

Implementation of Wayside Top of Rail Friction Control on North American Heavy Haul Freight Railways

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Abstract

Wayside Top of Rail friction control technology (TOR) has been extensively tested on North American heavy haul railways. This paper describes implementation of TOR over widespread territories. Application of multiple wayside TOR units in high tonnage highly curved territory results in consistent reduction in lateral forces of 30%. Rail wear rate reductions up to 60% have been recorded at three different test sites. The mechanism of friction modifier carrydown is discussed, and factors affecting unit spacing and application rates are described. Multiple application units lead efficiencies in unit spacing and application rate, primarily due to wheel conditioning effects. The technology has been successfully demonstrated at sites with tread braking and sand application. A territory wide implementation process is outlined, together with ongoing maintenance considerations.

Introduction

Top of Rail (TOR) friction control has received increasing attention to reduce curve noise, lateral forces, rail wear, and corrugations on transit and freight rail systems. For example, North American Class 1 freight railways have focused on lateral force and rail wear rate reductions [1,3,4,5,10,14,19]. As a result, the economic benefits associated with this technology are moving heavy haul freight railways to seek TOR implementation over widespread territories. In this paper, we describe key issues and considerations for system-wide implementation of TOR.

Top of Rail friction control is one approach to reducing the so-called “Stress State” of the railway. In the area of friction control this relates to the distribution of lateral curving forces exerted by the rolling stock, and the capability of the infrastructure to absorb these forces. Rather than continuously upgrading the infrastructure with increasing car loads (and therefore lateral curving forces), an alternative solution is to reduce the forces causing excess track damage. The availability of engineered thin film materials (friction modifiers) to provide an intermediate coefficient has been a critical factor in the emergence of TOR.

In freight, TOR measurable benefits have focused on lateral force reduction. The key economic benefit associated with reduced lateral forces has been rail wear reduction. Generally, wayside TOR is being implemented in areas where gauge face lubrication has already been optimized. Therefore, measured reductions in rail wear rates with TOR reflect the impact of TOR incremental to that with a well lubricated gauge face. Other benefits from reduced lateral forces include reduction in rates of gauge widening, dynamic wide gauge, and improvements in tie and fastener life. Reduction in specific fuel consumption with TOR has been reported by Cotter [5,8].

Testing and implementation of wayside TOR has focused on territories with extensive curvature, typically at least 30-60% of track length in curvature, and curve radius as low as 175 m (10 degrees). On curves < 291 m (6 degrees), rail replacement due to wear can occur as frequently as every two to three years on high tonnage lines. Wear is a combination of metal loss due to “natural” wear, together with metal loss from preventative grinding to control rolling contact fatigue (RCF). Other concerns driving implementation of TOR have included rates of gauge widening and spike breakage as well as derailments caused by wide gauge / rail rollover (high L/V).

As of February 2006 there are currently about two hundred and seventy wayside TOR units installed on North American freight systems, on all the six largest railroads, and covering more than about 650 km of high curvature and high tonnage track. Factors influencing the more rapid implementation of the wayside approach are as follows:

- Familiarity of the equipment to maintenance of way personnel (similarity to gauge face lubrication equipment).
- Logistical and operational issues with mobile TOR application systems.
- Ability to easily start with limited initial testing and roll-out over a gradually extending territory as results are obtained.

Goals and Methodology

Our goal is to develop the information needed to implement wayside TOR friction control over extended territories on heavy haul freight systems. To accomplish this, insight is required into the following:

- Performance targets for top of rail needed to achieve significant economic benefits.
- Mechanism of friction modifier transfer, and carrydown.
- Effects of train handling characteristics on unit placement selection.
- Monitoring of system effectiveness.
- Maintenance practices and requirements.

Rail based strain gauge instrumentation is used in this work to assess lateral force reductions achieved with friction modifier application, using standard techniques. Rail wear is measured either using a mobile optical rail profiling method, or with Miniprof manual profile measurements. The pros and cons of each approach have been previously discussed [10]. In all cases the results reported are for “natural” wear, i.e. the effects of metal loss due to grinding have been accounted for and removed from the calculations.

