



BSI Standards Publication

Railway applications — Current collection systems — Validation of simulation of the dynamic interaction between pantograph and overhead contact line

National foreword

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30 June 2022	Implementation of CEN amendment A1:2022

English Version

**Railway applications - Current collection systems -
Validation of simulation of the dynamic interaction
between pantograph and overhead contact line**

Applications ferroviaires - Systèmes de captage de
courant - Validation des simulations de l'interaction
dynamique entre le pantographe et la caténaire

Bahnanwendungen - Stromabnahmesysteme
- Validierung von Simulationssystemen für
das dynamische Zusammenwirken zwischen
Dachstromabnehmer und Oberleitung

This amendment A1 modifies the European Standard EN 50318:2018; it was approved by CENELEC on 10 January 2022. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this amendment the status of a national standard without any alteration.

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CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

Annex ZZ (informative)

Ⓐ Relationship between this European Standard and the Essential Requirements of EU Directive (EU) 2016/797 aimed to be covered

This European Standard has been prepared under a Commission's standardization request "M/483 Mandate to CEN and CENELEC for Standardisation in the field of interoperability of the rail system" to provide one voluntary means of conforming to (parts of) Essential Requirements of Directive (EU) 2016/797 of the European Parliament and of the Council of 11 May 2016 on interoperability of the rail system (recast) as specified in the relevant technical specifications for interoperability (TSI).

Once this standard is cited in the Official Journal of the European Union under that Directive, compliance with the normative clauses of this standard given in [Table ZZ.1](#) for "Locomotives and Passenger Rolling Stock", and [Table ZZ.2](#) for "Energy" confers, within the limits of the scope of this standard, a presumption of conformity with the corresponding Essential Requirements of that Directive as specified in the technical specifications for interoperability (TSI), and associated EFTA regulations.

Table ZZ.1 — Correspondence between this European Standard, Commission Regulation (EU) N° 1302/2014 concerning the Technical Specification for Interoperability (TSI) relating to the subsystem 'Locomotives and Passenger Rolling Stock' of the rail system in the European Union* and Directive (EU) 2016/797

Essential Requirements of Directive (EU) 2016/797	Clauses of the Annex to the Technical Specification for Interoperability (TSI)	Clause/ subclauses of this European Standard	Comments
Section 3 of the Annex to the TSI indicates the correspondence between the TSI clauses and the Essential Requirements of Directive (EU) 2016/797	4.2.8.2.9.7 (3) limited to identification of the poorest performing pantograph	6, 8	
	6.1.3.7 (3) limited to current collection quality and mean contact force	6, 7, 9	
* As amended by Commission Regulation (EU) No 919/2016, Commission Implementing Regulation (EU) 868/2018, Commission Implementing Regulation (EU) 2019/776 and Commission Implementing Regulation (EU) 2020/387			
NOTE The Technical Specification for Interoperability (TSI) can refer to other clauses of this standard making the application of those clauses mandatory. Possible references to such clauses are found in the Appendix J to the TSI.			

Table ZZ.2 — Correspondence between this European Standard, Commission Regulation (EU) N° 1301/2014 concerning the Technical Specification for Interoperability (TSI) relating to the subsystem 'Energy' of the rail system in the European Union* and Directive (EU) 2016/797

Essential Requirements of Directive (EU) 2016/797	Clauses of the Annex to the Technical Specification for Interoperability (TSI)	Clause/ subclauses of this European Standard	Comments
Section 3 of the Annex to the TSI indicates the correspondence between the TSI clauses and the Essential Requirements of Directive (EU) 2016/797	6.1.4.1 (2)	6, 7, 8, 9	
* As amended by Commission Implementing Regulation (EU) 2018/868 and Commission Implementing Regulation (EU) 2019/776.			

