



BSI Standards Publication

**Railway applications — Current collection
systems — Technical criteria for the
interaction between pantograph and overhead
contact lines on electrified roads**

National foreword

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**Railway applications - Current collection systems - Technical
criteria for the interaction between pantograph and overhead
contact lines on electrified roads**

Applications ferroviaires - Systèmes de captage de courant
- Critères techniques d'interaction entre le pantographe et la
ligne aérienne de contact sur routes électrifiées

Bahnanwendungen - Stromabnahmesysteme - Technische
Kriterien für das Zusammenwirken zwischen
Dachstromabnehmer und Oberleitungen auf elektrifizierten
Straßen

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Contents	Page
European foreword.....	6
Introduction.....	7
1 Scope.....	8
2 Normative references.....	8
3 Terms, definitions, and abbreviations.....	9
3.1 Terms and definitions.....	9
3.2 Abbreviations.....	11
4 System architecture.....	14
4.1 Pantograph environment on ERS vehicles for OCLS.....	14
4.2 Pantograph.....	15
4.3 Coordinate reference system.....	21
5 Safety concept.....	21
5.1 General.....	21
5.2 System safety requirements for ERS vehicles.....	22
6 Pantograph characteristics and requirements.....	24
6.1 General.....	24
6.2 Interface to infrastructure (Mechanical and electrical properties of the OCL infrastructure).....	24
6.3 Control interface of pantograph.....	33
6.4 Requirements for pantograph supply.....	35
6.5 Requirements for mounting and mechanical connection to the vehicle interface in case of a crash.....	35
6.6 Environmental conditions.....	36
6.7 Conditions arising from the application on a road.....	36
6.8 EMC and ESD requirements.....	37
6.9 Maintenance requirements.....	37
6.10 Basic pantograph requirements.....	37
7 Testing and simulation.....	38
7.1 General.....	38
7.2 Test definitions.....	41
7.3 Verification measures.....	56
Annex A (informative) Requirements for VIC and ERS vehicles with pantograph.....	57
A.1 General.....	57
A.2 Safety concept aspects for ERS vehicles with pantographs.....	57
A.3 Traction voltage supply situations.....	57
A.4 Functions of VIC.....	58
A.5 Recommended safety requirements and tests.....	58
A.6 SR13 Disconnection in cleared state.....	59
Annex B (informative) Overhead contact line infrastructure properties.....	60
B.1 Scope.....	60

B.2	Road characteristics	60
B.3	Capacity and service life of the OCL system	61
B.4	General geometric definitions	62
B.5	OCLS Properties.....	62
B.6	Contact forces	70
B.7	ERS clearance requirements	70
B.8	Electrical properties of the OCL	79
Annex C (informative) Responsibilities of the infrastructure operators of ERS featuring OCLS.....		80
C.1	General	80
C.2	Organisational premises	80
C.3	Operational monitoring.....	80
C.4	Recommendations for OCLS operator processes.....	82
Annex D (informative) CAN bus communication		85
Annex E (informative) Overview electric roads system and their environment		88
Bibliography		90

Tables

Table 1 — Pantograph interface	15
Table 2 — Pantograph components and ERS vehicle heights	17
Table 3 — Pantograph states and safety recommendations	18
Table 4 — Safety requirements overview	22
Table 5 — Pantograph components and ERS vehicle heights	28
Table 6 — Pantograph clearance requirements	30
Table 7 — Traction power supply voltage limits	32
Table 8 — Traction power supply current limits	32
Table 9 — Simulation levels for crash profile (taken from N3 in UN ECE R100)	36
Table 10 — catalogue of tests	39
Table 11 — Definition of pantograph dimensions	41
Table 12 — Collector head excitation.....	51
Table A.1 — Recommended safety requirements and tests	59
Table B.1 — Standard contact wire specifications	62

Table B.2 — National example for minimum contact wire height and vertical space for contact wire	63
Table B.3 — Contact wire vertical position parameters, all values measured perpendicular to the idealized top of the road surface (R)	65
Table B.4 — Contact wire height variables	65
Table B.5 — Contact wire uplift parameters	66
Table B.6 — contact wire differential heights parameters and maximum permissible values	67
Table B.7 — maximum change of contact wire height, measured for each contact wire	67
Table B.8 — Contact wire horizontal position parameters	67
Table B.9 — Defined points along the OCL (side view)	69
Table B.10 — Classification of clearance gauges for standard situations	72
Table B.11 — Composition of category A structure gauge clearance	73
Table B.12 — Composition of category B structure gauge clearance	74
Table B.13 — Composition of category C structure gauge clearances	76
Table B.14 — Composition of category D structure gauge clearances	77
Table B.15 — Structure gauge - width of clearances	78
Table B.16 — Electrical clearance values (static/dynamic)	79
Table D.1 — ENA_PAN_SYS CAN frame description	85
Table D.2 — ENA_PAN_SYS CAN signals description	85
Table D.3 — PAN_ENA_SYS CAN frame description	86
Table D.4 — PAN_ENA_SYS CAN signals description	86
Table E.1 — Technical domains for ERS safety concept	89
Figures	
Figure 1 — Pantograph, OCLS and vehicle schematic showing interfaces between sub-systems, see Table 1 for interface descriptions	14
Figure 2 — Pantograph terminology and height definitions	16
Figure 3 — States for pantograph operation	17
Figure 4 — Example for the arrangement of electrical layers of ERS vehicles	20
Figure 5 — Coordinate system according to ISO 8855	21

Figure 6 — Main dimensions of collector heads.....	25
Figure 7 — Angle of attack α at contact wire, measured towards idealized road surface	26
Figure 8 — Pantograph terminology and height definitions.....	27
Figure 9 — Exemplary ERS zones, lanes, and clearance gauge for ERS vehicles	29
Figure 10 — Clearance gauge detail with both contact wires in perspective of driving direction	30
Figure 11 — Traction current as a function of the vehicle's velocity	33
Figure 12 — height deviation between left and right contact strips	38
Figure 13 — Pantograph dimensions	41
Figure 14 — Static heights of the pantograph that are to be tested, identifiers according to Figure 1, please note that the base reference is subject to the variable vehicle chassis.....	43
Figure 15 — Test visualization for lowering tests.....	54
Figure 16 — Simulation of damaged ADD	55
Figure B.1 — Working range of the contact wire in standard installations	63
Figure B.2 — Contact wire vertical position parameters and relation to pantograph heights.....	64
Figure B.3 — Contact wire uplift and parameters (Left, Right).....	66
Figure B.4 — maximum permissible contact wire differential heights	66
Figure B.5 — Overlap span (plan view, exemplary design for anchoring, representation without electrical connections)	68
Figure B.6 — Defined points along the OCLS (side view, idealized)	68
Figure B.7 — Minimum angle of attack α in the limit case with maximum inclination of the pantograph $\varphi_{PAN, max}$ and maximum pantograph horn angle $\beta_{H, max}$	71
Figure B.8 — Category A structure gauge schematic	72
Figure B.9 — Category B structure gauge schematic	74
Figure B.10 — Category C structure gauge schematic	75
Figure B.11 — Category D structure gauge schematic	76
Figure B.12 — Structure gauge – width of clearance	78
Figure B.13 — Structural gauge – lateral clearances, L1 as defined in Figure 8.....	78
Figure E.1 — ERS and their environment	88

European foreword

This document (CLC/TS 50712:2024) has been prepared by CLC/TC 9X “Electrical and electronic applications for railways”.

