An Evaluation of Rolling Contact Fatigue in Light Rail Transit Tracks

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ABSTRACT
Rolling contact fatigue (RCF) has been identified as a cause of rail surface and subsurface defects. This is damage due to stress on the rail from repeated, intense and concentrated wheel-rail contact cycles that appears first on the surface as head checks and shelling. Intuitively the occurrence would be expected for heavy freight railroads but surprisingly, albeit less common, the phenomenon is apparent in Light Rail Transit (LRT) tracks as well. As LRT systems age this may become a cause for more maintenance and rail replacement costs. By observing in the field a section of track on a local light rail system that exhibits RCF, this paper will first record the state of the track condition, research possible causes, and evaluate expected improvements to the track life cycle based on implementation of some well-known techniques to treatment of this condition: increased inspections for gauge control and track component condition, rail defect detection, lubrication and friction management, rail profile grinding and addressing wheel profile. The paper will conclude with recommendations to prevent and treat RCF particularly targeted at Light Rail Transit (LRT).

INTRODUCTION
LRT track wear can be expected to be caused by plastic flow in slow-speed sharp curves, in special trackwork at frogs and switch points and as corrugation at approaches to station platforms. LRT maintainers have typically observed track wear that becomes severe with age and frequent loadings with sliding wheel/rail friction at these locations. Generally open tangent or slightly curved LRT track would not be expected to exhibit plastic flow of the rail head causing a wear lip resembling what is seen in freight railroad track.

Previous articles state this as a point of common knowledge in the industry regarding the occurrence of RCF:

“Rolling contact fatigue type rail defects, which are common under railroad loadings, generally do not occur under transit loadings because transit’s light wheel loads do not stress the rail steel anywhere near as much as freight loads.”

“Fatigue is rarely an issue in rail transit service since the loadings are much less than they are for railroad service and the plastic deformation that results from high contact stresses occurs much less often. Wear, on the other hand, is a significant issue in transit service, particularly in sharp curves.”

BACKGROUND
The recent appearance of shelly LRT rail on a fairly high speed sweeping curve became an item of concern for the Santa Clara Valley Transportation Authority (VTA) in San Jose California. The objective of this report is to investigate the rail wear phenomenon called rolling contact fatigue (RCF) as it occurs in VTA’s LRT tracks and LRT tracks in general. The contents of this report were compiled as the result of a review of the literature, interview with industry experts and field observations pertaining to RCF and wheel/rail interaction. RCF should be addressed along with other rail wear in maintenance programs. Management and maintenance guidelines that can be applied to transit operations are offered.
RCF INDICATIONS / DEFINITIONS

The FRA Track Inspector Rail Defect Reference Manual, August 2011 defines the rail head conditions that can be brought on by RCF. AREMA MRE Chapter 4, Part 4, Section 4.2 provides definitions for Identification of Rail Surface Conditions. The conditions are stated below. The FRA and AREMA definitions vary slightly and are summarized here. For the purposes of this paper the conditions are listed as gage side RCF indications and rail head running surface RCF indications in order of their severity.

Gage side RCF indications:

Head Checks or Head Checking
FRA: “...a slight separation of metal on the gauge side of the rail head, normally found in the high side of curves.” AREMA: “...shallow surface or hairline cracks in the gage corner of the rail head...a result of cold working of surface metal, due to the interaction between the wheels and the rail...a form of rolling contact fatigue (RCF).”

Shells or Shelling
FRA: …progressive horizontal separations…may crack out …usually at the upper gauge corner.
The AREMA definition adds that shelling originates under the surface of the rail head and states the cause as, “High contact stresses from wheel-rail interaction, especially when severe non-conformal wheel-rail contact occurs.”

When referring to gage side rail wear due to RCF the interpretation is that the initial indication is head checks starting as hairline cracks that become more severe leading to separations called Shells.

Running Surface RCF indications:

Spalls or Spalling
FRA: …slight flaking in the minimal stage of severity…the displacement of parent metal from the rail head from high contact stresses associated with cyclical loading. …Further deterioration … increase the amount of metal displacement, resulting in a significant spalling condition.” AREMA: …cracking and chipping of the rail surface. The AREMA definition includes that spalling is influenced by head checking of the gage side, characterized as micro-cracking or chipping and caused by “high horizontal wheel-rail creeping forces, transverse friction forces and extreme wheel-rail contact stresses.”

