

Railway Gazette

INTERNATIONAL



Optimising rail grinding strategies on the Malmbanan



EVOLUTION As traffic and axleloads increase, work has been underway of the past decade to improve rail life on Sweden’s heavy haul iron ore railway, including harder rail steels, changes to rail and wheel profiles and improvements to the rail grinding regime.

Over the next few years, annual iron ore traffic on Europe’s most northerly heavy haul railway is expected to reach 45 million gross tonnes per year, putting additional strains on the infrastructure.

Known as the Malmbanan in Sweden and Ofofbanen in Norway, the line runs from Luleå to Narvik via Gällivare and Kiruna, with much of the route lying north of the Arctic Circle. As well as the iron ore traffic, the line carries regular passenger and freight trains.

Following an upgrading programme launched in 1998, most ore trains are now 750 m long, formed of 68 wagons with 30 tonne axleloads. Operation of these heavier vehicles began in 2000 on the southern part of the route between Gällivare and Luleå, using a single trainset for testing and acceptance. The proportion of 30-tonne traffic on the southern section reached 80% by 2007 and almost 100% the following year. On

Dr Wolfgang Schoech
External Affairs Manager, Speno International

Anders Frick
Senior Metallurgist, Trafikverket

the busier northern section between Kiruna and Narvik, which is currently carrying 27 MGT, the use of 30-tonne axleloads began in 2007 and has now reached almost 100%.

Due to the recession, traffic volumes have been running below forecast for some time, but ore production

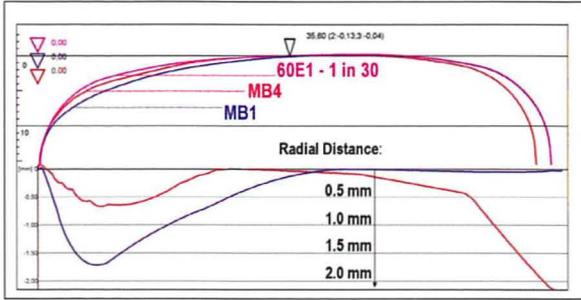
has returned to its earlier levels and is expected to increase steadily to reach 40 or 45 MGT in 2015.

Track maintenance strategies

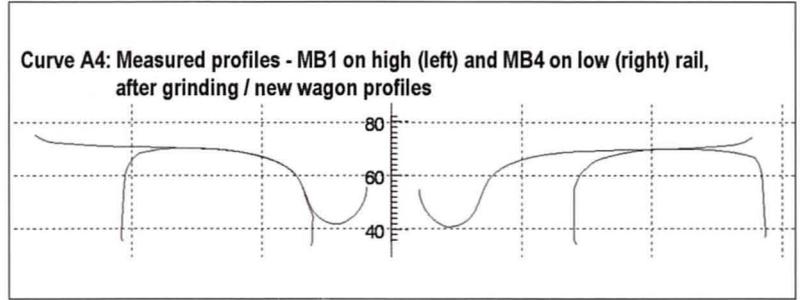
Track maintenance on the Malmbanan was originally very similar to conventional mixed-traffic lines, but the increasing loadings led to problems with rolling contact fatigue. Consequently rail grinding practices were reviewed, using a fixed cycle, and experiments were undertaken with different target profiles. Rail

Table I. Premium rail steels in regular use and on test sections at Malmbanan

Rail grade	Steel type	Tensile strength Mpa	Minimum elongation %	Hardness BHN	Properties & application
R350HT	Traditional head-hardened rail	1175	9	350 to 390	Three-fold resistance to wear and RCF compared to R260. Used on all European railways
R350LHT	Head-hardened 0.25% Cr	1175	9	350 to 390	Increased wear and RCF resistance. Established in Heavy Haul applications
R370LHT	Head-hardened 0.5% Cr	1175	9	370 to 440	Further increase in resistance to wear and especially to RCF. Increasingly used for heavily loaded tracks.