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Introduction

This document will help to establish a common technical base for overhead contact line type electric road systems (ERS) being built in public field trials in different European states. It enables vehicles and likewise infrastructure providers to develop and produce components and systems for interoperable use.

The main aspects being considered are:

- normative references to vehicle and infrastructure standards;
- definition of the pantograph to contact line system interface;
- requirements for safety concepts and provisions in contact line operation;
- requirements for test, operation, and maintenance of pantographs on commercial vehicles;
- distinction of use cases for externally supplied commercial electric road vehicles (informative).

To reduce carbon dioxide and other emissions caused by road traffic, ERS are being widely discussed and tested in public field trials on different European roads and highways. In this document, the pantograph of an overhead contact line type ERS is described. This ERS uses an overhead contact line system, a power supply and a pantograph to draw electrical energy from a static supply system suspended above a highway to power the propulsion and the battery charging of an electric road vehicle while driving.

As road traffic is highly internationalised and standardized, ERS solutions for commercial vehicles need to be standardized to allow interoperable and international vehicle operation.

This document's scope is limited to pantograph type current collectors for ERS. The electrical power supply of a commercial road vehicle within ERS is achieved through the collection of current from the overhead contact wires with a suitable pantograph system installed on the vehicle.

As the roadway cannot be used as an electrical return conductor, a 2-pole (positive and negative) contact line system and pantograph are employed. The overhead contact line (OCL) system and the connected vehicles form an electric circuit with the feeder system. This allows for electrical power flow between them. This is considered in terms of electrical safety concepts and protective provisions.

The pantograph and the overhead contact line system (OCLS) are separate mechanically oscillating sub-systems. The design of the sliding contact between them ensures continuous contact and allows for minimum wear of both contact partners conductor and pantograph carbon strips.

1 Scope

This document defines the general characteristics applicable to pantographs for ERS, to enable dynamic current collection of road vehicles from an overhead contact line system. It furthermore defines the electrical and mechanical interface between a pantograph and the infrastructure and between a pantograph and the vehicle.

The document also specifies tests for the pantograph. It includes recommendations for a common safety concept that is related to the electric vehicle and power supply infrastructure and gives recommendations for the maintenance of the pantograph.

This document is applicable to:

- Two-pole pantographs on commercial vehicles during operation on electrified public roads and highways.

This document is not applicable to:

- trolley busses and their electric equipment;
- vehicles in private applications on roads in restricted areas such as truck trolley applications in mines;
- commercial freight vehicles or electric busses with static-only charging systems at e.g. loading/unloading facilities or bus stops.

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.

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

EN 50124-1:2017, *Railway applications — Insulation coordination — Part 1: Basic requirements — Clearances and creepage distances for all electrical and electronic equipment*

EN 50124-2:2017, *Railway applications — Insulation coordination — Part 2: Overvoltages and related protection*

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

EN 60068-2-64:2008, *Environmental testing — Part 2-64: Tests — Test Fh: Vibration, broadband random and guidance (IEC 60068-2-64:2008)*

EN 61000-4-2, *Electromagnetic compatibility — Part 4-2: Testing and measurement techniques — Electrostatic discharge immunity test (IEC 61000-4-2)*

ISO 4892-2:2013, *Plastics — Methods of exposure to laboratory light sources — Part 2: Xenon-arc lamps*

ISO 6469-3:2021, *Electrically propelled road vehicles — Safety specifications — Part 3: Electrical safety*

EN ISO 9227, *Corrosion tests in artificial atmospheres — Salt spray tests (ISO 9227:2022)*

ISO 10605, *Road vehicles — Test methods for electrical disturbances from electrostatic discharge*

ISO 11452 (all parts), *Road vehicles — Component test methods for electrical disturbances from narrowband radiated electromagnetic energy*

ISO 16750-1, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment; Part 1: General*

ISO 16750-2, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment; Part 2: Electrical loads*

ISO 16750-3, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment; Part 3: Mechanical loads*

ISO 16750-4, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment; Part 4: Climatic loads*

ISO 16750-5, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 5: Chemical loads*

ISO 26262-5:2018, *Road vehicles — Functional safety — Part 5: Product development at the hardware level*

3 Terms, definitions, and abbreviations

3.1 Terms and definitions

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

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

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

3.1.1

electric road system

ERS

system that enables power transfer to electric road system vehicles whilst they are driving and during standstill

Note 1 to entry: By integrating power transfer technology into existing road infrastructure, the road itself will be accessible to both vehicles that use power transmission and other vehicles.

3.1.2

ERS vehicle

vehicle which is equipped to utilize the power supply of an ERS

Note 1 to entry: The vehicle is compatible with an OCLS type of ERS and contains pantograph, Enable device and VIC (Vehicle Infeed Circuit, Annex A).

3.1.3

ERS route

stretch or road section, which is equipped with an ERS infrastructure, in this case with an OCLS

3.1.4

pantograph

apparatus for collecting current from one or more contact wires, formed of a hinged device designed to allow vertical movement of the pantograph head

Note 1 to entry: Vehicle mounted device to establish an electrical connection with the overhead contact lines. Can be lifted upwards to OCL to transfer current from OCL to vehicle and vice versa.

[SOURCE: IEC 60050-811:2017, 811-32-02, modified – The note 1 to entry has been added]

3.1.5

pantograph collector head

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

Note 1 to entry: An ERS pantograph is usually equipped with two collector heads; one for each polarity. Other variants can exist.

3.1.6

enable device

device controlling the use of a pantograph (rising and lowering) depending on various inputs, such as drivers command, vehicle states and data gathered by sensors connected to the enable device

Note 1 to entry: Depending on the enable device's integration into the OEM vehicle, it can be used either as responsible for the functional safety decision whether it is safe to connect and stay connected or not, or as an assistance system to reduce error risks from driver operation.

3.1.7

vehicle infeed circuit

VIC

necessary components to utilize the power transferred from the OCL with the pantograph that are not part of the vehicles usual drive train

Note 1 to entry: See Annex A.

3.1.8

original equipment manufacturer

OEM

manufacturer of the ERS vehicle

Note 1 to entry: Vehicle with or without VIC.

3.1.9

integrator

<of pantograph and/or VIC> entity which integrates pantograph and/or VIC in vehicle

Note 1 to entry: Could be an OEM or a third party.

