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# A Good Practice Guide for Managing the Wheel-Rail Interface of Light Rail and Tramway Systems

This guide contains recommendations for best practice in wheel-rail interface management to reduce derailment risk over the whole life of the system. This work should be read in conjunction with RTU report 90/3/A, “Determination of Tramway Wheel and Rail Profiles to Minimise Derailment” [1]. The guidance is split into sections reflecting the life cycle of light rail projects from initial specification to eventual operation. It is not possible within this context to provide prescriptive specifications that can be followed in all cases. Light rail and tramway systems vary considerably in their track construction, track alignment, vehicle types and operational characteristics. However, the guidance below should form a useful checklist to ensure that wear and derailment risk are minimised.

## 1. Wheel-Rail Interface Specification

**Fundamental principle:** a detailed specification for the wheel-rail interface should be produced at an early stage that includes compatibility of the selected wheel and rail profiles for plain line and switches & crossings (S&C). The specification should state performance and expected life of both wheels and rails and consider future maintainability.

### Detailed considerations:

- 1.1. Wheel and rail profiles selected must be geometrically compatible for both plain line and S&C. With respect to the track, critical dimensions include the track gauge (for which a gauging point should be specified), the width and depth of rail groove, the check rail gauge and the need for flange tip running or for running on shared infrastructure (e.g. a mixture of light and heavy rail S&C with different check rail gauges). Further detailed advice on geometric compatibility issues for plain line and S&C may be found in [1] and [2]. Considering the wheelset, critical dimensions include the back-to-back dimension, the flange thickness and shape, tread conicity and wheel diameter.
- 1.2. Rail profiles should be selected and wheel profiles designed to achieve the best possible compromise between steering and vehicle lateral stability. This

requires the co-operation of track and vehicle designers and ideally should include vehicle dynamic simulation of the proposed vehicles by the manufacturer to optimise the chosen wheel profile. Advice on light rail wheel profile design together with suggested profiles for common rail profiles may be found in RTU report 90/3 [1].

- 1.3. The contact conditions generated by the chosen wheel and rail profiles should be checked to ensure that they do not produce excessive contact stress or wear.
- 1.4. All parties involved in the interface specification should understand that its eventual performance is a function of how the wheel and rail profiles work together and the profiles cannot therefore be selected in isolation.
- 1.5. When specifying new systems, provision should always be made for an underfloor wheel lathe, without which wheel profiles cannot be economically maintained.
- 1.6. The interface specification should consider how the system is to be maintained in future. This would provide allowance within the infrastructure necessary to enable currently available on-track plant such as tamping and grinding machines to be employed and suitable road and/or rail connections to allow supplies such as ballast and rails to be delivered to the network.
- 1.7. A key consideration is the maintainability of embedded rails in street running sections. The expected life of these rails should be predicted and the track system specified to facilitate eventual replacement. Rail steel grades for tight curves should be chosen to allow side or head wear to be rectified by welding. In practice this may dictate the use of 'normal' grade rail steel which does not require pre-heating to temperatures which degrade any surrounding rubber or polymer material. Detailed guidance on these issues may be found in [2].
- 1.8. Gauge widening is often applied on 'tight' curves in heavy rail alignments with the aim of allowing the wheelset to exploit the available conicity to steer. This may however be found to be counter-productive in light rail and tramways where very small radius curves preclude the wheelset steering other than through flange guidance. In this case gauge widening simply has the effect of decreasing the clearance between the flangeback and keeper rail, leading to premature wear and failure of the keeper. Gauge widening should therefore be restricted to curves which are large enough for flange free curving to occur.

- 1.9. Design of the track form should allow for positive gauge restraint, either by attaching rails to concrete sleepers / slab or through the use of tie-bars attached between the rails. It should be remembered that the installation of tie bars can themselves cause rail stress raisers if not installed at sufficiently small intervals and should never be installed singularly. Depending on the design of the track layout it may be possible use tie-bars only at the small-mid radius curves where gauge spreading forces are greatest.
- 1.10. The basic design layout of any new system should avoid tight (small) radius curves where at all possible. Small radius curves can often lead to wheel squeal (noise) and wear problems, coupled with an increased risk of derailment. These factors contribute significantly to increased maintenance costs for both vehicle (wheel wear) and the track. Considerable benefits can be gained through relatively small modifications to track layout at the design stage.

