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Rail Grinding Best Practice
For Committee 4, Sub-Committee 9.

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1.0 Reason for Rail Grinding

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

Grinding of rails has evolved as a maintenance technique to insert some controlled artificial wear and a way to manage wheel / rail contact stress. This maintenance strategy reduces rail wear, controls rail surface fatigue 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.

2.0 Rail Grinding Definitions

Rail grinding is a process that is usually performed by railbound machines. These machines remove metal from the rail using rotating grinding wheels (stones). The volume of metal removed is dependent upon the number and arrangement of stones on each rail, the characteristics and condition of the abrasive in the stones, the application pressure on the grinding stones, the forward speed of the machine and the hardness of the rail surface being worked on.

2.1 Production Rail Grinding

The grinding of long sections of curved and tangent (straight) track on a tonnage or time based frequency.

2.2 Spot Grinding and Switch and Crossing Grinding

The grinding of short sections of track such as switches (turnouts), crossings, areas with obstructions and small lengths of track using smaller grinding machines based on tonnage or time. To cover the rail surface usually more than one grinding pass is required.

3.0 What is Best Practice Rail Grinding?

The ultimate goal in rail maintenance is to achieve the longest possible rail life without increasing the safety risks and costs associated with unanticipated rail failures. This is accomplished when the rail is replaced because it has worn out rather than because of contact fatigue. For this reason, railroads in North America grind primarily to control surface fatigue defects and the most successful programs use preventive grinding combined with a proper lubrication strategy. A key component of a successful preventive grinding program is the installation and maintenance of so-called “optimal” engineered transverse rail profiles.

Best practice rail grinding includes the following characteristics and actions:

- *Rail wear and fatigue in balance*

- *Long rail life with minimal risk of defect related failures*
- *Regular maintenance of the rail shape*
- *Vertical profile within tolerance (corrugations and welds under control)*
- *Application of rail profiles that promote low wear, low stress and good riding stability*
- *Grinding cycles consistent with the needs of different track geometries*
- *Minimal grinding cost (per finished mile)*
- *Consistent surface quality (roughness, vertical profile, controlled facet widths, etc.)*
- *Minimal fire risk*

3.1 Best Practice Preventive Rail Grinding

Best practice rail grinding is always preventive grinding which is designed to remove just enough metal to prevent the initiation of rolling contact fatigue (RCF) and to maintain optimal rail profiles matched to the local operating conditions. Rail grinding should not be performed "correctively" i.e. when it is used to correct existing problems with multiple grinding passes.

A single point contact of wheels on a rail cause high contact and sheer stresses due to vertical and traction loading which cause the rail head to plastically deform. An unlubricated rail surface is subject to higher friction forces and therefore higher rates of plastic flow. As the contract stress exceed a certain limit, the metal at the near surface becomes slightly displaced in the direction of the tractive load and slip in the wheel / rail contact patch. The cumulative effect of thousands / millions of wheel loadings and slight displacements will eventually cause the metal to reach its ductility limit and generate a surface crack. These cracks are called Rolling Contact Fatigue cracks (RCF)

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 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 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). 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.

