RAIL ENGINEERING INTERNATIONAL

SPENO INTERNATIONAL SA

“Grinding Project Würzburg”: elaboration of specifications to control headchecks

Rolling contact fatigue of rails, originally mainly an issue affecting heavy-haul railway lines, has now also become a problem suffered by conventional mixed-traffic and high-speed railway lines worldwide. In 1996, German Rail (DB AG) and Speno International SA, Geneva, Switzerland, started a 10-year research project, the “Grinding Project Würzburg”, which investigated the effects of various transverse rail profiles and grinding tolerances on rolling contact fatigue. During the investigations, the development of headchecks - a typical rolling contact fatigue defect - and wear was monitored under pre-set conditions, which has yielded valuable information. The results obtained have underlined the importance of adopting an optimised rail grinding strategy that is based upon the removal of a minimum amount of metal, whereby material loss due to wear, as well as to the corrective grinding action, should be taken into account. In this article, results obtained from field tests are presented and, also, general strategies for the treatment of headchecks are discussed. Finally, recommendations for rail maintenance work are provided that are aimed at controlling rolling contact fatigue and extending the service life of the rail.

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BACKGROUND

Until about 1990, on DB AG as well as on the majority of railways in Europe, rail grinding was mainly aimed at the removal of corrugation and the correction of the transverse rail profile. Also, combining rail grinding with other track maintenance work was rarely considered. Furthermore, whereas on heavy-haul railway lines (axle load ≥ 25 tons), particularly in North America and Australia, rolling contact fatigue was addressed by specific rail grinding programs, this was not yet the case on conventional and high-speed railway lines.

The introduction of improved steel quality and high-strength rails, from about the mid-1980s, had led to a considerable reduction in rail wear and production-induced rail fatigue defects, such as tache-ovals and shelling. However, from about 1990, on many conventional mixed-traffic and high-speed railway lines, an increase in rolling contact fatigue (mainly resulting in headchecks and squats) was observed, which became the predominant factor for determining the service life of the rail [1].

While the reason for rolling contact fatigue on heavy-haul railway lines is related to the high axle loads adopted, on conventional mixed-traffic and high-speed railway lines, it is mainly attributable to the higher speeds adopted and the extremely powerful traction systems of modern locomotives. Despite the different mechanisms at work, the effects are quite similar: the wheel/rail contact stresses exceed the strength limits of the presently-used materials which, finally, results in damage of the rail surface.

In the early 1990s, no clear know-how was yet available with regard to the interaction between abrasive wear, crack initiation and crack development. As a consequence, no clear ideas on how to treat and avoid these defects existed. Thus, at the time, on DB AG, as all well as on other railways in Europe, no specific grinding strategies or maintenance specifications for eliminating rolling contact fatigue defects existed.

In 1989, a specific standard target profile for all rail grinding work was introduced by DB AG that was primarily based on considerations regarding stable running conditions for high-speed rail traffic. The DB-directive 824.9030 (today, DB-directive 824.8310) prescribed production tolerances for the target profile, depending on locally permitted line speeds. For instance, the permitted deviation from the target profile, measured radially within the tolerance zone at the gauge side of the rail, for V < 140 km/h was set at +0.7 mm to -1.0 mm. At the time, it was unknown what influence the target profile and the specified production tolerances would have on abrasive wear and rolling contact fatigue. The “Grinding Project Würzburg” aimed to find an answer to this.

GRINDING PROJECT WÜRZBURG: OBJECTIVES

In 1996, in view of the increasing occurrence of rolling contact fatigue, the long-term “Grinding Project Würzburg” was launched by DB AG and Speno International SA, which was aimed at addressing the following issues:

— what is the influence of the relatively wide tolerance band for producing the target profile on the subsequent development of cracks?
— what is the influence of the production tolerances on rail wear and, thus, the service life of the rail?
— what is the interaction between metal removal by grinding (tolerances, profile), rolling contact fatigue (i.e. crack initiation and development) and rail wear?

The complexity of these issues - determined by a large number of interacting parameters in practice - excluded, from the beginning, a complete investigation of all factors influencing rolling contact fatigue and rail wear, as well as quantitative statements for all individual parameters. This required careful planning and setting up of the test scenarios. It was considered that, by selecting representative and typical test conditions and a relatively long monitoring period (10 years), some generally valid conclusions could be drawn that would enable a grinding strategy for rails in curves to be established.

During the course of the research project, as a result of intermediate results obtained, some of the test configurations were adapted. Also, during the course of the project, a new recording system, based on eddy-current technology, was developed, which helped to better describe the deterioration process of rails under service conditions.

Test location

As a test location, the line Würzburg-Aschaffenburg was chosen, a typical conventional railway line on which mixed traffic is operated, which features four curves (named after the nearby villages Lohr, Langenprozelten, Wernfeld and Veitshöchheim), with radii ranging from 525 m to 782 m, and a maximum line speed of V ≤ 160 km/h.

