RAIL GRINDING BEST PRACTICES

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ABSTRACT

The Class 1 heavy haul railroads of North America are using rail grinding best practices to ensure maximum returns on their investment in rail to their shareholders.

AREMA Committee 4, Sub Committee 9, focus group consists of rail grinding managers responsible for implementing rail grinding best practice in North America. This group has issued a survey and gathered together the most recent knowledge of rail grinding best practices for the AREMA manual. This will provide railways worldwide a guideline for the implementation of a preventive grinding strategy with the supporting economic justification.

The most important reason for grinding in North America today is to control rail surface fatigue defects. The best way to control these defects is by preventive grinding and having in place a proper lubrication strategy. For preventive grinding to be successful a railroad must have engineered rail profiles ground onto the rail to reduce the wheel / rail contact stress. These rail profiles will significantly increase rail life, improve train stability and curving. Rail corrugations will be in control, however if they are present and severe they must be completely removed to minimize damage to the track structure. Railroads are continuously improving the metallurgy and hardness of the rail to increase rail life. Preventive grinding strategies have to be adjusted to reduce the amount of metal removed by grinding on these new rail steels to maximize their life. The best practices
for grinding new rail steels are developed from established test sites in typical track sections on the railroad. This paper contains the current industry best practice for preventive cycles and how much metal is removed from the rail each cycle.

This paper describes how a railroad not grinding with a best practice preventive strategy can immediately embark on a best practice preventive-gradual grinding strategy to gradually progress the rail towards the preventive rail surface condition.

There is a section devoted to the economic benefits gained by the Class 1 railroads with the implementation of a best practice preventive grinding strategy. This provides the information needed by railroad managers to justify their grinding programs for budget allocation purposes as this is a necessary maintenance practice on all railroads today.

This paper also discusses the planning of a preventive grinding program, the supervision and the quality control of the grinding program.

1.0 INTRODUCTION

AREMA Committee 4, "Rail", formed a Sub Committee No 9 in year 2000 to incorporate the industry established Best Practice for Rail Grinding into the AREMA Manual. The objective of the AREMA publication is to provide guidelines for railroads not grinding or
contemplating grinding to start with a best practice rather than going through an expensive learning process to develop their own grinding programs.

Sub Committee 9 formed a focus group that developed a questionnaire [1] to circulate to railroads known to have experience with best practices in rail grinding. The questionnaire was distributed to the rail grinding managers of all the Class 1 heavy haul railroads in North American as well as known heavy haul railroads with years of experience in best practices for rail grinding in Australia and South Africa. The responses as well as published technical papers and other internal railroad reports were used to develop the draft of Rail Grinding Best Practice for submission to Committee 4.

Most railroads surveyed in North America and Australia are grinding rail in a preventive [2, 3, 4] strategy rather than in a corrective strategy. Preventive grinding is the application of one pass with a large production grinder (or several passes with smaller grinders to cover the rail with grinding stones) to prevent severe rail surface defects from growing deep on the surface or into the subsurface of the rail. Corrective grinding is the application of multiple passes with a large production grinder to remove severe rail surface problems. The magnitude of the preventive rail grinding operation on the Class 1 North American railroads using large production grinders in 2002 is shown in Table 1.
These railroads also used a total of 16 smaller grinders with 16 or 24 grinding motors to grind switches, crossings and obstructions that cannot be ground by the large production grinders.

Railroads grind rail preventively to reduce rail wear, control rail surface and sub-surface fatigue, control rail surface plastic deformation to improve truck steering, improve the dynamic stability of rolling stock and improve rolling stock wheel life. This is achieved by implementing preventive grinding cycles based on track curvature and traffic tonnage to remove a thin surface layer of metal from the rail. Tables show the tonnage interval for preventive grinding cycles and how much metal is removed from the rail surface by grinding machines each grinding cycle based on curvature, rail hardness and track structure.

Preventive grinding produces the optimal transverse rail profile to ensure a low contact stress geometry between the wheel and the rail to reduce rail plastic flow and rail surface fatigue. These optimal rail profiles will improve vehicle stability in tangent track and improve wheelset steering in curves. Optimal rail profiles are designed using proprietary software and information gained from each particular railroad's operating environment, maintenance strategies and types of material used in the track structure. These design profiles have changed over the years with improvements in these railroad characteristics.
Railroads doing preventive grinding (which eliminates rail surface cracks) are able to best utilize proper lubrication strategies to reduce wear and the traction stresses (at the wheel / rail contact surface) and to increase the number of cycles before surface cracks develop and the profile plastically deforms. This strategy significantly increases the rail life. Wide gage is also controlled to less than 0.5 inch wide to prevent the wheel false flange from running on the low rail contact band and causing rapid plastic deformation and rail spalling.

Railroads are using rail with improved metallurgy, higher hardness, with preventive grinding to significantly reduce wear and the development of surface cracks. This has also modified the shape of the optimal rail profile and the grinding cycles used by these railroads for the preventive grinding of curved and tangent track. New rail is ground soon after installation to produce the optimal low stress profile and to remove the decarbonized layer that can rapidly produce rail surface cracks.

The most economical way for railroads to transition to preventive grinding from a corrective strategy is to start with a Preventive-Gradual grinding strategy. The preventive-gradual grinding strategy involves embarking straight to preventive grinding cycles without first undertaking the expensive task of “cleaning” the rail surface of fatigue damage. The rail is transitioned to the optimal profile and crack-free state on a gradual basis. The objective is to immediately gain the benefits of an optimized
preventive grinding strategy while gradually catching up to the profile and surface
cracks.

Best practice grinding requires that the railroad have well developed and well managed
grinding plans. This plan requires proper supervision of a high production grinding
operation, pre grind and post grinding inspection using specialized grinding inspection
tools, and, a coordinated support program to manage the risk of fires. Grinding machine
technology has improved significantly due to demands by railroads for higher
productivity in today's short track maintenance windows.

2.0 WHY RAILROADS GRIND RAIL

The natural processes of wear and surface deterioration of rail steel can proceed at a rapid
pace that results in a reduced service life.

Grinding of rails has evolved as a maintenance technique to insert controlled artificial
wear and manage wheel / rail contact stress. This maintenance strategy reduces rail wear,
controls rail surface and sub-surface fatigue, controls rail surface plastic deformation,
improves truck steering, improves the dynamic stability of rolling stock and improves
rolling stock wheel life.
The growth rate of rail surface (and subsurface) fatigue cracks (as shown in figures 1 and 2) is influenced by the level of contact stress between the wheel and the rail (refer to section 6.0). Figure 1 [5] shows the cycle of crack growth into the rail surface. Micro-cracks develop at the most stressed portion of the rail surface. In their early phase the microscopic cracks grow quickly in a somewhat vertical direction to a shallow depth in the rail surface. The cracks then enter a phase of shallow angle growth until they reach a branching phase. At this phase the rate of growth in the vertical direction accelerates.