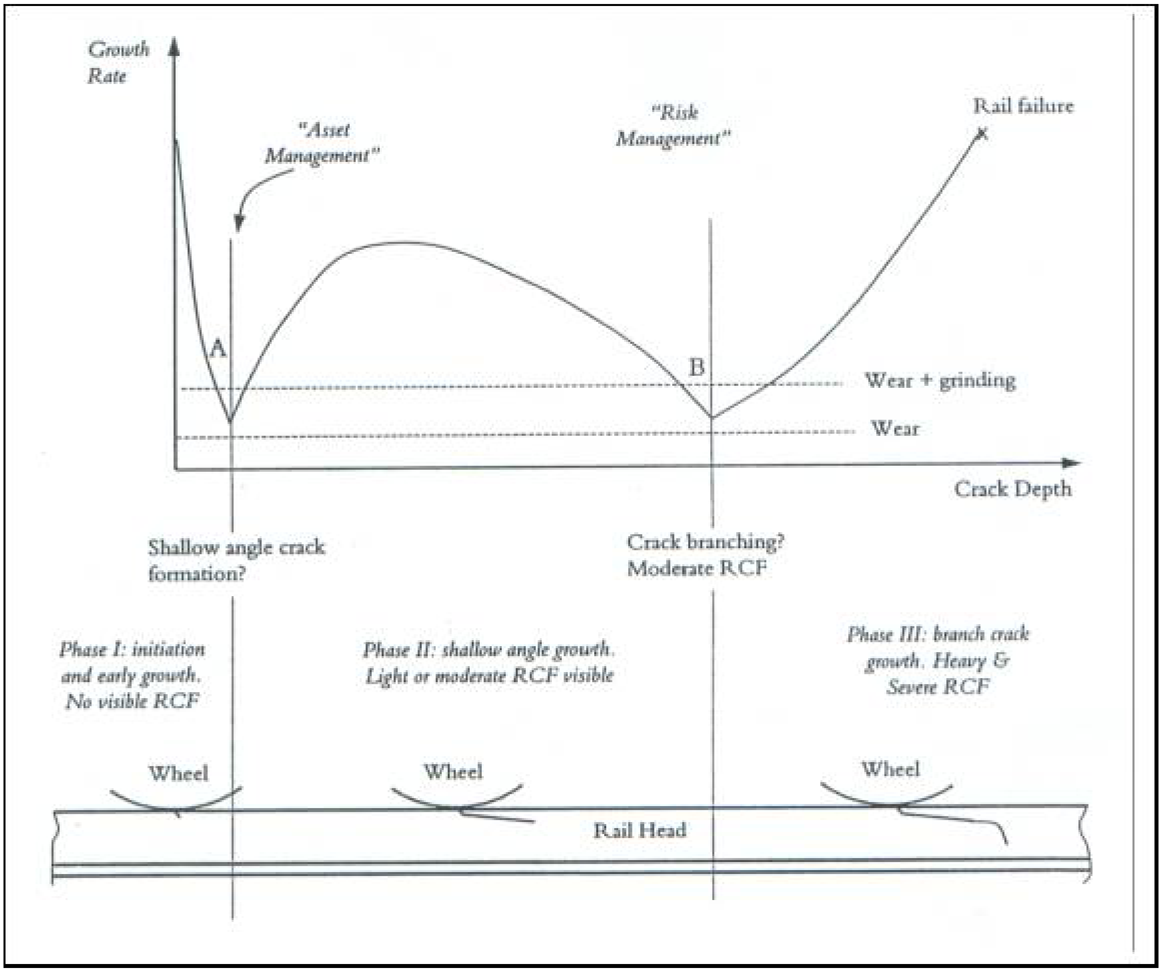

Figure 1. Shows how cracks grow in a phased process into the rail. Phase 1: early, somewhat vertical growth to a shallow depth. Phase 2: shallow angle growth to a moderate size. Phase 3: branching crack and rapid growth.

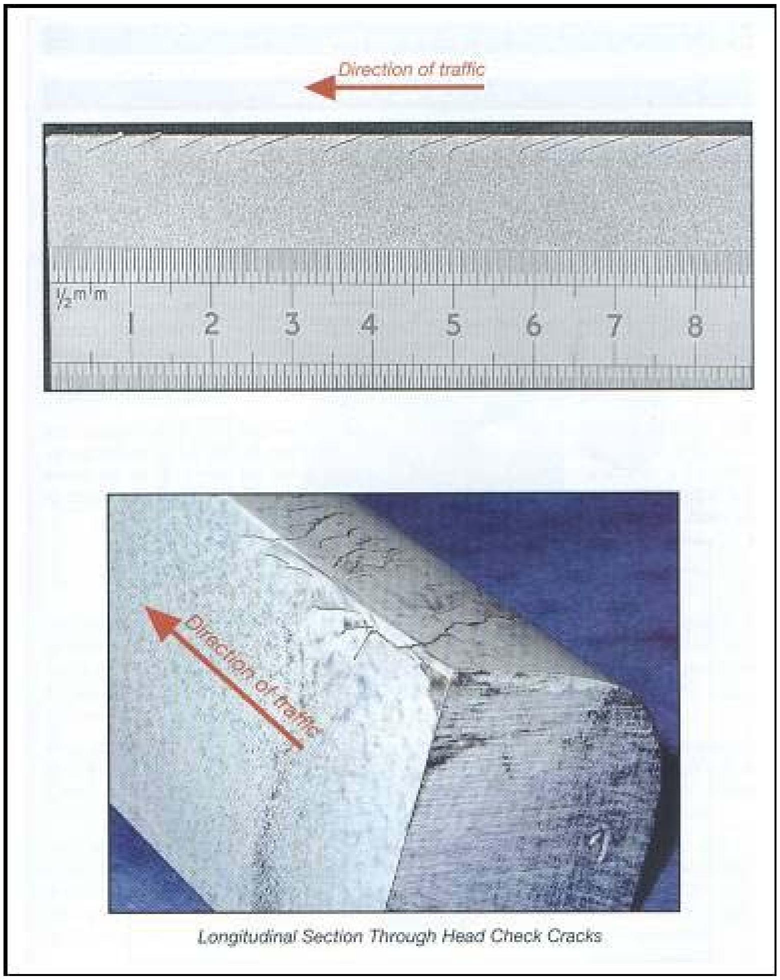

Figure 2 Section through the rail with typical RCF cracks; on the top left of the rail surface, shallow cracks are not branching deep into the rail, and top right of the rail surface cracks already branching vertically into the rail. Note each section of rail may have RCF cracks at various stages of development.

a) Low Rail

b) High 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.