Essential Requirements of Directive (EU) 2016/797	Clauses of the Annex to the Technical Specification for Interoperability (TSI)	Clause/ subclauses of this European Standard	Comments
NOTE The Technical Specification for Interoperability (TSI) can refer to other clauses of this standard making the application of those clauses mandatory. Possible references to such clauses are found in the Appendix E to the TSI.			

WARNING 1 Presumption of conformity stays valid only as long as a reference to this European Standard is maintained in the list published in the Official Journal of the European Union. Users of this standard should consult frequently the latest list published in the Official Journal of the European Union.

WARNING 2 Other Union legislation may be applicable to the products falling within the scope of this standard. 

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European foreword

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The following dates are fixed:

- latest date by which this document has to be (dop) 2023-01-10 implemented at national level by publication of an identical national standard or by endorsement
- latest date by which the national standards (dow) 2025-01-10 conflicting with this document have to be withdrawn

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This document has been prepared under a Standardization Request given to CENELEC by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s) / Regulation(s).

For relationship with EU Directive(s) / Regulation(s), see informative Annex ZZ, which is an integral part of this document.

Any feedback and questions on this document should be directed to the users’ national committee. A complete listing of these bodies can be found on the CENELEC website.

1 Scope

Simulation techniques are used to assess the dynamic interaction between overhead contact lines and pantographs, as part of the prediction of current collection quality. This document specifies functional requirements for the validation of such simulation methods to ensure confidence in, and mutual acceptance of the results of the simulations.

This document deals with:

- input and output parameters of the simulation;
- comparison with line test measurements, and the characteristics of those line tests;
- validation of pantograph models;
- comparison between different simulation methods;
- limits of application of validated methods to assessments of pantographs and overhead contact lines.

This document applies to the current collection from an overhead contact line by pantographs mounted on railway vehicles. It does not apply to trolley bus systems.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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. ^[A1]

EN 50119:2020, *Railway applications — Fixed installations — Electric traction overhead contact lines* ^[A1]

EN 50206-1:2010, *Railway applications — Rolling stock — Pantographs: Characteristics and tests — Part 1: Pantographs for main line vehicles*

EN 50317:2012, *Railway applications — Current collection systems — Requirements for and validation of measurements of the dynamic interaction between pantograph and overhead contact line*

^[A1] EN 50367:2020, *Railway applications — Fixed installations and rolling stock — Criteria to achieve technical compatibility between pantographs and overhead contact line* ^[A1]

3 Terms and definitions

For the purpose of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

NOTE Further definitions from the Normative References can be used.

3.1 contact point

⟨for a pantograph⟩ location of mechanical contact between a pantograph contact strip and a contact wire

3.2 contact force

⟨for a pantograph⟩ vertical force applied by a pantograph to the contact wire(s)

NOTE The contact force is the sum of the forces of all contact points of a pantograph.

3.3

static contact force

vertical force exerted upward by the collector head on the overhead contact line system at standstill

[SOURCE: EN 50206-1:2010, 3.3.5]

3.4

aerodynamic force

vertical force applied to the pantograph as a result of air flow around the pantograph components

3.5

mean contact force

statistical mean value of the contact force

[SOURCE: EN 50317:2012, 3.5]

3.6

standard deviation $\langle A_1 \rangle$ **<of contact force>** $\langle A_1 \rangle$

square root of the sum of the squared sample variance divided by the number of output values minus 1

3.7

skewness

parameter that quantifies the symmetry of the shape of a data distribution

$$sk = \frac{\sum \frac{(F - F_m)^3}{n}}{\left(\sum \frac{(F - F_m)^2}{n} \right)^{\frac{3}{2}}} \quad (1)$$

3.8

excess of kurtosis

parameter that quantifies whether the shape of the data distribution matches the Gaussian distribution

$$ek = \frac{\sum \frac{(F - F_m)^4}{n}}{\left(\sum \frac{(F - F_m)^2}{n} \right)^2} - 3 \quad (2)$$

3.9

minimum of contact force

minimum value of the contact force while the pantograph passes over the analysis section

3.10

maximum of contact force

maximum value of the contact force while the pantograph passes over the analysis section

3.11

loss of contact

physical separation of the collector head from the contact wire

NOTE In simulation this condition occurs when the contact force is zero or less.

