The Role Of Friction Control In Effective Management Of The Wheel / Rail Interface

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Abstract

An integrated approach to friction control using modern technology can contribute enormously to effective management of the wheel rail interface. Different friction control goals and appropriate technologies are needed for the two different interfaces, namely A) wheel flange / gauge face, and B) wheel tread-top of rail. Coefficients of friction <0.2 are appropriate for the former to minimize wear, and 0.35 for the latter to minimize energy usage and lateral forces. Alternative friction control technologies are described to achieve each of these objectives. Case study examples are presented of what is achievable with modern friction control technology – among which are large reductions in wheel and rail wear, energy and noise.

Introduction

Technically advanced railroads recognize that an integrated approach to the wheel-rail interface provides optimum solutions in terms of controlling wheel and rail wear, noise, and other significant cost and operating factors. The three main pillars for effective management of the wheel-rail interface are:

1. Proper selection and maintenance of wheel and rail profiles
2. Proper selection of grade and quality of wheel and rail metallurgy
3. Effective control of friction

Focusing on only one of the three "pillars" frequently leads to poor or non-optimal practices. Today friction control is probably the least advanced of the three "pillars". However the technology is advancing rapidly on many fronts. This ranges from development of reliable on-board and trackside lubrication systems, to new "Top of Rail" (TOR) friction control technology. The latter offers enormous promise for savings in energy, wheel and rail savings, and track structure preservation. The benefits of an integrated approach to friction control as part of the overall management of the wheel / rail include:

- Reductions in wheel and rail wear (including reduced corrugation onset)
- Reduced noise and vibration
- Significantly lower energy savings for tractive effort.

Friction Measurement

The only direct measurements on friction of rail are made with a tribometer. Either the push tribometer, or the more recently developed high-speed tribometer provide dynamic or sliding friction values. Push tribometers are relatively little used, but can provide useful insights if they are properly maintained and calibrated. Their major disadvantage is the limited track distance and data that can be generated – only a local "snapshot" is obtained. High-speed tribometers can simultaneously measure COF at the gauge corner and top of both rails over many kilometers. This can be a valuable tool to benchmark a system before a planned project to improve friction control.

Friction Control Objectives

The goals for friction control have been established (Ref 1,2)(Figure 1). All numbers are as measured on rail with a tribometer. These are:

- High rail gauge face / gauge corner friction in curves should be as low as possible, < 0.2. This friction level should be maintained around the full length of the curve.
- Top of both rails should target a COF of 0.35 in both curves and tangent. TOR friction should not be less than 0.25, nor greater than 0.4.

Other objectives can also be considered:

- Top of high rail friction should not be lower than top of low rail friction (a situation that can lead to increased lateral forces).
- The top of low and high rails should not differ by more than 0.1

Figure 1. Friction targets

Different friction targets at the two wheel / rail interface positions requires specialized friction control materials and accurate delivery systems.

The relationship between friction and creep is also significant. Beyond the point of creep saturation, the slope of the friction / creep curve is usually negative for both steel and iron oxides (Fig 2). Because this characteristic is one of the root causes of both wheel squeal and short pitch corrugations, an additional objective for friction control should be:

- Maintain positive friction between the TOR and wheel tread for curves < 500 m radius, as well as in areas of excessive longitudinal creepage.

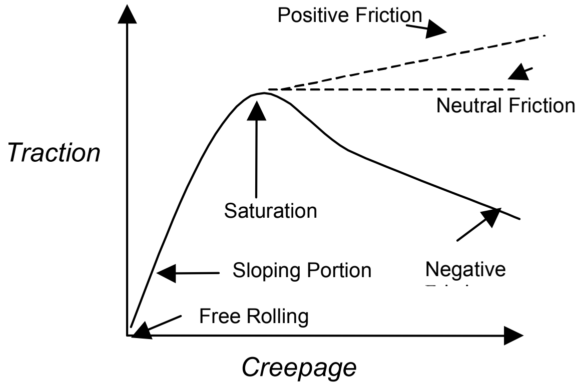

Figure 2. Friction / creep relationship

The Role Of The Interfacial Layer, Or How Mother Nature Makes Friction Difficult To Control

Even in the absence of contamination, friction levels on the top of the clean and apparently dry rail can range from 0.2 to 0.8. These differences can have a dramatic impact on system performance. One goal of friction control technology must be to overcome and minimize these variations induced by nature.

