Nominal diameter of tread

2 Area of measurement of Brinell hardness

B.4.4 Shot peening

B.4.4.1 Wheel surface condition

The peened appearance of the rim and hub shall not be cause for rejection. The peening operation shall not prejudice the ability to carry out ultrasonic inspection of the rim in the delivery condition.

B.4.4.2 Frequency of test

Arc height determination shall be made on Almen C strips attached to a test wheel as often as is required to ensure adherence to the specification. The test frequency shall be established; otherwise the arc height shall be measured at least once per eight hours of production or for any change of wheel type (i.e. design) being processed, as defined in *AAR Manual of standards and recommended practices: Section G – Wheels and axles – Specification M 107 M 208* [N1].

B.4.4.3 Retest

If a test fails to meet the arc height requirements of 0.20 mm (0.008 in) Almen C-2, two retests shall be made. These retests shall be averaged with the first test. The average shall not be less than 0.20 mm (0.008 in) and no more than one value of the three shall be less than 0.20 mm (0.008 in).

B.4.4.4 Re-peening

When test values fail to meet the requirements of **B.4.4.3**, corrective action shall be initiated and satisfactory test values secured before proceeding with production peening. If the average Almen value of the unsatisfactory test is below 0.20 mm down to 0.15 mm (0.008 in to 0.006 in), the last half of the wheels peened before the unsatisfactory test but after a satisfactory test shall be re-peened with at least half of the original exposure time. If the average Almen value is less than 0.15 mm (0.006 in), all the wheels peened since the last satisfactory test shall be re-peened with full exposure.

B.4.5 Visual inspection

The lighting levels shall be appropriate for the inspection process being undertaken.

Criteria shall be established with reference images as defined in the technical specification.

B.4.6 Quality plan

B.4.6.1 General

A quality plan refers to the manufacturer's quality policy and contains specific elements for the product. The technical specification shall set out any specific quality requirements.

B.4.6.2 Application of the quality plan

If the quality plan is cancelled, controls and tests defined by the "control by sampling of batches" shall be applied in their entirety instead of initial dispensations.

NOTE If a nonconformity is discovered by the customer on the products to be delivered, the clauses relating to application of the quality plan might be discussed and, if the result is unsatisfactory, the quality plan might be cancelled.

B.5 Allowable rectification

The elimination of surface defects by light grinding with a gradual transition shall be allowed within dimensional, geometric and finished surface tolerances, except on tread surface and bore.

Any rectifications shall respect the surface appearance requirements.

Elimination of any imbalance shall be achieved by eccentric machining of the fillet between the web and the rim, on the flange side. The thickness of the removed metal shall not exceed 4 mm and the resultant surface shall be carefully blended into adjacent material. If damping equipment is fitted in this area, the area for the removal of imbalance shall be defined in the technical specification.

Annex C (informative) Example of a test method for the determination of fatigue characteristics

C.1 Test specimen

The test specimen is the wheel.

Where the cast wheel has risers in the web, the force is applied in a radial position mid-point between risers, on the assumption that this represents the weakest part of the web.

C.2 Test rig

The principle of the test rig is shown in Figure C.1.

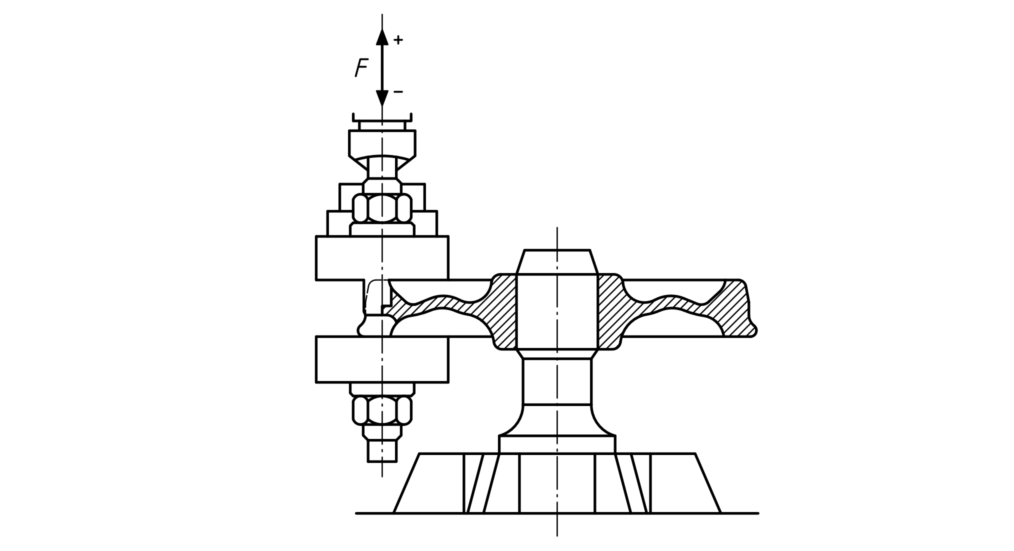
The wheel is fitted on a simulated axle which is fixed to a face plate. Forces are applied to the rim by a hydraulic actuator and the wheel remains fixed.

C.3 Test monitoring

The actuator is controlled by monitoring forces which are calibrated against the radial stresses. Radial stresses are measured in the area where the crack initiation is predicted.

The maximum and minimum forces applied are symmetrical about a mean load of 0 N.

Figure C.1 **Test rig**



Annex D (informative) Strain gauge method for determining the variation of circumferential residual stresses located deep under the tread (destructive method)

D.1 Principle

The strain gauge method consists of cutting operations leading to the progressive relief of residual stresses present in the rim.

The change in the state of residual stresses, which happens in each cutting operation, is evaluated at the surface by measuring local deformation using strain gauges.

The change in state inside the rim is obtained by a linear interpolation of the state evaluated at the surface.

The evaluation is usually performed for one radial cross section only, because it is known that the heat treatment induces effectively a uniform circular state of residual stress. However, for cast wheels with riser positions in the web, this test is performed at two radial positions; one radially in line with a riser position and the other radially in line with a between-riser position. In which case, two separate wheels are used for both sets of measurements.

D.2 Procedure

D.2.1 Fitting of a rim cross section with strain gauges before wheel cutting

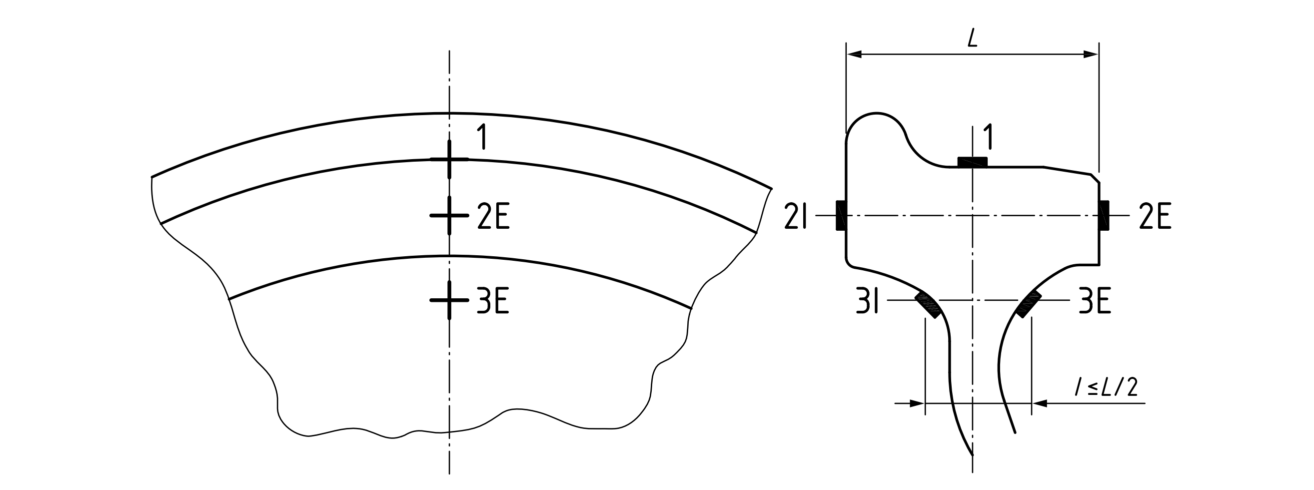
Figure D.1 shows the fitting of the strain gauges.

