DD CEN/TS 13979-2:2011

BSI Standards Publication

Railway applications — Wheelsets and bogies — Monobloc wheels — Technical approval procedure

Part 2: Cast wheels

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National foreword

This Draft for Development is the UK implementation of CEN/TS 13979-2:2011.

This publication is not to be regarded as a British Standard.

It is being issued in the Draft for Development series of publications and is of a provisional nature. It should be applied on this provisional basis, so that information and experience of its practical application can be obtained.

Comments arising from the use of this Draft for Development are requested so that UK experience can be reported to the international organization responsible for its conversion to an international standard. A review of this publication will be initiated not later than 3 years after its publication by the international organization so that a decision can be taken on its status. Notification of the start of the review period will be made in an announcement in the appropriate issue of Update Standards.

According to the replies received by the end of the review period, the responsible BSI Committee will decide whether to support the conversion into an international Standard, to extend the life of the Technical Specification or to withdraw it. Comments should be sent to the Secretary of the responsible BSI Technical Committee at British Standards House, 389 Chiswick High Road, London W4 4AL.

The UK participation in its preparation was entrusted to Technical Committee RAE/3/-/1, Railway Applications - Wheels and Wheelsets.

A list of organizations represented on this committee can be obtained on request to its secretary.

Normative – A (mandatory) requirement defined as an expression in the content of a document conveying criteria to be fulfilled if compliance with the document is to be claimed and from which no deviation is permitted [CEN/ CENELEC internal Regulations, Part 3: Rules for the Structure and Drafting of European Standards (PNE-Rules)].

Informative – Information (not mandatory) intended to assist the understanding or use of the document. Informative annexes shall not contain requirements, except as optional requirements. (For example, a test method that is optional may contain requirements but there is no need to comply with these requirements to claim compliance with the document.)

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The period of validity of this CEN/TS is limited initially to three years. After two years the members of CEN will be requested to submit their comments, particularly on the question whether the CEN/TS can be converted into a European Standard.

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Foreword

This document (CEN/TS 13979-2:2011) has been prepared by Technical Committee CEN/TC 256 “Railway applications”, the secretariat of which is held by DIN.

This document has been prepared as part of a mandate given to CEN by the European Commission and the European Free Trade Association and provides support for the main requirements of EU Directive 2008/57/CE.

This European Standard is part of a series *Railway applications — Wheelsets and bogies — Monobloc wheels — Technical approval procedure* which consists of the following parts:

- *Part 1: Forged and rolled wheels*;
- *Part 2: Cast wheels*.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to announce this Technical Specification: Austria, Belgium, Bulgaria, Cyprus, Croatia, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Iceland, Italy, Latvia, Lithuania, Luxembourg, Malta, Norway, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

Introduction

Part 1 of this series applies to monobloc wheels manufactured by forging and rolling. This process was the only authorized process accepted in the UIC regulations that were applicable in the recent past in most of the European countries.

Cast wheels are commonly used by AAR networks and have been introduced into Europe on some applications for freight wagons. This standard defines the specified requirements linked to the casting process for the technical approval of a monobloc wheel. It follows the same methodology as Part 1.

As this standard applies only to freight wagons and supports European interoperability, this standard defines in the informative Annex F the specific parameters for the thermomechanical assessment of a freight wagon wheel designed for European interoperability.

The standard describes how to assess the wheel design. To be able to apply the specifications, it is essential to define the use of the wheel; 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: to manage wheel deformations and to ensure that braking will not cause wheels to break;
- a mechanical aspect: to ensure that no fatigue cracks occur in the web;
- 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 proposed tend to limit the procedure; thus, the easier the objectives are to attain by the wheel under study.

This Technical Specification does not cover assessment of the hub nor of the static mechanical dimensioning of the wheel.

The main content of this standard is derived from Part 1. The only technical differences are linked to the needs of the cast process for the product.

1 Scope

This Technical Specification defines the requirements for a cast monobloc wheel of a freight railway vehicle non-powered axle for use on a European network.

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

These requirements are intended to assess the validity of the design choice for the proposed use.

The assessment of these requirements is the technical approval procedure.

This Technical Specification does not address the quality requirements for cast wheels. These quality requirements are defined in Technical Specification CEN/TS 15718.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the reference document (including any amendments) applies.

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

CEN/TS 15718, *Railway applications — Wheelsets and bogies — Product requirements for cast wheels*

3 Parameters for the definition of the application covered

The application for which the wheel is to be approved shall be defined by the following parameters.

If the application parameters are changed for an approved wheel, the customer and supplier shall review the assessments.

3.1 Parameters for geometric interchangeability

The application shall be defined by geometric interchangeability parameters divided into three categories according to whether they are linked to functional, assembly or maintenance requirements.

3.1.1 Functional requirements

- the nominal tread diameter that influences the buffer height and the loading gauge;
- the maximum rim width linked to the points and crossing and the track brakes;
- the tread profile outside the conical part of the tread;
- the position of the rim internal surface relative to the corresponding surface of the hub;
- the conicity of the hub bore;
- the space required for disc brakes mounted on the wheel;
- the space needed on the bogie frame, braking equipment and suspension equipment.

3.1.2 Assembly requirements

- the bore diameter;
- the hub length to ensure overhanging of the hub on the wheelseat.

3.1.3 Maintenance requirements

- the wear limit diameter or the last reprofiling diameter;
- the wear groove shape;
- the geometry of the area for wheel clamping on reprofiling machines;
- the position and shape of the hole and groove for displacement under oil pressure (where required);
- the general rim shape to allow ultrasonic measurement of residual stresses in wheels braked by shoes.

3.2 Parameters for thermomechanical assessment

The application shall be defined by:

- the maximum braking energy created by the friction of the brake shoes on the tread surface. 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 by agreement between the customer and the supplier. Required values of P_a for European interoperability are given in informative Annex F;

NOTE For interoperable freight rolling stock, the thermomechanical behaviour does not need to be verified when braking to a stop, but only when drag braking, because of the lower energy in braking to a stop.

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

3.3 Parameters for mechanical assessment

The application shall be defined by:

- the maximum vertical static force per wheelset;
- the type of service to be provided by the vehicles that will be fitted with the wheels to be approved:
  - description of the lines: geometric quality of the tracks, curve parameters, maximum speeds;
  - running times on these lines;
- the calculated service life of the wheel, in kilometres.

3.4 Parameters for acoustic assessment

The application shall be defined by all the parameters influencing the noise emitted by the wheel and not directly involved in the design of the wheel to be approved, such as:

- the reference track on which the wheel is to run;
- the reference wheel to which the design will be 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.

4 Description of the wheel to be approved

The designer of the wheel to be approved shall supply documentation comprising:

- the description of the fabrication process (casting, shot peening, heat treatment, machining condition);
- the definition of the wheel geometry (drawing);
- the following fabrication parameters:
  - geometric tolerances;
  - surface finishes;
  - steel grade;
- the parameters for defining the application for which the approval is requested.

At the end of this technical approval procedure and before being put into service, a wheel shall be subjected to product qualification as defined in Technical Specification CEN/TS 15718.

5 Assessment of the geometric interchangeability

The wheel design shall conform to the requirements of 3.1.

6 Assessment of the thermomechanical behaviour

6.1 General procedure

This assessment may comprise three stages.

The flowchart for this assessment is shown in normative Annexe A. It shall be noted that stages 1 and 2 can occur in any order as they are both mandatory for cast wheels. The following text maintains the same order as EN 13979-1; however, it shall be noted that the sequence shown in Annex A may be preferable in practice.

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).

In each case (new rim and worn rim), the web geometry of the tested wheels shall be the least favourable for thermomechanical behaviour within the geometric tolerance ranges. The wheel designer shall prove by numeric simulation that the tested wheels give the worst results. If that is not the case, the numeric simulation shall allow correction of the results to correspond with those that would be obtained on wheels in the most unfavourable 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.

6.2 First stage – Braking bench test

6.2.1 Test procedure

The test method and the measurements to be made are given in normative Annex A.

The power to be applied during this test shall be equal to 1,2 P_a (P_a is defined in 3.2). The duration of each drag braking period and the train speed are those defined in 3.2 (t_a and V_a).

6.2.2 Decision criteria

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

Wheel with new rim:

- maximum lateral displacement of the rim during braking: + 3 / -1 mm;
- level of residual stress in the rim after cooling:
  - $\sigma_{r\,n} \leq + \Sigma_r$ N/mm^2 as the average of three measurements;
  - $\sigma_{i\,n} \leq + (\Sigma_r + 50)$ N/mm^2 for each measurement;
- maximum lateral displacement of the rim after cooling: + 1,5 / - 0,5mm.