The TOR friction modifier (FM) used in this work is KELTRACK[®] Trackside Freight. This is a water based material of engineered solids and polymer composites [2,6,7]. Previous work has described the frictional characteristics resulting when a dry film of KELTRACK exists between the wheel and rail [14]. The desired frictional characteristics are achieved when the material exists together with the other naturally occurring “Third Body” materials, primarily iron oxides and wear particles.

The FM was applied in all cases using a Portec Rail Products Protector[®] IV TOR electric applicator [17,13]. This equipment utilizes four wiping bars (two per rail) mounted on the field side of the rail. Application is controlled using a non-contact active wheel sensor and digital controller. Application variables are 1) axles between pump activations and 2) pump activation time. This allows precise adjustment of friction modifier application rates and strategies.

North American Class 1 Freight Railway Test Sites:

Data reported in this paper comes from sites with significantly different characteristics [10,19], summarized in Table 1. Track conditions range from wood tie with cut spikes to concrete tie with premium fastening systems. Most sites have relatively high tonnage (49-91 mgt). Conditions include areas with significant gradient (up to 3.6%), with associated use of tread air brakes. Use of materials with lubricant characteristics (coefficient of friction < 0.2) on the top of rail at these sites would pose risks to braking and traction.

Site	Ties	Fasteners	Rail*	Traffic	Tonnage mgt (tons MGT)/yr
1	Concrete	Clips	136 RE / 141 RE (67.6 / 70.1 kg/m)	Single track, uni-directional, mixed commodity, freight, intermodal	91.4 (90)
2	Wood	Mix	136 RE (67.6 kg/m)	Single track, bi-directional, mixed commodity, freight, intermodal	87.4 (86)
3	Wood	Spikes	132 / 136 RE (65.6 / 67.6 kg/m)	Dual track, bi-directional, mixed commodity, freight	86.4 (85)
4	Concrete	Clips	133 / 136 / 141 RE (66.1 / 67.6 / 70.1 kg/m)	Single track, bi-directional, mixed freight, intermodal.	86.4 (85)
5	Wood	Mix	133 / 136 / 141 RE (66.1/67.6 / 70.1 kg/m)	Single track, bi-directional, mixed commodity, freight.	48.8 (48)

* In the sharp curves at these sites, rail metallurgy is either hyper-eutectoid or fully head hardened

Table 1: Site data

Lateral Forces and L/V ratios

The controlled reduction of coefficient of friction (COF) between the wheel tread and the top of the low rail under conditions of saturated lateral creepage results in a proportional reduction in lateral forces. On the predominant standard three piece North American bogies, lateral creepage is saturated at curvature sharper than 582 m (3 degrees). On frame braced bogies with improved steering as used on Test Site 2, creepage is believed to saturate above approximately 350 m (5 degrees). These performances are for bogies in generally good condition, with uniform side-frame and wheel wear. Bogies with excessively worn components will generally show poorer curving performance. Since all the lateral force data reported is measured on curves sharper than 350 m (5 degrees), it can be assumed in all cases that L/V or lateral forces are directly related to the low rail COF.

Dry top of rail coefficient of friction under North American freight conditions is typically measured at 0.5 and higher with a Salient Systems push tribometer [22]. The wheel / rail friction with FM applied is approximately 0.35 [14]. This leads to an expected reduction in lateral forces of 30%, and this has been set as a target for lateral force reductions in all the work described in this paper. Significant reductions in rail wear have been observed where approximately 30% lateral force reduction has been observed or inferred.

Figures 1 and 2 summarize the overall lateral force reduction on the low rail and high rail respectively observed across the five test sites in Table 1. Sites 3, 4 and 5 are located on steep grades, so data is separated to show the effect of direction/grade. These results represent a range of operating conditions, implementation strategies and measurement configurations as described in Table 2. In all cases, lateral force values reflect the average values of peak lateral force for leading axles of loaded cars (> 90.7 tonnes gross weight, 200000 lb). Data sets are filtered to remove trains traveling outside the normal speed range for the area.