After a short period of having been in service, the comparatively new rails on this line, of both steel grades R260 (900A) and R350HT (900A head hardened) had started to exhibit headchecks, which were eliminated at the beginning of the test program. For this, as a reference profile, the target profile for rail grinding specified at the time was used: UIC 60 rail inclined at 1 in 40, in accordance with DB-drawing Iots 136 (Edition 10, July 1989).

The test location was divided equally into 20 test sections, each 100 m long. In the centre of each test section, two measuring points were located, 5 m apart from each other.

Test program

The test program embraced two phases:

- the first test phase (1996-1999) was aimed at testing the influence of the production tolerances. To this end, five rail profile shapes were ground (two with positive tolerances - above the target profile, two with negative tolerances - below the target profile, and one with the nominal profile - no tolerance). Subsequently, the influence of these rail profile shapes on the development of rolling contact fatigue was investigated in the hope to find, from among the rather wide range of permitted profiles, the "ideal" one. However, as any metal removal by rail grinding involves artificial wear, and gauge corner relief increases natural wear (two-point contact), during the second test phase, the influence of rail grinding on wear and the development of headchecks was investigated, as both parameters determine the service life of the rail;
- the second test phase (2000-2006), thus, was aimed at establishing an appropriate rail grinding strategy to reduce the development of headchecks, whereby rail wear would be kept to a minimum. To this end, rail grinding campaigns were conducted at specific intervals, ranging from one to four years, which corresponds to cycles of 17 to 70 million gross tons (MGT) of traffic borne. As from the first test phase it had been learnt that negative production tolerances improve the wheel/rail contact conditions in the sensitive gauge area and, consequently, delay the onset of headchecks, only negative production tolerances (gauge corner relief) were applied during the second test phase. The amount of metal that was removed and the degree of gauge corner undercutting were based on the growth rate of the headchecks between the relevant rail grinding interventions.

The test program was set up in such a way that it could be adapted and extended, if required.

The problem of rolling contact fatigue can be reduced, or even eliminated, by regularly and completely removing the fatigued and damaged rail surface material and, simultaneously, undercutting the gauge corner. However, as noted earlier, the overall aim of the research project was not only to control rolling contact fatigue, but also to extend, to a maximum, the service life of the rail. This implies a controlled metal removal strategy, whereby a minimum amount of metal is removed. By putting metal removal, crack development and maintenance cycles into a useful relation to each other, it was finally possible to establish specifications with respect to metal removal rates and rail grinding intervals.

In the 20 test sections, various rail grinding cycles and different production tolerances were tested, which yielded interesting results.

In 2001, the optimised rail head geometry 60E2 with an inclination of 1 in 40, in accordance with DB-drawing Iots 136 (Edition 13, December 1999 - (since February 2004, DB-drawing Iog 60.10.0001)) was introduced as the standard target profile for rail grinding. The 60E2 profile had been optimised at the wheel/rail contact area and the gauge corner of the rail head, with a view to improve running stability and wear.

EVALUATION OF RESULTS OBTAINED

During the 10-year monitoring period, a lot of experience was gained and a substantial amount of data was collected. However, it is almost impossible to present and describe here all relationships and interdependencies observed. Such an attempt could even lead to the drawing of erroneous conclusions.

Nevertheless, after a painstaking period of comprehensive data collection and meticulous analysis, it was possible to put together relevant and clear findings regarding rail wear and crack development which, at various stages of the test program, have been presented at numerous international conferences [2]-[7].

During the test program, five rail grinding campaigns were executed, as well as 30 track inspection runs, during which 1,200 transverse rail profile recordings and an equal number of magnetic particle tests were conducted. Also, more than 5,000 pictures were taken that documented the different measuring points. Furthermore, eddy-current testing was conducted over a length of about 100 km, and also metallographic laboratory analyses of 21 rail samples that were cut out from the test sections were made.

Photo documentation

During each track inspection run, all measuring points were thoroughly checked and documented by taking close-up pictures of the running surface and the gauge corner of the rail. These pictures were used to evaluate the following parameters:

- the condition of the rail surface after grinding (roughness, scratch marks);
- the development of any roughness situation;
- the location and width of the wheel/rail contact band;
- signs of fatigue and damage on the running surface;
- wear and plastic deformation at the gauge corner;
- state of lubrication.

In Fig. 1, as an example, a picture is shown of a specific measuring point (steel grade R350HT), taken 12 months after grinding. Amongst other things, at the gauge corner, the presence of marks from the last grinding intervention can be observed. Also, as the gauge corner had been heavily undercut, the profile had not yet completely worn in nor any headchecks had developed.