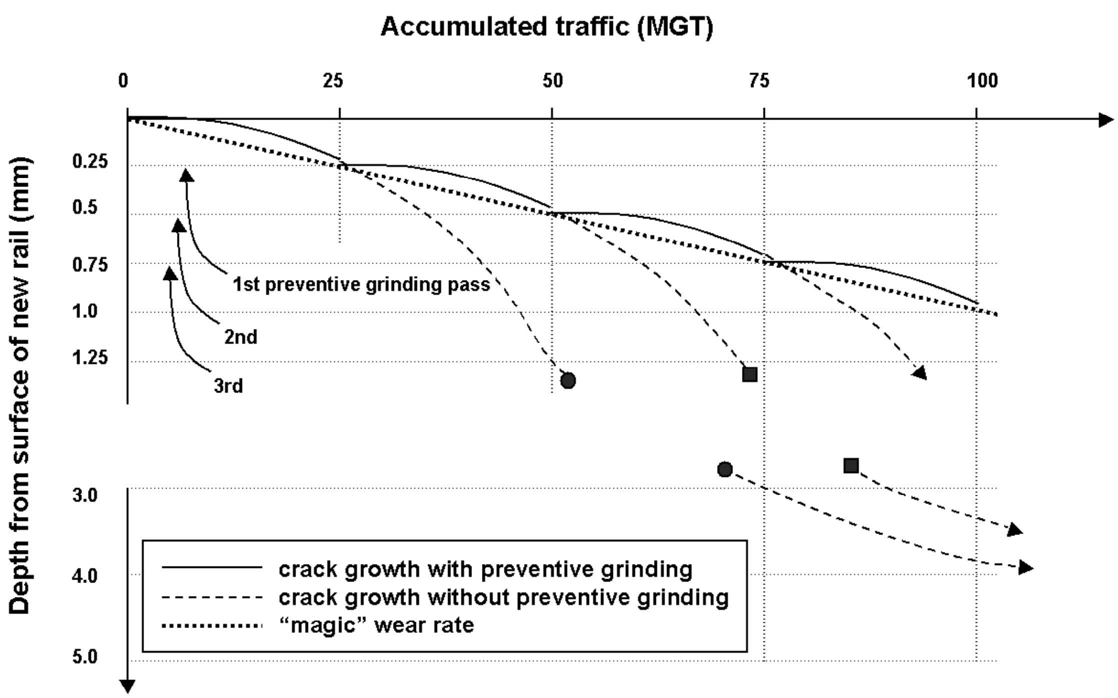

Figure 4. Shows the preventive grinding tonnage based cycles designed to remove the small surface initiating cracks just before their period of rapid growth. This is called the Optimal (magic) Metal Removal Rate. Note - increments of 0.25 mm (0.01inch).

4.0 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.

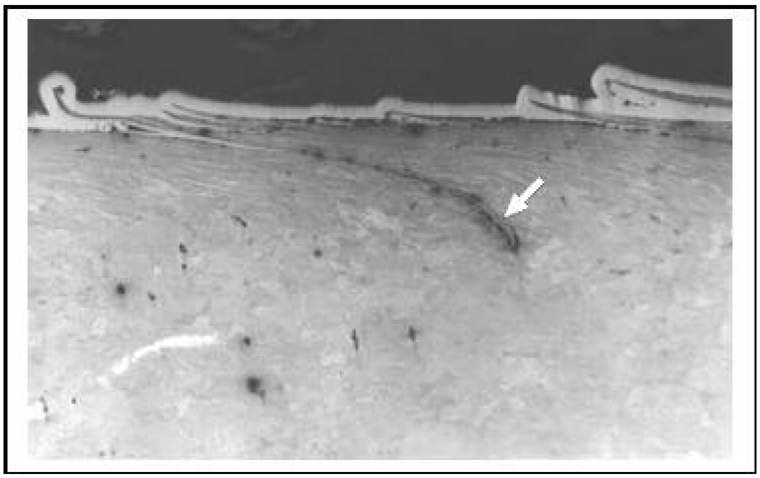

Figure 5 Ratcheting surface fatigue caused by traction and slip on the rail surface. Proper lubrication will significantly reduce the traction stress at the rail surface.

With lubrication that is confined to the gauge 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 gauge corner shelling (refer to Figure 6). Grinding of the gauge 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 gauge face lubrication.

Figure 6. High rail gage face shelling between 40 and 60 degrees, shown on the template, which is caused by lower natural wear and high lateral forces in curves with 100% effective gauge 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. 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 (refer to Section 12.0) "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.

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. Shows 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.

<u>5.0 Preventive Rail Grinding Objectives</u>

5.1 Restore the Transverse Rail Profile

The key objective of preventive grinding is the 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 which causes 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.

5.2 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; rail manufacture, contact fatigue defects, rail welds, rail joints, etc. By grinding a corrugated rail surface the wheel/rail dynamic loads are significantly reduced.

6.0 Rail Metallurgy and Crack Propagation

Rail wear and rail surface fatigue occurs in all rail steel regardless of hardness and metallurgy. Improved metallurgy, harder steel, profile grinding and proper lubrication can significantly reduce wear and fatigue.

Rail surface flow cannot be eliminated however it can be reduced substantially by increasing the hardness of the rail.

Gauge corner collapse (refer to figure 9) cannot be prevented in heavy haul even with harder rails. It can be removed by reducing the frequency of loading of the gauge corner, i.e. by frequent grinding of the gauge corner. The length of the grinding interval is governed by the rate of surface flow into the gauge corner.

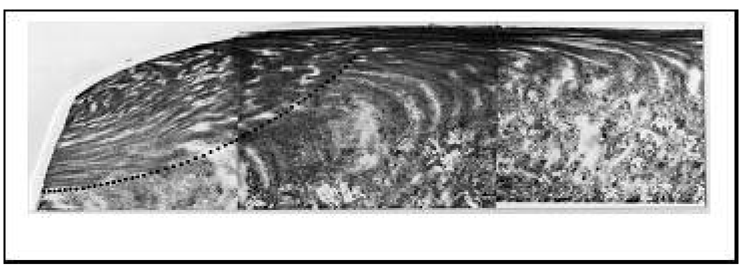

Figure 9. Shows how the high rail gauge corner collapses under heavy wheel loads. Also shown is the metal flow from the center of the rail to the mid gauge area of the rail where RCF cracks form

Softer rails plastically deform more rapidly and therefore must be ground more often or more frequently. Harder rails are more resistant to plastic flow and will require less frequent grinding. However, soon after installation, the 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 surface fatigue cracks.

Also when new rail is installed into track the thin surface de-carbonized layer must be ground off as it is very soft and will rapidly produce cracks.

7.0 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. Wheel/rail interaction software is used to design the optimal rail for curved and tangent track to minimize rail contact stresses and improve train stability and curving performance. Rail profiles have changed over the years with improvements in the railroads operating environment and the introduction of improved maintenance strategies and materials.

7.1 Tangent Track Profiles

Tangent track profiles are designed to be ground onto straight track to produce between an 8 to 10 inch (200 to 250 mm) radius running band in the center or biased towards the field side or the gauge 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.

7.2 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 separately to high rails of mild, intermediate and sharp curves.

