Rail Safety & Standards Board

Research Programme

Engineering

Investigating the potential for improvements in electrification systems - Summary report

T346 INVESTIGATING THE POTENTIAL FOR IMPROVEMENTS IN ELECTRIFICATION SYSTEMS

SUMMARY REPORT

August 2007

Executive Summary

RSSB Project T346 'Investigating the Potential for Improvements in Electrification Systems' is concerned with examining key issues that affect the reliability, safety and performance of electrification systems in Great Britain.

The objective of the project is to assist Network Rail and their suppliers in identifying opportunities to improve the operation of electrification systems, particularly at the current collection interface where any failures may cause severe disruption to train services.

The project has been undertaken in two phases, a series of reports being produced for each phase. Phase 1 commenced with a questionnaire to industry stakeholders, with phase 1 studies considering electrification issues generally within the subject areas:

- The pantograph/OLE system;
- The shoegear/conductor rail system; and
- Power supply systems.

Cross industry review of the phase 1 findings via the RSSB Vehicle-Traction System Interface Committee (V/TS SIC) directed phase 2 studies to more specific subject areas, viz:

- Pantograph Carbons and ADD Systems;
- Conductor Rail Ramp Ends; and
- Conductor Rail Interface Specification.

This document reports on, and summarizes, the findings of all the above studies.

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1 Glossary

The following abbreviations and acronyms are used in this report:

AC	Alternating Current
ADD	Automatic Dropping Device, as applicable to pantograph operation
AWAC	Steel reinforced aluminium catenary wire
BW	Brecknell, Willis & co ltd
CTRL	Channel Tunnel Rail Link (also branded as High Speed 1)
DB	Deutsche Bahn (German Railways)
DC	Direct Current
EC	European Commission
ECML	East Coast Main Line
EMU	Electric Multiple Unit
FADD	Fast acting Automatic Dropping Device (a development of ADD)
FRAME	Network Rail fault reporting database
GB	Great Britain
NR	Network Rail
NMT	New Measurement Train
OLE	Overhead Line Electrification (predominantly 25,000 Volts a.c. in Great Britain)
RAR	Network Rail Asset Register Database
RSSB	Rail Safety and Standards Board
SNCF	French National Railways
TRUST	Network Rail train delay database
TSI	Technical Specification for Interoperability

2 Introduction

RSSB Project T346 ‘Investigating the Potential for Improvements in Electrification Systems’ is concerned with examining key issues that affect the reliability, safety and performance of GB electrification systems.

The objective of the project is to assist the Rail Industry and their suppliers in identifying opportunities to improve the operation of electrification systems, particularly at the current collection interface where any failures may cause severe disruption to train services.

The project has been undertaken in two phases, a series of reports being produced for each phase. Phase 1 commenced with a questionnaire to industry stakeholders and the phase 1 studies consider electrification issues generally within the subject areas:

- The pantograph/OLE system;
- The shoegear/conductor rail system; and
- Power supply systems.

Cross industry review of the phase 1 findings via the RSSB Vehicle-Traction System Interface Committee (V/TS SIC) directed the phase 2 studies to more specific subject areas, viz:

- Pantograph Carbons and ADD Systems;
- Conductor Rail Ramp Ends; and
- Conductor Rail Interface Specification.

This document reports on the findings of the phase 1 and phase 2 studies and provides extracts and summaries of the information given in the various individual reports.

3 The Pantograph/OLE System

Four studies have been undertaken with regard to the pantograph/OLE interface, these being:

- Improving the Pantograph/OLE System (Report [1]);
- Pantograph Carbons and ADD Systems (Report [2]);
- Pantograph Interface Modelling (Report [3]); and
- OLE Systems for the Future (Report [4]).

3.1 Improving the Pantograph/OLE System

3.1.1 OLE Types

A diverse range of overhead equipment types is currently in use because of the long period in which electrification has been carried out in GB. This ranges from types that were initially installed energised at 1500 V dc with 1940s/50s technology, to more modern 'standard' types that have benefited from a better understanding of current collection and efforts made to standardise and rationalise components and configurations.

Excluding the Tyne & Wear (Nexus) 1500 V dc system, all GB OLE is now 25 kV ac. Some routes are conversions of earlier electrifications therefore some elements are of greater age. For example Manchester South Junction & Altrincham has main steelwork dating from 1928 and both Manchester-Glossop-Hadfield and London Liverpool Street to Shenfield have main steelwork and some wiring dating from circa 1939.

The standard configuration of main line OLE is now auto-tensioned sagged simple design, whilst fixed termination simple equipment continues to be used in some suburban areas of slow speed line. Several earlier configurations exist, for example compound and non-sagged, however upgrade schemes (for example the West Coast project which has introduced the UK1 design range) generally include the conversion of these to the standard configuration.

Early designs of OLE, those originally intended for 1500 V dc operation and later converted to 25 kV ac operation consist of 'heavyweight' compound equipment utilising a contact wire gauge up to 193 mm^2 area.

AC electrification has generally been carried out with 'Lightweight' GB OLE equipments, comprising the Mk1 through to Mk4 designs and their variants (Figure 1). These utilise a contact wire gauge of 107 mm^2 area; either cadmium copper or hard drawn copper is used, with copper tin having recently been introduced as a replacement for cadmium copper. Depending on the location and age, the OLE is either configured as auto-tensioned with a design tension ranging from 8.9 kN to 11.0 kN, or fixed termination with tensions of up to 17.58 kN.

The 'UK1' upgrade of the WCML has introduced the use of 120 mm^2 silver copper contact wire tensioned at 11.9 kN (auto-tensioned equipment). On Channel Tunnel Rail Link (CTRL) 150 mm^2 hard drawn copper contact wire is used, following the European practice of heavier OLE equipment for high speed lines. Modern heavyweight OLE was also installed at Dollands Moor by Network Rail on main lines interfacing with the Channel Tunnel equipment at the network interface.

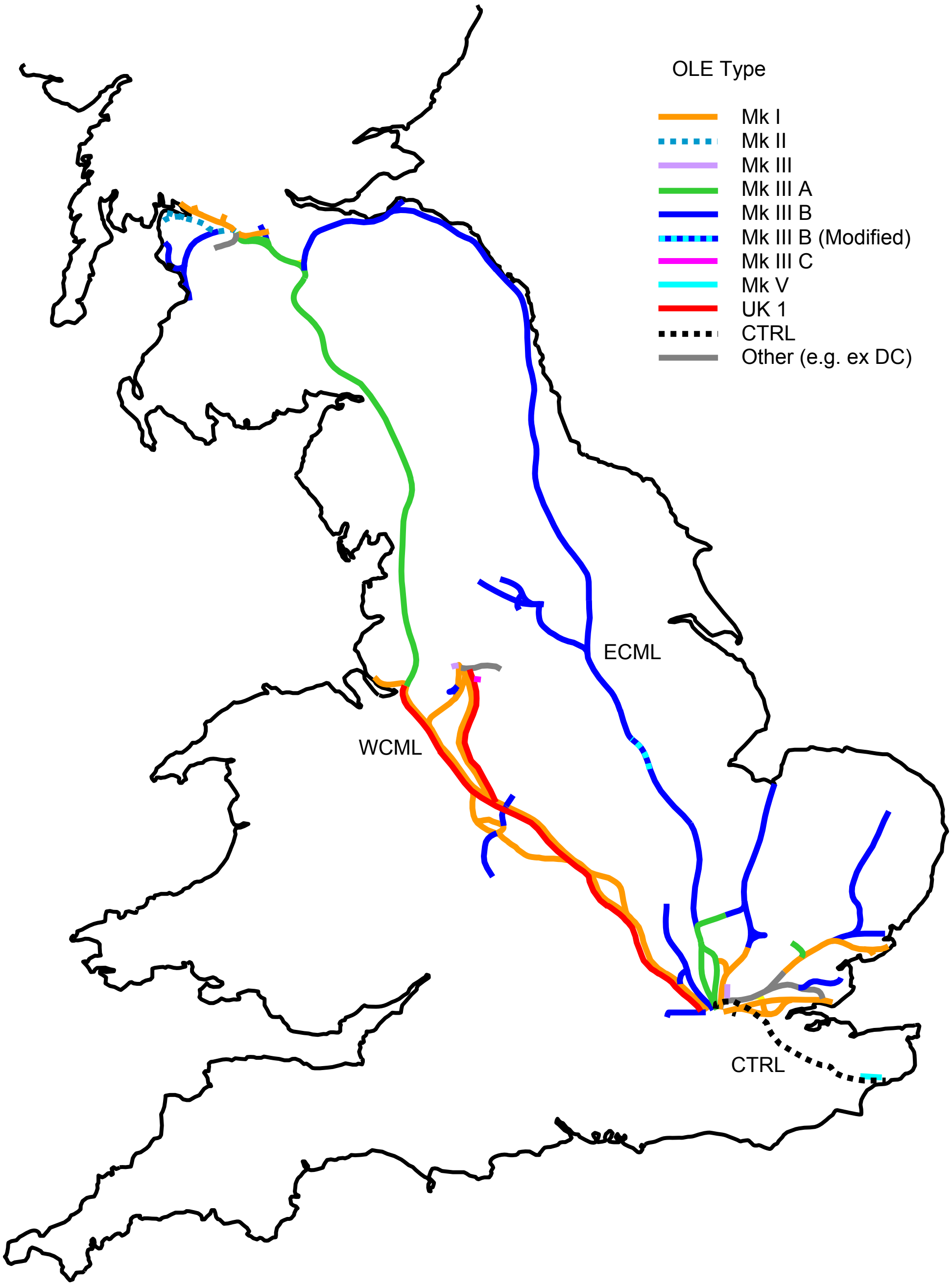

Figure 1 GB 25 kV Electrification

For the catenary wire, multi-stranded cadmium copper wire was typically the choice for earlier designs of electrification (ex DC, Mk 1 and Mk 2 equipment). Later generations of OLE (Mk 3a, 3b) utilise AWAC (steel-reinforced aluminium) catenary wire, however the UK1 design has seen a return to the use where practicable of copper alloy catenary wire.