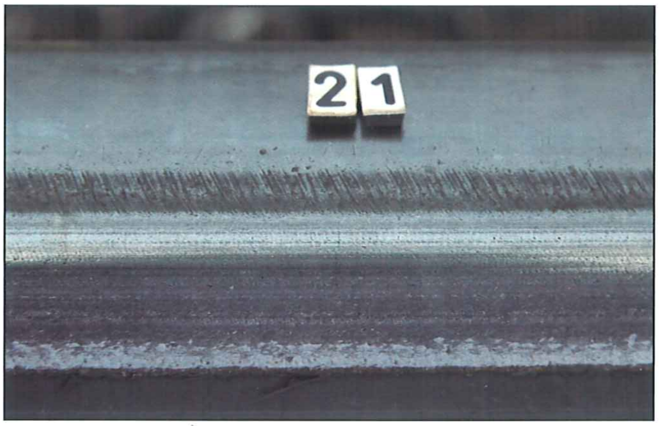


Fig. 1: Picture taken at a specific measuring point, 12 months after grinding (steel grade R350HT)

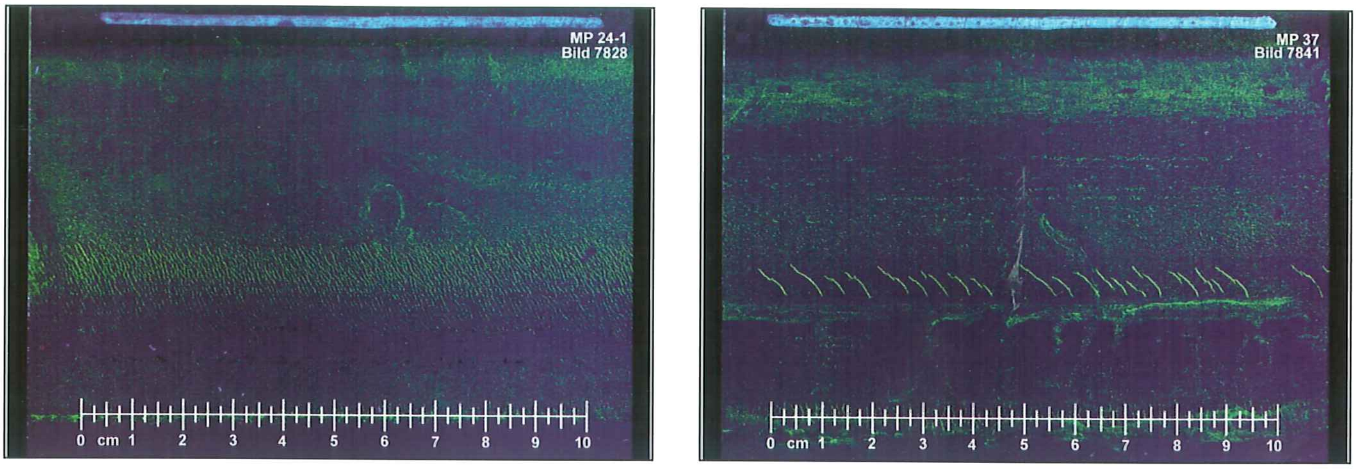


Fig. 2: Pictures showing the rail surface at two specific measuring points (left: steel grade R350HT, right: steel grade R260)

Magnetic particle testing
At all measuring points, magnetic particle testing (MT) of the running surface of the rail was conducted, whereby cracks were copied onto a foil and, afterwards, photographed under UV-light. In this manner, the development of cracks (time of first appearance and subsequent growth) on the running surface could be followed. A mark made on the foil enabled the MT pictures to be superimposed by transverse rail profile recordings and, thus, cracks to be located precisely.

In Fig. 2, an example of a MT picture taken at two specific measuring points (left: steel grade R350HT, right: steel grade R260) is shown.

Transverse rail profile recording
Using a DQM device, as well as a MiniProf apparatus, transverse rail profile recordings were conducted. The DQM recordings were made, in order to check the rail profiles and production tolerances, both during and after grinding, as well as to determine when the wear-adapted profile (WAP) had been reached.

For analysing the development of rail wear resulting from material loss (either natural wear due to traffic or artificial wear due to grinding), until 1998, a MiniProf Singlehead and, from 1998, a MiniProf Twinhead device (produced by Greenwood Engineering A/S) were used.

