Identifying Root Causes of Heavy Haul Wheel Damage Phenomena

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Summary: The paper illustrates how damage patterns, in particular in the form of rolling contact fatigue (RCF), can be employed to identify underlying operational conditions. In particular the focus is on RCF of wheel occurring at the Iron Ore line in north Sweden and Norway. The paper charts seasonal changes and damage patterns, and potential root causes are identified and investigated. Finally mitigating actions are proposed.

1. BACKGROUND

Fatigue cracks, and rolling contact fatigue damage of heavy haul wheels in particular, has a tendency to occur in "epidemics". These may lead to significant operational disturbances and economical costs due to increased need for re-profiling. On such occasions it is essential to make swift and accurate identifications of root cause(s) in order to identify and implement suitable counter-actions that decrease the magnitude of the problem. The current paper details investigations setting out from operational cases from the Iron Ore line / Ofotbanen in northern Sweden and Norway. The study includes observations from loco wheel inspections in 2011 (November 22, December 19) and 2012 (January 25, March 05-06, April 26-27 and June 15).

The trains on the Iron Ore line / Ofotbanen have gradually upgraded the axle load. As of 2011 all trains are operating at an axle load of 30 tonnes. In addition, the length of the trains has been increased from 52 to 68 wagons. The locos are run as two coupled sections, each with two three-axle bogies. The braking is mainly carried out as regenerative electrobraking using the locos.

2. DAMAGE CHARACTERISTICS

2.1 Seasonal variations

The seasonal variations in loco wheel reprofilings are presented in Fig. 1. These data show one peak in wheel reprofilings in early autumn (with indications of starting already in early summer) and one peak in December.

Figure 1: Seasonal variations in loco wheel reprofilings owing to RCF or thermal cracks, 2008 to 2011.
In particular one can note the increase in reporfilings in autumn 2010 and 2011, predominantly owing to RCF. As a contrast, wheel damage data from the literature [1] and reporfilings data for wagon wheels on the same line typically show a peak from mid to late winter.

In Fig. 2 the distribution of wheel reporfilings owing to RCF or thermal cracks in year 2011 are presented together with an indication of the variations in ambient line temperature (valid for Kiruna and compiled from [2]) over the seasons.

2.2 Wheel damage patterns

Though the wheels generally showed a broad range of damage types, the most common type of damage was a band of cracks some 3.5 to 4 centimeters from the field side of the wheel. A similar type of damage surfaced in 2009. In Fig. 3a these types of damages are compared. It is seen that the location of the damage band is roughly the same. However the damage occurring in January 2009 was more fierce in that the band was more narrow leading to a “peeling-type” fracture of the surface material. Further, discoloration and flange wear was more common in January 2009 than in November 2011.

Typical damage evolution is presented in Fig. 3b where the same wheel has been investigated with an interval of about one month. Apart from the increase in damage (further material roll-out and more pronounced / deeper RCF cracks), it is interesting to note the sharp division between

![Figure 2](image1.png)

**Figure 2**: Seasonal variations in temperature and loco wheel reporfilings owing to RCF or thermal cracks in 2011.

![a) Damage band close to the field side of a loco wheel as evaluated in 2011-11-22 (top), and 2009-01-20 (bottom).](image2.png)

![b) Evolution of damage formation on a loco wheel (first axle in front bogie) as evaluated 2011-11-22 (top) and 2012-12-19.](image3.png)

**Figure 3**: Typical wheel tread damage patterns.
the damage band on the field side and the subsequently evolving damage band on the running band (zones 1 and 3, respectively following the categorisation of [3]; see also Fig. 4b).

As mentioned additional types of damage, although more uncommon, were found in the winter season of 2011. An example is presented in Fig. 4a where RCF cracks are found in zones 1, 2 and 3, see Fig. 4b.

During the winter season of 2011 wear magnitudes were generally low; rolling contact fatigue was the completely dominating cause of reprofiling.

There were very few signs of any significant influence of thermal loading. To rule out thermal loading as a significant factor, measurements of applied braking power were combined with numerical simulations [4]. These showed induced temperature levels to be far from potentially harmful magnitudes.