## 2. Contractual Arrangements

**Fundamental principle:** Contracts should recognise the wheel-rail as a key interface and contractual arrangements at all stages of the life-cycle should ensure that responsibility for the wheel-rail interface is clearly defined. Contracts should encourage active and integrated management of the interface.

### **Detailed considerations:**

- 2.1. During the design and delivery of a light rail project, there should be a nominated design authority whose remit covers both sides of the wheel-rail interface. The authorities' responsibilities should include cross interface requirements such as vehicle mounted lubrication.
- 2.2. The delivery contract for the system should include preparation of suitable wheel-rail interface maintenance standards (see below) and sufficient technical documentation of track and bogie design to allow investigation of future interface problems.
- 2.3. Design, delivery and maintenance contracts should be checked to ensure that key parts of the interface are the responsibility of only one party in the contract, thereby reducing the risk of incompatibility issues.

- 2.4. Maintenance contracts should specify performance indicators that encourage active management of the interface. These might include, for example, passenger comfort and rail life.
- 2.5. Where possible both vehicles and track should be managed by a single organisation with the necessary skills, knowledge and equipment to carry out the majority of routine maintenance in-house.
- 2.6. Where maintenance of track and/or vehicles is sub-contracted by the system operator to third parties, the operator should retain sufficient technical knowledge in-house to ensure the competence of the sub-contractor. These competences should be subject to regular audits of completed work by the operator which should include inspection of the works themselves rather than just the supporting documentation.
- 2.7. A formal relationship should be agreed between the operator, track maintainer and vehicle maintainer/manufacture which allows for performance and safety enhancing changes to be made across the system, without commercial or political obstruction.
- 2.8. Consideration should be given to specifying the expected life of key components in the wheel-rail interface and who rectifies them if expectations are not met. This applies particularly to rails (plain line and S&C) where problems may develop over considerable time periods and early investigation / rectification is often neglected.
- 2.9. Contracts should allow for a rational approach to managing the wheel-rail interface. A relatively common example of this not happening is where a maintainer is discouraged from carrying out certain track maintenance as the cost for all track renewals is borne by the system owner.

### 3. Standards

**Fundamental principle:** standards should be set which control all key components in the wheel-rail interface, ensuring that coherent wear limits are set for both sides of the interface that retain a margin of safety when wheel and rail are at their respective outer limits.

#### **Detailed considerations:**

- 3.1. Track and vehicle standards must not be developed in isolation. For example standards governing wheel flange height and rail head wear should be matched to preclude the possibility of a wheel at maximum flange height striking fishplates or rail grooves.
- 3.2. Wheel standards should as a minimum specify:
  - limits on flange height and thickness and wheel flange angle where required.;
  - maximum sizes for defects such as wheel flats, rolling contact fatigue, tread rollover, toe-radius build up, hollow wear etc;
  - minimum acceptable surface finish on newly turned wheels;
  - inspection frequencies for wheel geometry and defects;
  - minimum actions, with timescales, when wheel wear or defects are identified.
- 3.3. Rail standards should specify as a minimum:
  - limits on side and head wear for plain line with additional limits for keeper rail wear in grooved rail;
  - limits on wear through switches including at the toes, through stock rails and at the crossing nose;
  - minimum value for the toe opening at switches
  - maximum permissible gap between switch and stock rails at switch toe
  - minimum and maximum check rail clearance in S&C and plain line
  - maximum sizes for defects such as rolling contact fatigue, lipping, rail foot defects, squats etc.;
  - minimum standards for smoothness of cross sectional profiles following weld repairs to plain line and S&C including restoration of correct profiles at switch toes;

