SLOVENSKI STANDARD
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Railway applications - Aerodynamics - Part 5: Requirements and test procedures for aerodynamics in tunnels

Bahnanwendungen - Aerodynamik - Teil 5: Anforderungen und Prüfverfahren für Aerodynamik im Tunnel

Applications ferroviaires - Aérodynamique - Partie 5: Exigences et procédures d'essai pour l'aérodynamique en tunnel

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45.060.01	Železniška vozila na splošno	Railway rolling stock in general
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Railway applications - Aerodynamics - Part 5: Requirements and test procedures for aerodynamics in tunnels

Applications ferroviaires - Aérodynamique - Partie 5: Prescriptions et méthodes d'essai pour aérodynamique en tunnels

Bahnanwendungen - Aerodynamik - Teil 5: Anforderungen und Prüfverfahren für Aerodynamik im Tunnel

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

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Foreword

This document (EN 14067-5:2006) has been prepared by Technical Committee CEN/TC 256 “Railway applications”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by February 2007, and conflicting national standards shall be withdrawn at the latest by February 2007.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive 96/48/EC as amended by Directive 2004/50/EC.

For relationship with EU Directive, see informative Annex ZA, which is an integral part of this document.

This European Standard is part of the series "*Railway applications — Aerodynamics*" which consists of the following parts:

— *Part 1: Symbols and units*

— *Part 2: Aerodynamics on open track*

— *Part 3: Aerodynamics in tunnels*

— *Part 4: Requirements and test procedures for aerodynamics on open track*

— *Part 5: Requirements and test procedures for aerodynamics in tunnels*

— *Part 6: Cross wind effects on railway operation*

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

1 Scope

This European Standard applies to the aerodynamic loading caused by trains running in a tunnel.

2 Normative references

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

EN 14067-1:2003, *Railway applications — Aerodynamics — Part 1: Symbols and units*

3 Terms, definitions, symbols and abbreviations

For the purposes of this document, the terms, definitions, symbols and abbreviations given in EN 14067-1:2003 and the following apply.

NOTE Additional definitions, symbols and abbreviations are explained in the text.

3.1
tunnel
closed structure enveloping track(s) with a length of more than 20 m

4 Methodologies for quantifying the pressure changes in order to meet the medical health criterion

4.1 General

The relevant pressure changes caused by trains running in a tunnel may be measured at full-scale, estimated from approximating equations (see Annex A), predicted using validated numerical methods or measured using moving model tests. The determination of the pressure variations in order to meet the medical safety pressure limits may be undertaken in the same way.

Full-scale test data may be the basis for train and tunnel acceptance and homologation.

Each single train/tunnel combination is described by a train-tunnel-pressure signature.

4.2 Train-tunnel-pressure signature

4.2.1 General

The static pressure in the tunnel as shown in Figure 1 develops as follows when a train enters the tunnel:

— there is a sharp first increase in pressure Δp_N caused by the entry of the nose of the train into the tunnel;

— there is a second increase in pressure Δp_{fr} due to friction effects caused by the entry of the main part of the train into the tunnel;

— there is then a drop in pressure Δp_T caused by the entry of the tail of the train in the tunnel;

— there is a sharp drop in pressure Δp_{HP} caused by the passing of the train head at the measurement position in the tunnel.

Real measurements of pressure may differ from the idealised signature shown in Figure 1, for instance if the train cross sectional area varies along the train. In such a case special consideration shall be given to determining the individual Δp values.

All Δp values are to be considered as absolute values.

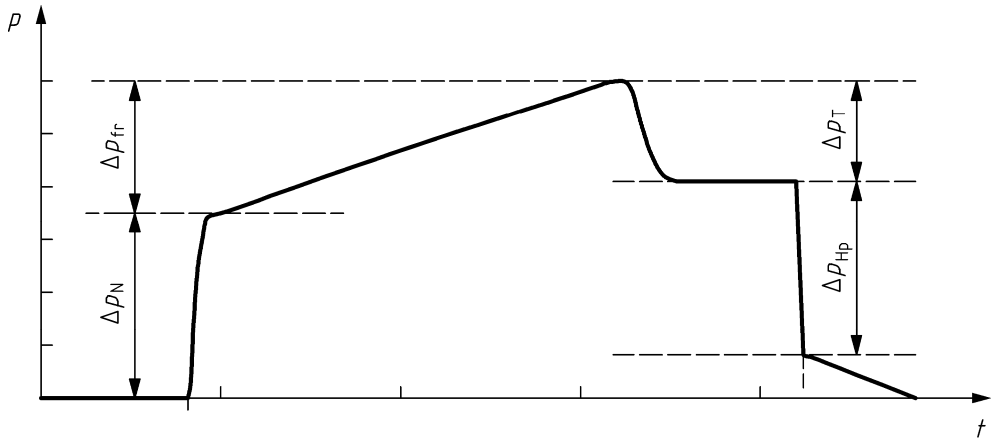


Figure 1 — Train-tunnel-pressure signature at a fixed position in a tunnel (detail)

The following methods are suitable for characterising the aerodynamic quality of a train in a tunnel.