Above: Fig 1. After using the MB1 rail head profile since the 1990s, Trafikverket is now testing the MB4 variant.



Right: Fig 2. A new wheel profile is also being tested against the two rail profiles.

grinding in turnouts was also adopted as standard.

In the 1990s, a modified rail head profile was developed, known as MB1 (for Malmbanan). This was designed to optimise the wheel-rail contact conditions compared to the 60E1 profile originally used, with the then-typical hollow worn wheel profiles. The MB4 variant with less under-cutting of the gauge corner was tested later (Fig 1). Annual grinding campaigns were adopted, corresponding to cycles of between 18 and 27 MGT¹.

During 2006-09 the whole line from Kiruna to the Norwegian border at Riksgränsen was equipped with 60E1 head-hardened rails of grade R350 LHT, inclined at 1:30 and laid on concrete sleepers with elastic fastenings. All high rails in curves were ground to a specific 'anti-head check' profile, and similar profiles were also adopted for some sections of low rail and tangent track. New rails of grade R370 LHT were tested in selected locations.

In order to optimise the grinding strategy, a joint programme was launched in 2007 (RG 6.07 p369), bringing together infrastructure manager Banverket (now Trafikverket), grinding contractor Speno International and rail supplier Voestalpine Schienen. Selected curves were monitored in detail, initially only by measuring the transverse profile but later including eddy-current recordings to assess RCF development and its removal by grinding. Systematic track visits and data evaluation were used to optimise the grinding strategy and target profiles, in order to keep RCF

under control and minimise wear to prolong rail life.

Wheel profiles

As with many heavy haul railways, the iron ore wagon wheelsets often suffer from hollow wear, leading to overloading of the gauge and field corners on the rail head. With the introduction of new wagons, a modified wheel profile was adopted, in order to provide conformal contact with the specific rail profiles used on the Malmbanan, notably for the high rails in curves (Fig 2). To achieve adequate stability against hunting on tangent track, the new profile has a reduced radius differential compared to the previous one.

Operator MTAB's new IORE electric locomotives were delivered with standard P8 wheel profiles, but following problems with RCF on the wheel tread a new profile similar to that of the wagons was developed in 2009 by MTAB in co-operation with the Swedish and Norwegian infrastructure managers. The resulting close conformal contact between wheel and rail led to changes in the specifications for rail grinding.

Rail steels

Harder grades of rail steel have also been adopted to resist both wear and RCF (Table I). Traditionally, hardness is increased by raising the carbon content and by adding alloying elements such as manganese and chromium. The Brinell hardness of alloyed steels is limited to about 350 to ensure reasonable toughness, and higher hardness levels can only be achieved by heat treatment of the rail head².

R350HT is the basic heat-treated steel grade, used widely across Europe in tight curves with all types of rail traffic. During the EU funded Innotrack project (RG 1.10 p48), it was confirmed that this grade also offers advantages in curves suffering from head checking, in conjunction

with a proper grinding strategy³.

R350LHT is a Cr-alloyed version of R350HT with a Brinell hardness around 10 points higher. This grade has been used on the Malmbanan since 2000, and is used as the basis for all comparisons with other steel grades. Further increasing the Cr-content to about 0.5 % allows a Brinell hardness of 370 to 410 to be achieved with a fully pearlitic microstructure. Such a grade, designated 370LHT, is being tested in a curve with a radius of 500 m, and we expect that the higher hardness will extend the time until head checks develop. Our current tests are intended to quantify this improvement, so that it can be incorporated into longer grinding intervals.

Rail grinding strategy

Good results were obtained with the original maintenance strategy based on cyclic rail grinding, but with changes to parameters such as wheel profile and traffic loads it was felt that ongoing monitoring of rail conditions could help to optimise the maintenance strategy and provide a good quality of rail surface more efficiently.