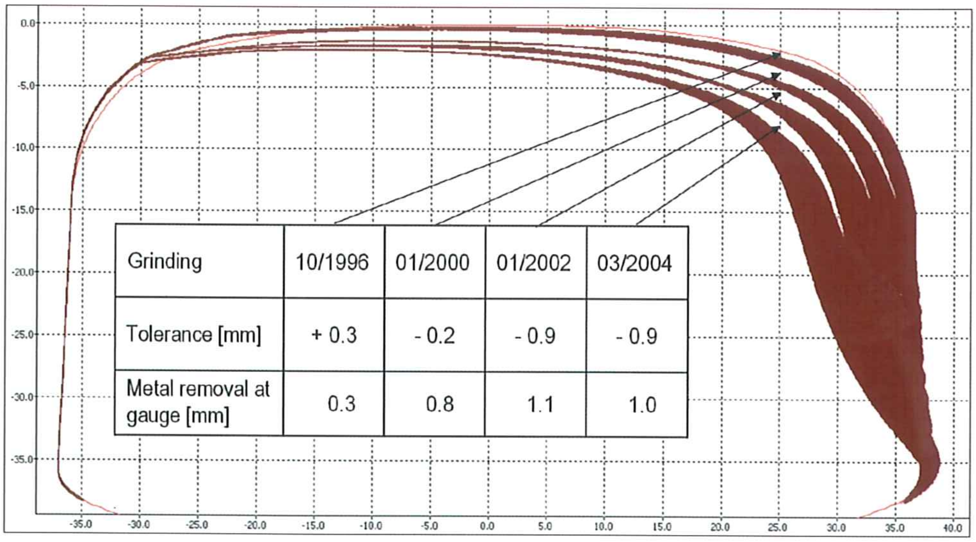
The rate at which rail wear develops depends on:

- the metal removal rate required to eliminate the damaged surface layer (influenced by the development of headchecks between grinding interventions);
- the degree of gauge corner undercutting (production tolerance);
- the extent of natural wear due to traffic between grinding interventions.

In Fig. 3, the development of a transverse rail profile at a specific measuring point is shown for the entire 10-year monitoring period (1996-2006).

From Fig. 3, it can be observed that:

- following the long interval of more than three years after grinding, in January 2000, a metal removal rate of 0.8 mm was required at the gauge corner of the rail, in order to completely eliminate the headchecks. The high-precision rail grinding adopted to achieve the -0.2 mm tolerance required at the gauge corner resulted in an (in principle, unnecessary) high metal removal rate in the centre of the rail head;
- during the rail grinding interventions of January 2002 and March 2004, much less metal needed to be removed, in order to eliminate the headchecks. However, in these cases, the specified production tolerance of -0.9 mm required an unnecessarily high amount of metal to be removed at the gauge corner;
- the (too) large negative tolerance of -0.9 mm caused a high adaptation wear at the gauge corner.



Grinding	10/1996	01/2000	01/2002	03/2004
Tolerance [mm]	+ 0.3	- 0.2	- 0.9	- 0.9
Metal removal at gauge [mm]	0.3	0.8	1.1	1.0

Fig. 3: Development of a transverse rail profile at a selected measuring point (steel grade R260), during the period 1996 to 2006