The preventive grinding strategy is designed to cycle the rail grinder (in the range A to B in figure 1) based on curvature and tonnage at frequent intervals to remove a thin surface layer of metal from the rail to prevent the micro-cracks entering the rapid phase of growth. Figure 2 [6] shows how cracks are at different phases of growth on the rail surface. Figure 3 shows an advanced stage of RCF that has spalled / shelled out on the rail surface. A large production grinder can remove short micro-cracks with a single grinding pass (as shown in figure 4) [7]. Note: a production grinder must have at least 20 grinding stones per rail to maintain a rail profile with one grinding pass. This process is designed to maintain an "optimal designed rail profile", remove the short micro-cracks that have formed since the last grinding cycle and to maintain the protective work-hardened material on the rail surface.
3.0 IMPORTANCE OF LUBRICATION AND TRACK GAGE FOR PREVENTIVE GRINDING

Rail surface fatigue cracks grow fastest when contaminated by water and somewhat slower when contaminated with a mixture of water and lubricant. On the other hand, lubrication substantially reduces the traction stress at the wheel/rail surface and therefore increases the number of contact cycles by wheel loads before RCF initiates (figure 5). For this reason, preventive rail grinding (where surface cracks are eliminated) in combination with lubrication can significantly increase rail life. Conversely, the application of lubricants to damaged rail can increase the rate of crack growth.

With lubrication that is confined to the gage face, the top of the high and low rail remain dry and cause truck curving lateral forces to significantly increase. This can result in high rail gage corner shelling [8] (refer to Figure 6). Grinding of the gage face area of the rail must remove at least 16/1000 inch at the 45 degree location on the rail to compensate for the higher lateral forces and the lower artificial wear rates provided by gage face lubrication.

If the coefficient of friction (COF) on the high and low curve rail is controlled in the range 0.3 to 0.4 on both rails, it will reduce the anti-steering moment on the trailing axle, thereby helping to reduce the angle of attack of the truck. This will reduce the L/V ratio
on the low rail by about half, and the flange force on the high rail to about 2/3 of its original value. This will also reduce the traction force on high rail and the low rail. As a result, lateral creep forces, ratcheting and plastic flow on the top of both rails will be reduced. Friction control of the top of rail will therefore reduce the wear rate between grinding intervals to half of its original value [9]. It will also reduce the need to aggressively grind the high rail and low rail, resulting in further savings in rail metal.

Wide gage in curves causes the false flange (the rim side of hollow tread wheels as shown in figure 7) to contact the running area of the low rail, resulting in very high contact stresses and the rail is dished (as shown in figure 8) causing poor wheelset steering. The presence of wide gage greater than 0.5 inches (13mm) in sharp curves has required up to 9 preventive-gradual "catch-up" cycles to achieve the optimal profile. Generally three grinding passes each cycle by high production grinding machines are required to speed this process.

4.0 PREVENTIVE RAIL GRINDING OBJECTIVES

4.1 Restore The Transverse Rail Profile

The key objective of preventive grinding is to restore the “optimal” rail transverse profile.
As the rail wears with tonnage over the surface the wheel/rail contact geometry creates excessive wheel/rail contact stress that cause rail surface plastic flow and surface fatigue (spalling, shelling and head checks). This contact geometry also increases the internal stresses in the rail which gives rise to rail defects within the railhead, such as transverse defects. By rectifying the profile in the transverse plane with rail grinding the contact geometry is improved between the wheel and the rail. Producing conformity between the worn wheel and the rail reduces the contact stresses. Also an optimal rail profile will improve vehicle stability in tangent track and improve wheelset curving.

### 4.2 Control Rail Corrugation

Corrugations are controlled by preventive grinding and proper lubrication. Rail corrugations initiate from: rail head de-carbonization (on new steel) and irregularities such as; rolling defects from the steel making process, contact fatigue defects, rail welds, rail joints, etc. By grinding a corrugated rail surface the wheel/rail dynamic loads are significantly reduced and the track structure (fastenings, ties and ballast) will last longer.

### 5.0 RAIL METALLURGY AND CRACK PROPAGATION
Rail wear and rail surface fatigue occurs in soft (250 to 300 BHN), intermediate (300 to 340 BHN) and hard (340 to 420 BHN) steels. Improved metallurgy, harder steel, profile grinding and proper lubrication can significantly reduce wear and RCF.

Rail surface flow (refer to figure 9) will cause RCF and shelly spots to develop. The flow cannot be eliminated in heavy haul, however it can be reduced substantially by increasing the hardness of the rail.

Gage corner collapse (refer to figure 9) causes deep-seated shells and cannot be prevented in heavy haul even with harder rails. It can be minimized by reducing the frequency of wheel loading on the gage corner, i.e. by frequent grinding of the gage corner. The tonnage between grinding cycles is governed by the rate of surface flow into the gage corner.

Softer rails plastically deform more rapidly and therefore must be ground more often and more metal needs to be removed each grinding cycle [10]. Harder rails are more resistant to plastic flow and will require less frequent grinding and less metal removal each cycle. However, soon after installation, harder rail will require profile correction to a worn conformal profile to compensate for the harder steel tendency to resist natural wearing. This resistance to plastic flow can cause the rapid initiation of RCF cracks. Also, when new rail is installed into track the thin surface decarbonized layer should be removed as it is very soft and will rapidly produce RCF cracks.
6.0 PREVENTIVE GRINDING AND “OPTIMAL” RAIL PROFILES

The rail in track must deal with a large distribution of wheel profiles – from unworn to very worn, new to hollow, wide flange and thin flange. In “best practice”, wheel/rail interaction software is used to design the optimal rail profile for curved and tangent track to minimize rail contact stresses and improve train stability and curving performance [11]. Optimal rail profiles have changed over the years with improvements in the railroads’ operating environment, the introduction of improved maintenance strategies and new and harder materials. For example, on CPR the “as ground” profiles introduced in 1988 changed in 1991, 1997 and 2000. Figures 10 and 11 show a comparison between the 1991 and 2000 template designs [12, 13].

6.1 Tangent Track Profiles

Tangent track profiles are designed to be ground onto straight track to produce 8 to 10 inch (200 to 250 mm) radius running band in the centre or which may be deliberately biased towards the field side or the gage side of the rail head. Used together, these rail profiles broaden the pattern of wear on the wheel tread, reducing both the number of hollow wheels that develop and the rate at which they hollow. The benefits of this profile strategy will increase rail life in curves and tangent track, reduce grinding effort,
lower lateral track forces (through better steering overall), increase wheel life and reduce fuel consumption. Figures 12 and 13 show examples of tangent rail profiles. Figure 12 shows a TT profile used throughout the 90’s and used today by several railroads to grind a central 8 inch radius on the rail. Figure 13 shows a shows the 2000 design Tangent Field profile on a location with crushed heads to produce a 10 inch contact band biased by 0.5 inch (13mm) towards the field to prevent crushed heads from developing. Figure 14 shows how this Tangent Field profile redistributes the high wheel / rail contact stresses to a location away from the crushed head and prevents the rapid growth of cracks [14].