The effects of grinding are being monitored at a number of test sites, using both transverse profile recordings and eddy-current measurements at regular intervals. Though it would be ideal to undertake these recordings at short intervals, such as every three months, this was not possible because of operational and meteorological constraints. Manual transverse recordings have therefore been taken twice a year, before and after grinding. Eddy-current measurements are taken four times per year on selected sections of track.

In order to limit the test zones and data evaluation, six representative categories were established: five for curves and one for tangent track (Table II). The number of sites for each category was chosen to reflect their

Table II. Representative track categories

Category	Geometry	Radius m	Test sites
A	Curve	< 550	9
B	Curve	550 to 650	17
C	Curve	650 to 750	3
D	Curve	750 to 850	2
E	Curve	850 to 1500	6

frequency on the whole line. The six locations shown in Table III contain a total of 43 test sites, which were also selected because of their comparatively easy access.

Transverse recordings

Transverse profiles are measured using a MiniProf device before and after grinding at every catenary mast in curves, giving a spacing of 50 m to 60 m, and at every second or third mast in tangent track. Each cycle requires about 800 measurements. Figs 3 and 4 show examples of measurements taken at the same point over a number of years, with the superimposed measurements at the top and the radial distances between the profiles below. Beginning from the initial measurement after grinding in 2007 on top, the red line shows the position before grinding in 2008, and so on showing natural and artificial wear.

Fig 3 is a representative example showing annual vertical wear of about 0.15 mm and side wear less than 0.5 mm. Metal removal in the centre of the rail head to restore the target profile is up to 0.75 mm per grinding cycle, which can be considered high.

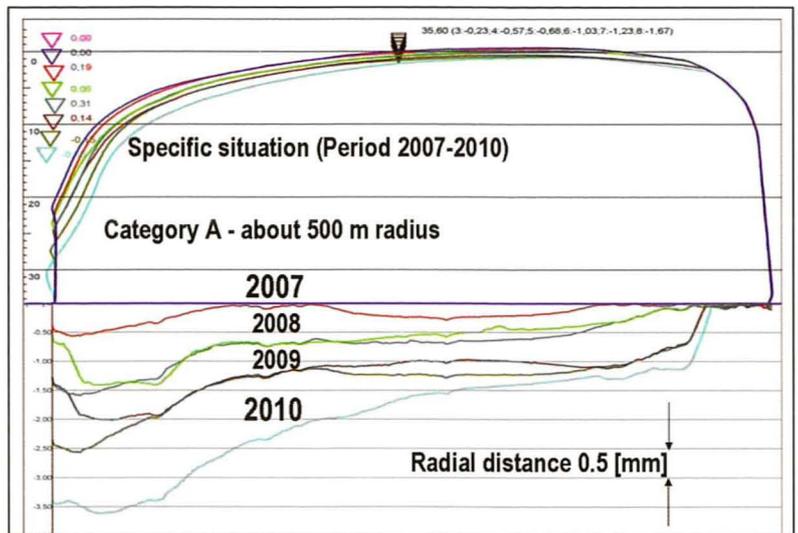
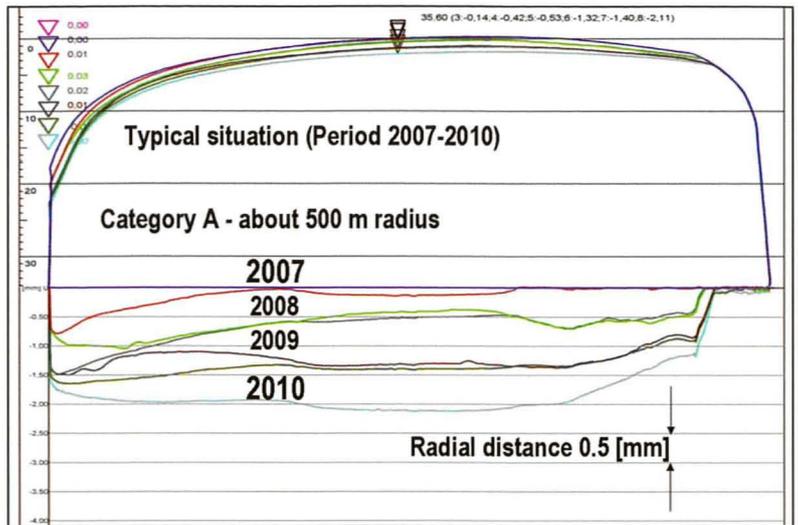
Fig 4 shows an exceptionally high degree of vertical and lateral wear. Even with the big natural side wear, more metal removal was needed to keep the development of head checks under control. The difference in wear development might be influenced by the location of this curve, which is close to a station entry signal.