2.3 Comparison to deterioration of wagon wheels

An inspection of damaged wagon wheels on 18 axles was carried out April 27, 2012. The inspection revealed mainly two types of damage: Some of the wheels were subjected to brake-related damage in the form of wheel flats, discoloration, RCF in zone 3 etc. Other wheels had a form of damage very similar to that found on loco wheels. Examples of the latter are presented in Fig. 5. Note that the wagon wheels are about 50 mm thinner (in the axle direction) than the loco wheels, but have a similar wheel profile.

5. POTENTIAL CAUSES

The occurring cracks relate to surface initiated rolling contact fatigue. An index for this type of damage has previously been developed [5] setting out from the shakedown map [6]. According to this criterion, surface initiated RCF is predicted to occur if

\[
F_{\text{sat}} = \frac{2\pi a b k}{3F_z} > 0
\]

Here \( f \) is the traction coefficient (full slip presumed), \( a \) and \( b \) are semi-axes of the hertzian contact patch, \( k \) the material yield limit in cyclic shear and \( F_z \) is the normal wheel–rail
contact force. From Eq. 1 it is seen that a small wheel–rail contact patch and/or a high friction are likely causes for the surface initiated RCF.

### 3.1 Wheel and rail profiles

The RCF band on the field side is related to low rail contact during curve negotiation, possibly with some additional load owing to braking /traction. The fairly localised damage band is an indication of a rather small contact patch width, which relates to a poor wheel/rail profile match on at least a fairly high proportion of the curves. Further, the sharp divisor between RCF zones 1 and 3 (following [3]) should be related to a discontinuity in the rail profile curvature of the low rail (no pertinent discontinuity was found on the wheel). It could here be noted that different rail profiles on the low rail were employed on the Norwegian and Swedish parts of the line.

In comparison to the damage pattern evaluated in 2009 the conclusion is that the matching between wheel and high rail in curves has improved significantly. This is evidenced by the fact that flange wear has decreased and there is evidence of a continuous contact transition towards the flange. This is in contrast to 2009 when there was a tendency of the contact to shift abruptly from the running band to the flange. This improvement is related to an altered wheel profile, and a shift in grinding profiles, see [7].

### 3.2 Track geometry

A poor track geometry will generally influence the propensity for surface initiated RCF. To this end, several parameters such as nominal geometry, cant, track irregularities etc will play a role. Each of these can be influenced to decrease the general degree of RCF. However there are no indications that they have changed significantly for the worse over the last years.

### 3.3 Lubrication

As mentioned, a high wheel–rail friction will promote surface initiated RCF. To decrease the friction magnitude, lubrication is being employed. This is partly carried out by track-based lubricators, and partly by loco-based lubricators. The track-based lubricators are mainly lubricating the high rail in curves. Thus the effect of RCF initiated on wheels in contact with the low rail (corresponding to the location of the damage band) is confined to an overall improved steering in the curve. The oil-based lubricators that are primarily used do not function during cold temperatures. Consequently these are turned off from at least mid October to end of March and probably longer.

The loco-based lubrication should be in operation during the entire year. However investigations showed that these had not been operating as intended during summer and autumn of 2011. One could note that the loco-based lubrication primarily lubricates the flange. Thus, although lubrication is migrating over the wheel tread, the influence on reducing the friction on contact with the low rail is less than the effect on reducing flange wear and RCF in zone 2.

### 3.4 Sanding

Indentations were found on many of the wheels, in particular on the front wheels where sanding devices are installed. To establish whether the indentations

![Figure 6: Wheel treads of front bogie inspected in 2011: Right wheel on first axle inspected (a) November 22 and (b) December 19. Right wheel on third axle inspected (c) November 22 and (d) December 19.](image-url)
promoted surface initiated RCF, results from subsequent investigations can be compared as presented in Fig. 6. These investigations did not find a correlation between initial indentation damage and subsequent surface initiated RCF cracking. A likely explanation is that an increased tendency to RCF formation owing to the rugged surface is balanced by an increased wear rate. Since the statistical material was limited and operational distances between reprofilings low owing to the rapidly developing RCF (the total distance at reprofiling December 19 was about 49' km, of which roughly 10' km since the inspection in November 22), it was not possible to formally validate this hypothesis.

