DESIGN STANDARDS STRAY CURRENT MANAGEMENT

Tramway Technical Guidance Note 3

OFFICE OF RAIL REGULATION

Contents

Introduction

This guidance is issued by the Office of Rail Regulation. Following the guidance is not compulsory and you are free to take other action. If you do follow the guidance you will normally be doing enough to comply with the law. Railway inspectors seek to secure compliance with the law and may refer to this guidance as illustrating good practice.

Author

Andy Steel, B Sc, M Sc, C Eng, M I Mech E

At the request of HM Railway Inspectorate and with the assistance of the members of -

- The Light Rail Engineer's Group
- The ORR Tramway Standards Group
- HM Railway Inspectorate.

1. Stray current management

a. The power circuit of any direct current supplied electric tramway (or railway) can be considered as consisting of four fundamental elements, namely:

- the substations, from which the direct current at the designated nominal voltage for the line is supplied (nominal voltages should be to BS EN 50163 “Supply Voltages for Traction Systems” unless the system already uses an alternative voltage);
- the positive conductor (i.e. the overhead line) connecting the supply to the trams;
- the load, i.e. the trams;
- the negative conductor (i.e. the rails), through which the current is returned to the substations.

b. Ohms Law states that for any conductor the passage of an electrical current will result in a voltage drop along its length, proportional to the resistivity of the conductor.