3.1.10

static contact force

force of one collector head towards its corresponding contact line measured while standstill of the vehicle

3.1.11

dynamic contact force

contact force of one collector head towards contact line during operation measured while vehicle is driving

3.1.12

contact cycle

cycle starting with a pantograph rising from cleared state until it is connected to the OCL in nominal height and ends once the pantograph has returned to its lowest position

Note 1 to entry: Unsuccessful attempts are also covered.

3.1.13

automatic dropping device

ADD

device that initiates immediate lowering of the pantograph in event of contact strip failure

Note 1 to entry: See also EN 50206-1:2010, 4.8.

3.1.14

collector head

part of the pantograph, at least comprised of one contact strip and the respective suspension system for connection to one contact wire

3.1.15

pantograph pole

electrical pole of the pantograph (e.g., positive, or negative)

Note 1 to entry: The pantograph and OCL of the ERS feature at least two electric poles with different electrical potentials.

3.1.16

controller area network bus

CAN bus

communication bus standard (message-based protocol) used for communication between vehicle and pantograph

Note 1 to entry: Definition according to SAE J1939:2018 – ISO 11898.

3.1.17

cleared state

position of the pantograph when fully retracted and ready for operation

3.2 Abbreviations

Abbreviation	Explanation
A	Pantograph Clearance value: Height of the mechanical clearance profile above the idealized road surface
ADD	Automatic Dropping Device
ASIL	Automotive safety integrity level
CAN	Controller Area Network
CSM	Common safety methods
CTI	Comparative Tracking Index
CW	Contact wire, sometime CW1, CW2 as denomination of each wire
CW _{UL}	Contact wire uplift due to pantograph contact force
CW _{UL, ac}	Maximum permissible contact wire uplift in case of an accident
CW _{UL, op}	Maximum permissible contact wire uplift during regular operation
DC	Direct Current
EMC	Electromagnetic compatibility
ERS	Electric road system
ESD	Electrostatic discharge
FIT	Failure in time
FMEA	Failure Mode and Effects Analysis
GND	Ground (0 V)
G _{A,v}	OCL Structure gauge: Category A vertical clearance

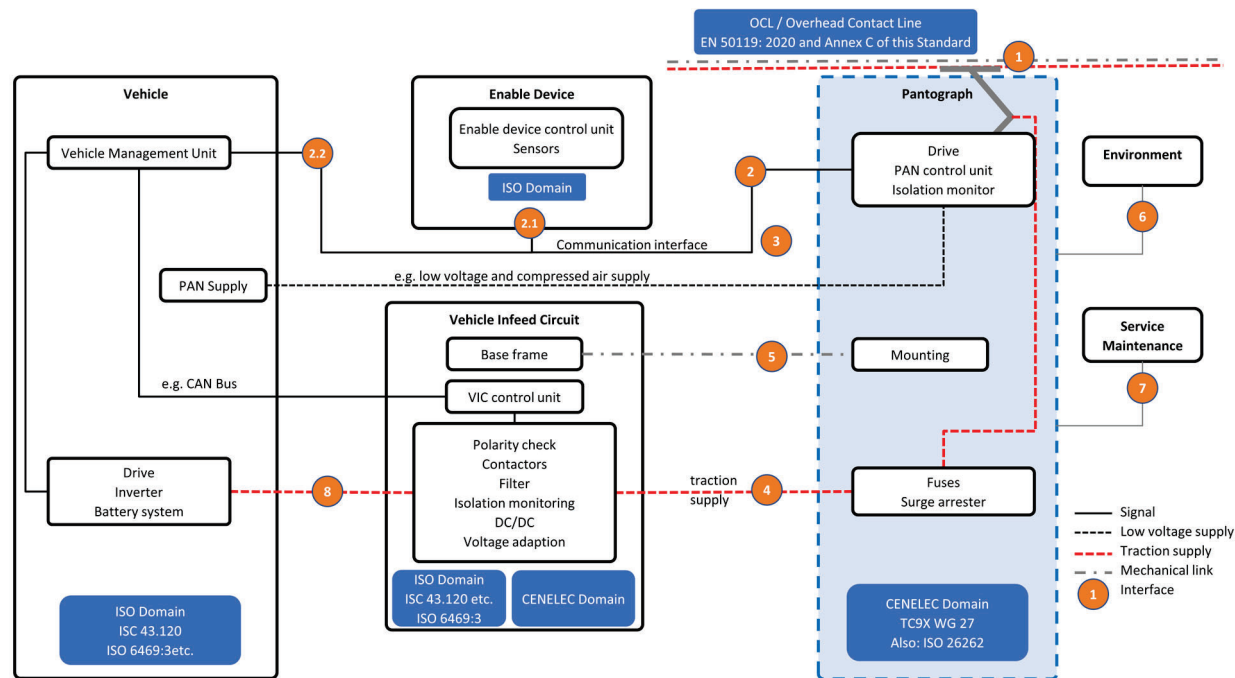
Abbreviation	Explanation
$G_{B,v}$	OCL Structure gauge: Category B vertical clearance
$G_{C,v}$	OCL Structure gauge: Category C vertical clearance
$G_{D,v}$	OCL Structure gauge: Category D vertical clearance
HARA	Hazard Analysis and Risk Assessment
$H_{\max, \text{veh}}$	Maximum permitted vehicle height
$H_{\text{clearance}}$	Minimum clearance below contact wire
HCW_L	Contact wire height (left)
$HCW_{\max}$	Maximum contact wire height (incl. contact wire uplift CW_{UL})
$HCW_{\max, \text{op}}$	Maximum operation height of contact wire
$HCW_{\max, \text{stat}}$	Maximum contact wire height (static, in resting position)
$HCW_{\min}$	Minimum contact wire height (in resting position, non-operational)
HCW_n	Nominal height of contact wire
HCW_{op}	Contact wire height in operation
HCW_{range}	Lifting / lowering range of contact wire
HCW_{safe}	Safety clearance height/safety height of vehicle and pantograph
HCW_{stat}	Static (not connected) contact wire height
HCW_R	Contact wire height (right)
IR	ERS infrastructure required
$I_{\max, \text{per}}$	Maximum continuous current above 5 km/h
$I_{\max, 05}$	Permanent current for vehicle velocity 0 km/h to 5 km/h
KP/NTV	Known type of pantograph on new type of vehicle
$LC_{\max}$	Maximum conductive length of a contact strip
L1	Pantograph Clearance value: Radius of clearance area for pantograph at the sides
L2	Pantograph Clearance value: Angle of the clearance profile to the side of the contact wires in any height.
L3	Pantograph Clearance value: Width of the clearance profile to the side of the contact wires in any height
L4	Pantograph Clearance value: Height of the mechanical clearance profile above the contact wires in any height
L5	Pantograph Clearance value: Height of the electrical clearance profile above the mechanical clearance profile
L7	Pantograph Clearance value: Lifted height of the contact wires when in contact to pantograph above the idealized road surface
L8	Pantograph-OCL Clearance value: Distance between the edges of both contact wires CW
NP	New pantograph