Wheel with worn rim:

- maximum lateral displacement of the rim during braking: + 3 / -1 mm;
- level of residual stress in the rim after cooling:
  - $\sigma_{r\,w} \leq +(\Sigma_r + 75)$ N/mm^2 as the average of three measurements;
  - $\sigma_{i\,w} \leq +(\Sigma_r + 100)$ N/mm^2 for each measurement;
- maximum lateral displacement of the rim after cooling: + 1,5 / - 0,5mm.

For steel grade CER7, a value of $\Sigma r = 200$ N/mm^2 is adopted. For CER8, the value of Σr shall be determined.

The lateral displacement is positive if the distance between the two inner faces of the wheel of the wheelset increases.

For domestic traffic, if the track tolerances differ from general tolerances used in Europe, other values of lateral displacement may be agreed between the parties concerned.

6.3 Second stage – Wheel fracture bench test

6.3.1 General

This second stage is mandatory for cast wheels due to the currently limited European experience on those products.

6.3.2 Test procedure

The test procedure is given in normative Annex A.

6.3.3 Decision criterion

The tested wheels shall not fracture.

6.4 Third stage – Field braking test

6.4.1 General

This third stage shall be proceeded with if one of the results of the first stage does not meet the decision criteria and the wheel is not rejected after the second stage.

6.4.2 Test procedure

The test method and the measurements to be taken are given in normative Annex A.

The power to be taken into account for this test is 1,2 P_a (P_a is defined in 3.2). The duration of each drag braking and the running speed of the train are those defined in 3.2 (t_a and V_a).

6.4.3 Decision criteria

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

Wheel with new rim:

- maximum lateral displacement of the rim during braking: + 3 / -1 mm;
- level of residual stress in the rim after the tests and after cooling:
  - $\sigma_{r\,n} \leq + (\Sigma_r - 50)$ N/mm^2 as the average of the three measurements;
  - $\sigma_{\mathrm{i\,n}} \leq + \Sigma_r$ N/mm^2 for each of the measurements;
- maximum lateral displacement of the rim after cooling: + 1,5 /- 0,5 mm.

Wheel with worn rim:

- maximum lateral displacement of the rim during braking: + 3 /-1 mm;
- level of residual stress in the rim after the tests and after cooling:
  - $\sigma_{\mathrm{r\,w}} = + \Sigma_r$ N/mm^2 as the average of the three measurements;
  - $\sigma_{\mathrm{i\,w}} = + (\Sigma_r + 50)$ N/mm^2 for each of the measurements;
- maximum lateral displacement of the rim after cooling: + 1,5 /- 0,5 mm;

- For steel grade CER7, a value of Σr = 200 N/mm^2 is adopted. For CER8, the value of Σr shall be determined.

The lateral displacement is positive if the distance between the two inner faces of the wheel of the wheelset increases.

For domestic traffic, if the track tolerances differ from the general tolerances used in Europe, other values of lateral displacement may be agreed between the parties concerned.

7 Assessment of the mechanical behaviour

7.1 General procedure

This assessment shall comprise two stages. The purpose of this assessment is to ensure that there will be 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.

Both for the calculation and the test, the wheel geometry shall be the least favourable with regard to the mechanical behaviour. If that is not the case for the test, the test parameters shall be corrected by the calculation.

The flowchart for this assessment is shown in normative Annex B.

7.2 First stage - Calculation

7.2.1 Applied forces

Conventional forces shall be used. They are calculated on the basis of the value of load P. Load P is defined in EN 13103. It is half the vertical force per wheelset on the rail.

On the basis of the parameters necessary for the mechanical assessment defined in 3.3, additional forces shall be used if these parameters generate greater forces (for example, curve parameters, frozen track, etc.).

Three load cases shall be considered (see Figure 1):

- Case 1: straight track (centred wheelset)

  $F_z = 1,25\ P$

  $F_{y1} = 0$

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

  $F_z = 1,25\ P$

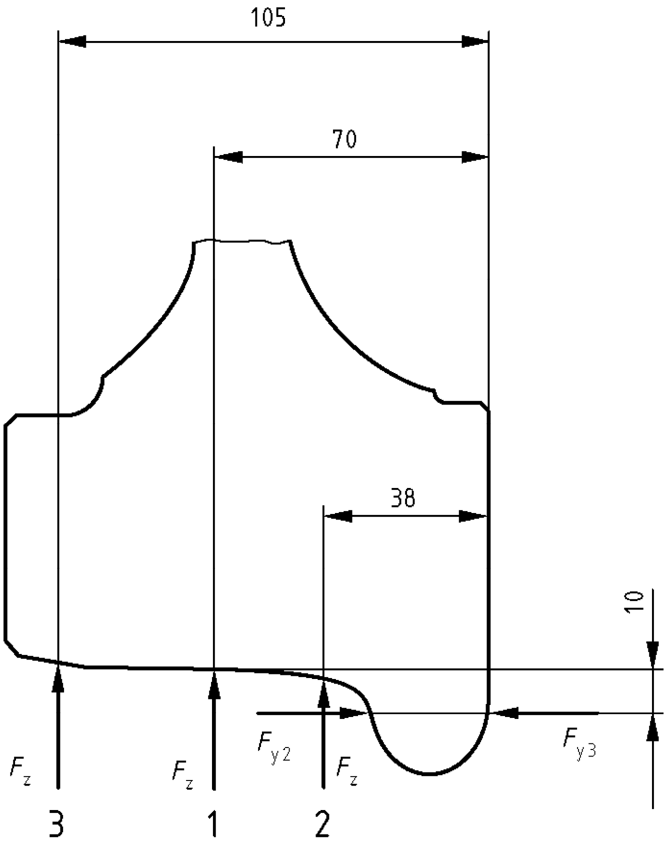
  $F_{y2} = 0,6\ P$ for non-guiding wheelsets

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

  $F_z = 1,25\ P$

  $F_{y3} = 0,6\ F_{y2} = 0,36\ P$ for non-guiding wheelsets.

Dimensions in millimetres



Key

1 Straight track

2 Curve

3 Negotiation of points and crossings

Figure 1 — Application points of the different forces

7.2.2 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. Informative Annex C gives one method of demonstrating this.

The stresses shall be analysed as follows:

- determination of the principal stresses at all points in the mesh (nodes) for each of the three load cases;
- assessment, for each node, of the maximum principal stress for the three load cases (σ_{max}) and of the direction of this principal stress;
- assessment, for each node, of the minimum stress equal to the lowest normal stress in the direction of σ_{max}, for the three load cases (σ_{min});
- calculation for each node of:

$\Delta\sigma = \sigma_{max} - \sigma_{min}$

7.2.3 Preliminary assessment criterion

The range of dynamic stress $\Delta\sigma$ 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), $A = 290\ N/mm^2$ is adopted.

7.3 Second stage – Bench test

7.3.1 General

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

7.3.2 Definition of bench loading and of the test procedure

They shall be agreed between the designer of the wheel and the appointed Notified Body.

The loading and the test procedure shall reproduce in the web the stresses representative (direction, level and number of cycles) of those the wheel is subjected to throughout its entire life.

Informative Annex D gives one method of doing this.

7.3.3 Decision criteria

Four wheels shall be tested.

No fatigue cracks shall be observed after the test. A fault is considered to be a crack if its length is greater than or equal to 1 mm.

8 Assessment of the acoustic behaviour

8.1 General procedure

The assessment of the acoustic behaviour of a wheel is widely dependent on several parameters that are not directly related to the design of the particular wheel to be approved. This is why the result of a new wheel design shall be compared with that of a rail system/reference wheel for a given state of maintenance of the rail surface.

A schematic diagram representing the acoustic approval procedure for the wheel is given in informative Annex E. The acoustic technical approval of the wheel may be obtained by a calculation if the type of wheel to be approved allows reliable results to be obtained and/or from field measurements if requested:

- case 1: a procedure based on calculations is considered adequate. This concerns monobloc axisymmetric wheels of "standard" diameter (greater than or equal to 800 mm) for which the numerical calculations have already been validated1);
- case 2: a procedure based on calculations and supplemented by an experimental modal analysis of the wheel may be selected. This procedure concerns non-axisymmetric monobloc wheels (except for those

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1) This procedure has been validated by ERRI reports [2] and [3] and the model has been simplified for the specific requirements of the test for the technical approval.

with holes) and small diameter (less than 800 mm) monobloc wheels for which retuning of the calculated modal base is required (e.g. when absorbing devices are mounted on the wheel). This retuning is due to results of an experimental modal analysis of the wheel;

- case 3: a range of measurements is required for the acoustic technical approval of the wheel. This procedure concerns non-monobloc wheels with holes, non-axisymmetric wheels, wheels with shielding devices, for which the calculation approach is not yet a sufficiently reliable approval criterion.