- inspection frequencies for rail wear and defects;
  - minimum actions, with timescales, when wear or defects are identified;
- 3.4. Track geometry standards should specify:
- minimum permissible curve radii, this will be dependent on many factors, including; the vehicle axle and bogie spacing, suspension design, wheel flange design, rail groove width, wheel-rail conicity etc, absolute minimum values are therefore system dependant and it is that these parameters are studied before quoting a minimum curve radius;
  - The combination of vertical and horizontal curvature, together with cant should be considered, so as not to impart unnecessary wheel unloading in curved track sections.
  - permissible ranges of design values for gauge, cant, rate of change of cant, cant deficiency and rate of change of deficiency (vehicle and track dependant);
  - the largest track twist permissible (vehicle dependant);
  - whether or not gauge widening is to be applied in small radius curves, this should consider the vehicle configuration, curve radii and wheel-rail conicity, in general low conicity systems (DIN type wheel and rail profiles) will not benefit from gauge widening;
  - maximum values for vertical and lateral irregularities and minimum and maximum values for gauge;
  - inspection frequencies for track geometry defects;
  - minimum actions, with timescales, when defects are identified;
- 3.5. Standards should specify simple wheel and rail inspection gauges where appropriate, e.g. flange height / thickness gauge, rail side and headwear gauges, switch tip wear go / no-go gauge, wheelset back-to-back gauge etc.
- 3.6. It is essential that standards not only define how the interface is to be maintained in a safe condition, but the competencies required of those who inspect, maintain and sign-off work on both sides of the wheel-rail interface.
- 3.7. Responsibility for reviewing and updating standards related to the wheel-rail interface should be placed with a single individual with sufficient knowledge and competence to carry out the task. The ownership of standards should form part of the safety management system such that it is re-allocated when individual staff members leave the company.

- 3.8. The reasons for changes in standards should be documented in technical reports which should be retained so that the 'history' of a given standard can be understood in future.

## 4. Inspection and Monitoring

**Fundamental principle:** formal inspection and monitoring regimes should be implemented which identify gross defects, ongoing degradation and emerging wear problems in a timely manner.

### **Detailed considerations:**

- 4.1. It is essential that sufficient equipment is available to allow inspection and monitoring of the wheel-rail interface. This is likely to include off-the-shelf equipment such as cant and gauge sticks, track geometry trolleys, Miniprof wheel and rail profile measuring devices, ride comfort meters etc, for strategic management of the system by engineers, as well as custom made hand-held gauges such as those detailed in 3.5 above for use as simple maintenance checking devices by track workers.
- 4.2. Use of electronic wheel and rail profile measuring equipment is useful in determining wear patterns and wear rates. An example of such equipment is the MiniProf manufactured by Greenwood Engineering.
- 4.3. All tram and light rail systems should have a means of measuring track geometry which is suitable for both flat bottomed and grooved rail. Standard track geometry trolleys may require modification for use on tight curves, with grooved rail, on light rail S&C and on raised check rails.
- 4.4. The level of sophistication of track geometry trolleys varies considerably. For example a lightly trafficked system constructed entirely on slab track requires less rigorous inspection than a heavily trafficked one on ballasted track. A minimum requirement should be for a trolley to measure track gauge, check / keeper rail gauge and track twist.
- 4.5. It should be noted that the ability of track geometry trolleys to measure short wavelength lateral and vertical irregularities and long wavelength curvature is often very limited. This should be reflected in maintenance standards which specify limits which can actually be inspected using the available equipment.

- 4.6. Measurement of passenger comfort using either temporary or permanently installed on-board equipment may prove useful in detecting both gross vertical and lateral alignment faults and trends in deterioration. However, it should be noted that as such measurements are effectively 'filtered' by the vehicle suspension, they should not be relied upon as the sole means of detecting emerging wear problems. Certain wear problems may reach an advanced stage before they can be reliably detected by passenger comfort measurements, and having reached this point may be very difficult to correct.
- 4.7. All staff carrying out inspection of the wheel-rail interface should hold the relevant competencies and should have received specific training on the common causes of interface problems in general and derailment risks in particular.
- 4.8. In addition to the frequent track walks carried out by patrolmen to identify gross faults and maintenance requirements, including items such as loose rail clips or fixings, there should be a programme of inspection to identify longer term issues associated with build up of wear to rails and wheels. This would normally be carried out by engineers with specialist wheel-rail interface knowledge.
- 4.9. Managers responsible for the safety of the interface should not rely solely on reports from patrolmen but should ensure they frequently update their own knowledge by track walking and examining vehicles. This also presents the opportunity to ensure that track and rolling stock technicians have an appreciation of the issues surrounding safety of the interface and derailment prevention.
- 4.10. Typical wear rates should be calculated and recorded for wheels and for rails. For wheels this should include separate rates of change for flange height and thickness for motor bogies, trailer bogies and bogies with Independently Rotating Wheels (IRWs) as applicable. For rails this should include side and head wear for straight track and a variety of curve radii for both flat bottomed and grooved rail. When selecting sites for calculating rail wear the effects of cant deficiency, varying traffic tonnage, rail grade and lubrication should be considered.
- 4.11. Should the system deteriorate to a point where contact occurs on keeper rails, keeper rail wear rates should be calculated and inspection enhanced until the problem can be rectified.

