HIGH SPEED GRINDING
PREVENTATIVE RAIL CARE

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ABSTRACT

To prevent rolling contact fatigue and rail corrugation, Stahlberg Roensch has developed a new rail grinding method called High Speed Grinding (HSG). HSG enables working speeds of 50 mph (80 km/h) without interrupting scheduled traffic – a world first. It is not necessary to dismantle any signal devices or other track components to use HSG. German authorities gave their unrestricted approval to use the machine at the end of 2006.

The test phase for the technique was completed in autumn 2007. Since then, it has been in regular use on Deutsche Bahn tracks in Germany, combating RCF problems and reducing corrugation. High speed lines up to a maximum speed of 180mph (300 km/h) as well as mixed and freight traffic lines are all treated. In the latter case, HSG is deployed with freight traffic, with trains running immediately before and after the grinding pass. At the end of 2008, Stahlberg Roensch regularly treated about 500 km of track and more lines will follow in 2009.

The results of systematic measurements and testing both by Deutsche Bahn and Stahlberg Roensch prove the effectiveness of HSG. Sections that have been left unground for comparison with treated tracks show growing RCF problems, while ground sections in otherwise identical conditions have no signs of RCF. Both the technical and economic potentials are very high.

Stahlberg Roensch plans to introduce HSG internationally. Talks with interested rail network operators from various countries are in progress at present.
1 INTRODUCTION

A railway track represents a large investment that is not only meant to enable safe, fast and comfortable passenger and freight traffic, but is also expected to be permanently available. The track should allow decades of intense use with no major interruptions. Track possessions for maintenance work or premature failure of track components imply major costs for the infrastructure operator.

2 ROLLING CONTACT FATIGUE

For decades wear on the corner gauge was the predominant cause of a limited rail life span, until rolling contact fatigue (RCF) related damage (headchecks, squats) took over in the final years of the last century. These rail flaws have been subject to extensive research regarding their appearance, their possible cause and their consequences. In the early 90’s approximately 30 % of the rail flaws on the DB-infrastructure in Germany were credited to RCF [1], ten years later this figure was raised to 60 % for Japan [2]. High speed trains have shown to be particularly “aggressive”. The average growth rate for headchecks on tracks with traffic up to 125 mph (200 km/h) is reported to be 0.016” (0.4 mm) per year (equiv. to 20 MGT) [3]. After just a few years the gauge corner cracks will develop to a degree which requires substantial machining in order to remove the cracked and damaged material layers. On high-speed lines, with trains using powered axles, the local growth rate of cracks can be significantly higher still.

Another characteristic of RCF-related flaws is the non-linear growth. Initially there is no crack at all, but the material is being strained and fatigued by every passing train. Once the cracks have been initiated, they propagate more and more rapidly. Environmental influences like rain penetrating into the crack can accelerate crack growth further. After a phase of propagating under a constant angle into the rail head, the headcheck typically changes direction at a certain critical depth and either returns to the surface causing severe shelling at the gauge corner or turns to grow deep into the rail with possible fracture as the ultimate consequence. For safety reasons, but also to protect the investment of the infrastructure, effective maintenance measures are necessary to prolong the rail life span.
3 CHALLENGES FOR RAIL MAINTENANCE

Because of high track utilisation, but also due to a necessary administrative effort, track possession for maintenance work requires long lead times and offers only limited time for track access, frequently only a handful of hours. The net time to actually conduct the respective work is typically not more than 60% of that, because of a long transfer distance between the station and the site or for other operational reasons. Secondly conventional maintenance measures are applied as soon as rail flaws exceed a certain critical threshold. This process requires that during cyclical inspection of the track the flaw is not only detected but also characterised regarding its severity. The threshold is typically selected such that when exceeded functional restraints with regards to safety, noise or riding comfort would apply. Only as long as the flaw can be readily found and categorized, provided that maintenance measures can be initiated and conducted in a timely manner, and the further flaw development remains sufficiently slow, this is a proper method to keep the availability of the track high. This does not imply that it is also the most cost-effective strategy.

4 PREVENTATIVE RAIL MAINTENANCE BASED ON HIGH SPEED GRINDING TECHNOLOGY

RCF is an established failure mechanism that does not occur at random. Rather than waiting until the flaws become critical, it should be anticipated and treated in a proactive manner with an effective maintenance strategy.

Since all RCF-related flaws are initiated at the surface and then progress into the rail head, the rail can be restored by removing this impaired or damaged material. This reduces the material reserve of the head, so that such a measure cannot be repeated all too often. In addition there is a substantial cost and time effort to remove enough material to eliminate all cracks. State-of-the-art technology is rail milling which removes up to 0.08” (2mm) per pass.