Where problems with AWAC catenary have been experienced copper alloy catenary wire is being retro-fitted to upgrade Mk3a/b to Mk3c (or Mk3d). For future projects it is understood that magnesium copper is an approved/accepted material for catenary wire and this may be used as a replacement for both AWAC and cadmium copper.

In total there are 7,780 track-km of 25 kV ac and 19 track-km of 1500 V dc on Network Rail controlled infrastructure. Additionally there are 74 route-km of high speed French designed 25 kV OLE in operation on Section 1 of the high speed CTRL with a further 39 route km of Section 2 due to come into operation from November 2007.

GB OLE equipment thus comprises many design types and variants of those types.

3.1.2 OLE Performance and Reliability

Many of the inherent limitations of the GB OLE electrification system have been determined by the nature of the existing railway infrastructure to which electrification equipment has, in most cases, been retrospectively installed. Thus the ideals of level contact wire and generous electrical/mechanical clearance are compromised by the presence of numerous overbridges, tunnels, level crossings and other features that require deviations from the standard wire height and reduced clearances.

The equipment has also been engineered to the prevailing line speed limitations. Compared to the dedicated 'high speed' lines of Europe and elsewhere, GB OLE (except CTRL) is comprised of 'lightweight' equipment that is not well suited to increases in operational speeds without significant re-engineering.

It is also recognised that design compromises were necessary to limit the capital cost of some electrification schemes. There is now a much better understanding of the costs associated with delays ('delay minutes' costing) and whole life equipment costs that would presently favour increased capital costs for an overall reduction of lifetime costs, inclusive of operational and maintenance considerations.

By its nature, the OLE catenary system is fabricated from different types and numbers of component spread out over a wide geographical area; there is little inherent component redundancy and the overall system reliability is dependent on the unfailing operation of those large numbers of individual components and sub-systems.

Report [1] considers the make up of the catenary system and discusses the limitations and degradation factors that typically affect OLE catenary systems, particularly with regard to GB electrification infrastructure.

3.1.3 Pantograph Operation

Correct pantograph operation is fundamental to the reliable operation of the pantograph/OLE interface. The design of the pantograph is critical in achieving the required dynamic characteristics, including aerodynamic characteristics that become dominant at higher speeds.

Also important are the features in the design that enable robust operation, yet allow some measure of protection to the infrastructure should the pantograph(s) of a train sustain damage. For example, most pantographs in operation in GB are fitted with an Automatic Dropping Device (ADD) that is designed to lower the pantograph in the event of significant damage occurring to the pantograph.

Maintenance of pantograph condition and performance is also a key requirement; the collector strips and suspension system are subject to wear and tear throughout the working life and the condition of each operational pantograph must be appropriately managed.

3.1.4 Pantograph Types

There are four basic types of pantograph operating on GB infrastructure:

- Stone Faiveley AMBR (several variants) – fitted to older EMUs and locomotives and suitable for service speeds to 160 kph
- Brecknell Willis High Speed – fitted to all modern locomotives and a number of Classes of EMU currently operated at speeds up to 200 kph;
- Brecknell Willis Low Height – fitted to a several Classes of EMU introduced from 1994 and suitable for service speeds to 160 kph; and
- Faiveley Grand Plongeur Unique (GPU) – fitted to Class 373 Eurostars for operation up to 300 kph on the CTRL and up to 177 kph on the ECML.

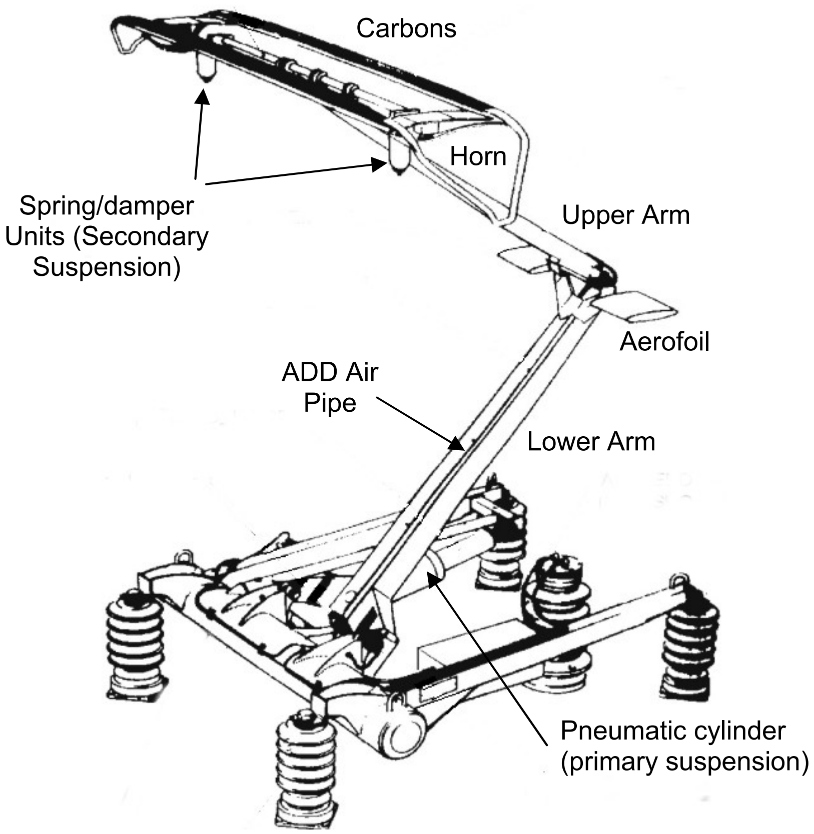

Figure 2 Typical Pantograph Features (Example shown BW Low Height)

3.1.5 Pantograph Features

Standard features typical of present day pantographs operating on GB infrastructure are (example Figure 2):

- Single arm design with a constant static uplift force provided by either a spring (of the above examples only Stone Faiveley AMBR) or by pneumatic suspension.
- Incorporation of an ADD (Automatic Dropping Device) system designed to lower the pantograph in the case of excessive carbons wear or damage to the pantograph. Some Stone Faiveley pantographs, as fitted to 'slow' EMUs, do not incorporate ADD.
- Two carbon strip lightweight head mounted on a secondary suspension system. Some Stone Faiveley pantographs, as fitted to 'slow' EMUs, do not incorporate secondary suspension and may be fitted with a 'heavy' three strip head developed by BR for running on heavy ex 1500 V dc equipment.
- All Brecknell Willis and GPU pantographs are fitted with aerofoils that must be accurately set to provide sufficient aerodynamic neutrality of the pantograph.

These features are subject to detailed discussion in Report [1], including comparison of the standard 'BR' design of pantograph horn profile to the standard European ('TSI' specified) horn profile. This is of particular interest with the drive towards interoperability that is encouraging standardised designs of pantographs and electrification equipment throughout Europe.

3.1.6 Pantograph Developments

3.1.6.1 Independently Sprung Carbon Carriers

Some recent designs of European high speed pantograph employ independently sprung carbon carriers. Decoupling the two carrier strips in this way is claimed to give superior current collection capabilities. Such a design of pantograph head has yet to be run on GB OLE.

3.1.6.2 Open Loop Control Systems

At least two European pantograph manufactures have developed and service-tested an 'open loop' method of uplift control where the static uplift is varied according to vehicle speed and pantograph orientation by means of a digitally controlled electro-pneumatic system. It is claimed that such a system eliminates the need for aerofoils, provides for more precise control of uplift characteristics and allows for re-programming of the speed-uplift characteristic according to the type of OLE equipment the pantograph is required to operate on.

3.1.6.3 Closed Loop Control Systems

Closed loop control systems that utilise an uplift control mechanism similar to that described above but incorporating closed-loop control (i.e. with onboard uplift measurement and feedback) to adjust uplift force in response to contact force variations, has for many years been seen as a technique for significantly improving pantograph capability. Such a system would, by limiting the extremes of contact force, reduce system wear and tear and consequently increase equipment life or alternatively allow for higher speeds of operation on existing designs of OLE.

There are significant technical challenges to overcome in producing a reliable and effective closed loop controlled pantograph and this remains an area of continuing research and development by European pantograph manufacturers.

3.1.6.4 Pantograph Carbons and ADD Systems

The potential to improve pantograph operation through the use of improved current collection strips and better damage protection systems are key areas that have been subject to detailed study that is described in Report [2] and summarised in section 3.2 of this report.

3.1.7 Influence of Environmental Factors

Operation of the pantograph/OLE interface is affected by the environmental factors identified below, with further details and discussion in the full report:

- Pantograph sway - due to vehicle body sway arising from train/track interactions;
- Train turbulence - due to passing trains, giving rise to a ‘pressure pulse’ causing vehicle sway, also aerodynamic disturbance to the pantograph;
- High winds – cause wind induced perturbations of the OLE wires and may significantly affect pantograph aerodynamics;
- Conductor Icing – causes poor electrical contact and rapid electrical erosion of contact strips.

Wind effects are a particular problem area which give rise to complex interactions between the pantograph and OLE catenary with a resultant increased risk of ‘dewirement’. That risk is mitigated by the enforcement of speed restrictions at periods of high wind.

3.1.8 Dewirement Incidents

The term dewirement generally refers to a major failure of the OLE catenary system that leaves it in an unfit state to continue train services. A dewirement can be initiated by a variety of causes, often involving a unique set of circumstances that may have adversely affected the system dynamic behaviour or have led to a critical component failure of either the OLE or pantograph.

