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Translation

O R

Characteristics of a.c. overhead contact systems for high-speed lines worked at speeds of over 200 km/h

Caractéristiques des caténaires alimentées en courant alternatif pour les lignes parcourues à des vitesses supérieures à 200 km/h

Kenndaten für Oberleitungen mit AC-Versorgung für Strecken, die mit Geschwindigkeiten über 200 km/h befahren werden

UNION INTERNATIONALE DES CHEMINS DE FER
INTERNATIONALER EISENBAHNVERBAND
INTERNATIONAL UNION OF RAILWAYS

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Warning

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Contents

Summary

This leaflet contains requirements and recommendations to ensure reliable interaction between pantograph and a.c. overhead equipment at speeds of over 200 km/h.

The recommendations contained in the leaflet are in line with the state of the art and reflect the experience gained by the railways in high-speed Rail transport whilst ensuring reliability and cost-effectiveness.

Account has been taken of the stipulations laid down for international traffic in the Technical Specifications for Interoperability (TSI).

Pantographs with a bow profile corresponding to that defined in *UIC Leaflet 794* can be used in conjunction with the overhead contact systems defined in this leaflet.

Definitions

Speed ranges, voltage and frequency levels, rolling stock profile, assessment criteria for pantograph/ OHL interaction.

Key characteristics of overhead lines

Static characteristics

Standard height of contact wire, maximum difference in contact wire height, minimum contact wire height for design speed ≤230 km/h, maximum contact wire height for design speed ≤230 km/h, permissible contact line gradient and change of gradient, maximum distance between OHL sections supplied at different phases.

Dynamic characteristics

Maximum permissible uplift of contact wire as pantograph passes at the support (without climatic influences), maximum aerodynamic contact force at maximum speed, maximum permissible dynamic contact force of the pantograph, minimum permissible dynamic contact force of the pantograph.

Electrical characteristics

Constant current capacity, short time rating, short-circuit current, thermal time constant, permissible current when stationary.

Climatic influences

Ambient temperature range, maximum wind speed, ice load.

Design parameters

Maximum span lengths, maximum difference in length between two successive spans, length of shortest dropper for standard system, standard system height (encumbrance), design of support, minimum uplift at the support, design of registration arm for supports, dropper spacing, sag, maximum lateral deflection of contact wire at support (stagger), minimum lateral variation in horizontal profile of contact wire per 100 m length, permissible lateral deflection of contact wire within one span with

maximum side wind, number of spans per changeover of tension length, run-in of contact wire at switches, type of tensioning of contact wire and messenger wire.

Parameters for the conductor material

Contact wire, number of contact wires, nominal cross-section of contact wire, specific tensile stress of contact wire, maximum permissible tensile stress in contact wire with worn cross-section, maximum permissible wear of contact wear, number of messenger wires, auxiliary messenger wire, stitch wire, length of stitch wire, tensile stress of stitch wire, reinforcing wire, return conductor, protective conductor.

Physical parameters

Compliance, degree of variability, wave propagation speed, Doppler effect, reflection factor, amplification factor.

Simulation programs and measuring procedure

Simulation programs, provisions relating to measurement of contact forces, provisions relating to arc measurement.

Relationships between the various structural parameters governing dynamic performance and the wear of overhead equipment on high-speed lines

Static criteria

Compliance, variability of overhead lines.

Dynamic criteria

Wave propagation speed/Doppler effect, reflection factor/amplification factor.

Relationships and effects

Static and dynamic criteria, their inter-relationships and effects.

1 - General conditions

1.1 - Scope

The European high-speed network comprises lines suitable for speeds of 250 km/h and above, upgraded lines for speeds of around 200 km/h and other lines from the European rail network.

New high-speed lines will preferably be built with a.c. systems. This leaflet contains requirements and recommendations for the overhead systems of such high-speed lines and for those of the upgraded lines and other lines concerned for speeds over 200 km/h, taking into account the existing situation on the railways.

On existing lines that are a constituent part of the European high-speed network, attempts should be made to satisfy these requirements.