3.12

simulation method

numerical method that uses a fixed set of input parameters describing a system (e.g. pantograph/overhead contact line system) to calculate a set of output values representative of the dynamic behaviour of this system

3.13

pantograph model

mathematical model in a one- or more-dimensional geometry describing the dynamic characteristics of the pantograph

3.14

mass - spring - damper - model

lumped parameter model

method representing a dynamic mechanical system (e.g. pantograph) as a series of discrete concentrated masses connected together by spring and damper elements

3.15

transfer function

(of a pantograph) $\frac{A_1}{A_2}$ ratio of an applied input on pantograph head to the response of the pantograph, depending on frequency $\langle A_1 \rangle$

3.16

apparent mass

(of a pantograph) transfer function describing the relation between applied contact force and resulting acceleration at the contact point for the frequency range of interest

3.17

hardware in the loop

hybrid simulation/test rig measuring method, where a real pantograph responds interacting with a simulation model of the overhead contact line

3.18

multi-body model

method representing a dynamic mechanical system (e.g. pantograph) based on interconnected rigid or flexible bodies

3.19

collector head

part of the pantograph supported by the frame, which includes contact strips, horns and can include a suspension

3.20

overhead contact line model

mathematical model in a two- or three-dimensional geometry describing the characteristics of an overhead contact line for interaction with pantographs

3.21

$\frac{A_1}{A_2}$ wave propagation velocity <of the contact wire> $\langle A_1 \rangle$

speed of a transversal wave, which runs along the contact wire

3.22

maximum uplift at the support

maximum value of the vertical uplift of the contact wire at a support

3.23

analysis section

subset of the total overhead contact line model length over which the simulation will be evaluated

3.24

frequency range of interest

frequency range within which the dynamic performance of the overhead contact line - pantograph system is considered

NOTE For validation with measurements this range correlates with the frequency range defined in EN 50317.

3.25

dynamic interaction

$\square_{A1}$ behaviour between pantograph(s) and overhead contact line when in contact, described by contact forces and vertical displacements of contact point(s) $\square_{A1}$

3.26

frequency band analysis

analysis inside a frequency range of interest using subranges of frequencies to study special topics

3.27

elasticity of overhead contact line

uplift divided by the force applied to the contact wire in a static state

3.28

range of vertical position of the point of contact

difference between maximum and minimum dynamic height of the contact point, relative to the track, during dynamic interaction between the pantograph and the contact wire

$\square_{A1}$ 3.29

height at operating position

vertical distance between actual operating position of the pantograph and pantograph housed height $\square_{A1}$

4 Symbols and abbreviations

For the purpose of this document, the following symbols and abbreviations apply.

Abbreviations:

AW	auxiliary wire
CT	centre of the track
CW	contact wire
CWH	contact wire height
$\square_{A1}$ FFT	fast Fourier transformation $\square_{A1}$
HIL	hardware in the loop
MT	type of support
MW	messenger wire
Mxx	support or mast number
OCL	overhead contact line
$\square_{A1}$ ROCL	rigid overhead contact line $\square_{A1}$
SDx	number of dropper to stitch wire
STx	span type number as reference to Figure Span number

SW stitch wire

Symbols:

