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Translation

Characteristics of direct-current overhead contact systems for lines worked at speeds of over 160 km/h and up to 250 km/h

Caractéristiques des caténaires alimentées en courant continue pour les lignes parcourues à des vitesses jusqu'à 250 km/h
Kenndaten für Oberleitungen mit DC-Versorgung für Strecken, die mit Geschwindigkeiten bis 250 km/h befahren werden

Union Internationale des Chemins de fer
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Warning

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Contents

Summary

The leaflet contains the requirements and recommendations required to ensure reliable interaction between pantographs and 1500 V and 3000 V dc overhead equipment for lines operated at speeds of over 160 km/h as well as the parameters for qualification of pantograph-OHL interaction and definition of the interaction qualification indicator.

The values recommended reflect the state of the art and experience gained by the railways in the field of high speed rail whilst ensuring reliability and cost effectiveness.

A section is devoted to simulation programs and measurement methods and includes suggestions on criteria to assess the validity of simulation models used, details about measurement of the contact force and measurement of electric arcs.

The basic OHL parameters stipulated or recommended as well design parameters including those relating to conductors and the physical parameters given for the three speed ranges in km/h:
$160 \leq V \leq 200$, $200 < V \leq 220$ and $220 < V \leq 250$, are set out so that these requirements may be applied to existing dc lines belonging to the European High Speed Network.

The basic parameters stipulated or recommended for OHL are classified into static, dynamic, electrical and climatic parameters.

The design parameters to be observed such as the design of supports, contact wire uplift at the support, sag at the reference temperature, permissible lateral deflection of the contact wire with maximum side wind, the number of spans per changeover of tensioning, contact wire run-in at switches and contact wire tensioning are important for the OHL to function properly at high speed.

1 - General

1.1 - Leaflet content

This leaflet contains requirements and recommendations to ensure reliable interaction between pantograph and direct-current overhead lines at speeds of over 160 km/h and up to 250 km/h.

The recommendations issued in leaflet are in line with the state-of-the-art and reflect the experience gained by the railways in high-speed transport taking account of reliability and cost factors.

Account has been taken in this leaflet of the provisions covering international traffic as laid down in the Technical Specifications for Interoperability (TSI) (see "List of abbreviations", on page 20). These may be supplemented by the national laws and regulations specific to each railway.

The OHL characteristics set out in this leaflet can be used in conjunction with the bow profile defined in *UIC Leaflet 794-1*.

1.2 - Scope

Direct-current networks comprise lines suitable for a mix of very different speeds. Technological progress has seen speeds increase from the modest levels of the first systems to around 200 km/h for upgraded lines of the European high-speed network and even to 250 km/h, the highest speed currently used in revenue operations.

The speed ranges shown in the tables reflect the general features of OHL (see "List of abbreviations", on page 20) equipment and experience gained by the railways.

The aim is to ensure that existing lines forming part of the European high-speed network comply with these requirements.

1.3 - Symbols

Symbol	Name
α	Doppler effect
χ	Amplification factor
σ	Standard deviation
e_{max}	Maximum compliance (electricity)
e_{min}	Minimum compliance (electricity)
F_{max}	Maximum permissible dynamic contact force of pantograph
F_{min}	Minimum permissible dynamic contact force of pantograph
m_{fd}	Specific mass of contact wire
m_{ts}	Specific mass of messenger wire
U	Degree of variability
r	Reflection factor
V_b	Design speed
V_c	Wave propagation speed
Z_{fd}	Tensile load in contact wire
Z_{ts}	Tensile load in messenger wire

1.4 - Definitions

1.4.1 - Speed ranges

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

$160 < V \leq 200$ km/h,

$200 < V \leq 220$ km/h,

$220 < V \leq 250$ km/h

1.4.2 - Voltages

The parameters given in this leaflet are valid for 1500V and 3000V systems.

1.4.3 - Rolling stock profile

The requirements and recommendations contained in this leaflet apply to rolling stock complying with the "GC" gauge profile.

1.4.4 - Pantograph/OHL interaction

The parameters to be met by the pantograph and OHL equipment to ensure proper pantograph/OHL interaction are contained in *UIC Leaflet 794-1*.