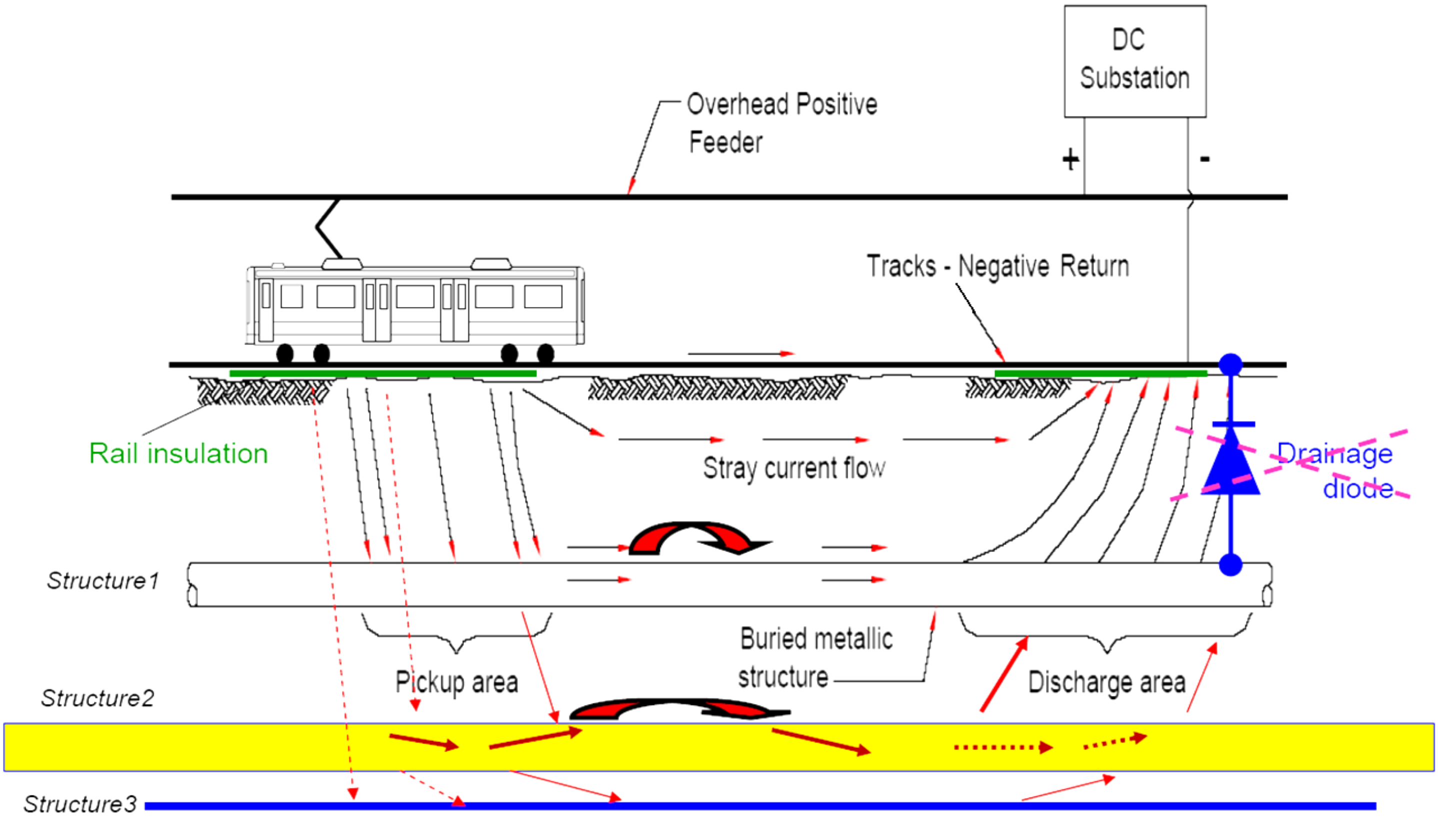

Figure 1. Stray current flows required to be avoided by good design.

c. The consequence of this is that parts of the rails will be at a different voltage than that of other objects buried in the earth, such as metallic pipes and cables belonging to other statutory undertakers such as utility companies.

This voltage will be dependent on the location and power flow within the system and may be positive or negative with respect to local earth. As there will be some resistance to earth the voltage distribution along the track at any instant in time will be in some way averaged around zero with some parts positive and some parts negative. This distribution will vary depending upon the operating conditions and vehicle locations and whether the vehicles are motoring or braking (but negative voltages are not caused specifically by regenerative operation).

d. Because the earth is a less than perfect insulator, the potential difference between the rails and nearby buried conductors will result in some of the traction return current “leaking” to earth and some of this total leakage returning to the substation, in part, via those buried pipes. The extent to which this will occur depends upon the relative total resistance of the many possible return paths, via the rails and via other pipes and the ground.

e. The consequence of stray current is that where it leaves a buried metal object, electrolytic corrosion will occur, frequently in highly localised areas and potentially leading to loss of material. However for any significant loss of material to occur needs current to flow over time. Short duration peaks should not be an issue.

This is clearly undesirable in the case of metallic pipes carrying gas and water, as leakage and/or rupture has obvious safety and/or operational risks to both the tramway and the general public. In the case of cables, particularly the older lead sheathed types, such loss occurs even more rapidly and can lead to breakdown of the (now) unprotected inner insulation of the cable. However see Section 5 (2nd bullet point) below regarding campaign replacement of such equipment by the utility companies.

2. The legal position

In the early days of tramway electrification, damage to apparatus was a significant issue to the various statutory undertakers who sought to prevent the tramway operators from allowing any current to return via the earth. This resulted in a court judgment (National Telephone Company versus Graff-Baker, 1893) which ruled that the earth was not exclusively for the use of the statutory undertakers, and that the tramway companies were as entitled to use it as much as they were, providing that they did not exceed reasonable limits. These were expressed in terms of maximum voltage drop in the running rails and promulgated via a series of recommendations published over time by the Board of Trade and the Ministry of Transport.

Importantly, it established the principle that some leakage current is inevitable, and that provided measures are taken to maintain it within reasonable limits, its existence has to be accepted by the utility companies and others who elect to bury their apparatus in the ground.

Such recommendations are now in the form of European Standards which are referenced below at Section 6.

3. Overall stray current management policy

Stray current management has to form an integral part of an overall EMC Policy for a tramway. It must therefore be compatible with the design of the tramway for earthing, bonding and lightning protection.

The electrical design of tramways must, as far as practicable and consistent with overall safety, be optimised in order that the potential to generate stray currents will be kept to the minimum practical throughout the life of the system.

This stray current management strategy sets out to assist a tramway to demonstrate, mitigate and manage the stray current risk where this is still considered to be potentially significant during electrical design optimisation.

4. Information exchange and co-operation

It is in the interest of the tramway promoter (this may be the operator or the maintainer) that this will be best achieved by co-operation and information exchange between all of the parties involved leading to agreement.