8.2 Calculation procedure

This shall be applied in case 1 or 2 defined in 8.1. A calculation procedure is given in informative Annex E.

8.3 Field measurements

The field measurements shall be carried out in the following cases:

- the calculation procedure has not been carried out or is unable to be carried out in a reliable enough manner (case 3 of 8.1);
- the calculation procedure has been carried out but has not led to acoustic technical approval of the wheel.

A field measurement procedure is detailed in informative Annex E[2].

8.4 Decision criteria

If ${}^{R_{\mathrm{ref}}}_{S_{\mathrm{ref}}}L^{T_{\mathrm{ref}}}_{W_{\mathrm{ref}}}$ represents the average acoustic pressure level emitted at a distance of 3 m from the track:

- by a reference wheel W_{ref};
- on a reference track T_{ref};
- at a reference speed S_{ref};
- for a reference roughness spectrum R_{ref};

W_{opt} represents the new wheel design and ${}^{R_{\mathrm{ref}}}_{S_{\mathrm{ref}}}L^{T_{\mathrm{ref}}}_{W_{\mathrm{opt}}}$ its noise emission level in the same conditions as the reference wheel, the performance indicator ${}^{R_{\mathrm{ref}}}_{S_{\mathrm{ref}}}G^{T_{\mathrm{ref}}}$ is given for:

$${}^{R_{\mathrm{ref}}}_{S_{\mathrm{ref}}}G^{T_{\mathrm{ref}}} = {}^{R_{\mathrm{ref}}}_{S_{\mathrm{ref}}}L^{T_{\mathrm{ref}}}_{W_{\mathrm{opt}}} - {}^{R_{\mathrm{ref}}}_{S_{\mathrm{ref}}}L^{T_{\mathrm{ref}}}_{W_{\mathrm{ref}}}$$

In the following text, and to simplify the notations, it is assumed that the values of G and L in the above equation are expressed for the fixed parameters of speed, track and roughness. The above equation may then be written as:

$$G = L_{W_{\mathrm{opt}}} - L_{W_{\mathrm{ref}}}$$

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[2] Numerical calculations using the TWINS model developed at ERRI have been validated.

This expression may be evaluated both globally and on a 1/3 octave band. With the new notations, this expression is written as:

$$G^i = L^i_{W_{\mathrm{opt}}} - L^i_{\mathrm{ref}}$$

where

i is the 1/3 octave considered in the frequency range [100, 5000 Hz].

Considering that the new wheel shall be quieter than the reference wheel, the acceptance criteria may be written as:

$$\begin{cases} G = L_{W_{\mathrm{opt}}} - L_{W_{\mathrm{ref}}} \\ G^i = L^i_{W_{\mathrm{opt}}} - L^i_{W_{\mathrm{ref}}} \end{cases}$$

Thus, the acceptance criterion shall be the total noise radiation gain between the reference wheel and the optimized wheel, assessed on a reference track, with a reference roughness spectrum. It is expressed in dB(A) for the global value $G_{S,T_{\mathrm{ref}}}$ supplemented by a 1/3 octave band analysis ${G^i}_{S,T_{\mathrm{ref}}}$.

In both cases (calculations and field test), the acoustic acceptance criteria are applied to the wheel under test: calculation of the global noise gain thresholds, $G_{S,T_{\mathrm{ref}}}$, and by 1/3 octave band, ${G^i}_{S,T_{\mathrm{ref}}}$, according to the standards and regulations. These thresholds are based on the reference system noise radiation and their minimum value is zero.

9 Technical approval documents

A file shall be built up as the technical approval procedure is progressed. It shall comprise the following parts:

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.

Annex A
(normative)

Assessment of the thermomechanical behaviour

A.1 Assessment flow chart

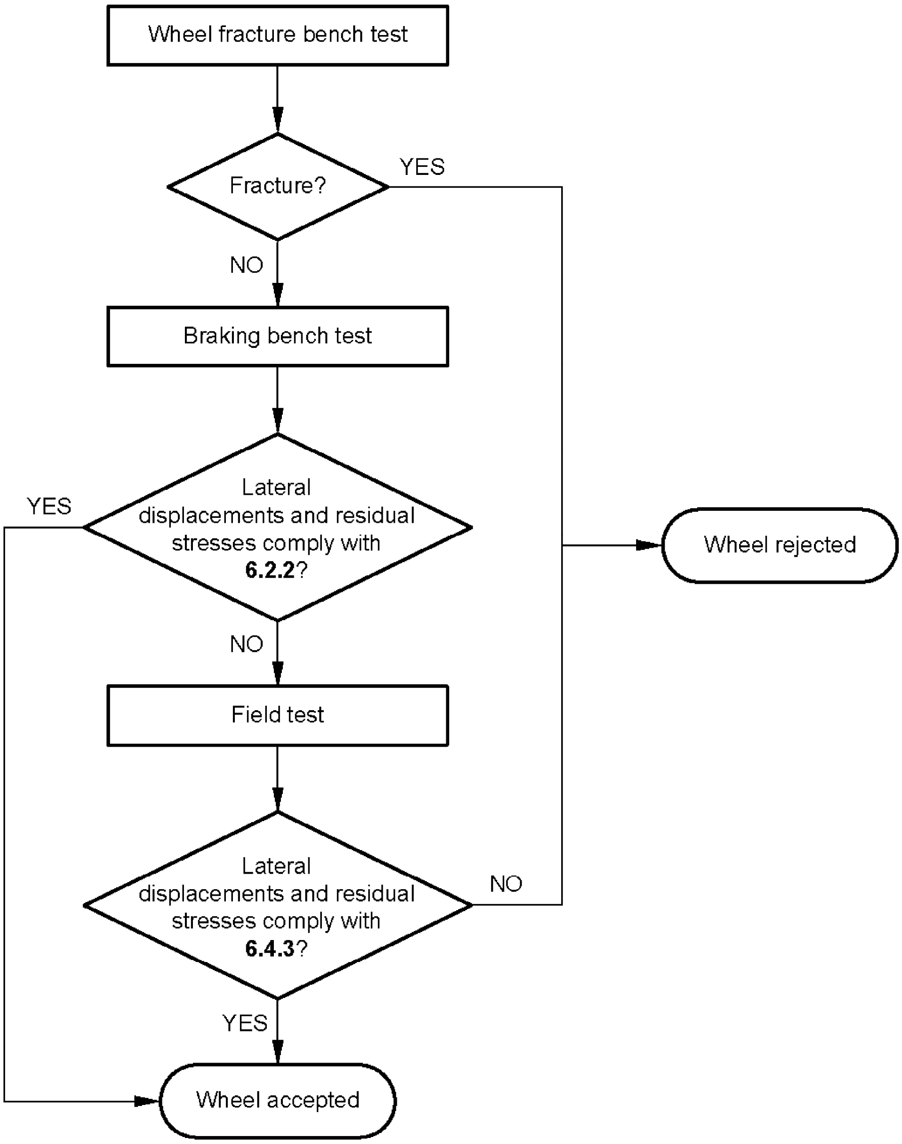


Figure A.1

A.2 Braking bench test procedure

A.2.1 Principle of the test

The braking bench test consists of making 10 drag brakings on a wheel and measuring their effects 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.

A.2.2 Definition of braking

The parameters of the drag braking cycles are obtained from the parameters defining the application (see 3.2):

- 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 shall be maintained within the range given above for the duration of the test.

Control is effected:

- either on the basis of measuring the braking torque;
- or on the basis of 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.

A.2.3 Method of measuring the decision criteria

A.2.3.1 Measurement of lateral displacements

The lateral displacements of the rim are 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 is 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 may appear some minutes after braking has stopped.

A.2.3.2 Measurement of residual stresses

The residual stresses are measured by a destructive method as described in CEN/TS 15718, Annex C.

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.

A.2.4 Tests and measurements

A.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.

A.2.4.2 Braking tests

The ten drag braking cycles are 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 is calculated at the end of each cycle.

The brake shoes shall be changed when they are half-worn or after 5 braking cycles. New shoes shall be worn in as described in A.2.4.1.

NOTE Measurement of the rim temperature is not mandatory, but may 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.

A.2.4.3 Measurements after the braking cycles

After 10 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.

A.2.5 Anomalies

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

A.3 Wheel fracture bench test procedure

A.3.1 Principle of the test

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

A.3.2 Definition of drag braking

The drag braking cycle parameters shall be obtained from the parameters defining the wheel application (see 3.2):

- nominal braking power $P_r = 1{,}2\ P_a$;
- duration of braking $t_r = t_a$;
- linear speed $V_r = V_a$;
- 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 shall be maintained within the range given above for the duration of the test.