1.4.5 - Assessment criteria for pantograph/OHL interaction

These are characterised by a single current-collection quality criterion: contact force or number of arcs *(see EN 50119)*.

For assessing the quality of current collection, the decisive criteria are contact force and electric arcs.

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

1.4.6 - Assessment indicator for pantograph/OHL interaction

This is characterised by the number of pantograph passes performed before maximum permissible contact-wire wear is reached.

This number must equal at least 1 million passes with carbon pantograph friction strips.

2 - Fundamental parameters to be met by overhead lines

2.1 - Static characteristics

Serial No.	**Parameters, comments** for design speeds of	160 < V ≤ 200 km/h	200 < V ≤ 220 km/h	220 < V ≤ 250 km/h	**Unit**
*** 1**	**Standard contact-wire height** Contact wire height is taken in a plane perpendicular to the rail running surface Standard height Tolerance Standard heights are given for the GC gauge profile and are dependent on specific criteria (e.g. electrical distances, ice burden, construction and maintenance tolerances, etc.)	5 000 - 5 500 0 + 60	5 000 - 5 500 0 + 60	5 000 - 5 300 0 + 20	[mm]
*** 2**	**Maximum difference in contact-wire height measured between two successive supports with constant standard contact-wire height on construction**	30	30	10	[mm]
*** 3**	**Minimum contact-wire height for a design speed of ≤ 220 km/h (at special points)**	4900	4900	---	[mm]
*** 4**	**Maximum contact-wire height for a design speed of ≤ 220 km/h with account taken of uplift (at special points)**	6200	5500	---	[mm]
*** 5**	**Permissible contact-line gradient and change of gradient**	2	1	1	[‰]

NB : 1, 2, 3, 4, 5 are obligatory

2.2 - Dynamic parameters

Serial No.	**Parameters, comments** for design speeds of	160 < V ≤ 200 km/h	200 < V ≤ 220 km/h	220 < V ≤ 250 km/h	**Unit**
* 6	**Maximum permissible uplift of contact wire as pantograph passes at support without climatic influences**				[mm]
	- **tension-regulated catenary**	100	100	100	
	- **compound catenary**	60	60	---	
* 7	**Maximum permissible average force at maximum speed (absence of wind)**	180	220	260	[N]
* 8	**Maximum permissible dynamic contact force of pantograph** This force must be consistent with the permissible uplift of the contact wire at support and with the composition of the pantograph contact strips				
	$F_{max} = F_m + 3\sigma$[a] F_m is the mean value of the contact force based on statistical analysis. To minimise wear, the smallest possible value for F_m should be used.	350[b]	380[b.]	450[b.]	[N]
* 9	**Permissible minimum dynamic contact force of pantograph** Parameter contributing to the quality of current collection and avoidance of arcing, losses of contact and high electrical wear.				
	$F_{min} = F_m - 3\sigma$		>0[c]		[N]

a. See point 4 of Table 2 in Leaflet 794-1 (these references may change with new on-line production of UIC leaflets) on "Pantograph-OHL interaction in direct-current systems"

b. Values to be confirmed

c. Provisional value to be confirmed by analysis of current and future measurements

NB : 6, 7, 8, 9 are obligatory

2.3 - Electrical characteristics

Serial No.	**Parameters, comments** for design speeds of		
10	**Permissible constant current capacity** The permissible constant current capacity is defined in most cases for a final temperature of 80°C with a wind speed of 0.6m/s. The initial temperature for European railways is defined as an ambient temperature of + 40°C. For compound catenaries, the permissible constant current capacity is defined as for a final temperature of 55°C.	---	[A]
11	**Short-time rating** This is the current permissible for a period of 10 minutes (recommended value as per *UIC Leaflet 798*), with an assumed ambient initial temperature of +40°C and the temperature rise caused by the permissible constant current load.	---	[A]
12	**Short-circuit current** This is the current permissible over a period of 0.2s allowing for an ambient temperature of +40°C and the temperature rise caused by the permissible constant current load.	---	[A]
13	**Thermal time constant** At a wind speed of 0.6m/s, the initial temperature for European railways is defined as the ambient temperature of +40°C.	Reference value 5 to 10	[min]
14	**Permissible constant current when stationary**[a]	Pending	[A]

a. See point 7 of Table 1 in Leaflet 794-1 on "Pantograph-OHL interaction in direct-current systems" (these references may change with new on-line production of UIC leaflets)