Flaking
FRA: …originates at the surface of the rail…where concentrated loading cold works the steel. …horizontal separation characterized as “scaling or chipping” of the rail head. AREMA: Flaking occurs when “conjoining of head checks results in surface metal separation...indicated by small chipping and cavities. It is a progressive horizontal separation on the running surface of rail near the gage corner, with scaling or chipping of small slivers. Flaking should not be confused with shelling, as the flaking takes place only on the running surface, usually near the gage corner of the rail, and is not a deep as shelling. Cause: Flaking is the result of surface metal friction, flow and plastic deformation. It is caused by the concentrated wheel loads, resulting in severe compressive shear deformation of the rail surface.”

Burned Rail
FRA: “Burned rail is a rail head condition that is the result of friction from slipping locomotive drivers.”

The FRA provides a definition of “Detail Fracture” in 49 CFR 213.113 Defective rails. (b) (8): “Detail fracture means a progressive fracture originating at or near the surface of the rail head. These fractures should not be confused with transverse fissures, compound fissures, or other defects which have internal origins. Detail fractures may arise from shelly spots, head checks, or flaking.”

RCF OCCURRENCE GENERALLY

Occurrence of RCF in the freight railroad is common where “damaged rail can result from flat or broken wheels, incidental hammer blows or derailed or dragging equipment….Flattened rails (localized collapsed head rail) are also caused by mechanical interaction from repetitive wheel loadings. FRA and industry research indicate that these occurrences are more accurately categorized as rail surface conditions, not rail defects, as they do not, in themselves, cause service failure of the rail.”

The cross sectional sketch from the AREMA Manual for Railway Engineering is shown with the “typical” freight rail wear initiated by RCF:
AREMA MRE: Figure 4-4.65. Typical changes to the rail geometry due to wear and plastic flow.

With RCF a major contributor to rail wear in high-tonnage freight & commuter track the rail is the largest cost area of the three maintenance categories for track components – rail, ties & ballast/surfacing. For the lower tonnage railroads and LRT the rail replacement costs are exceeded by tie replacement and surfacing costs. Low-tonnage track does not undergo cumulative tonnages to develop either excessive wear or a significant number of fatigue defects. For example, at an annual traffic level of 1 MGT, the rail will have accumulated only 100 MGT in the course of 100 years of service. Under these conditions, the rail will "rust out" before it wears out. The corresponding annual costs for rail replacement under these conditions is lower than for ties which deteriorate under light-tonnage as a result of environmentally caused decay. "This will result in a higher annualized tie replacement cost." 5

RCF Occurrence in LRT

In comparison with AREMA figure 4-4-65 an LRT rail cross section could be similar in wear dimensions and section loss to the point of condemnable limits but the expected source of the wear is generally characterized as friction not impact.

LRT213.114 from MBTA Track Maintenance Standards shows Rail Wear limits for the Green Line LRT.

RCF may be distinguished from other causes of rail wear such as gage side and rail head wear due to sliding friction. Or RCF may be considered a related component of the LRT track wear typically found in sharp curves, special trackwork and station platform approaches. The occurrence of RCF in tangent and large radius LRT curves track is due to the accumulated tonnage factor that is the concern in heavy haul railroads. Observing that RCF occurs in both light rail and heavy rail leads to the conclusion that it occurs in both for the same reason. The effect on LRT is just not as severe because accumulated tonnage is less for LRT over time. The concern is that all can lead to a detail fracture (see definitions).

RCF is now recognized as an issue in both Transit and Heavy Haul. The steel-on-steel impact of wheel to rails causes RCF eventually over time. The lighter LRT axle loads means that it takes more loadings to initiate RCF. Heavy haul freight lines will find RCF propagates quicker and may have more severe consequences because of its ability to spread very quickly once it starts. Transit operators have the ability to test and inspect more frequently before RCF becomes critical.

Figures 1 through 4 are examples of RCF in transit track provided courtesy of Mr. William Moorehead, TRAMMCO, LLC:

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Figure 1 - Early-stage RCF in 65-mph track.

Figure 2 - Short-wave corrugation and some incipient RCF (to right of pointing finger).

Figure 3 - Short-wave corrugation (SWC) and wheel-slip marks (WSM) on the high rail in a sweeping curve. RCF not visible yet, but these conditions will eventually result in RCF developing at the single-point contact line on the gage corner.

Figure 4 - Grinding residual marks that may induce subsequent corrugation.

