

Guidance Document

G183 Guidelines for the Engineering of Underfloor Arc and Thermal Protection Requirements

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Contents

1	Purpose	3
2	Scope	3
3	Guidance	3
3.1	Introduction	3
3.2	Background	4
3.3	Minimising risk of arc initiation	4
3.4	Minimising the duration and severity of an arc	5
3.5	Minimising the release of smoke, fumes and toxic products	5
3.6	Arc Containment	5
3.7	Passenger saloon protection	6
3.8	Ensuring arc extinction	6
3.9	Arc splash protection	7
3.10	Thermal protection	7
3.11	Additional protection	8
3.12	Categorisation of performance requirements	8
3.13	Details of test requirements	8
3.14	Stage 1 approval for arc barrier materials	9
3.15	Stage 2 approval for arc barrier materials	9
3.16	Stage 3 approval for arc barrier materials	10
3.17	Design requirements	10
3.18	Maintenance requirements	11
3.19	Environmental considerations	11
3.20	Supplier assurance	11
3.21	Safety considerations	11
4	Responsibilities	11
5	Supporting information	12
5.1	Arc protection experience	12
5.2	Arc barrier testing	13
5.3	Drawings	14
6	References	18
6.1	References	18
6.1.1	Statutory documents	18
6.1.2	British Standards	18
6.1.3	LU engineering standards	18
6.2	Abbreviations	18
6.3	Definitions	19
6.4	Subject Matter Expert	20
6.5	Document history	20
7	Attachments	21
7.1	Minimum Required Distances for the Design of Bogie Mounted Arc Barriers	21

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1 Purpose

- 1.1 The purpose of this document is to provide additional guidelines to ensure that arcing from unprotected electrical cables and other defects that have the potential to cause high heat release do not cause a fire or smoke incident during the operation of the train.
- 1.2 The arc protection philosophy is to:
- a) minimise the risk of arc initiation;
 - b) minimise the severity and duration of an arc;
 - c) contain an arc;
 - d) minimise the release of smoke, fumes and toxic products;
 - e) avoid saloon penetration; and
 - f) ensure arc extinction.
- 1.3 The thermal protection philosophy is to:
- a) assess the level of protection required;
 - b) containment of heat, fire or smoke;
 - c) minimise the release of smoke, fumes and toxic products;
 - d) avoid saloon penetration; and
 - e) ensure fire/smoke extinction.

2 Scope

- 2.1 This document supplies additional guidelines for arc, arc splash and thermal protection on rolling stock owned or leased by the Company, in order to provide a safe environment for users and operators. It applies to a 4-rail d.c. traction supply where neither pole is normally bonded to earth, but either pole of which may occasionally become so. It also applies to vehicles that run for part of their schedule on National rail infrastructure where the traction supply system is 3rd rail 750Vdc and the negative traction supply is effectively bonded to one of the running rails. Guidelines regarding the materials used for this protection are also defined.
- 2.2 The expected users of this document are LU procurement agents, suppliers contracted under any subsequent specifications and technical staff within LU and Tube Lines.

3 Guidance

3.1 Introduction

The protection of passengers and staff from the effects of arcing, fire, smoke and toxic fumes is fundamental. In order to prevent arcing, (which can lead to a serious train fire), or fire as a consequence of excessive temperature causing damage to the vehicle, stringent precautions must be taken during the design and installation of electrically unprotected cables.



3.2 Background

- 3.2.1 Arcing occurs when two electrical conductors connected to a high energy power source, at different electrical potential, become shorted together momentarily. Arcing can only be sustained while the total electrical impedance of the circuit is sufficiently high enough to prevent the traction system protection device(s) operating and low enough to allow sufficiently high enough currents to flow to form an arc corona.
- 3.2.2 Where arcing occurs between a drop lead and large masses of earthed metalwork, e.g. bogie frame or sole bar, the drop lead will erode faster.
- 3.2.3 As the distance over which the arcing increases, usually due to erosion of the electrodes, the 'arc resistance' increases, its current decreases and the electrical potential difference between them increases.
- 3.2.4 Flames, from burning materials, and ionised air provide low resistance paths for arcs.
- 3.2.5 Arcs are dynamic, and they will move around between the two points of contact.
- 3.2.6 Sustained arcing incidents involve high energy levels, and extremely high temperatures can be reached in the local vicinity.
- 3.2.7 Toxic fumes and smoke will be given off by the copper cable, its sheath and by the earthed object as they are consumed by the arc.
- 3.2.8 The 'near field' effects of the arc corona give rise to the most heat, most erosion and the lowest arc resistance.
- 3.2.9 The Company's experience of pole-to-pole Traction Supply arcs created under test conditions, are that they can be sustained up to dimensions in the order of 450mm.
- 3.2.10 Materials used in the construction of rolling stock (e.g. aluminium alloys) can be permanently affected in terms of physical strength by the heating effects of an arcing incident.