6.2 High Rail Profiles

High rail profiles must avoid concentrations of stress and fatigue but also maximize the vehicle curving performance when mated with worn wheels. Improved profiles are applied that are tailored to high rails of mild, intermediate and sharp curves, respectively. The improved wheelset steering and much better contact stress distribution will minimize wheel/rail wear and contact fatigue and reduce locomotive fuel consumption. Figures 15, 16, and 17 show examples of high rail profiles. Figure 15 is a H4 profile used in the early 90’s to grind softer rail in curves (refer to section 5.0). Figure 16 shows a H2 profile used by several railroads today for the high rail of sharp curves, and Figure 17 shows the 2000 design high rail profile used by two railroads to reduce metal removal by 0.010 inch (0.25mm) per grind cycle compared to the H2.
6.3 Low Rail Profiles

Optimal low rail profiles must avoid concentrations of stress and fatigue caused by the presence of hollow wheels and wide gage on heavy haul railroads. Some benefits are also attributed to steering to maximize the vehicle curving performance.

Figures 18 to 21 show examples of low rail profiles for sharp curves. Figure 18 is an L3 profile used in the early 90’s to grind softer rail and wide gage (refer to sections 3.0 & 5.0). Figures 19 and 20 show L2 and L1 profiles, respectively, which are used by several railroads today for the low rail of sharp curves. Figure 21 shows the NRC 2000 design low rail template used by two railroads to reduce metal removal per grind cycle. This design reduces metal removal by 0.071 inch (1.8 mm) compared to the L2, and 0.038 inch (0.95 mm) compared to the L1 template, while still controlling contact stresses.

6.4 Using Templates For Preventive Rail Grinding

The production of the optimal transverse rail profile is measured using some of the templates described in section 6.3. These templates are mounted on a bar (which is a manual tool), or, digitally installed into laser profile systems on-board rail mounted vehicles (including the grinding machine), to measure the track. The templates should cover the entire rail surface from the gage corner at 45 degrees to the field side edge to
ensure correct shaping of these critical locations. The finished transverse profile should be satisfactory if at least 80% of measurements of a section of track are within the desired tolerance range of the template (refer to Table 4).

Use of the template should correctly locate the contact band, except in locations where there is significant loss of rail cant under loading. This can be verified by spray painting the rail and observing the width and location of the contact band after the passage of one train, or by using a specialized track tool to measure the contact band as shown in section 14.5.

6.5 Grinding For Corrugation Removal

Preventive grinding cycles are designed to control corrugations by grinding frequently enough and removing sufficient metal in one grinding pass to maintain the desired rail profile, and at the same time remove the corrugations that have grown since the last grinding cycle. If corrugations cannot be removed in a single pass, then multiple passes are applied. Corrugations left in the rail until the next grinding cycle will grow to an unacceptable level prior to the next grinding cycle.

Figure 22 shows rail corrugation that has not been completely removed after 1 grinding pass. More grinding passes are completed to remove the corrugation.
7.0 PREVENTIVE GRINDING METAL REMOVAL RATES

The optimal wear rate is the rate of rail wear required to just control rail surface fatigue. Insufficient wear results in rail fatigue, while excessive wear reduces rail life. Preventive grinding is an optimized rail surface maintenance process that achieves the required optimal rail profile and removes the RCF cracks.

The optimal wear rate is tonnage and track specific and depends on some of the following: accumulated tonnage since the last grinding cycle, the axle load, type of traffic, rail metallurgy, track curvature, environment / season, track gage, lubrication standards, etc.

Table 2 shows the current best practice depth of metal to be removed from the gage (+45 degrees to +6 degrees), crown (+6 degrees to – 2.5 degrees) and the field (greater than -2.5 degrees to field) used by railroads in North America for their preventive grinding programs [15].

8.0 GRINDING CYCLES FOR PREVENTIVE GRINDING
Preventive grinding cycles are the tonnage (or time) based grinding intervals that remove and control the small initiating surface fatigue cracks that have been caused by millions of wheel cycles over the rail. For effective preventive grinding, the following grinding cycles and metal removal rates are utilized by railroads to maintain their rail (refer to Table 3).

9.0 IMPORTANCE OF RAIL GRINDING TEST SITES

As railroads introduce improved track materials, better maintenance practices, heavier trains, longer trains, and trains running at higher speeds, rail grinding test sites are used to establish the metal removal rate to control the growth of RCF cracks. Rail samples are valuable in analyzing the fatigue crack growth rates and their internal direction of propagation. The objective is to develop the optimal metal removal rate and the preventive grinding cycles to manage the rail grinding strategy for the changing railroad environment. Test sites are the best way to manage the risks of implementing changes to established preventive grinding cycles. If any serious failure of a new strategy takes place, it will happen in the test site. Test sites are used to calculate the economics of a new preventive grinding strategy, for example for the introduction of new premium rails for resistance to RCF, reduced wear, reduced grinding effort, and reduce grinding costs.
10.0 HOW TO GET TO BEST PRACTICE PREVENTIVE GRINDING
BY USING THE PREVENTIVE-GRADUAL GRINDING
TECHNIQUE

Preventive-Gradual Grinding [16] is a grinding practice that transitions the rail from a corrective condition to a preventive condition. The preventive-gradual grinding strategy involves embarking straight onto preventive grinding cycles without first undertaking the expensive task of “cleaning” the rail surface of fatigue damage. The rail is transitioned to the desired profile and crack-free state on a gradual basis. This strategy starts with frequent one-pass grinding as with traditional preventive grinding, but with additional metal removal each pass. Additional metal removal is achieved with slower grinding speeds and/or higher grinding motor horsepower. This metal removal rate is higher than that defined in Table 2, "Optimal Metal Removal Rate". The objective is to immediately gain the benefits of an optimized preventive grinding strategy while gradually catching up to the profile and surface cracks. Figure 24, section 10.1 shows the saving in rail steel for various grinding strategies with preventive-gradual grinding being the most efficient.

Figure 23 shows the staged profiling and crack removal process. Stage 1 shows how successive one pass grinds achieve the desired rail profile within one to three grinding cycles. Stage 2 shows cycles 2 to 6 of one pass grinding, which gradually stops the initiation of new cracks and reduces crack (hydraulic) pressurization. Stage 3 shows cycles 4 to 9 of one grinding pass to remove the remaining inactive cracks to produce a
clean rail surface and renew the work hardened layer. On heavy haul railroads utilizing a large production grinder the entire process typically takes three cycles of one pass on tangent track, shallow curves and sharp curve high rails, and up to nine passes on the low rail of sharp curves with wide gage (refer to section 4). On high-speed passenger railroads using a high production grinder this process requires 3 cycles of one pass to remove RCF damage primarily on the high rail of sharp curves with cant deficiency.