Apply the strain gauges as follows:

a) in the circumferential and axial directions, at point 1 of the tread located in the plane of symmetry of the web-rim connection; and

b) in the circumferential and radial directions, at point 2E of the external side and 2I of the internal side of the rim and at points 3E of the external side and 3I of the internal side of the web-fillet.

Figure D.1 **Fitting of strain gauges**



D.2.2 Execution of cutting

The chosen cutting method should have no effect on the residual stresses at the test position (e.g. a fine-tooth saw).

Perform three cutting operations in the following order:

a) extract a rim section of a length *s* that is at least twice the rim width, cutting along two radial directions and a plane parallel to the axle and located at a minimum depth of *t* below strain gauges 3I and 3E (see Operation 1 of Figure D.2a);

b) cut along a plane parallel to the axle, located at the start of the web-rim connection (see Operation 2 of Figure D.2b);

c) cut along a plane parallel to the axle crossing the rim (see Operation 3 of Figure D.2c). Only perform this cutting process if the thickness of the rim is greater than 30 mm.

D.2.3 Operations to be executed during cutting

Perform the following operations during cutting:

a) measure the strains after cutting operation 1;

b) record the exact profile of the radial cross section on one of the ends of the rim sections;

c) bond strain gauge 4 (see Figure D.2b);

d) measure the strains of gauges 1 and 4 after cutting operation 2 (see Figure D.2b);

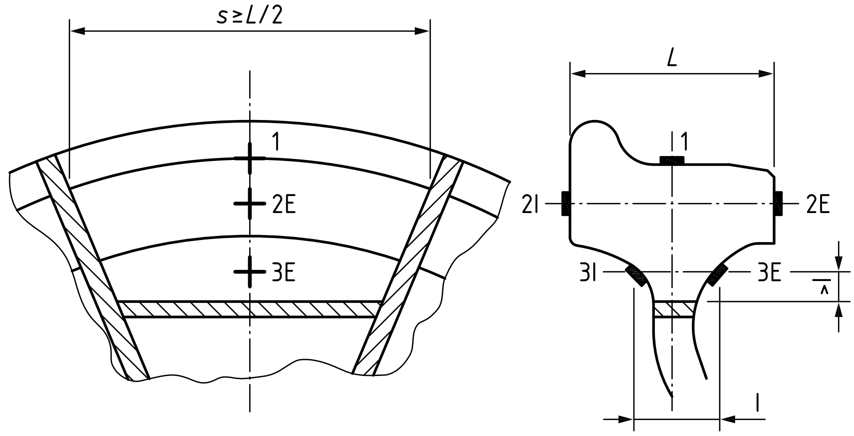
e) measure the thickness of h_1 and h_2 (see Figure D.2b);

f) bond strain gauge 5 (see Figure D.2c);

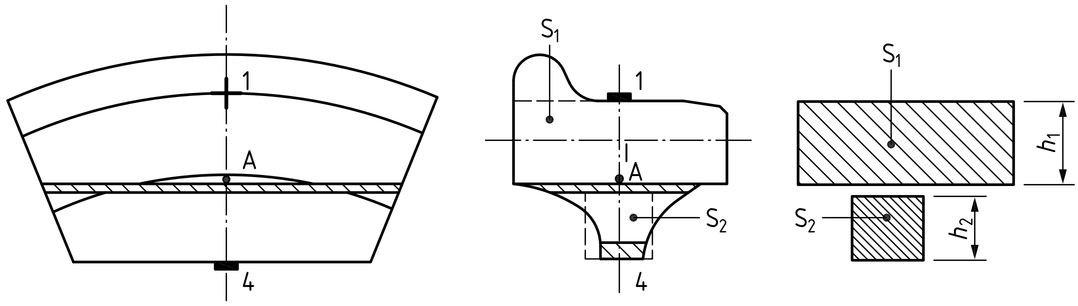
g) measure the strains of gauges 1 and 5 after cutting operation 3 (see Figure D.2c);

h) measure the thickness h_1 and h_2 (see Figure D.2c).

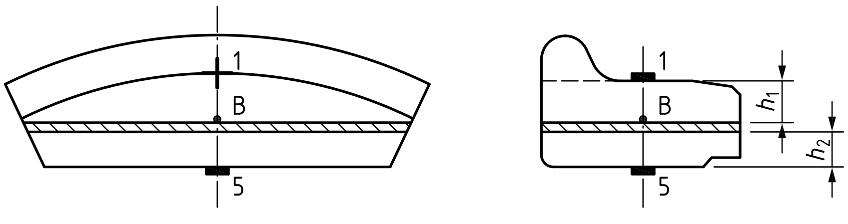
Figure D.2 – Cutting operations



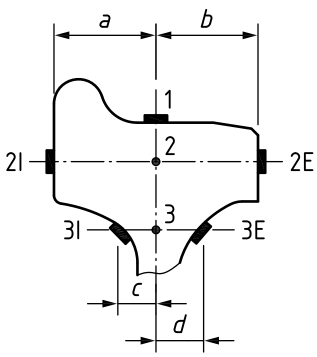
a) Operation 1



b) Operation 2



c) Operation 3



d) Calculation parameters

D.3 Expression of results

D.3.1 Calculation of the variation of the circumferential residual stress located deep under the tread

Calculate the variation of the circumferential stresses, σ_j^i , resulting from each cutting operation “i” at measurement point “j” using the following formula:

$$\sigma_j^i = -\frac{E}{1-v^2}\left(e_{cir}{}_j^i + ve\perp_j^i\right)$$

where:

- E is the Young’s modulus with a constant of 210 000 expressed in megapascal (MPa);
- v is the Poisson’s ratio with a constant of 0.28;
- $e_{cir}{}_j^i$ is the circumferential measured strain;
- $e\perp_j^i$ is the axial (or radial) measured strain;
- σ is the stress in MPa.

D.3.2 Calculation of the variation of the circumferential stress created by cutting operation 1

Calculate stresses σ_1^1 , σ_{2E}^1, σ_{2I}^1, σ_{3E}^1, and σ_{3I-}^1 . The stress values at points 2 and 3 on Figure D.3a shall be given by the following formulae:

$$\sigma_2^1 = \frac{a}{a+b}\sigma_{2E}^1 + \frac{b}{a+b}\sigma_{2I}^1$$

$$\sigma_3^1 = \frac{c}{c+d}\sigma_{3E}^1 + \frac{d}{c+d}\sigma_{3I}^1$$

a, *b*, *c* and *d* are defined in Figure D.2d.