When the values indicated in the leaflet constitute mandatory requirements, they are marked with the symbol "0".

1.2 - Definitions

1.2.1 - Speed ranges

The OHL characteristics are sub-divided into three speed ranges:

$$200 < v \leq 230 \text{ km/h}$$

$$230 < v \leq 300 \text{ km/h}$$

$$v > 300 \text{ km/h}$$

1.2.2 - Voltage and frequency levels

The values given in this leaflet apply to the following systems:

25 000 V, 50 Hz,

15 000 V, 16 2/3 Hz.

1.2.3 - Rolling stock profile

The requirements and recommendations contained in this leaflet refer to application of the "GC" gauge profile.

1.2.4 - Pantograph/OHL interaction

The parameters to be satisfied by the pantograph and OHL in order to ensure pantograph/OHL interaction are contained in *UIC Leaflet 794*.

1.2.5 - Assessment criteria for pantograph/OHL interaction

These criteria comprise:

- one criterion for the pantograph: contact force or number of arcs *(see EN 50119)*.
- contact wire wear: at least 2 million pantograph passages before the maximum permissible usage of the contact wire is reached
- contact wire uplift at the support.

For assessing the quality of current collection, the decisive criteria are contact force, arcing and losses of contact.

Whilst both methods are suitable for identifying irregularities, measuring contact forces is particularly helpful in indicating mechanical wear and arc measurement in indicating electrical wear.

2 - Key characteristics of overhead lines

o 2.1 - Static characteristics

Serial. No	Parameters, comments for design speeds of:	>200 to 230 km/h	>230 to 300 km/h	>300 km/h	Unit
1	**Standard height of contact wire**				
	Contact wire height is taken in a plane perpendicular to the rail running surface				
	Standard contact wire height	5000 to 5500	5080/5300		[mm]
	Tolerance	±30	0 + 20 / ±10		
	Standard heights are applicable to the GC gauge profile and are dependent on specific criteria (e.g. electrical distances, ice burden, construction and maintenance tolerances, etc.)				
2	**Maximum difference in contact wire height measured between two successive supports where contact wire height on construction was constant**	30	10	10	[mm]
3	**Minimum contact wire height for design speed of ≤230 km/h (at special points: bridges, tunnels, etc.)**	4920			[mm]
4	**Maximum contact wire height for design speed of ≤230 km/h with account taken of uplift (at special points)**	6500			[mm]
5	**Permissible contact line gradient and change of gradient**	*As per EN 50119*	0	0	[‰]
6	**Maximum distance between OHL sections supplied at different phases**	As per TSI - page 17			

2.2 - Dynamic characteristics

Serial. No	Parameters, comments for design speeds of:	>200 to 230 km/h	>230 to 300 km/h	>300 km/h	Unit
7	**Maximum permissible uplift of contact wire as pantograph passes at the support (without climatic influences)**	120	120	120	[mm]
8	**Maximum aerodynamic contact force at maximum speed**		As per *UIC Leaflet 794*		[N]
9	**Maximum permissible dynamic contact force of the pantograph** This force must be consistent with the permissible uplift of the contact wire and the composition of the pantograph contact strip $F_{max} \approx F_m + 3\sigma$ F_m is the mean value of the contact force based on statistical analysis of the results of a contact force measurement. To minimise wear, the smallest possible value for F_m should be used, with account taken of contact wire uplift.	250	250	250	[N]
10	**Minimum permissible dynamic contact force of the pantograph** This is a parameter contributing to the quality of current collection and the avoidance of arcs, losses of contact and high electrical wear. $F_{min} \approx F_m - 3\sigma$		As per *EN 50119*		[N]

NB : 7 and 8 are obligatory.