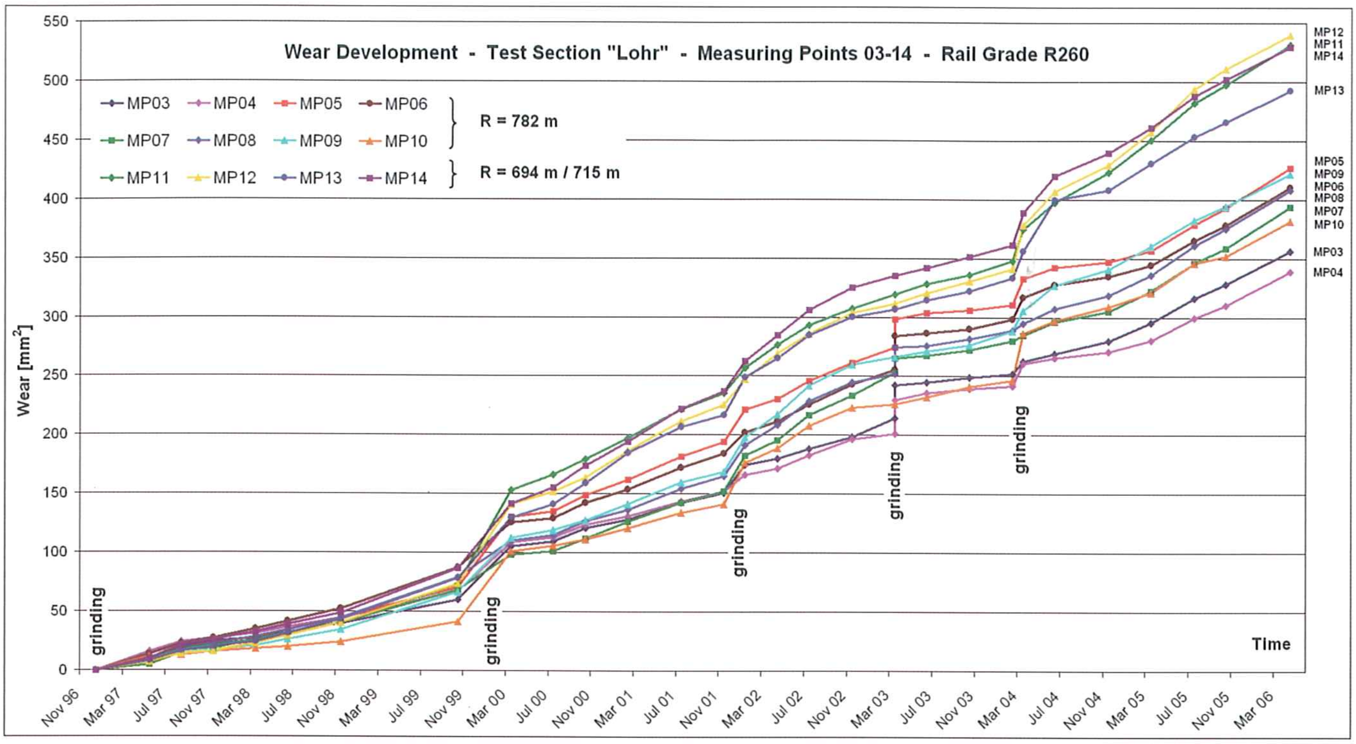


Fig. 4: Rail wear development at various measuring points (site Lohr), steel grade R260

In Fig. 4, the increase in rail wear at various measuring points is shown for the period 1996-2006.

From both Figs. 3 and 4, the sequence of artificial wear due to rail grinding and natural wear due to traffic can be observed.

Eddy-current testing

As noted earlier, the development of rail surface cracks was evaluated both optically, by photo documentation, and by magnetic particle testing. However, a substantial shortcoming of these two methods is that the severity of the cracks (damage depths) cannot be checked. Only of a number of selected rail samples, crack propagation could be determined in the laboratory. However, as the severity of headchecks varies along the length of a track, the crack depths detected were not representative for the entire test section concerned,.

Starting in July 2000, a newly-developed, non-destructive testing method, based on eddy-current technology, was used to determine crack depths. This new method underwent subsequent modifications and improvements, which were then used for the research project. Towards the end of the project, an automated eddy-current testing (ET) system mounted on a small trolley was available.

Despite the fact that, at the beginning, the new technology did not provide consistently good and reliable results and, in the time left, could not be used to cover all test sections, it contributed greatly to an increase in knowledge about formation and development of rail surface cracks. The research project also contributed to get the final approval for use of the ET system on DB AG, in March 2006.

Using the ET system, not only the extent of cracks at selected locations could be checked, but over the entire length of the test sections. By also using data on the inclination of cracks obtained by metallographic laboratory tests, the actual damage depth and, thus, the amount of metal to be removed by rail grinding, could be calculated. Furthermore, the ET recordings were used to detect the location of the deepest crack in a test section and, then, a rail sample was cut out for laboratory analysis.

In Fig. 5, an example of an ET recording conducted on a 100 m test section is given. The upper part of the diagram shows the crack density per metre, whereas the lower part shows the maximum crack depth per metre which, as can be observed, ranges from 0.2 mm (at position 48 m) to 0.7 mm (at position 35 m). At the first measuring point (position 55 m) the crack depth is 0.3 mm, at the second measuring point (position 59 m) it is 0.6 mm.

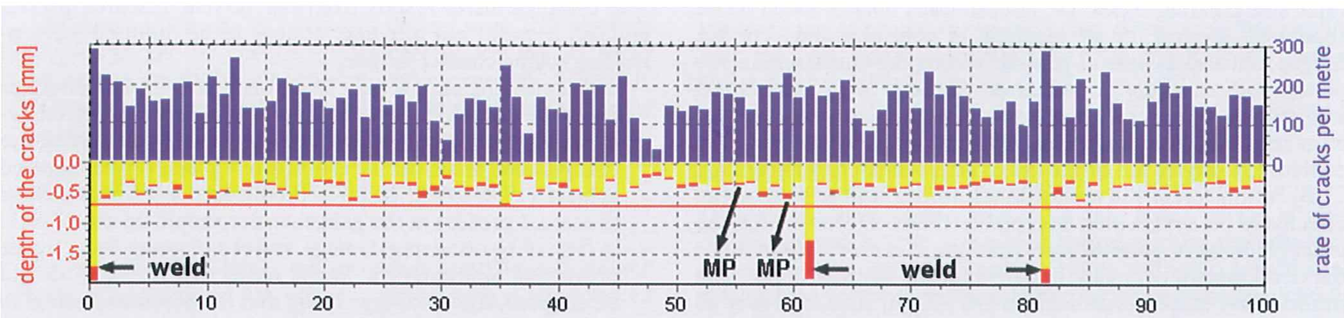


Fig. 5: Analysis of an ET recording over a length of 100 m

In Fig. 5, on the left hand (position 1 m), the signal indicates the presence of an alumino-thermic weld. At positions 61 m and 81 m, two more welds can be observed, which were made after a rail sample had been taken out for metallographic laboratory analysis.