3.3 Minimising risk of arc initiation

- 3.3.1 Minimising arc initiation is the first level of arc protection. The most likely places for arcing to occur are at cable connections, and in exposed locations, e.g. drop leads, shoe gear and electrically unprotected cables on the bogie. Consequently, there should be no earthed electrical conductor within 300mm of any of these items. The Company recognises that 300mm is difficult or impractical to achieve around the body of shoe-gear and a justified reduction in this dimension may be acceptable.
- 3.3.2 All electrically unprotected cables should be routed and installed on the vehicle such that risk of physical damage is minimised. Physical protection should be given to all cables installed on the underframe. This should be capable of providing protection against damage from including, but not limited to, flying objects, e.g. ballast thrown up from the track or detached shoes, and routine maintenance malpractices.
- 3.3.3 Creepage (or Clearance) Path Extenders should be installed around any unprotected installation where the 300mm dimension cannot otherwise be achieved.
- 3.3.4 All cable fastenings should be sized and rated for the cables in accordance with industry best practice and standards.
- 3.3.5 Mechanically clamped connections should preferably utilise at least two bolts. Where this is not practical, alternative means should be provided to ensure the connection cannot be misaligned on assembly.
- 3.3.6 Castellated nuts with split pins should not be used. Any bolt or stud employed on the connection of electrically unprotected cables should be anchored to the surrounding insulated enclosure to prevent it rotating.





- 3.3.7** Clamping forces between terminals should not be transmitted, directly or indirectly, through or into the insulating mounting medium.
- 3.3.8** Any cable passing between parts of the structure designed to move relative to each other, e.g. drop leads, should be secured at both ends to prevent strain being transmitted to the connection and to prevent localised strain damaging the cable.
Note: A diminishing strain relief gland is a method of achieving this.
- 3.3.9** All cables should be installed to prevent them from chafing against parts moving relative to the cables.
- 3.3.10** Exposed cables on the underframe should be protected from the deposition of spray and dirt thrown up from the track.

3.4 Minimising the duration and severity of an arc

- 3.4.1** The design of the installation should be such that in a situation where an arc has initiated, the duration of the arc, its severity and volume of toxic material released should be kept to a minimum.
- 3.4.2** The length of drop lead cables between the points of mechanical attachment to the bogie and underframe should be kept to the minimum necessary for the maximum dynamic movement of the bogie in all planes.
- 3.4.3** The cross sectional area of drop lead cables should be the minimum necessary, considering the cables are generally installed in “free air”, for the current rating determined by the duties given in the particular specification.

3.5 Minimising the release of smoke, fumes and toxic products

The design of the complete electrically unprotected installation should be such that minimising the release of smoke, fumes and toxic products is commensurate with ensuring that the duration and severity of an arc is kept to a minimum, and that the materials aspect of all components are in accordance with best practice and industry standards.

3.6 Arc Containment

- 3.6.1** Should an arc be initiated, it should be contained within a specific area, called the containment zone, that is protected with arc resisting materials, in order to protect passengers and reduce the extent of damage to the vehicle and its sub-systems.
- 3.6.2** Cables (other than those directly associated with the relevant electrically unprotected installation), pipework and car structure should not be installed within the containment zone. Where the elimination of pipework or other cables is not practical within the design of the arc / fire protection arrangements then a justified risk assessment should be undertaken to assess the effects or loss of functionality of those affected systems in the event of an arc/fire.
- 3.6.3** Electrically unprotected cables of opposite polarities may be installed adjacent to each other (e.g. for EMC reasons) provided that there is sufficient mechanical protection to prevent damage to the cables.
- 3.6.4** The design of the installation should not allow the high temperature generated in an arcing incident to cause any breach of the passenger saloon, or for the train to become totally immobilised.
- 3.6.5** The integrity of any arc protection system should not be degraded if it is formed from more than one element.