To measure RCF development, a manual prototype eddy-current measurement system was tested after the grinding campaign in 2008. During 2009 more-advanced commercial equipment was used. All sites were measured just before and after grinding, and some were also checked in October and April to give four measurements per year.

A typical situation is shown in Fig 5. After grinding in 2009 there is a clear reduction in the depth and density of head checks, and by 2010 virtually all cracks had been removed by grinding.

By contrast, Fig 6 shows an exceptional site. After grinding in 2009 only a minor reduction in head checks can be observed, and grinding in 2010 could not remove the RCF. Crack depths before grinding were recorded at 0.2 to 0.3 mm, but after grinding the device indicated crack depths

Figs 3 (right) and 4 (below). Recordings of the transverse profile shows different wear patterns in Category A curves.



of approximately 0.25mm, despite the measured removal of 0.4 mm. This may be an effect caused by the geometry of the cracks, or another unknown phenomenon affecting the device itself.

When using the measurement results as basis for optimisation of rail grinding strategies, it is important to consider their accuracy and the impact of uncontrolled changes to other parameters. These could include:

- lubrication conditions at different recording points, which might mean that wear and head check

development might not be always directly comparable;

- track layout, including curve radii and super-elevation, but curves in tunnels or snowsheds behave differently to those in the open air;
- train operations, where acceleration, braking and coasting at different parts of the line are likely to affect rail performance;
- weather conditions, with wear developing at a lower rate during wet conditions than at dry times.

Having an adequate number of recording points is also important, and

Table III. Test locations

Site	Location	Length m	Comments
1	Bergfors – Torneträsk	344	MB1 profile/different tolerances 2008
2	Bergfors – Torneträsk	1 102	Test with 60E1 profile
3	Stordalen – Abisko	2 378	Representative sites
4	Björkliden – Kopparåsen	6 582	Representative sites
5	Låktatjåkka – Vassijaure	1 511	Strain gauge measurements, test with MB 3 profile
6	Vassijaure – Riksgränsen	5 209	Test with R370LHT rail on high rail

it is necessary to interpret the data with care. Very often trends need to be carefully observed and sometimes corrected using skilful interpretation; pure mathematical statistics will not be sufficient to understand complex changes. A description of the average situation with an indication of deviations from the mean values is the best way to describe trends and limits.

Strategic considerations

When establishing a rail grinding strategy, it is important to consider two main aspects: target profiles to assure optimal wheel/rail contact conditions, and the grinding intervals and metal removal needed to remove the fatigued surface layer and maintain the transverse profile.

During 2007 all rails in a 66 km long section of track were renewed and ground to the MB1 target profile, with production tolerances of 0/-1.0 mm. This was expected to assure sufficient gauge corner relief, reduce hunting and improve the steering ability of the older conventional bogies which still formed the majority of the fleet. For continuity this strategy was kept during the grinding campaign in 2008.

However, the average ground profile turned out to be consistently closer to the lower limit, and the resulting distinct two-point contact increased lateral wear considerably. Therefore the tolerances were changed to ±0.5 mm for 2009.