The results from the ET recordings were also used to:
- follow the rate at which cracks develop between track inspection runs;
- specify the amount of metal removal required for the rail grinding campaigns of January 2002, March 2003 and March 2004;
- document cracks that remained after grinding (indicating that the amount of metal removed had been insufficient);
- to assess the length of the crack-free period after grinding.

In Fig. 6, the development of a crack over a two-metre section at four given moments is demonstrated, from which crack growth due to traffic and elimination by grinding over a two-year period can be observed.

Metallographic laboratory analysis
During the research project, 21 rail samples, each about 50 mm in length, were cut out for laboratory analysis from the high rail of curves, close to the measuring points, some of steel grade R260 and some of steel grade R350HT.

The metallographic laboratory analaysis provided, amongst other things, an insight into crack orientation (inclination, depth, branching) within the rail head. Knowledge about the length and damage depth of the cracks helped to determine the metal removal rates required for the grinding campaigns of January 2000 and March 2003. For the latter, also the results from ET recordings were taken into account.

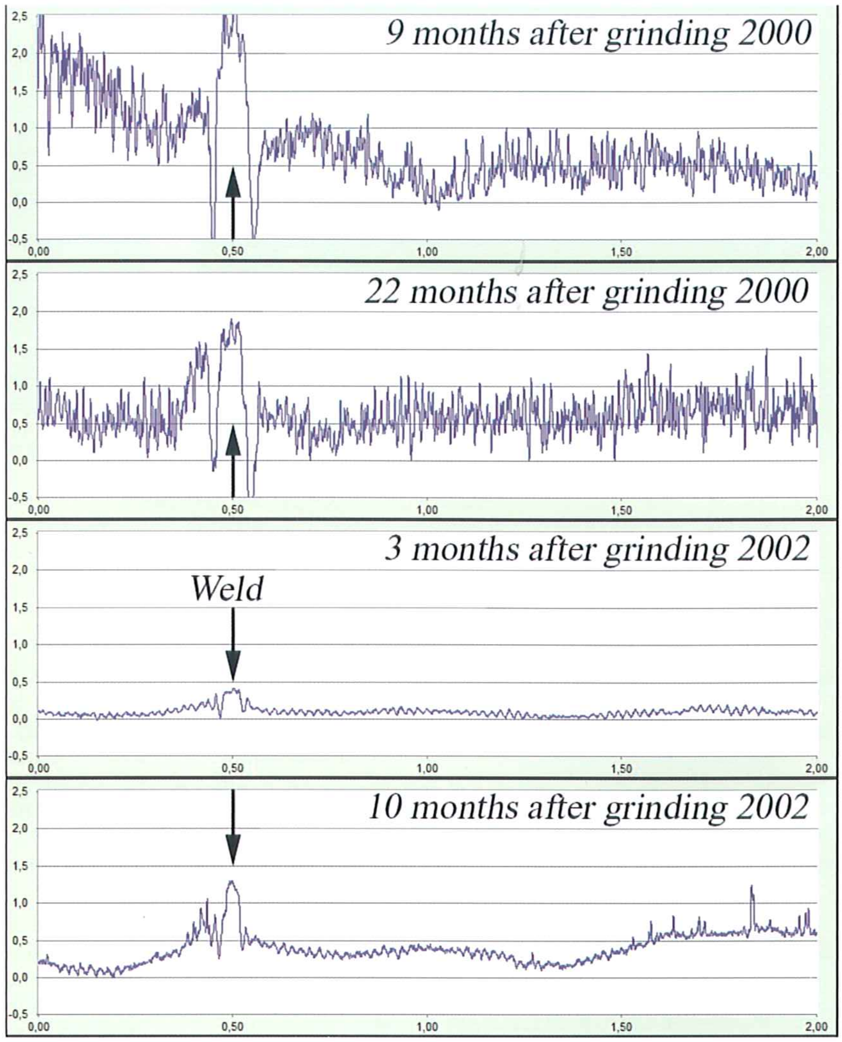


Fig. 6: Crack development over a two-year period (2 m section, steel grade R260)

The metallographic laboratory analyses yielded damage depths of between 0.55 mm and 1.14 mm for steel grade R260, and between 0.19 mm and 0.47 mm for steel grade R350HT.

Taking into account information regarding the first occurrence of rail surface cracks that were obtained by magnetic particle testing and ET recordings, and assuming a linear growth characteristic, the following average crack depths per 100 MGT of traffic borne were found:
- 1.55 mm for steel grade R260;
- 0.52 mm for steel grade R350HT.

