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INNOTRACK

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Thematic Priority 6: Sustainable Development, Global Change and Ecosystems

D4.5.3 – Fields of improvement in grinding practices as input for LCC evaluations

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RE	Restricted to a group specified by the consortium (including the Commission Services)	
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Table of Contents

Table of figures

Glossary

Abbreviation/acronym	Description
EMGT	Equivalent million gross tons
LCC	Life cycle costs
MGT	Million gross tons

1. Executive Summary

The work package 4.5 summarized the present grinding strategies and target profiles used in order to identify potential for improvements aiming at reducing LCC.

This document describes fields of improvement such as specifications and logistics, to maintain rails more economically and how to change towards a preventive cyclic grinding strategy.

2. Introduction

When the INNOTRACK project started, it has been hoped, that new rail maintenance technologies would be developed helping to reduce LCC. This is not the case. However, it has been found, that there is a great potential for improving the effects of the existing rail grinding technology.

The represented IM's have based on their experience put together information on how to maintain rails in a way to prolong rail life and reduce LCC. These may serve as examples for other IM's not yet having established a particular maintenance strategy.

3. Potential for increasing efficiency of present rail maintenance work

3.1 Optimization of grinding interventions

3.1.1 Initial grinding

General

Initial grinding of new rails in track is carried out for a number of reasons:

- Removal of mill-scale and rust
- Removal of (minor) damage resulting from track construction work
- Improvement of (minor) irregularities at welds
- Optimization of the transverse profile (reduction of deviations from production tolerances of all track components)
- Application of specific target profiles (if not milled), such as asymmetric profiles, anti-headcheck profiles, gauge widening profiles etc

The positive effects result in reduced forces and vibrations (perfect and smooth longitudinal profile) and optimized contact conditions which both contribute to delay and reduce onset of surface problems (corrugation in the longitudinal plane and surface fatigue)

Present situation

Initial grinding is done with all newly constructed lines (in particular high-speed). It is also done after renewal of long sections of rail. Due to operational restrictions it may be executed up to 6 months after re-railing.

Specifications usually demand a (minimum) metal removal of 0.3 mm, as-rolled profiles and symmetric tolerances (e.g. +/-0.3 mm).

Some IM have started to specify specific target profiles (wear adapted – BV, low conicity profiles – ÖBB) and request negative tolerances (e.g. 0/-0.6 mm) in case of expected gauge corner fatigue (DB AG, BV), see D 4.5.2.

Potential improvement

As a rule grinding should always be carried out as soon as possible after re-railing. The target profile should always be optimized, e.g. “anti-headcheck-profiles” with adapted production tolerances (usually only negative) or wheel-adapted profiles.

3.1.2 Maintenance Grinding

Present situation - Sporadic corrective actions:

In Europe – apart from some exceptions (see below) - there are no specific and harmonized grinding strategies applied. Grinding is mainly executed to control corrugation and related noise problems. Occasionally, but in a growing number, grinding is executed, when RCF seems to be more severe. Exceptionally, some IM have started to program grinding work in fixed (shorter) intervals. European wide accepted specifications do not exist yet. Current practice varies from 0.2 mm metal removal at shorter intervals (15 – 30 MGT), complete damage removal (which is not checked) to partial damage removal (no values specified), special target profiles (usually designed from experience) become more widely used.

Basic problem is the influence of the available grinding budget, which is usually insufficient in order to apply a more strategic maintenance regime. Short time considerations (repair of damaged components) dominate over a long term approach (prevention of damage to reduce LCC).

Exceptions

Regarding headchecks DB uses manual inspection trolleys based on eddy current and ultrasonic technology. The point in time for rail maintenance (grinding or renewal) depends on the value of depth of damage and from the result of ultrasonic testing (see INNOTRACK deliverable D4.5.1).