Abbreviation	Explanation
NP/NV	New pantograph on new vehicle
NTP	New type of pantograph
NTP/ATV	New type of pantograph on any type of vehicle
OCL	Overhead contact line
OCLS	Overhead contact line system, lines, poles, and all other equipment needed to install an overhead contact line
OEM	Original equipment manufacturer
PAN	Pantograph
R	Idealized road surface
RT	Routine Test
SR	Safety Requirement
TS	Technical Specification
TT	Type Test
t_{ADD}	Process time of Automatic Dropping Device (ADD)
U_{dis}	Lowest voltage treshhold for disconnect
$U_{max,1}$	Highest permanent voltage
$U_{max,2}$	Highest non-permanent voltage
$U_{max,3}$	Long-term overvoltage
$U_{min,1}$	Lowest non-permanent voltage
$U_{min,2}$	Lowest permanent voltage
U_n	Nominal voltage
VIC	Vehicle Infeed Circuit
$v_{des,OCL}$	maximum design speed (incl. dynamic reserves) Based on permissible maximum vehicle speed v_{max}
v_{max}	Maximum permitted vehicle speed
α	pantograph-OCL clearance: Angle of attack to contact wire
ΔHCW_{max}	Maximum vertical deviation between the two contact lines (in any state operation / resting)

4 System architecture

4.1 Pantograph environment on ERS vehicles for OCLS

Vehicles intended for use with a pantograph in an OCLS are divided into general subsystems as defined in Figure 1. The figure shows the main interfaces, and it also defines the related standards for the subsystems.



- Key**
- 1 OCL infrastructure
 - 2 pantograph communication
 - 2.1 enable device control
 - 2.2 vehicle control
 - 3 pantograph supply
 - 4 VIC
 - 5 mounting
 - 6 environment
 - 7 maintenance

Figure 1 — Pantograph, OCLS and vehicle schematic showing interfaces between sub-systems, see Table 1 for interface descriptions

Figure 1 shows functional subsystems of vehicles suitable for usage in OCLS. The first subsystem is the base electric vehicle. The VIC contains all equipment necessary to transform and handle the energy supply of the OCLS for the vehicles drive system. Next to the pantograph, that transfers the current from the OCL to the vehicle, an enable device is defined as a separate subsystem. The purpose of the enable device is to decide whether it is safe to connect the pantograph to the OCL, stay connected to the OCL or if the pantograph shall disconnect from the OCL. However, the enable device may be integrated into one of the other subsystems. The designated interfaces 1 - 7 will be used as a structure to describe interface properties in Clause 6. The defined interfaces of the pantograph are labelled as defined in Table 1.

Table 1 — Pantograph interface

Number of Interface	Interface	Description
1	OCL infrastructure	Electrical and mechanical interface, see Annex B of this specification and 6.2 for a detailed description.
2	Pantograph communication	Pantograph communication interface to other systems
2.1	Enable device control	Control interface, see 6.3
2.2	Vehicle control	Control interface, see 6.3.
3	Pantograph supply	Low voltage and compressed air supply from vehicle, see 6.4
4	VIC	Traction supply from OCL, see Annex A
5	Mounting	Mechanical interface including loads, 6.5
6	Environment	Environmental conditions for design and operation, see 6.6
7	Maintenance	Interface for maintenance and service operation, proprietary interface, not further defined within this document

The VIC may be integrated into the vehicle or be contained within the base frame below the pantograph. The individual components may also be distributed over the vehicle and the base frame.

The pantograph components are explained in detail within the next subclauses. All components of the three other subsystems are just exemplary and may be part of other specifications.

4.2 Pantograph

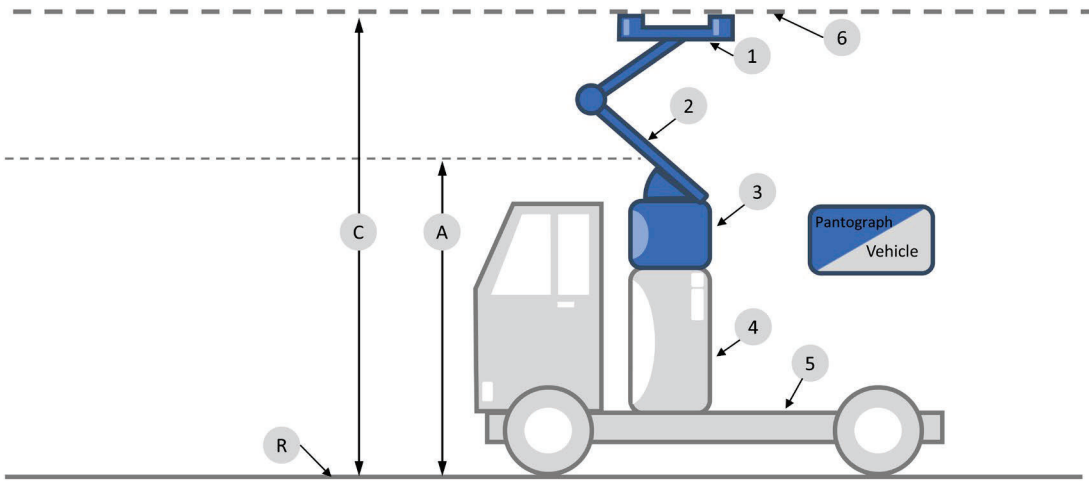
4.2.1 General

The main function of the pantograph is to transfer a current from the OCL to the vehicle. The pantograph shall also be able to connect and disconnect to the OCL. The third function is the insulation system of the pantograph that prevents risks of electrical shocks. These functions are distributed over the mechanical subsystems.

A pantograph designed for the usage in ERS environments consists of three mechanical subsystems. The collector head carries the contact strips, the arms move the collector head up and down and the main frame usually contains the drive system, the control system and is the mounting interface to the vehicle.

4.2.2 Pantograph design and heights

Figure 2 shows a sketch of a pantograph as an example and does not exclude other types of pantographs like diamond type, for example. The figure defines the main components of an ERS pantograph and its basic operating dimensions. This document mainly covers the blue parts of the drawing (No. 1 to 3).



Key

- A maximum pantograph height in cleared state
- C nominal operating height of pantograph
- R clean idealized road surface (without snow/ice)
- 1 collector heads
- 2 arms
- 3 main frame
- 4 base frame
- 5 vehicle frame
- 6 contact wire

Figure 2 — Pantograph terminology and height definitions

As shown in Figure 2, various heights and ranges of movement for the pantograph mounted on an ERS vehicle are defined perpendicular (at a right-angle, z-direction) in reference to the idealized road surface. The pantographs position when fully retracted and ready for operation is defined as the cleared state. More details can be found in Table 2.