The improved wheelset steering and much better contact stress distribution will minimize wheel/rail wear and contact fatigue and reduce locomotive fuel consumption.

7.3 Low Rail Profiles

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

7.4 Using Templates of Optimal Rail Profiles

The production of the optimal transverse rail profile by rail grinding machines is measured with a steel "template" that is mounted on a bar (bar gage) that sits on the plane of the top of the two rails or as profiles installed into laser profile systems on board rail test vehicles (including the grinding machine) to measure the track. The templates should cover the entire rail surface from the gauge 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.

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.

8.0 Grinding for Corrugation Removal

Preventive grinding cycles are designed to control corrugations by grinding frequently enough and remove 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.

9.0 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 initiating 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 1 shows the current best practice depth of metal to be removed from the rail to control initiating cracks 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) as used by railroads in North America for their preventive grinding programs.

Table 1
Table of Typical Optimal Metal Removal Rate (in 2002) in inches (mm) from the Rail Surface to control RCF cracks with Preventive Grinding Cycles.

Track Location (Rail Hardness BHn)	Cycle MGT Timber Ties metal removal inch (mm) depth	Cycle MGT Concrete Ties metal removal inches (mm) depth	Passenger Inches (mm) depth (all standard rail)
New Rail (340 – 420)	15 MGT 0.012 (0.3)	15 MGT 0.012 (0.3)	10 MGT 0.012 (0.3)
High Rail (340 - 420) Gauge (poor lube) Gauge (good lube) Crown Field	25 MGT 0.010 (0.25)* 0.016 (0.40)* 0.004 (0.1) 0.010 (0.25)*	15 MGT 0.010 (0.25)* 0.016 (0.40)* 0.004 (0.1) 0.010 (0.25)	10 MGT 0.008 (0.2) Not Known 0.004 (0.1) 0.008 (0.2)
Low Rail (340 – 420) Gauge Crown Field	25 MGT 0.010 (0.25)* 0.004 (0.1) 0.010 (0.25)*	15MGT 0.010 (0.25)* 0.004 (0.1) 0.010 (0.25)*	10 MGT 0.008 (0.2) 0.004 (0.1) 0.008 (0.2)
Tangent (320 to 340) Gauge Crown Field	50 MGT 0.010 (0.25)* 0.004 (0.1) 0.010 (0.25)*	60 MGT 0.012 (0.3)* 0.006 (0.15) 0.012 (0.3)*	30 MGT 0.008 (0.2) 0.004 (0.1) 0.008 (0.2)

* Note: double the metal removal if standard rail hardness (260 to 320 Bhn) is used (refer to Table 1). Metal removal is governed by tonnage cycle and rail metallurgy.

10.0 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 2).

Table 2
Preventive Rail Grinding Cycles (in 2002) for the Optimal Metal Removal Rates shown in Table 1

Track / Rail Definition **MPH- miles per hour** **MGT - Million Gross Tons** **Metres radius - mR**	**Preventive GrindingCycles** **Concrete Ties** **Rail**	**Preventive Grinding Cycles** **Timber Ties** **Rail**	**Preventive Grinding** **Rail Hardness (260 to 320 Bhn)**	**Preventive Grinding** **Passenger/Transit** **Rail Hardness (260 to 320 Bhn)**
1) New Rail **- 141RE** **-136 RE (14 inch Crown)** **- UIC 60, 113 A**	 15 MGT 5 MGT NA	 15 MGT 5 MGT NA	 NA NA 10 MGT	 NA NA 10 MGT
2) Sharp curves **(3 degrees and sharper)**	15 to 25 MGT (340 to 420 Bhn)	15 to 25 MGT (340 to 420 Bhn)	8 to 12 MGT	Sharper 2000mR 5-7 MGT
3) Mild curves **(shallower than 3 degrees)**	30 to 50 MGT (320 to 340 Bhn)	30 to 50 MGT (320 to 340 Bhn)	16 to 24MGT	Shallower 2000mR 10-15 MGT
4) Tangent track	60 (320 to 340 Bhn) 100 MGT (340 to 420 Bhn)	50 (320 to 340 Bhn) 100 MGT (340 to 420 Bhn)	40 to 60 MGT	20-30 MGT
Grinding speed	6 to14 MPH	6 to 14 MPH	6-14MPH	6 - 14 MPH
Grinding passes (64 to 96 stone grinders)	1	1	1	1
Grinding passes a) 24 stone/speed b) 16 stone/speed grinders)				a) 3@6MPH b)5@6MPH
Characteristics	Grinding interval depends on curvature and truck type	Grinding interval depends on curvature and truck type	Grinding interval depends on hardness & curvature	Grinding interval depends on speed, superelevation & curvature

11.0 Importance of Rail Grinding Test Sites

As railroads introduce; improved materials to the track, better maintenance practices, heavier trains, longer trains, and trains running at higher speeds, test sites are used to establish the metal removal rate to control the growth of RCF cracks. Rail samples are analyzed to determine 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 can also be used to calculate the benefits of a new preventive grinding strategy used to; control rolling contact fatigue, reduce wear, reduce grinding effort, and reduce the cost of grinding.

12.0 How to get to Best Practice Preventive Grinding by using the Preventive-Gradual Grinding Technique

Preventive-Gradual Grinding 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 1, "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 11, section 12.1 shows the saving in rail steel for various grinding strategies with preventive-gradual grinding being the most efficient.

Figure 10 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 4 to 6 of one pass grinding, which gradually stops the initiation of new cracks and reduces crack (hydraulic) pressurization. Stage 3 shows cycles 6 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 3). 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.