2.4 - Climatic influences

Serial No.	**Parameters, comments** for design speeds of	**Unit**	
15	**Ambient temperature range** This parameter is decisive for the OHL design. It is dependent on regional and local conditions	To be set by the railways	[°C]
16	**Maximum wind speed** This parameter is decisive for maximum lateral wire clearance. It is dependent on regional and local conditions.	To be set by the railways	[m/s]
17	**Ice load** This parameter is not considered separately when calibrating the OHL system. National provisions should be applied	To be set by the railways	

3 - Design parameters

The following parameters are of importance for OHL operation at high speed.

Serial No.	**Parameters, comments** for design speeds of	160 < V ≤ 200 km/h	200 < V ≤ 220 km/h	220 < V ≤ 250 km/h	**Unit**
18	**Maximum span lengths**	65	65	65	[m]
19	**Maximum difference in length between two successive spans**	≤ 18	≤ 18	≤ 18	[m]
20	**Minimum dropper length (distance between conductors)** This is determined particulary by reference to the dropper design				
	- tension-regulated catenary	0.200	0.200	0.200	[m]
	- compound catenary	0.050	0.050	---	
21	**Standard system height (encumbrance)** Vertical distance between contact-wire axis and messenger-wire axis at suspension				
	Maximum/Minimum				
	- tension-regulated catenary	1.45/0.80	1.45/0.80	1.45/0.80	[m]
	- compound catenary	1.50/0.35	1.50/0.35	---	
*** 22**	**Establishment of suspension point on running track**	This is obtained using an independent support or rigid portal structure			[m]
*** 23**	**Free uplift at suspension point**				[mm]
	Because of its design and consistent with *EN 50119*, minimum uplift at any suspension point is double the value of permissible maximum uplift of the contact wire as the pantograph passes in the absence of any uplift limiting mechanism				[N]
	- tenion-regulated catenary	200	200	200	
	- compound catenary	120	120	---	
*** 24**	**Type of registration arm**	Lightweight design subject to tractive force			

NB : 22, 23, 24 are obligatory

Serial No.	**Parameters, comments** for design speeds of	160 < V ≤ 200 km/h	200 < V ≤ 220 km/h	220 < V ≤ 250 km/h	**Unit**
25	**Spacing between two consecutive droppers on a contact-wire** This parameter is significant for contact-wire sag between two successive droppers	< 10.50	< 10.50	< 9.50	[m]
*** 26**	**Sag at +15°C (or at reference temperature given by each railway)** This is the difference in height of the contact wire between the first dropper after the support and the mid-span in relation to the total span length	≤ 1	≤ 1	≤ 1	[‰]
27	**Maximum lateral deflection of contact wire at support (stagger)**	≤ 0.300	≤ 0.300	≤ 0.300	[m]
28	**Mimimum cumulated deflection 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]
*** 29**	**Permissible staggering of contact wire with maximum side wind**	≤ 0.4	≤ 0.4	≤ 0.4	- [m]
*** 30**	**Number of spans per tension-length changeover**	≥ 0.3	≥ 0.3	≥ 0.3	
*** 31**	**Contact-wire run-in at switches** The run-in of the contact wire at switches may be from above or from the side. When the contact wire of the other track is incoming from the side, the contact wire of the track on which the pantograph is located and that of the other track must be positioned on the same half of pantograph				
*** 32**	**Contact-wire tension regulating**	required	required	required	
*** 33**	**Messenger-wire tension regulating**[a]	optional	optional	optional	