Variations are mainly caused by the changing composition of the interfacial layer between the wheel and rail (the "Third Body" (Ref 3)). The major component of the Third Body is wear particles of sub-micron size. The surface of these particles is iron oxides. Different iron oxide chemical forms have different frictional behaviour. Interconversion of the different forms occurs with variations in weather: temperature, humidity and moisture (rain). These subtle differences are not apparent to the human eye. Magnetite, or "black iron oxide" has the highest friction of the family. This is the dominant form present under warm dry conditions, and can lead to friction levels as high as 0.8. A slurry of limonite can form in light mist or dew, with COF of 0.2, leading to traction problems.

Effect Of Friction Levels

The control of friction is in itself only a means to an end. The following are some general comments about the impact of friction levels on factors of direct interest to railroads.

Wear

The relationship between wear and friction is fundamental to tribology. The difference between a well lubricated and poorly lubricated interface between the flange and side of the rail is at least a factor of 20 in absolute wear rates, depending on variables such as flanging forces, creep levels, etc. There is little quantitative information on the effect of top of rail COF on head wear rates.

Energy consumption

Although intuitively obvious that lower friction levels should mean reduced energy, this is an area of some controversy. Reductions in fuel consumption can come from:

1) Lower curving and flanging forces, primarily determined by top of rail friction levels
2) Reduction in rolling resistance in tangent track – primarily related to top of rail friction.
3) Reduction in flanging forces by determined by gauge face / flange friction levels

Drawbar energy reductions of up to 40% have been measured in closed loop testing. However the translation of this into "real world" fuel savings remains problematic. The contribution of TOR and gauge friction levels to energy consumption remains to be clarified.

Noise

Wheel / rail interface noise can be divided into:

1) Rolling noise – mostly related to wheel and rail roughness levels.
2) Wheel squeal in curves, related to top of rail frictional characteristics (negative friction)
3) Flanging noise – due to high COF at the gauge face.

Fatigue

Contact mechanics suggest that a controlled intermediate COF on the top of the rail should reduce rolling contact fatigue. However there is no quantitative information in this area, and should be a topic for future research and testing.

Options For Friction Control

Gauge face / wheel flange interface

The major options available to achieve the desired friction control at < 0.2 are:

- Trackside application of oil or (usually) grease
- On board application of oil or grease
- On board application of solid stick lubricants

Trackside application of lubricants

Traditional trackside lubrication technology with mechanical or hydraulic actuation can have issues with control and reliability. The recent development of electric lubricators has provided improved control of this form of lubrication. The result is less uncontrolled migration to the TOR, and proper deposition of the lubricant where it is required, on the gauge face / gauge corner. However even state of the art trackside units still lead to grease migration to the top of rail in the first few hundred feet after the bars. New bar developments have led to greatly enhanced carry down of grease. A recent paper by Roney et al. (Ref 4) provides some of the best recent information in this area.

On – board flange application of oil or grease

On board application of oil or grease to the wheel flange is a mature technology. In transits the application is usually of oil, whereas in locomotive application grease predominates. The major concerns are fling off of the oil both onto the top of rail causing traction problems, and onto the vehicle underside. This causes build up of oil mixed with dirt and cleanliness problems. Accurate control of lubricant deposition appears to be a difficult challenge.