Table 2 — Pantograph components and ERS vehicle heights

No.	Title	Description
A	Maximum pantograph height in cleared state	Height of vehicle with pantograph if not in use, above idealized road surface (R).
C	nominal operating height of pantograph	Typical operating height of the pantograph mounted on ERS vehicle; height might differ between countries
R	Clean idealized road surface (without snow/ice)	Reference for all above defined heights
1	Collector heads	Part of pantograph
2	Arms	Part of pantograph
3	Main frame	Part of pantograph
4	Base frame	Mounted on vehicle frame, carries pantograph, could be part of the vehicle, the pantograph or be manufactured by a third party.
5	Vehicle frame	Part of the vehicle chassis
6	Contact wire	Part of the OCLs which is in contact with the pantograph's collector heads

4.2.3 Physical pantograph states

The pantograph shall be either on or off. Due to errors or unforeseen events, it shall be able to change its state from any state to off. During normal operation (no errors), the pantograph shall be in a cleared state (resting in lowest position) when switched on (see also Figure 3).

To change to a connected state, the pantograph shall be in rising state for a short time (see 6.10.2). From connected state the pantograph shall change to lowering state first and then return to cleared state. If rising state is aborted, the pantograph shall change from rising to lowering state. Due to safety concerns the pantograph shall never change state from lowering to rising without entering cleared state first.

To enable a variety of service and maintenance works the pantograph shall also allow the change from cleared to maintenance state, see Figure 4.

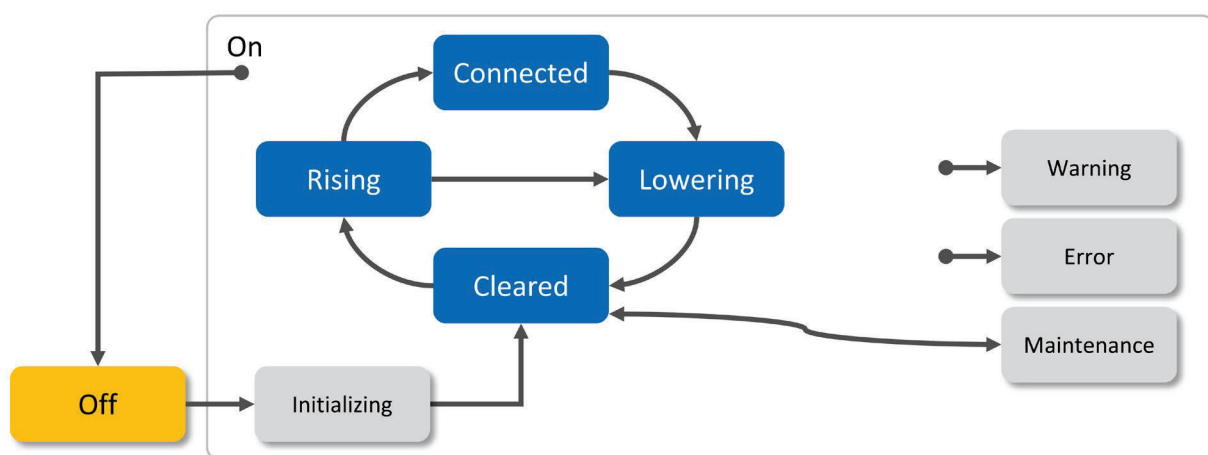


Figure 3 — States for pantograph operation

Table 3 contains further definitions on pantograph states which shall be transmitted via the communication interface (No. 2 in Figure 1) towards vehicle and enable device. See Clause 5 for safety relevant details of the description within the table.

A lateral movement of the pantograph collector heads is possible, e.g. to adjust its relative position towards the contact wire. The definition of this function is not part of this document.

Table 3 — Pantograph states and safety recommendations

Pantograph state transmitted via communication interface	Description
0: Initializing	The current state and position are unknown. The pantograph shall be lowered or be raised, e.g. during service in this state. After power is switched on the pantograph shall be in this state for e.g. self-tests for normal operation.
1: Cleared (mechanic state)	The pantograph shall be in its lowest position (cleared position) and without faults. All actuators shall be deactivated. Only in this state a rising request (ENABLE) shall lead to rising state in normal operation.
2: Rising (mechanic state)	The pantograph shall be rising but has no or no safe contact with the OCL in this state. The pantograph shall be without faults. The duration of this state (6.10.2) shall be limited. If the pantograph does not detect an OCL within 7,0 s, it shall stop rising and shall lower.
3: Lowering (mechanic state)	The pantograph shall be lowering in this state but shall not be in cleared state. It shall be without faults. The duration of this state shall be limited. If the pantograph does not detect the cleared state within 3,5 s, it shall change into state "Cleared Position Error".
4: Connected (mechanic state)	The pantograph shall be raised in this state and shall have safe contact with the OCL. It shall be without faults.
5: Maintenance	The pantograph shall be in maintenance state if maintenance state is activated e.g. by a maintenance key switch or another device. Safety measures within pantograph could be deactivated and information about faults could not be provided. It shall not be allowed to drive within this state. It shall be handled in the same way, like state "Cleared Position Error".
6: Warning	The pantograph shall be in this state if a fault occurred within the pantograph. The pantograph shall be in cleared position or lower to the cleared position. It shall be possible to drive within this state but shall not be possible to trigger the rising of the pantograph. If it was a temporary fault, the pantograph shall go to state "Cleared" after a few seconds. Otherwise, it shall stay in this state until power off. The pantograph shall be inspected in a workshop, if it is permanently in state "Warning" or if this state occurs very often.
7: Cleared Position Error	The pantograph shall be in this state if it should be in cleared position, but it is not. This state shall be activated if the pantograph starts to lower (state "Lowering" or state "Warning") and doesn't reach the cleared position within 3,5 s or if the pantograph leaves the cleared position without receiving a rising request. Driving in this state is very dangerous. The pantograph can collide with the OCL infrastructure or with bridges, signs etc. The driver shall stop immediately and carefully with respect to the other traffic and check visually the position of the pantograph.
> = 8 Undefined	These states are reserved for future applications.

4.2.4 Pantograph current transfer system

The current transfer system of the pantograph shall contain at least:

- two collector heads with each including at least one contact strip;
- cables to transfer the current to the vehicle;
- fuses at the end of the cables;
- a surge arrester (to be placed between + and - poles of OCLS which shall not be connected to vehicle chassis in any state/condition, see Figure 1) to protect against over voltage transients, e.g. due to a lightning strike.

Use of options other than cables to conduct the current between the contact strips and the vehicle is possible.