- 4.12. Inspection regimes must recognise the increased derailment risk presented by S&C. Critical areas include the planed part of the switch and the crossing nose with particular emphasis on the initial 1-2m at the switch toes where the blade is weakest and the impact forces are highest. Attention must be given to damage to switch, stock and crossing rails, lipping that obstructs the correct seating of the blade against the stock rail and maintenance of toe opening and check rail clearances. The ongoing compatibility between the worn wheel flange shape (flange angle and thickness changes) and the switch toe should also be monitored.
- 4.13. All inspection and monitoring activities should record information about the performance of the wheel-rail interface in a detailed and systematic manner. This should not just include faults and maintenance requirements but also wear rates, track geometry, maintenance records, wheel and rail profiles, details of technical investigations etc. This latter set of information is essential to ensure that emerging interface problems can be identified and investigated.
- 4.14. It is advisable to enhance inspection frequencies when events occur which may affect the equilibrium of the interface examples of which include grinding, major renewals, extensions to the network, changes in wheel turning regime (e.g. due to a change in wheel profile or wheel lathe faults) or the introduction of new types of vehicles. A checklist of items to be considered when introducing new vehicle fleets onto existing systems is given in Appendix 1. Major rail renewals or the introduction of a greater than normal population of new wheels (e.g. from new vehicles or bogie overhauls), may have a significant effect on wear rates on both sides of the interface.

## 5. Maintenance

**Fundamental principle:** vehicle and track maintenance should be carried out in an integrated manner to established standards that ensure the safe operation of the wheel-rail interface.

### Detailed considerations:

- 5.1. Responsibility for every component in the wheel-rail interface should be clearly defined.
- 5.2. Wheel lathe operators should record appropriate information about each wheel turned including date of turning, km run since last turning, pre and post turning diameter, defects and the depth of cut required to remove them.
- 5.3. Vehicles may become susceptible to derailment if wheel loads are not evenly distributed within each bogie. Some vehicle primary suspension designs may require the use of wheel weighing equipment or a specially designed test rig to ensure even load distribution following bogie overhaul or attention to the primary suspension.
- 5.4. Wheel turning should restore the full flange thickness in order to guard against derailments (possibly through increased flange angle interacting with S&C) and to help minimise the possibility of flangeback contact with the keeper rail.
- 5.5. Consideration should be given to regular planned wheel turning to maintain conicity and/or desirable contact conditions. This may be considerably more frequent than required to stay within flange height and thickness limits.
- 5.6. A number of factors should be taken into account when determining the optimum wheel turning regime. For example where reliable on-board and/or track mounted lubrication is used, wheel turning intervals may be extended, whereas a system having tight curves and poor lubrication may require frequent wheel turning. A governing factor in this latter case is often the avoidance of excessive depth of cut (and hence reduction in wheel diameter and life) to restore a full flange thickness.
- 5.7. When considering wheel turning regimes, it should be noted that the rail will wear to the average shape of the worn wheels in the fleet. If wheels run very large mileages between turning their shape, and hence the worn shape of the rail, may change very radically from the original design profile. Newly

turned wheels will then be geometrically mismatched with the worn rail shape leading to high contact stresses and wear rates on both sides of the interface. High mileages between turning are therefore only practical if the worn wheel exhibits only modest changes in shape from the new profile. These conditions are less likely on light rail systems where a variety of track types and alignments are encountered. In practice is often found that a regular turning regime provides optimum interface performance. The management of the interface in this way can also be achieved through rail grinding/milling.