Information exchange and co-operation with all potential stakeholders should be carried out during the planning, design and construction stages. This can continue throughout the operation of the system when significant changes to the tramway are planned. In this way, possible effects, suitable precautions and remedies can be assessed. It is also important that the existence of stray currents from other non-tramway sources, (not restricted to other electric railways), is identified.

5. Stray current working party (SCWP)

It is recommended that tramways set up a stray current working party (SCWP) for each project. It is hoped that all statutory undertakers, particularly the utility companies who have any concerns that their apparatus may be affected by stray currents, would wish to be involved and contribute to this working party. The tramway should determine the membership and propose a terms of reference /constitution for the SCWP. It would be hoped that this can be agreed by the members on a simple majority basis. However the outline issues to be considered should include the following:

- to agree the establishment of a schedule of susceptible assets. It should be both understood that such assets must both be metallic and close to the tramway rails, and capable of forming an effective path between different parts of the tramway. Continental experience is that provided the measures described in the sections below are achieved, then buried metallic apparatus over 1metre away from the rails in any direction will not be susceptible to stray currents;
- cognisance must also be taken of any ongoing programmes to which the utility companies are committed to replacement of apparatus currently metallic with plastic or similar thus reducing the range and extent of susceptible apparatus;
- to scrutinise the project for the electrical system design and stray current management of the system;
- to agree the level of testing of measures to mitigate stray current during the construction phase of the system;
- to agree the level monitoring of change in these measures during the operation phase of the system. This is returned to at Section 10 below;
- to review results of testing during construction;
- to review issues as they arise during the operation phase of the system;
- the frequency of meetings should be by agreement. It will be expected that the need will vary throughout the life of the project. However once tramway operations are established it would be expected that meetings will only be required where specific issues require to be reported or discussed.

It would be expected that, where appropriate, other statutory undertakers such as Network Rail and London Underground may wish to deal with individual tramway projects in a broader forum which considers other interface issues (such as EMC) as well as stray currents. The tramway should accommodate this approach.

6. Appropriate standards

The base standard is BS EN 50122-2 (Protective provisions against the effects of stray currents caused by direct current (DC) traction systems)[1]. This applies to all electrifications of a DC railway or tramway system. The principles may also be applied to existing electrified systems where it is necessary to consider the effects of stray currents.

---

[1] It should be noted that as at September 2008, this standard was in the latter stages of revision with a view to publication in 2009. Cognisance has been taken of this prEN 50122-2 in the preparation of this Guidance Note. Tramway projects in preparation, or where the design of the electrical system is not complete, should be aware of this revised standard and adopt its recommendations where appropriate.

This standard gives comprehensive advice on the design of systems as well as recommended requirements. The design and management of tramways must meet the requirements of this European standard.

Inextricably linked with this standard is BS EN 50122-1 (protective provisions relating to electrical safety and earthing).

It should always be remembered that the protective provisions against electric shock in this second standard will take precedence over provisions against the effects of stray currents where safety of staff, or protection of the public, are concerned (Clause 4.1 of BS EN 50122-2 refers). This aspect is returned to later at Section 8.

The following European standard will also be considered during the design process: BS EN 50162 (protection against corrosion by stray current from direct current systems). This standard assists with the identification and measurement of potential corrosion from stray currents should they still be considered a risk. The stray current design and management of the tramway should take account of this standard where it is appropriate and following consultation with the SCWP. It should be noted that prEN 50122-2 referred to above has full compatibility with this standard.

Other standards may be referred to as appropriate. Overall the tramway will be designed, constructed and operated to comply with appropriate legislation in force at the time.

7. Electrical design of the system

a. Fundamental principle of stray current design and management

It is not possible to obtain infinite resistance between the tracks and surrounding earth for the full length of the alignment, and certainly not for the life of the tramway and under varying weather conditions.

Therefore it is possible to limit the risk of stray current, but not to remove it entirely. The design and ongoing management strategy will be to ensure that as far as is reasonably practicable, the level of stray current is minimised.

This principle is in accordance with the standards listed above at Section 6.

b. Designing to keep stray current low

For reasons based upon sound experience with early tramway electrification schemes it is the established convention to determine the insulated overhead conductor as the positive pole of the supply, with the running rails as the negative return.