10.1 Test Site Economics Of Preventive-Gradual Grinding Over Other Grinding Strategies

Figure 24 shows data from a Class 1 North American railroad test in 1999 and 2000 to prove the benefits of various grinding strategies. This test, conducted on a 60 MGT per year heavy haul territory with premium rail, concrete ties and typical lubrication practices determined total rail wear from grinding and traffic for various grinding strategies in 6 degree curves. After 125 MGT (bottom segment of each bar shows results after 60 MGT) the preventive-gradual strategy followed by a preventive grinding strategy proved to be the most economic strategy. The graphs shown are in the following order - sets of three columns - preventive-gradual, corrective, preventive immediate (correct profile with multiple passes then one pass grinding cycles implemented), maintenance and no grinding.
11.0 HOW GRINDING MACHINES PRODUCE THE OPTIMAL METAL REMOVAL RATE

The net reshaping of the rail by a grinding machine is produced by a grinding pattern. A grinding pattern refers to a sequence of grinding motor angle settings and accompanying pressures on grinding stones. Profile specific grinding patterns concentrate the metal removal where it is needed most to address the transverse rail profile and rail surface condition without wasting metal. Optimized use of grinding patterns will produce a profile that conforms closely to the optimal rail profile to good geometric smoothness.

Target optimal rail profiles are installed into laser based measurement systems on rail grinders and rail-bound profile measurement cars, computer based field measurement devices and BAR Gages (refer to Figure 25). These tools are used to measure metal removal requirement by rail grinding machines at the preventive grinding cycle to approximate conformance to the optimal profile. Metal removal rates are used to design the grinding patterns based on the capability of a grinding machine. Patterns are regularly fine-tuned to match the changing rail condition and updated optimal rail profiles. As a grinding machine configuration changes, so too will the grinding patterns needed to suit the new configurations.
12.0 FACTORS THAT INFLUENCE THE METAL REMOVAL OF RAIL GRINDING MACHINES

The following factors influence the production of the design rail profiles using rail grinding machines:

- **Grinding Stones and the abrasive used in them.** Grinding stones are engineered to balance good cutting performance for a given range of energy input to the cutting surface and to maintain its performance over a long service life. Proper matching of the grinding wheel/abrasive and the grinding equipment is an important feature in an efficient grinding operation.

- **Surface finish left by the grinding stone.** Surface finish is measured by the ridges left between the facets of each stone pass and the surface roughness left by the grinding marks or scratches. Excessive facet widths can lead to localized plastic flow of highly stressed peaks causing increased wear and wheel/rail noise. Table 4 shows the typical acceptable grinding facet widths with preventive grinding. The rough nature of the as-ground rail surface is dependent upon the stone grit size, the transverse length of the scratch marks, the grinding motor horsepower control and the dynamic stability of the grinding motors. Grit size refers to the physical size of the abrasive grain particles.

- **The grinding speed and grinding motor pressure.** Grinding machines control the rate of removal of metal from the rail surface by adjusting the grinding pressure
and/or changing the forward speed of the grinding machine. Higher grinding
speeds and reduced pressures will reduce the metal removal rate.

- **Controlling long and short wave corrugations.** Short wave corrugations are
  considered to be those within the width of the grinding stone. Long wave
corrugations are considered to be greater than the width of the grinding stone and
may be up to 10 feet (3 metres) in length (a length that will cause an increase in
the dynamic load to the track caused by train traffic traveling over the
corrugation). Grinding machines can remove corrugations by varying
horsepower, grinding speed and/or “controlling” the grinding system to remove
metal from corrugation peaks and not the valleys.

### 13.0 RAIL GRINDING ECONOMICS

Railroads that have a good history of preventive grinding have shown substantial
benefits. In the following paragraphs there are several recent examples of savings to
North American Class 1 railroads.

#### 13.1 Rail Savings With Preventive Grinding

13.1.1 Case History 1
Table 5 shows a North American Class 1 railroad with extensive experience with various grinding strategies; no grinding, corrective grinding and preventive grinding program (in this example preventive grinding was introduced in 1993) [17, 18]. This table shows the significant increase in rail life with preventive grinding as the rail being replaced due to wear rather than for fatigue.

In the preventive grinding mode rail replacement requirements are in steady state. Rail in sharp curves, for example, are ground frequently (every 15 to 25 MGT) with a single pass of a large production grinder. Table 6 shows System-wide annual rail replacement experience on a Class I North American railroad with a preventive, corrective and no grind strategy.

As Table 6 shows, corrective rail grinding (compared to no grinding) is estimated to save $US 13 million per year in rail replacement at an annual grinding cost of around $US 8 million.

Preventive rail grinding (compared to no grinding) is estimated to be save $US 16 million per year in rail replacement at an annual grinding cost of $US 7.5 million. The benefit/cost ratio is greater than 2. Note that at the same time, total traffic tonnage handled by this railroad over the period 1990-2003 has increased by more than 40%, and 286,000 lb. GVW cars were introduced as the bulk haul standard.
13.1.2 Case History 2

Tests conducted on another Class I railroad demonstrate wear rates (combined grinding and wear) on sharp curves up to 45% higher under corrective grinding than with preventive grinding. Also annual grinding passes required to maintain curves are up to 35% higher with corrective grinding.

13.2 Preventive Grinding and Reductions in Rail Defects

13.2.1 Case History 1

Experience with grinding on a Class I railroad demonstrates what happens when preventive grinding cycles are changed to corrective grinding cycles due to work programs in sharp curve territories and budget cuts. This grinding cycle on sharp curves and tangent crushed head locations increased from 18 MGT to 37 MGT. As shown in figure 26, in 1999, the grinding cycles were lengthened and the budget cut to reduce the amount of grinding each year. There was a corresponding increase in detail fractures and crushed heads until grinding pass miles increased to previous steady state values.

13.2.2 Case History 2

Another Class I railroad, with a 40 year history in rail grinding, has demonstrated the impact of various grinding strategies on detail fracture rates as shown in figure 27. In 1987 the grinding strategy was corrective profile grinding strategy on curves at 35 MGT
intervals. The rail surface was in good condition, however rail-wear rates were excessive because of the contact profile. In 1988 the grinding strategy changed to a conformal one-point wheel/rail contact condition in order to reduce rail-wear rates. Grinding intervals were lengthened to as much as 90 MGT and grinding speed increased by 40%. The increased grinding speed, longer grinding intervals and reduced grinding of the gage-corner led to increased fatigue damage on curves, and detail fracture rates increased dramatically.