On board application of solid stick lubricants

Solid stick lubricants directed at the wheel flange are a reliable means of controlling and minimizing flange wear. There have also been cases where protection of the gauge face has been demonstrated. The application technology (hardware) is an integral part of the solution, and customized for the specific application. The solid stick is pressed against the wheel flange with a constant force spring. The solid stick lubricant is comprised of a solid lubricant component in a polymer matrix. The mechanism of solid stick flange lubrication is as follows:

1. The solid lubricant and carrier transfer from the stick to the wheel flange under the pressure of the constant force spring
2. As flanging contact occurs, polymer is oxidized off and solid lubricant transfers to the gauge face of the rail
3. Material on the gauge face transfers to the wheels that do not have direct application
4. The wheel flange is "replenished" in tangent running track when there is no flanging contact.

Key advantages of this approach are:

- The dry film of solid lubricant cannot migrate to the wheel tread or to the top of rail.
- The system has built in redundancy and reliability compared to flange spray systems.
- The consumption of solid lubricant is "self-regulating", meaning sticks are consumed only to the extent required by the wear and flanging forces.

The lack of migration from the gauge face interface can mean that the top of rail may have a higher COF than with oil and grease systems, where there is some uncontrolled migration to the top of rail. Therefore the optimum solution for overall is solid stick flange lubrication for the flange / gauge face interface, and top of rail friction control for the tread / top of rail interface. The latter can be provided by solid stick HPF friction modifiers applied to the tread or liquid friction modifiers applied to the top of rail. With this approach appropriate materials for each interface are provided to achieve the desired friction control objectives.

The figure below shows flange wear rates for a variety of systems with on-board solid stick lubrication (Fig 3). In all cases the wear rates are extremely low. Compared to the controls without the on-board technology, wear rates are typically reduced by a factor of 3-5. Controls include some cases where oil and grease systems were in place prior to the implementation of solid sticks.

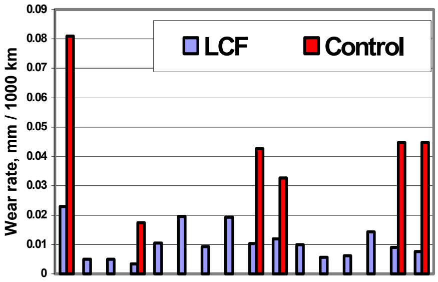

Figure 3. Flange wear rates, different systems

Top of rail friction control

Control of friction on the top of rail is a more recently emerging technology. Most of the world's railroads still operate today with no TOR friction control. This represents a large opportunity for the future in reduced energy consumption and wear.

Accurate control of top of rail friction at intermediate value is central to this technology (Fig 4). In this example liquid friction modifier is delivered through a trackside device on a transit system. Friction values are shown as a function of distance from the applicator bars, for the "dry" case, (before application), and with TOR friction control. The friction modifier clearly provides an optimum and closely controlled COF.

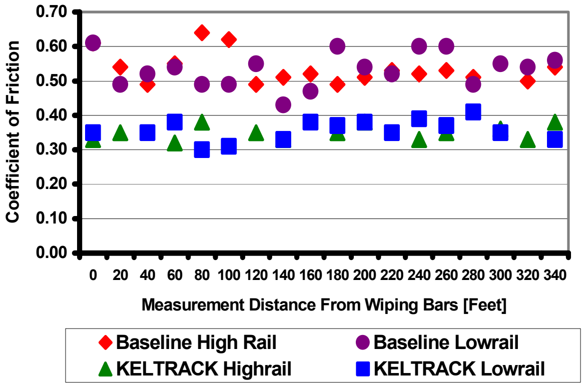

Figure 4. Friction control, top of rail

Case Studies

Case 1 – Allowing a preferred wheel profile with minimal flange wear

This European railroad hauls both long haul passenger and freight consists. The operator had experienced a history of low wheel life because of excessive flange wear on certain six axles locomotives. A consultant recommended changing wheel conicity from 1:40 to 1:20 to extend wheel life. This change increased wheel life to about 190,000 miles, but at the cost of a perceived ride quality deterioration. After the change in profile, re-profiling was predominantly for tread wear. The use of locomotive mounted solid stick lubricants (Kelsan LCF) was tested in combination with a return to the original 1:40 profile. The premise was that ride quality and tread wear would be improved at the 1:40 profile, and flange wear would be controlled with the on-board solid stick flange lubrication. This turned out to be the case. Solid LCF flange lubrication sticks were applied to the leading and trailing axles of each locomotive (Fig 5).