DB AG and ProRail use rail inspection trains equipped with an eddy current detection unit (see INNOTRACK deliverable D4.4.1). This unit is able to examine the rails with inspection speeds of up to 100 km/h. The eddy current testing with the rail inspection train, which is currently undergoing trials, will be incorporated into the scheduled rail inspection programme in the near future. After assessment the results of the combined eddy current and ultrasonic testing with rail inspection trains will be the basis of planning maintenance activities for rails with headchecks.

Present situation - Strategic preventive actions

The represented IM's have already specified strategic actions based on their local conditions and experiences. They differ in detail, as described below, but have a basic common approach, which is summarized in chapter 3.1.2.4.

DB AG

In 2008 a preventive cyclic rail grinding programme has started for rails in curves with radii from 500 to 5.000 m for lines with high capacity (40% of the whole network). Preferred action is rail machining with a metal removal of 0.5 mm. The machining interval depends on the load of the track per year and varies from 0.5 to 2 years (see figure 1). Target profile is 60E2 with an inclination of 1:40 with only negative tolerances (0 to -0.6 mm). The installation of an anti-headcheck-profile (e.g. 60E2 1:40 with 0.6 mm undercutting at the gauge corner and with symmetric production tolerances of +/- 0.3 mm) is under discussion.

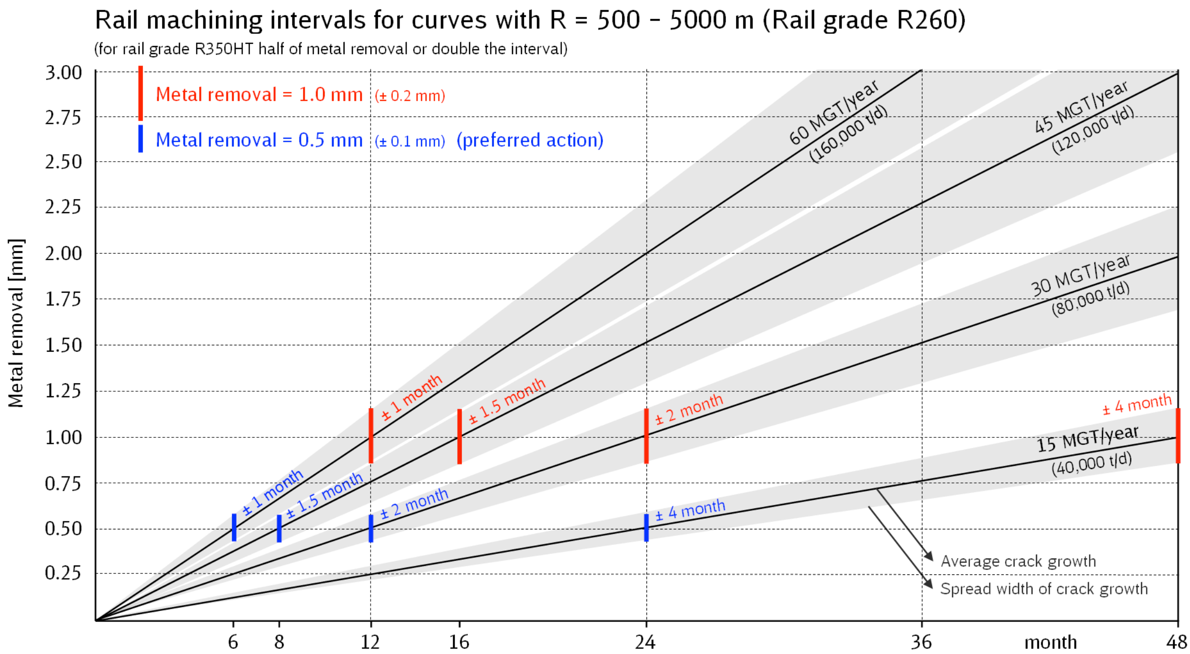

Figure 1 - Specifications for DB preventive cyclic rail machining programme started in 2008 for rails in curves with radii from 500 to 5.000 m for lines with high capacity in the DB network

SNCF

Until 2007 rail maintenance was done in a corrective mode:

On conventional lines treatment was programmed when defects (headchecking) could be visually detected or influences in track geometry became apparent.