In 1991 the grinding approach changed again, instituting a mild 2 point contact profile and curve grinding intervals of 18 to 40 MGT were implemented. By 1995 preventive grinding was fully established. The rail surface was again in good condition and curve detail fracture rates had declined. In 1994 traffic, tonnage and territory increased, however without a proportional increase in grinding resources. Track time available for grinding steadily decreased, resulting in additional lost productivity. By the end of 1997 there was a corrective grinding strategy with grinding intervals between 60 to 200 MGT. Rail condition deteriorated rapidly, and detail fracture rates on tangent rail had increased by 76% over 1994 levels. In 1999 a preventive-gradual grinding program was started on parts of the System and defect rates started to come down.

13.2.3 Case History 3

In 2001 another Class 1 railroad changed from a corrective grinding program to a preventive grinding program to reduce their rail surface initiated service failures as well
as defects overall to reduce the costs of train traffic interruptions and repair costs (manpower and materials) [19]. A defect monitoring study demonstrated a 65% reduction in rail service initiated service failures. Also a Six Sigma investigation into the defect rates per MGT miles with various grinding strategies (see figure 28) found that preventive grinding had a significantly lower rate compared to no grinding and corrective grinding.

13.2.4 Case History 4

Rail surface condition on another Class 1 railroad improved dramatically on its preventive-gradual territories. Premature rail relay because of rail surface condition in 2000 was 53% lower. Additionally main track rail detection exceptions, where poor rail surface condition prevents ultrasonic rail flaw inspection, decreased from 238 locations in 1998 to 5 in 2000.

13.3 Productivity Improvements with Preventive Grinding

Track occupancy time for performance of maintenance tasks is at a premium on heavy haul railroads. Maximum track window length on the Class 1 railroads are short (refer to Table 1). Because of the multiple corrective passes required in corrective grinding, track segments often cannot be completed in one track window - resulting in significant travel time to clear for traffic. Preventive grinding is a more productive way to grind. Table 7 examines grinding equipment utilization on a heavily curved single track segment under
preventive and corrective strategies. This segment is 17.7 km (11 miles) long with 27
sharp curves totaling 11.3 km (7.0 miles). Locations to clear equipment for traffic are
available at each end of the segment. Table 7 shows that in this example corrective
grinding requires 59% more time than preventive grinding to grind the curves in the
segment. In practice the preventive grinding efficiency is even greater, as fewer passes
per year would be required than for corrective grind, and higher grinding speeds could be
utilized.

14.0 PLANNING AND QUALITY CONTROL OF RAIL GRINDING

Good grinding planning involves the following best practices [20, 21]:

- grinding program is strictly adhered to
- proper supervision of the grinding operation in place
- pre and post grinding inspection program of the quality of grinding desired
- grinder is working in a high production mode during available grinding time
- coordinated program of back up fire fighting support to manage the risk of fires
- operation is run in a safe manner

14.1 Preventive Grinding Contracts
In North America, production grinding operations are usually carried out by contractors. Preventive grinding contracts may be structured based on payment for the pass miles of track ground. The contractor and the railroad strive to achieve higher efficiencies in some of the following areas; higher grinding speeds, higher track time for work and a pass to finished mile ratio near 1.0. The contractor may also be involved in surveys of grinding machine performance and rail conditions. Performance in terms of metal removal at various grinding speeds is sometimes stated in contractual agreements. This can be an effective way to operate as it encourages the contractor to plan and innovate and can improve the railroad’s control of the grinding costs. At the same time, it requires that the railroad have a good understanding of rail conditions and the track time available for work.

14.2 Grinding Supervision

The goal of a preventive grinding program is to have every programmed mile ground to the optimal profile and to within the desired tolerances. A successful preventive grinding strategy can only be implemented with vigilant management of the grinding program. To meet the needs of the ever changing rail condition; the grinding cycle, the grinding patterns and the grinding speed (to achieve the metal removal from the rail) are closely monitored throughout the program to make the necessary adjustments to maximize rail life and optimize the grinding budget.
In order to implement a preventive grinding program a comprehensive pre-inspection and planning process is needed. Field inspections are carried out with measurement tools incorporating target rail profiles shortly before the planned grind and after the grind to measure the result. The appropriate patterns are selected at the appropriate grinding speed to achieve the optimal metal removal to maintain the rail profile and remove initiating rail surface fatigue cracks.

The preventive grinding program must be strictly adhered to. There must be proper supervision of the high production grinding operation; to achieve the grinding program targets, guarantee accurate placement of the pre-selected grinding patterns at the right grinding speeds, coordinate support equipment, and maintain a safe operation.

Management of the risk of fires is critical for any rail grinding operation. Preventive grinding programs require frequent grinding of rail even at the hottest times of the year when vegetation is dry. Rail grinders require spark protective systems on the outside of the grinding motors and the back up of specially designed, rail bound water carrying vehicles to prevent fires. Fire suppressants are sometimes added to the water to enhance the capability of fire control. In some instances grinding programs are adjusted to ensure fire sensitive areas are avoided during high risk times of the year.

Rail grinding machines may have an on-board automatic, laser profile measuring system with the target profiles to measure before and after grinding. The before grinding
measurement shows where metal should be removed in order to achieve the profile desired and the post grind measurement shows the final profile tolerance.

14.3 Grinding Planning Software

The goal of a preventive grinding plan is to have rail ground on time and to the right profile. This can be achieved by having good management tools.

- Maintaining the appropriate grinding cycle interval on each line segment is the most critical factor in the success of any preventive grinding program, and even more so for preventive-gradual grinding. Arrangement of the grinding territory in a loop, with the annual tonnage on individual lines at even multiples of a base tonnage, is the best configuration to minimize equipment travel and variance from the desired cycle.

- Grinding planning software. A grinding production plan (as shown in figure 29) must be available in advance of the arrival of the grinder on site. The plan is based upon an advance survey of the territory identifying the types of conditions that are being targeted for correction. The grinding plan will specify the patterns to be used, the number of passes and the grinding speed. This program has the following benefits for rail grinding planning:
  - Maintain a permanent record of past rail grinding plans. The permanent record is important for pre-inspection and post grind inspection.
- Provide a grinding plan to the contractor and district staff that has ALL the required information to complete the plan.

14.4 Quality Assurance of Grinding Operations

It is considered here that the rail is ground effectively if the following conditions are satisfied:

- Either a) the desired transverse profile is obtained within the specified tolerance range OR b) any stated minimum depth of material is removed from the rail to control rolling contact fatigue defects.