Control is effected:

- either on the basis of measuring the braking torque;
- or on the basis of measuring the tangential forces between the wheel and brake shoes and measuring the speed.

A.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 ± 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 ± 1 mm).

A.3.4 Tests and measurements

A.3.4.1 Pre-cracking of the rim

This is done under the conditions described in A.3.3 or using any other method giving the same result.

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

A.3.4.2 Fracture of the wheel

The braking cycles described in A.3.2 are applied successively to the wheel until:

- either a radial fracture occurs;
- or 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 10 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 is calculated after each cycle.

A.3.5 Anomalies

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

A.4 Field braking test procedure

A.4.1 Principle of the test

The field braking test consists of making 10 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.

A.4.2 Definition of braking

The drag braking cycle parameters shall be obtained from the parameters defining the application of the wheel (see 3.2):

- 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 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 that shall be maintained within the range given above for the duration of the test.

Control is effected:

- either on the basis of measuring the braking torque;
- or on the basis of measuring the tangential forces between the wheel and brake shoes and measuring the speed.

A.4.3 Method of measurement of the decision criteria

A.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 is 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 may appear some minutes after braking has stopped.

A.4.3.2 Measurement of residual stresses

The residual stresses are measured by a destructive method as described in CEN/TS 15718, Annex C.

A.4.3.3 Vehicle parameters

For this test, a vehicle on which the wheel to be approved will 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 so as to have their external faces between 10 mm and 20 mm from the outer edge of the rim.

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

A.4.3.4 Other parameters

The composition of the test train set is left to the test team.

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

A.4.3.5 Meteorological conditions

They should be as close as possible to the following conditions:

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

A.4.3.6 Track parameters

The track should be as straight as possible.

A.4.4 Tests and measurements

A.4.4.1 Measurements before the test

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

The distance E_i between the internal faces of the wheelset is 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.

A.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, etc.

The average power is calculated at the end of each cycle.

The brake shoes shall be changed when they are half-worn or after 5 braking cycles. New shoes shall be worn in as described in A.4.5.1.

NOTE Measurement of the rim temperature is not mandatory, but may 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.

A.4.4.3 Measurements after the braking cycles

After 10 braking cycles and complete cooling down of the wheel, the following shall be measured:

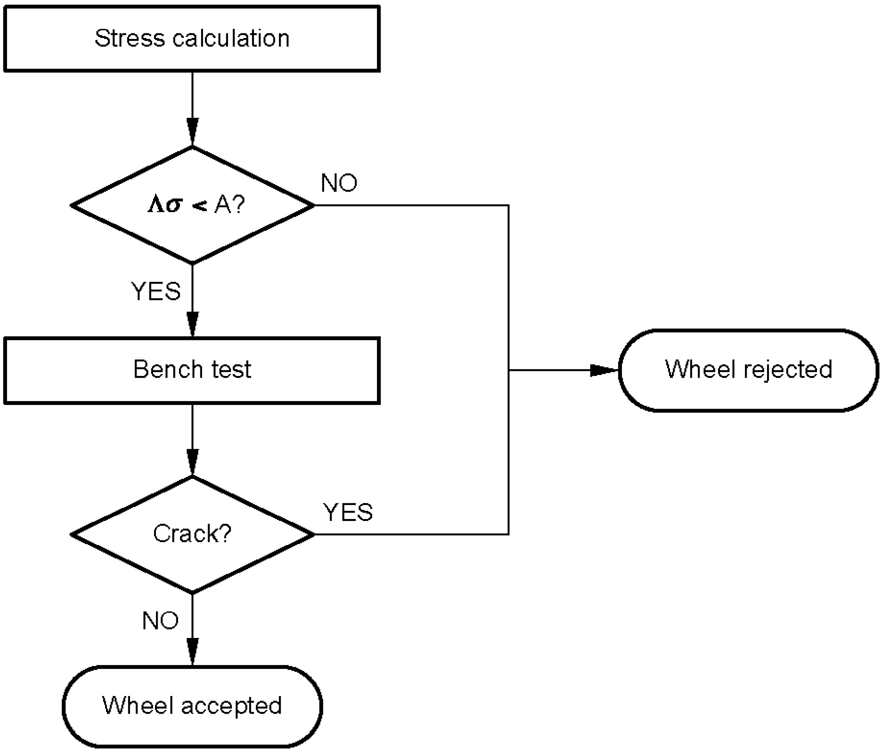
- the residual stresses;
- the residual lateral displacement of the rim;
- the position of the brake shoes on the rim;
- the distance E_i between the internal faces of the rims on the wheelset.

A.4.5 Anomalies

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

Annex B
(normative)

Flow chart of the mechanical behaviour assessment



Where

$\Delta\sigma$ is the amplitude of the calculated stress;

A is the permissible limit of dynamic stress.

Figure B.1

Annex C
(informative)

Mechanical behaviour – Finite element code assessment

The stress calculations are made using a standard finite element code.

The analysis is 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 should 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 should meet the criteria imposed by the code.

The precision of the mesh should 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 imposes 3D meshing.

Annex D
(informative)

Mechanical behaviour – Bench loading and test procedure

D.1 Principle of bench loading and test procedure

The schedule for assessment by test of the mechanical behaviour is as follows:

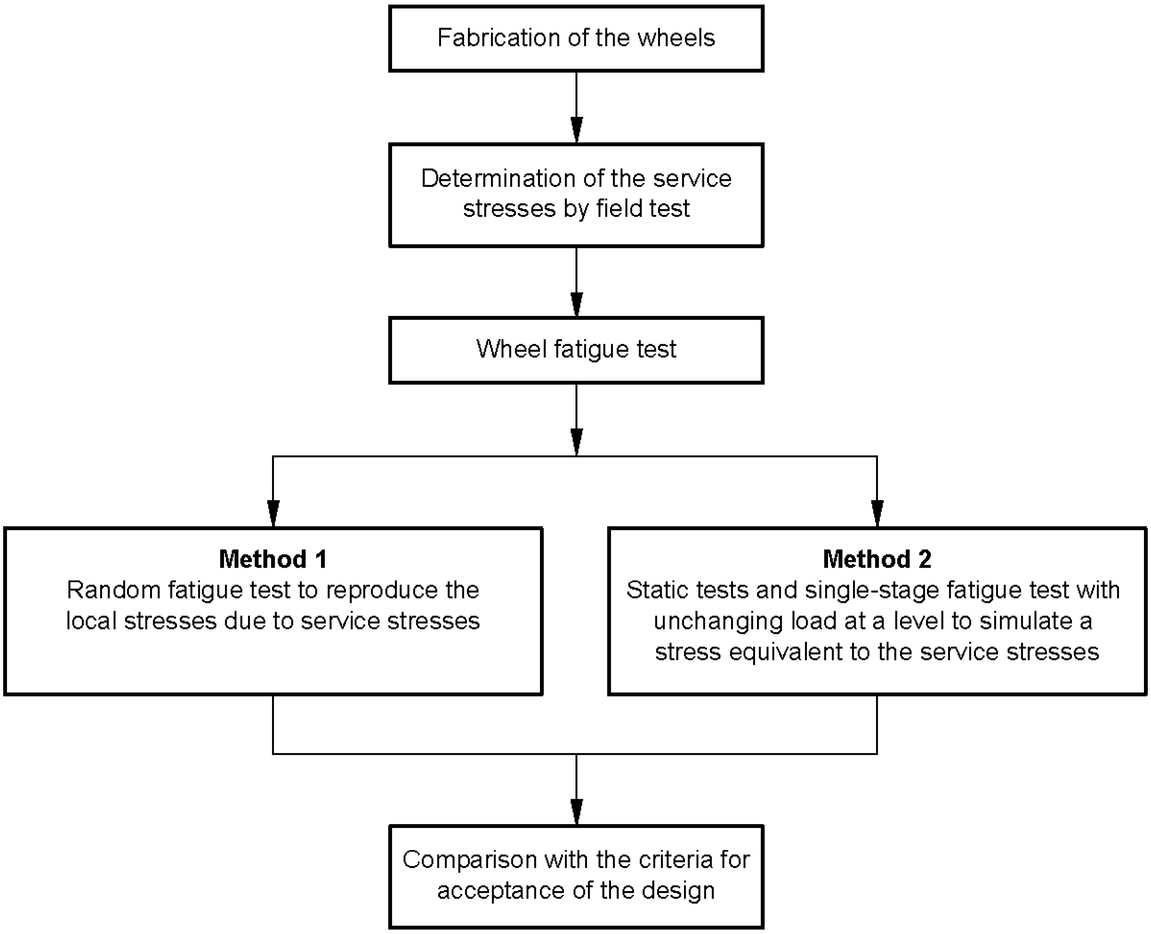


Figure D.1

D.2 Definition of loading

D.2.1 General

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

This load is determined using the method specified in the ERRI report B169/RP12.