On high-speed-lines rail grinding was executed when ballast stone imprints or headchecking occurred.

SNCF Infrastructure Maintenance Division has undertaken an econometric study[1]. Consequently a new maintenance strategy has been envisaged and will be implemented from 2008:

- Preventive cyclic grinding first on lines UIC groups 1 to 4 and then 5 and 6
- Gradual reduction of the amount of corrective work (the corrective treatment becomes exceptional);
- Continuous treatment of lines with flexible metal removal according to the rail condition assured by variable grinding speed, the final aim being a constant one;
- Grinding cycles:

UIC group	Cycle [years]	Minimum Metal Removal [mm]	Remarks
High-speed-lines	1	0.15	From 2009
1 and 2	2	0.2	Starting 2012 after transition from corrective mode
3 and 4	4	0.2	
5 and 6	6	0.2	Depending on experiences

With long term programming (interventions are known years ahead) longer possession times can be organized in order to increase productivity of grinding sites and thus reduce costs;

The application of special Anti-Headcheck-Profiles as described in D4.5.2 has resulted in a prolongation of rail service life of at least 5 years.

ProRail

Preventive cyclic grinding has been started at 2005 by adoption of the Canadian grinding policy (NRC). Before coming in the preventive cyclic grinding mode, it was important to reach a zero level by corrective grinding when necessary.

Therefore in Holland it takes 2 years of planning grinding capacity to reach the preventive cyclic grinding policy 100% for straight track and curves.

For the switches ProRail started in 2007 to grind in the Anti Head Check profile. Preventive cyclic grinding for switches focused on the straight part and not the curved side.

<u>Preventive cyclic grinding:</u>

Grinding frequency (based on tonnage of track and switches):

15 MGT Radius R < 3000m

30 MGT Radius 3000 < R < 9000m

45 MGT Radius R > 9000m

Target profiles:

Straight track: 54 E1 profile
Curves (upper leg) and switches: 54 E1 AHC (Anti Head Check) profile

Metal removal:

Minimum of 0.2 mm within one grinding pass

[1] “Impact of preventive grinding on maintenance costs and determination of an optimal grinding cycle” (C. Meier-Hirmer, Ph. Pouligny).

Corrective (RCF) grinding:

Grinding maintenance is executed 6 to 9 months after inspection by a measurement train. Head Checks cracks not deeper than 2 mm or squats with a diameter up to 6 mm are efficient to grind (LCC). Aim is to erase the defects with a removal of maximum of 1.5 mm on radius 80 mm and radius 300 mm of the rail profile 54 E1 (target profile). For switches and the upper leg in curves with radius R<3000 m the 54 E1 AHC profile will be used.

Preventive initial grinding:

Grinding just after installation or renewal of track. Best effect is achieved by grinding within 6 weeks after installation and allowed is a maximum of 3 months after installation. Metal removal is minimum 0.5 mm of the total profile 54 E1 (target profile). At switches and the upper leg in curves with radius R<3000 m the 54 E1 AHC profile will be used.

Corrugation grinding:

After corrugation measurements (geometry) by the measurement train corrugation is removed completely. A minimum of 0.5 mm removal of the total profile 54 E1 (target profile) is needed. At switches and the upper legs in curves with radius R<3000 m the 54 E1 AHC profile will be used.

Acoustic grinding:

Preventive cyclic maintenance to lower the noise energy for people living aside the track;

Manual grinding:

Especially for the short length of some switch parts it is cost efficient to do grinding manually instead of using the grinding train (for example squat defects).

Milling on bridges:

Instead of grinding on open brigdes which requires actions to avoid disturbances of the environment, milling is used. Metal removal of 0.5 to 1.5 mm. It is possible to reprofile the rail.

There is no difference within the UIC classes 1 till 5. For the other UIC classes, if necessary, there is a tailormade grinding programm made by the track experts in the ProRail regions.