A dewirement does not necessarily involve or require the presence of a pantograph; an OLE failure can occur through factors such as environmental extremes, wildlife intervention, vandalism or ongoing deterioration mechanisms that have led to out of gauge equipment or a ‘static’ component failure.

Well maintained OLE, pantographs and track (including OLE/track alignment) minimises the risk of dewirement. An effective and reliable ADD device on the pantograph is essential to minimise infrastructure damage in the event of pantograph involvement.

3.1.9 Effect of Legislation

A set of European Directives and associated Technical Specifications for Interoperability (TSI) have been devised to establish conditions for compatibility between European railways. The main objectives of these TSIs are to:

- Allow inter running of trains between the countries of Europe, this being a prime aim of the EU Directives particularly where related to freight; and
- Allow increased rail industry trade between the countries of Europe.

Both the WCML and ECML are classed as European High Speed lines but require special dispensations to achieve High Speed TSI compliance. True interoperability is not, in effect, possible with the existing WCML and ECML electrification infrastructure and the requirement to move towards such standards as far as practicable may have implications regarding equipment renewals and certainly for future upgrades.

The CTRL 'High Speed 1' line is currently the only GB electrification system that meets European High Speed Interoperability requirements (it is not known whether certification of interoperable constituents has been achieved).

Interoperability issues are discussed further in Report [4] 'OLE Systems of the Future' (see section 3.9 of this document).

3.1.10 Pantograph/OLE System Recommendations

Recommendations made in Report [1] are:

1. The development of a national standard relating to pantograph specification. This should address issues relating to the supply, maintenance and operation of all pantographs required to operate on GB OLE infrastructure.
2. The development of an improved pantograph force measurement device is required for pantograph checking/maintenance purposes. Such a tool should be standard equipment for those concerned with the maintenance and overhaul of pantographs.
3. Review strategic monitoring of OLE by means of train based measurement systems such as the NMT, with the output from such systems being set against stated (i.e. Railway Group Standard) OLE performance requirements.
4. Increase understanding of high wind effects by use of suitable modelling tools to:
    - Assess the potential for vehicle body sway resonance as a result of gusting.
    - Gain a better understanding of air flow with regard to embankment and other high risk topologies to more precisely identify at risk equipment and to identify how equipment placing (e.g. mast spacings) can be optimised.
    - Understand how OLE catenary resonates and how such resonances can be reduced by application of uneven mast spacing (new installations) or by the economic placement of wind stays and dampers.
5. Consider use of NMT data to study contact wire displacement and movement under windy conditions.

6. Revise RT/E/C/27039 (wind code – formerly ECP34) on the basis of the above studies.
7. Devise an approach for reducing the impact of service speed restrictions by localised rather than blanket speed restrictions.
8. Using existing dynamic pan/OLE simulation software as part of a study to assess the benefits of operating new designs of pantograph on the GB OLE system, in consideration of:
   - Independently sprung heads
   - Open Loop control (‘semi-active’ pantograph)
   - Closed Loop control (‘active’ pantograph)

9. To ensure that data sets such as FRAME and TRUST are more fully exploited for management of the infrastructure, including understanding the root causes of equipment unreliability, it is recommended that more attention is given to coding of the data. Regular audits should be undertaken to ensure that the data is correctly coded in a consistent manner throughout the rail network (NB the FRAME fault reporting system has been superseded by the F2000 database which has not been investigated for this report).

3.2 Pantographs – Collector Strips and ADD Systems

3.2.1 Collector Strips

Pantograph collector strips used on GB and European OLE systems typically comprise a carbon strip fixed to a lightweight metal carrier (usually aluminium), the pantograph head incorporating two, sometimes three, such collector strips.

Carbon has excellent current collection characteristics and the use of carbon current collectors gives very long (up to 50 years) contact wire life. The disadvantages are its comparatively brittle nature and limited wear life.

European preference is to use plain carbons on 25 kV pantographs and metal impregnated carbons on pantographs operating on DC OLE where the higher current levels may cause overheating of plain carbons. GB practice is to utilise the greater strength and impact resistance of metal impregnated carbons and this type is fitted to all GB 25 kV pantographs.

Alternative carbons grades (both plain and metal impregnated) are available and use of the optimal grade(s) may have a significant effect on collector strip reliability in terms of impact and wear resistance. A comparison of different carbon grades, based on physical characteristics and laboratory tests, is given in Report [4].

More robust collector types such as metal collector strips as used on Japanese electrification, or the Kasperowski design (Figure 3) where the carbon is encased in copper on three sides, are unsuitable for use on GB OLE. Use of such collectors would be damaging to equipment that is designed for use with carbon collector strips and would severely limit contact wire life (NB Japanese practice is to replace the contact wire every few years)

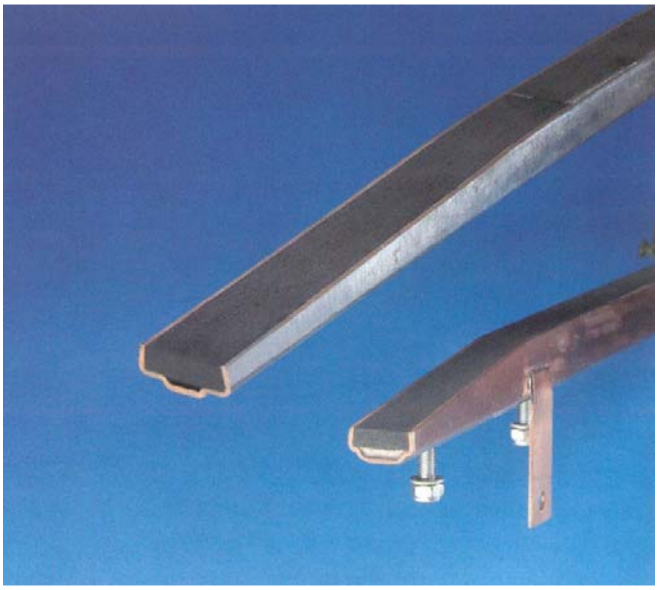

Figure 3 – "Kasperowski" type collector strip

3.2.2 Recent Developments

Older designs of collector strips are fabricated from carbon segments that are retained by clips to the carbon carrier. Newer designs avoid using clips, which can be susceptible to arcing damage, by means of a swaged carrier design, or by directly bonding the carbon to the aluminium carrier. One-piece carbons have lately been used by some train operators in GB with great success, where increased reliability is obtained compared to segmented carbons that are susceptible to damage at the joints between carbon sections.

One manufacturer has recently developed an all carbon collector strip that eliminates the aluminium carrier. The design incorporates an integral glass fibre strengthening tube; such a fabrication is particularly resistant to arcing damage and is employed for winter service use on High Speed trains in Germany. This is shown in figure 4.

Another manufacturer has developed a carbon current collector utilising composite carbon material. The bulk of the collector strip is made up of traditional carbon with the leading /trailing edges comprising high conductivity composite carbon – this material has inferior wear properties compared to the standard carbon but can sustain much higher current densities. This design is intended for use with DC OLE where collection strips may be susceptible to heat damage.

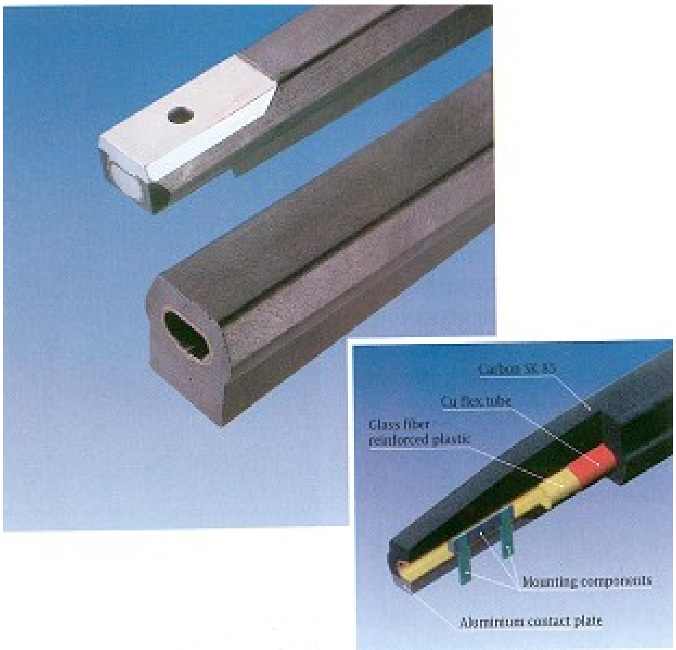

Figure 4 One piece carbon carrier design

3.2.3 Future Materials

The composite carbon material used in the dual material current collector described above was developed for brake pad applications. Ongoing developments in this area may lead to the availability of harder wearing composite carbon materials that could see greater application for current collection purposes.

Looking further into the future, research into carbon nanotubes is showing great promise for developing high performance composite materials. Carbon nanotubes are cylindrical carbon molecules that exhibit extraodinary strength and electrical properties. Their discovery more than a decade ago has attracted a great deal of ongoing research interest. Dramatic improvements to the mechanical and electrical properties of carbon fibre composites has been demonstrated for material incorporating only 5% by weight of carbon nanotubes.

3.2.4 ADD Systems

All ADD systems currently in use are based on pneumatic principles whereby carbon or pantograph head damage leads to leakage of air from a frangible pipe or air seal at the pantograph head; this loss of air is detected as a pressure drop in the ADD system air reservoir, consequently triggering dropping of the pantograph through the opening of the pneumatic dropping valve.

The disadvantages of a pneumatic ADD system include relatively slow response, particularly for earlier designs, and the possibility of false activation due to air leaks at poorly sealed hose fittings or poor seals at the pantograph carbons.