From any point in the system the return current has the possibility of returning to the negative busbar of the substation by:

- the designated return path (primarily the rails but may include cables as well); or
- via the earth (i.e. as stray current)

The extent to which each path is chosen is governed by Ohm's Law. This states:

- current = voltage difference / electrical resistance in circuit.

Therefore to keep stray current to a minimum a primary design objective of the electrical power supply system must be to:

- keep the rail to local earth *voltage* low; and
- keep the rail to local earth *resistance* high.

c. **Designing so that rail to local earth voltage remains low**

The tramway will be supplied with electricity suitably transformed and rectified from the local electricity network supplier through substations located along the route. The local rail to local earth voltage at any point depends on the overall electrical resistance between that point and the sub-station. Tramways should achieve a low value of resistance in the following manner.

- Frequent feeding points from the traction supply along the alignment thus reducing the distance that return current has to travel. For each feeder point:
  - a robust incoming supply at each feeder point must be provided to the extent that this can be arranged with the local electricity network supplier. Ideally this should be from a ring main rather than a spur connection. This will keep emergency feeding due to the outage of a feeder point to a minimum;
  - in general dual end feeding to each electrical section on the tramway must be specified; i.e. each section will be fed from the two adjacent sub-stations. This will reduce the effective distance return current has to travel even further. However care must be taken to ensure that the open circuit voltages of the two feeding transformers are as equal as possible (by use of the secondary tapping adjustment) in order to ensure that the traction load is indeed shared;
  - it is also acceptable, but not common practice within Great Britain, to provide single feeding points at the midpoint of each section, with coupling switches as necessary to allow for a loss of local supply;
  - at the extremities of the line the final section may be single end fed, but the overall length of the electrical section must be lower to compensate.
- The system must be designed such that the permitted accessible voltage is achieved with any one feeder point out of service. This is defined for Great Britain at Section 8 below.
- Welding by an approved process of all continuous lengths of rails in order that the electrical resistance of the rail is not increased by more than the level specified in BS EN 50122-2.
- Where welding of adjacent rail lengths is not possible then the rails will be connected by low resistance track bonds. Incorporating sufficient redundancy in bonding must be considered.
- A similar arrangement shall apply at special track installations such as points, crossings, and breather switches/expansion joints. It may be desirable for parallel return conductors to be installed across the length of special work to facilitate maintenance of the return path during maintenance operations.
- Frequent cross bonding between rails must be provided. In particular this is to give several parallel paths for return current all at equal potential, making maximum availability of return conductor capacity and additionally giving a level of redundancy in event of a failed bond, or rail discontinuity. The bonding shall encompass:
  - between both rails of each individual track. Experience has shown that a bond separation of around 200m is appropriate;
  - all four rails on double track. Experience has shown that a bond separation of around 400m is appropriate for these bonds;
  - the actual appropriate intervals for each type of bond must be established at the design phase of the tramway.
- The majority of tram projects are “drive on sight” tramways. It should therefore not be necessary to employ traditional heavy rail signalling track circuits requiring impedance bonds or insulated joints unless there are particular site or alignment conditions which require it.
- Rail sections should be chosen to give the maximum cross sectional area in order to minimise electrical resistance. Cognisance must be taken of the fact that wear to the rail will cause an increase in resistance over time up to the

point that the rail is renewed. The calculations that determine the maximum accessible voltage should take into account the renewal limit of wear defined in the maintenance manual. See also the later reference at Section 7d below to the ORR technical note "Design Requirements for Street Track".

- Consideration will be given to providing parallel negative low resistance return cables should the project specific power supply studies show them to be required at any point of the alignment (see below at Section 8), where it is not practical for other reasons to use a larger rail section or for example an isolated section of single track within a feeder section.

d. Designing so that rail to local earth resistance remains high

Tramways should seek to achieve this by ensuring a high level of insulation from earth of the running rails and the whole return circuit. The design and method of construction should be such that the overall conductance per unit length throughout the system must not exceed the values recommended in Table 1 of BS EN 50122-2 during routine operations throughout the life of the tramway.

It would be expected that the tramway as initially constructed will have conductance values several times better than the values given in the above standard. The inspection and maintenance regime adopted by the tramway should have intervention thresholds such that the track conductance values should never reach the values in the standard during normal operations at any time in the life of the tramway.