Remarks:

The introduction of the preventive cyclic grinding strategy has resulted in a reduction of rail maintenance costs of about 50 percent.

A similar approach at the wheel side (introduction of anti-headcheck wheel-profiles and regular wheel turning) has resulted in a reduction of wheel maintenance costs by some 30 percent.

NR (Network Rail)

Network Rail currently uses three large plain line grinders, capable of grinding 32km of curved track or 96km of straight track per overnight shift (single pass regime) and three smaller grinders, capable of grinding a maximum of 6.5km of curved or straight track in a shift (multiple pass regime) in order to fulfil the following objectives:

- to produce a regular and consistent running band on the crown of the rail
- to impose and maintain a profile that reduces contact stresses on the gauge corner and shoulder of the rail
- to remove localised misalignment at welds and other track features
- to remove the fatigue damaged surface of the rail, which has or is likely to initiate rolling contact fatigue (RCF) cracks.

Rail grinding activity is prioritised as follows, targeted so that the highest priority curves with radii less than 2500 m as well as switches and crossings are ground approximately every 15 EMGT and straight track every 45 EMGT of traffic:

- Rails with light or moderate RCF (to reach the target profile as quickly as possible)
- Rails with heavy or severe RCF (to reach the target profile as quickly as possible)
- Rail in a curve that has been previously re-railed due to RCF (to reach the target profile as quickly as possible)
- Rails with severe corrugation (to reduce peak-to-peak amplitude of the corrugation).

Rail grinding on curved track is carried out to manage the rail profile and provide a consistent running band towards the crown of the rail (gauge corner shoulder relief). This is required more frequently due to the more rapid deterioration and loss of the ground rail profile as a result of side wear.

Rail grinding on straight track is undertaken to control corrugation and squats, to maintain a near new rail profile and to give a variation to the shoulder relieved profile used on the high rail of curves. This is required less frequently as wear rates and profile deterioration is much lower.

Where RCF exists, grinding of long sites is undertaken using a grinding train so as to produce a uniform running band towards the crown of the rail and to relieve load from the cracked area and slow the development of the existing cracks. Train based grinding of cracked rail may not remove the cracks unless they are very small and shallow. .

Where train based grinding is being used regularly on RCF affected rail, the rate of crack growth will be retarded, allowing cracks to be progressively removed with subsequent grinding passes.

Where grinding is being used regularly on new rail, this will provide an improved profile and remove the fatigue damaged surface layer and reduce the rate at which the profile deteriorates. The profiles, frequency and minimum metal removal rates have been developed to slow down or stop the rate at which cracks initiate and grow.

Rail head profiles:

Both BS113A and UIC60 rail sections are ground to have the same nominal head profile. The NR HR1 profile is used for the high rail of all curves and has additional relief on the shoulder and gauge corner of the rail. The NR 113lb profile is used for all other rail, which is a low rail profile equivalent to a new BS11 113A or CEN56E1 profile.

Table 1 shows the profile tolerances and minimum metal removal for plain line. For all rail grinding, compliance to target profile tolerances and minimum metal removal shall be achieved in at least 80% of the track ground length.

Track location	**Target profile** (Profile definition angle range) (see also D 4.5.2)	**Tolerances for:** (Tolerance angle range)	**Minimum metal removal** (MMR to be achieved in the angle ranges)
High rail	NR HR1 (-5º to +50º)	+0.3mm to -0.3mm (-5º to +50º)	0.2mm (see note 2) (0º to 45º)
Low rail	NR 113A (-5º to +50º)	+0.3mm to -0.3mm (-5º to +50º) (see note 1)	0.1mm (see notes 1 and 2)
Straight track – Both rails	NR 113A (-5º to +50º)	+0.3mm to -0.3mm (-5º to +50º)	0.1mm (see note 2) (0º to 45º)
Corrugated track – Both rails	NR HR1 or NR 113A (-5º to +50º) (see note 3)	+0.3mm to -0.3mm (-5º to +50º)	0.2mm (0º to 45º)