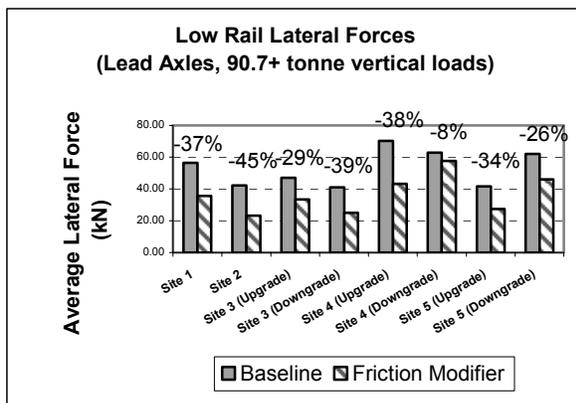


Figure 1: Low rail lateral forces at different sites, control and FM

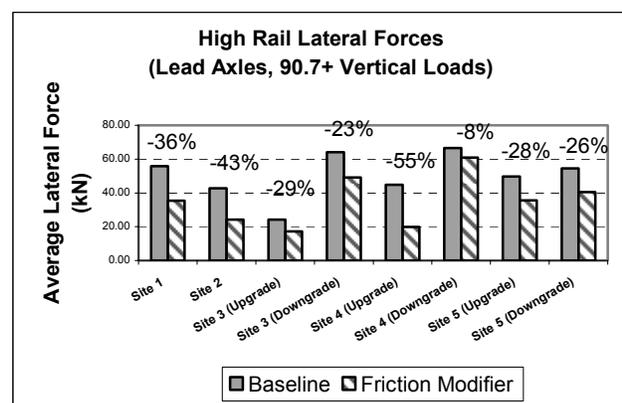


Figure 2: High rail lateral forces at different sites, control and FM

Lateral force reductions of approximately 30% have been observed at all but one site. Downhill (tread braked) trains at Site 4 showed an average reduction of 8%. Future optimization of application rates is expected to lead to reductions close to 30%. Tests at the other downhill sites have shown that use of tread braking requires closer spacing of TOR units and / or an increase in FM. This is likely due to the effect of tread brakes removing the friction modifier from the wheels, requiring a compensating increase in FM. Higher wheel temperatures caused by tread braking will also be a factor.

This effect can be illustrated by comparing results between Sites 1 and 4. Site 1 (zero gradient, measurements on a 218 m (8 degree) curve) achieved 37% reduction in low rail lateral forces with 0.35 L / 1000 axles application rate and TOR units spaced 3.2 km (2 miles) apart. By contrast, on Site 4, with downgrade (-2.02%, 182 m radius) loaded trains under air braking showed a reduction of 26% in low rail lateral forces, with TOR units spaced 1.6 km (1 mile) apart and FM application rate of 0.5 L / 1000 axles.

Site	TOR Units, Approximate Spacing	FM Application rate (L/1000 axles)	System Conditions	Measurement Site details
1	5 TOR units 3.21 km spacing	0.35	Continuous curvature, river grade.	218 m (8 deg) curve 0% gradient 3.54 km West of last TOR site.
2	8 TOR units (7 sites) 2.4 – 3.2 km spacing	0.50	Continuous curvature, river grade.	269 m (6.5 deg) curve -0.6% gradient 0.3 km West of TOR site #3.
3 (Westbound / upgrade)	28 TOR units (14 sites) 1.6 km spacing	0.35	Continuous curvature, Moderate grade ($\leq 1.2\%$), Tractive effort (no sanding)	257m (6.8 deg) curve +1.0% gradient 0.8 km West of TOR site #11
3 (Eastbound / downgrade)	28 TOR units (14 sites) 1.6 km spacing	0.70	Continuous curvature, Moderate grade ($\leq 1.2\%$), Continuous tread braking	257 m (6.8 deg) curve -1.0% gradient 0.3 km East of TOR site #3
4 (Southbound / upgrade)	6 TOR units 1.6 km spacing	0.50	Continuous curvature, Heavy grade ($\leq 2.2\%$), Continuous sanding, TOR grease contamination	182 m (9.6 deg) curve +2.02% gradient 0.3 km South of TOR site #3
4 (Northbound / Downgrade)	6 TOR units 1.6 km spacing	0.50	Continuous curvature, Heavy grade ($\leq 2.2\%$), Continuous tread braking, Hot wheels, TOR grease contamination	182 m (9.6 deg) curve -2.02% gradient 1 km North of TOR site #3

Table 2: Operating conditions, implementation strategies and measurement configurations

Rail Wear

While lateral force reduction is an important objective, data is required on parameters directly related to either capital or maintenance costs incurred. To date this has focused on reduced rail wear rates, with the ancillary extension in rail life and deferment of capital expenditures for rail replacement. Rail wear rate reductions with TOR were first reported by Hooper for application of friction modifier on an intermediate tonnage line using a TOR spray applied to the low rail from a track maintenance vehicle [14]. At all test sites conventional wayside gauge face lubrication is practiced, and rail wear reductions recorded for TOR are incremental to a baseline value with wayside gauge face lubrication in place.