3.7 Passenger saloon protection

3.7.1 A protection system, meeting the material guidelines of 3.12, should be installed between the carbody and the following equipment, unless the clearance distance under all dynamic conditions between the carbody and the equipment is greater than 300mm:

- a) The complete electrically unprotected drop lead installation from the shoe and shoe gear to the first point of mechanical attachment to the carbody.
- b) All electrically unprotected cable runs on the bogies.
- c) Shoe gear.
- d) Main traction overload clearance devices.
- e) Shed receptacle boxes.
- f) Electrical connections associated with any part of the electrically unprotected installation.

3.7.2 A protection system, meeting the material guidelines of 3.12, should be installed between the carbody and standby batteries, unless the clearance distance between the carbody and the battery is greater than 75mm.

3.7.3 The arc barrier system for saloon protection should be demonstrated for compliance by testing or modelling, or both. Where this is not practicable, they should extend at least 300mm in all directions in any plane from any point on the periphery of the shoe gear or drop lead, under all dynamic conditions of the bogie.

3.7.4 The fixing of the barrier(s) to the vehicle should not compromise the 300mm distance requirement.

3.7.5 Smoke and fumes should be prevented from entering the Passenger Saloon in the event of an arcing incident.

3.7.6 The design of the passenger saloon arc protection system should take into account the relationships between the size (C) of the electrically unprotected cable between shoe-gear and underframe, the thickness of the arc barrier (T) and the minimum space between the cable and the arc barrier (S). The Company undertook a series of tests in the mid-1990's to understand the properties of arc barrier materials and from that evolved the design principles to be adopted for future designs.

3.7.7 An empirical formula was derived from the results of these tests which, for the arc barrier materials, cables and standard-off parameters used at that time, suggest that the relationship between the three variables C, T & S (above) can be defined as shown in the following: ~~formula :-~~

$$T = e^x$$

where $x = 3.07 - P - (0.1 * S) + 0.2 ((C/150)-1)$

and $P = 0$ (Class I) or 0.2 (Class II)

3.8 Ensuring arc extinction

3.8.1 A pole-to-pole arc on an electrically unprotected Traction Supply cable, once initiated, can be sustained for some considerable time and extend over a significant arcing distance. If a single pole earth fault exists on the Traction Supply, either on a train or elsewhere, or the train is operating on National Rail 3rd rail infrastructure (where the negative conductor rail is electrically bonded to a running rail), an opposite polarity earth fault on a train will produce a pole-to-pole arc.

3.8.2 The arc protection system should incorporate a snuffer assembly at the first point of mechanical attachment of each drop-lead to the underframe, and should be





manufactured from arc resistant material meeting the guidelines of 3.12. This should also provide a suitable environment for the connection of the drop-lead to the underframe mounted shoe lead, supporting the requirement to keep the drop lead as short as possible.

- 3.8.3** The snuffer should have sufficient length or a labyrinth system, or both, to ensure that an arc will be extinguished before the walls of the device are breached.
- 3.8.4** The snuffer should have sufficient length to ensure that should an arc be initiated at any electrical connection within the snuffer, it will not propagate beyond the limits of the snuffer along any cable, and should be extinguished before the walls of the device are breached.

3.9 Arc splash protection

- 3.9.1** Arc splash protection should be provided wherever incandescent material emitted by a transient arc, e.g. from the collector shoes or high current switching device, may cause damage to any part of the vehicle, and should be demonstrated for compliance by testing or modelling, or both.
- 3.9.2** Materials used for arc splash protection should meet the guidelines of 3.12. The materials should comply with industry best practice and standards for electrical creepage and clearance, and should also comply with the Electrical: Passive requirements also detailed in 3.12.

3.10 Thermal protection

- 3.10.1** Thermal protection barriers should meet the guidelines of 3.12, and should be installed between the carbody and heat producing equipment. This includes:
- a)** Where surfaces which people could be in contact with, would otherwise reach or exceed a localised hazardous temperature of 60°C.
 - b)** Where other devices and equipment exceed safe working temperature as a result of heat output from elsewhere on the vehicle, e.g. above, or in the path of the air outlet from, a brake resistor.
 - c)** Where long-term exposure to a heat source would shorten the life of equipment, e.g. cable insulation.
- 3.10.2** These conditions should be met for:
- a)** Normal operation.
 - b)** Malfunction prior to disconnection of heat source, including failure of any cooling device and allowing for any stored heat which may dissipate abnormally following cooling failure.
- 3.10.3** This should include, but is not limited to, the following items:
- a)** Main traction and/or braking resistors.
 - b)** Starting and permanent resistors for auxiliary traction voltage rotating machines.
 - c)** Any electrical equipment with a thermal output greater than 200 watts or with a surface temperature capable of exceeding 100°C at any time.
 - d)** Standby and/or traction batteries.
- 3.10.4** The thermal barrier system should be demonstrated for compliance by testing or modelling, or both. Where this is not practicable, it should extend at least 300mm in all directions from all points on the perimeter of the equipment, and the contractor should ensure that the mounting of the barrier will not compromise the requirements for electrical creepage and clearance requirements referred to in 3.9.