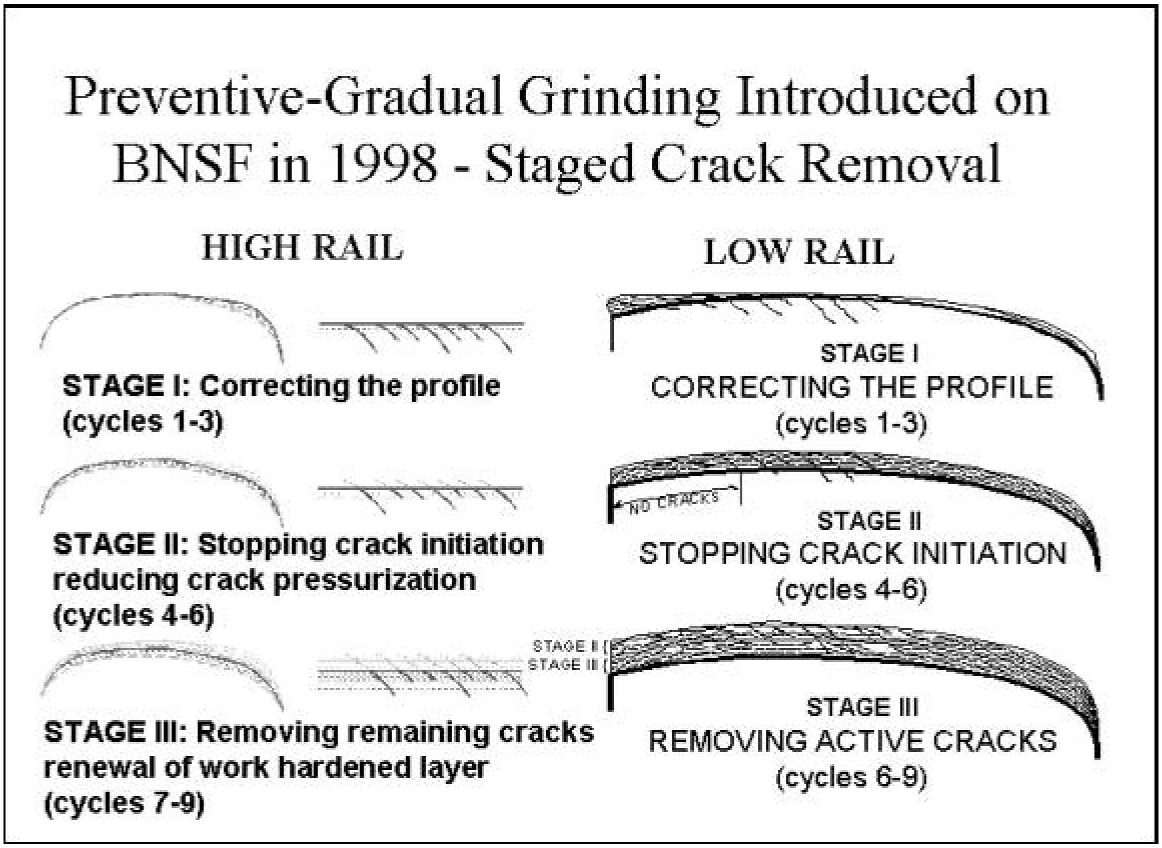

Figure 10 shows the staged profiling and crack removal process with Preventive-Gradual grinding.

12.1 Test Site Economics of Preventive-Gradual Grinding over other Grinding Strategies

Figure 11 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.

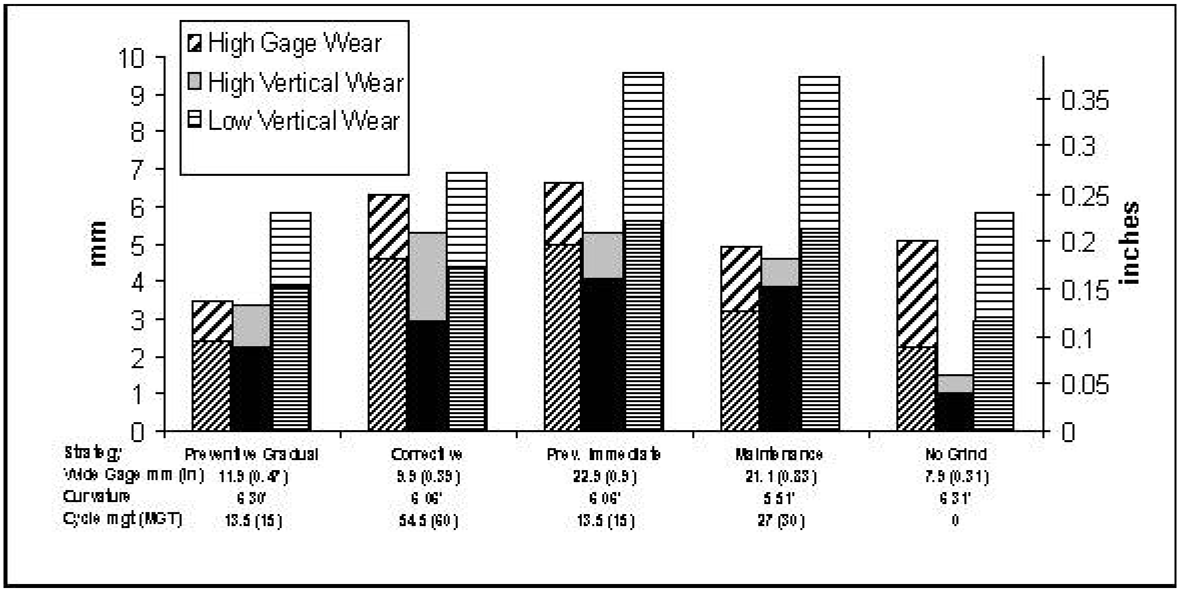

Figure 11. Heavy haul test on the effect of different grinding strategies on total vertical rail wear from high and low rails of premium rail in 6 degree curves.