The tramway promoter and designer must make absolutely clear and tabulate the conductance values for all track forms at all points of the route to which the system is being designed, and will be achieved immediately after construction. The intervention (and eventually renewal) thresholds to which the maintainer of the system will be required to achieve throughout, must also be clearly stated in a similar manner.

The methods of achieving high levels of track insulation will vary according to the track form adopted. The following therefore covers the basic principles for the principal track forms.

- On open formation where the running rails are laid above ground level as would be expected on a traditional railway formation.
  - Sleepers typically of concrete.
  - Insulated type rail pads between the rail-foot, the fastener and the sleeper which also meet the required rail toe loads and vibration/fretting performance.
  - Ensure the ballast is:
    i. not in contact with the rail as far as possible;
    ii. clean;
    iii. well drained.
  - If grass or similar aesthetic feature is proposed it should be absolutely clear how contact between the medium proposed and the rails is to be prevented. This may include for the medium to be contained in separate containers located around the rails.
  - In certain areas it will be expected that the trams will regularly use sand to assist with adhesion. Build up of sand deposits providing any direct path between rail and ballast must be routinely dealt with.
  - At points and crossings ensure that there are no direct electrical paths between the rails and any electrical apparatus in the point machine, particularly the neutral and earth connections.
  - All other rail-mounted conductive equipment will be insulated from earth. In particular the use of non-metallic connections to drain boxes is recommended.

- o The exposed metal parts of all bonds or other connections to the rail must be kept as short as possible and clear of fasteners, sleepers or ballast or any other conductive structure connected to earth.

- On slab track with rails proud of surface.
  - o For rail pads, bonds and switches, essentially the same issues as for ballasted track.
  - o Run-off and drainage must avoid standing water.
  - o Prevention of build-up of sand deposits is equally important.
  - o Measures to be taken with any reinforcement material within the slab are dealt with below at Section 9a.
- On closed formation where the top of the running rail is level with the surrounding surface. Typical examples will be the highway and pedestrian areas. Guidance as to the physical characteristics of embedded track are given in the tramway technical guidance note1 (TTGN1) "Design Requirements for Street Track" (http://www.rail-reg.gov.uk/upload/pdf/ttgn1-StreetTrack.pdf). The points below relate only to electrical considerations.
- An insulating layer must be interposed between the rails and the surrounding structure. This can be achieved by the following means:
  - o using a rail coated with insulating material; or
  - o surrounding the rail with a form of insulated "boot", or
  - o embedding the rail in an insulating medium, or
  - o the use of insulating filler blocks on either side of the rail web;
  - o it may be acceptable to encapsulate the rail directly in concrete. However in this case the thickness of the concrete and its composition must be carefully considered. A minimum thickness of 100mm is recommended;
  - o if grass or similar aesthetic feature is proposed it should be absolutely clear how contact between the medium proposed and the rails is to be prevented.
- The choice and design of the insulating system must be consistent with:
  - o noise and vibration attenuation policy, but must not compromise the insulation level. In considering the appropriate solution for a particular area there must be a clear understanding between the differing requirements for electrical insulation (essentially a thin layer) and noise and vibration (which would normally require a thicker layer which coincidentally provides electrical insulation);
  - o all proposed processes which require access to the rail to attend to defects or make new connections, and to undertake routine welding of rails in order to make good side and head wear.
- Particular attention must be paid to sealing the joint between the rail and the surface of the surrounding surface to minimise water penetration down the side of the rail. The method and materials chosen must take account of the extent to which the alignment at any point is shared or crossed by other forms of road traffic.
- Particular attention must be paid to local insulation of the rail.
  - o At all rail welds, particularly if these are carried out after track installation.
  - o Where rail bonds or negative return cables are attached to the rails. There should be no exposed metal on either the rail, bonds or cables both at first installation and after maintenance.
  - o Attachment and insulation of tie-bars connecting both running rails if used.
  - o At any rail joints not capable of being welded. Continuity bonds should be provided at all such joints.