- corrugation is removed so that residual irregularities are within the specified limits

- desired surface finish is achieved

- grinding operation is conducted as productively as possible i.e. the greatest distance of finished ground track is produced per operating hour

To assist railroads with the implementation of productive grinding program some of the best practices are shown below.
14.5 Rail Grinding Quality

Maintaining a regular inspection of the grinding operation can yield premiums in grinding effectiveness. Typical checks that the grinding supervisor performs on a grinding operation to ensure profile quality are:

- Computer Control of Horsepower and Grinding Angles. Good grinding performance requires that each grinding motor is operating at the correct pressure and angle.

- Checking the Ground Rail Profile. Inspection tools are used to check the rail soon after the grinding operation to ensure that the grinding plan has produced an effective treatment of the rail.

- Track Location that influence the performance of the grinding operation. There are many factors that need to be considered when assessing a particular track location. The following may have adverse influences on the rail profile:
  
  **Structures** - bridges, crossings, switches, signals, etc.

  **Switches and Crossings** - rail grinding is usually performed by using smaller dedicated grinding machines for switches. These machines are capable of grinding in the narrow gaps at the various locations (i.e. guard rails, frog, points, etc) and changes in the width of the rail section. The normal practice is to ensure that the wheel / rail contact band is located central to the rail and at the correct cant (orientation to the wheels). A specialized tool is used to ensure that the final rail profile has the correct cant and radius in key parts of
the switch prior to leaving the site (refer to Figure 30). Crossings are also
ground by these smaller grinders and by specialized grinding buggies and
stones on production grinders.

**Rail Discontinuities** - welds, joints, plugs, hunting, bad rail alignment (e.g. dips at pumping ties, straight rail in curves, etc.), non typical surface defects (less than 80% of the curve or tangent, e.g. shelling, corrugation, spalling, etc.), plate cut ties, seat abraded concrete ties, etc.

**Compound Curves** - assess the grinding requirement at the highest degree of curvature.

**Lubricators** – obstruction around the rail head at lubricator locations either have to be picked up for or ground with smaller specialized rail grinders.

**Rail Cant** - plate cut timber ties or abraded concrete ties change the orientation of the rail relative to the wheel profile. Extra relief is required on the gage corner of the high and field side of the low rails to protect the rail.

**Rail Hardness** - The rail material strength and amount of work hardening in the tangent/curve being ground will influence the profile to be ground.

**Transposed Rail** - requires significant amounts of metal to be removed from the gage and field sides of both rails.

**Rail Head Loss** - The rail vertical wear will influence the location of the final wheel/rail contact band.

**Grinding of New Rails** - New rail is ground to remove the decarbonized layer and to produce a low stress optimal profile.
• Contact Band on the Rail (visual)

A very simple way of visualizing if there is a problem with the transverse profile is to spray the rail with paint before the passage of a train. The train should wear a single running band on the rail surface with the location dependent on the rail position (tangent or curve).

• Rail Grinding Surface Finish (visual)

Inspections should determine if there has been grinding stone malfunctions, for example: gaps in grinding marks (grinding chatter), missing grinding facets leaving un-ground gaps on the rail surface, large ridges left on the rail surface, large grinding facets, deeper striation marks than normal (that do not wear down with substantial traffic over the rail), grinding gouges on the surface, continuous "blueing" or blackening of the rail surface, wandering of some grinding facets to different positions on the rail surface, etc.

• Rail Surface Roughness

The centre-line-average roughness of a worn rail, $R_a$, is typically 0.5 to 2 microns. However, a ground surface is relatively rough because the grits in a grinding stone (like sand on a sanding disc) cut small grooves in the rail (the value of $R_a$ for a freshly ground rail is typically less than 12 microns). Measurement of surface roughness is a standard workshop procedure, for which a number of instruments are commercially available.

• Metal Removal Measurement
The metal removal over an area of the railhead can be measured and monitored using an instrument such as the EZ11 (figure 31) or “Miniprof” (figure 32), although this is not practical as part of daily routine grinding operation. Measurements are made periodically on typical track locations to verify the performance of the rail grinder.

15.0 CONCLUSIONS

AREMA Committee 4, "Rail", formed a Sub Committee No 9 in year 2000 to incorporate the industry established Best Practice for Rail Grinding into the AREMA Manual. The objective of the AREMA publication is to provide guidelines for railroads not grinding or contemplating grinding to start with a best practice rather than going through an expensive learning process to develop their own grinding programs.

A survey of current grinding practices verified that most railroads in North America and Australia are grinding rail in a preventive strategy rather than in a corrective strategy. Preventive grinding is the application of one pass with a large production grinder (or several passes with smaller grinders to cover the rail with grinding stones) to prevent severe rail surface defects from growing deep on the surface or into the subsurface of the rail. Corrective grinding is the application of multiple passes with a large production grinder to remove severe rail surface problems.
The survey demonstrated the scale of the preventive grinding program in North America on the Class 1 railroads. These railroads have had many years of experience with various grinding strategies. The economics demonstrate that preventive grinding is the best practice grinding strategy. This paper provides guidelines for those railroads not grinding, or grinding other than preventively, the best practice for metal removal rates and grinding cycles that should be implemented. The design of optimal rail profiles is strongly recommended to ensure that there is a lower stress state between the wheel and the rail and asset life is maximized.

Preventive rail grinding is an important strategy in rail asset management, enabling railroads to get the most out of their rail, with the least risk, and is particularly important as a companion to an effective lubrication and rail testing strategy.

16.0 REFERENCES

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6. Several authors, "Rolling Contact Fatigue in Rails; A Guideline to Current Understanding and Practice, Railtrack publication, February 2001.


18. Roney M, "Key Note presentation to IHHA Conference, Dallas, TX, 2003".

    Connections 99 Rail Wheel Interface Seminar, Chicago IL, May 1999.

    Burlington Northern Railroad”, Proceedings of the Fifth International Heavy haul
    Conference, Beijing China, June 1993.

| Table 1: Scope Of Preventive Rail Grinding On Class 1 North American Railroads. |
|-------------------------------------------------|-------|
| Number of Production Grinders (84 to 96 grinding |
| motors with 30 horsepower capacity)              | 14    |
| Total track miles ground                         | 78,164|
| Total pass miles ground (one pass over one mile) | 87,304|
| Average number of grinding passes per finished  | 1.12  |
| mile                                            |       |
| Average grinding speed - mph                     | 6.4   |
| Average shift hours per day                     | 12    |
| Average number of grinding hours per shift      | 3.8   |
| Average total miles finished each grinding shift| 23.4  |
Table 2: Table Of Typical Optimal Metal Removal Rate In Inches (mm).