The radial variation of the stress is represented by the straight line passing through the ordinates corresponding to points 1 and 3 in the stress diagram, in relation to the distance between point and tread.

The representation of the calculated stress (see Figure D.3a) at point 2 shall be located at ±20 N/mm² from this straight line.

D.3.3 Calculation of the variation of the circumferential stress created by cutting operation 2

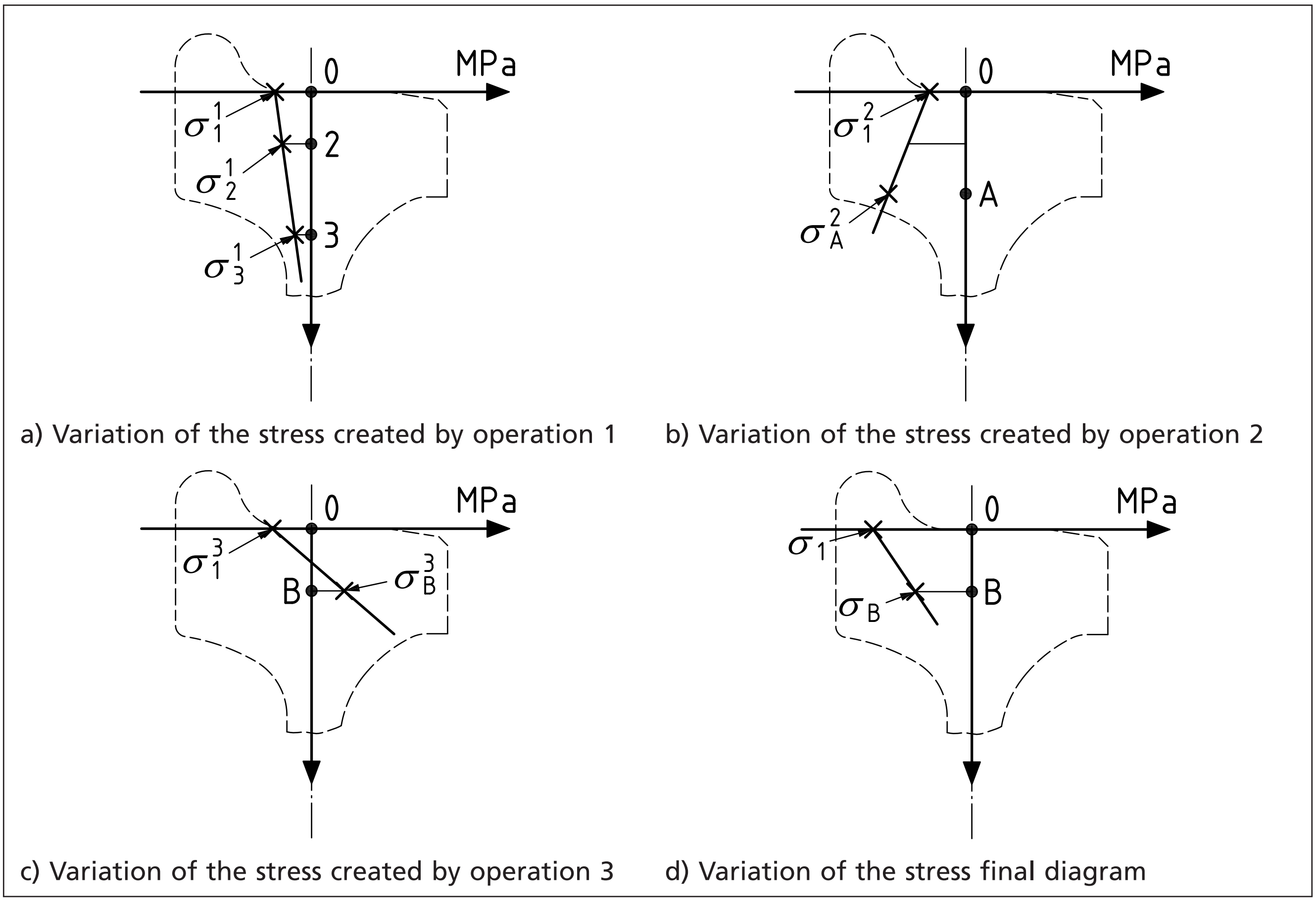
Calculate stresses σ_1^2 and σ_4^2 then the stress at point A (see Figure D.2b) using the following formula:

$$\sigma_A^2 = \frac{-\left(2h_1+h_2\right)S_1\sigma_1^2 + h_2 S_2 \sigma_4^2}{S_1\left(h_1+h_2\right)}$$

h_1, h_2, S_1 and S_2 are defined in Figure D.2b.

The radial variation of the stress is represented by the straight line passing through the ordinates corresponding to points 1 and A in the stress diagram, in relation to the distance between point and tread (see Figure D.3b).

Figure D.3 – Method for determining the variation of the circumferential stress located deep under the tread



a) Variation of the stress created by operation 1

b) Variation of the stress created by operation 2

c) Variation of the stress created by operation 3

d) Variation of the stress final diagram

D.3.4 Calculation of the variation of the circumferential stress created by cutting operation 3

Calculate stresses σ_1^3 and σ_5^3 then the stress at point B (see Figure D.2c) using the following formula:

$$\sigma_B^3 = -\frac{(2h_1 + h_2)}{h_1 + h_2}\sigma_1^3 + \frac{(h_2)^2}{h_1(h_1 + h_2)}\sigma_5^3$$

h_1 and h_2 are defined in Figure D.2c.

The radial variation of the stress is represented by the straight line passing through the ordinates corresponding to points 1 and B in the stress diagram, in relation to the distance between point and tread (see Figure D.3c).

D.3.5 Final diagram representing the variation of the circumferential stress located deep under the tread

Determine stress values: σ_B^1 and σ_B^2 , see Figure D.3a and Figure D.3b.

The value of the circumferential residual stress σ1 at point 1 is equal to the algebraic sum of the measured values of the stresses after each cutting process:

$$\sigma 1 = \sigma_1^1 + \sigma_1^2 + \sigma_1^3$$

Similarly, the σ_B value at point B is equal to:

$$\sigma_B = \sigma_B^1 + \sigma_B^2 + \sigma_B^3$$

The final diagram of the variation of the deep-located circumferential stress is represented by the straight line passing through the ordinates σ_1 and σ_B corresponding to points 1 and B in the stress diagram, in relation to the distance between point and tread (see Figure D.3d).

Annex E (informative) Parameters for drag brake assessment

Power input for drag brake simulation is given by the equation:

$P_a = m \times g \times V_a \times a$ for a period t_a.

Table E.1 shows the drag brake parameters for European interoperability and Table E.2 shows the parameters for vehicles operating solely in Great Britain.

Table E.1 **Drag brake parameters for European interoperability**

Symbol	Description	Units	Value [A)]
m	vehicle mass on rail per wheel	kg	—
g	gravitational acceleration	m/s²	9.806665 m/s²
a	average slope of the line	slope in ‰/1000	21‰ [A)]
t_a	time (test duration)	s	45 min
V_a	vehicle velocity	m/s	60 km/h

A) Values based on South Gothard Slope (the reference slope for interoperability).