While reductions in vertical wear rates may be expected based on the reduced tread / top of rail friction level, changes in gauge face wear rate may be less intuitive, since the FM is not thought to reach the gauge corner of the high rail with wayside application. Any reductions are presumably due to reduced flanging forces caused by the reduced rail head friction, or put another way, by improved steering by the bogie through the curve. Significant reductions in high rail gauge wear were also reported by Hooper [14] even though application was to only the top of the low rail.

Tables 3 to 5 summarize wear rates seen in mild (degree of curvature (DOC) > 350 m (5 degree)), moderate (218 m (8 degree) < DOC 350 m (5 degree)) and sharp (DOC < 218 m (8 degree)) curves at sites where rail wear monitoring programs have been conducted.

Wear rate ($\mu\text{m}/\text{MGT}$)	Low rail vertical		High rail vertical		High rail gauge	
	Baseline	TOR (% change)	Baseline	TOR (% change)	Baseline	TOR (% change)
Site						
1	22	18 (-17%)	16	18 (10%)	16	10 (-38%)
2	12	5 (-58%)	9	5 (-44%)	-3	-1 (n/a)
4	n/a	n/a	n/a	n/a	n/a	n/a

Table 3: Mild Curves (DOC > 350 m (5 degree))

Wear rate ($\mu\text{m}/\text{MGT}$)	Low rail vertical		High rail vertical		High rail gauge	
	Site	Baseline	TOR (% change)	Baseline	TOR (% change)	Baseline
1	31	26 (-16%)	22	20 (-11%)	24	13 (-48%)
2	23	10 (-58%)	15	6 (-58%)	-6	-2 (n/a)
4	n/a	n/a	n/a	n/a	n/a	n/a

Table 4: Moderate Curves (DOC < 350 m (5 degree) to 218 m (8 degree))

Wear rate ($\mu\text{m}/\text{MGT}$)	Low rail vertical		High rail vertical		High rail gauge	
	Site	Baseline	TOR (% change)	Baseline	TOR (% change)	Baseline
1	46	31 (-33%)	22	25 (12%)	32	18 (-45%)
2	45	21 (-53%)	16	8 (-50%)	-9	-1 (n/a)
4	82	34 (-59%)	17	22 (26%)	49	55 (11%)

Table 5: Sharp Curves (DOC < 218 m (8 degree))

Baseline wear rates were greatest on the sharpest curves as expected. Examination of Tables 3 to 5 shows large reductions in rail wear with TOR. Results show the most consistent reduction for low rail vertical wear, with results on high rail vertical wear being more variable. Low rail vertical wear was reduced by 33-59% on sharp curves, and high rail vertical wear by 12-50%.

The greatest variability was seen in the effect of TOR on gauge face wear. At Site 2, no reductions in high rail gauge face wear were observed. The gauge face lubrication on this territory had already been highly optimized [20], and gauge face wear had thereby been already eliminated. At Site 1, 45% reduction in high rail gauge wear was reported. The gauge face lubrication over this territory, although effective, was not as highly optimized as at Site 2. Hence the baseline gauge face wear rates were higher, and were reduced by application of TOR. On Site 4, the quality of gauge face lubrication was erratic and frequently poor, largely due to the use of poor quality grease. In this case no significant reduction was observed due to TOR. Work is ongoing to assess the effect of TOR on rail wear at this site once gauge face lubrication has been optimized.

Mechanism of wayside Top of Rail

To understand implementation of TOR, some insight is needed into the mechanism of pickup, carrydown, and distribution of the friction modifier film. We here report two important aspects of the TOR mechanism that relate to territory implementation.