$a_{cp, meas}$	measured vertical acceleration at the contact point
$a_{cp, model}$	simulated vertical acceleration at the contact point
C_s	structural damping matrix
c_n	damping of element n
Dx	dropper number
E	modulus of elasticity
e	elasticity of $\overline{A_1}$ overhead contact line $\overline{A_1}$
ek	excess of kurtosis of contact force
F	contact force
$F_{applied, meas}$	measured vertical force applied at the contact point
$F_{applied, model}$	simulated vertical force applied at the contact point
f_i	actual frequency
F_m	mean contact force
f_n	maximum frequency
F_{sa}	lateral force at steady arm
f_1	minimum frequency
K	stiffness matrix
k_n	stiffness of element n
L_{dr}	dropper length
L_{xdr}	dropperlength (for CW no. x)
L_{sa}	length of steady arm
M	mass matrix
$m_{app, meas}$	measured apparent mass
$m_{app, model}$	apparent mass of the model
m_n	mass of element n
Q	accuracy of the pantograph simulation model
sk	skewness of contact force
X	distance between left mast and dropper no. x
α, β	proportional damping coefficients

σ standard deviation of contact force

5 General

5.1 Typical application

One of the purposes of the application of this standard is to inform the process for seeking authorization for an OCL or pantograph design. In [Annex C, Figure C.1](#) shows the route through to assessment of an OCL system in accordance with the [\[A1\] TSI ENE \[A1\] \[1\]](#), and [Figure C.2](#) the assessment of a pantograph in accordance with the [\[A1\] TSI LOC & PAS \[A1\] \[2\]](#), for European Interoperability.

NOTE Other applications, not related to TSI authorizations (e.g. research, technical development, etc), may require a different process.

5.2 Overview of the validation process

The theoretical study of the dynamic interaction between pantograph and overhead contact line by computer simulation makes it possible to obtain much information about the system and to minimize the costs of line tests.

In order to be used with confidence the simulation method shall be validated. The validation for a simulation method shall be done in a process described in [Figure 1](#).

A simulation method validated according to this standard, shall be considered for application to overhead contact line/pantograph combinations and conditions only within the limits of validity defined in [10.3](#).

A new validation shall be made when the conditions to apply simulation are outside the limitations defined in [10.3](#) for existing validations.

The validation for a simulation method shall be done with the steps which are shown in [Figure 1](#). The steps are:

- 1) A first validation step shall be done by a “desktop assessment” in accordance to [Clause 11](#). The most relevant reference model data shall be chosen from the reference models in [Annex A](#) for the conditions for which validation is required.

NOTE This desktop assessment will improve the confidence in the simulation method. As [Annex A](#) cannot cover all possible solutions and combinations a choice from this subset is necessary.

For validation of simulation methods implemented for new technologies in ways that are totally different from the current state of the art, and which are not able to use models with the data according to [Annex A](#), the “desktop assessment” may be omitted.

- 2) The final assessment shall be done by a “Line Test Data Validation” based on test results according to [10.1](#) to demonstrate the accuracy of simulation according to [10.2](#).

[Annex B](#) provides data sets from line test measurements in accordance with EN 50317 to allow for a validation for a given model within the limitations according to [10.3](#).

If the accuracy according to either [10.2](#) or to [11.4](#) cannot be achieved then the simulation method shall be improved according to [6.3](#) for pantograph model adjustments and according to [7.3](#) for [\[A1\]](#) overhead contact line [\[A1\]](#) model before revalidation.