Table E.2 **Drag brake parameters for vehicles operating solely in Great Britain**

Symbol	Description	Units	Value [A)]
m	vehicle mass on rail per wheel (axleload)	kg	—
g	gravitational acceleration	m/s²	9.806665 m/s²
a	average slope of the line	slope in ‰/1000	14.3‰ (1 in 70) [A)]
t_a	time (test duration)	s	17.6 min (at 120 km/h)
			21.1 min (at 100 km/h)
V_a	vehicle velocity	m/s	120 km/h up to 20.5 tonnes axleload
	—	—	100 km/h above 20.5 to 25.4 t axleload

A) Values based on Perth - Inverness (the reference slope for GB operation)

Annex F (normative) Assessment of the thermomechanical behaviour

F.1 Assessment flow chart

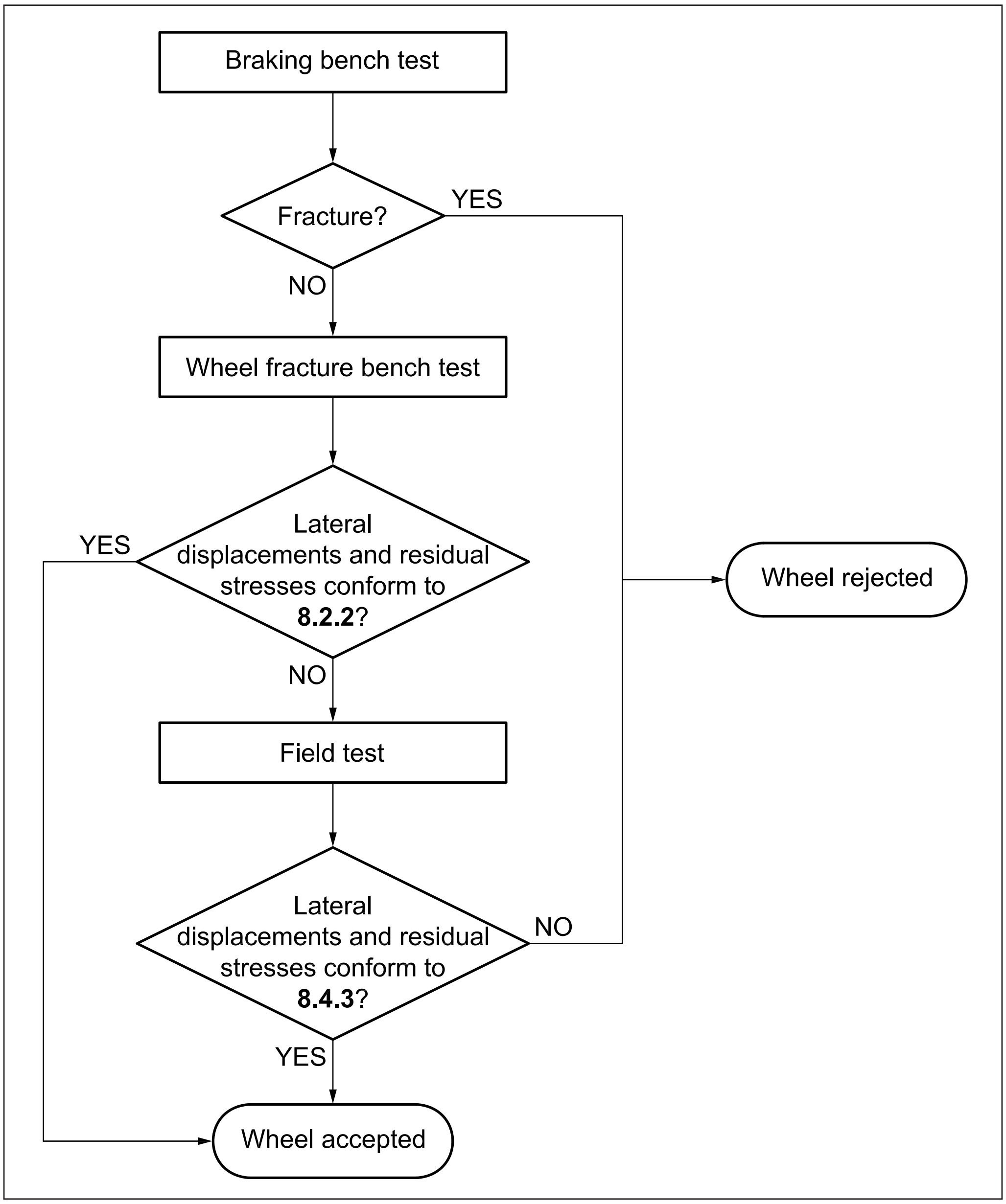
Assessment of the thermomechanical behaviour shall be carried out in accordance with the flow chart shown in Figure F.1.

F.2 Braking bench test procedure

F.2.1 Principle of the test

In the braking bench test, ten drag brakings are made on a wheel and their effects measured on the development of residual stresses in the rim, on the maximum lateral displacement of the rim during braking and on the residual lateral displacement of the rim after cooling.

Figure F.1 **Assessment flow chart**



F.2.2 Definition of braking

The parameters of the drag braking cycles shall be obtained from the parameters defining the application (see **6.3**):

- nominal braking power P_b = 1.2 P_a;
- duration of braking $t_b = t_a$;
- linear speed of the wheel $V_b = V_a$;
- type of brake shoes;
- speed of simulated wind: $V_a/2$ measured 700 mm from the axle with the unit at a halt.

During the cycles, variations in these parameters shall remain within the following ranges:

- instantaneous power: ±10% P_b;
- average power: ±5% P_b;

- duration of braking: ±2% t_b;
- linear speed: ±2% V_b.

The test shall be driven by the instantaneous braking power that is maintained within the range given above for the duration of the test.

Control shall be effected either:

- by measuring the braking torque; or
- by measuring the tangential forces between the wheel and brake shoes and measuring the speed.

Following agreement between the parties involved, the effect of the wind may be taken into account by a calculation that modifies the parameters used or measured during the test.

F.2.3 Method of measuring the decision criteria

F.2.3.1 Measurement of lateral displacements

The lateral displacements of the rim shall be measured on the internal lateral face of the rim at the wear limit diameter level with one face of the hub being used as a reference.

The measurement of the displacement during braking shall allow the extremes of displacement occurring during the ten braking cycles to be obtained.

The residual displacement after cooling shall be equal to the average of three measurements carried out at 120° intervals around the rim.

The measurement accuracy shall be at least ±0.1 mm.

NOTE The maximum value of the displacement might appear some minutes after braking has stopped.

F.2.3.2 Measurement of residual stresses

The residual stresses shall be measured by a destructive method as described in Annex D.

NOTE Other techniques (for example, relative ultrasonic methods) for measuring residual stress in the wheel may be employed where they are proven to give an equivalent and consistent level of accuracy and repeatability.

F.2.4 Tests and measurements

F.2.4.1 Measurements before tests

The parameters of the geometric definition of the wheel shall be recorded.

The brake shoes shall be worn in with a braking power not exceeding 1.2 P_a/2 until the contact surface between the wheel and the shoe is equal to at least 80% of the total shoe surface.

F.2.4.2 Braking tests

The ten drag braking cycles shall be carried out successively.

At the beginning of each cycle, the wheel rim temperature (measured at mid-thickness of the rim on the external face) shall be less than 50 °C.

Cooling of the wheel may be accelerated by water spraying as soon as the rim temperature is lower than 200 °C.