The train-tunnel-pressure signature can be derived from calculations or measurements at a fixed position in a tunnel, i.e. the four pressure changes Δp_{N}, Δp_{fr}, Δp_{T} and Δp_{HP} at a given point in the tunnel (see 4.2.2).

4.2.2 Full scale measurement of Δp_{N}, Δp_{fr}, Δp_{T} and Δp_{HP} at a fixed location in the tunnel

The tunnel should have constant cross section, no airshafts and no residual pressures waves. Ideally there should be no initial air flow in the tunnel. However, if there is, its influence on the measurements should be checked.

Pressures are measured using transducers in the tunnel. These should be calibrated prior to use over the expected pressure range, typically ± 4 kPa. The measurement error should be less than 1 %.

The speed of the train shall be known within an accuracy of 1 % and should be constant during the entry into the tunnel within 1 %.

Data should be sampled at a rate of at least 5 v_{tr}/L_{N} Hz, with anti-aliasing filters with a cut-off frequency of one quarter of the sampling rate.

In order to obtain precise values of Δp_{N}, Δp_{fr}, Δp_{T} and Δp_{HP} for a fully developed wave pattern, it is necessary to ensure the following conditions when the train speed v_{tr} and the length of the train L_{tr} are given:

— the distance x_{p} between the entrance portal and the measuring position is

$$x_{p} = \frac{cL_{tr}}{c - v_{tr}} + \Delta x_{1} \quad (1)$$

where the additional distance Δx_{1} ensures a good temporal separation of the individual pressure variations and ideally should be about 100 m. The measuring system should be installed at x_{p} to avoid wave damping effects;

— the minimum tunnel length is

$$L_{\mathrm{tu,min}} = x_{\mathrm{p}} + \frac{cL_{\mathrm{tr}}}{2v_{\mathrm{tr}}} + \Delta L_1 \qquad \text{if } \Delta p_{\mathrm{HP}} \text{ is not needed} \qquad (2)$$

$$L_{\mathrm{tu,min}} = \frac{x_{\mathrm{p}}}{2}\left(1 + \frac{c}{v_{\mathrm{tr}}}\right) + \Delta L_1 \qquad \text{if } \Delta p_{\mathrm{HP}} \text{ is needed} \qquad (3)$$

where the additional length ΔL_1 ensures a good temporal separation of the individual pressure variations and ideally should be about 150 m.

4.2.3 Full scale measurements of $\Delta p_{\mathrm{N,o}}$, $\Delta p_{\mathrm{fr,o}}$ and $\Delta p_{\mathrm{T,o}}$ on the exterior of the train

If it is not possible to carry out measurements at fixed locations in a tunnel, Δp_{N}, Δp_{tr} and Δp_{T} can be approximated by measurements of $\Delta p_{\mathrm{N,o}}$, $\Delta p_{\mathrm{fr,o}}$ and $\Delta p_{\mathrm{T,o}}$ on the exterior of the train. If needed, Δp_{HP} can be derived either from predictive formulae or assumed to be equal to $\Delta p_{\mathrm{N,o}}$.

The tunnel shall have constant cross section, no airshafts and no residual pressures waves. Ideally there should be no initial air flow in the tunnel. However, if there is, its influence on the measurements should be checked.

Pressures are measured using transducers on the exterior of the train. These should be calibrated prior to use over the expected pressure range, typically ± 4 kPa. The measurement error should be less than 1 %.

The speed of the train shall be known within an accuracy of 1 % and should be constant during the entry into the tunnel within 1 %.

Data should be sampled at a rate of at least 5 $v_{\mathrm{tr}}/L_{\mathrm{N}}$ Hz, with anti-aliasing filters with a cut-off frequency of one quarter of the sampling rate.