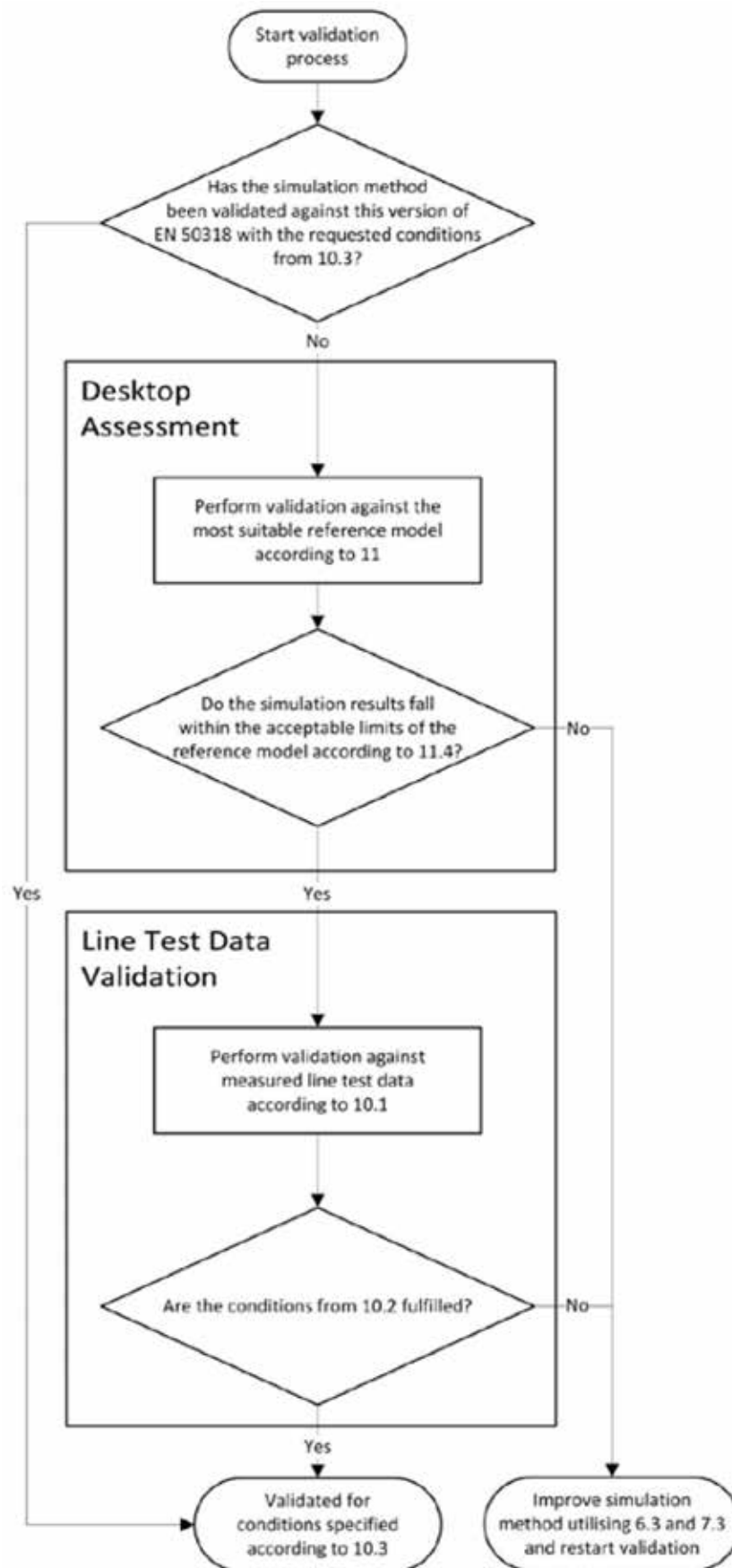


Figure 1 — Evaluation process

6 Modelling of the pantograph

6.1 General requirements

A pantograph model shall describe the dynamic characteristics of a pantograph, regarding interaction with overhead contact lines, in the frequency range of interest.

Commonly used pantograph models are:

- mass – spring – damper – models (lumped parameter models);
- transfer function models;
- multi-body models;
- physical pantographs, when hardware in the loop (HIL) is adopted.

The pantograph may be modelled with one or more dimensional geometry, depending on the phenomena to be investigated.

For the modelling of active pantographs the characteristics of control and the dynamic characteristics shall be available.

A1 Aerodynamic effects on the pantograph shall as a minimum be considered by adjusting the mean contact force as a function of speed. **A1**

6.2 Input data requirements

6.2.1 General

Depending on the modelling method and the individual pantograph characteristics, the relevant parameters appropriate to fully describe the pantograph shall be available for simulation.