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.

D.2.2 Measurement of the stresses during field tests

- 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 7.2).

- test route:

The test routes are determined in accordance with the ERRI/B169 report RP12. The choice of test routes based on routing of the vehicle provide a representative section of the service life of the vehicle.

- 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).

- global loading matrix:

The global loading matrix is obtained by:

  - 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;
  - adding all the weighted elementary matrices;
  - multiplying this sum in order to obtain a life of approximately 10 000 km.

This global matrix is called G.

D.3 Fatigue bench test

D.3.1 Method 1 – Random fatigue test

D.3.1.1 Loading matrix

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

Then, the MARKOV random sampling method requires symmetrization of the matrix. This is 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 will be 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.

D.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.

In the case of monitoring by stresses, the matrix H may possibly be modified to a matrix H_1 to take account of the differences in shape of the wheel used in the field test to determine matrix G (see D.2.2) and the wheel used for the bench test. An FEM calculation may provide the means for transforming matrix H.

In the case of monitoring by forces, the stresses of matrix H should 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 D.2.2). This matrix is called H_2.

D.3.1.3 Random fatigue test

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

D.3.1.4 End of test criterion

The criterion is as follows:

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

D.3.1.5 Example of fatigue test bench

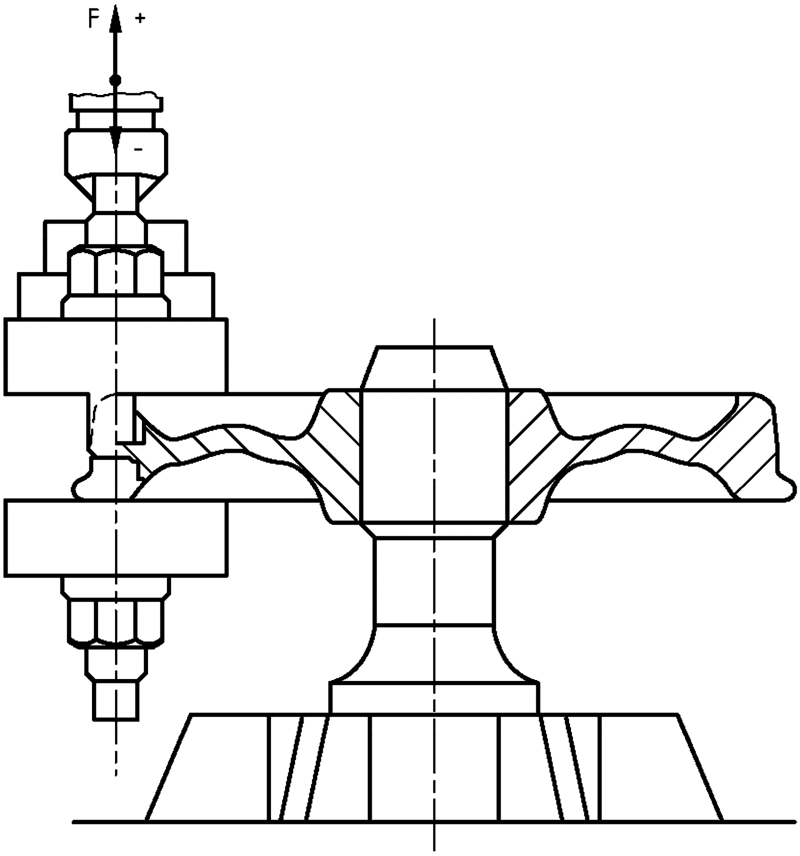


Figure D.2 — Example of fatigue test bench

D.3.2 Method 2 – Single-stage fatigue test

D.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 is determined from this matrix G. Then, transition to the full life section should be made by means of a multiplying coefficient, calculating the sum of maxima and minima frequency distributions and, if necessary, converting elongations into stresses. Finally, the load spectrum should 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 is determined to represent the stress differences. The load spectrum stresses are multiplied by this factor.

D.3.2.2 Equivalent stress

The load spectrum obtained as indicated above is divided into 10 similar stress stages. The equivalent stress is then 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.

D.3.2.3 Single-stage fatigue test

Before the start of the fatigue test, a static test is carried out to establish the relationship between the stresses and loads (F_y and F_z). The dynamic test then starts. The test stresses are determined as follows:

- first test wheel:
  - 1st stage; the test stress is equal to the equivalent stress;
  - 2nd stage; the test stress is equal to 1,4 times the equivalent stress;
- subsequent wheels; the test starts with a stress equal to 1,4 times the equivalent stress.

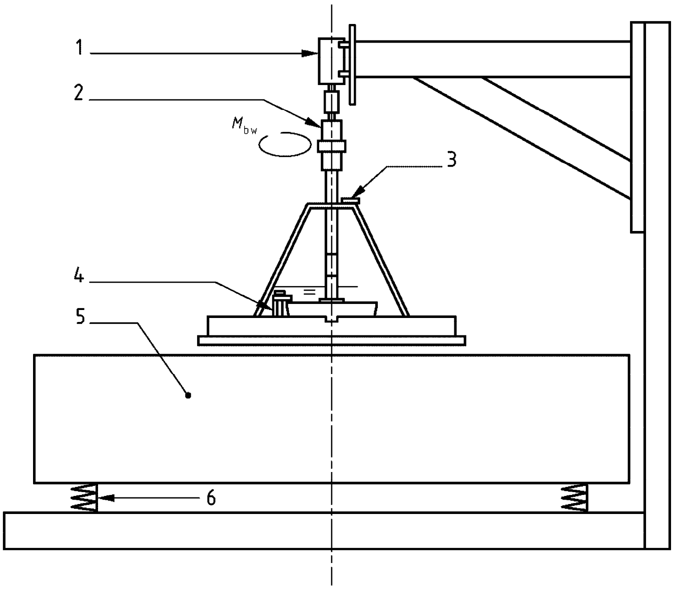
The test is carried out for 10^7 cycles at each loading level. The ERRI report B169/RP10 gives details of the procedure.

D.3.2.4 Acceptance criterion

The criterion is 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.

D.3.2.5 Example of fatigue test bench



Key

1 motor
2 sleeve with unbalanced oscillator
3 displacement probe
4 clamping device
5 anti-vibration foundation
6 springs

Figure D.3 — Example of fatigue test bench

Annex E
(informative)