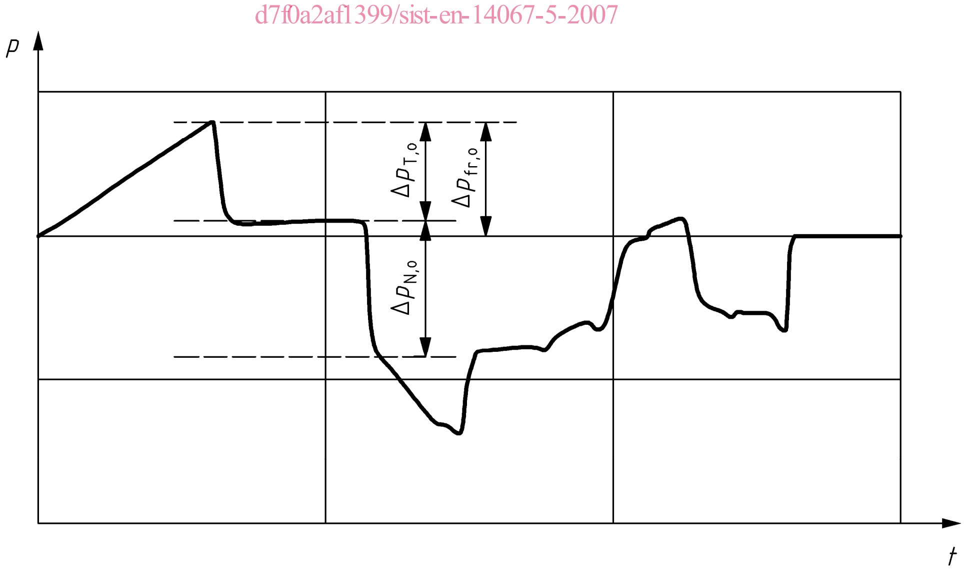


Figure 2 — Train-tunnel-pressure signature at an exterior position just behind the nose of the train

To get the whole friction pressure rise Δp_{fr} it is necessary to measure the pressures on the outside of the train just behind the nose at a position where the full cross section is reached.

The minimum tunnel length $L_{\mathrm{tu,min}}$ is

$$L_{\text{tu,min}} = \frac{L_{\text{tr}}}{2} \frac{c}{v_{\text{tr}}} \left(\frac{c + v_{\text{tr}}}{c - v_{\text{tr}}} \right) + \Delta L_2 \qquad (4)$$

where the additional length ΔL_2 ensures a good temporal separation of the individual pressure variations and ideally should be about 200 m.

As the tunnel length reduces the amplitude of the first reflection of the head wave $\Delta p_{\text{N,o}}$ by friction, the tunnel should not be much longer than $L_{\text{tu,min}}$.

4.2.4 Predictive formulae for Δp_{N}, Δp_{fr}, Δp_{T} and Δp_{HP}

Estimates for Δp_{N}, Δp_{fr}, Δp_{T} and Δp_{HP} can be made using the equations given in Annex A, A.2 and A.3. For tunnels with varying cross section the smallest cross section shall be considered.

4.2.5 Assessment of Δp_{N}, Δp_{fr}, Δp_{T} and Δp_{HP} by numerical simulation

Calculations can be done with validated numerical methods. Tunnel length and measurement position shall be derived from Equations (1), (2) and (3).

4.2.6 Reduced scale measurement of Δp_{N}, Δp_{fr}, Δp_{T} and Δp_{HP} at a fixed location in the tunnel

Models of the test train should be constructed which accurately represent the train head and tail, and have a good representation of the bogies, intercar gaps and train exterior surface features (e.g. roughness, shape). The test models shall be at scale 1/25 or larger for the test train to ensure that Reynolds number effects are minimised. It is essential that the full-scale train Mach number is respected.

With scaled tunnel and train models, the pressure waves in the tunnel will reproduce those at full-scale, except that the time base will be decreased by model scale. For instance, in a 1/25 scale test, all the pressure waves will occur on a time base 25 times faster than at full-scale.

In most cases it is not practicable to use models which represent the full scale train length. A train model consisting of the leading and end cars, with two intermediate coaches is a minimum for this purpose. The frictional part of the pressure signature for these reduced length models reproduces the full pressure rise, as long as the full scale length is accounted for by extrapolation. The use of shorter train models will produce conservative values for Δp_{T} and Δp_{HP}.

The tunnel model shall be rigid and very well sealed onto the test rig bed to ensure that no reduction of pressure wave amplitude occurs. The minimum tunnel length and measurement position shall respect the dimensions given in 4.2.2 scaled by the model scale.

Pressures are measured using transducers in the tunnel. These should be calibrated prior to use over the expected pressure range, typically ± 4 kPa. The measurement error should be less than 1 %.

The speed of the train shall be known within an accuracy of 1 % and should be constant during the entry into the tunnel within 1 %.

Data should be sampled at a rate of at least 5 $v_{\text{tr}}/L_{\text{N,model}}$ Hz, with anti-aliasing filters with a cut-off frequency of one quarter of the sampling rate.