1) Multi unit effects

Multiple unit (or “Zone”) effects refer to results achieved when more than two wayside TOR units are in place and sufficiently close together that wheel / rail friction is fully controlled between the units. In the examples below, testing was carried out with several configurations of TOR units close to a lateral force measurement site. In Case A, testing was carried out at Site 1 (Tables 1 and 2), uni-directional traffic. Figure 3 shows that a single unit 1.6 km (1 mile) from the measurement site provided an average lateral force reduction of 14.7% from the baseline values. As expected, a single unit 3.2 km (2 miles) from the measurement site produced a lower reduction in lateral forces (10.8%). However activation of an additional four TOR units each spaced 3.2 km (two miles) apart resulted in a much greater reduction (37%) at the measurement site. This result is consistent with a mechanism whereby there is significant conditioning of wheels and the top surface of the rail by multiple units. As shown in the next section, it is probable that this is primarily an effect of *wheel* (rather than rail) conditioning.

Case B is illustrated in Figure 4, from testing at Site 3, (Eastbound, downgrade). In this case the units are spaced approximately 1.6 km (1 mile) apart. Results (129.7 tonne cars, (286000 lbs)) indicate that the wheel / rail conditioning effect has been achieved with two TOR units, since two TOR units produced a significantly greater reduction in lateral forces than one unit. An additional further small reduction is achieved with three TOR units.

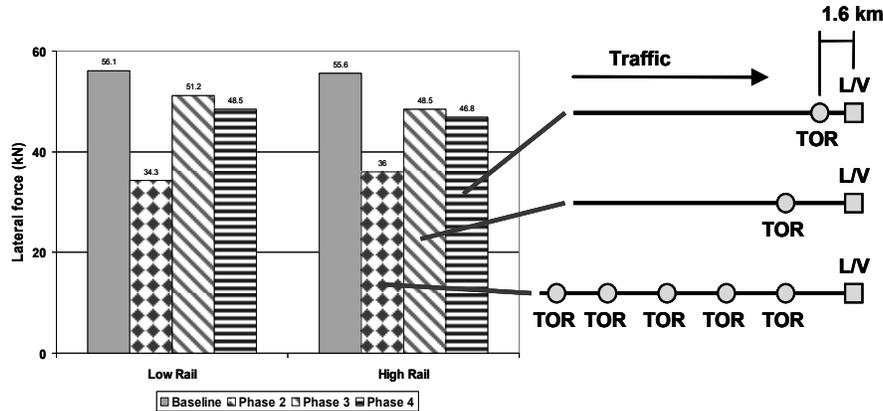


Figure 3: Lateral forces, averaged over low and high rails, Case A

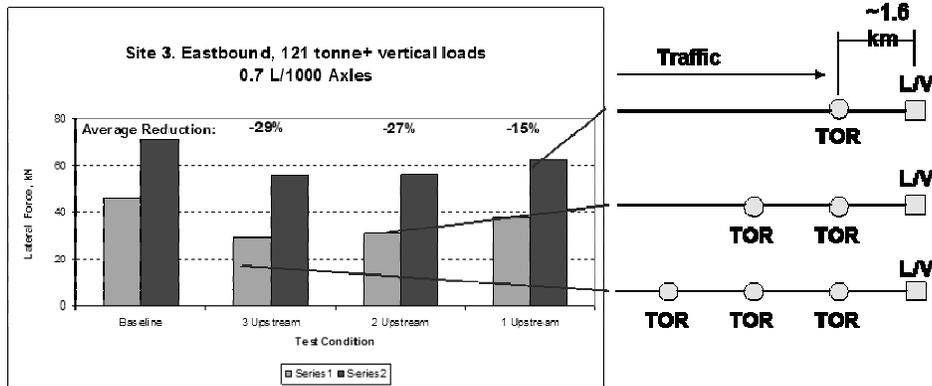


Figure 4: Lateral force averaged over low and high rail, Case B

II) Evidence for FM carry on wheels.

A separate test at Site 2 utilised two TOR units placed on either side of a lateral force measurement site. Lateral force reductions were measured while varying the location of one of the two units. The percent reductions in L/V ratio are shown in Figure 5. For Case TOR 4B, TOR4 is 3 km (1.9 miles) from the measurement site, and TOR 2 is 2.8 km (1.7 miles) from the L/V site, where modest reductions in L/V were noted for both east and west bound traffic. The wayside unit east of the measurement site was then relocated to a position 0.3 km (0.19 miles) from the measurement site. Results are shown as Case TOR 5. It can be seen that L/V reduction increases significantly for west bound traffic, from 15% to 42%. By contrast, the east bound traffic is little changed with L/V reduction changing from 20% to 21%.

