TOWARDS PERFECTED RAIL MAINTENANCE – COMBINING ROUTINE AND LONG-TERM RESEARCH ACTIVITIES

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SUMMARY

In 2007 the new grinding strategy with “Malmbanan”, Europe’s only heavy-haul railway, has been presented at the IHHA-conference in Kiruna. Four years later an update was given, as in between some adaptations concerning the target profiles and the metal removal requirements have been introduced. The monitoring process on selected test sections using MiniProf- and Eddy-current devices never stopped and provided since valuable understanding of the effect of applying optimized specifications. This was particular important in view of the increasing traffic load and the hence required doubling of the yearly grinding campaigns. The combination of the once fixed routine grinding operations with the research activities resulted in a consistently good rail surface situation and revealed further insight in the complex matter of wheel-rail interaction. The latest findings and further development is presented in this article.

1. INTRODUCTION

“Malmbanan” is the Swedish expression for ore line and it characterizes a really unique railway operation: Situated north of the Arctic Circle this railway operation undergoes harsh climatic conditions. As a matter of fact, Malmbanan consists of several different sections: The southern part from Gällivare to Lulea carries less traffic than the Northern one from the mine in Kiruna to the Norwegian harbour in Narvik; whereby the last part in Norway is called “Ofotbanen” (Figure 1).

It is interesting to note that several companies work together: The mines are operated by LKAB, which is also responsible for the ore trains and their operation. The railway infrastructure is in the hands of Trafikverket in Sweden and by Jernbaneverket in Norway. A further mining company “Northland” operated temporarily in 2013 and 2014.

This paper concentrates essentially on the Northern part of the Swedish side between Kiruna and the Norwegian border at Riksgränsen. It is characterized by a high percentage of curves with small radii from and 480 m upwards. The climate there is characterized by very dry periods in summer and by extremely cold winters that are interrupted by rather wet weather conditions in spring and autumn. This is reflected by measurements of lateral forces – and can also can be seen in the different development of surface fatigue.

This became apparent, when monitoring surface fatigue development increased following the need to execute two grinding campaigns per year, as the traffic load increased from previously 27 MGT per year to 34 MGT at present. Originally in the curves a yearly grinding cycle has been fixed and assured basically fatigue free rail surfaces.

Figure 1: Geographic situation of Malmbanan

As traffic load increased steadily, in 2014 for the first time two grinding campaigns have been...
programmed and executed. Both have been monitored by pre- and post-grinding measurements in the same way as in previous years. The findings are extremely interesting as will be discussed in detail in the following chapters.

2. REVIEW OF THE GRINDING ACTIVITIES

2.1 Grinding Strategy at the Beginning – 2007

At the IHHA-conference in Kiruna 2007 the development of a new grinding strategy was presented [1]. Since then annual grinding campaigns were executed on Malmbanan and consequently rail condition and quality of the track have improved significantly.

The introduction of the adapted profile MB1 on rails affected by severe RCF defects improved the fatigue situation considerably. Even when deep defects could not be removed completely from the gauge corner, the MB1 profile resulted in a decrease of the contact stresses at the gauge corner. Consequently the crack situation was improved, although it did not stop the following growth of the RCF defects completely. However, this approach resulted in a much longer rail service life and avoided premature replacement of rails.

The introduction of further optimized grinding profiles in some specific curves was proposed and the increasing use of trains with 30 tons axle load was closely monitored. Tests with new steel grades and lubricating equipment were considered.

Grinding operations has shown its large importance to achieve a beneficial technical and economical result, which leads to improvement of the life cycle costs for Malmbanan.

2.2 Summary of Intermediate Situation – 2011

In 2011 at the IHHA-conference in Calgary an update of the rail maintenance activities was given [2]. From 2006 to 2009 the line from Kiruna to Riksgränsen was equipped with 60E1 head-hardened rails of grade R350LHT and concrete sleepers. At selected places new rail grades R370LHT were installed for test reasons. All high rails in curves received specific so-called “Wear-adapted profiles”. In some areas similar profiles have also been tested with low rails in curves and tangent track.

In the year 2007 a rail monitoring program was launched in a big number of curves regarding the transverse profile situation. Soon afterwards Eddy-current recordings followed in order to monitor the development of Rolling Contact Fatigue (RCF) under traffic and its removal by grinding.

Systematic track visits and data evaluation helped to fine-tune the target profiles for grinding and to optimise the grinding strategy.

3. RAIL MONITORING ACTIVITIES

Following the establishment of an annual rail grinding strategy its effect has been studied and documented in detail starting in 2007. Six representative track categories (based on ranges of curve radii) have been defined and a number of representative test sites have been inspected in regular intervals as shown in table 1.