Table 1 - Profile tolerances and minimum metal removal – Plain line

Notes on Table 1:

1. Total passes for the low rail of a curve shall be equivalent to the total passes required to produce the high rail target profile. If the target NR 113A profile cannot be achieved on the low rail within this total number of passes the minimum metal removal of 0.1mm between 0º to 45º shall be achieved.
2. In order to maximise productivity. Network Rail will instruct, on a site and/or route specific basis, where the profile, but not the minimum metal removal, needs to be achieved. Where necessary this may result in little or no metal removal from the centre of the rail head. For in-traffic one pass grinding the above criteria might not be reached in one grinding cycle.
3. Due to severe RCF and corrugation, it is applicable to use NR HR1 for the high rail and NR 113A on low rails and straight track with a tolerance of +0 to -0.6mm except on the centre of the rail where +0.3mm to -0.3mm is to be used to get a more aggressive grind to the same target profile. The aim is to keep the profile close to the lower (-0.6mm) tolerance. The need for grinding as above shall be agreed with the Network Rail representative.

Potential improvement – General introduction of strategic preventive actions

Headcheck-detection systems have been developed and are now also available on rail grinding machines. These systems allow to checking the defect depth. Thus a certain damage level could be accepted (as intervention threshold or as remaining depth after treatment) - small enough to be removed in a short time and not interfering with safety issues – and of a certain dimension not to intervene too often – in order to reduce interference with traffic.

Basically, it must be kept in mind that the longer the maintenance interval, the higher the metal removal rate and – most importantly – the longer the period with growing surface problems (mind also other irregularities, corrugation and high internal stresses). Equally the ratio of natural wear (by traffic) over artificial wear (by grinding) needs to be well balanced.

The maintenance interval should depend on actual measurements, as well as requested metal removal – which needs to be checked during grinding work. Such a policy would limit artificial wear by grinding. Specific target profiles (with defined gauge corner relief) and respective production tolerances need to be applied (see INNOTRACK deliverable D4.5.2).

When establishing a strategic headcheck controlling approach, logistical issues need to be addressed as well: Grinding interventions require track possession time. If the used grinding technology matches all the requirements high production rates at comparatively low prices can be expected.

When working in cycles (for any given surface problem) all other irregularities such as corrugation, imprints, squats etc will be controlled or eliminated simultaneously and their negative effects will be removed equally.

Remark 1: Metal removal recording is at present limited to spot-check measurements. Mainly the superposition of transverse profiles with devices which record the complete railhead (e.g. MiniProf) is used. Alternatively specific rail height measurement devices using a micrometer are applied. It would be a great progress, if devices for controlling the metal removal rate in a continuous way could be developed.

Remark 2: If wheel profile management was undertaken in a similar preventive way with improved intervention threshold, rolling contact fatigue would be positively influenced as well, with all resulting positive consequences for LCC.

3.1.3 Proposal for a strategy change

In order to move from the present corrective maintenance regime to a preventive cyclic one, the following steps are proposed:

- Measure and document the actual situation with regard to rolling contact fatigue
- Classify the track sections in the following categories:
    - Preventive cyclic work sufficient
    - Corrective work required
    - Heavily damaged (to be replaced in due time)
- Prioritize required corrective actions
    - Corrective to zero (preventive mode) in one step - Preferred scenario
    - Corrective to zero (preventive mode) in several steps - (If budget or grinding capacity limited)
    - Keep present situation by preventive cyclic interventions - (Minimal solution)
- In any case keep all existing and corrected sections in preventive cyclic mode
- Prioritize preventive cyclic work over corrective work

3.2 Logistics optimization

3.2.1 Present situation

Grinding is executed according to programs, which are based on a mix of various rail surface phenomena:

Originally corrugation removal and related noise reduction was the main application for grinding. Removal of ballast stone imprints and similar surface defects followed. Today RCF – correction plays an increasing role.