3.11 Additional protection

3.11.1 The connection of the shoe lead to the Overload Clearance Device should be protected in a manner that will protect the Passenger Saloon to the same performance as that described for the drop lead connection.

3.11.2 A particular specification may nominate additional specific items of equipment to meet the requirements specified above, including cables and cable terminations that are considered to require arc or thermal barrier protection because they constitute an unacceptable hazard to the integrity of the vehicle. The Contractor should undertake hazard assessments to identify and deal with any such arising during the course of the design.

3.12 Categorisation of performance requirements

These are categorised in Table 1:

Barrier type	Fire		Electrical	
	Passive	Active	Passive	Active
Arc splash barrier	◆		(◆)	
Clearance path extender	◆		◆	
Surface tracking path extender	◆		◆	
Arc barrier	◆	◆	◆	◆
Heat barrier	◆	◆		

Table 1 - Categorization of test requirements.

In respect of Fire and Electrical properties the general descriptions of the terms Passive and Active are as follows:

Fire:

Passive : Good flame retardancy, low smoke emission and low toxic fume emission

Active : Good fire resistance

Electrical:

Passive : High insulation resistance and high resistance to tracking

Active : Good resistance to arc erosion/penetration.

These terms are quantified in the tests and associated guidelines in 3.13.

3.13 Details of test requirements

3.13.1 Fire: Passive and active

Heat release in BS 476 Part 6.

Flame spread in BS 476 Part 7.

Temperature index in BS 6853 A.

Smoke emission in BS 6853 B5.2.

3.13.2 Fire: Active

To BS 476 Part 22 Integrity and Insulation >60 minutes.



3.13.3 Electrical: Passive and active

To BS 6233 Volume Resistivity $>10^{10}$ ohmcm

To BS 6233 Surface Resistivity $>10^{10}$ ohm

To BS EN 60112 Comparative Tracking Index >600

3.13.4 Electrical: Active

General foreword

Stage 1 approval is mandatory for all categories of material. For full Arc Barrier approval Stage 3 approval is required. Stage 2 approval may be used at the discretion of the Contractor or the Engineer in order to screen materials prior to the more costly Stage 3 testing programme.

Stage 1 Approval: A plaque should not penetrate in less than 180 seconds.

Stage 2 Approval: The arc should self-extinguish. The material should not flame for longer than 30 seconds following the cessation of arcing. No current flow in the detector plate circuit should be permitted.

Stage 3 Approval: The material must have Stage 1 approval; Stage 2 is desirable, prior to Stage 3 testing.

Sheet Material: The arc should self-extinguish, and should not penetrate the test sheet. Any flaming should self-extinguish within 15 seconds from the extinction of the arc. No current flow should be detected from the steel detector plate. See Figure 3.

Conduit: The arc should self-extinguish within the conduit. There should be no penetration through the conduit, and the arc should not penetrate the rear sealed cable entry to the conduit. Any flaming should self-extinguish within 15 seconds from the extinction of the arc. No current flow should be detected from the steel detector plate. See Figure 3.

3.14 Stage 1 approval for arc barrier materials

A plaque 100 x 100 x 3mm (length x width x thick) should be tested to BS 4145.

3.15 Stage 2 approval for arc barrier materials

3.15.1 Introduction - This test is intended as an intermediate test in between the Stage 1 and Stage 3 requirements, but does not qualify material for Arc Barrier approval. It is intended as a screening test, which if invoked by the Contractor or the Engineer, may be used to eliminate candidate materials which have passed the Stage 1 requirements, prior to incurring the more costly Stage 3 testing.

The only variables in this test are the material type and its thickness.

3.15.2 Test Procedure - The size of the test panel should be 600mm x 200mm x appropriate thickness under test. It should be arranged in a test rig as shown in Figure 1. This should be protected with a suitable chamber, faced on five sides by a fibre/cement board or equivalent; the front face should be open. The supporting structure of the test panel should be further protected by appropriate ceramic fibre.

A d.c. power supply of 630V that is capable of delivering 500A should be applied across 16mm diameter touching copper electrodes. The current should be increased until arcing occurs and sustained for at least 200 seconds.