These parameters shall take into account other dependencies (operation height, stagger, nonlinearities, frequency **A1** , contact wire height) **A1**, as required.

Common parameters of pantographs are:

- kinematics;
- transfer function;
- natural frequencies;
- mass distribution;
- degree of freedom of joints;
- damping characteristics;
- spring characteristics;
- friction values;
- stiffness;
- bump stops;
- location of application of the static contact force;
- location of application of the aerodynamic forces.

NOTE Aerodynamic forces usually depend on the orientation, operation height $\langle A_1 \rangle$, contact wire height $\langle A_1 \rangle$ and position of the pantograph and the type of train.

6.2.2 Mass — spring — damper — models (lumped parameter models)

For mass – spring – damper – models (lumped parameter models), the following input is required:

- mass values of a minimum of two discrete mass elements;
- $\langle A_1 \rangle$ stiffness characteristics of joints connecting the discrete masses, including any nonlinearity (if applicable);
- damping characteristics of joints connecting the discrete masses, including any nonlinearity (if applicable); $\langle A_1 \rangle$
- friction values (if applicable);
- bump stops (if applicable);
- $\langle A_1 \rangle$ Text deleted $\langle A_1 \rangle$

6.2.3 Multi-body models

$\langle A_1 \rangle$ For multi-body models, the input set out in 6.2.2 and the following input is required: $\langle A_1 \rangle$

- definition of all parts of the model including mass distributions, inertia characteristics, flexibility (if applicable);
- kinematics, describing transmission of movements, kinds of joints and their position and limitations (if applicable);
- internal forces applied to the system and their application points for springs, dampers and friction elements;
- $\langle A_1 \rangle$ Text deleted $\langle A_1 \rangle$.

6.2.4 Transfer function models

For transfer function models the following input is required:

- an analytical definition of the Laplace transform function, e.g. zeros and poles inside the frequency range of interest, between the vertical displacement of the contact point and the contact force.

6.2.5 Hardware in the loop

Hardware in the loop uses the pantograph in its final configuration on the test rig. Aerodynamic effects shall be implemented as an adjusted static contact force.

6.3 Validation of pantograph models

The validation of the pantograph models shall be carried out by comparison of the dynamic properties of the pantograph model with those of the real pantograph as measured with a pantograph test rig. The comparison shall be carried out using the same principle as used in the procedure “Calibration of the measurement system” defined in EN 50317:2012, 7.5.

The test shall be carried out with the pantograph of interest and with its extension at a typical height inside 20 % to 80 % of the working range, as defined in EN 50206-1. The force shall be applied centrally to the pantograph head.

The results are usable for 20 % to 80 % of the pantograph working range. Values outside this range require additional investigations.

This test shall be carried out at the predicted mean contact force appropriate to the maximum design speed for the pantograph. The mean contact force shall fulfil the requirements of [A1](#) EN 50367:2020 [A1](#), 7.3, Table 6 for the designated speed.

Measurements of the applied vertical force ($F_{applied}$) and the resulting vertical acceleration at the contact point (a_{cp}) shall be taken applying sinusoidal excitations for the frequency range of interest in suitable steps. For comparison and validation purposes the excitation shall be from 0,5 Hz up to 20 Hz in 0,5 Hz steps.

The intervals may be reduced at resonant frequencies.

The amplitude of excitation shall be high enough to overcome the static friction in the pantograph.

NOTE 1 A range of amplitude of the greater between $\pm 15\%$ of the mean contact force and ± 20 N usually gives representative results.

Based on the measurements of the applied force and the acceleration at the contact point, the measured apparent mass ($m_{app,meas}$) in kilograms shall be determined for the frequency range of interest:

$$m_{app,meas} = \frac{F_{applied,meas}}{a_{head,meas}} \quad (3)$$

The apparent mass of the simulation model shall be determined in the same way as for the test rig measurement based on the values for applied force and resulting acceleration at the contact point identified in the simulation environment:

$$m_{app,model} = \frac{F_{applied,model}}{a_{head,model}} \quad (4)$$

The apparent mass of the pantograph model ($m_{app,model}$) shall be calculated in kilograms using the same frequencies in the same frequency range as the measurements.