The term „preventative grinding“ stands for a modern and sustainable maintenance strategy, which is derived from the perception that rail flaws grow over time in a non-linear, progressive way: Hence, one grinding (or milling) operation after a given time requires more material removal than the sum of two or more operations within the same time span. For this reason some infrastructure operators
systematically conduct regular and frequent maintenance operations in a phase where the cracks are still short. With this additional effort (more possession time, more grinding operations) the material reserve of the rail head is preserved, so that with continued grinding the life span of the rail can be extended. Hempe predicted in a theoretical analysis, that by grinding every 3 instead of 6 years, the life span of a rail can be prolonged from 27 to 40 years [3].

The economical aspect of a maintenance strategy addresses the question of how often and how intensely the rails need to be machined, so that the extra service will pay off in the future with regard to a reduced renewal cost. A proper answer to this can only be provided with a Life-Cycle-Cost analysis (LCC), which sums up the net present value of all service and maintenance works during the life time of the rail and compares it to the price for a track renewal [3]. Based on current shift prices for grinding operations Hempe calculated the optimal cycle for periodic grinding operations to be between 40 and 80 Mio t, depending on the crack growth rate (=damage function). This translates roughly to a 2 – 4 year cycle.

The minimum material removal and hence the highest possible life span for the rail could be achieved, if cracks were to be avoided altogether by removing the hardened and brittle surface layer on a regular basis before cracks appear. Such a procedure implies an artificial wear in the same order of magnitude as the damage rate in the material. Kalousek and Magel have introduced the term „magic wear rate“ [4]. According to a UIC report a material removal of 0.1 mm for every 50 Mio. t would already reduce RCF related flaws by 50 % [5].

Such a procedure may only be considered, if the rail machining could be conducted cost-effectively and quickly, preferably without the need for possession time altogether. This implies grinding during train runs. For this purpose Stahlberg Roensch (SR) has developed the technology of High Speed Grinding (HSG).

5 TECHNICAL PRINCIPLE OF HIGH SPEED GRINDING

High Speed Grinding features a series of free rotating, non-powered grinding stones, which are offset by a certain angle relative to the rail. When dragged along the rail this offset angle produces an autorotation and a relative motion which grinds the rail. The rail is not reprofiled but is artificially worn. Because of the respective contours of rail and grinding stone, the contact line between the two is
shaped like a stretched „S“ of roughly 2.36“ (60 mm) length, which helps to smoothen short corrugations. See Fig.1+2

The most outstanding feature is the grinding speed of approximately 50mph (80 km/h). Based on this technology the grinding machine RC01 was developed to operate without track possession. RC01 (see Fig.3) uses 48 stones per rail at any given time (divided over 4 grinding units). A revolver system on each grinding unit allows an on-the-fly exchange between four rows of grinding stones, putting a replacement set of grinding stones onto the rails whenever one set is used up. Grinding is conducted during scheduled train traffic with no need to dismantle any track components. The vehicle is fully within the G-1 gauge; however, switches are excluded from the grinding process. RC01 is not powered, but requires the traction of a locomotive with at least 1,350 hp (1000 kW) for operation on a level track. In cooperation with the DB research departments the designated material removal is > 0.004“ (0.1 mm), which can be achieved with three grinding passes. The process has in 2007 been approved for operation on DB’s High Speed network. It is the first maintenance machine approved for operation within regular traffic schedule.

6 NUREMBURG-Ingolstadt PILOT PROJECT

The success of preventative rail grinding is highly dependant on how consistently the regular operations are conducted. The challenge is to find the ideal operating sequence. For HSG this is currently determined in the course of a long term validation project together with DB-AG, starting with measured crack growth data and subsequently derived damage functions.

In May 2006, the new high speed line from Nuremberg to Ingolstadt in southern Germany (Bavaria) was inaugurated, although regular traffic didn’t start until December of the same year. The project was one of the most important track construction ventures of the last decades in Germany. It was built with slab track technology, long rails (120 m), flash-but-welding and other high performance superstructure components allowing for maximum speeds of 185 mph (300 km/h) on a section of about 43 miles (70 km). Travel time between the two cities was cut from 66 minutes to 27 minutes. The line has inclinations of up to 6.29” (160 mm) and gradients of 20 ‰. The yearly load is approximately 13 MGT; mainly ICE trains and regional express trains but no freight trains use the track.
6.1 Project Setup

After a two-year period for testing and evaluation of the HSG-principle it was decided to use the new high speed line for a pilot project based on the new preventative rail maintenance approach.

