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On some aspects of the wheel/rail interaction

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ABSTRACT

Problems in tribology and contact mechanics are becoming increasingly amenable to solution through models and simulation. But in application to the wheel/rail contact, there remain a number of very important features for which either gross simplifications or a lack of understanding or ability severely limits the success of those efforts. Examples include models of friction and material response (including damage functions). This paper examines a rather eclectic mix of wheel/rail factors with the goal of encouraging researchers to begin tackling and eradicating some of the bigger problem areas that remain in wheel–rail interaction modeling and to consider more rigorous implementation of real world conditions in simulations.

1. Introduction

Although the sophistication of computer models is increasing at a steady rate, there remain a number of input parameters for which only simplifications are applied or possibly available, but which might have a dramatic impact on the final results. The two most significant of these are friction and material response, though there are others.

The art of modeling wheel/rail performance is to know which elements can be simplified and which require more rigorous application. Several such elements will be explored in the following sections.

2. Surface roughness

With respect to contact stress, and hence the mechanisms of surface failure, roughness can have a strong impact. Kapoor and Johnson [1] found that even under light loads, surface roughness can lead to plastic flow in the near surface region. Elastic models with rough surfaces invariably show very high contact stresses at the asperity tips e.g. [2]. But in practice, Johnson concludes that elastic contact models can be applied with errors of only a few percent if the combined roughness of the two surfaces is less than about 5% of the bulk elastic compression ([3], Section 13.5), i.e.

$$\alpha \equiv \frac{\sigma}{\delta} = \sigma \left(\frac{16E^{*}R}{9P} \right)^{1/3} < 0.05$$

It is further understood that surface roughness can have a profound impact on wheel/rail noise with the severity of rolling noise increasing roughly linearly with roughness [4]. Very rough wheels running at 140 kph on smooth rail were measured to generate noise levels of 125 dBA at 0.5 m from the track. Such noise is especially problematic in Europe where there are a large number of passenger rail systems with relatively light axle loads operating in close proximity to large population areas. For this reason, the ISO guidelines place tight limits on allowable roughness, and even vary that level based on wavelength. In North America, acoustic grinding is a relatively new phenomenon, since it is accepted that the martensitic peaks generated by rail grinding are quickly obliterated by the passing wheels of even light axle load vehicles (see Fig. 1).

This observation of the temporary nature of surface roughness is consistent with a study conducted by Lundmark et al. [5] which found the roughness of freshly ground rail decreased from $S_a = 10$ μm to a value of about 1 μm within the first 1 ½ days of traffic (27,000 t). They similarly found that the highest peaks on a newly machined wheel would be halved within one 200 km journey. For both wheels and rails it was noted that the roughness can be expected to endure for a much greater time for harder materials. Grassie [6] found that same order of roughness change for freshly ground rail after 1 day of iron ore traffic (about 50,000 t).

But in the case of very rough surface, particularly freshly machined surfaces, it seems sensible that the roughness will impact the way that surfaces mate and the effectiveness of lubrication. This is a large concern regarding wheel climb derailment of freshly trued wheels. In Ref. [8] it is simply noted that "rough surface from wheel truing can increase the risk of flange climb derailment", presumably based on reports that wheel climbs

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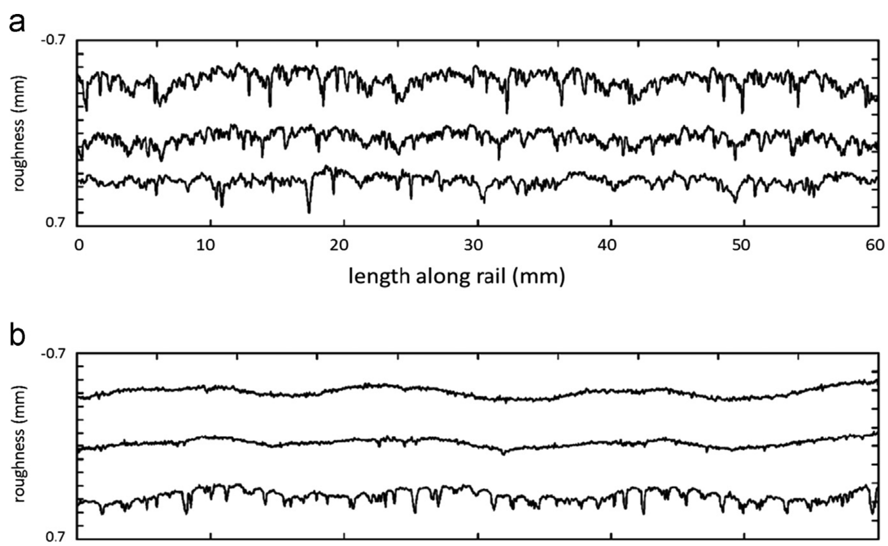