Various designs of pneumatic ADD and the factors affecting the speed of operation and sensitivity are discussed in Report [2]. There have been recent advances in ‘fast acting’ pneumatic ADD systems that are currently fitted to some classes of high speed locomotive (Class 91 operating on ECML, Class 390 ‘Pendolino’ operating on the WCML).

As most modern pantographs are air actuated it is convenient to use an air based ADD system, however sensing technologies other than the air leakage principle might be applied to ADD system design. In particular fibre optic sensor technology, with its inherent immunity to electrical interference and electrical insulating properties, might be utilised in future ADD systems. The practicalities and options regarding the implementation of a fibre optic based ADD system are discussed in Report [4].

3.2.5 ADD Operational Considerations

Clear indication of an ADD activation to the train driver is important in order that he/she may take appropriate actions as specified in the Railway Rule Book to minimise the potential for damage to the OLE.

In multiple pantograph operation where, for example, a train is made up of two or more Electric Multiple Units coupled together, the ADD systems operate independently and the train driver may receive no indication of ADD activation on a rear Unit; he/she may not therefore be aware of the need to bring the train to a halt.

OLE damage may be particularly severe in the event of a dewirement incident involving a multiple pantograph train. The concept of cross-coupled ADD systems is explored in Report [4], with the potential to minimise OLE and pantograph damage under multiple pantograph operation. The concept can be readily incorporated into new build rolling stock and could be retrospectively fitted to existing rolling stock with relatively little vehicle modification.

3.2.6 Legislation

The fitting of fast acting ADD is mandated in the European High Speed TSI, therefore pantograph installations of rolling stock deemed to be TSI compliant must incorporate this feature.

The TSIs also require that the materials used in the pantograph contact strips are compatible with the contact wire material in order to avoid excessive abrasion of the surface of the contact wires. Contact strip material is required to comply with clause 6.2 of EN 5037:2006.

The TSIs also state that materials used shall not constitute a health hazard. This has implications for the use of lead impregnated carbons which, at present, are fitted to the majority of GB pantographs.

The European Directive for Hazardous Substances In Electronic and Electronic Equipment requires that lead (amongst other materials) must not be used in electrical equipment; this directive does not have juristiction over the use of pantograph carbons though clearly European policy is to discourage the use of lead where possible.

3.2.7 Recommendations

Recommendations made in Report [2] are:

1. **Ilford three strip** – this particular design of pantograph head does not incorporate secondary suspension or ADD and, where still in use, should be replaced with a more modern design incorporating one or both of these features for improved protection of the infrastructure.

2. **Universal adoption of bonded carbons** – the bonded carbons design of collector strip (also incorporating continuous tube ADD) is a significant development that should be considered for use on every pantograph. Train operators who have not considered this option should assess the reliability benefits, and potential savings as well as complying with all European legislation, of changing to this form of contact strip.
3. **Use of better carbons** – where clipped and swaged designs of carbon strip are retained alternative grades of carbon should be considered that may give improved wear life and impact resistance compared to the grade currently in use.

4. **Use of carbons which do not contain lead** – to move into line with European legislation and to remove a potential health hazard changing to carbon strips which do not contain lead is strongly recommended.
5. **Development of chip resistant/protected carbons** – research should be encouraged to develop ‘chip resistant’ carbons for the GB market. One approach to this might be to incorporate a resilient/toughened strip into the front face of ‘hybrid’ design of pantograph carbon. A hybrid design of contact strip incorporating composite carbon material has already been produced by one manufacturer, albeit for a different purpose.

6. **Alternative carrier designs** – research should be encouraged to develop an arc-resistant carrier for the GB market. Possible approaches include a protective layer over the vulnerable parts of the aluminium carrier, fabrication of the carrier from a suitable carbon fibre resin material and provision of an all-carbon collector strip inclusive of carrier. In the latter case a commercial design is already available but further development may be necessary to reduce weight for acceptable dynamic performance.

7. **Use of FADD** - Fast acting ADD (FADD) significantly increases the speed of ADD operation and is a TSI specified requirement that should be fitted on all new vehicles and may be appropriate for retrofitting to existing classes of vehicle.

8. **Improved ADD Indication** – the train driver must be given clear and unambiguous indication of an ADD activation, particularly in multiple pantograph operation, in order for he/she to be able to carry out the appropriate actions (as recommended in the Rule Book) to minimise damage in the event of an incident. This philosophy should be applied to all new designs of rolling stock and should be considered as a potential modification to existing rolling stock.

9. **Cross linked ADD** – in multiple pantograph operation, ADD activation of any one pantograph should cause all pantographs on the train to be lowered in order to reduce the risk of secondary equipment damage (to pantographs and OLE), as per advice given in the Railway Rule Book. Cross linked ADD should ideally incorporate FADD to maximise the advantages of employing this approach. Cross linked FADD should be specified for all new designs of rolling stock and should be considered as a potential modification to existing rolling stock.

10. **Euro Norms** - consideration should be given to revising the European Standard EN50405 as it does not give enough information to the train operator to make a choice between carbons. Consideration should also be given to revising the European Standard EN50206 due to anomalies with requirements specified in the new high speed TSI.

3.3 Pantograph Interface Modelling

A study of Pantograph and OLE computer modelling systems is reported in Report [3].

The objective of the study was to:

- Identify the modelling systems currently available;
- Identify what would be desired of them in the future; and
- outline if and how those aspirations can be met.

3.3.1 Modelling Methods

Modelling methods discussed are:

- Dynamic (lumped mass) modelling of the OLE;
- Rigid body spring-damper modelling of the pantograph;
- Finite Element Analysis; and
- Computational Fluid Dynamics.

3.3.2 Existing Simulation Packages and Capabilities

The systems presently available concentrate on modelling contact force between pantographs and OLE on open routes to determine mean force and standard deviations.

Examples are given of existing simulation packages. Known examples within the GB are:

- AEA Technology (now DeltaRail) OVERHEAD package;
- Atkins Rail OLEDS package; and
- Balfour Beatty package.

Examples of existing European simulation software are:

- Package developed by the Politechno de Milan (PoliMi); and
- Siemens system.

3.3.3 Other Applications

There are many more applications that may benefit from modelling, such as pantograph sway, aerodynamic performance, effects of high cross winds, pantograph performance at specific OLE features such as neutral sections and modelling suspected failure modes in incident investigations. Many of these are feasible using standard Engineering analysis packages or development of existing railway-specific packages, however others, particularly those concerning aerodynamics require more research before feasible and reliable modelling may be undertaken.

Report [3] gives in depth consideration of these, and other ideas, where modelling tools might be usefully applied/developed in future.

3.3.4 Modelling and European Interoperability

The advent of the Energy TSI (ENE TSI) as part of the European regulations for high-speed railway interoperability may significantly increase the demand for pantograph and OLE modelling. The certification process for a potentially interoperable pantograph, as defined in the revised HS ENE TSI, requires that its performance be assessed on at least two certified interoperable designs of OLE. Similarly the certification of a potentially interoperable type of OLE requires its performance to be assessed against at least two certified designs of interoperable pantographs. Modelling provides a useful tool to undertake such assessments, it being far easier than undertaking full scale field trials particularly considering the geographic and administrative difficulties of undertaking such trials throughout Europe.

An EC funded project named Europac has as one of its goals a new simulation code for pantograph/OLE interaction and it is possible that the result will be just such a pan-European modelling system. The main partners in that project are SNCF, DB, Polytechnic of Milan, Technical University of Lisbon (IST), Czech Railways, Trenitalia and Faiveley. Such a unified response to OLE and pantograph modelling may be of use in the development of a harmonised modelling system. The extent to which existing British modelling systems may be adapted for the pan-European system is not known and will depend heavily on the level of British involvement in this project. There is a possibility that if a modelling system aimed at European interoperability issues becomes dominant, purely British modelling systems may become largely obsolete.

3.3.5 Model Validation

Modelling relies on availability of accurate input data and requires some form of validation, often involving field tests on a real system. The requirement for laboratory test rigs and field test facilities, including a test track, to assist in such areas are discussed.

3.3.6 Recommendations

Report [3] advises on a number of measures that might be carried out to develop electrification modelling tools for the GB rail industry, from which the following key recommendations are derived:

1. Active British involvement in European contact force simulation developments, including development of both software and a new European Standard for such simulation systems.

2. Development of a suite of software modules – as an overall strategic move for the future of pantograph/OLE modelling, creating a modular system gives a framework around which other developments may fit.

3. Upgrading existing contact force simulations to include vehicle body vertical movement – this will address a significant omission from present GB dynamic simulations.

4. Research into Panel Methods for pantograph aerodynamic modelling – this would fill perhaps the biggest gap in the present modelling capability. A successful and reliable tool for aerodynamic modelling would seriously reduce the extent of field trials presently required when introducing new or altered pantographs or vehicles.

5. Assessment and application of software to allow detailed modelling of pantograph passages over specific features of OLE. This may help to significantly improve reliability of problem OLE features.

3.4 OLE Systems for the Future

Report [4] concentrates generally on the engineering aspects of railway electrification, with an emphasis on learning from best and worst present practice while considering possible applications of better practice and principles to deliver future systems. Topics discussed include:

- Performance of present designs and electrified routes
- Maintenance and upgrade requirements for present electrified routes to maintain and augment train operations
- Interoperability under the Energy TSI
- Future electrification with regard to
    - present line speed
    - moderately increased line speeds (up to 200 or 225 kph)
    - radically increased line speed (up to 300 or 350 kph)
- Socio-economic benefits of railway electrification
- Train operator-specific factors
- Passenger/journey factors

3.4.1 Effects of Interoperability

The effects on European Interoperability and adoption of the Energy TSI on the future design of OLE and pantographs will depend on the extent to which the overall principles of interoperability are embraced. Ideally the interoperable system would comply with all clauses of the main body of the TSI without the need for any country-by-country exemption clauses.