<table>
<thead>
<tr>
<th>Category</th>
<th>Layout</th>
<th>Radius (m)</th>
<th>Number of test sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Curve</td>
<td>&lt; 550</td>
<td>9</td>
</tr>
<tr>
<td>B</td>
<td>Curve</td>
<td>550 - 650</td>
<td>17</td>
</tr>
<tr>
<td>C</td>
<td>Curve</td>
<td>650 - 750</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td>Curve</td>
<td>750 - 850</td>
<td>2</td>
</tr>
<tr>
<td>E</td>
<td>Curve</td>
<td>850 - 1500</td>
<td>6</td>
</tr>
<tr>
<td>T</td>
<td>Tangent track</td>
<td>&gt; 1500</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 1: Different categories of curves and tangent track

Track characteristics, accessibility and not at least the climatic conditions limited the number of test sites. At the beginning however, 43 test sites have been retained in the monitoring plan [1-2]. Transverse profile recordings have been made twice a year, basically before and after grinding. Eddy-current measurements were made in parallel; some sections have been measured even 4 times a year.

The amount of data recorded was enormous and hence the evaluation work became a painstaking and time consuming action. Fortunately the recordings confirmed the expected profile- and headcheck development in the chosen categories and therefore the number of test sites and originally chosen recording points could be reduced.

A further reduction of recording points became necessary when a second grinding campaign was considered. It was preferred to double the number of recordings per measuring point by accepting a reduction of sites to be inspected. However the total number of days spent visiting and documenting the sites has been increased since.

Additionally the project team met twice a year to discuss results and to decide on further activities. The first one has been usually programmed for May – June, a season, which is characterized by having still some snow in track. All monitoring sites have been visited, including a trip to the Norwegian part.

Together with travel times from central Europe and intensive discussion of the observations a complete week has to be reserved for this project follow-up. The second project meeting is usually held in the North in early December –
characterized by the very short daylight period of a few hours only.

Figure 2 shows the annual workflow for this project according to the PDCA-cycle (Plan-Do-Check-Act).

<table>
<thead>
<tr>
<th>Act</th>
<th>Monitoring Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan</td>
<td>Field visit and decide grinding</td>
</tr>
<tr>
<td>Check</td>
<td>Measurement 1a</td>
</tr>
<tr>
<td>Do</td>
<td>Grinding 1</td>
</tr>
<tr>
<td>Check</td>
<td>Measurement 1b</td>
</tr>
<tr>
<td>Check</td>
<td>Measurement 2a</td>
</tr>
<tr>
<td>Do</td>
<td>Grinding 2</td>
</tr>
<tr>
<td>Check</td>
<td>Measurement 2b</td>
</tr>
</tbody>
</table>

Figure 2: Yearly project activities

4. SPECIFIC AREAS OF CONCERN

4.1 Defect development - Expectations and experiences

Generally the rail situation with RCF was well controlled. Figures 3 and 4 illustrate the contact band on a low rail after grinding the wear-adapted MB5 target profile. This profile is developed based on a large amount of wheel profiles made by the automatic wheel profile system located on the Iron Ore Line [3].

Figure 3: Ideal contact band of MB5-profile (after passage of 1 ore train)

However, in some specific curves fatigue problems with the low rails and exceptional growth of damage occurred. Figure 5 shows an example the contact conditions of the MB5-profile – but sometime after grinding. It reveals several parallel lines of concentrated contact.

Fortunately it has been decided to continue the monitoring program. The ongoing research activities allow to combining the well supervised routine maintenance activities with testing of new modified rail-head profiles and varied metal removal rates.

Figure 4: Transverse profile MB5-profile compared with 60E1-profile

Already when fixing the specifications for grinding in 2007 it was clear that only one target profile and one metal removal rate for each grinding cycle would not be sufficient in order to suit all track sections optimally.

Therefore different target profiles for low and high rails in curves have been specified. For tangent track the low rail profile was prescribed. Metal removal was set as 0.2 mm in the rail head centre, and the grinding cycles were specified as 27 MGT (yearly) for curves and 80 MGT for tangent track.

It was expected that in the different test categories metal removal requirements may vary as lateral did. The influence of the growing fleet of new vehicles with 30 ton axle load might furthermore require a more general modification of the grinding specifications as well as their different wheel profile and wheel maintenance scheme with respect to the one of the older vehicles.