a. Distinct tensioning procedure

NB : 26, 29, 30 31, 32, 33 are obligatory

4 - Parameters for the conductor material

Serial No.	**Parameters, comments** for design speeds of	160 < V ≤ 200 km/h	200 < V ≤ 220 km/h	220 < V ≤ 250 km/h	**Unit**
*** 34**	**Grooved wire**	As per *EN 50149*			
35	**Number of contact wires**	2	2	2	
36	**Nominal cross-section of contact wire**	≥ 100	≥ 150	≥ 150	[mm^2]
37	**Specific tensile stress of contact wire in tensioning zone**	≥ 100	≥ 150	≥ 125	[N/mm^2]
*** 38**	**Permissible maximum tensile stress in contact wire (case of used wire)**	As per national regulations			
39	**Permissible maximum wear of contact wire**	As per national regulations			
40	**Main messenger wire Number**				
	- tension-regulated catenary	1 or 2	1 or 2	1 or 2	
	- compound catenary	1	1	---	
41	**Auxiliary messenger wire**				
	- compound catenary	1	1	---	
42	**Feeder**				
	Calibrate according to electric load	optional	optional	optional	
43	**Return conductor** Calibrate according to electric load	not required	not required	not required	
44	**Protective cable**	As per national regulations	As per national regulations	As per national regulations	

NB : 34 and 38 are obligatory

5 - Physical parameters

Serial No.	**Parameters, comments** for design speeds of	160 < V ≤ 200 km/h	200 < V ≤ 220 km/h	220 < V ≤ 250 km/h	**Unit**
45	**Compliance** These values are determined, for maximum span length, over the full span with a contact force of 100 N				[mm/N]
46	**Regularity coefficient** The difference between the maximum and minimum compliance within a span is expressed as the regularity coefficient $U = \frac{e_{max} - e_{min}}{e_{max} + e_{min}} \times 100$				[%]
	Tension -regulated catenary				
	- without switch wire	< 40	< 40	< 40	
	- with switch wire	< 35	< 35	< 35	
	Compound catenary	< 70	< 70	---	
47	**Wave propagation speed** This is the speed of progagation of a mechanical impulse along the overhead wire. It constitutes a criterion for the behaviour of the OHL system. $v_c = S_{qrt} \frac{Z_{fd} + Z_{ts}}{m_{fd} + m_{ts}}$				[m/s]
	Tension-regulated catenary				
	- without Y stitch wire	> 100	> 100	> 100	
	- with Y stitch wire	> 100	> 100	> 100	
	Compound catenary	> 110	> 110	---	

48	**Doppler effect** This is the relationship between wave propagation speed and train running speed $\alpha = \frac{v_c - v_b}{v_c + v_b}$ **Tension-regulated catenary** - without Y - with Y **Compound catenary**	 > 0.28 > 0.28 > 0.33	 > 0.24 > 0.28 > 0.29	 > 0.18 > 0.28 ---	

Serial No.	**Parameters, comments** for design speeds of	160 < V ≤ 200 km/h	200 < V ≤ 220 km/h	220 < V ≤ 250 km/h	**Unit**
49	**Reflection factor** This parameter characterises the reflection of the mechanical wave $r = \frac{Sqrt(Z_{ts} \times m_{ts})}{Sqrt(Z_{ts} \times m_{ts}) + Sqrt(Z_{fd} \times m_{fd})}$ **Tension-regulated catenary** - without Y - with Y **Compound catenary**	< 0.6 < 0.6 < 0.4	< 0.5 < 0.5 < 0.4	< 0.5 < 0.5 ---	
50	**Amplication factor** This parameter characterises the effect of the reflected wave on the dynamic vibrational behaviour of the overhead line $\chi = \frac{r}{\alpha}$ **Tension-regulated catenary** - without Y - with Y **Compound catenary**	< 2.1 < 2.0 < 1	< 2.1 < 2.0 < 1	< 2.3 < 2.0 ---	

6 - Simulation programs and measuring procedure

6.1 - Simulation programs

To assess the probable performance for different overhead lines in combination with different pantographs, mathematical simulation models should be used.

The parameters adopted for the overhead-line designs should be checked for their suitability, particularly with respect to the maximum contact-force values recorded during these simulations.