Assessment of the acoustic behaviour

E.1 Assessment flow chart

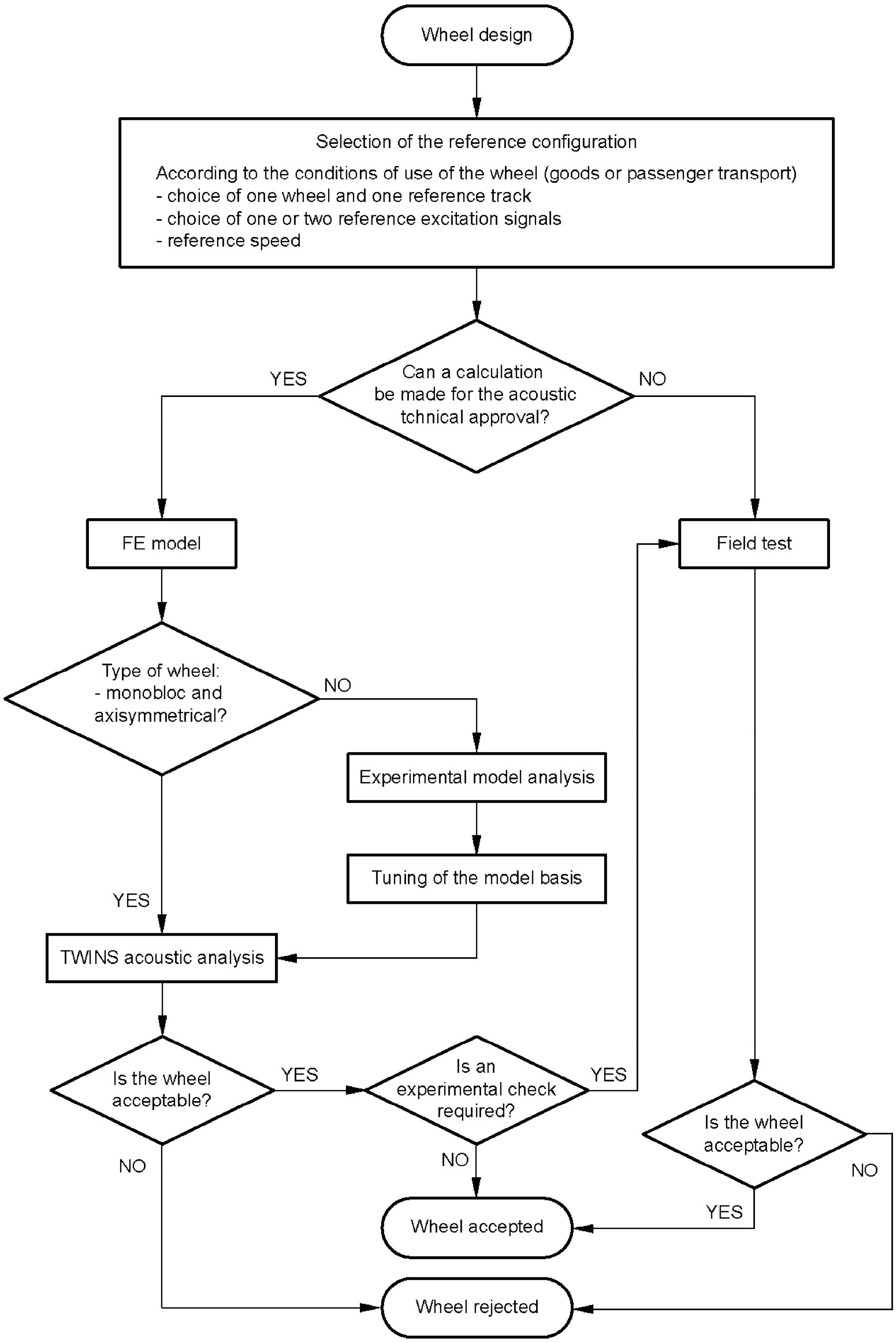


Figure E.1

E.2 Calculation procedure

E.2.1 Preliminary comment

This annex describes the way in which to assess the calculated quantity $L_{W_{\mathrm{opt}}}$, as defined in 8.4. The notation used is $L_{W_{\mathrm{opt}}} = L_W$, in the knowledge that it is not possible to confuse this value with the reference value $L_{W_{\mathrm{ref}}}$

This procedure is based on the TWINS calculation model developed by ERRI[3].

E.2.2 Calculation of the wheel modal basis

Wheel to be assessed:

- finite element model to determine the wheel modal basis;
- tuning of the wheel modal basis according to an experimental modal analysis, if necessary (see 8.1).

Selection of the reference wheel modal basis.

E.2.3 Selection of the reference track model

The reference track model should be selected.

E.2.4 Definition of the calculation parameters

- excitation signal options:

the calculations are made using a reference "unit" roughness (1 m).

- wheel and rail vibration options:

the wheel responses are calculated by incorporating the rotational effect. The wheel response is calculated in three positions of the point of contact of the wheel/rail (nominal position ± 10 mm). For example, the nominal position may be chosen 80 mm from the internal face of the tread. The average track response is calculated over 26 m. The frequency range examined is 100 Hz – 5 000 Hz.

- sound radiation option:

the sound radiation of each component (rail, sleeper and wheel) is calculated in the form of sound power from 1/3 octave bands. This power level may be calculated for the three contact point positions. The wheel radiation is calculated using the separate radiation levels for the modal deformations of the wheel with n = 0, n = 1 and n = 2 (where n is the number of nodal diameters of the different wheel modes). For the rail, the sound radiation from vertical and lateral movements may be calculated using the TWINS model. For the sleepers, the baffle plate model may be used.

E.2.5 Power calculation

Calculation of the overall power radiated (track + wheel) $L_{W_{\mathrm{u,i}}}$ for the reference and optimized wheels

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[3] The conditions for using and acquiring the TWINS software should be agreed with UIC.

where

u is the unit roughness;

i is the 1/3 octave band.

Calculation of the average power for the three contact point positions on the wheel:

$$L_{W_{\mathrm{u,c,i}}} = 10 \cdot \lg\left(\frac{1}{3}\left(10^{\frac{L_1}{10}} + 10^{\frac{L_2}{10}} + 10^{\frac{L_3}{10}} \right)\right)$$

where

L_1, L_2, L_3 are the power levels (over microphones A, B, C), calculated for the contact positions 70 mm, 80 mm and 90 mm from the inner surface of the tread.

E.2.6 Insertion

Insertion of:

- the reference roughness spectrum;
- the filtering effect;
- the A-weighting.

The contact filtering is calculated according to the REMINGTON formula:

$$H_{\mathrm{i}} = 20 \cdot \lg\left(\frac{1}{1 + \frac{\pi}{4}\left(\frac{2\pi\, a\, f_{\mathrm{i}}}{V} \right)^{3}} \right)^{1/2}$$

where

a is the half-length of the contact area in the rolling direction (in m), see reference [6] for calculation of this parameter;

V is the rolling speed (m/s);

f_{i} is the central frequency of the 1/3 octave band *i*.

NOTE For the calculation of *a*:

- the static load per wheel should be defined. It depends on the type of rolling stock chosen for the reference configuration;
- the rail transverse radius of curvature should be chosen (for example, 0,3 m for a new rail).

Each power level (calculated for a unit roughness) over a 1/3 octave band i is weighted according to the following relationship:

$$L_{W_{\mathrm{i}}} = L_{W_{\mathrm{u,c,i}}} + C_{\mathrm{i}} + R_{\mathrm{i}} + H_{\mathrm{i}}$$

where

$L_{W_{\mathrm{u,c,i}}}$	is the average power for a unit roughness (1 m), in dB(lin);
C_{i}	is the A-weighting, in dB;
R_{i}	is the roughness level, in dB (ref. 1 m);
H_{i}	is the contact filter, in dB.

E.2.7 Calculations of the decision criteria for acoustic technical approval of the wheel

See 8.4 of this Technical Specification.

— $G_{s,T_{\mathrm{ref}}}$, expressed as a single index;

— $G^{i}_{s,T_{\mathrm{ref}}}$, expressed as a 1/3 octave band;

— G_{W} , expressed as a single index.

E.2.8 Optional calculations

Influence of the tread wear: the calculations are made for a new wheel profile. They may also be made with a tread wear of 50 % and 100 %. The comparison between the optimized and the reference wheels is then made for the two types of wheels with 50 % and 100 % tread wear.

E.3 Field measurement procedure

E.3.1 Objective and preliminary remark

An optional objective is to deduce from field measurements the influence of the wheel on the general noise emitted. It is assumed4) that the wheel is the predominant noise source between the 1/3 octave bands 1600 Hz to 5 000 Hz. Therefore, the contribution of the wheel to the noise emission may be estimated by the overall sound power emitted in the 1/3 octave bands 1600 Hz to 5 000 Hz ($L_{W_{1600-5000}}$).

The main error source comes from emissions from the track in this frequency range. For a standard track, this error is unacceptable but it may be reduced significantly if a "low-noise" track is used for the wheel assessment.

Therefore, a supplementary procedure is proposed to define the wheel’s contribution to the ambient noise.

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4) Result of ERRI C163 RP22 "OFWHAT" draft.

E.3.2 Recommendations for the operating conditions

The operating conditions should be the same as for the optimized and reference wheels. They should be carefully selected in order to limit measurement errors. This subclause contains recommendations for:

- the test train composition;
- the wheel and rail roughness.
- the test site selection.

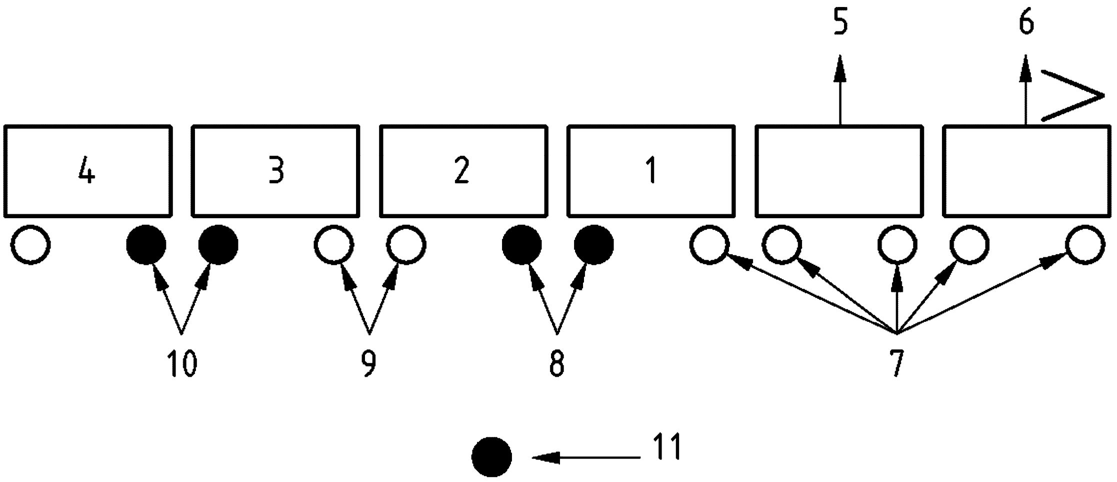
E.3.2.1 Train composition

The wheel to be assessed should be mounted on the same train as the reference wheel (Figure E.2). The following recommendations should be taken into account:

- the optimized and reference wheels are mounted on the test train. If the optimized wheels are likely to be very quiet, a buffer wagon with optimized wheels shall be used;
- the emitted pressure measurements are carried out under the same operating conditions (same speed, same meteorological conditions and same measuring equipment);
- the wagons used for the wheel assessment shall be as long as possible in order to limit the noise pollution from adjacent wheelsets;
- a buffer wagon shall be inserted between the locomotive and the first wheels to be assessed (reference wheels) in order to limit the noise pollution from the locomotive.