<table>
<thead>
<tr>
<th>Track Location</th>
<th>Cycle MGT Timber Ties metal removal inches (mm) depth</th>
<th>Cycle MGT Concrete Ties metal removal inches (mm) depth</th>
<th>Passenger inches (mm) depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Rail (between +45 to -2.5 degrees)</td>
<td>15 MGT 0.012 (0.3)</td>
<td>15 MGT 0.012 (0.3)</td>
<td>10 MGT 0.012 (0.3)</td>
</tr>
<tr>
<td>High Rail Gage (poor lube) Gage (good lube) Crown Field</td>
<td>25 MGT 0.010 (0.25)* 0.016 (0.40)* 0.004 (0.1) 0.010 (0.25)*</td>
<td>15 MGT 0.010 (0.25)* 0.016 (0.40)* 0.004 (0.1) 0.010 (0.25)</td>
<td>10 MGT 0.008 (0.2) 0.004 (0.1) 0.008 (0.2)</td>
</tr>
<tr>
<td>Low Rail Gage Crown Field</td>
<td>25 MGT 0.010 (0.25)* 0.004 (0.1) 0.010 (0.25)*</td>
<td>15 MGT 0.010 (0.25)* 0.004 (0.1) 0.010 (0.25)*</td>
<td>10 MGT 0.008 (0.2) 0.004 (0.1) 0.008 (0.2)</td>
</tr>
<tr>
<td>Tangent Gage Crown Field</td>
<td>50 MGT 0.010 (0.25)* 0.004 (0.1) 0.010 (0.25)*</td>
<td>60 MGT 0.012 (0.3)* 0.006 (0.15) 0.012 (0.3)*</td>
<td>30 MGT 0.008 (0.2) 0.004 (0.1) 0.008 (0.2)</td>
</tr>
</tbody>
</table>

Note: double the metal removal if standard rail is used. Metal removal is governed by tonnage cycle and rail metallurgy.
Table 3: Preventive Rail Grinding Cycles For Optimal Metal Removal Rates Used By Railroads In 2002.

<table>
<thead>
<tr>
<th>Track / Rail Definition</th>
<th>Preventive Grinding Concrete Ties Rail</th>
<th>Preventive Grinding Timber Ties Rail</th>
<th>Preventive Grinding Standard Rail</th>
<th>Preventive Grinding Passenger/Transit Standard Rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Rail</td>
<td>15 MGT</td>
<td>15 MGT</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>141 RE</td>
<td>5 MGT</td>
<td>5 MGT</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>UIC 60, 113 A</td>
<td></td>
<td></td>
<td>10 MGT</td>
<td>10 MGT</td>
</tr>
<tr>
<td>Sharp curves (3 degrees or more)</td>
<td>30 - 50 MGT Intermediate Rail</td>
<td>30 - 50 MGT Intermediate Rail</td>
<td>16 - 24 MGT Standard Rail</td>
<td>10 -15 MGT Standard Rail</td>
</tr>
<tr>
<td>Mild curves (&lt; 3 degrees)</td>
<td>60 MGT Intermediate 100 MGT Premium Rail</td>
<td>50 MGT Intermediate 100 MGT Premium Rail</td>
<td>40 - 60 MGT Standard Rail</td>
<td>20 - 30 MGT Standard Rail</td>
</tr>
<tr>
<td>Tangent track</td>
<td>60 MGT Premium Rail</td>
<td>50 MGT Premium Rail</td>
<td>60 MGT</td>
<td>60 MGT</td>
</tr>
<tr>
<td>Grinding speed</td>
<td>6 - 14 MPH</td>
<td>6 - 14 MPH</td>
<td>6 - 14 MPH</td>
<td>6 - 14 MPH</td>
</tr>
<tr>
<td>Grinding passes (64 to 96 stone grinders)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Grinding passes a) 32 stone/speed b) 16 stone/speed</td>
<td></td>
<td></td>
<td></td>
<td>a) 3 @ 6 MPH b) 5 @ 6 MPH</td>
</tr>
<tr>
<td>Characteristics</td>
<td>Grinding interval depends on curvature and truck type</td>
<td>Grinding interval depends on curvature and truck type</td>
<td>Grinding interval depends on hardness &amp; curvature</td>
<td>Grinding interval depends on speed, superelevation &amp; curvature</td>
</tr>
</tbody>
</table>
Table 4: Sample Of Surface Finish And Profile Tolerance Acceptable To Railroads Using Preventive Grinding.

<table>
<thead>
<tr>
<th>Finish /Tolerance Description</th>
<th>Lower Gage corner (+45 to +15 degrees) Inches (mm)</th>
<th>Mid Gage corner (+16 to +6 degrees) Inches (mm)</th>
<th>Crown of Rail (+6 to 0 degrees) Inches (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facet Width (Heavy Haul)</td>
<td>0.2 (5)</td>
<td>0.3 (8)</td>
<td>0.47 (12)</td>
</tr>
<tr>
<td>Tolerance to template</td>
<td>+/- 0.01 (0.25) High Rail Gage (+45 to +6 degrees)</td>
<td>+/- 0.01 (0.025) Low Rail Field (&gt; -2.5 degrees)</td>
<td></td>
</tr>
<tr>
<td>Facet Width (Passenger)</td>
<td>0.16 (4)</td>
<td>0.28 (7)</td>
<td>0.4 (10)</td>
</tr>
<tr>
<td>Tolerance to template</td>
<td>+0 to - 0.024 (+0 to -0.6) High Rail Gage (+45 to +6 degrees)</td>
<td>+/- 0.012 (+/- 0.3) Low / Tangent Rail Gage (&gt; -2.5 degrees to field)</td>
<td></td>
</tr>
<tr>
<td>Roughness of grind marks (striations)</td>
<td></td>
<td></td>
<td>12 microns (average)</td>
</tr>
</tbody>
</table>

Table 5: Increased Average Rail Life With Various Grinding Strategies.

<table>
<thead>
<tr>
<th>Wear Criteria</th>
<th>No Grind</th>
<th>Corrective Grinding</th>
<th>Preventive Grinding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail wear rate in inches (mm)/ MGT</td>
<td>0.0016 (0.04)</td>
<td>0.0024 (0.06)</td>
<td>0.0012 (0.03)</td>
</tr>
<tr>
<td>Rail wear limit in inches (mm)</td>
<td>0.67 (17)</td>
<td>0.79 (20)</td>
<td>0.91 (23)</td>
</tr>
<tr>
<td>Rail life MGT (mgt)</td>
<td>469 (425)</td>
<td>367 (333)</td>
<td>844 (766)</td>
</tr>
<tr>
<td>Rail fatigue life MGT (mgt)</td>
<td>331 (300)</td>
<td>496 (450)</td>
<td>1322 (1200)+</td>
</tr>
</tbody>
</table>
Table 6: History Of Grinding Strategies And Rail Replacement.