The finite element method (FEM) is recommend as a simulation model. The following input data should be used:

- geometrical parameters of OHL system,
- conductor characteristics (cross-sections, materials, etc.),
- apparent dynamic mass of pantograph in relation to frequency,
- mass, spring and damper modelling of the pantograph,
- number and spacing of pantographs,
- aerodynamic force as in *UIC Leaflet 608*

Resulting values:

- contact-force development curve
- dynamic condition of OHL system in time and space.

The behaviour of the OHL system should be checked during test runs (involving contact-force measurement and determination of the number and duration of arcs).

The simulation should use the same sampling and evaluation frequency as for the contact-force measurement.

Assessment of the suitability of the simulation models used can only be obtained through comparison of the test running measurements with the simulation results.

6.2 - Provisions relating to measurement of contact forces

6.2.1 - Measuring point

The contact force should be measured as near as possible to the point of contact between contact wire and contact strip, or at least at the suspensions of the contact strip. When recording contact-force values the exact point at which each measurement was taken must be specified.

6.2.2 - Analysis steps

A sampling frequency of ≥100 Hz and an evaluation frequency of ≥15 Hz must be used when measuring contact forces.

6.3 - Provisions relating to arc measurement

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

- running speed of test train,

- aggregate arc duration in relation to current-collection time in traction mode for arc durations of 0.5 ms (minimum) and a minimum collected-current value representing 30% of the nominal current of the tractive unit.
  Arc duration can, however, be affected by weather conditions.

Appendix A - Relationships between the various design 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 contact-wire uplift caused by the increase in the contact force of the pantograph at incremental speeds, compliance should be low.

To achieve this:

- the contact-wire and messenger-wire tensile stresses should be maintained as high as possible,

- the span lengths selected should be as short as is economically feasible.

A.1.2 - Contact-wire variability

In order to improve OHL/pantograph interaction the contact wire should exhibit uniform compliance (i.e. low variability):

- within each individual span,

- between successive spans.

The level of variability can be improved, for instance, by:

- installing a stitch wire suspension,

- selecting a sag value adapted to the tensile load,

- increasing the tensile load of the contact wire,

- adopting shorter span lengths,

- setting similar span lengths (variations lower than 15%).

A.2 - Dynamic criteria

A.2.1 - Wave propagation speed - Doppler effect

To ensure optimum dynamic behaviour, the wave propagation speed of the disturbance impulse generated by the pantograph in the OHL system should be higher than the train speed.

A higher wave-propagation speed can be achieved by:

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

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

The Doppler effect indicates the relationship between wave propagation speed and 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 effect of disturbance impulses on the pantograph, the reflection factor should be low. The reflection factor can be reduced by increasing:

- contact-wire tensioning,

- the mass per contact-wire unit length,

and/or by reducing:

- messenger-wire tensioning,

- the mass per messenger-wire unit length.

The amplification factor is the ratio of the reflection factor to the Doppler effect and indicates the effect of the reflected disturbance impulses 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 decisive criterion is therefore the increase of 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 compliance,

- reduces the degree of compliance 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 through compliance reduction,
- a deterioration through increased reflection factor.

Bibliography

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"Leaflet 600 - Electric traction with aerial contact line",

"Leaflet 605 - Protection from corrosion - Measures to be taken on direct current catenaries to reduce the risks on adjacent piping and cable systems",

"Leaflet 606-1 - Consequences of the application of the kinematic gauges defined by UIC leaflets in the 505 series on the design of the contact lines",

"Leaflet 608 - Conditions to be complied with by the pantographs of tractive units used on international services",

"Leaflet 794-1 - Pantograph/OHL interaction on direct-current railway lines",

"Leaflet 505-1 - Railway transport stock - Rolling stock construction gauge",

"Leaflet 791 - Quality assurance of overhead line equipment",

European Standards on overhead lines and power supply

"EN 50119 - Overhead contact systems",

"EN 50149 - Copper and copper-alloy contact wires",

"EN 50163 - Voltage systems on railway power-supply networks",

List of abbreviations

TSI	Technical Specifications of Interoperability
OHL	Overhead line
FEM	Finite element message