- 5.8. Wheel lathes should produce a smooth profile that meets the surface finish requirements defined in standards (see above). Steps or grooves, particularly on the wheel flange are unacceptable and will promote derailment.
- 5.9. On-vehicle flange lubricators should be inspected and maintained frequently. Where stick-lube is used, a simple setting gauge should be used to check the correct positioning of the stick. If wheels are required to run for very long periods without turning (e.g. through failure of a wheel lathe), the position of the stick should be adjusted to prevent a large, flat, unworn facet developing at the flange root in the position that the lubrication is applied.
- 5.10. Independently rotating wheels (IRW) have a tendency to offset running, whereby the lack of steering forces associated with IRW's leads to the bogie running in arbitrary positions within the gauge (offset) and may not therefore collect lubricant effectively from trackside lubricators. In this case wear issues may need to be addressed with on-board stick or grease wheel lubrication systems.
- 5.11. In conditions where increased derailment risk might exist, for example from newly ground switches, or when check/guard rails have been removed for maintenance etc, supplementary lubrication should be applied to the gauge corner / face of the rail by hand.
- 5.12. Street running systems should normally be maintained to avoid wear of the keeper rail by controlling sidewear, wheel flange wear and gauge spreading. Wear of keeper rails will eventually lead to their failure, at which point a wheel flange is likely to strike the broken keeper, leading to derailment.
- 5.13. A feature of many derailments is discrete track twist or cyclic twist / top track geometry which causes wheel unloading. It should be noted that the degree of wheel unloading in response to track twist is largely independent of speed

and temporary speed restrictions may only mitigate the consequences of a derailment rather than preventing it happening.

- 5.14. Repairs to S&C by welding and grinding carry a particular risk due to the possibility of producing a profile on the switch blade which encourages flange climbing, coupled with increased friction as a result of the 'rough' surface produced by grinding. Such repairs should always be carried out by persons who have an assessed competency in weld repair of S&C and the completed work should be inspected and signed off by a competent engineer having checked both the profile of the repaired rail including assessment of surface roughness (for friction conditions) together with the mechanical operation of the switch. Consideration should be given to hand lubrication of the ground gauge face for a short period following repair.
- 5.15. Rail grinding is commonly used on light rail systems to control corrugation. Whilst undoubtedly beneficial, this may change the rail profile shape in a manner that is undesirable from the point of view of the contact conditions. Grinding contractors work should be carefully audited to ensure changes are understood and changes made if appropriate (e.g. lubrication if conicity reduced). Consideration may be given to techniques such as offset grinding which attempt to restore the original rail profile.

## 6. Operational Management

**Fundamental principle:** the wheel-rail interface should be actively managed to ensure its safety both during normal operations and during periods of change. The management of the interface should not be impaired by the traditional divide between track and vehicle engineering.

### **Detailed considerations:**

- 6.1. Wear of wheels and rails (which cause both derailment risks and interface problems) is usually progressive over a period of time. Good record keeping is therefore essential to the management of wheels and rails.
- 6.2. If possible, records for both sides of the interface should be stored together to allow both track and vehicle engineers access to the information and to encourage the interface to be viewed as a system.

- 6.3. Management of the wheel-rail interface will be improved if the separation of vehicle and track engineering functions is reduced. This may be achieved by designating responsibility for the performance of the interface to a single engineering manager or setting up regular interface management meetings where track and vehicle engineers evaluate wheel-rail performance.
- 6.4. Both professional and technician staff should receive appropriate training in the wheel-rail interface management with particular emphasis on avoiding conditions likely to promote derailment.
- 6.5. When changes occur that may impact the performance of the wheel-rail interface, appropriate short term actions should be taken to ensure that the system remains within safe limits and that any accelerated wear is identified and managed. Examples of system changes include introduction of new fleets, extensions to the network, major bogie overhauls, significant re-railing or track renewal, changes to the established maintenance practices (wheel turning, wheel profile, rail grinding etc.).
- 6.6. Another type of major system change to be considered is the extension of an existing light railway. Some of the advice provided in appendix 1 is relevant, but a key consideration is ensuring compatibility of new and existing interfaces. Where different rail profiles are selected for the extension (usually on the grounds of cost / availability), the geometric compatibility checks described in Section 1 should be carried out to confirm their suitability.