<table>
<thead>
<tr>
<th>Grinding Strategy</th>
<th>Year</th>
<th>Grinding Cycle MGT</th>
<th>Annual Rail Replacement Miles</th>
<th>Cost of Rail Per Year $US (MILL) 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Grinding</td>
<td>1970</td>
<td>n/a</td>
<td>384</td>
<td>81</td>
</tr>
<tr>
<td>Corrective Grinding</td>
<td>1985</td>
<td>35 to 40</td>
<td>321</td>
<td>68</td>
</tr>
<tr>
<td>Preventive Grinding</td>
<td>2003</td>
<td>25</td>
<td>282</td>
<td>65</td>
</tr>
</tbody>
</table>

Table 7: Track Time Comparison Of Preventive And Corrective Grinding.

<table>
<thead>
<tr>
<th></th>
<th>Preventive</th>
<th>Corrective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curve Passes / cycle</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Cycles per year</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Grinding speed</td>
<td>9.6 kph (6 mph)</td>
<td>9.6 kph (6 mph)</td>
</tr>
<tr>
<td>Travel speed</td>
<td>16 kph (10 mph)</td>
<td>16 kph (10 mph)</td>
</tr>
<tr>
<td>Time to reverse direction</td>
<td>n/a</td>
<td>0.75 min / pass</td>
</tr>
<tr>
<td>Grinding time per cycle</td>
<td>70 min</td>
<td>362 min</td>
</tr>
<tr>
<td>Travel time per cycle</td>
<td>34 min</td>
<td>300 min</td>
</tr>
<tr>
<td>Total track time per cycle</td>
<td>104 min</td>
<td>662 min</td>
</tr>
<tr>
<td>Number of 2 hr windows/cycle</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Number of 2 hr windows/year</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Total track time per year</td>
<td>416 min</td>
<td>662 min + 59%</td>
</tr>
</tbody>
</table>
Figure 1: Shows How Cracks Grow In A Phased Process Into The Rail. Phase 1: Early, Somewhat Vertical Growth To A Shallow Depth. Phase 2: Shallow Angle Growth To A Moderate Size. Phase 3: Branching Crack And Rapid Growth.
Figure 2: Section Through The Rail With Typical RCF Cracks; On The Top Left Of The Rail Surface, Shallow Cracks Are Not Branching Deep Into The Rail, And Top Right Of The Rail Surface Cracks Already Branching Vertically Into The Rail.
Figure 3: Shows the typical a) Low Rail  b) High Rail, Advanced Stage Of Rolling Contact Fatigue Cracks (RCF) That Have Developed Into Spalling / Shelling On The Rail Surface.
Figure 4: Shows The Preventive Grinding Tonnage Based Cycles Designed To Remove The Small Surface Initiating Cracks Just Before Their Period Of Rapid Growth. This Is Called The Optimal (Magic) Metal Removal Rate. Note - Increments Of 0.25 mm (0.01 inch).
Figure 5: Ratcheting Surface Fatigue Caused By Traction And Slip On The Rail Surface. Proper Lubrication Will Significantly Reduce The Traction Stress At The Rail Surface.

Figure 6: High Rail Gage Face Shelling Caused By Low Natural Wear And High Lateral Forces In Curves With 100% Effective Gage Face Lubrication.

Figure 7: The Rim Side Of The Wheel May Have A "False Flange" Which Can Cause Significant Damage To The Low Rail Of Sharp Curves.
Figure 8: A 12 inch (300mm) Radius Gage On The Low Rail And The Damage Caused By The False Flange. Grinding Of Wide Gage Track Must Remove A Substantial Amount Of Metal From The Field Side To Protect The Rail From Wheel False Flange Damage.

Figure 9: Shows How The High Rail Gage Corner Collapses Along A Shear Plane Under Heavy Wheel Loads. Also Shown Is The Metal Flow From The Centre Of The Rail To The Mid Gage Area Of The Rail Where RCF Cracks Form.
Figure 10: NRC 1991 Rail Grinding Templates High Rails: H4 (Highest) = 24.9 mm², H2 (Middle) = 11.2 mm², CPR-H (Lowest) = 8.5 mm². Reference Rail Is 141RE @ 1:20.

Figure 11: NRC 1991 Rail Grinding Templates For Low Rails: L3 (Highest, Field) = 33.8 mm², L1 (Middle, Field) = 36.3 mm², CPR-L10 (Lowest, Field) = 33.9 mm². Reference Rail Is A 141 RE Rail @ 1:20 With 8 MGT Of Traffic.
Figure 12: NRC TT Rail Grinding Template.

Figure 13: NRC CPF Rail Grinding Template.
Figure 14: Comparison Of Contact Stress For 2 Different Tangent “As Ground” Rail Profiles TT And TF.

Figure 15: NRC H4 (1991) Template For Soft Rail In Sharp Curves.
Figure 16: NRC H2 Template Used In The 90's And Today.

Figure 17: NRC CPH Template.
Figure 18: NRC L3 Template.

Figure 19: NRC L2 Template.
Figure 20: NRC L1 Template.

Figure 21: NRC CPL Template.
Preventive-Gradual Grinding Introduced on BNSF in 1998 - Staged Crack Removal

**HIGH RAIL**

- **STAGE I:** Correcting the profile (cycles 1-3)
- **STAGE II:** Stopping crack initiation reducing crack pressurization (cycles 4-6)
- **STAGE III:** Removing remaining cracks renewal of work hardened layer (cycles 7-9)

**LOW RAIL**

- **STAGE I**
  - CORRECTING THE PROFILE (cycles 1-3)
- **STAGE II**
  - STOPPING CRACK INITIATION (cycles 4-6)
- **STAGE III**
  - REMOVING ACTIVE CRACKS (cycles 6-9)

Figure 22: Corrugation Not Completely Removed With 1 High Speed Grinding Pass.

Figure 23: Staged Crack Removal With The Preventive-Gradual Strategy.
Figure 24: Heavy Haul Test On The Effect Of Different Grinding Strategies On Total Vertical Rail Wear From High And Low Rails Of Premium Rail In 6 Degree Curves.

Note: the no grind strategy was not considered a viable option at the end of the test due to the development of severe surface defects which would necessitate the replacement of the rail after 300 MGT.
Figure 25: NRC BAR Gage Used For Mainline, Switches And Crossings.

Figure 26: Shows The Increase In Detail Fracture Rates In 1999 When Grinding Cycles Increased On Sharp Curves From 18 To 37 MGT.
Figure 27: Detail Fracture Rates Per Year With Various Grinding Strategies.

Figure 28: Defect Rates Per MGMT Measured On Territories With Different Rail Grinding Strategies.
Figure 29: Shows One Form Of A Rail Grinding Plan Which Specifies Grinding Patterns, Passes And Speeds For Each Track Section.
Figure 30: Specialized Bar Gage Tool Used To Measure Rail Head Radius and Cant In The Switch Area.

Figure 31: EZ 11, A Commercially Available Tool For Measurement Of Rail Profile And Metal Removal.
Figure 32: MiniProf, A Commercially Available Tool For Measurement Of Rail Profile And Metal Removal.