From 2007 the high rails in two curves were ground towards the as-rolled 60E1 profile in order to provide a control sample to confirm the advantage of the MB1 profile. This test was terminated in 2010 as the head checks reached a depth far beyond that controllable using the usual rate of metal removal.

The MB1 profile on the low rail

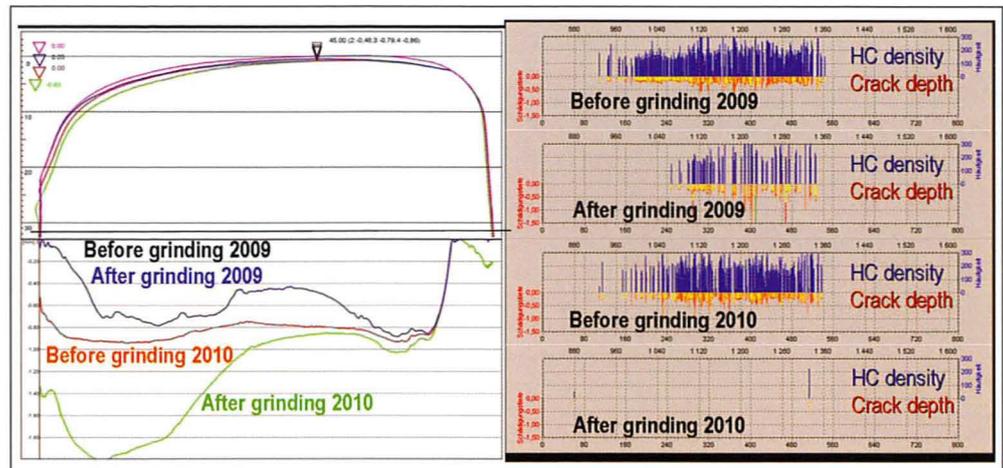


Fig 5. Eddy current testing shows a clear reduction in RCF following grinding in 2009 and 2010.

resulted in a small contact band, which did not widen quickly enough, as the growing number of wagons with 30-tonne axleloads provided a much better curving behaviour. Therefore during the 2009 campaign some curves were reprofiled to MB4, and some to 60E1 to widen the contact band on the low rails in curves and tangents. The precisely monitored use of different profiles helped us to better understand the balance between target profile, metal removal and RCF development.

Usually wear, head check development and grinding cycles can be related to time, for example expressing them as mm² of head loss per year or per cycles of one or two years. Technically, it would be more meaningful to talk about cycles with respect to traffic volume in MGT. However weather conditions and organisational matters restrict interventions to certain periods. North of the Arctic Circle work can only be carried out in the summer period. Thus, the requirements for metal removal are based on the expected defect depth which may be reached before the next possible intervention, imposing a yearly cycle.

If defect development can be kept small, an annual cycle is sufficient.

Fig 6. It is not yet clear why head checks persist at this test site despite regular grinding.

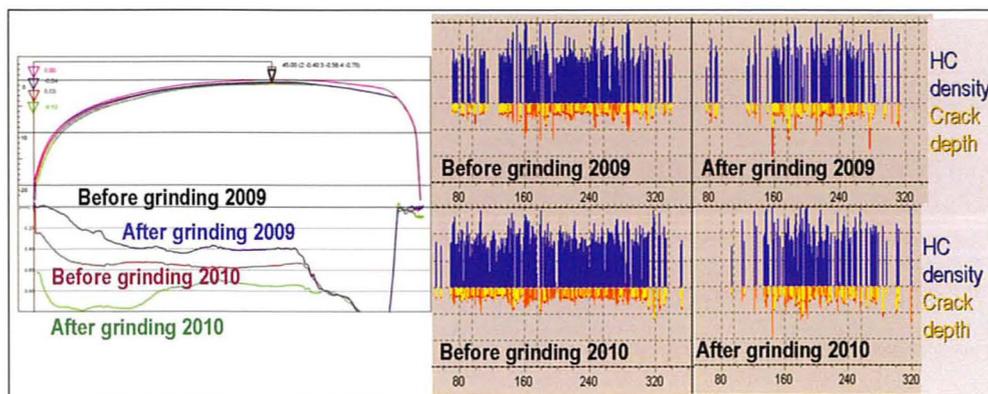
But with growing traffic volumes likely to accelerate the development of defects, discussions are now underway about the feasibility of fitting in two grinding campaigns per year.