3.4.1.1 OLE

For GB electrification there are significant cost implications associated with the above ethos. For example GB ‘high speed’ routes such as the ECML and WCML operating at speeds to 125 mph (201 kph) and designated TSI category II would require the following changes for exemption free compliance:

- Gradient free conductor wire at higher nominal contact wire height
- OLE electrical sectioning comprising overlap type neutral sections rather than present in-line insulator designs.

Those existing routes would require comprehensive re-engineering of the infrastructure and such measures are only likely to be implemented as part of a new high-speed route which would be required to conform with the Category 1 target system.

OLE design issues are discussed further in Report [4].

3.4.1.2 Pantograph

For TSI compliance the pantograph must be capable of collecting current in accordance with accepted quality criteria, and the speed/force profile would be set in accordance with the TSI target mean force curve. The head may be equipped with insulated rather than the present metal horns.

Again, full compliance might only be implemented as part of a new high speed route or comprehensive re-engineering of existing routes; insulated pantographs horns, for example, are considered to be incompatible with existing GB OLE due to a perceived increased risk of arcing at boosted overlaps.

More probable is the adoption of interoperable components and standards into the existing GB electrification system as far as is reasonably practicable. For example, the pantograph of the Class 390 Pendolino trains has been tuned in accordance with TSI recommendations even if it is not fully TSI compliant in other respects.

The Faiveley GPU pantograph fitted to Eurostars operating on the East Coast Main Line between Kings cross and Leeds is, in TSI terms, an interoperable component that has been developed and approved elsewhere in Europe (we are not aware however of any formal certification as an interoperable constituent). The operation of this pantograph on GB OLE is presented as a case study in Report [4] that demonstrates the challenges of achieving full interoperability.

3.4.1.3 Wind Effects

The effects of cross winds on pantographs do not appear to be directly covered by the TSI, however GB experience is that this is a significant operational factor. In general, increasing pantograph head size increases susceptibility to cross wind effects; pantographs in use elsewhere in Europe that are possibilities for interoperable constituents have heads larger than those used in the GB, making them more susceptible to high cross winds.

High winds also have an effect on the OLE and further research is required to fully understand how OLE and pantographs behave under such conditions so that reduced susceptibility OLE configurations and pantograph designs might be developed.

3.4.2 Factors Influencing OLE and Pantographs

Report [4] includes further discussion of factors and experience relating to present day OLE and pantograph operations with a view as to how this experience may influence the design of future systems.

3.4.3 Use of New Technologies

Specific areas considered are:

- OLE Technologies;
- Improved Pantograph Designs (see also Report [2]);
- Pantograph Maintenance;
- New Technologies from other Industries; and
- Practices of other Railway Administrations.

3.4.4 Conclusions

Various options exist for electrification that could enhance performance, reduce cost and help with the overall system management. The strategy of selecting which areas to investigate must be driven by the need to maximise cost-effectiveness and formulate a strategy for individual routes as well as a complete electrified railway. Several areas have been identified previously as being potentials for cost reduction, viz:

- An effective asset management system, which enables targeted maintenance;
- Effective condition monitoring which can, when integrated with a good system management system, drive down costs by eliminating needless work and identifying hitherto unpredicted deterioration mechanisms;
- High performance pantographs, which may reduce the wear and tear on and required performance specification of the OLE (NB TSI is intended to allow innovation while achieving compliance);
- Introduction of construction methods and materials proven in other industries which reduce capital costs.

3.4.5 Recommendations

Further work with regard to future electrification should critically examine how the above areas could assist electrification engineers, possibly on the basis of case studies, for example:

1. ‘Electrify the route from Bedford to Kettering at 100 miles/hour’
2. ‘Electrify the route from Paddington to Bristol at 150 miles/hour’
3. ‘Extend CTRL from London to Manchester with whole-life electrification costs reduced by 15%’
4. ‘Cut maintenance costs from Doncaster to York by 10%’
5. ‘Improve blow-off performance of exposed sections of the East Coast Main Line without wholesale installation of new stanchions’
6. ‘Increase line speed between Norwich and Ipswich by 10% without wholesale replacement of OLE’
7. Gather instantaneous sway/blow-off data to allow a better understanding of necessary sway and stagger limits (NB RSSB study T689: Further investigation work on pantograph sway, will study this)
8. Replace former DC OLE suitable equipment

9. Identify alternative components to replace those no longer readily available, to ensure service availability of OLE

It should be noted during the duration of this project, RSSB research project T633 ‘Future electrification of the GB railway network’ has been completed and project T689 ‘Pantograph Sway’ has been initiated. T633 cost and economic modelling has already been applied to generic exemplar routes indicating characteristics returning desirable cost benefit ratios. It will hopefully be beneficial to study the routes identified here, using the available modelling techniques. Research Project T689 will include a study of item 7, instantaneous pan sway/blow off, and is expected to increase understanding.

4 Conductor Rail Electrification

Three studies have been undertaken specifically with regard to the shoegear /conductor rail system, these being:

- Improving Conductor Rail Interfaces (Report [5]);
- Conductor Rail Ramp Ends (Report [6]); and
- Conductor Rail Interface Specification (Report [7]).

4.1 Improving Conductor Rail Interfaces

4.1.1 General Description of NR System

Network Rail infrastructure comprises 4737 single track kilometres of 750 V dc conductor rail system (out of a total of 38,000 single track kilometres of railway) in three areas as follows:

- Lines on the South Eastern, South Central and South Western areas: 4360 single track kilometres.
- Lines north of the Thames to Watford and the North London Line: 142 single track kilometres.
- Lines in Liverpool and surroundings: 235 single track kilometres.

All of these routes are electrified with the positive conductor rail located outside the 4-foot space of the running rails, as shown in Figure 5

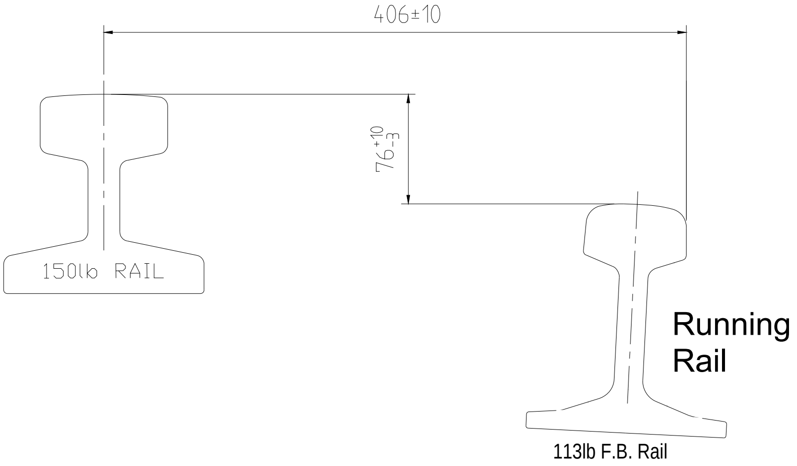

Figure 5 Running Rail/Conductor Rail Geometry

Some limited areas of shared running with London Underground are additionally equipped with a negative fourth rail that is located in the centre of the track.

Contact with the rail is made by train-mounted collector shoes which are brought into contact with the upper face of the rail.

The maximum speed on third rail lines is 100 miles per hour, and all new rolling stock introduced circa 2000 or after is rated at this speed.

4.1.2 Conductor Rail

The large majority of conductor rail in service is high conductivity steel of 106 or 150 lb/yd (52 and 74 kg/m mass respectively) with some remnants of older 100 lb rail. The resistivity of such rail is 16.6 mΩ/km (106 lb/yd) and 11.7 mΩ/km (150 lb/yd).

There is also approximately 28 miles of aluminium conductor rail installed, mostly in the Liverpool area and some on the southern region, either of 15 kg/m mass (12 mΩ/km resistivity) or 18 kg/m mass (7 mΩ/km) shown in Figure 6 below.

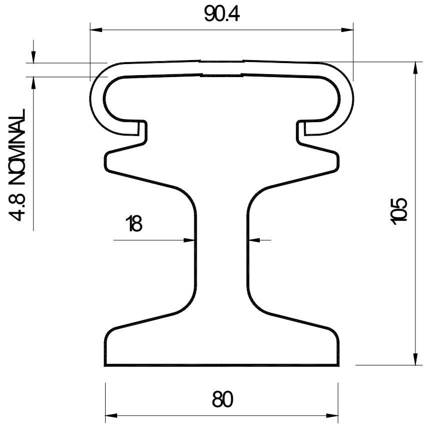

Figure 6 Aluminium Conductor Rail Profile

The lower mass of the aluminium conductor means lower installation costs, with long term savings in running costs due to the reduced resistance compared to the equivalent steel conductor rail.

The conductor rails are typically mounted on porcelain insulators generally spaced at 6 sleeper pitch. Facing and trailing ramps guide conductor shoes onto and off the contact surface, with gaps between adjacent ramps to allow for thermal expansion.

Aluminium conductor rail has proven successful on LUL. Network Rail have some experience of high localised wear to conductor rail in certain areas. The reason is not yet fully explained but one theory attributes the high wear to high current passing through Network Rail collectors when only one shoe is in contact with the conductor rail. This localised wear is evident both on steel and aluminium rail, but steel rail is more tolerant of this local damage.

4.1.3 Shoegear Development

Early designs of shoegear in use on the Southern Railway comprised a cast iron shoe which was towed along the rail head by a linkage. The contact force was determined by mass and gravity alone. Later designs also relied on gravity, and the PNS4 design of the 1960’s retained this feature, with the shoegear mounted on a beam suspended between axleboxes.

Experiments in the 1940’s showed that improvements to current collection could be made with extra force applied by springs; this was taken further on the Mk 1 trains in the 1960’s to produce the PNS7 and 8 designs which feature the shoe arm being mounted on the bogie frame, with the vertical alignment of the free-hanging shoe being maintained by a lightweight downstop beam.