Before each braking cycle, the position of the brake shoes shall be checked to ensure that there is at least 10 mm between the external face of the brake shoe and the external face of the rim.

During each cycle, the following shall be measured:

- instantaneous power;
- linear speed;
- lateral displacement of the rim;
- temperature of the web-rim fillet (optional);
- duration of the braking cycle;
- parameters of the simulated wind.

The average power shall be calculated at the end of each cycle.

The brake shoes shall be changed when they are half-worn or after five braking cycles. New shoes shall be worn in as described in **F.2.4.1**.

NOTE Measurement of the rim temperature is not mandatory, but might in certain cases explain aberrant residual stresses. Monitoring of the power level is mandatory and replaces monitoring of the pressure in the brake cylinder because of the variations in the coefficient of friction between the wheel and the brake shoe.

F.2.4.3 Measurements after the braking cycles

After ten braking cycles and complete cooling down of the wheel, the following shall be measured:

- the residual stresses at the same points as before the braking cycles;
- the residual lateral displacement of the rim.

F.2.5 Anomalies

If a power-monitoring anomaly occurs during the cycles, the test shall be restarted with a different wheel.

F.3 Wheel fracture bench test procedure

F.3.1 Principle of the test

The fracture bench test consists of verifying that a wheel with a pre-cracked rim withstands specified drag braking without undergoing any radial fracture.

F.3.2 Definition of drag braking

The drag braking cycle parameters shall be obtained from the parameters defining the wheel application (see **4.3.2**):

a) nominal braking power $P_r = 1.2\ P_a$;

b) duration of braking $TR = t_a$;

c) linear speed $V_r = V_a$;

d) type of brake shoe.

During the braking cycles, these parameters shall remain within the following limits:

- instantaneous power: ±10% P_r;
- average power: ±5% P_r;
- duration of braking: ±2% t_b;
- linear speed: ±2% V_b.

The test shall be driven by the instantaneous braking power that is maintained within the range given above for the duration of the test.

Control shall be effected either:

- by measuring the braking torque; or
- by measuring the tangential forces between the wheel and brake shoes and measuring the speed.

F.3.3 Pre-cracking of the rim

The wheel to be tested shall have a crack on the external edge of the tread. The depth of this crack, measured on the external lateral face of the rim, shall be 8 mm ±1 mm.

This crack may be obtained using the following method:

- machining of three mechanical notches on the edge of the tread, 120° apart;
- application of two drag brakings at a nominal power of 0.66 P_a for a period of t_a and at a speed V_a;
- application of stop brakings to initiate and propagate cracks from the mechanical notches until one of them attains the required depth (8 mm ±1 mm).

F.3.4 Tests and measurements

F.3.4.1 Pre-cracking of the rim

This shall be done under the conditions described in **F.3.3** or using any other method giving the same result.

The parameters of the geometric definition of the rim shall be recorded.

F.3.4.2 Fracture of the wheel

The braking cycles described in **F.3.2** shall be applied successively to the wheel until either:

a) a radial fracture occurs; or

b) a state similar to a fracture occurs, for example, rapid propagation of a crack into the web which is then stopped by the curvature of the web.

If after ten cycles of drag braking there is evidence of crack propagation, the drag braking cycles shall continue until the crack stabilizes or the wheel fractures.

The cooling of the wheel may be accelerated by water spraying as soon as the rim temperature is less than 200 °C.

The following measurements shall be carried out during each cycle:

- instantaneous power;
- linear speed;
- lateral displacement of the rim;
- temperature of the web-rim fillet (optional);
- duration of the braking cycle.

The average power shall be calculated after each cycle.

F.3.5 Anomalies

If, during the cycles, a power monitoring anomaly occurs, the test shall be restarted with a different wheel.

F.4 Field braking test procedure

F.4.1 Principle of the test

The field braking test consists of making ten drag brakings on one wheel and measuring their effects on the development of residual stresses in the rim, the lateral displacement of the rim and the residual lateral displacement of the rim after cooling.

F.4.2 Definition of braking

The drag braking cycle parameters shall be obtained from the parameters defining the application of the wheel (see **4.3.2**):

a) nominal braking power $P_b = 1.2\ P_a$;

b) duration of braking $t_b = t_a$;

c) linear speed of the wheel $V_b = V_a$;

d) type of brake shoe.

During the braking cycles, these parameters shall remain within the following limits:

- instantaneous power: ±10% P_b;
- average power: ±5% P_b;
- duration of braking: ±2% t_b;
- linear speed: ±2% V_b.

The test shall be driven by the instantaneous braking power maintained within the range given above for the duration of the test.

Control shall be effected either:

- by measuring the braking torque; or
- by measuring the tangential forces between the wheel and brake shoes and measuring the speed.

F.4.3 Method of measurement of the decision criteria

F.4.3.1 Measurement of lateral displacements

The lateral displacements of the rim shall be measured on the internal lateral face of the rim at the wear limit diameter level with one face of the hub being used as a reference.

The measurement of the displacement during braking shall be continuous to obtain the minimum and maximum displacement occurring during all the braking cycles.

The residual displacement after cooling shall be equal to the average of three measurements carried out at 120° intervals around the rim.

The measurement accuracy shall be at least ±0.1 mm.

NOTE The maximum value of the displacement might appear some minutes after braking has stopped.

F.4.3.2 Measurement of residual stresses

The residual stresses shall be measured by a destructive method as described in Annex D.

F.4.3.3 Vehicle requirements

For this test, a vehicle on which the wheel to be approved is to be fitted shall be selected. Its braking control system shall be disabled to replace it with a braking system allowing monitoring of the braking power.

The brake shoes shall be positioned to have their external faces between 10 mm and 20 mm from the front face of the rim towards the flange.

The vehicle loading shall be 'empty, ready to run'.

F.4.3.4 Other requirements

The wheelsets with the wheels to be approved shall be in a leading position on the vehicle or on the bogie.

F.4.3.5 Meteorological conditions

The meteorological conditions shall be as close as possible to the following:

- little wind (wind speed less than 20 km/h);
- dry weather (no rain); and
- temperature between 10 °C and 25 °C.

F.4.3.6 Track parameters

The track shall be as straight as possible.

F.4.4 Tests and measurements

F.4.4.1 Measurements before the test

The parameters of the geometric definition of the wheel shall be recorded.

The distance a_1 between the internal faces of the wheelset shall be measured over three sectors 120° apart.

The brake shoes shall be worn in with a braking power not exceeding 1.2 $P_a/2$ until the contact surface between the wheel and the shoe is equal to at least 80% of the total shoe surface.

F.4.4.2 Braking tests

The ten drag braking cycles shall be carried out successively.

At the beginning of each cycle, the wheel rim temperature (measured at mid-thickness of the rim on the external face) shall be less than 50 °C.

Cooling of the wheel may be accelerated by water spraying as soon as the rim temperature is lower than 200 °C.

Before each braking cycle, the correct position of the brake shoes shall be checked.

During each cycle, the following shall be measured and recorded:

- the instantaneous power;
- the linear speed;
- the lateral displacement of the rim;
- the temperature of the web-rim fillet (optional);
- the duration of the cycle;
- the meteorological conditions: e.g. wind speed, atmospheric pressure, temperature.

The average power shall be calculated at the end of each cycle.

The brake shoes shall be changed when they are half-worn or after five braking cycles. New shoes shall be worn in as described in **F.4.4.1**.