If the conditioning mechanism were to affect wheels and rail equally, the unit located close to the measurement site would then be expected to condition the rail at this location, and additional L/V reduction would be expected for both west *and* east bound traffic. The fact that east bound trains show little change argues strongly for the FM film being predominantly distributed on the train wheels rather than on the rail. This conclusion is supported by measurements of rail friction with a push tribometer, which showed little reduction in friction with TOR application, even though significant lateral force reduction was achieved.

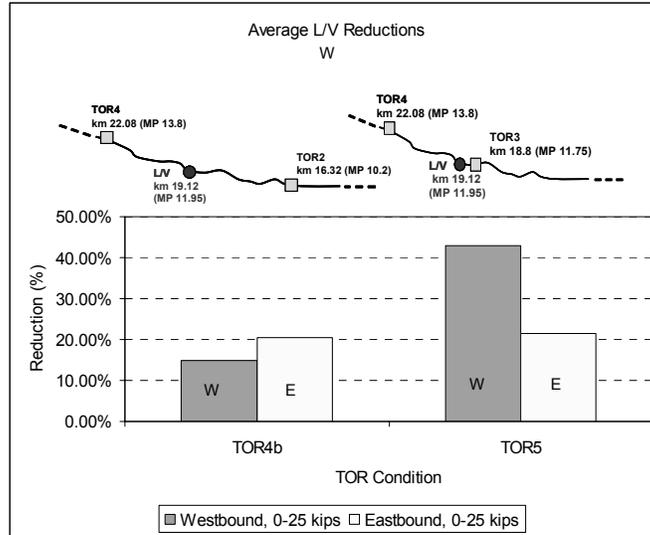


Figure 5: L/V reductions with two different TOR site placements

TOR Territory Implementation Methodology

When implemented on a territory-wide basis (versus one or two unit applications for specific problem curves), wayside TOR system placement is typically determined using a “top-down” approach. Figure 6 illustrates the approach schematically.

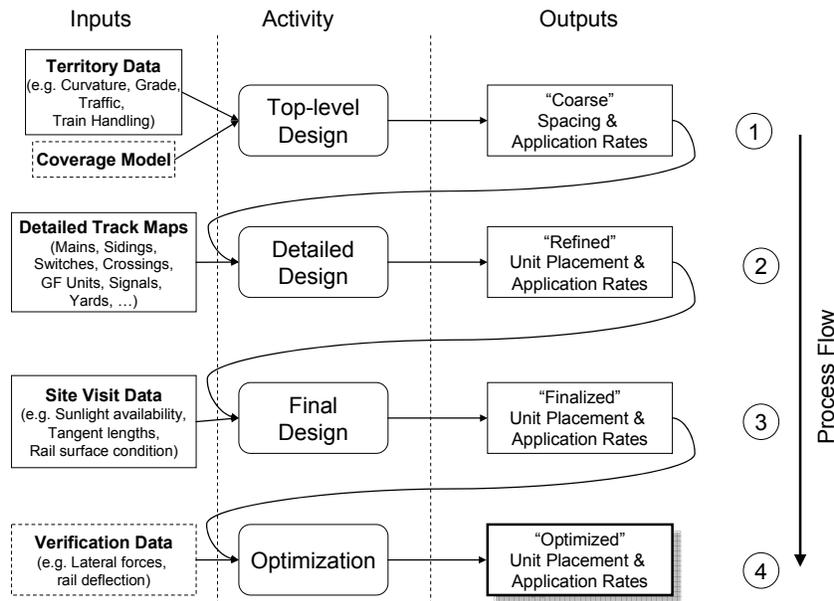


Figure 6: Schematic illustration of "design flow" used in TOR wayside unit placement and application rate selection.

Phase 1: Top-Level Design

The first step in the selection of unit placement and application rates is a top-level design phase, in which territory-wide data on curvature, grades, traffic and train handling are considered. Current best knowledge (based on extensive experimental programs at both the laboratory and field scales) is utilized to incorporate the effects of these parameters on FM performance and carry (i.e. coverage per unit) at a given application rate. Based on these effects, a spacing and application rate strategy is designed to deliver the appropriate level of coverage throughout the territory.