3.5 Influence of friction vs profile

Considering Eq. 1, it is seen that the $F_{I_{surf}}$ magnitude is linearly dependent on the traction coefficient, $f$, and the contact patch size $A_{c}$. The contact patch size in turn depends on the vertical contact load and the radii of the contacting bodies. For a wheel radius of $R=0.44$, a transversal radius of the wheel and a longitudinal radius of the rail taken as infinity, Fig. 7 shows the influence of the railhead radius, $r$, and the traction coefficient on predicted magnitudes of $F_{I_{surf}}$. It is seen that in the studied ranges ($0.01 \leq r \leq 0.3$ and $0.2 \leq f \leq 0.4$) the influence of the traction coefficient dominates.

![Figure 7: Influence of railhead radius and traction coefficient on the $F_{I_{surf}}$ magnitude.](image)

| Table 1: Seasonal variations in operational conditions and likely consequences on RCF damage. |
|---|---|---|---|---|
| 2011 | Jan-Mar | Apr-Jun | Jul-Sep | Oct-Dec |
| Climate | winter | summer | summer | winter |
| Profile | basically worn-in | worn-in | mis-match | mis-match |
| Loco lubrication | probably OK | probably OK | probably not OK | probably not OK |
| Track lubrication | off | off → on | on → off | off |
| Crack initiation | moderate due to better profile match but insufficient lubrication | low due to better profile match and lubrication | high due to profile mismatch and poor lubrication | high due to some profile mismatch and poor lubrication |
| Crack propagation | probably moderate due to better profile match and loco lubrication | probably moderate due to better profile match and loco lubrication | high due to profile mismatch and intermittent lubrication | high due to profile mismatch, poor lubrication and melting snow |

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3.6 Causes for seasonal variations in damage rates

An hypothesis that matches the observed seasonal pattern is as follows: In mid winter basically all wheels have been reprofiled rather recently. The increased loading due to winter conditions will impose more wheel tread damage, but cracks will take a while to develop. In late spring the track based lubrication is turned on, which will caused initiated cracks to propagate faster corresponding mainly to a first peak in late summer. Further, grinding removes residual lubrication on the rail surface, which may have an effect in increasing friction. This will increase RCF formation, which causes needs for reprofiling in the autumn. As autumn and early winter progresses the profile mismatch is gradually worn down, wheels reprofiled, etc, see Tab. 1.

4. MITIGATING ACTIONS

To reduce RCF damage, the loco-based lubrication was overhauled. In this process, the lubrication interval was decreased from 300 meters to 200 meters. In addition, the track based lubrication was progressively turned on as weather permitted. The consequence has been a decrease in wheel reprofiling during the spring of 2012. A similar decrease occurred also previous years, so one should not draw major conclusions from this. However an inspection in June revealed a somewhat different damage pattern as shown in Fig. 8. A comparison to a damaged wheel in December 2011 reveals that the band of RCF 3 damage remains, but the RCF cracks in zone 1 are absent. It should be noted that this damage was only found on two wheels (of 13 investigated; 11 with no significant damage and one also with skid marks). Consequently it is too early to say if this is a sign of an altered trend. With this being said, it may be a sign that curving friction has decreased and that the dominating cause of surface initiated RCF has shifted to braking. It may also be related to a wear-in of the inner rail profile. It should be noted that owing to the head hardened rails used on the line wear-in is generally a rather slow process.

To further enhance operational conditions, modified grinding profiles will be introduced. This will make Norwegian and Swedish profiles basically harmonised. Further, there is a push for track based lubrication that can function in winter conditions and top-of-rail lubrication is being investigated.

One further potential mitigating action is to increase traction and thereby wear off incipient cracks. The downside of such an approach is that it may promote profile deterioration (e.g. hollow wear) especially since rather significant wear rates are needed to suppress RCF under current conditions.

5. CONCLUDING REMARKS

The study of seasonal variations in the need for wheel reprofiling together with an analysis of observed damage patterns has been a basis for an analysis of root causes of excessive wheel damage. The study indicated profiles of the inner rail in (some) curves together with insufficient lubrication as main causes of the observed damage. The influence of observed indentation damage owing to sanding was investigated, but could not be linked to the increase RCF formation.

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