NOTE Measurement of the rim temperature is not mandatory, but can in certain cases explain aberrant residual stresses. Monitoring of the power level is mandatory and replaces monitoring of the pressure in the brake cylinder because of the variations in the coefficient of friction between the wheel and the brake shoe.

F.4.4.3 Measurements after the braking cycles

After ten braking cycles and complete cooling down of the wheel, the following shall be measured:

- the residual stresses are measured by an ultrasonic method using a procedure and apparatus in accordance with BS EN 13979-1:2003+A2:2011, **A.2.3.2**;
- the residual lateral displacement of the rim;
- the position of the brake shoes on the rim;
- the distance a_1 between the internal faces of the rims on the wheelset.

F.4.5 Anomalies

If a power-monitoring anomaly occurs during the cycles, the test shall be restarted with a different wheel.

Annex G (normative) Assessment of the mechanical behaviour

G.1 Flow chart of the mechanical behaviour assessment

Assessment of the mechanical behaviour shall be carried out in accordance with the flow chart is shown in Figure G.1.

G.2 Mechanical behaviour – Finite element code assessment

The stress calculations shall be made using a standard finite element code.

The analysis shall be three-dimensional: mesh with load on one section, or axisymmetrical mesh with non-axisymmetrical load (harmonic analysis) if the code permits an adequately high number of modes representative of a load on one section.

The type of element chosen shall be assessed (through classical beam theory calculation and/or by tests) and the deformation of each element of the model in relation to its reference elements shall meet the criteria imposed by the code.

The precision of the mesh shall take account of the type of element and the convergence of the results as a function of the fineness of the mesh.

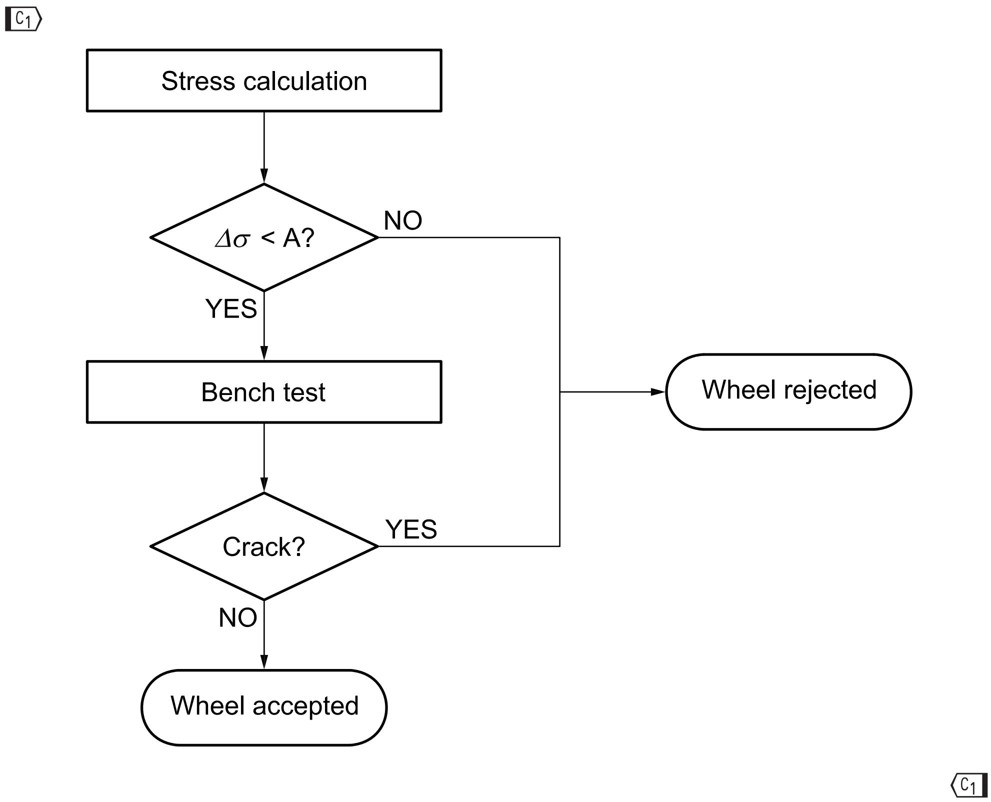
The presence of holes in the web shall impose 3D meshing.

G.3 Mechanical behaviour – Bench loading and test procedure

G.3.1 Principle of bench loading and test procedure

The schedule for assessment by test of the mechanical behaviour shall be carried out in accordance with Figure G.2.

Figure G.1 **Mechanical assessment flow chart**



where:

△σ is the amplitude of the calculated stress;

A is the permissible limit of dynamic stress.

G.3.2 Definition of loading

G.3.2.1 General

The load to be reproduced shall be representative of a part of the service life of the vehicle fitted with the wheels to be approved.

This load shall be determined using the method specified in the ERRI report B169/RP12 [N6]. This method consists of assessing the stresses on the wheel web surface by measurements on the track and determining the forces to be imposed on the bench to reproduce the same stresses as those measured on the track.

G.3.2.2 Measurement of the stresses during field tests

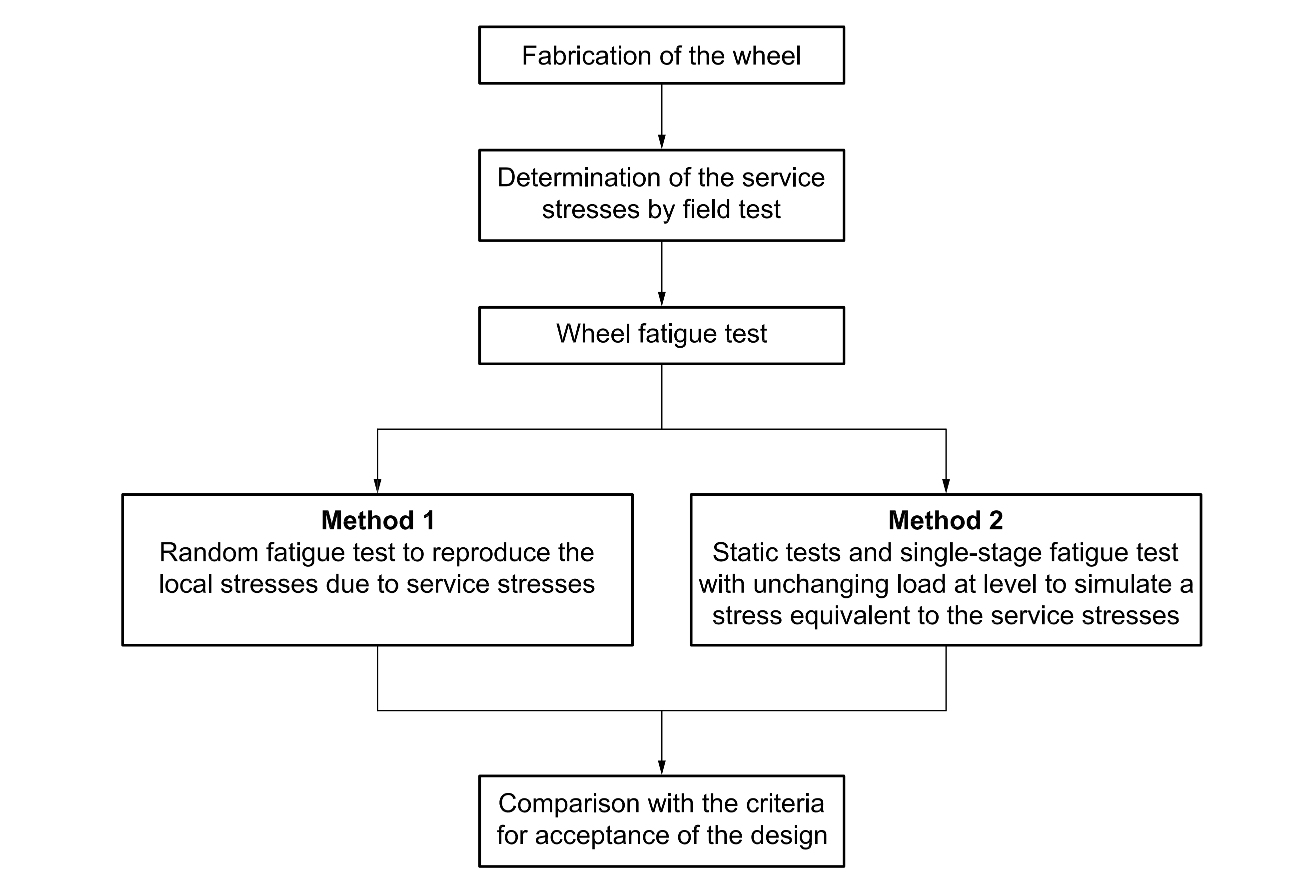
The following stresses shall be measured.