However, some specific variations of the defect development could be observed, too. The low rail in a few curves developed surface problems. At some places two distinctly different contact bands could be identified. When experimenting with
modified target profiles it has been found that the influence of the low rail plays at least the same important role for curving as the high rail profile. Thus, quite some more knowledge has been accumulated and it is worth-while to be discusses in this paper.

4.2 Wear rate of rails

The wear rate of rails depends on the curve categories. Small radius curves have a larger rail wear rate then large radius curves and of course tangent track. There is also a difference between curves within the same category. For instance, curves A01 and A04 have almost the same radius and cant, but they different in length (see table 2), consequently they differ in wear behaviour.

<table>
<thead>
<tr>
<th>Curve</th>
<th>Radius (m)</th>
<th>Length (m)</th>
<th>Cant (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A01</td>
<td>476</td>
<td>176</td>
<td>60</td>
</tr>
<tr>
<td>A04</td>
<td>498</td>
<td>278</td>
<td>60</td>
</tr>
</tbody>
</table>

Table 2: Data of test curves A01 and A04

Figure 6 shows natural, artificial and total wear development of the high rail in mm², the A01 curve in green and the A04 curve in blue colour over the period from 2007 until 2012. The two rails differ by around 30%.

4.2 Gauge widening

Between the years 2006 and 2009 all rails of the whole Northern part of the Malmbanan has been changed towards 60E1 rails of grade R350LHT inclined at 1 in 30. Before 2006 the hole line had wooden sleepers (except a tunnel and some track in stations), and they were replaced with new concrete sleepers during the track renewal.

During the track visits, in some curves rolling contact fatigue could be detected on the low rails. The then programmed 0.2 mm metal removal in the centre of the rails could not remove the surface cracks and consequently in the following year some centre line spalling developed. There was a need to consider some heavier metal removal, which nevertheless could not eliminate everywhere the defects in the following grinding intervention.

At first some different train behaviour at these locations has been suspected as possible reason. However not all places, where this situation occurred, had the same line characteristics. There must have been something else which was special in these curves and different from the majority of the other curves not suffering from low rail fatigue.

Careful study of the track parameters revealed finally the common feature – wide gauge. Wherever centre-line spalling was found the gauge width was above 1450 mm. With all the affected rails the fastenings have moved the rails towards the field side. This resulted in a shift of the contact band in the same direction and provoked a very small contact band after grinding of the wear adapted MB1-profile, sometimes only 15 mm wide, an example is shown in figure 7.

Figure 6: Wear development of the high rails in curves A01 and A04

Figure 7: Low rail – concentrated contact

The yearly gauge widening amounted up to 2 mm/year in curves with radii smaller than 550m. For tangent track the gauge growth is zero.

Obviously the surface stress concentration provoked fatiguing. Consequently it has been decided to correct the gauge width using reinforced fastening clips (figure 7).

Figure 7: Picture of the new fastening
However not all affected sections could receive a clip change within a short period of time. Therefore it has been decided to apply the flatter 60E1-profile instead of the usual MB4-profile which resulted in a sufficiently wide contact band after grinding. To reach an even larger contact zone the MB5-profile could be applied and this will be tested for some time before a regular use. Figure 9 shows the contact zone between MB4-profile and MB5-profile.

It is important to note, that where the gauge has been corrected or was programmed to be corrected soon, the MB-4 profile had to be ground and therefore careful programming and supervision on site was a must.

After some years of such adapted grinding work – a combination of different target profiles and corrective metal removal rates, the mentioned low rails are mainly back to a defect free situation.

As a consequence of the concentration of the wheel load in the centre of the low rail surface cracks develop and grow into the rail head reaching a depth of several millimetres. When grinding is executed, the top surface of the rail head is removed, the remaining deeper cracks are overloaded and spalling results.

Figure 10 shows a typical example of isolated spalls. Figure 11 is a striking example of centre-line spalling; the crack orientation indicated the strong force component across the rail head due to the lateral movement of the wheelsets in a wide gauge track. Finally an accumulation of cracks has developed near a sleeper forming a typical heavy-haul corrugation.

4.3 Influence of Low Rail Profile on High Rail Performance

Originally more emphasis was put to the high rails, as they suffered earlier from gauge corner fatigue. The monitoring activities confirmed that the cyclic
grinding strategy worked quite well for them. Occasionally there were some curves with a little bit of remaining head checks after grinding and some were almost not affected even before grinding.

Very often these variations were found to be related to the low rail profile which was treated differently, often due to the aforementioned spalling problem.

A very small and distinct contact zone on the low rail steers the wheels differently – actually better – with respect to a wide contact area. But curving is only one part of the equation and providing a considerably wide contact zone on the low rail to reduce the risk of spalling is counterproductive for keeping gauge corner fatigue on the low rail under control.