It is recommended that particular care be taken to ensure:

- the absence of superstructure noise;
- the absence of aerodynamic noise.



Key

1	test 1	7	buffer wheels
2	test 2	8	reference wheels
3	test 3	9	optimized or buffer wheels
4	test 4	10	optimized wheels
5	buffer wagon	11	wheels under test
6	locomotive		

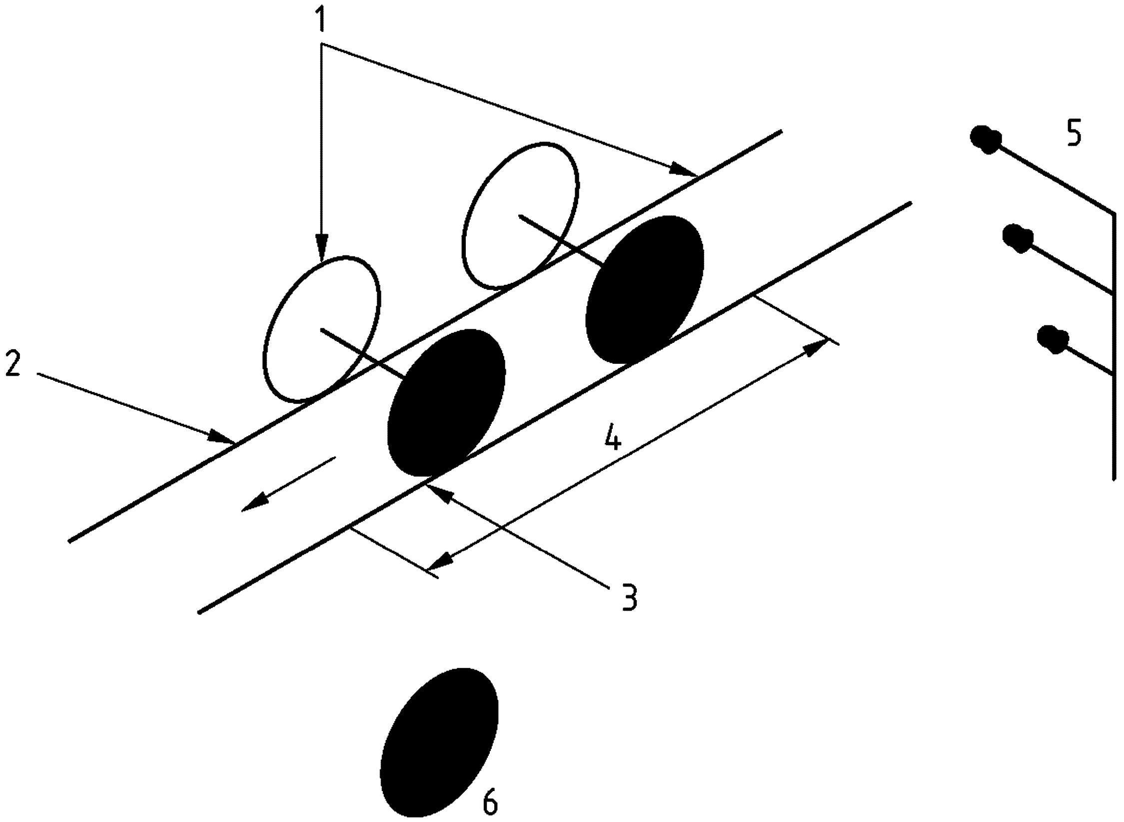
Figure E.2 — Recommendations for the train composition

E.3.2.2 Wheel and rail roughness

The wheel-rail roughness in the measurement section should be the same for the reference wheels and the optimized wheels in order to allow an immediate comparison between these two types of wheels. One way of achieving this result (Figure E.3) is to use a wheel of low roughness compared with that of the rail over the measurement section (with at least 10 dB difference for each octave).

In addition, the roughness spectrum (in the wavelength range) should be as regular as possible (i.e. no pronounced spectral line that may favour the excitation of a specific wheel mode).

After the wheel roughness has been measured and during the approval measurements, the braking system should be disconnected if the wheels are tread-braked. Thus, the wheel roughness will not be altered during the tests.



Key

1	low wheel roughness	4	measurement zone (10 m -15 m)
2	high rail roughness	5	microphones situated 3 m from the nearest rail
3	high rail roughness in the measurement zone	6	wheel to be validated

Figure E.3 — "Ideal" roughnesses for the measurement procedure

The recommendations for the wheel and rail roughness are summarized in Table E.1:

Table E.1 — Roughness recommendations

Recommendations	Comments
— low wheel roughness — high rail roughness in the measurement zone — no pronounced spectral line in the combined wheel/rail roughness spectrum	— it has to be ensured that the rail roughness is greater (at least 10 dB) than the wheel roughness
— disconnection of the braking system during the measurements (if the wheels are tread-braked).	— during the test, the wheel roughness shall remain approximately 10 dB less than that of the rail.

E.3.2.3 Selection of the test site

Apart from the rail roughness criterion, the following recommendations have a bearing on the selection of the test site (Table E.2):

Table E.2 — Selection of the test site

Recommendations	Comments
— perfect straight line (no curve close to the measurement zone).	— the contact zone between the wheel and the rail shall remain constant along the measurement zone.
— no obstacles to outdoor acoustic propagation (e.g. tunnel, bridge, buildings, etc.) close to the test site (free field condition).	— to avoid acoustic reflections over surfaces other than the ground.
— narrow contact zone on the rail head.	— to limit the influence of the rail roughness.

E.3.3 Measurement procedure

E.3.3.1 Roughness measurements

The wheel and rail roughness should be measured in order to check that the wheel roughness is actually less than that of the rail (a difference greater than 10 dB on each 1/3 octave band is desired over the frequency range in question). The wheel roughness measurements should be carried out before and after the field tests. The objective is to obtain the 1/3 octave spectra as a function of the frequency. The 1/3 octave bands between 100 Hz and 5 000 Hz should be covered. This corresponds approximately to wavelengths from 20 cm to 1 cm (for rolling speeds from 60 km/h to 200 km/h).

The rail roughness measurement should be carried out bearing in mind that:

- the measuring zone length is 10 m, centred on the measuring section;
- an adequate number of parallel measurement lines is required:
  - if the contact zone on the rail head is narrow enough (width < 1,5 cm), one single line centred on the contact zone is required;
  - if the width is greater than 1,5 cm, the measurement shall be on 2 parallel lines;
- there should be a gap of 5 mm between the lines.

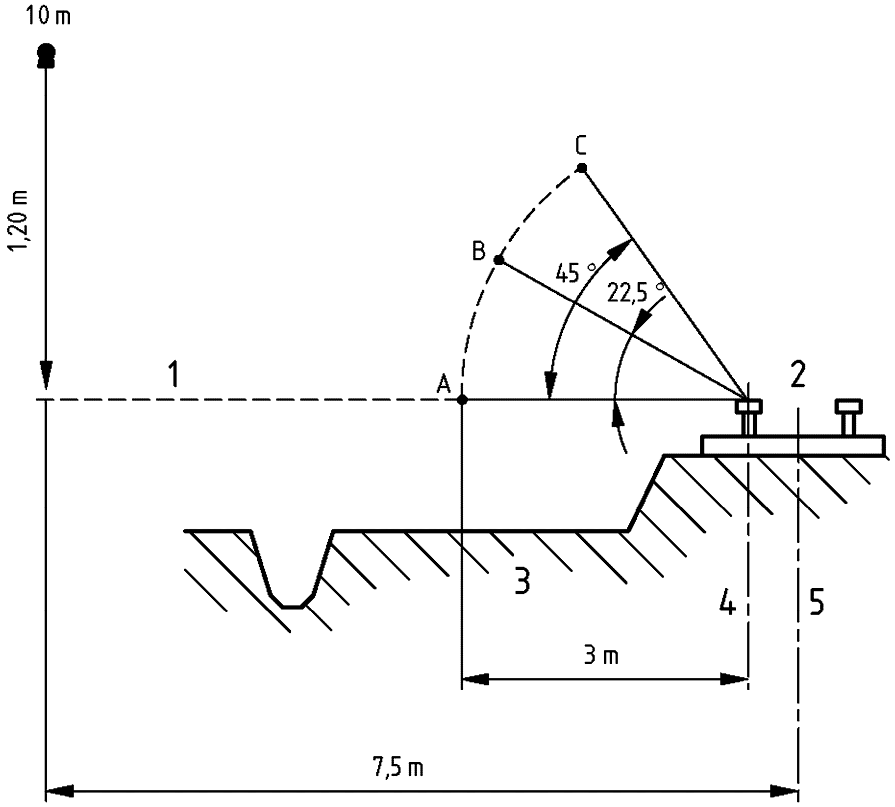
The wheel roughness measurement should be carried out bearing in mind that:

- a measurement length is associated with 3 complete wheel rotations;
- at least 4 parallel measurement lines centred on the wheel contact zone are required;
- there should be a gap of approximately 5 mm between the lines in order to cover at least the contact zone ± 7,5 mm.