a) Location of the stress measurements: The stresses are measured in the crack initiation zone. The finite element calculation, carried out during the first stage of the assessment, determines this zone (see **9.2**).

b) Test route: The test routes are determined in accordance with the ERRI/B169 report RP12 [N6]. The choice of test routes based on routing of the vehicle provide a representative section of the service life of the vehicle.

c) Field tests: During the field test associated with a test route, the local stresses in the wheel web are measured in real time according to the MARKOV principle. An elementary matrix corresponds to each test route (see ERRI report B169/RP12 [N6]).

Figure G.2 **Mechanical behaviour test assessment schedule**



d) Global loading matrix: The global loading matrix is obtained by:

1) multiplying the elementary matrix elements of each test route by the weighting coefficient that is the ratio of the number of kilometres travelled during the service life portion and the number of kilometres travelled during the test;

2) adding all the weighted elementary matrices;

3) multiplying this sum to obtain a life of approximately 10 000 km.

This global matrix is called G.

G.3.3 Fatigue bench test

G.3.3.1 Method 1 – Random fatigue test

G.3.3.1.1 Loading matrix

This simulates the life of the wheel. The matrix G that simulates 10 000 km shall be multiplied by a coefficient to represent the full life.

Then, the MARKOV random sampling method requires symmetrization of the matrix. This shall be done by forming the algebraic mean of the sum of the matrix and its transpose.

Finally, to reduce the duration of the fatigue test, transitions that generate cycles with low dynamic stress ranges and no damage are eliminated from the matrix. For example, the total number of cycles for the fatigue test may be fixed conventionally at 2×10^6.

This final load matrix is called H.

G.3.3.1.2 Monitoring of the bench test

The bench test may be monitored either by the stresses measured on the web in the zone where the crack is initiated or by the forces applied to the wheel.

For monitoring by stresses, the matrix H may possibly be modified to a matrix H1 to take account of the differences in shape of the wheel used in the field test to determine matrix G (see **G.3.2.2**) and the wheel used for the bench test. An FEM calculation may provide the means for transforming matrix H.

For monitoring by forces, the stresses of matrix H shall be transformed into corresponding forces creating on the bench the same stresses as those in the wheel used in the field test to determine matrix G (see **G.3.2.2**). This matrix is called H_2.

G.3.3.1.3 Random fatigue test

Each transition of matrix H_1 or H_2 shall be sampled randomly and then reproduced in the bench fatigue cycle. This method is described in the ERRI report B169/RP12 [N6].

G.3.3.1.4 End of test criterion

The criterion shall be as follows:

- a fatigue crack. It is considered a crack if its length is greater than or equal to 1 mm;
- no crack after application of all the matrix cycles.

G.3.3.2 Method 2 – Single-stage fatigue test

G.3.3.2.1 Load matrix and spectrum

Matrix G represents a 10 000 km section of service life. The frequency distribution of the maxima and minima shall be determined from this matrix G. Then, transition to the full life section shall be made using a multiplying coefficient, calculating the sum of maxima and minima frequency distributions and, if necessary, converting elongations into stresses. Finally, the load spectrum shall be symmetrized and converted for a mean stress of zero.

This load spectrum may possibly be modified to take account of the differences in shape between the wheel used to determine matrix G and the wheel used for the bench tests. A factor shall be determined to represent the stress differences. The load spectrum stresses shall be multiplied by this factor.

G.3.3.2.2 Equivalent stress

The load spectrum obtained as indicated above shall be divided into ten similar stress stages. The equivalent stress shall then be calculated according to the Serensen-Koslov method. It is based on the elementary Miner law, also called the Corten/Dolan method.

The details of the calculation of the equivalent stress are given in the ERRI report B169/RP10 [N7].

G.3.3.2.3 Single-stage fatigue test

Before the start of the fatigue test, a static test shall be carried out to establish the relationship between the stresses and loads (Fy and Fz). The dynamic test shall then be started. The test stresses shall be determined as follows:

a) first test wheel:

   1) 1st stage; the test stress is equal to the equivalent stress;

   2) 2nd stage; the test stress is equal to 1.4 times the equivalent stress;

b) subsequent wheels; the test starts with a stress equal to 1.4 times the equivalent stress.

The test is carried out for 10^7 cycles at each loading level. The ERRI report B169/RP10 [N7] gives details of the procedure.

G.3.3.2.4 Acceptance criterion

The criterion shall be as follows:

- no crack is permitted after 10^7 cycles with a stress level of at least 1.4 times the equivalent stress;
- a crack is considered to exist if its length is greater than or equal to 1 mm.

G.3.4 Examples of benches for fatigue tests

G.3.4.1 Test piece

The test piece shall be the wheel itself.

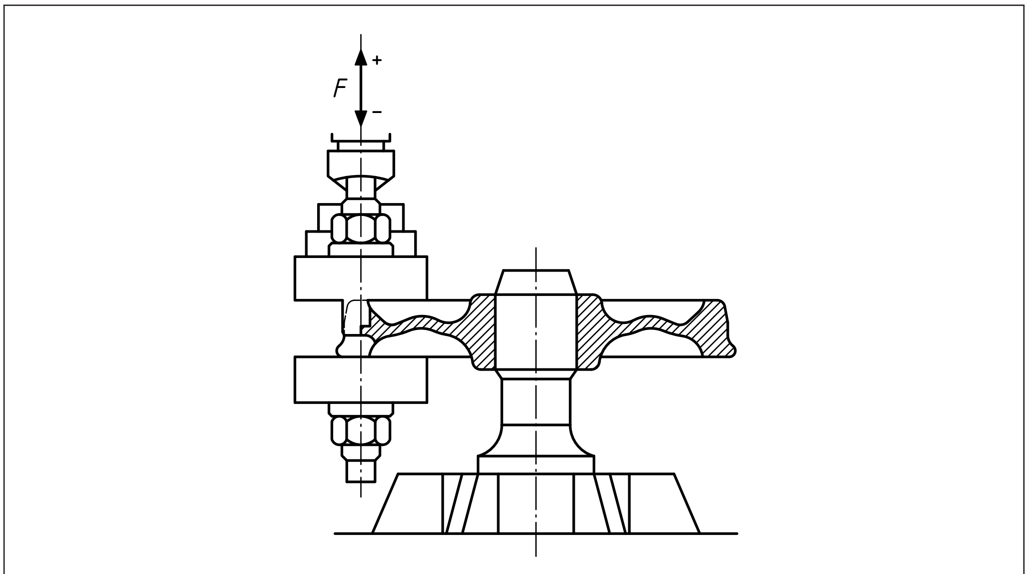
G.3.4.2 First test method

G.3.4.2.1 Test rig

The principle of the test rig is shown in Figure G.3:

- the wheel is fitted on a simulated axle which is fixed to a face plate;
- forces are applied to the rim by a hydraulic actuator;
- the wheel remains fixed.