Initial results

At present, grinding on the Malm-banan is undertaken once a year. Between Kiruna and Riksgransen, all curves and turnouts should be ground after every 27 MGT, and tangent track after about 80 MGT, or every third year. The southern section Gällivare and Luleå is currently carrying 18 MGT a year, and here curves up to 600 m radius are also ground every year. Curves with bigger radii are ground every second year, and tangent track every three or four years, up to 72 MGT. As expected, the head check recordings show that some curves need more metal removal at the gauge face each time or a more frequent grinding cycle. The present specifications are characterised by shaping the profile towards the target within tight tolerances and a minimum metal removal of 0.2 mm for both preventive grinding with new rails and maintenance grinding on existing track.

High rails ground to the MB1 profile are behaving well, and the current focus has shifted to the low rails, where the MB4 and 60E1 profiles are used depending on the location. Further profile development is underway for both low rails and tangent tracks, and a change in specifications is envisaged based on the Innotrack results, in particular deliverable D4.5.5.

The use of specific wear-adapted profiles has now stabilised, and the grinding specifications concentrate on metal removal requirements.



A constant metal removal rate of 0.1 mm in the centre of the rail head is considered sufficient. As the formation of head checks tends to occur closer to the gauge face, the specified metal removal is based on measurements and experience. A maximum removal of 0.6 mm in the affected zone relieves any gauge corner contact and keeps the resulting two-point contact within acceptable limits.

The need to undertake two grinding campaigns to cope with the projected annual loading of 45 MGT on the northern section after 2015 creates some logistical problems, as it is not possible to undertake any work before mid-May and after mid-October. This means that the metal removal specifications will probably have to be modified.

Further investigation

Rail maintenance is a long-term process, and it is important to follow it closely over a long enough period

to assure statistically-valid data and respond to any positive or negative effects of the chosen strategy.

Trafikverket's current programme to collect and evaluate rail condition data, including transverse profile and head check measurements, will continue at all recording sites. One idea now under consideration is to use grinding machines equipped with a head check detection system, allowing live information about RCF conditions to be collected during grinding.

Regular site visits, usually in May and October, help to refresh the memory about specific track sites, and enable a continuous discussion about wheel-rail interface issues in general and the local effects in particular. Bringing together the infrastructure manager, rail supplier and grinding contractor allows all parties to learn from experience. The accumulated knowledge is not simply added, but multiplied by comparing different viewpoints and specific expertise of all three parties. ◀