4.3 Maximum pressure changes

The maximum pressure change (peak-to-peak) Δp_{max} under worst case conditions (e.g. critical tunnel length, critical crossing or parallel running, critical location) are given by the following equations.

At a fixed location in a tunnel for a 2 train situation: $\Delta p_{\text{max}} = 2\Delta p_{\text{N}} + 2\Delta p_{\text{fr}} + 2\Delta p_{\text{T}} + 2\Delta p_{\text{HP}}$ (5)

(crossing or parallel running)

At a fixed location in a tunnel for a 1 train situation: $\Delta p_{max} = \Delta p_N + \Delta p_{fr} + \Delta p_T + \Delta p_{HP}$ (6)

Onboard a train in a 2 train crossing situation: $\Delta p_{max} = 2\Delta p_N + 2\Delta p_{fr} + 2\Delta p_T + \Delta p_{HP} + \Delta p_{alt}$ (7)

Onboard a train in a 1 train situation: $\Delta p_{max} = \Delta p_N + \Delta p_{fr} + \Delta p_T + \Delta p_{alt}$ (8)

where

$$\Delta p_{alt} = g\rho_0 |\Delta h| \qquad (9)$$

is the natural pressure variation due to the difference in altitude

where

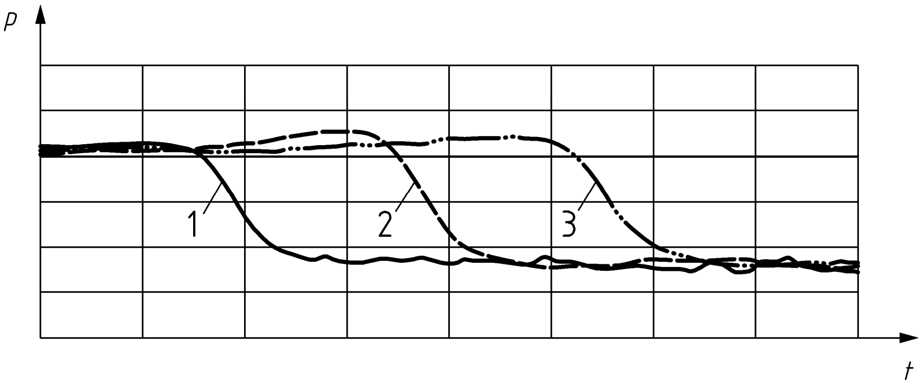
ρ_0 = 1,225 kg/m³

Δh is the difference between maximum and minimum altitudes in the tunnel.

The maximum pressure variations are useful information for comparison with TSI and national pressure limits and for load estimates.

5 Pressure loading on unsealed crossing trains

When the head of a train passes another train a pressure drop occurs, which travels with the relative speed of the trains (see Figure 3). A pressure increase happens when the tail passes. The gradient of these pressure changes may be much steeper than the gradients of the train induced pressure waves. Due to this steepness these pressure changes may lead to the loading of unsealed vehicles.



Key

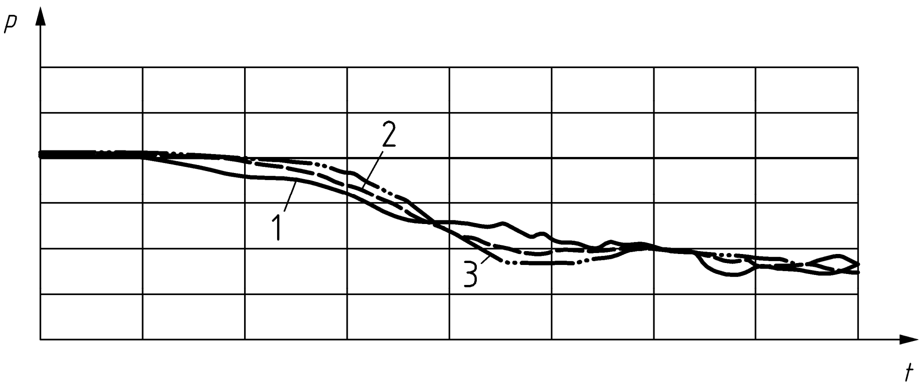
1 external pressure at the front

2 external pressure in the middle

3 external pressure at the rear

Figure 3 — External pressure drop due to the head passage of a crossing train

When the head of the opposing train passes the front of the unsealed vehicle the internal pressure starts to decrease too. As the information about the pressure drop travels with the speed of sound inside the vehicle, the internal pressure is nearly independent of the location inside the vehicle (see Figure 4).



Key

1 internal pressure at the front

2 internal pressure in the middle

3 internal pressure at the rear

Figure 4 — Internal pressure evolution inside an unsealed vehicle due to the head passage of a crossing train