4.4 Influence of Different Rolling Stock

As mentioned in the introduction in 2013 a second mining company started to operate ore trains over the Malmbanan, figure 13 shows the two different wagon types. After a while different contact zones compared to previous times have been detected at some places.

Additionally to the usually wider contact area two small distinct contact zones became apparent. It was found that the wheels of the wagons of the so-called “Northland trains” had different wheel profiles and thus provoked the new concentrated contact zones as illustrated in figures 14 and 15.

Due to the recession of the iron ore market the services of the second mining company were suspended in autumn 2014. The project team requested that the standard Malmbanan wheel profiles have to be used in future by all new mining companies should they start or resume services.
wheel rail interface does not be challenged too much by different rolling stock and in particular different wheel profiles.

5.2. Required Strategy Changes

Finally in 2013 it has been realized that more metal removal was needed per year in order to keep up with the fatigue growth rate. Consequently it has been decided to change from the yearly grinding cycle to a higher frequency in order not to run from a basically preventive strategy into a corrective one, with all the well-known negative effects.

Seasonal and operational constraints limit however the options for more frequent interventions. Just to recall: In the past, grinding was undertaken in mid-summer (July – August), where work conditions are the best in the year.

First of all the mine works with reduced output to allow for some planned maintenance work in their facilities and this opens more possession time for track maintenance activities.

Secondly the weather is much more pleasant than in any other period of the year and longer work-shifts are possible.

A second grinding campaign some 4 to 6 months after this summer work would definitely fall into the worst work season, as in winter there is a lot of snow, temperatures drop below 20 degrees Celsius and basically all work had to be undertaken in darkness – as the sun does not move above the horizon for some time.

Definitely the ideal summer campaign had to be given up. After careful consideration the following new regime has been decided:

One grinding campaign called “heavy” should every year cover all curves and the relevant parts of tangent track. This campaign would basically cover all the sections ground annually and be programmed in May just after the hard winter season.

The second grinding intervention should be scheduled for October, as close towards the winter season as possible. There, all more RCF-sensitive sections, basically small radius curves, should get a second preventive grind.

In 2014 this regime was carried out for the first time.

6. THE WHEEL – PARTNER OF THE RAIL

As mentioned before, the wheel profile plays the same important role for ensuring optimized contact conditions as the rail profile. It should be noted here, that at Malmbanan there is certain cooperation between the infrastructure manager and the train operator.

For example, the wheel profiles of the new wagon wheels are a result of common considerations. It would have been counter-productive had both sides developed their profiles independently.

For instance some lessons had to be learned in this respect, when a second mining company started to operate trains. The respective wagons used have been bought with the standard UIC S1002 profiles, which resulted in a rather different contact area wheel/rail as already discussed in chapter 4.4.

From earlier times locomotive wheels had different wheel profiles as the ore wagons. This has resulted in some particular wear and fatigue signs on some of the locos.

Figure 16 shows the fatigued surface of such a locomotive wheel – close cooperation is under way to fine tune the wheel profiles and to find methods to reduce surface fatigue.

![Figure 16](image16.jpg)

**Figure 16: Surface fatigue on a locomotive wheel.**

Besides the use of harder steel grades and modified electro-dynamic braking different wheel profiles, as shown in figure 17 will be tested in various combinations. The WPL9 profile is the actually used locomotive profile. WPL2V2 and WPL4V2 are new profiles that have been generated in the wheel optimisation project.

![Figure 17](image17.jpg)

**Figure 17: Modified wheel profiles for testing**
7. RESULTS OF NEW STRATEGY

7.1. HC - Recordings

The overall metal removal of both grinding campaigns together was generally lower than with the heavy intervention in the previous years (gauge corner area) – confirming the chosen strategy.

During winter and spring (between grinding actions in October and May) RCF-defects grew considerably slower than in the warm and dry summer period between the grinding actions undertaken in May and October. This phenomenon might be due to the climatic conditions: drier January – February and June – September, wetter in March-May and October – December.

The following two figures explain the head check development according to seasonal weather variations. A compilation of head-check recordings before and after the grinding campaigns in 2013 and 2014 illustrate the situation:

Figure 18 demonstrates the head check development in test curve A04. As expected due to experience in the previous years some RCF on the gauge corner has developed when the recordings before the grinding campaign in summer 2013 have been made. All these cracks could have been eliminated by the following grinding campaign.