(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 early replacement of the rail at 300 MGT. Refer to table 4).

13.0 How Grinding Machines Produce the Optimal Metal Removal Rate

The net reshaping of the rail 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 design rail profile with good geometric smoothness.

Target optimal profiles are installed in; laser based measurement systems on rail grinders and rail-bound profile measurement cars, computer based field measurement devices and manual profile measurement devices. 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 performance capability of a grinding machine.

Patterns are regularly fine-tuned to match the changing rail condition and updated optimal rail profiles. Also as a grinding machine configuration changes, so too will the grinding patterns needed to suit the new configurations.

14.0 Factors that Control the Rail Grinding Machine Metal Removal Process and Rail Surface Finish.

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

- 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 a measure of the ridges left between the facets of each stone pass and the surface roughness left by the grinding marks or scratches. The rough nature of the as-ground rail surface is dependent upon the stone grit size, 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. Excessive facet widths can lead to localized plastic flow of the highly stressed peaks under wheel load which can cause increased wear and wheel/rail noise. Table 3 shows the typical acceptable grinding facet widths and tolerances to profile with preventive grinding. There are two grinding methods which will result in two types of surface finish:
    - One type is where the pivot point of the rail grinder motor is located such that the grinding stone maintains contact on the rail on an axis that passes through the inside diameter of the stone under all grinding positioning.

This method leaves a surface scratch pattern that is transverse to the running surface of the rail.

- The other method is called offset grinding which addresses the full rail surface from gage to field with two stones placed at fixed angles. Both stones on each rail are shifted horizontally to where the outer peripheral of one stone just overlaps the gage side and the other stone overlaps the field corner to cover the field side of the rail. This method leaves a surface scratch pattern that is longitudinal to the running surface of the rail.

Table 3.
Sample of Surface Finish and Profile Tolerances Acceptable to Railroads using Preventive Grinding

Surface Finish /Profile Tolerance Description	Lower Gauge corner Inches (mm)	Mid Gauge / Field Inches (mm)	Crown of Rail Inches (mm)
Facet Width (Heavy Haul)	0.2 (5) (+45 to +15 degrees)	0.3(8) (+16 to +6 degrees)	0.47 (12) (+6 to –2.5 degrees)
Profile Tolerance (Heavy haul)	+/- 0.01(0.25) High Rail Gage (+45 to +6 degrees)	+/- 0.01(0.25) Low Rail Field (> -2.5 degrees)	8 to 10(200 to 250) Radius
Facet Width (Passenger)	0.16 (4) (+45 to +15 degrees)	0.28 (7) (+16 to +6 degrees)	0.4 (10) (+6 to –2.5 degrees)
Profile Tolerance (Passenger)	+0 to - 0.024 (+0 to - 0.6) High Rail Gage (+45 to + 0 degrees)	+/- 0.012(+/- 0.3) Low (+35 to + 0 degrees)/ Tangent Rail (+45 to + 0 degrees)	10 to 12 (250 to 300) Radius
Roughness of surface scratch pattern			10 to 12 microns (average)

- 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.

15.0 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.

15.1 Rail Savings with Preventive Grinding

15.1.1 Case History 1

Table 4 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). This table shows the significant increase in the System rail life with preventive grinding as the rail is being replaced due to wear rather than for fatigue.

Table 4
Increased Average System Rail Life with Various Grinding Strategies

Wear Criteria	No Grind	Corrective Grinding	Preventive Grinding
Rail wear rate in inches (mm)/ MGT	0.0016(0.04)	0.0024(0.06)	0.0012(0.03)
Rail wear limit in inches (mm)	0.67(17)	0.79(20)	0.91(23)
Rail life MGT	469	367	844
Rail Fatigue life MGT	331	496	1322+

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 5 shows System-wide annual rail replacement experience on a Class I North American railroad with a preventive, corrective and no grind strategy.

Table 5
History of Grinding Strategies and System Rail Replacement
On a Class 1 North American railroad

Grinding Strategy	Year	Grinding Cycle	Annual Rail Replacement	Cost of Rail Per year
		MGT	Miles	$US (Mill) 2003
No Grinding	1970	n/a	384	81
Corrective grinding	1985	35 to 40	321	68
Preventive grinding	2003	25	282	65

As Table 5 shows, corrective rail grinding (compared to no grinding) is estimated to save $US13million per year in rail replacement at an annual grinding cost of around $US8million.

Preventive rail grinding (compared to no grinding) is estimated to save $US16million per year in rail replacement at an annual grinding cost of $US7.5 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 286,000lb gross vehicle weight cars were introduced as the bulk haul standard.

15.1.2 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.

15.2 Preventive Grinding and Reductions in Rail Defects

15.2.1 Case History 1

Experience with grinding on a Class 1 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. The grinding cycle increased on sharp curves and tangent “crushed head” locations from 18 MGT to 37 MGT. As shown in figure 12, 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.