OPTIMAL RAIL GRINDING STRATEGY

An optimal rail grinding strategy entails optimal metal removal rates and grinding cycles: i.e. in each case, only as much metal should be ground off as required to control rolling contact fatigue, but also as little as possible during the entire service life of the rail, in order to minimise abrasive wear. Combined information about crack and wear development (both natural wear resulting from traffic and artificial wear due to grinding) enables the service life of the rail to be extended to a maximum.

By routine cyclic rail maintenance, rolling contact fatigue can effectively be kept within acceptable limits. However, for the exact planning of grinding interventions, it is crucial to monitor the development of cracks, in particular the damage depth. The introduction of ET recordings on DB AG, in 2006, whereby all main lines are inspected at regular intervals, now provides the means to accurately plan timely interventions.

In general, two rail grinding strategies can be distinguished:
- *preventive grinding:* this type of rail grinding is conducted before any damage has been detected, i.e. cracks are not yet visible but, knowing from experience gained earlier, could be about to develop. However, the risk exists that more material is removed than required. If preventive grinding is conducted at regular intervals, this may lead to a shortening of the maximum possible service life of the rail;
- *corrective grinding:* this type of rail grinding entails the removal of existing damage. Depending on defect severity, a respective higher amount of work may be necessary, which might be substantial and would usually be costly.

Findings from the research project
The comprehensive results from the 10-year research project enabled a useful rail grinding strategy to be outlined for controlling rolling contact fatigue:
- initial grinding of new rails, in accordance with DB-directive 824.4010, has to be undertaken with an average metal removal rate of 0.3 mm whereby, taking into consideration the observations made during the first test phase of the research project (1996-1999), positive production tolerances (above the target profile) at the gauge corner should be excluded;
- in case of re-occurring damage, instead of going for a "cyclic preventive approach", a "cyclic corrective strategy" should be adopted, the advantage being that the amount of metal to be removed can be limited to the actual damage depth. As is well known, very small cracks in an early stadium, if removed

completely, do not pose a safety risk. This means that rail grinding should be executed at a time at which the damage can still be corrected with a relatively small amount of work. With longer intervals, there is a great risk that some of the cracks may have become so deep that they are not removed completely, and continue to grow after the intervention. Deeper cracks generally require larger amounts of metal removal, which finally results in a shorter service life of the rail. In a wider sense, cyclic corrective grinding is also a preventive measure, as it prevents ongoing or severe rolling contact fatigue from developing - and that with a minimum of artificial wear.

Recommended rail grinding strategy

The following rail grinding strategy is recommended to prevent rolling contact fatigue from becoming a problem:

— the ideal intervention threshold when working with the usual grinding equipment is a damage depth of between 0.2 mm and 0.6 mm. In general, the amount of metal removal at the centre of the rail head should be 0.1 mm. The standard wear-adapted profile 60E2 should be used as a target profile for grinding, executed only with a negative production tolerance of a maximum of -0.6 mm, which can be achieved with a minimum amount of metal removal. By limiting the negative production tolerance, adaptive wear and subsequent crack initiation in the production tolerance zone can be kept to a minimum. It should be noted, that an optimised use of cyclic corrective grinding can only be ensured by precise recording of crack locations and severity;

— particularly when starting a strategic rail grinding regime to remove rolling contact fatigue, or when - for whatever reason - corrective grinding cannot be executed as required, quite a number of track km may be affected by different stages of headchecks (small, medium, severe). In these cases, apart from exchanging rails, the adoption of corrective measures may still be appropriate and economically justified. If there is still a sufficient wear reserve in the rail head, which is often the case, headchecks can be removed completely and the rails remain in service for many more years - provided that the corrective grinding intervention is followed by cyclic controlled interventions.

Thus, when headchecks exceed the 0.6 mm threshold and, instead of a replacement of the affected rails, an intervention is still economically viable, a one-off corrective grinding campaign should be conducted. In such cases, a maximum metal removal rate of 3 mm is to be considered. The required amount of metal to be removed at the centre of the rail head is determined by the specified target profile for grinding. In order to reduce the amount of metal removal to a minimum, when headchecks are deeper than 1 mm, a maximum negative production tolerance of -1.0 mm could be allowed, even if this may provoke a higher adaptive wear afterwards;

— for the one-off corrective rail grinding action, the use of heavy-duty rail grinding equipment is recommended, in order to reduce the number of grinding passes required. Alternatively, planing and milling machines could be used, as they only need a few passes to remove more than 1 mm of metal. However, the use of these machines offers limited flexibility in exploiting the variable negative production tolerances and, thus, metal removal cannot be limited to an absolute minimum. In any case, during work, the damage depths should be checked (eddy-current testing), in order to ensure cracks have been removed completely. Should it, nevertheless, not be possible to remove the damage completely, due to a limited track possession time, it may also be considered to perform the corrective action in several steps, within an appropriate time span.