Figure 5. Onboard stick application

Results are illustrated in Fig 6. Historical intervals between re-profiling for the 1:20 profile were 38000 miles (without the solid stick flange lubrication system). Although the trial was concluded before the new limits of flange life could be determined, a dramatic reduction in flange wear rate is apparent.

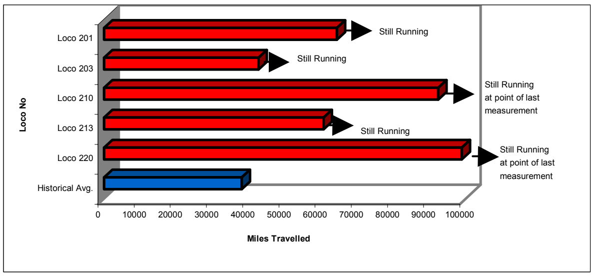

Figure 6. Extended reprofiling interval with LCF

Case 2 Reducing side rail wear with on-board solid stick flange lubrication

This new European Metro system was experiencing excessive track wear within nine months of service. The most severe wear was recorded on the two R125m mainline access curves connecting the depot to the track system. The system had no on-board or track lubrication capability. A solid LCF flange lubrication system was mounted on-board the cars, with 25% of the wheels directly applied. Figure 7 shows the results of side rail wear for four locations around a single 125 m radius curve and shows a dramatic reduction with the on-board solid stick system.

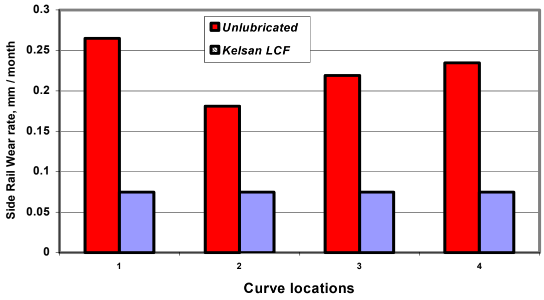

Figure 7. Side rail wear rates, LCF and control

Case 3- Reducing squeal noise with top of rail friction modifier

A North American transit system was experiencing difficulties with complaints from neighbouring residents related to wheel squeal. An electric trackside applicator delivering liquid friction modifier to the TOR was evaluated. Measured noise results are shown below before and after the top of rail friction modifier application (Fig 8). A significant reduction in wheel squeal noise is apparent.

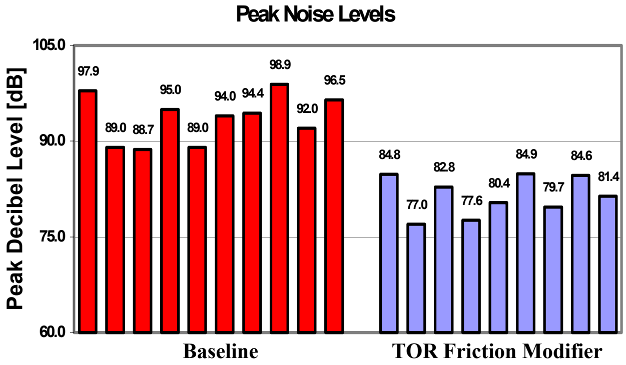

Figure 8. Noise reduction with top of rail friction control

Summary

Friction control tools have advanced dramatically in recent years. Separate approaches are needed to control friction at appropriate levels at the gauge face and the top of rail. On-board solid stick flange lubrication overcomes many of the past disadvantages of on-board oil and grease, and can also provide protection to the side of rail. Top of rail friction control is an emerging technology with significant potential to reduce fuel consumption, noise, lateral forces and wear. Appropriate choices in friction control technology require careful consideration of the overall goals and benefits desired.

References

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