In 1979 BR produced a new design which again was bogie frame mounted, but with additional force from a compression spring.

In 1989 the design concepts for shoegear were extended for the forthcoming Eurostar trains, which consequently feature lightweight shoes with advanced bracketry and shoebeams designed for sustained running at 100mph; this design was refined further for the EMU deliveries subsequent to 1995. Figure 7 presents the relevant features of each design.

Contact force has remained standard, with several experiments carried out over the years to establish the optimum value.

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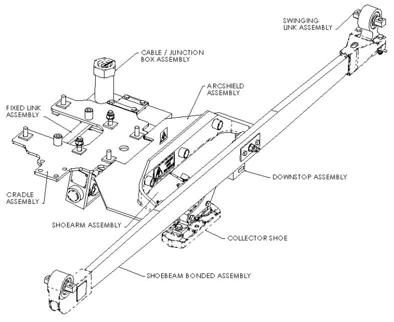
<td>
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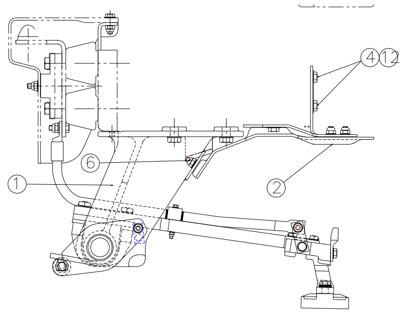
<td>
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<tr>
<td><i>Desiro, Non Retractable</i></td>
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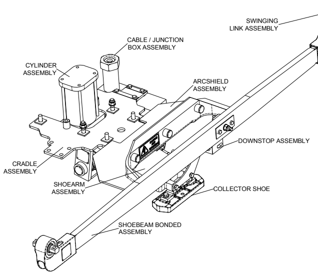
<td>
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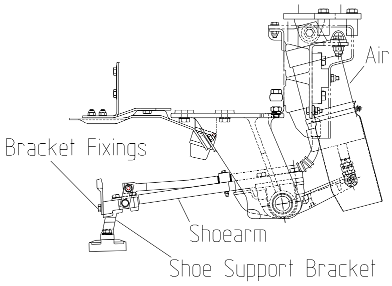
<td>
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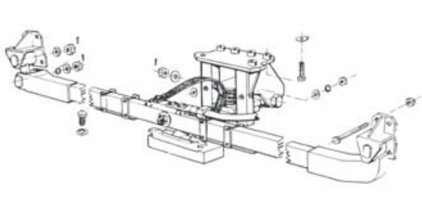
<td></td>
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<td><i>Electrostar, Retractable</i></td>
<td><i>Class 465</i></td>
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Figure 7 Types of Shoegear

4.1.4 Ideal Collector Shoe Characteristics

The ideal collector would have the following features:

- Minimum mass, to enable rapid response to undulations in the rail geometry;
- Maximum strength, to withstand the vibration and shock environment;
- Minimum electrical resistance;
- Simple interface with the bogie for electrical mechanical and pneumatic systems;
- Ability to clear ice from the conductor rail;
- Able to withstand arcing at ramps;
- Materials which do not cause rapid abrasion of the conductor rail.

Traditionally the routes to a successful design have been steady step-by-step development, but it is important that these ideas are condensed into proper design guides and performance standards.

4.1.5 Service Life and Reliability

Report [5] contains detailed discussion regarding shoegear and conductor rail life and reliability, also including fault and delay statistics derived from analyses of the Network Rail FRAME fault recording database and TRUST database train delay data over the period 2001/2 to 2004/5.

4.1.6 Snow and Ice Issues

Ice or snow on the surface of the conductor rail acts as an electrical insulator, preventing proper current collection, and is an obstruction to the free sliding of the shoes. The loss of contact between shoes and rail causes severe arcing, and also reduces the voltage seen by the train. For modern rolling stock this voltage reduction may be sufficient to trigger the low voltage limit and shut down the train.

The problem has existed since the beginning of Southern Railway traction and there are several decades of history of attempts to mitigate the problem, some of which have been documented, but much is in anecdotal form. Means of alleviating icing problems are:

- Prevention of adhesion of ice to the railhead by application of a mineral oil or, other environmentally inert equivalent;
- Lowering the freezing point of slush/snow on the railhead by application of a suitable chemical such as Ethylene Glycol;
- Mechanical ice breaking methods – various methods have been tried but with limited success; and
- Conductor rail heating – limited application due to the amount of power required.

4.1.7 Safety Issues

There are inherent dangers with live, ground level conductors that are mitigated by various measures such as protective boarding where appropriate, access limitations and warning signs/general awareness of the travelling public.

Incidents of accidental contact by persons are documented in official statistics and are often the result of careless maintenance practices for staff, for example research has shown many worker injuries/fatalities could be mitigated by wearing clean protective clothing covering limbs and torso (for further reading in this area see T345: Review and development of safe working practices in electrified areas Report No. 2). Incidents involving members of the public are usually related to discrete geographical sites, for example damaged fences near schools, where trespassers may be ignorant of the dangers posed by the conductor rail.

Dislodged conductor rail shoes are extremely rare - there are no HMRI incident records of personal injury from such events but there are incidents of damage to lineside equipment.

Lineside fires may arise from electrical faults that may not necessarily be detected by normal electrical protection systems, and some lineside fires have been attributable to arcing/sparking of collector shoes where combustible material, such as rubbish accumulation, has been present.

4.1.8 Recommendations

The following areas of further work are suggested by this study:

1. Develop an interface specification for third rail contact system defining the requirements for shoegear running on conductor rail, but without restricting the design of shoegear present or future; and the particulars of the conductor rail system (NB further work carried out as reported, see section 4.3).

2. Optimise the contact force with the shoegear running on the new rolling stock.

3. Investigate the possibilities of improving the shoe/ramp interface to reduce wear, increase speeds, reduce arcing and hence the possibilities of a lineside fire (NB further investigation carried out, see section 4.2 below).

4. Carry out a detailed study of lineside fires on dc electrified routes to determine any correlation with the position of conductor rail gaps etc.

5. Carry out a feasibility study into the economics of using aluminium conductor rail.

6. Undertake some properly-documented tests on icing conditions in the laboratory and on the track and study alternative shoe (e.g. slotted) designs that are more effective at clearing ice.

7. Investigate the possibility of improving current collection by changing the shoe material or contact surface design e.g. narrow longitudinal slots may reduce eddy currents/arcing for a minimal decrease in contact area and thus mechanical wear rate.

8. Investigate whether there is any evidence to suggest that current collection is superior or inferior at locations where aluminium conductor rail is used.

9. Carry out an initial design study for a current collection measurement system.

10. Investigate why the reporting rate for the Merseyrail system is 4.7 times greater than the rate for the former NSE system on a reports per train mile basis.

4.2 Conductor Rail Ramp Ends Study

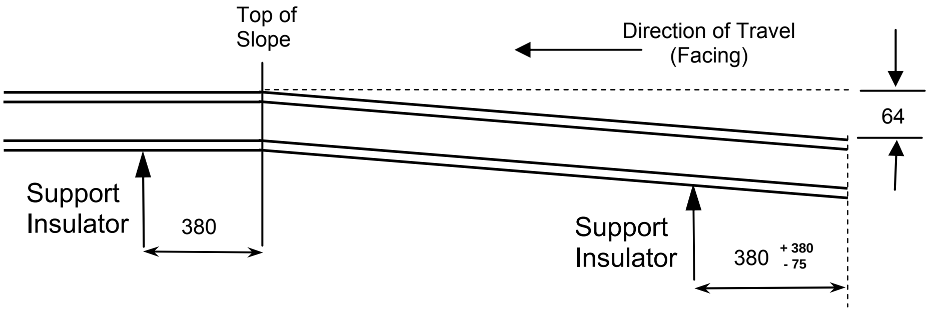
The following aspects of conductor rail ramp end design have been considered:

- Optimisation of the shape of facing ramps for improved shoe ‘pick-up’ performance (reduced impact force, shoe bounce and arcing; and
- Consideration of arc control methods on trailing ramps to reduce the likelihood of arcing damage, flashovers and lineside fires.

These studies are reported in Report [6] and summarised below.

4.2.1 Facing Ramp Dynamics

When free-hanging, the collector shoe will be at some height below conductor rail level (typically up to 50 mm below) thus facing ramps are used to pick-up the collector shoe and guide it onto the conductor rail contact surface. On Network Rail a simple constant gradient ramp is used to achieve this (Figure 8)