- Adequate drainage must be provided such that water runs off quickly and does not remain in the vicinity of the rails. Drainage must be cleaned regularly so that ponding does not occur except briefly under the most extreme conditions.
- Standing water must be avoided.
- Rail grooves must be kept clean of debris (including sand deposited from the tramcars).
- At points and crossings ensure that there are no direct electrical paths between the rails and any electrical apparatus in the point machine.
- Any other rail-mounted equipment must be insulated from earth. This particularly relates to drain boxes and point machines.
- Measures to be taken with any reinforcement material within the slab below and/or around the track are dealt with below at Section 9a.

8. Safety considerations

a. Permissible accessible voltages

As described above, high levels of insulation between rails and earth means that in general whilst the tram is operating there will be a potential difference between the rails and surrounding earth. Under fault conditions this potential difference can rise significantly to the extent that it could cause a danger.

There are limits to the permissible accessible voltages due to the traction return current and touch voltages due to currents under fault conditions set by BS EN 50122-1 at Clause 7.3. In brief these are:

- accessible voltage for Permanent Conditions will not exceed 120V (except in workshops where it will be 60V). Clause 7.3.3 refers. However see below for the particular requirement of HMRI in Great Britain;
- table 4 at Clause 7.3.1 of the above standard for Short-time Conditions (as defined in the standard);
- table 5 at Clause 7.3.2 of the above standard for Temporary Conditions (as defined in the standard).

All tramway projects must meet these limits throughout the life of the system.

It should also be noted that there are specific requirements of HMRI in Great Britain for tramways. These are currently given in the document Railway Safety Publication 2, published by the Office of the Rail Regulator at Page 31, Clause 183. This requires that accessible voltages do not exceed 60V at any point in the system.

As the electrical system design is progressed and tram performance and service levels confirmed, each project must conduct a series of computer based power supply simulations. These will investigate inter-alia accessible and touch voltages at representative points along the system under normal and emergency (i.e. with the designed level of feeder point outage) feeding, and under fault conditions. This will assist in determining whether or not additional measures are required to keep within the required limits. A reassessment should always be made when there is any significant increase in the level of service proposed or the introduction of new tramcars.

In general any additional measures will relate to reducing further the return circuit resistance by for example the provision of additional return conductors. It will be appreciated that low accessible voltages under permanent conditions will also assist with the minimising of stray current.

Under fault conditions it may be necessary to connect the return circuit temporarily to earth until other protection measures (such as tripping to interrupt a short circuit current) become operative. This will be achieved by the provision of voltage limiting devices. Whilst this gives the risk of a short term increase in the local level of stray current, safety considerations dictate that this approach is taken. Such events should be both rare and of practically no consequence for third party apparatus.

b. Voltage limiting devices

All voltage limiting devices used shall meet the requirements of Clause 7.4 of prEN 50122-2 in terms of reset after operation. Ideally this should have the facility to be monitored through the SCADA system.

Experience has shown that there is a particular failure mode with some types of voltage limiting devices. If they experience a high fault current or a large number of operational duty cycles due to short-term impermissible accessible voltages then they may fail in the short circuit mode. This then creates a direct path to earth for the traction return which could if undetected for some time lead to corrosion on other nearby metallic structures. Testing and maintenance procedures must take account of this failure mode.

For this reason hybrid switching types composing of a solid state control and separate DC contactor are preferred.

9. Additional or special measures

a. Negative earthing and drainage diodes

On first generation tramway systems, it was accepted practice to connect the negative pole of the supply, usually a dynamo, to earth, and similarly, to connect all external ironwork, such as the traction poles to the running rails. It was also accepted practice to connect buried pipes, etc, to each other and to the running rails, with the intention that such stray current as did leak out of the rails would be returned via a solid electrical connection, obviating the risk of electrolytic corrosion.

Whilst having some apparent advantages, this method can result in increased current leakage simply by increasing the number of potential current paths from the rail to the surrounding earth and is therefore flawed in practice because the voltages that drive stray currents go both positive and negative in normal tram operation.

Initial practice with Great Britain’s second generation tramways was to electrically connect all of the steel reinforcement in the track slab and connect this to the negative terminal of the DC rectifier via a diode. Although this was seen to offer a theoretical advantage by ensuring that the reinforcement should act as a collector mat such that any stray current can only return directly to the substation, it is also flawed in practice because the voltages that drive stray currents go both positive and negative in normal tram operation.