In the following Table, the proposed grinding actions and related specifications for rails in curves with a pronounced headcheck risk are summarised. All requirements and specifications shown can be realised by grinding.

Activity	Initial grinding	Cyclic corrective grinding	One-off corrective grinding
Specified metal removal rate at the damaged gauge corner	0.3 mm	0.2 to 0.6 mm	0.6 mm to 3.0 mm
Specified metal removal rate at the centre of the rail head		0.1 mm	Depending on transverse profile
Specified maximum negative production tolerance	WAP -0.6 mm	WAP -0.6 mm	WAP -1.0 mm

Grinding strategies and specifications to control headchecks in headcheck-sensitive curves (WAP = wear-adapted profile)

Preferred rail grinding strategy

Any recommendation for an optimal rail grinding strategy should include considerations regarding operational aspects and all relevant track parameters that have an influence on the development of rail wear and rolling contact fatigue. Ideally, a regular rail maintenance intervention should allow the removal of all fatigued rail surface material and, simultaneously, minor transverse rail profile corrections to be performed in a single pass.

As a preferred rail grinding strategy, as yielded by the research project, the cyclic corrective variant (allowing only negative production tolerances), with a metal removal rate of 0.3 mm to 0.4 mm in the damaged zone, is recommended. Taking a typical conventional railway line, featuring rails of steel grade R260, this would result in a grinding interval of 30 to 40 MGT of traffic borne. As higher steel grades (e.g. head-hardened rails) have a lower rolling contact fatigue growth rate, the grinding intervals would be longer, when specifying the same metal removal rate requirements.

Adaptation of present regulations and specifications

When the "Grinding Project Würzburg" was started in 1996, the then valid specification of DB AG required the production of a target profile UIC 60 inclined at 1 in 40, in accordance with DB-drawing Iots 136 (Edition 10, July 1989), with a production tolerance zone of +0.7 mm to -1.0 mm, in accordance with DB-directive 824.9030.

During the first test phase (1996-1999), it was found that plus (+) tolerances have a negative effect on the development of rolling contact fatigue and that minus (-) tolerances (gauge corner undercutting) delay the onset of headchecks. This fact has already been incorporated in DB-directive 824.8310 ("Acceptance of rail maintenance work") and in this respect, from 1 July 2003, "in order to delay the formation of headchecks, the transverse rail profile of the outer rail in curves, with disregard to line speed, may lie between 0 mm and -0.6 mm".

As noted earlier, in 2001, an optimised rail head geometry 60E2 with an inclination of 1 in 40, in accordance with DB-drawing Iots 136 (Edition 13, December 1999 - (since February 2004 DB-drawing Iog 60.10.0001)) was introduced as the standard target profile for rail grinding. Comparing this profile with the wear-adapted profile (WAP) in the four test curves showed very similar shapes.

CONCLUSIONS

The "Grinding Project Würzburg", undertaken jointly by DB AG and Speno International SA, which was started in 1996 and completed in 2006, was aimed at investigating the influence of rail grinding on rolling contact fatigue and wear, as well as at establishing an appropriate rail grinding strategy for headcheck-sensitive locations. The ultimate aim was to develop a method to effectively control rolling contact fatigue.

The results obtained have enabled a practicable rail grinding strategy to be developed that reduces the problem of headchecks:

- the standard target profile for grinding adopted on DB AG, the 60E2, has been verified as the ideal wear-adapted profile (WAP) for headcheck-sensitive locations. When grinding rails, however, only negative production tolerances are permitted. In the case of one-off heavy-duty corrective work, a deviation from the target profile of up to -1.0 mm is allowed. However, for all cyclic work, it should be limited to -0.6 mm;
- a cyclic rail grinding intervention, at 1-4 year intervals, allows a complete removal of rail surface damage, thus avoiding an uncontrolled growth of surface cracks. Using eddy-current testing, crack elimination can be checked directly at the worksite. A preferred rail grinding interval could not be identified; however, because of differing crack growth rates (and also for operational reasons), shorter intervals are of benefit;
- rail grinding work should be planned in such a way that, in order to eliminate surface cracks, a maximum of 0.6 mm of metal needs to be removed. Taking operational aspects into account, a typical conventional main line featuring rails of steel grade R260 would need grinding after every 50 MGT of traffic borne. For head-hardened rails, when specifying the same metal removal rate requirements, this interval would be about double.

The cyclical removal of rail surface fatigue cracks and the simultaneous correction of the transverse rail profile, within appropriate tolerances, has transformed the safety-relevant problem of rolling contact fatigue into a comparatively simple wear-management problem. Because of the subsequent increase in the service life of the rail, the timing of rail replacement does only depend on reaching the wear limits.

The results of the "Grinding Project Würzburg" have been implemented successively in the work specifications of DB Netz AG, and adopted accordingly.

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