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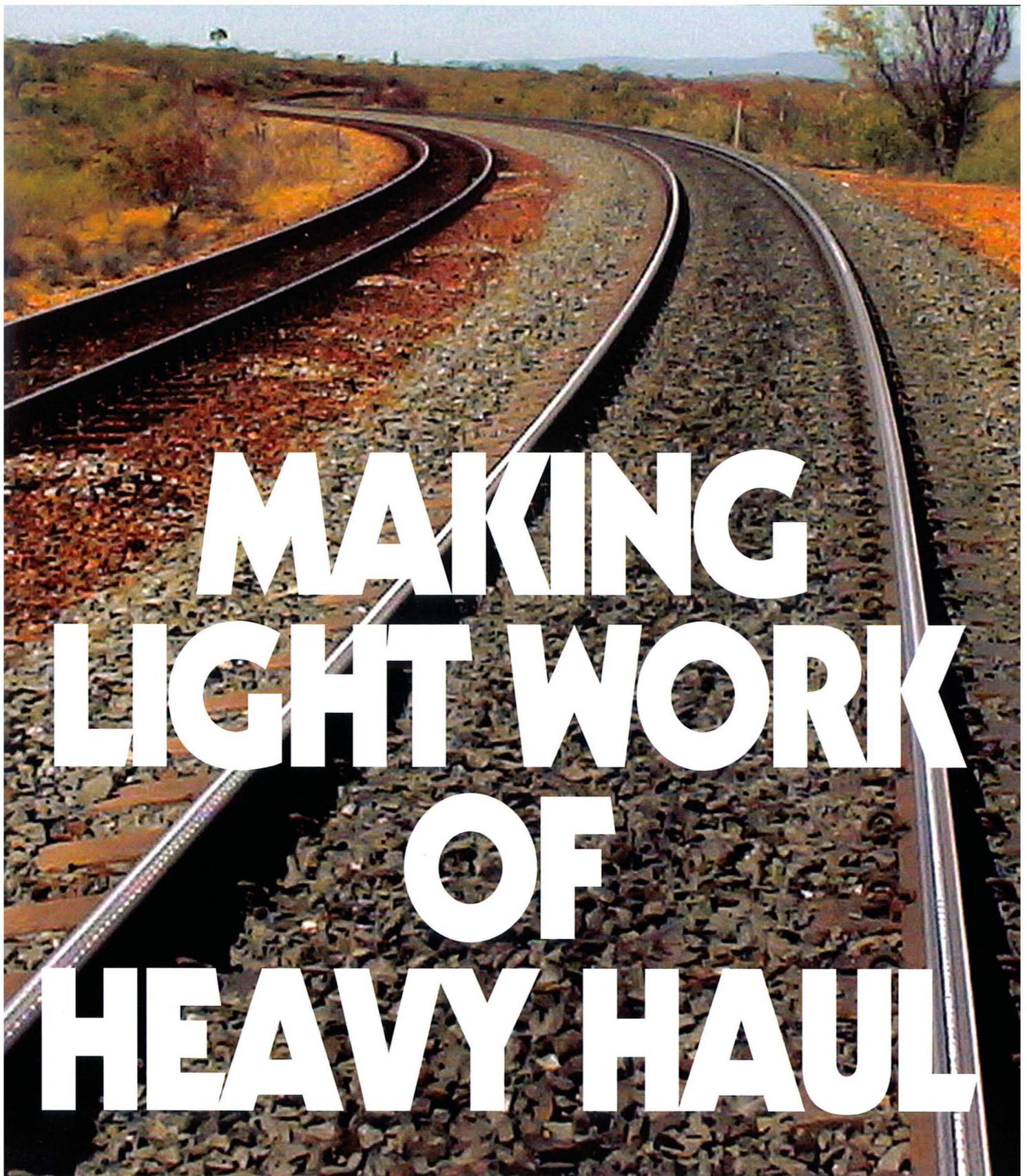
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Acknowledgements

The development of rail grinding practices on the Malmabanan is a result of a close co-operation within the project group. The authors would like to acknowledge the work done by Malin Syk and Per Gustafsson from Trafikverket, Alexander Baltzewitsch of Speno International and Norbert Frank from Voestalpine Schienen GmbH, who have contributed greatly to the preparation of this article.

Speno's RR16M6 grinder in operation on the Malmabanan.





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SPENO INTERNATIONAL SA

26, Parc Château-Banquet, POB 16, 1211 Geneva 21, Switzerland

Tel: +41 22 906 46 00 - Fax: +41 22 906 46 01

e-mail: info@speno.ch - website: www.speno.ch



SPENO INTERNATIONAL SA

26, Parc Château-Banquet, P.O. Box 16, 1211 Geneva 21, Switzerland

Tel: +41 22 906 46 00 Fax: +41 22 906 46 01

e-mail: info@speno.ch website: www.speno.ch

Reprinted from Railway Gazette International, January 2012