Therefore, current practice, as exemplified by the more recent systems is not to provide any permanent connections between the negative bus-bar and earth, leaving the rails “floating” relative to earth. As the resistance between the rails and the earth is not infinite, the rails will adopt an average potential close to that of the earth.

It should be noted that the diodes have been removed in some of the earlier tramways with demonstrable improvement in stray current performance.

BS EN 50122-2 is written around this “floating” system. For the avoidance of doubt HMRI require this approach on all new systems.

Where steel meshes or similar reinforcement are used as part of the track form for structural reasons or as a crack control measure then the tramway must review whether they should continue to be electrically connected. However in that case they must not be connected to the traction return circuit. Detailed specifications and design for this should be developed during the design of the track forms.

In general provided that proper attention is paid to the return circuit resistance and insulation the special provision of a stray current mat should not be required. It should be noted that it is common practice amongst established tramway systems in mainland Europe to employ an un-reinforced concrete track slab.

Special requirements may apply to tunnels as described in BS EN 50122-2. Early consultation with HMRI is recommended.

b. Structures adjacent to the tramway

Care must be taken that the resistance between conductive structures adjacent to the tramway, which are not insulated from earth, and the track return system, are high. The only exception will be at depots which are dealt with below.

Where such structures fall within the zone that it would be possible for a person to be in contact, directly or indirectly, with both the structure and any conductive material connected to the track return then the requirements for accessible and touch voltages of BS EN 50122-1 must be met.

This will normally involve the use of voltage limiting devices as described above in Section 8.

c. Special arrangements for the depot

For reasons of the safety of personnel working in the depot the traction return within the depot must be directly connected to earth. The depot must be fed from its own separate rectifier or power supply. The running rails within the depot must be separated from the main line by means of insulated rail joints. The layout of the depot should be planned to avoid any necessity for a tram to be stationary such that it will bridge these insulated rail joints. Operational procedures should support this.

All of the above will be in accordance with BS EN 50122-1 Clause 9.2.3.4 and prEN 50122-2 Clause 9.

It should be noted that a depot site will normally comprise of an area within which maintenance activities will be undertaken normally within an enclosed structure, together with stabling areas. The tramway must consider whether the whole site or merely the maintenance area is to be subject to the above feeding arrangements. The decision will depend upon:

- the overall maintenance philosophy of the tramway; i.e. the extent to which maintenance is restricted to one particular area;
- the location of the depot site. Where for example it is contained entirely in an “all enclosed” urban development then it is likely the whole site will require to be considered;
- the effect of the current draw when the fleet is stabled but with much of the auxiliary load enabled. This will determine the maximum voltage drop along the tracks and thus determine whether a direct connection between structural earth and the return circuit is tolerable.

d. Other railway traction systems

Care must be taken to ensure that there will be no direct conductive connection to track sections of other railway traction systems.

Special arrangements must be taken where conductive structures are adjacent to both systems (and in the case of alternating current (AC) traction systems are bonded directly to the tracks of the AC system). These arrangements will be agreed with the owners of each system and must take account of the particular earthing and bonding arrangements on both systems. They must not compromise stray current levels on the tramway, except for extremely short periods under fault conditions as described above in Section 6.

e. Cathodic protection measures

The overall design including the methods described in this section should ensure that there will be no consequences due to stray current for third party apparatus. However owners of third party apparatus may still wish to install specific cathodic protection measures on particular apparatus, as for example described in BS EN 12954. The tramway should not be expected to bear the costs of such work or take any consequences for the performance or monitoring of that apparatus in the future.

10. Ongoing monitoring and control of stray currents

a. Tests and measurements

It is not practical to directly measure stray currents. The only practical measurement is a local potential difference between the traction return and "mother" earth.

It is sensible to take measurements of this potential difference in order to confirm that rail potentials stay within a consistent range relative to the design values and those measured at first installation. This information can then be used to calculate the track conductance along the route at any point in time thus allowing changes or trends to be identified and where necessary additional inspection and remedial actions instigated.

These measurements may be taken on a continuous or discontinuous basis. One of the procedures described at Section 10 of prEN 50122-1 and its associated annexes should be adopted by all new tramway systems. Existing tramways should consider changing their present arrangements to those described in this standard.