2.3 - Electrical characteristics (definitions)

Serial. No	Parameters, comments	Unit
11	**Constant current capacity** The constant current capacity is defined essentially for a final temperature of 80°C in the contact wire with a wind speed of 0,6 m/s. The initial temperature for European railways is defined as an ambient temperature of +40°C.	[A]
12	**Short-time rating** This is the current permissible for a period of 10 minutes (preferred value as per *UIC Leaflet 798*), the boundary conditions being assumed to be the initial temperature (ambient temperature) of +40°C and the final temperature according to the constant current load.	[A]
13	**Short-circuit current** This is the current permissible for a period of 0,2 s at 16 2/3 Hz, or for 0,1 s at 50 Hz, the boundary conditions being the initial temperature (ambient temperature) of + 40°C and the final temperature according to the constant current load. As a result of the dynamic forces occurring due to the short-circuit current the minimum distances between the conductors (contact wire, messenger wire, reinforcing wire) or between the conductors and the structural components must be respected for 15 kV 16 2/3 Hz.	[A]
14	**Thermal time constant** The initial ambient temperature for European railways is defined as + 40°C, and the final temperature as 80°C with a wind speed of 0,6 m/s Reference value 5 to 10.	[min]
15	**Permissible constant current when stationary** Determining parameters here are the materials used for the contact wire and pantograph contact strip as well as the contact force. The setting must be such that the temperature reached at the point of contact does not alter the properties of the contact wire.	[A]

2.4 - Climatic influences

Serial. No	Parameters, comments		Unit
16	**Ambient temperature range** This is decisive for the constructional design of the overhead system and is dependent on regional and local conditions.	To be set by the railways	[°C]
17	**Maximum wind speed** This is decisive for the maximum deflection of the contact wire and is dependent on regional and local conditions.	To be set by the railways	[m/s]
18	**Ice load** This is not considered separately when dimensioning the overhead system. National provisions should be applied.	To be set by the railways	

3 - Design parameters

The following parameters are of importance for the functioning of a high-speed contact line.

Serial. No	Parameters, comments for design speeds of:	>200 to 230 km/h	>230 to 300 km/h	>300 km/h	Unit
19	**Maximum span lengths**				[m]
	Open track	65	65	65	
	Tracks in tunnels	50	50	50	
20	**Maximum difference in length between two successive spans**	≤15	≤10	≤10	[m]
21	**Length of shortest dropper for standard system** With account taken of the dynamic forces arising during short circuits and/ or the design of the droppers.				[m]
	15 kV	0,45	0,60	0,60	
	25 kV	0,20	0,25	0,25	
22	**Standard system height (encumbrance)** Vertical distance between contact wire and messenger wire at the supports				[m]
	- Open line				
	• 15 kV	1,80	1,80	1,80	
	• 25 kV	1,25	1,40	1,40	
	- Tunnels				
	• 15 kV	1,10	1,10	1,10	
	• 25 kV	0,60	0,80	0,80	
23	**Design of support** Mechanically-separated individual supports				
24	**Minimum uplift at the suppor** Depending on the design. In accordance with *EN 50119*				[mm]
	- 2x value of maximum permissible uplift of contact wire as pantograph passes without uplift limitation	240	240	240	
	- 1,5x value of maximum permissible uplift of contact wire as pantograph passes with uplift limitation	180	180	180	
25	**Design of registration arm for supports** Lightweight design under tension which may be fitted with wind-securing device and/or uplift limitation device	required	required	required	

26	**Dropper spacing** This is significant for the sag of the contact wire between two successive droppers.	<9,50	<9,50	<9,50	[m]
27	**Sag** This is the difference in the height of the contact wire between the first dropper after the support and the centre of the span in relation to the total length of the span.	≤1	≤0,5	≤0,5	[‰]
28	**Maximum lateral deflection of contact wire at support (stagger)**	≤0,30	≤0,30	≤0,30	[m]
29	**Minimum lateral variation in horizontal profile of contact wire per 100 m length** This is a value to ensure that the wear on the pantograph contact strip is as uniform as possible	0,50	0,50	0,50	[m]
30	**Permissible lateral deflection of contact wire within one span with maximum side wind**	As per *UIC Leaflet 606-1* and *UIC Leaflet 794*			
31	**Number of spans per changeover of tensioning**	≥3	≥4	≥4	[number]
32	**Run-in of contact wire at switches**	The run-in may be from above or from the side. In the case of run-in from the side, both contact wires should, in the transfer zone, be positioned on the half of the pantograph corresponding to the contact wire running in.			
33	**Type of tensioning of contact wire and messenger wire** Separate tensioning	Recom -mended	Required	Required	

NB : 23, 24, 25, 27, 30, 31, 32 and 33 are obligatory.