The accuracy (Q) of the pantograph simulation model shall be calculated by using the following formula based on the magnitudes of the apparent mass:

$$Q = \left(1 - \frac{1}{f_n - f_1} \sum_{i=1}^{n-1} (f_{i+} \right. \quad (5)$$

A1 For the calculation of Q , the frequencies with a measured apparent mass below 2 kg shall be excluded. **A1**

NOTE 2 The limit of 2 kg is defined to avoid the denominator approaching zero.

The accuracy Q of the simulation model shall be greater than 90 % for the whole frequency range 0,5 Hz to 20 Hz and for the band 0,5 Hz to 5 Hz.

NOTE 3 The accuracy value Q quantifies the differences between test rig measurements and pantograph model in the shape of the logarithmic curves used to represent the apparent mass. This value does not describe an absolute accuracy.

Any change in a pantograph component directly connected to a model parameter shall be accepted without requiring a new validation of the pantograph model. New validation of the pantograph model is necessary for all other changes.

NOTE 4 For example, for lumped parameter models the mass and the spring coefficient at the collector head, m_3 and k_3 according to [Figure A.4](#), are components directly connected to model parameters.

A comparison between different pantograph models for the same pantograph may be performed by comparing the transfer function calculated from the different models.

7 Modelling of the overhead contact line

7.1 General requirements

The model of the overhead contact line shall describe the dynamic characteristics, regarding interaction with pantographs, in the frequency range of interest.

The overhead contact line may be modelled with two- or three-dimensional geometry, depending on the phenomena to be investigated.

A1 ROCL has very small vertical displacements in operation. The validation of these models and interaction simulations is only possible for the contact force in direct comparison with the measured results. **A1**

NOTE The displacement of a rigid overhead contact line during operation is currently not measured with acceptable accuracy.

7.2 Data requirements

The length of overhead contact line model shall be greater than the analysis section, so that the passage of the pantographs is not influenced by initial transients and end effects of the model. To investigate special sections of overhead contact line (e.g. overhead contact line over turnouts, etc) the length of analysis section may be reduced. Depending on the modelling method and the individual overhead contact line characteristics, the relevant geometrical and mechanical parameters of the overhead contact line shall be available for simulation:

- **A1** length of each span, or distance between supports; **A1**
- position of droppers;
- contact wire height (sag, dropper length, wire gradients);
- encumbrance at the supports;
- geometry and mass distribution of steady arms;
- stagger and offset of all wires;
- number and types of wires (contact wire, catenary wire, auxiliary wire, stitch wire, droppers, etc);
- mass per unit length of each wire or density and cross-section;
- mechanical tension of wires. Where the tension depends on temperature, this relationship shall be specified;
- section properties and stiffness for the beams of rigid overhead contact line;
- mass of links between wires and droppers (clamps);
- the mechanical characteristics of the supports and structures;
- the stiffness characteristic of droppers;
- damping of all components of the overhead contact line or a damping rate of the system, if available.

NOTE Typical damping rates (ratio of damping vs. critical damping) of overhead contact lines are between 0,05 % and 0,2 %.

7.3 Static check of overhead contact line model

The usability of the overhead contact line model shall be checked by comparing the results of a static behaviour calculated with this model with measurements or design calculations.

The outcome of the calculation based on the overhead contact line model in the static condition needs to be evaluated to validate the implemented numerical calculations in the addressed simulation method. The following results shall be extracted to evaluate the method:

- static position of the contact wire at each dropper and at the steady arm;
- elasticity of overhead contact line at the same points;
- dropper length.

The numerical results shall be compared to reference results from [Annex A](#), from [Annex B](#), from measurements or from design calculations.