Figure G.3 **Functional diagram**



G.3.4.2.2 Test monitoring

The actuator shall be controlled by monitoring forces that are calibrated against the radial stresses that are measured in the area where the crack initiates.

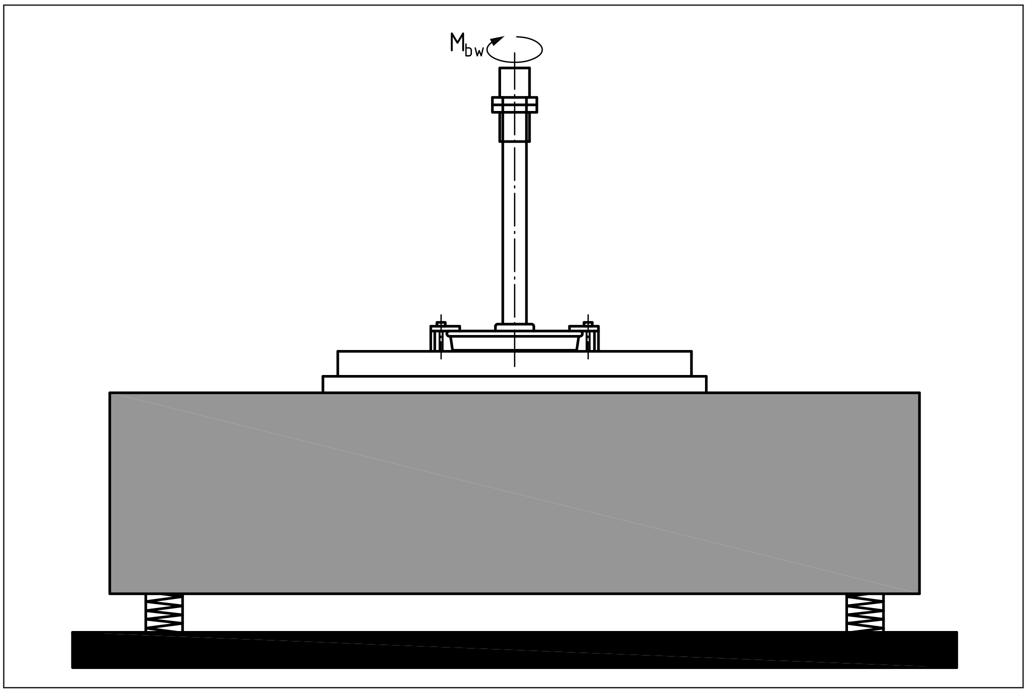
The maximum and minimum forces applied shall be symmetrical about a mean load of 0 N.

G.3.4.3 Second test method

G.3.4.3.1 Test rig

The operating principle of the test rig is shown in Figure G.4.

Figure G.4 **Rotational bending fatigue test rig**



The rotational bending fatigue test rig is a resonance testing machine in which the test piece acts as a spring in the machine's oscillating system. The vibrational response of the test piece shall be determined primarily by the parameters mass, stiffness (spring constants) and damping. The excitation of the oscillating system shall be induced by a vibration motor. The load on the test piece shall be controlled by changing the rotational speed of the driver motor. Load changes shall be induced on the rising branch of the resonance curve below the resonant frequency.

The test rig shall comprise a clamping plate fixed to a spring-mounted (anti-vibration) concrete block.

The half-wheelset shall be mounted on the clamping plate.

An electric motor with an unbalanced mass shall be placed on the wheelset axle shaft.

G.3.4.3.2 Test monitoring

The drive motor, which is mounted on the axle shaft and has an unbalanced mass attached to it, shall induce a rotational bending motion in the wheelset axle. The controller shall be adjusted so that the stress generated in the wheel web is that associated with the chosen load level. The test piece shall then be subjected to 10^7 stress cycles at this stress level.

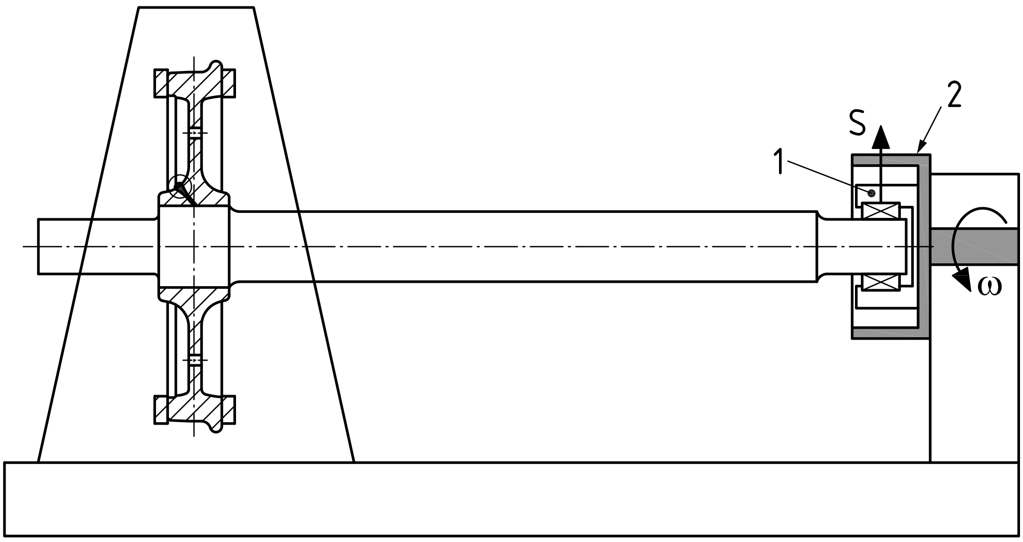
G.3.4.4 Third test method

G.3.4.4.1 Test rig

The operating principle of the test rig is shown in Figure G.5.

The wheel rim shall be fixed to the test rig structure.

Figure G.5 **Rotational bending fatigue test rig**



Key
1 Sledge
2 Rotor

On the journal at the opposite side of the axle, a bearing shall be fitted and placed in a metal sledge which can be displaced radially inside a rotor (the displacement is called S in Figure G.5).

The rotational bending fatigue test rig shall be obtained by a rotating the displacement (S).

The displacement (S) shall be regulated in order to obtain the required strain in the area of the axle or the wheel that has to be verified.

The strain shall be measured through strain gauges.

The rotation shall be given by an electric motor that acts on the rotor.

G.3.4.4.2 Test monitoring

The strain gauges applied on the sections of the axle or the wheel to be tested shall be constantly monitored in order to prove the constant amplitude loading throughout the test.

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