4 - Parameters for the conductor material

Serial. No	Parameters, comments for design speeds of:	>200 to 230 km/h	>230 to 300 km/h	>300 km/h	Unit
34	**Contact wire**		As per *EN 50149*		
35	**Number of contact wires**	1	1	1	
36	**Nominal cross section of contact wire**	≥100	≥120	≥120	[mm^2]
37	**Specific tensile stress of contact wire**	≥100	≥125	≥133	[N/mm^2]
38	**Maximum permissible tensile stress in contact wire with worn cross-section**		As per national regulations		[N/mm^2]
39	**Maximum permissible wear of contact wire**		As per national regulations		
40	**Number of messenger wires**	1	1	1	
41	**Auxiliary messenger wire**		optional		
42	**Stitch wire**		optional		
43	**Length of stitch wire**		20 % to 30 % of the span length		
44	**Tensile stress of stitch wire** Specific tensioning of stitch wire		25 % to 50 % of the messenger wire tensile stress		
45	**Reinforcing wire** Dimensioning according to current load		optional		
46	**Return conductor** Dimensioning according to current load		optional		
47	**Protective conductor** Depending on the power supply system, the protective conductor may also be used as a return current conductor.		As per national regulations		

NB : 34 and 38 are obligatory.

5 - Physical parameters

Serial. No	Parameters, comments for design speeds of:	>200 to 230 km/h	>230 to 300 km/h	>300 km/h	Unit
48	**Compliance** These values are determined for the maximum span length over the full span with a contact force of 100 N.				[mm/N]
49	**Degree of variability** The difference between the maximum and minimum compliance within a span is expressed as the degree of variability. $U = \frac{e_{max} - e_{min}}{e_{max} + e_{min}} x100$				[‰]
	OHL system without stitch wire	<40	<40	<25	
	OHL system with stitch wire	<20	<10	<10	
50	**Wave propagation speed** This is the speed of propagation of a mechanical impulse along the overhead wires; it thus constitutes a criterion for the dynamic behaviour of the overhead system.				[m/s]
	$v_c = Sqrt\frac{Z_{fd} + Z_{ts}}{m_{fd} + m_{ts}}$	>110	>120	>V_{max}[m/s] + 40	
51	**Doppler effect** This is the relationship between wave propagation speed and train speed. $\alpha = \frac{v_c - v_b}{v_c + v_b}$	>0,26	>0,18	>0,17	
52	**Reflection factor** This is a parameter for the reaction of the mechanical wave. $r = \frac{Sqrt(Z_{ts} x m_{ts})}{Sqrt(Z_{ts} x m_{ts}) + Sqrt(Z_{fd} x m_{fd})}$	<0,5	<0,4	<0,4	
53	**Amplification factor** This is a parameter for the effect of the reflected wave on the dynamic vibrational behaviour of the overhead line. $\chi = \frac{r}{\alpha}$	<1,9	<2,2	<2,3	

6 - Simulation programs and measuring procedure

6.1 - Simulation programs

To assess the performance to be expected of certain overhead lines in combination with different pantographs, mathematical simulation models are useful. The planning parameters adopted for the overhead line should be checked for their suitability with respect to contact force peaks.

The finite element method (FEM) is recommended as a simulation model.

The following input data should be used:

- system dimensions of the overhead line, variable
- cables, wires (cross-sections, materials, etc.), variable
- pantograph characteristics by means of frequency-dependent dynamic apparent masses
- mass-spring model of the pantograph
- number and spacing of pantographs
- aerodynamic force *UIC Leaflet 608*

Resulting values:

- contact force curve
- dynamic condition of the overhead system.

The overhead system once built should be checked by means of field measurements involving contact force measurement and determination of the number and duration of any arcs.

The simulation should use the same sampling and evaluation frequency as the measurement.