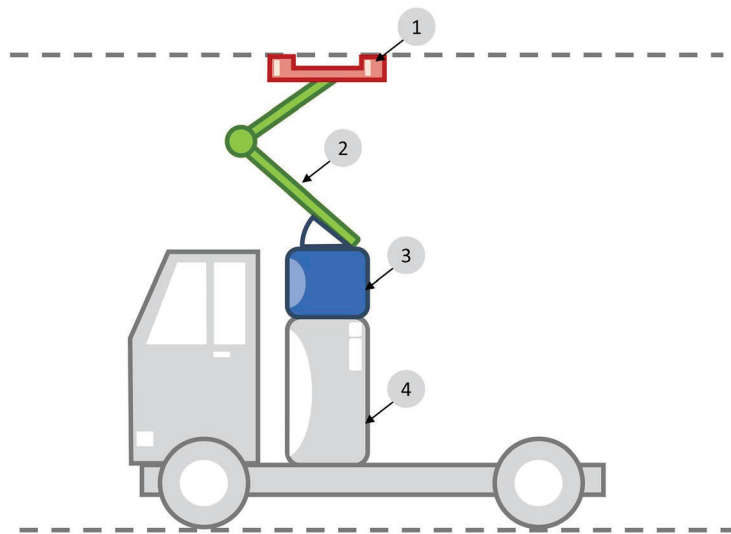
4.2.5 Pantograph drive and control system

A drive system operates a mechanical assembly that shall move the collector head up and down. The pantograph's control system shall control this movement. Other functions, such as the system safety, could also be included into the control system of the pantograph.

The enable device connected to the pantograph shall trigger the states connecting and disconnecting as well as maintaining the connection to the OCL but is not necessarily part of the pantograph. Once the enable device commands the pantograph to disconnect, the pantograph shall disconnect promptly. If the enable device requests the pantograph to connect, the pantograph may connect to the OCL, if there are no pantograph internal reasons against connecting.

4.2.6 Pantograph insulation system

Figure 4 shows an example for the arrangement of different electrical (insulation) layers of the pantograph. The pantograph shall provide at least three different electrical layers to ensure safe operation. The OCL voltage layer can, on a raised pantograph, be in conductive, electrical contact with the OCL. The vehicle chassis layer is connected to vehicle ground and the intermediate layer is located between these two. The insulation resistance between the layers shall be monitored (continuously or periodically) by the pantographs control system and the electrical connection to the OCL shall be interrupted by it if any of the insulations between the layers is violated (not in order). Components marked as layer selectable can be completely or in parts connected to OCL voltage layer or intermediate layer.

**Key**

- 1 OCL voltage layer
- 2 layer selectable
- 3 intermediate Layer
- 4 vehicle chassis layer

Figure 4 — Example for the arrangement of electrical layers of ERS vehicles

The general insulation coordination for the pantograph, regarding air clearance and creepage distance is to be conducted in accordance with EN 50124-1. Depending on the expected area of operation, insulators can be exposed to salt spray from road de-icing. This shall be taken into account for the dimensioning of the creepage distances.

- For air clearance calculation the overvoltage category and the pollution degree shall be taken in consideration.
 - Overvoltage category:
 - Components connected direct to OCL: Overvoltage category: OV4
 - Components connected direct to OCL, but lower requirements are valid because of additional protection, e.g. by installation of surge protection devices: Overvoltage category: OV3
 - Pollution degree:
 - Components outside of compartments: Pollution degree: PD4
 - Components inside of compartments: Pollution degree: PD2
- Creepage distance requirements depend on the pollution degree and the Comparative Tracking Index (CTI).
 - Comparative Tracking Index (CTI):
 - Use CTI according to manufacturer's specification. Material with unknown CTI is classified in IIIb group.

- To ensure sufficient insulation resistance, continuous artificial pollution (with e.g. salt mist) of the isolators surface shall be prevented by suitable materials or coverings.

4.3 Coordinate reference system

The coordinate system is based on the definitions of ISO 8855 as shown in Figure 5.

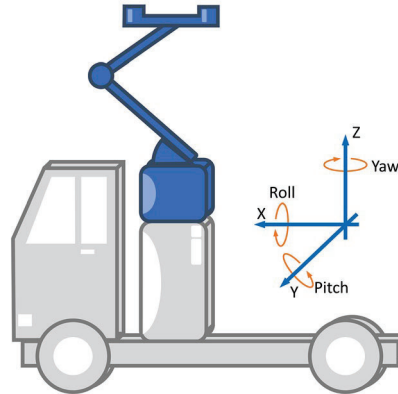


Figure 5 — Coordinate system according to ISO 8855

5 Safety concept

5.1 General

Electric vehicles equipped with pantographs that adhere to this specification may participate in the defined ERS. If the pantographs are in cleared position, they are to be considered as integral part of the electric vehicle system. Once connected to the OCLS the pantographs form an electric traction system with several subsystems as indicated in Figure 1. This “double” nature of electric road vehicles is known from trolley busses and truck-trolley systems in mines and not unique to this type of ERS.

This subclause describes how the different domains in Figure 1 can be integrated in a safety concept. As far as the vehicle and especially the pantograph are to be considered, 5.2 lists a minimum of derived safety requirements (SR).

The outlined safety concept and the derived SR listed below are to be considered as generic description and reasonable minimum. Both cannot replace a product specific safety assessment for the pantograph and the ERS vehicle according to prerequisites by local authorities, ERS operators and vehicle manufacturers.

Specifically, the pantograph safety considerations shall fulfil the following operational requirements:

- Not raise if not requested to; any internal error that would lead to an unrequested connection shall be detected and corrected before a potentially dangerous situation occurs,
- Lower if the connection to the OCL is lost before a potentially dangerous situation could occur,
- Not enter areas outside the defined areas outlined in Figure 10,
- Lower at the end of the OCL or if leaving the lane,
- Feature an ADD system for lowering in case of excess wear or damage to the contact strips,
- Lower if the contact strip surface exceeds the maximum OCL height,
- Lower if the contact wire laterally leaves the permissible contact area of the related contact strip(s),

- Be designed in a way that prohibits all parts of it from hooking into the OCL infrastructure, ERS safety concept, requirements, and safety functions,
- Immediately lower if power supply to pantograph is lost / disconnected.

Users, operators, designers, suppliers and third parties agree that ERS shall be safe to be used without posing unacceptable dangers to any user, all other traffic, operator and third parties. This includes prevention of loss or damage of the system or components as well as hazards for the environment. The risk evaluation and risk matrix calibration are handled within the domains since predictability and individual chance to prevent hazardous situations as well as the potential extents of loss or damage differ among the transport systems and technical domains.

5.2 System safety requirements for ERS vehicles

The pantograph safety requirements listed here serve as a common basis to ensure interoperability between ERS projects.

The below defined safety requirements are valid for the pantograph's scope and define the general set of safety requirements. ISO 26262 remains the leading standard for safety relevant issues, especially for FIT rates, durations, ASIL classifications, etc. those are to be aligned with requirements as defined from the vehicle system.

Table 4 describes the defined safety requirements and the hazards that shall be prevented, clarifies the responsibilities, and includes the concerned interface regarding the ERS vehicle schematic (Figure 1). Besides the pantograph requirements, the table is extended with requirements for an enable device, VIC, and vehicle. Tests related to these requirements are content of 7.2 for the pantograph and content of Annex A for all other requirements.