E.3.3.2 Trackside measurements

The measuring equipment should be located in the middle of the measurement zone. It comprises:

- a vertical accelerometer on the rail, at mid-span (underneath the rail foot, below the rail web);
- a lateral accelerometer on the rail head, at mid-span;
- three microphones 3 m from the rail centre line (A, B, C, see Figure E.4 for the positions of the microphones). The radiated power is estimated from these microphones.



Key

1 track running zone
2 track
3 ground
4 rail centre line
5 track centre line

Figure E.4 — Position of the microphones

These vibration and noise data should be analysed to give an average level over a period corresponding to a train movement of twice the length of half the reference coach so that all the noise/vibration associated with the central wheelset or bogie is effectively taken into account.

Two lateral accelerometers may optionally be implanted (in the middle of the measurement zone) on the rail (one on a sleeper, one at mid-span).

E.3.3.3 On-board measurements

The axial and radial vibration levels are important for a precise assessment of the wheel (in particular for wheels with a very low noise emission for which the track noise emission is the predominant source). However, this information is not necessary for the final acoustic approval of the wheel that only takes into account the overall noise emitted by the track and the wheel.

E.3.3.4 Additional measurements

Checking of the reference track:

- the conformity of the dynamic behaviour of the track to what was expected should be verified. The main reasons for non-conformity are as follows:
  - the rail stiffness may vary with time;
  - the static pre-load applied by the fastening system may be incorrect;
  - the dynamic stiffness of the rail depends to a large extent on the temperature;
- the simplest way in which to verify the reference track is to measure the vertical acceleration of the rail at mid-span and compare it to a reference vertical acceleration.

Meteorological conditions:

- these may influence the acoustic measurements. This is why the meteorological measurement conditions of ISO 3095 should be applied.

E.3.4 Analysis of results

All the measurements (sound pressure, vibration, roughness) should be analysed by 1/3 octave band (at least in the 200 Hz to 5 000 Hz 1/3 octave band).

E.3.4.1 Roughness analysis

The wheel and rail roughnesses are analysed separately. The following precautions should be taken when producing an excitation spectrum:

- pitting: the roughness sensor has a much smaller radius of curvature than that of the wheels and is therefore able to detect small marks on the wheel or rail surface that will not be seen by the wheel-rail contact. These marks should be eliminated from the analysis by simulating the effect of a roughness sensor with a radius of curvature equal to that of the wheel;
- different windows may be used: uniform window, 10 % cosine window, window with amplitude
- squared between 0 and T of 1 $\left(\sqrt{\frac{2}{3}\left(1-\cos\frac{2\pi t}{T}\right)}\right)$;
- filtering: a filter is intended to eliminate the long wavelengths (that generate very high amplitudes) and the short wavelengths (anti-aliasing filter);
- conversion to real frequency: the FFT produces a narrow roughness spectrum in the (1/l wavelength) range. This spectrum should be converted into the frequency range according to the relationship $f = V/\lambda$;

where

V is the rolling speed (m/s);

λ is the wavelength (m).

The wheel and rail roughnesses are then integrated by 1/3 octave band:

- if several parallel lines are measured, the average value should be calculated. The parallel lines are assumed to be non-coherent;
- total roughness: the total roughness excitation R corresponds to the sum of the wheel and rail roughness spectra (S_W and S_R) added in terms of energy:

  $R = 10 \cdot \lg (S_W + S_R)$

E.3.4.2 Sound pressure level and track vibration levels

The noise and vibration data are analysed to give an average level over a period corresponding to the movement of the train over twice the length of half a coach.

The sound pressure levels 3 m from the track, L_{PA}, L_{PB}, L_{PC} are given per 1/3 octave band, in dB(A). The resulting sound pressure level L_{PABC} corresponds to a weighted average of these three sound pressure levels, given by the following relationship:

$$L_{PABC} = 10 \cdot 1g\left(0{,}4 \cdot 10^{\frac{L_{PA}}{10}} + 0{,}2 \cdot 10^{\frac{L_{PB}}{10}} + 0{,}4 \cdot 10^{\frac{L_{PC}}{10}} \right)$$

This acoustic spectrum (per 1/3 octave band) is proportional to the sound power.

The track vibration levels are expressed in terms of velocity levels:

$$L_V = 10 \cdot 1g\left(\frac{\tilde{V}^2}{V_0^2} \right)$$

where

V^2 is the square velocity;

V_0 is 1 m/s.

It is recommended carrying out several measurements of L_{PABC} and L_V (at least 4) to produce average values.

The standard deviation should not exceed ± 1 dB.

E.3.4.3 Calculation of the acceptance criteria

The optimized wheel is assessed initially by 1/3 octave bands (acoustic gain $G^i_{s,T_{\mathrm{ref}}}$ is placed opposite the reference wheel for each 1/3 octave band):

$$G^i_{s,T_{ref}} = \left(L_{PABC}\right)^i_{referencewheel} - \left(L_{PABC}\right)^i_{optimizedwheel}$$

The single index $G_{s,T_{ref}}$ should be calculated for a reference roughness spectrum. Therefore, a correction of the 1/3 octave levels is required.

Two methods are available:

— **Method 1:**

All the 1/3 octave spectra are first corrected on the basis of the wheel/rail roughness levels measured on site and according to the reference roughness spectra. For example, for the sound levels, the correction is as follows:

$$(L_{PABC})^i_{corrected} = L^i_{PABC} - R^i_M + R^i_R$$

where

R^i_M is the combined wheel/rail roughness level at the 1/3 octave band *i*, measured on site;

R^i_R is the reference roughness spectrum, representative of the rolling stock;

L^i_{PABC} is the average pressure level (dBA) measured on site.

The global acoustic levels L_G corresponding to the 1/3 octave spectrum $(L_{PABC})^i_{corrected}$, are calculated:

$$L_G = 10 \cdot \lg\left(\sum_i 10^{L^i_{PABC,corrected}/10}\right)$$

where

i represents the 1/3 octave bands.

The index $G_{s,T_{ref}}$ is obtained by the relationship:

$$G_{s,T_{ref}} = (L_G)_{referencewheel} - (L_G)_{optimizedwheel}$$

This method may introduce measurement errors associated with the roughness measurement.

— **Method 2:**

It is assumed that the noise level $(L_{PABC})^i_{reference\_roughness}$ (per 1/3 octave band) of the reference wheel on the reference track is known for the reference roughness spectrum. This may be obtained by applying method 1 **once and once only**.

All the 1/3 octave spectra measured are corrected according to this reference noise spectrum $(L_{PABC})^i_{reference\_roughness}$ and the measured spectrum $(L_{PABC})^i_{measured}$ of the reference wheel on the reference track. To introduce the reference roughness, the correction is as follows:

$$C^i = (L_{PABC})^i_{referenceroughness} - (L_{PABC})^i_{measured}$$

and the relationship of method 1 giving $G_{s,T_{ref}}$ is replaced by:

$$\left(L_{PABC}\right)^{i}_{corrected} = L^{i}_{PABC} - C^{i}$$

These last two relationships are then used to determine the index $G_{s,T_{ref}}$.

Annex F
(informative)

Drag braking values for interoperability

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

$$P_a = m \times g \times V_a \times \alpha$$

for a period t_a,

Where:

Symbol	Description	Units	Value [a]
m	vehicle mass on rail per wheel	kg	
g	gravitational acceleration	m/s^2	9,806665 m/s^2
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).			

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