Only the feedback obtained from the field measurements is decisive in assessing the suitability of the simulation models used.

6.2 - Provisions relating to measurement of contact forces

6.2.1 - Measuring point

For the purpose of system design in terms of permissible speed, the contact force should as far as possible be measured directly between contact wire and contact strip, or at least at the mounting clips of the contact strip. When recording the contact forces it is essential to specify at exactly what point each measurement was taken.

6.2.2 - Analysis steps

The sampling frequency should be ≥100 Hz and the evaluation frequency ≥15 Hz.

6.3 - Provisions relating to arc measurement

The following points should be indicated when recording the arc measurements:

- train speed,
- arc duration in % of time,
- arc count after 10 ms (without exceeding a maximum arc duration of 25 ms) per 100 m,

The arc duration is, however, affected by weather.

Appendix A - Relationships between the various structural parameters governing dynamic performance and the wear of overhead equipment on high-speed lines

A.1 - Static criteria

A.1.1 - Compliance

In order to minimise the lift of the contact wire, which is caused by the increase in the contact force of the pantograph at increasing speed, the compliance should be low.

To achieve this:

- the tensile stresses in the contact wire and messenger wire should be set as high as possible, and
- the span lengths selected should be as short as is economically feasible.

A.1.2 - Variability of overhead lines

With a view to improving the interaction of contact wire and pantograph the overhead line should exhibit uniform compliance (i.e. low variability):

- within each individual span, and
- between successive spans.

An improvement in the level of variability can be achieved, for instance, by:

- installing a stitch wire,
- installing an auxiliary messenger wire,
- selecting a sag value adapted to the tensile load,
- increasing the tensile load of the contact wire,
- reducing the lengths of the spans,
- setting similar span lengths.

A.2 - Dynamic criteria

A.2.1 - Wave propagation speed/Doppler effect

A decisive factor in the dynamic behaviour of the system is that the wave propagation speed of the disturbance impulse in the overhead line - generated by the pantograph - should be higher than the train speed.

An increase in the wave propagation speed can be achieved by:

- increasing the tensioning of the contact wire and/or the messenger wire,

- reducing the mass per unit length of the contact and/or messenger wire.

The Doppler effect indicates the relationship between the wave propagation speed and the train speed. It must be as high as possible. Its value increases with the wave propagation speed.

A.2.2 - Reflection factor - amplification factor

In order to minimise the reaction of the disturbance impulse on the pantograph it is important that the reflection factor should be low. The reflection factor can be reduced by increasing:

- the tensioning of the contact wire,

- the mass per unit length of the contact wire,

and by reducing:

- the tensioning of the messenger wire,

- the mass per unit length of the messenger wire.

The amplification factor is the ratio of the reflection factor to the Doppler effect and indicates the effect of the reflected disturbance impulse on the dynamic behaviour between overhead line and pantograph. It should be as low as possible.

To achieve this:

- the reflection factor must be reduced, and/or

- the Doppler factor increased.

The criterion is therefore the increase in the tensile stress in the contact wire.

A.3 - Relationships and effects

Increasing the tensile stress in the contact wire improves the situation in that it:

- reduces the compliance,

- reduces the degree of variability,

- increases the wave propagation speed,

- increases the Doppler factor,

- reduces the reflection factor,

- reduces the amplification factor.

Increasing the tensile stress in the messenger wire brings about:

- an improvement by reducing the compliance,
- a deterioration by increasing the reflection factor.

List of abbreviations

α	Doppler factor
χ	Amplification factor
σ	Standard deviation
e_{max}	Maximum compliance
e_{min}	Minimum compliance
F_{max}	Maximum permissible contact force of pantograph
F_{min}	Minimum permissible contact force of pantograph
m_{fd}	Specific mass of the contact wire
m_{ts}	Specific mass of the messenger wire
r	Reflection factor
TSI	Technical Specifications for Interoperability
U	Degree of variability
v_b	Design speed
v_c	Wave propagation speed
v_{max}	Maximum design speed
Z_{fd}	Tensile load in the contact wire
Z_{ts}	Tensile load in the messenger wire

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