Usually grinding concentrates on problematic areas often dispersed geographically. As depots for the grinding machines are located at considerable distances (sometimes over 100 km), the grinding machines have to be transferred every day over long distances (as low priority trains), thus useful working time is lost. Due to the need to organize possession intervals for the execution of work further time is lost for organization and waiting during the work shift.

3.2.2 Potential improvement

RCF grinding should be programmed strategically: A regular (preventive cyclic) grinding program should cover a whole line. Possession times should be organized accordingly. Depots adapted to the maintenance requirements of the machines should be available at strategic points.

An ideal maintenance plan would provide that the grinding machines (size to be adapted to required metal removal in a one-pass operation) starts from the first depot and moves over the line in order to grind wherever required. The working speed would be dependent on the required metal removal (mind cycle) and could vary from 3 km/h (exceptionally in case of more severe defects) to a maximum of 20 km/h (at present grinders are limited at about 10 km/h).

Present experience does not reveal any negative effects of “normally” ground rail surfaces. Excessive roughness and wide facets with sharp ridges between them are usually excluded by the grinding specifications. This might be different for light axle traffic (urban systems) and would require further investigation.

On-board recording equipment has to assure continuous documentation without the need to check the result in track (some effort for respective development is required, also with a view to avoid accumulated grinding material falling down from the machines). Available track possession time is generally short and shall thus be used as effectively as possible. Organising daily grinding work needs to be perfected in a way to increase the ratio working period over effective grinding time to a maximum.

Predictable time requirements are favourable – multiple pass work should be limited. Production rates would increase tremendously when one-pass grinding could be executed uninterrupted. With an average grinding speed of 10 km/h it should be possible to achieve a production rate of up to 50 km per day.

At present grinding contracts are directly or indirectly based on daily shift prices, which determine the costs for a finished kilometre. As very often the grinding equipment is used at short sections (problematic curves) often many kilometres apart, and corrective work requires a higher number of working passes, the price per finished meter is fairly high.

Carefully planned machine deployment leads to cost reductions. Internationally, production time (time for grinding, reversing, measuring, cleaning) amounts to about 60 % of the machine deployment time at present. If the ratio production time / deployment time could be increased to 70 %, this would lead to a cost reduction of 14 %. For example with an estimated budget requirement of 50 million Euro per annum, this would lead to an achievable saving of 8.4 million Euro annually. [2]

Costs would drop further considerably, if continuous operations could be programmed. With uninterrupted one-pass grinding over long sections a 30 % reduction is easily within reach.

In order to achieve such an ideal situation, respective high-capacity machines need to be provided. A respective investment is only justified, when these machines can consistently work in a high-production regime. Short grinding sections with severe defects requiring multiple passes in further distances are of course to be attributed to more flexible compact machines. As a consequence respective contracts have to cover periods of several years, which also would allow lowering basic rates for daily shifts.

In order to implement a preventive cyclic strategy for a given track section, line or network, circumstantial corrective actions are required in order to bring the concerned track section, line or network in similar conditions regarding grinding requirements. This implies a heavy investment in maintenance followed by economically beneficial cyclic measures.

Grinding work reduces dynamic forces and vibrations and thus helps to reduce track degradation. It should therefore be - whenever possible - coordinated with other track maintenance activities, e.g. whenever tamping work is required, it should be checked whether existing corrugation should be

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[2] Hempe, Thomas & Siefer, Thomas: “Rail grinding as an integral part of technically and economically efficient track maintenance”, ZEVrail Glasers Annalen 131 (2007) 3 März. – see annex A1

removed in connection, preferably after tamping. Suitable machines providing the required production capacity need to be considered.

3.3 Specifications optimization

3.3.1 Present situation

The CEN - specifications for grinding work deal mainly with acceptance criteria for the executed work; - this applies also with many European infrastructure managers. Intervention thresholds and / or cycles are rarely addressed. Considerations relating the work to be organized and executed are not formalized. Qualifications for the respective machines to achieve the target in a technically and economically optimal way do not exist.