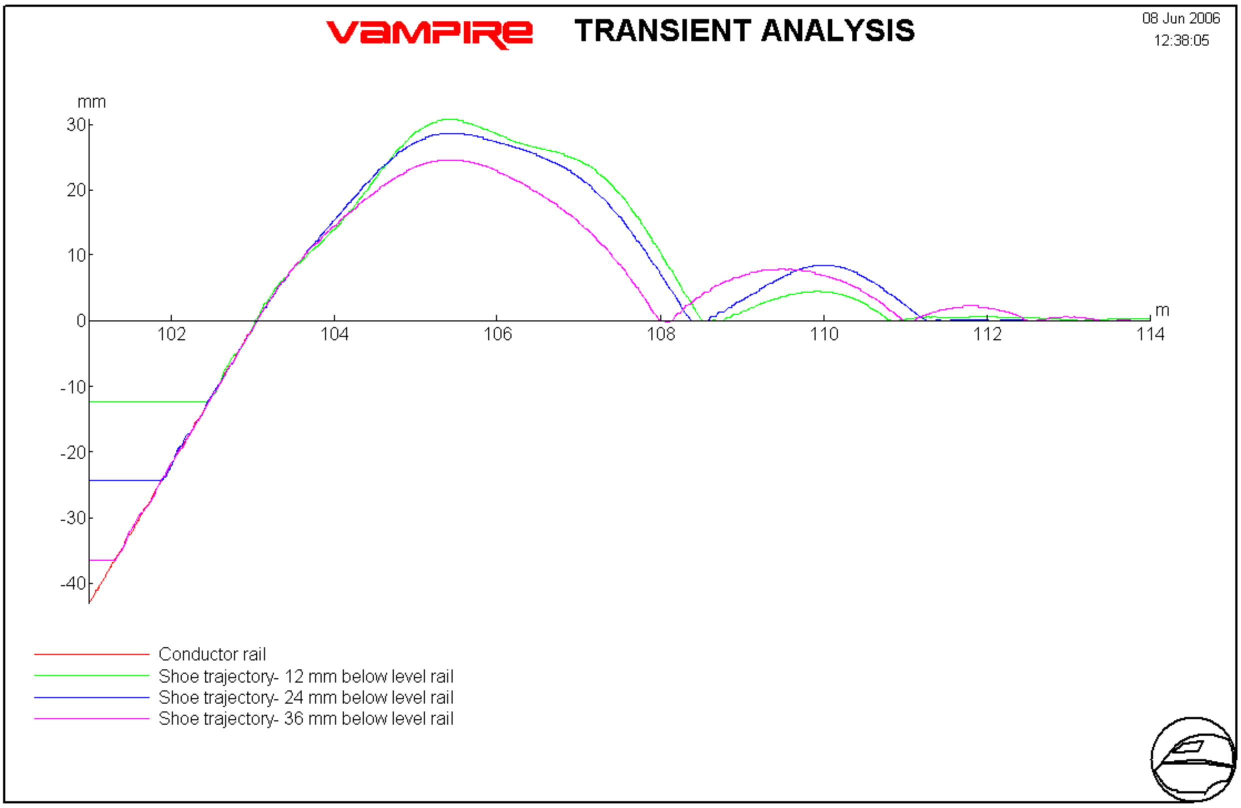


Facing Ramp Dimensions:
High Speed: Ramp Length = 3050, Gradient = 1:48
Low Speed: Ramp Length = 1830, Gradient = 1:30

Figure 8 Network Rail Facing Ramp Dimensions (Single Slope Type)

An initial appreciation of shoegear/ramp dynamics was developed through hand calculations to gain an understanding of the impact energies and forces involved. Those calculations show that peak impact force and acceleration are proportional to line speed and ramp gradient, whereas subsequent shoe bounce (flight height) is proportional to the square of line speed

An analysis of facing ramp dynamics was then undertaken by means of dynamic computer simulation, using VAMPIRE simulation software. A ‘complex’ model was developed incorporating rail stiffness, shoe pitching inertia and stiffness and shoe longitudinal stiffness, it having been found necessary to include these factors to satisfactorily model shoe dynamics. An example ‘shoe bounce’ plot is shown in Figure 9 below.



New 1980 shoegear, 100 mph, 1 in 48 ramp

Figure 9 Shoegear Overshoot Plot Obtained from VAMPIRE Model

The study has shown the importance of ramp slope, with the present 1 in 48 High Speed design considered to be a good compromise between overall ramp length, impact force and limited shoe bounce on initial contact. The initial impact causes a small amount of bounce with most loss of contact occurring with shoe overshoot at the top of the ramp.

The simulation results have been used to determine a ramp transition shape that should eliminate this overshoot such that loss of contact is minimised for speeds up to 100 mph (Figure 10 below).

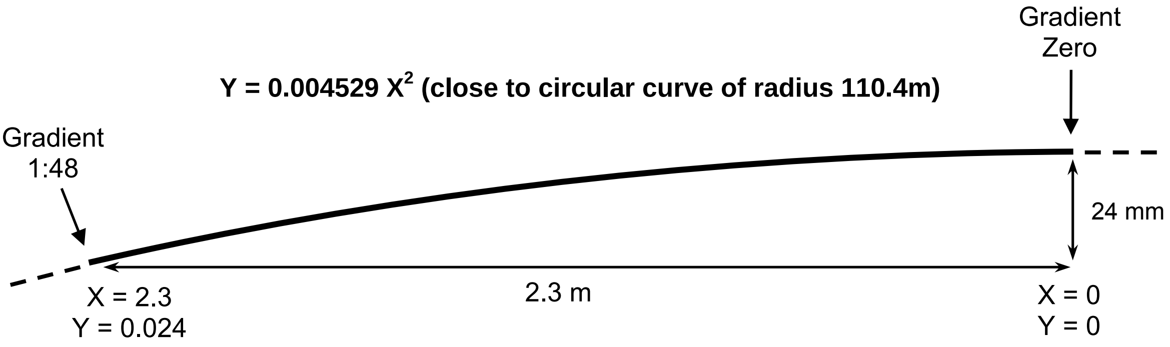


Figure 10 Facing Ramp Transition Shape for Minimal Loss of Contact

4.2.2 Trailing Ramp Arcing

4.2.2.1 Arcing Effects

Severe arcing at trailing ramps may occur if the exiting shoe is the only one on the traction vehicle picking up current due to loss of contact or ‘gapping’ of the other shoes. That collector shoe is then forced to continue drawing traction current after losing contact with the ramp and an arc is set up.

Problems associated with excessive arcing are:
- Risk of damage to the collector shoe apparatus;
- Risk of flashover to running rail, vehicle frame or ground; and
- Risk of lineside fire should combustible materials be present.

4.2.2.2 Arc Control Methods

Various arc control methods have been suggested, which might be employed at specific sites where arcing is known to be a particular problem. Those methods, discussed in detail in Report [6], are:
- Use of arc guides/chutes;
- Use of arc runners;
- Insulating ramp end;
- Semi conducting ramp end; and
- LUL type arc control ramp.

It is concluded that the potential exists to provide control of arcing at trailing ramps by means of a suitable design or designs, however in-service evaluation would be required to select the most effective and appropriate design.

4.2.3 Recommendations

The following recommendations are made in Report [6]:

1. Trackside measurements of the dynamic behaviour (facing ramp shoe bounce height, flight distance) of modern shoegear are required to provide sufficient validation data for the simulation model, as only very limited suitable test data are currently available. Such measurements should also include instrumentation of a shoegear for measurement of impact force.

2. Further to, or in conjunction with the above measurements, a prototype version of the ‘no contact loss’ ramp shape should be installed at a suitable location for technical evaluation and to enable practicality and cost issues to be explored for cost/benefit evaluation.

3. The simulation should be extended to modelling level conductor rail/shoegear dynamics for the purpose of quantifying overall system interface dynamics (NB validation data are however required as per recommendation 1). Characterisation of the current collection interface is required for a prospective Conductor Rail Interface Specification that will be beneficial to equipment suppliers, train operators and infrastructure maintainers.

4. In service trials of one or more designs of arc-control ramp should be undertaken such that cost/benefit may be evaluated.

4.3 Conductor Rail Interface Specification

Further to the recommendation made in Report [5], progress has been made with developing a conductor rail interface specification (Report [7]).

Such a specification is primarily concerned with the geometry and mechanics of the interface between the collector shoe and conductor rail, and is intended to be applicable to Network Rail and Merseyrail dc third rail electrification schemes.

The interface specification is intended to cover the follow aspects of the shoegear/conductor rail interface:

- Conductor Rail size, shape and materials;
- Conductor Rail geometry including ramp ends;
- Collector Shoe size, shape, materials and static contact force;
- Collector Shoe swept envelope and hanging height limits;
- Dynamic interaction between the Collector Shoe and Conductor Rail – impact force and current collection performance requirement;
- Acceptable wear limits; and
- Protective measures.

Much of the information incorporated into Report [7] is derived from existing Network Rail standards and documents and includes commentary, where appropriate, on the rationale underlying the derivation of interface parameters.

It is has become apparent in the course of developing the interface specification that, unlike for the pantograph/OLE interface, the dynamic environment at the shoe/conductor rail interface is not well understood or characterised. For example, there is very little test data that can be referred to for an understanding of contact force variations or the range of impact forces typically experienced by collector shoes.

Such information might be derived from theoretical studies and dynamic simulations (recommendation 3 of section 4.2.3), but validation of simulation results would also be required (recommendation 1 of section 4.2.3) and suitable measurements are therefore necessary to properly characterise present current collection dynamics. Furthermore, effective infrastructure monitoring (i.e. measurement of conductor rail quality as seen by shoegear) would require the development of an instrumented collector shoe. Such a device might be operated on an infrastructure monitoring train, in a similar manner to the well established practice of using an instrumented pantograph to monitor the condition of the OLE.

5 Power Supply Systems

Two studies have been undertaken with regard to electrification power supply and distribution systems:

- Life Expectancy of Electrical Equipment (Report [8]); and
- Improving the Power Supply (Report [9]).

5.1 Life Expectancy of Electrical Equipment

This section is intended to provide a broad overview of electrification life expectancy and equipment management issues that have been considered in more detail in Report [8].

5.1.1 Electrification Asset Management

In judging the life expectancy of assets system managers must try to draw from the experience not only of their own asset base, but where possible should also consider similar systems in other applications. Railway electrification assets are similar to those employed in the electricity supply industry and indeed in several instances common components have been procured.

It is logical therefore for electrification asset managers to consider the experience of this other industry when planning maintenance and renewal strategies. However, this consideration must take into account the differences that exist for example in system voltages, duty cycle (particularly short-circuit and other peak loadings) and local environment.

5.1.2 Asset Types

GB electrification asset types includes a range of electrical equipment, including:

- Traction supply transformers (feeder and auto-transformers)
- Traction supply rectifiers (DC system)
- Booster Transformers
- A variety of cabling (e.g. insulated feeders, bare feeders, return conductors, earthing and bonding etc)
- OLE contact system and supporting structures
- Conductor rail
- Insulators
- Switchgear (Circuit breakers of various types, isolators)
- Control and monitoring equipment (SCADA).