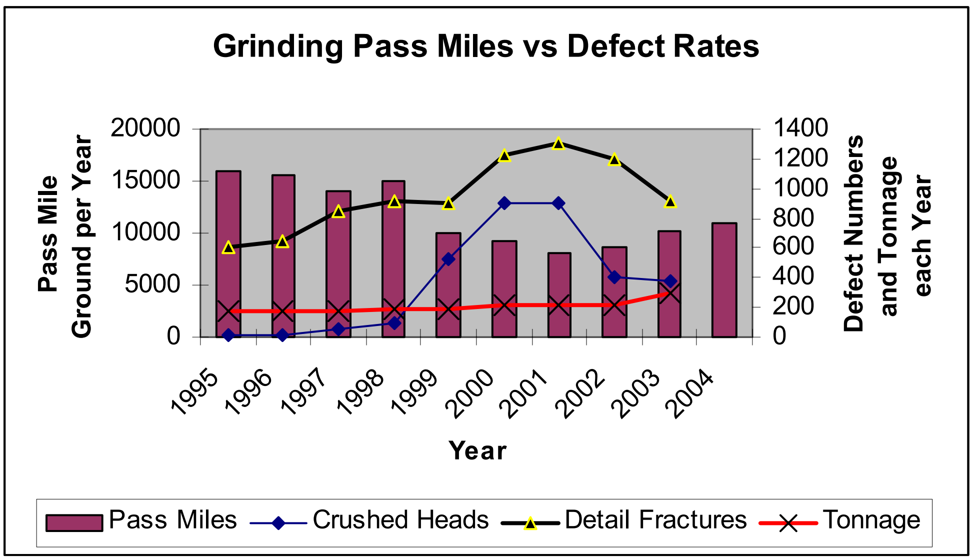

Figure 12. Shows the increase in detail fracture rates in 1999 when grinding cycles increased on sharp curves from 18 to 37 MGT.

15.2.2 Case History 2

Another Class 1 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 13. In 1987 the grinding strategy was corrective profile grinding 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.

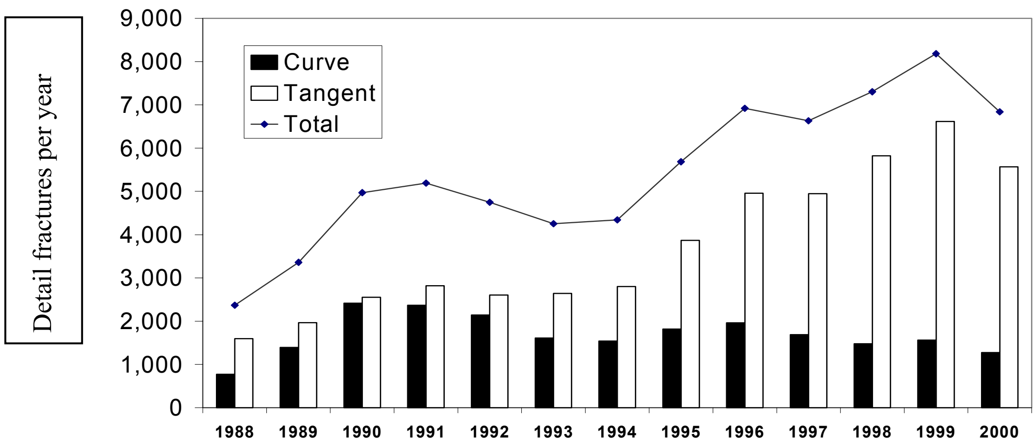

Figure 13. Detail fracture rates per year with various grinding strategies.

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.

15.2.3 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). A defect monitoring study demonstrated a 65% reduction in rail surface initiated service failures. Also a Six Sigma investigation into the defect rates per Million Gross Ton Miles (MGTM) with various grinding strategies (figure 14) found that preventive grinding had a significantly lower rate compared to no grinding and corrective grinding.

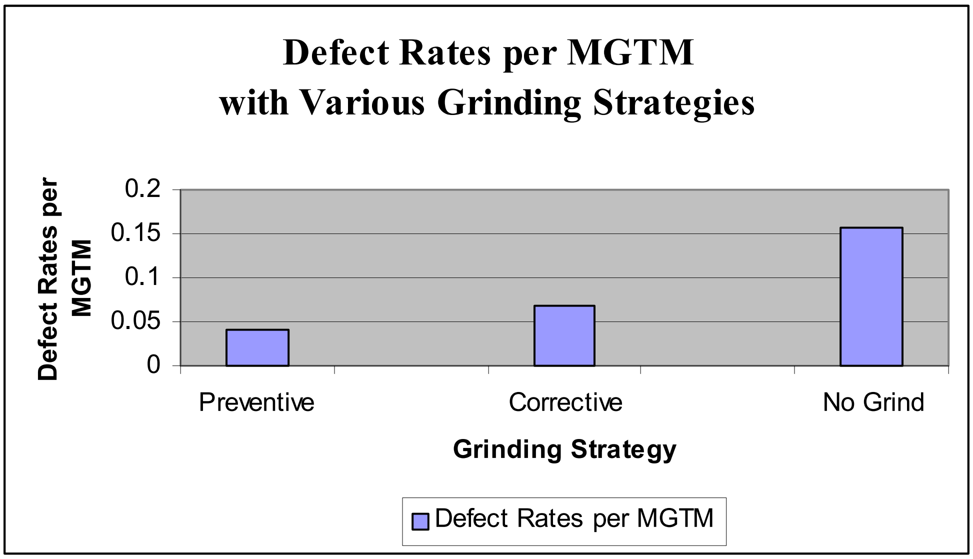

Figure 14. Defect Rates per MGTM measured on territories with different rail grinding strategies

15.2.4 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.

15.3 Productivity Improvements with Preventive Grinding

Track occupancy time for performance of maintenance tasks is at a premium on heavy haul railroads. The track time available for grinding on the Class 1 railroads is reducing each year. 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 6 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. This table shows that in this example corrective grinding requires 59% more time each year than preventive grinding to grind the curves in the segment. In practice the preventive grinding efficiency is even greater, as fewer passes per year are required than for corrective grind, and higher grinding speeds can be utilized.