FRA investigators have found that shells can develop “under the gauge corner of the high rail and most commonly on heavy haul railroads. However, they have also been found on tangent track with local cross-level errors … and on light axle load transit systems with particularly poor wheel-rail profile matching.” 6
**Figure 9.** Gauge Corner Fatigue on a Light Rail System from *FRA Report*. Rolling Contact Fatigue: A Comprehensive Review, 2011.

**RCF Occurrence in VTA Track**

In March 2003 Magel et al. of the National Research Council of Canada (NRC) provided a Wheel/Rail Interface Study to VTA from field work conducted in January and April of that year. In addition to evaluating the rail wear issues NRC provided wheel and rail profiles designed for application to VTA track. The study found four examples of RCF induced spalling in three curves. The following figures show two occurrences of RCF as A. and B at 1st & San Carlos St: A sharp radius curve with Ri59 Girder Rail embedded in a downtown roadway intersection subject to vehicular traffic. RCF on open track with 115RE rail are shown as C. and D.  

**Figure 5 – A.)** Guadalupe Line at First and San Carlos – outside girder rail. (since Replaced by embedded Tee Rail 115RE in 2006)

**Figure 6 – B.)** Guadalupe Line at First and San Carlos – inside girder rail. (since Replaced by embedded Tee Rail 115RE in 2006)
VTA Operations and Maintenance Department staff conducted a track inspection in March of 2014 finding a section of track exhibiting RCF. The occurrence is over about 600 track-feet in the northbound track of a double track section known as the “Virginia Curve” shown in Figures 9 -11. This was notable because it occurred in nearly tangent large radius curve in 35 mph track. At that time this track was not considered to be under any particular influences that would cause RCF. The section was inspected again in May of 2015, Figures 12 – 14.
VTA determined to take the NRC recommended approach to implement a rail profile grinding program as a maintenance strategy going forward. The strategy to mitigate RCF blends with the strategy to mitigate corrugation and wheel/rail wear focusing on the gage face and top of rail, wheel/rail noise and skid flats. The record of rail grinding and other RCF mitigations is under review as part of a current study to establish a standard preventive rail grinding strategy and interval.

**Recommendations: Methods of controlling RCF**

The guidelines for the maintenance and management of LRT track in regard to RCF include: 1.) Optimizing wheel/rail profiles, 2.) Optimizing vehicle suspension, 3.) Applying friction modifiers to the rail head & gage face and 4.) Using harder rail steels.⁸

This paper focuses on 1.) Optimizing wheel/rail profiles with emphasis on rail maintenance grinding and corrective grinding.

**The AREMA Approach**

Tonnage over the surface is the driving factor causing RCF spalling, shelling and head checks on the rail due to wheel/rail contact stress. Restoration of the optimal rail profile by grinding improves the wheel/rail contact geometry to reduce contact stress and improve vehicle stability in both tangent track and curves.
The AREMA MRE addresses RCF in Volume 1 – TRACK, Chapter 4 Rail, Part 4 Maintenance of Rail. MRE Section 4.8.4.1 describes preventive rail grinding as a Best Practice approach to rail maintenance. The preventive-grinding strategy is to cycle the rail grinder at frequent intervals removing “just enough metal to halt the uncontrolled growth of RCF” mitigating RCF cracks when they first appear as small defects because “as their length increases, the rate of growth increases.” The MRE goes on to make the point, “In comparison, corrective grinding is performed at longer intervals but with a disproportionately larger amount of grinding to try to remove the longer, rapidly growing cracks.”

The chart shows that keeping up a program of preventive grinding keeps the crack growth near a theoretical “magic” wear rate for the top of the rail, or stated another way, if we use preventive grinding to establish the “magic” wear rate the crack growth will be minimal. Where crack growth is in the realm of the dashed lines “crack growth without preventive grinding”, then corrective grinding is needed – several passes to remove the cracks – then get back to the program of preventive grinding. Assuming 3.5 MGT as a reasonable estimate of VTA’s annual tonnage, a 7 year preventive grinding interval is a basis for establishing a grinding program.

**Industry Experience in RCF Occurrence, Rail Profile and Maintenance grinding**

One observation is that RCF is more prevalent in installations of European groove rail than in US installations of 115RE rail. This could have something to do with the groove rail chemistry and more concentrated wheel/rail contact area – this is “theory”, still unknown.

A general observation is that long tangents and sweeping curves where trains run at “high LRT speed”, having stiff track modulus (typically concrete ties), with track that has been in service 10+ years would tend to be the areas where RCF can be expected.