Thus the scope of assets involved is broad, with an expected life for much of this equipment in the region of 40 – 60 years.

5.1.3 Asset Age Profile

The age profile of Network Rail electrification assets, specifically relating to OLE isolators, AC/DC switchgear and power transformers, has been determined by examination of the RAR database and is shown in Figure 11 below.

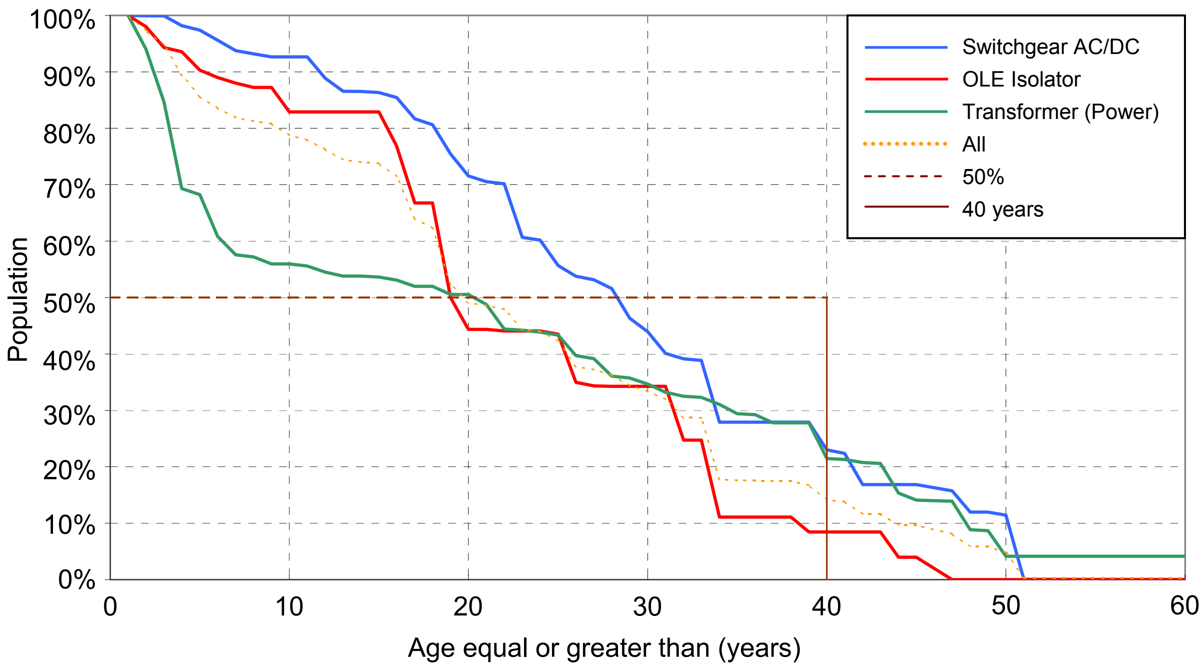


Figure 11 Age Distribution of Network Rail Infrastructure Electrification Assets

5.1.4 Renewal Strategies

For particular situations, a balance needs to be struck between drivers falling within the range of issues to be addressed. There is recognition of the inevitable need to replace equipment at some stage once it has gone beyond its economic life whilst at the same time a need to avoid unnecessary early replacement. Within the overall strategies that exist, individual replacement decisions need to address factors other than age.

Various condition assessment and monitoring techniques can be used to determine fitness for purpose and identify priority situations thereby contributing to the replacement or refurbishment decision.

5.1.5 Key Questions

The following comments relate to key questions raised in the specification for RSSB Project T346 in relation to life expectancy of electrical equipment.

What are the criteria that determine 'life expiry'?
The criteria that determine 'life expiry' includes age as one factor only in a range of particular location or plant issues embracing safety, fitness for purpose, cost of continued duty and whether a modern version would justify replacement.

Is it possible to safely extend the life of this equipment and if so, how far?
It is possible to extend the life of equipment provided that the safety issues for specific types and usage of equipment are adequately considered. The degree of possible life extension depends on fitness for purpose, condition, ongoing reliability and economics of replacement as determined through appropriate risk based assessment of particular items of equipment.

What factors need to be considered in making this decision?

The factors that need to be considered are those specific to the type of plant, its location, usage and as determined by risk based assessment methods to be developed within an overall plant asset management strategy that includes consideration of plant population age profile.

Are there techniques that can accurately predict the point at which the equipment needs to be replaced?
Condition assessment and monitoring techniques can provide a foundation for detecting or predicting increases in the likelihood of failure and prioritising plant replacement. However, they rarely predict the precise point at which the equipment needs to be replaced.

Should changes be made to the maintenance regime and is any additional monitoring necessary?
The maintenance regime should be assessed and appropriate changes implemented to adopt the risk based techniques currently available such as Reliability Centred Maintenance (RCM) and Condition Based Maintenance (CBM). From such approaches, the application of and benefits to be gained from various condition monitoring techniques will emerge for integration within an overall asset management strategy that addresses both asset maintenance and asset renewal.

Is an increase in electrical failures due to degraded insulation expected in the near–to-medium term future?
Partial discharge condition monitoring techniques can be used to provide a broad indication of insulation degradation and thereby an increase in the likelihood of failure. However, the electrical failure event itself is not readily predicted. Partial discharge monitoring can be valuable in locating discharge points and providing an input to decisions about maintenance and replacement of specific items of plant to reduce the likelihood of failure.

What strategies are available to undertake replacement work in a manner that is cost effective, yet minimises system risk?
Risk based asset management techniques are available for assessing overall issues in specific situations such as safety, the operational risk resulting from continued operation of aging plant, risk of spares replacement etc. Such risks can be expressed in economic terms and combined with costs of renewal and maintenance in an overall cost minimisation approach. If potential discharge surveys were to indicate generally increasing activity levels that would point to future increases in insulation failures.

Should replacement be driven by condition and system risk?
Both condition and system risks are aspects that feature alongside others (e.g. safety, age, reliability, maintenance cost, losses, obsolescence, environmental issues) within an overall asset management strategy embracing plant replacement.

Consider the increasing risk of delaying the start of any replacement schedules.
The typical risk factors to be considered in delaying the start of replacement schedules include safety, reliability, maintenance cost, obsolescence, environmental issues and operational system risk.

5.1.6 Recommendations

Recommended areas of further work or development in respect to electrical equipment life are:

1. Ongoing studies to determine in detail the present extent and age profile of electrical equipment assets, how replacement decisions are currently made, current asset replacement rates, future projections for asset age profiles, assessment of appropriate target lifetimes, assessment of requirements for asset renewal funding and assessment of overall asset management plans. The existing railway industry asset management policies, strategies and plans should be assessed for their adequacy and improvements identified that will enable the implementation of best practice in accordance with immerging standards.
2. Review the present asset management information systems in use to determine their adequacy or identify necessary improvements and ongoing asset reviews/surveys to establish the extent of assets of particular type, age and usage and enable asset age profiles to extended.
3. Review existing assumptions for the service lives of electrical equipment in use, establish ‘targets’ for average plant age and from available asset age profiles, identify improved models for renewal planning that will clarify the levels of forward investment necessary for achieving and maintaining the ‘targets’.
4. Review the current approaches to condition assessment and the renewal decision processes that are in use within the railway network. Where appropriate, consider improvements to the processes including the application of qualitative risk based methods.
5. Assess the applicability of appropriate condition monitoring techniques and programmes that will contribute to the forward analysis and planning for asset renewal.
6. Assess and identify revised inspection and maintenance regimes that will benefit from the approaches of condition assessment, condition monitoring and analytical risk based optimisation as part of an overall asset management programme.

5.2 Improving the Power Supply

The safety, reliability and performance of the power supply is critical for the successful operation of any electrified railway.

Consideration has been given to the following specific areas:

- A review of recent failures data, including identification of any failure trends;
- Common modes of failure of 25 kV ac and 750 V dc power supply systems;
- The detection of failed traction bonding;
- The detection of failed booster transformers;

- The reliability of rectifier open circuit arm detectors; and

- Undetected failure modes.

5.2.1 Recommendations

The recommended areas of work or development with the potential for improving the reliability of the power supply/distribution equipment are:

1. Obtain improved failure statistics for supervisory equipment on the 750 V dc routes and compare these with the 25kV routes. Compare the types of supervisory equipment fitted on all the routes (25 kV and 750 V dc) and investigate why the failure rate varies significantly between 25 kV routes. The recent replacement of the SCADA system on the ECML and WCML must be taken into account when undertaking this work.

2. Analyse dissolved gas analysis records for booster transformers to determine how effective the method is at predicting the failure of booster transformers.

3. Investigate further the failure of low voltage equipment to determine if there are any common failure modes.

4. Do not introduce any additional monitoring equipment until the investigation into low voltage equipment failures is complete so that any lessons learned can be incorporated in the design/specification of the equipment.

5. Obtain improved failure statistics for rectifier open circuit arm detectors.

6. Use Failure Modes and Effects Analysis to determine whether there are any undetected failure modes.

7. Investigate further the possible correlation between OLE failures and power supply/distribution equipment failures.

6 Bibliography

Further information may be found in the following RSSB project T346 ‘Investigating the Potential for Improvements in Electrification’ reports (available on request).

Report [1] Improving the Existing Pantograph/OLE system

Report [2] Pantographs – Collector Strips and ADD Systems

Report [3] Pantograph Interface Modelling

Report [4] OLE Systems for the Future

Report [5] Improving Conductor Rail Interfaces

Report [6] Conductor Rail Ramp Ends

Report [7] Conductor Rail Interface Specification

Report [8] Life Expectancy of Electrical Equipment (summary only)

Report [9] Improving the Power Supply (summary only)

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