Table 4 — Safety requirements overview

No.	Hazard	Description	Responsibility	Interface
SR01	Collision with an obstacle, parts of pantograph can fall and injure persons. Injure persons that are close to the pantograph for service purposes.	The pantograph shall not be raised if not requested by the enable device (except in a special maintenance mode).	Pantograph	2.1
SR02	Collision with an obstacle, parts of pantograph can fall and injure persons.	The pantograph shall be lowered if requested by the enable device.	Pantograph	2.1
SR03	Collision with an obstacle, parts of pantograph can fall and injure persons.	The pantograph shall be lowered if no OCL is detected during rising or if the contact to the OCL is lost.	Pantograph	1
SR04	Collision with OCL infrastructure components, parts of pantograph can fall and injure persons.	The pantograph shall be disconnected from OCL and lowered rapidly so that it never intrudes the forbidden area above the OCL.	Pantograph	1
SR05	Collision with OCL infrastructure components, parts of pantograph can fall and injure persons.	The pantograph shall not exceed the specified maximum contact force.	Pantograph	1

No.	Hazard	Description	Responsibility	Interface
SR06	Risk of electrical shock.	The pantograph shall be lowered if the insulation of traction current path is damaged or if other critical electrical faults occur.	Pantograph	4
SR07	Collision with OCL infrastructure components, parts of pantograph can fall and injure persons.	The pantograph shall be disconnected from OCL rapidly if a carbon strip or an outer horn is damaged.	Pantograph	1
SR08	Driver could be confused by wrong warnings - resulting in sudden braking and rear end collisions.	The pantograph shall provide correct status information about potentially hazardous situations.	Pantograph	2.2
SR09	All hazards from other SR might occur.	All systems shall detect internal faults that would violate the above-mentioned safety requirements and enter a non-hazardous state before a hazardous situation occurs. ^a	All	n.a.
SR10	If the pantograph receives an ENABLE signal to connect to OCL close to the end of OCL or after the end of the OCL it shall be raised and lowered again fast enough to avoid a collision with e.g. bridges.	The pantograph shall be connected quick enough to OCL so that it can be lowered again within a reasonable time if it does not connect to an OCL.	Pantograph	1
SR11	Collision with an obstacle, parts of pantograph can fall and injure persons. Injure persons that are close to the pantograph for service purposes.	The enable device shall not permit or request rising when the pantograph is not correctly placed under OCL.	Enable Device	2.1
SR12	Collision with an obstacle, parts of pantograph can fall and injure persons.	The enable device shall request lowering when the pantograph is not correctly placed under OCL.	Enable Device	2.1
SR13	Risk of electrical shock.	The overall vehicle shall take care that there is no dangerous voltage within pantograph if the pantograph is not raised, see also EN 50122-1. This can be realized either by the pantograph or by an interface definition between pantograph and VIC/vehicle that transfers the responsibility towards VIC/vehicle.	Pantograph, VIC or Vehicle	4
SR14	High temperatures at contact point might damage OCL and may lead to deformations or disintegration, parts might fall and injure persons	The VIC shall limit the transferred current at the speed dependent specified maximum values.	VIC	4

No.	Hazard	Description	Responsibility	Interface
SR15	Electrical or mechanical damage of the vehicle could lead to risk of electrical shock or sudden loss of traction	The vehicle shall not request rising when the vehicle cannot connect to OCL in a safe way.	Vehicle	2.2
SR16	Electrical or mechanical damage of the vehicle could lead to risk of electrical shock or sudden loss of traction	The vehicle shall request lowering if the vehicle cannot stay connected to OCL in a safe way.	Vehicle	2.2
SR17	Hazards that are not covered by the overall safety concept, e.g. obstacles that are tangled within the OCL or a fire/accident close to the route.	The vehicle shall provide a function that enables the driver to manually disconnect the Pantograph.	Vehicle	2.2
^a If it is not possible to enter a non-hazardous state within a safe time, redundant systems and fault detection of each redundant system should be used.				

The above defined responsibilities for the safety requirements can be understood as a practical example. However, the integrator may define a variation of responsibilities if at least the hereby defined hazards are covered.

Correct non-hazardous state definition and the requested duration for reaching those, as well as other solution specific conditions shall be defined by the responsible vehicle system integrator.

6 Pantograph characteristics and requirements

6.1 General

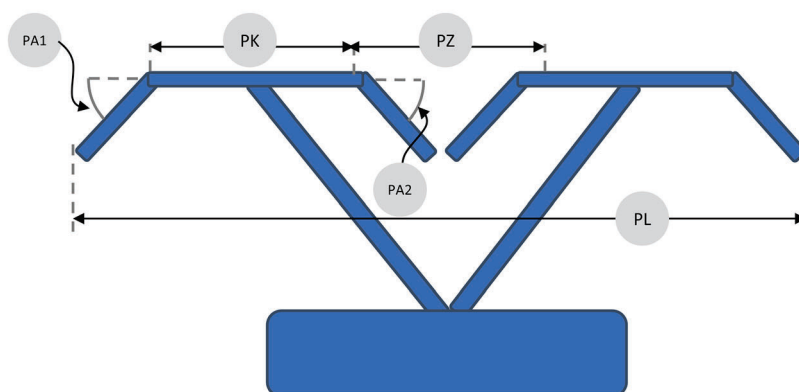
Clause 6 lists and describes the characteristics and requirements of the pantograph.

For a better understanding of the overall system additional information regarding the OCL infrastructure is included in Annex B.

6.2 Interface to infrastructure (Mechanical and electrical properties of the OCL infrastructure)

6.2.1 Dimensions of the collector head

Figure 6 shows the main dimensions that are to be considered for the design of the collector heads, as defined in 3.1.



Key

- PA1 outer horn angle, angle of outer horns
- PA2 inner horn angle, angle of inner horns
- PK conductive length, length of conductive part of collector heads in y-direction
- PL combined length of collector head assembly, overall horizontal width of the two collector heads in y-direction
- PZ gap length, length of the gap between collector heads in y-direction