Experienced operators in the rail grinding field have developed some cautionary notes and have at their disposal more modern, high speed grinders targeting LRT. Some information is based on the experience in European LRT grinding practice.

Early attempts at rail profile grinding in LRT followed a freight regime where too much material was taken off the
head of the rail with too coarse of a stone. When deep grinding marks are left in a freight rail head, they are quickly worn smooth by the heavy wheel loads. But in LRT the deep grinding marks remain and can cause a noise issue. The European grinding method uses a softer stone with finer grit – this could become a recommendation for a US grinding specification. A Maintenance grind is a way to remove about .002” of work-hardened material from the head of the rail. Corrective grinding to remove shells/head checks can be made by multiple grinding passes.

Past grinding practice has followed the viewpoint that grinding should be done when the rail profile needs adjustment or there are visible cracks or damage to be repaired. More recent philosophy contends that RCF is best managed by removal generally before it becomes visible. Optimally the frequency of grinding should be increased with the metal removal rate reduced. The removal of a thinner top layer of steel from the rail head before it becomes too brittle, and subject to damage, would be preferable. This is evident to most railroads and transit operators but implementation of a more frequent program is difficult due to the limited availability of grinding contractors and support. The grinding industry is developing high speed grinders to address this. With limited metal removal rates and working speeds up to 35 mph high speed grinders will allow the higher frequency grinding intervals with little to no interruption of present traffic or maintenance schedules. This method will keep the desired profile, once established, and remove the top layer of brittle metal before it can propagate cracks in the rail.

**Rail Profiles for LRT**

AREMA recommends that all railroads maintain the optimal rail profile. The optimal rail profile for LRT is a custom design for the specific local operating conditions. A rail grinding program, properly managed and targeted to LRT, is the goal.

LRT track routes can have a large percentage of curves, stations and turnouts. Light rail vehicles (LRV’s) operate with frequent speed changes through sharp and gentle curves, tangents and turnouts. LRV wheels, axels and suspension designs are a trade-off to meet certain performance characteristics. A common rail profile standard for LRT is lacking because different rail transit agencies apply different designs and practices making standardization of wheel/rail profiles difficult. Newer LRT systems benefit from the increased understanding of wheel/rail interaction in recent years.

**UT and Eddy Current Testing**

The key to minimizing the detrimental effects of RCF is early detection. Frequent inspection and testing can find minor defects before severe rail deterioration can take place. Visual track inspection of the rail head surface is a valuable tool. To complement visual inspection, the industry standard in the United States for automated rail defect detection is Ultrasonic Testing (UT). UT imparts a sonic wave into the rail and measures the wave reflection to find internal rail defects that may or may not be associated with surface-initiated RCF because UT technology finds defects deeper than 3mm from the top of the rail head. If RCF is not detected by visual inspection of the surface and is not detectable by UT it may be that the damage is extensive enough to need corrective action with multiple grinder passes to remove the damage. The recent implementation Eddy Current technology is a positive first step in the early identification and correction of RCF on the rail head surface. Eddy Current testing uses induction and detection of a magnetic field in the surface rail head steel to identify RCF between the top of the rail head to a depths of 3mm. This technology allows the identification of pending RCF damage before it becomes extensive. Maintenance of the rail can then take place with less metal removal. Frequent testing cycles can help detect and allow removal of RCF in its early stages.

In Europe where High Speed Grinding and Rail Milling is used for LRT it is generally mandatory to provide Eddy Current testing results after every milling or grinding session to test that the rail is free of any surface defects before acceptance. Eddy Current testing has been proven to find defects in the top 3mm of the rail head. This testing and maintenance grind programs are reported to have cut rail renewal programs by over 60%

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2 Ibid., p. 5-5

3 Federal Railroad Administration Track Safety Standards Compliance Manual, United States Department of Transportation Office of Safety Assurance and Compliance, January 1, 2002, p 5.60

4 Ibid., p. 5.65.


Email and Phone interview:
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Appendix A: TRAMMCO Corrugation Inspection Reports: Illustrative Photos from SNJLRT, Sound Transit & other Properties - Figs 1 through 34

EUROPEAN STANDARD EN 13231-3, May 2006

TRANSIT SYSTEM RAIL GRINDING SPECIFICATION (includes capabilities for operations on embedded track)
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AREMA Manual of Railway Engineering Volume 1 – TRACK, Chapter 4 Rail, Part 4 Maintenance of Rail.

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