Those results shall be compared to the numerical model for one span which shall remain within the following ranges.

Table 1 — Deviation of simulated static values

Parameter	Required accuracy
Contact wire position	±5 mm
Elasticity	±0,1 mm/N or ± 10 % whichever is greater
Dropper length	±10 mm

NOTE 1 The values in [Table 1](#) are not applicable to rigid overhead contact line.

NOTE 2 The ranges for deviation of elasticity is to cover $\overline{A_1}$ overhead contact lines $\overline{A_1}$ with high and low tension forces.

This validation shall be renewed if the parameters of the overhead contact line differ more than the limitations given in [10.3.3](#).

8 Parameters of simulation

The parameters of the pantograph and overhead contact line shall be given according to [Clauses 6](#) and [7](#).

Depending on the modelling method and the problem to be investigated by simulation, the relevant parameters appropriate to fully describe the simulation shall be available.

Common parameters of simulations are:

- train speed;
- analysis section;

The analysis section shall consist of those parts of the overhead contact line model over which the passage of the pantographs is not influenced by initial transients and end effects of the model.

Depending on the phenomena to be studied, the analysis section should be defined accordingly. For validation purposes see [Clause 10](#) and for the reference models see [Clause 11](#).

- number of and distances between pantographs;
- static contact force of each pantograph;
- aerodynamic effects on each pantograph, taking into account the pantograph orientation;

NOTE Aerodynamic effects can be covered by specifying the applied mean contact force as a function of speed.

- operating height of the pantograph if needed by the pantograph model;
- wire temperatures if relevant to the overhead contact line model;
- damping of the overhead contact line (if not provided according to [7.2](#));
- frequency range of interest.

Depending on the phenomena to be studied, the frequency range of interest shall be defined in advance and shall be consistent with the pantograph model, overhead contact line model and simulation method and with the measurement system.

9 Output

9.1 General

The simulation shall calculate the variation of the contact forces, the contact wire displacements and the pantograph displacements when the pantograph passes along the overhead contact line model.

The output parameters shall be filtered to exclude frequencies outside the frequency range of interest.

Filter characteristics and type depend on the problem to be investigated. For validation purposes see [Clause 10](#) and for comparison with benchmark see [Clause 11](#).

Information about filters used shall be given with results as output.

The outputs from the simulation shall be analysed over the analysis section.

The following clauses specify the outputs for a single pantograph. If the train has more than one pantograph, then the output shall be available for each pantograph.

9.2 Contact force

Within the frequency range of interest, outputs should be analysed within two additional frequency bands, relating to span passing and dropper passing frequencies.

For validation and comparison purposes the frequency range of interest shall be 0 Hz to 20 Hz and the bands shall be 0 Hz to 5 Hz and 5 Hz to 20 Hz.

If the standard deviation of the contact force has to be calculated in several bands, the calculation can be performed in the time domain by applying proper pass-band filters or in the frequency domain. When comparing different values, e.g. numerical and measured values, the same calculation method shall be adopted.

Required outputs:

- the time history of the contact force;
- the mean contact force F_m ;
- the standard deviation of contact force σ ;
- actual maximum and minimum of contact force, F_{min} and F_{max} ;
- statistical distribution (histogram) of contact force including information about skewness and excess of kurtosis.

NOTE The statistical distribution with the base figures of skewness and kurtosis will give information about the variation from Gaussian distribution.

9.3 Contact wire displacement

Required output:

- the maximum uplift of the contact wire at all supports of the analysis section for each pantograph separately.

A1 The time history of the vertical position of the contact wire at any specified point shall be available for output. **A1**

Where it is necessary to check at special locations for the minimum height of the contact wire according to **A1** EN 50119:2020, 5.10.4.2 **A1**, the maximum downwards movement of the contact wire and the location where this occurs for those special sections shall be calculated during the simulation run.