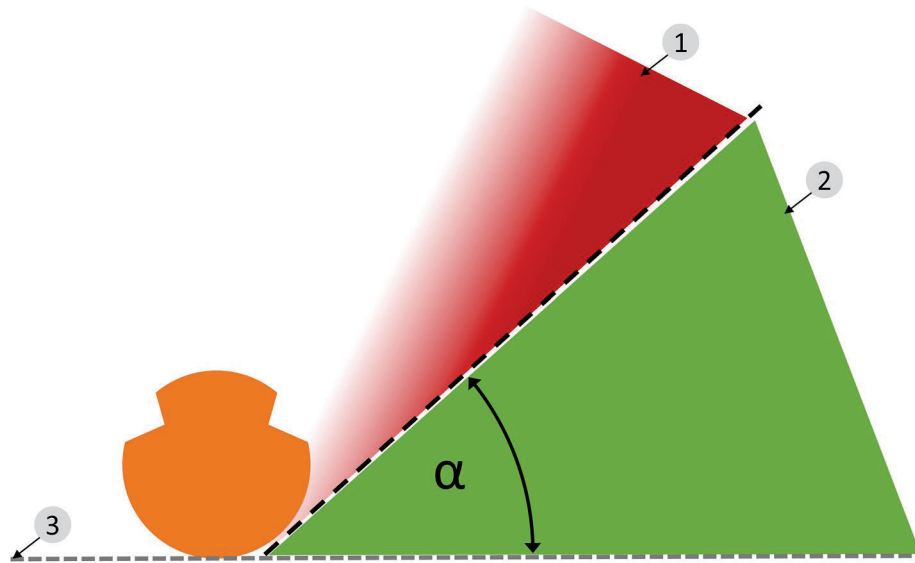
Figure 6 — Main dimensions of collector heads

The design of the panto and its control system shall meet the following requirements:

- Maximum overall length PL shall be 2,55 m.

NOTE This is mentioned in EU Directive 96/53/EC, appendix 1, subclause 1.2).

- The design of the pantograph and its function shall prevent a short-circuit of the two poles of the OCL, thus the maximum conductive length PK of the carbon strips and the gap between both collector heads PZ shall be defined considering at least the minimum contact wire distance, an insulation distance, and an angle between the vehicles driving direction and the lane to exclude a short circuit, see also B.5.1.4, Table B.8.
- The design of the pantograph and its function shall prevent entanglement of wires entering the area between the two collector heads preventing damage of the OCL or other infrastructure elements.
- The dimensions of the inner- and outer horns and their angles PA1 and PA2 shall be designed considering that:
 - The lower ends of the horns of the pantograph heads shall always be below the contact wires.
 - The horns shall stay within the angle of attack as defined in Figure 7 to avoid collisions with OCL infrastructure elements (e.g. clamps).

**Key**

- 1 prohibited area for pantograph
- 2 allowed area for pantograph
- 3 plane parallel to idealized road surface

Figure 7 — Angle of attack α at contact wire, measured towards idealized road surface

Concerning infrastructure components, the angle of attack α is measured parallel to the idealized road surface at the lower edge of the contact wire and limits the space towards the centre of the electrified lane as well as outwards towards the edge of the electrified lane. The design of the pantograph and its collector head mounted on a vehicle shall ensure that the pantograph does not enter the area above α during operation. The angle of pantograph design and vehicle movement shall be: $\alpha < 49^\circ$, see also Annex B.

6.2.2 Height definitions

Figure 8 defines the main components of an ERS pantograph and its basic operating dimensions.

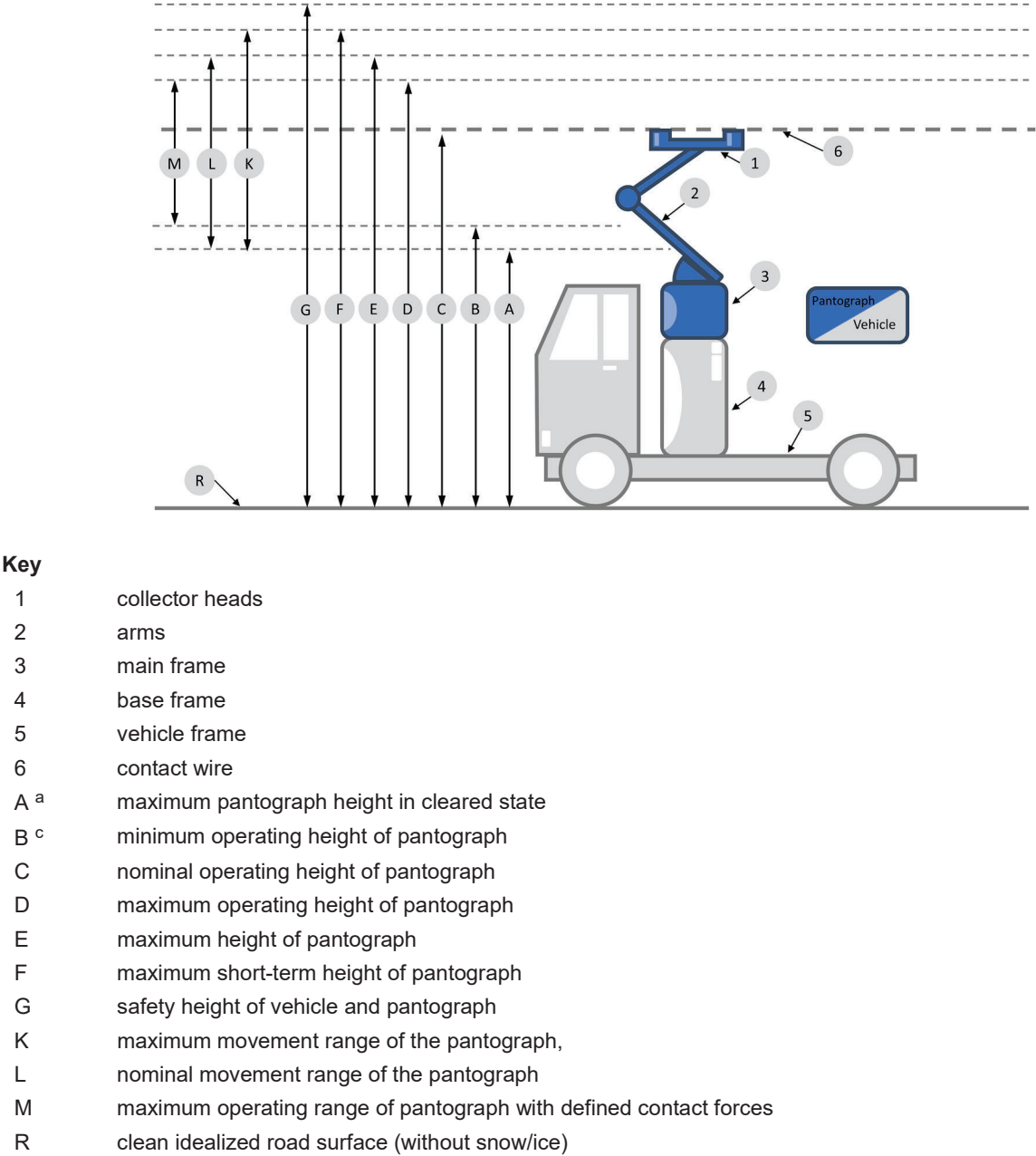


Figure 8 — Pantograph terminology and height definitions

As shown in Figure 8, various heights and ranges of movement for the pantograph mounted on an ERS vehicle shall be defined perpendicular (at a right-angle, z-direction) in reference to the idealized road surface with the corresponding values given in Table 5. The pantographs position when disabled is defined as the cleared state.