Presently, the catalogue of available data is referenced by the designer and used to develop a coverage strategy that is largely driven by experience. As indicated by the dashed-border at the top-left of Figure 6, a longer term goal is the development of a predictive coverage model that incorporates all relevant effects and determines the optimum spacing and application rate throughout the territory based on cost-benefit optimization.

Phase 2: Detailed Design

With the “coarse” spacing and application strategy determined for the territories, the practicalities of wayside unit placement are first incorporated through consideration of detailed track map data. This includes consideration of location of TOR units relative to main lines, sidings, switches, crossings, gauge face lubricators, signals and yards.

On heavy haul freight, TOR units are placed in tangent track, at least 30 m (100 ft) from the spiral entrance to a curve. This is to conform with guidelines from the Association of American Railroads [19] designed to avoid localized spalling caused by crack hydropressurization of friction modifier still in the wet form. In addition application efficiency and pick up by passing wheels from the field mounted application bars are considerably better in tangent track than when placed in the spiral or curve body.

Phase 3: Final Design

Following the detailed design phase, a site visit through the territory is required to determine the detailed feasibility of all proposed locations. The purpose is to:

- Confirm availability of sufficient tangent track for unit placement.
- Confirm sufficient sunlight availability to ensure operation of solar powered units throughout the year.
- Consider locations in sidings, cross overs, yards, junctions, bridges, tunnels.
- Consider proximity to thermite welds, insulated joints, lubricators, switches.
- Review site for any pre-existing RCF cracks at the proposed installation site (to avoid localized spalling).

Phase 4: Optimization

Each of the design phases produces deviations from the “ideal” spacing and application strategy. As such, there will typically be some adjustment to application rate required to generate the target level of product performance at the site. This involves ongoing review and assessment of performance, using the tools described in the next section.

Monitoring System Effectiveness

An important consideration for TOR implementation is monitoring of system effectiveness. Traditionally gauge face grease lubrication can be visually assessed for effectiveness, coupled with tribometer measurements. In the case of TOR, this approach is impracticable, as the FM thin film is often invisible to the naked eye even when present and effective as measured by lateral force reduction. This is not surprising considering the calculated film thickness can be < 1 micron for film 3.2 km (2 miles) down track from the wayside applicator. No analytical method currently exists for detecting FM film at these levels.

A separate paper at this conference describes the development and validation of rail deflection gauges (RDG) as a means of inferring lateral forces [16]. RDG's can be used to map a territory prior to implementation of TOR, followed by assessing the effects after TOR implementation. Some railways install lateral force measurement sites to monitor long term performance. Other useful monitoring methods being used include rail wear measurement using optical / laser profile data and analysis of geometry car data for progressive gauge.

Remote monitoring of wayside equipment is an anticipated future development which is expected to provide information on system effectiveness. This would provide centralized information confirming that individual TOR applicators are operating satisfactorily.

Maintenance Considerations

Where TOR has been implemented over a significant territory, sufficient resources are required both to maintain the wayside units, and to ensure that friction modifier is replenished. The most efficient method has been found to have

1) dedicated equipment maintainers who cover both TOR and gauge face wayside applicators, and 2) separate material handling personnel and resources to ensure reservoirs are refilled, using a bulk delivery system. The latter uses 1125 litre totes of friction modifier mounted on track maintenance vehicles, with ancillary pumping equipment.

Routine items for maintenance include inspection and possible replacement of rubber seals on the applicator bars, removal of bars to ensure they are not damaged during other maintenance practices such as grinding or tamping, and scraping the area between the seal tip and the contact patch clear of any FM residue. Efficient distribution requires that applicator bar ports are open so that FM can flow freely across the railhead.

Conclusions

This work shows that:

- TOR friction control can be implemented over extended areas of high curvature using multiple wayside application units, including areas with heavy gradient.
- TOR provides significant reductions in lateral forces and rail wear.
- Improved understanding of the TOR mechanism and performance factors has allowed the development of a robust approach to territory wide implementation.
- A systematic approach to TOR system implementation has been developed, which includes ongoing monitoring and maintenance considerations.

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