## 7. References

1. Allen P and Bevan A, 'Determination of Tramway Wheel and Rail Profiles to Minimise Derailment', Manchester Metropolitan University, RTU report 90/3/A, February 2008.
2. 'Local and regional railway tracks in Germany', (in German and English), VDV, Cologne, 2007, ISBN 978-3-87094-674-6

## **Appendix 1: Checklist for the Introduction of New Vehicles onto an Existing System**

A number of systems issues should be considered when introducing new vehicle fleets onto existing tramway or light rail systems. The following is intended to provide a checklist of items from the perspective of the wheel-rail interface.

### **1. Existing Interface Conditions**

- Is a monitoring and data collection regime in place?
- Parameters for monitoring might include, wheel and rail profiles, track geometry, rail and wheel defects, noise, lubrication, rail clip / fastening breaks, renewal rates, route tonnages, braking / acceleration patterns, friction levels etc.
- Checks should be made that rail clip/fastenings are not broken, and whether they are loose/out of alignment.
- Is the monitored data (wheel and rail) stored in a central location and analysed in a manner that yields an understanding of the prevailing interface conditions for both track and vehicle engineers?
- Has the relevant data (particularly track geometry and wheel / rail profiles) been made available to the vehicle manufacturer?

### **2. Geometric Compatibility**

- Will the new fleet use existing wheel profiles?
- If so, does this profile give optimum performance if the vehicle design is significantly different to existing vehicles?
- Could overall system costs be optimised by a new wheel profile or revised turning interval?
- If a new profile is to be introduced, has analysis been carried out to check derailment risk under the full range of expected conditions? Is the new profile compatible with the existing S&C geometry?

### **3. Vehicle Design**

- Is the vehicle designed using a realistic conicity range?
- Could the design be improved by controlling the conicity by other means (e.g. rail grinding)?

- Has a passenger comfort benchmark been set against existing fleet performance (often neglected in new train performance)?
- How does the curving ability of the new fleet compare with the existing vehicles (important implications for wheel life, rail wear, rolling contact fatigue etc)?
- How tolerant are the new trains of degraded track conditions, i.e. how far 'out of spec' can the track be before the vehicle derails? – important if new trains are less tolerant than the old fleet for example in their ability to negotiate track twist.
- Has adequate provision been made for on-board flange lubrication?
- Does the Train Data Recorder have the ability to measure interface related parameters (e.g. vertical acceleration, suspension displacement). Would such provision be useful in improving infrastructure monitoring?

#### **4. Wheel and Rail Wear**

- Are existing wheel and rail wear rates calculated and understood?
- Have wear predictions (for wheels and rails) been carried out using simulations of the actual route from measured track geometry?
- Will the new fleet improve or degrade wheel / rail life?
- Unless the curving and wear performance of the new fleet is identical to the old, changes in the track maintenance regime are likely to be required (e.g. flange contact may occur at larger curve radii requiring additional lubricators). Have the track engineers been made aware of the likely changes?

#### **5. Track Degradation, Rail Damage and Rolling Contact Fatigue (RCF)**

- Are existing track degradation and damage conditions understood?
- How do new and existing fleets compare in terms of their impact on the track (steering ability, wheel load, contact stress, unsprung mass, suspension stiffness, simulated track forces etc.)?
- Have the vehicle design decisions been tested in any existing track deterioration / asset management models?
- Has consideration been given to the design of wheelsets with regard to limiting noise and propensity to generate corrugation?

## **6. Monitoring and Maintenance Regime**

- Is a robust monitoring regime in place on both wheel and rail sides of the interface that will collect data from the day the first new vehicle is introduced on test? (if data is not collected then the opportunity to solve problems as they arise can be limited)
- Will the data be centrally stored and analysed to ensure joint understanding by track and vehicle engineers?
- Are track engineers informed and prepared for the likely changes needed to the track maintenance regime when the new fleet is introduced?
- With the rapid introduction of new fleets the age profile of the wheels will change rapidly (i.e. majority of new wheels) – this can result in short term changes, such as increased wear levels while the fleet ‘beds in’. Are contingency measures in place?
- Are contingency measures in place in case of a sudden emergence of interface problems (wheel or rail rolling contact fatigue, corrugation, wear)?