3.3.2 Potential improvement

Due to variable traffic and track conditions it will not be possible to define only one target profile for grinding or for RCF-maintenance work (see deliverable D 4.5.2). However, guidelines could help to standardize the approach and to prescribe production tolerances to be used.

Metal removal rates depend on maintenance cycles, which in itself depend on machine availability, operational and budgetary aspects. It is not appropriate to ignore such conditions but to integrate them as much as possible in flexible regimes. A strategy which aims at minimal metal removal rates between 0.15 and 0.3 mm is recommended.

In an ideal world specifications should combine technical, operational and economic considerations. The best result-for-prize combination has to take into account availability of suitable machinery, working conditions (depots, transfers, possession times) and metal removal requirements (the order of these three points is not essential as they all interfere with each other anyway).

4. Conclusions

Putting the three preceding points together leads to the following hypothetical result:

Modern railway traffic operation provokes at many places (though depending from local, operational conditions) rail surface fatigue phenomena, usually referred to as Rolling Contact Fatigue (RCF). Headchecks and similar defects develop sooner or later. The rail steel quality plays a determining role, but there is no material available at present, which can withstand fatigue. Furthermore the majority of rails in track today, with adequate but lower fatigue resistance, have a future life span, which makes it much more economic to maintain them in an appropriate manner rather than to change them.

Thus, rail maintenance is an inevitable must. Predictable work - at least in a medium time horizon - organized in a strategic way needs to be defined, in order to profit most from existing technologies and to guide the industry for future development. However, it must be assured that the chosen approach provides enough flexibility to adapt to changing situations in both directions: Increased requirements for maintenance due to higher loads and dynamic forces, reduced requirements for maintenance due to lower loads (improved vehicle characteristics) and better performing rails (reduced fatigue development).

Based on current practice and foreseeable developments rail maintenance can be classified in three sectors:

- Preventive initial work on short to long sections
- Corrective work on (more or less) short sections dispersed over the network
- Preventive cyclic work on (as much as possible) long sections

Depending on the size of a railway network a certain number and different types of machines may be required. The third mentioned sector applies specifically to RCF – treatment. It must be emphasized that any maintenance regime has to assure ideal contact conditions wheel-rail (optimal rail profile within tight tolerances) and ideal metal removal rates (big enough to eradicate defects but as low as necessary in order to keep artificial wear at a minimum).

Under the given present circumstances a reasonable approach seems to aim at repetitive maintenance work with easily achievable metal removal rates and the least possible interference with track operations. Consequently a metal removal of up to 0.6 mm at the critical gauge area and a maximum of 0.2 mm in the centre of the railhead should be envisaged. Such work can be done by modern grinding machines in one pass at working speeds of up to 10 km/h. These results - depending on work planning - in up to 50 km of maintained track per day (or night).

If defects are deeper (longer maintenance interval) such a grinding machine could work in a one-pass regime at lower speeds (down to about 3 km/h) or the use of bigger machines can be considered. Defects smaller than the above mentioned do not pose a problem for the rails but would increase organisation, supervision and execution of work.

Future machine development should aim at even higher – but controllable – working speeds with the same metal removal capacity range.

In this context it is important to announce future grinding needs and capacities to the grinding industry as early as possible. Such information allows building and providing production capacities in an economic way. The benefit is then two-fold: On one-side, optimal rail surface conditions prolong rail life and reduce general track deterioration (save money on the long run), on the other hand present maintenance costs (grinding) can be reduced considerably.

5. List of annexes

Annex 1: “Impact of preventive grinding on maintenance costs and determination of an optimal grinding cycle” (C. Meier-Hirmer, Ph. Pouligny).

Annex 2: Hempe, Thomas & Siefer, Thomas: “Rail grinding as an integral part of technically and economically efficient track maintenance”, ZEVrail Glasers Annalen 131 (2007) 3 März.