Fig. 1. Surface profiles on three different facets of a freshly ground rail surface (top) and after 3 days (< 0.1 MGT) of traffic (bottom) on a light axle load LRT system in California [Fig. 8 from Ref. [7]].

in transit systems are more frequently encountered with freshly trued wheels, often in yards right after the vehicle leaves the truing facility. Especially for milled wheels, until the roughness is smoothed through wear in operation it is likely that contact is able to break through surface contaminants, perhaps enabling asperity welding and most certainly increasing friction. For this reason a smoother surface is preferred. But in an article being presented at this conference, a detailed numerical model found that the friction creepage-characteristic is negligibly affected by roughness under dry conditions [9]. Similarly, laboratory testing in Japan of this specific feature [10] found that the increased surface roughness did not give rise to higher friction levels, and in fact friction tended to be lower for the higher surface roughness. This in turn suggests that roughness may not be the most important factor but rather that the relatively uncontaminated wheel surface is contributing to high friction, either at the low (inside) rail or at the wheel-flange/rail-gauge-face contact, and that a treatment might simply be light greasing of the freshly trued surface.

As for longitudinal roughness, the impact is less due to contact geometry and more to vertical [11] or lateral dynamic forces that can develop which give rise to noise [12,13] or further corrugation development [14]. Clearly, for long wavelength roughness the impact on contact geometry will be insignificant, but at shorter wavelengths, the roughness can be expected to cause a longer (in direction of travel) contact patch when the wheel is positioned over the corrugation trough and a shorter patch at the peak. Analysis of the corrugated surface shown in Fig. 2 found that the transverse radius of the rail crown did not change much at all, ranging from about 410 to 460 mm, but in the longitudinal direction, the radii of the peaks (looking from left to right in the figure) were 716, 366 and 627 mm, and of the troughs were −1180 and −880 mm. A Hertzian analysis suggests that the net impact on contact mechanics for a coned wheel is not large, with the contact stress being about 20% higher at the peaks than at the troughs, all other things being equal. Of course, all things are not equal, as the vertical wheel load cycles at the same time, tending to be lower at the troughs, explaining why the periodic wheel slip, in a self reinforcing cycle, causes greater wear at the troughs.

This situation was modeled by Piotrowski and Kalker [15] who found a significant change in the contact patch shape depending on the position of the wheel with respect to corrugation troughs and crests. They also showed large changes in the contact patch size, and hence the contact pressure, when a sinusoidally

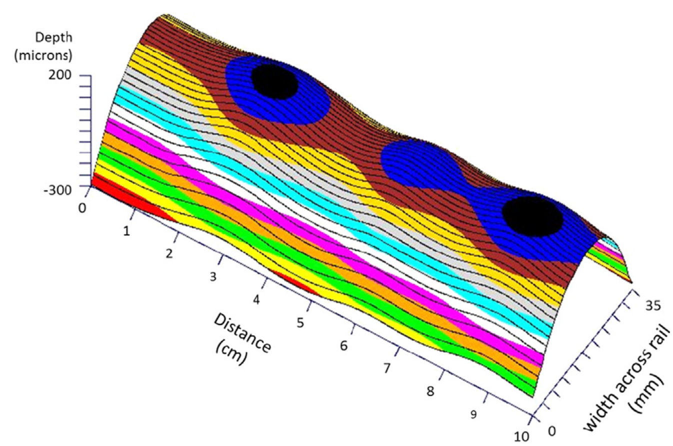

Fig. 2. Surface map collected from an acrylic replica of short pitch corrugations on the light rail system. The peak-to-peak corrugation depth is about 0.09 mm with a wavelength of about 32 mm.

fluctuating normal load is also included. For their case of a relatively shallow corrugation (0.05 mm, with a wavelength of 33 mm), variations in maximum contact stress of ±30% from the nominal (non-corrugated) conditions could be attributed to the geometry. In the case of a deeper and shorter wavelength corrugation, the effect could be expected to be much more dramatic with shapes varying significantly from the elliptical Hertzian shape (e.g. Fig. 3b).

They suggest that a corrugation can be considered shallow for

$$\alpha = \frac{L^2}{4\pi^2 R h_0} > 1$$

which for a 32 in. (0.812 m) diameter wheel gives $L^2/h_0 > 16$. This is plotted in Fig. 4 with a point representing the corrugation of Fig. 2 falling into the deep corrugation category. For deep corrugations they determined that the rate of change of shape and hence the change in creep coefficients is large and calls for a non-linear (transient) analysis.

2.1. Surface roughness: conclusion

Surface roughness is an important factor in high frequency phenomena and microsurface deformation, but with respect to