The infrastructure maintainer must use this information continuously, particularly that of any adverse trends to programme early inspection and remedial action. Intervention thresholds must be clearly defined and acted upon. The methods outlined in Section 10c below are a guide to appropriate actions.

By such approach the tramway must demonstrate that it is maintaining its return circuit insulation at the levels specified in their maintenance instructions. These in turn must be higher than those in the standard BS EN 50122-2.

Provided this is achieved and demonstrated then no other testing regime should be required.

It is for the utility companies to carry out any additional monitoring of their own apparatus as a part of their internal inspection and maintenance procedures. Any measurement and criteria for intervention due to measured stray-current interference for apparatus without cathodic protection must be in accordance with the procedures given in BS EN 50162. Acceptable positive potential shifts should be as given in Table 1 of the same specification. Notes 1 and 2 to the table should be considered in determining whether the thresholds in Columns 3 or 4 are appropriate.

In particular it should be noted that as return circuit insulation levels will always be high compared with soil resistivity changes in the latter locally over time will have insignificant effect.

The above should only apply to utility apparatus installed before the granting of the Transport & Works Act Order or equivalent legislation for any tramway project. It shall be the responsibility of the owner/installer of any new or modified apparatus to take full cognisance of the presence of the tramway and to design and install such that the apparatus is not susceptible to corrosion from stray current.

b. Construction phase

The tramway must recognise that the achievement of the agreed design standards for track insulation and bonding (see Section 7 above) will require continuous attention to detail throughout the construction phase of the project. Therefore procedures must be documented and in place which:

- continuously review the practicality of the design for construction;
- provide rigorous quality control at all stages;
- carry out formal testing and recording at appropriate stages.

The detail of the above must be developed as the design and procurement proceeds and must be incorporated into the overall project quality and test and commissioning documentation.

The above should be shared with the SCWP during the design and construction phase.

c. Maintenance during the operational period

The tramway must ensure that a regime of preventative and corrective maintenance of the system is in place throughout the operating period. Maintenance of return circuit insulation levels will form a key part of this. The majority of these actions are essentially good house-keeping activities such as:

- monitoring of return circuit potentials, with reaction to changes (see Section 10a above);
- keeping ballast clean and free of vegetation;
- on grass tracks applying regular vegetation management to ensure no direct contact between the rail and the growing medium;
- keeping drains clear;
- cleaning sand deposits away from rails;
- addressing highway surface failures promptly;
- checking bonds for soundness and that they are still in place (i.e. they have not been stolen);
- checking cables for insulation damage; and
- checking protection devices for functionality.

d. Renewals of equipment

Over the operating life of the system equipment of both the tramway and third parties will require renewal. This may arise for several reasons:

- life expiry;
- obsolescence;
- damage.

For all renewals it will be appropriate to consider the stray current implications of;

- the point at which renewal is judged necessary. For example the remaining cross sectional area of a rail may be considered more important than the physical state of the rail head;
- service experience;
- changes in technology or materials.

The quality of renewals, upgrades etc must be, as a minimum, consistent with the original construction. It would also be expected to take account of any changes in legislation or any appropriate European standards that may have been introduced or modified since the original construction.

In particular third parties should note that any renewal of their apparatus must take full cognisance of the presence of the tramway.

11. Heritage and museum tramways

It is accepted that most current heritage and museum tramways will have been constructed to meet rules issued many years ago by the Ministry of Transport (see Section 2).

However all tramway installations have a duty to consider stray current implications. In doing so it should be remembered that for corrosion due to stray current to be an issue significant current must flow for some time.

Therefore such tramways should consider;

- the length of the return path to their feeding point(s) and its specific resistance;
- the maximum current draw to be expected from the tramcars to be operated on the line, taking into account operating speeds and likely loading;
- the operational periods of the line;
- the level of service to be provided during these operating periods.

They should also consider the likelihood of significant underground metallic services in close proximity to the alignment of the tramway.

Careful consideration of these points will allow a judgement to be taken as to whether any additional insulation of the traction return would be advisable at times of renewal or extension to the existing systems. Consultation with HMRI is recommended.

All future new museum lines will be expected to follow the main sections of this guidance note.