- Immediately after installation in the track, the rails received their initial grinding, which removes the decarbonised layer and optimises the head profile. Directly after the track was cleared for traffic up to 185 mph (300 km/h).

- By strictly following a specified maintenance cycle, the RCF-hardened surface layer of the rails is regularly removed and thus crack growth avoided. Based on DB Netze experiences with other high speed lines an approach with a metal removal rate of 0.004” (0.1 mm) every 4 months was chosen. This equates a grinding cycle after each 4.5 MGT of traffic. The aim of this approach is to control corrugation and reduce RCF problems through consistent removal of fatigued material, leading to lower costs and an improved quality for Deutsche Bahn. The metal removal rate of 0.004” (0.1 mm) per treatment was chosen according to DB research and scientific investigations showing that 0.004” (0.1 mm) is the surface layer thickness where RCF starts to propagate.

- Measuring trains regularly monitor the actual condition of the entire track using ultrasound, eddy current testing and/or image processing. In order to verify the results of HSG a detailed inspection program was established in connection with the grinding operations. It covered metallurgical analyses, profile measurements as well as eddy current crack detection gauging. All results were contrasted with the results from reference track sections which had been left unground after the initial grinding of 2006 to obtain a track section for comparison.

6.2 Technical and economical results

The outcome of the inspection program revealed the effectiveness of HSG. The reference sections that had been left unground showed growing RCF problems, while ground sections in otherwise identical conditions had no signs of RCF and displayed a smooth longitudinal profile.

In detail, the eddy current scans conducted before the first grinding cycle in January 2008 revealed small head checks about 0.004” (0.1 mm) at all inspection points in all sections. HSG was run
afterwards on the whole track except for two reference sections which included two of the inspection points.

The scans were repeated before the second grinding operation in May 2008. Again, head checks up to 0.012” (0.3 mm) could be identified – but only in the non-ground reference sections. All ground sections were head check free [6]. (see Fig.4)

Secondly, cross and longitudinal profile measurements conducted before and after grinding passes have shown that even after 4 grinding cycles and a total metal removal of approximately 0.02” (0.5 mm) the rail profile is maintained with no indication of degradation. By the use of special gauge corner stones the artificial wear for RCF prevention is predominantly conducted at the gauge corner. These stones machine the area between y-35 to y 0 indirectly optimizing the cross profile of the rail. Figure 5 shows the cross profile after 20 passes with approx. 0.033” (0,8mm) metal removal. A corrective profile machining is not possible with High Speed grinding concept but the potential to copy and maintain the initial cross profile has been proven within the project.

And finally, a section of the rail was cut out by Deutsche Bahn to examine its metallurgic condition. No abnormalities were encountered, and it was especially remarked that grinding with HSG is not causing any uncontrolled negative effects on the rail such as cracks.

The Nuremberg-Ingolstadt track has been ground 4 times now (June 2009) and continues to show an intact profile and predominantly no RCF. HSG will continue on the track, as will the inspection programs to analyse the effects of the grinding.

The Nuremburg-Ingolstadt project has clearly indicated the non-linear development of rolling contact defects and the necessity for preventative rail maintenance. An economical project summary has been conducted by a comparison to the unground reference sections. Pricing the engaged effort to maintain a crack-free rail in comparison with the costs to remove developed defects after 12 month show a 40% cost saving with the High Speed Grinding approach compared to a corrective grinding strategy. Furthermore, the project has shown a 50% saving of metal removal.
7 Conclusions

The consequent approach “as often as possible but not more than necessary” has proven its economical and technical success.

Meanwhile High Speed grinding is also working on seven different lines at the Deutsche Bahn network. Among them are High Speed Lines, mixed traffic lines and freight lines with up to 50 MGT. Due to different loads and track topographies it will be the future challenge to develop specific grinding cycles for further tracks. Parallel projects are proceeding using eddy current testing with high working speeds in order to optimise early crack detection.

High Speed Grinding follows a preventative grinding philosophy and realises it in the most consequent way by the means of removing fatigued surface layers before cracks initiate. Thereby the operational challenges have been successful handled through working speeds of 50 mph (80km/h) which enable rail maintenance within traffic schedule.
References


[6] Dr. von Diest, Konstantin: Internal Report Stahlberg Roensch on the inspection results for the pilot project Nuremberg-Ingolstadt (undated)
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