Following the new strategy the next grinding intervention was planned already for spring 2014. The project team was curious to see the head check development. Some light head checking was expected to develop until the spring campaign of 2014.

The pre-grind recordings however showed no signs of fatigue cracks – and of course also the post-grind recordings after the light preventive intervention in early June proved a fatigue free rail surface.

There was however an unexpected surprise in October, when after a fairly short time period just before the so-called “light” intervention on some special sections already head-checks of the usual 0.3 mm depths could have been measured.

Therefore the second programmed grinding intervention of the year was really necessary in order to get again a defect free surface. The rectification work was correctly executed as shown in the last recordings of figure 18 at the bottom.

Figure 19 shows the situation in a curve where fatigue development appears at a somewhat slower speed. Head checks are basically kept under control throughout the observation period. Just over the drier summer period surface fatigue cracks developed in 2014 as the traffic load has increased.

The pre-programmed preventive grinding campaign eliminated all headchecks.
7.3 Proposed Strategy Adaptation

Inverse spring and autumn grinding campaigns are the logic consequence: Therefore the grinding of all curves and relevant tangents will be shifted to autumn and the lighter intervention on the selected curves categories undertaken in May. By doing this it is assured that zones with more critical growth of headchecks are treated before the more sensitive RCF-season.

All the other zones are corrected after this season and should then be ready for another year. Of course in the first year some flexibility will be required as there is an 18-months period between the “heavier” basic campaigns for all curves and a 6-months period between the “lighter” additional campaigns for the more critical categories.

The Eddy-current measurements would allow fine-tuning the metal removal rates for each grinding campaign. However, this would only be possible if such recordings could be made in all curves and ideally during grinding work.

Such measuring equipment has been mounted on some grinding machines and provides valuable information on head check development and reduction or removal by the grinding intervention.

Due to contractual issues such grinding machines equipped with Eddy-current systems are foreseen to be introduced with the next contract period.

8. ADDITIONAL REMARKS

8.1 New Steel Grades

Some intended rail renewals already planned will be postponed due to the good results of grinding. In one curve, the steel grade R370CrHT was tested as high rail. While it showed less wear compared to R350HT due to the higher hardness, the advantage of less RCF development observed was not sufficient to stretch the grinding cycle from one year to two years.

As a consequence, the even harder steel grade R400HT will be tested as a high rail expecting to have even better wear and RCF properties and fulfill this requirement to reduce the grinding. This steel grade already replaced R370CrHT at the Ofotbanan and also performed best in low rails at Malmbanan. [4]

8.2 Top-of-Rail Friction Modification

Some tests with top-of-rail friction modification using stationary equipment have been undertaken, but no definite conclusion could be drawn regarding its influence in fatigue and wear due to operational and maintenance issues. Further activities in this field are considered.

8.3 Future Project Activities

The monitoring activities and the project group meetings for the next project year been programmed and there is a clear objective to keep the research activities going in the once fixed way in order to profit most from the ever growing data collection. This enables on one side to learn from the past and on the other to project trends into the future.

The wagon wheels perform very well, and they are usually turned because of wear after approximately 180'000 – 200'000 km. On the contrary the loco wheels have never been turned because of wear; the main reason has been surface damage sometimes appearing already after 10'000 – 20’000 km, when nearly no wear had occurred during that short time period.

Therefore wheel profile modifications and braking regimes as well as wheel lubrication in different combinations will be tested with selected locomotives.

The traffic load is stable for the moment. However, an increase from the present 34 MGT per annum to 50 MGT in 2017 has been announced. A further adaptation of the grinding cycles or intensity respectively is most likely.

Some further tests with top-of-rail friction modification are considered.

9. CONCLUSION

The development of the grinding practice with Malmbanan has been a long-term project. Today keeping rolling contact fatigue under control has become a routine operation.

Nevertheless the former project team continues with systematic applied research activities, which enable to consistently improve the knowledge in the field of wheel-rail contact and fatigue and to optimize the grinding strategy as well as to adapt it to the ever changing conditions of railway traffic and exploitation.

10. ACKNOWLEDGEMENTS

The present rail maintenance strategy is the result of a close cooperation within a small, but dedicated group of track experts.

Frequent and intense contacts have pushed forward to improve know-how and understanding. The authors would particularly acknowledge the work done by the other group members, in particular Anders Frick and Malin Syk from Trafikverket, Stefan Kallander (from Sweco), Per Gustafsson from LKAB, Norbert Frank from Voestalpine Schienen GmbH, Alexander Baltzewitsch from Speno International and Björn Larsen from Jernbaneverket, who also contributed greatly to the preparation of this article.
11. REFERENCES