Table 6
Track Time Comparison for Preventive and Corrective Grinding Strategies on a Class 1 North American Railroad

	Preventive	**Corrective**
Curve Passes / cycle	1	4
Cycles per year	4	1
Grinding speed	6 mph (9.6 kph)	6 mph (9.6 kph)
Travel speed	10 mph (16 kph)	10 mph (16 kph)
Time to reverse direction	n/a	0.75 min / pass
Grinding time per cycle	70 min	362 min
Travel time per cycle	34 min	300 min
Total track time per cycle	104 min	662 min
Number of 2 hr windows/cycle	1	6
Number of 2 hr windows/year	4	6
Total track time per year	416 min	662 min +59%

16.0 Planning and Quality Control of Rail Grinding

Good grinding planning involves the following practices: the grinding program is strictly adhered to, proper supervision of the grinding operation, pre and post inspection of the quality of grinding desired, high production during available grinding time, coordination of the back up fire fighting support to manage the risk of fires, and a safe operation.

16.1 Preventive Grinding Contracts

Production Grinding operations are usually carried out by contractors in North America. Preventive grinding contracts may be structured based on payment for the pass miles of track ground or by the shift of work. The contractor and the railroad strive to achieve higher efficiencies in some of the following areas; higher grinding speeds, higher track time for work, a pass to finished mile ratio of one. 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.

Preventive grinding contracts 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 expense. At the same time, it requires that the railroad to have a good understanding of rail conditions and the track time available for work.

16.2 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 cycle interval on each line ground 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 with even multiples of a base tonnage, is the best configuration to minimize equipment travel and variance from the desired interval.
- Grinding planning software. A grinding production plan should be available in advance of the arrival of the grinder on site. The plan should be based upon an advance survey of the territory identifying the types of conditions that are being targeted for correction. The grinding plan should 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.

16.3 Grinding Supervision

The goal of preventive grinding is to have every programmed mile ground to the design 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 (which determines the metal removed from the rail by grinding) 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 remove the existing rail surface fatigue cracks and maintain the rail profile.

The preventive grinding program must be strictly adhered. 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. Grinding programs are usually 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.

16.4 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 on material is removed from the rail to control rolling contact fatigue defects.
- corrugation is removed so that residual irregularities are within the specified limits
- the desired surface finish is achieved

- the 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.

16.5 Rail Profile 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:

- 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 Road Crossings** - rail grinding is performed by using smaller or offset grinding stones. The extent of grinding is dependent on the width of the gaps at the various locations (eg, guard rails, frog, points, etc) and the width of the head of the rail section.
- **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.
- **Rail Cant** - plate cut ties or abraded concrete ties change the orientation of the rail relative to the wheel profile. Extra relief is required on the gauge corner of the high and field side of the low rails to protect the material.
- **Rail Hardness** – the hardness of the rail will influence the metal removal.
- **Transposed Rail** - requires significant amounts of metal to be removed from the gauge and field sides of both rails.
- **Rail Head Loss** - rail approaching head loss limits may show signs of collapse in the under head radius area of the rail. It is advisable to grind this rail with a contact band centered above the web of the rail.
- **Grinding of New Rails** - New rail is ground for several reasons. Removal of scale and the de-carbonized layer was the usual reason in the past. However, grinding new rail into a worn and, therefore, correct

profile can prevent the early initiation of contact fatigue cracks and shelling.

- Contact Band on the Rail

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

Inspections should determine if there has been a grinding stone malfunction, 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, diagonal grinding marks (with grinding stones centered on their axis and offset grinding stones), deeper striation marks than normal (that do not wear down with traffic), grinding gouges on the surface, continuous "blueing 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 10 to 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 “Miniprof” or “EZ11”, 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.

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Appendix B: Glossary of Terms

- **Ball area of rail**– *the grinding area of the rail head defined by the center larger radii of the rail head.*
- **Class 1 Railroad –** *North American heavy haul freight railroads, usually owning and operating thousands of miles of track with interconnection to other Class 1 and short-line railroads.*
- **Concrete ties –** *The lateral connection that supports the two rails in a track structure are of reinforced concrete construction.*
- **Contact band location –** *The range of angles across the transverse profile where the distribution of wheel contact frequency is greatest for the running surface of the rail.*
- **Contact band radius –** *The radius (in inches or millimetres) of the running surface of the rail throughout the contact band location.*
- **Contact band width –** *The width (in inches or millimetres) of the range of angles that make up the contact band location.*
- **Corrective grinding –** *A grinding strategy whereby the rail grinder has to "rescue" a corrugated and spalled rail surface. Generally, a large rail grinder completes 3 to 9 grinding passes each cycle.*
- **Corrugation –** *A pattern of peaks and valleys that form on the running surface of rails at a variety of wavelengths. This condition is self-propagating, and if left unchecked can quickly become severe enough to necessitate changing the rail.*
- **Crushed heads** – *a flattening or crushing down of the head of the rail.*
- **Curvature** – *The angle subtended at the center of a curve by a 100-foot chord.*
- **Cycle Times –** *The period, expressed in MGTs, which elapses before the rail grinder returns to a given area to grind the track.*
- **Detail fractures** – *a progressive fracture originating near the rail surface from a shell or head check.*
- **Detector car efficiency –** *The percentage of internal rail flaws that an ultrasonic detection car actually detects, compared to the number that are actually present in the rail that is being inspected. Poor rail surface quality will reduce detector car efficiency.*
- **Facet width –** *The width of the flat surface left by an interaction of grinding stones as measured on the transverse profile of the rail surface.*
- **Fastenings –** *The means by which the rail is held in place to the ties. Can be spring clips and roll plates, or cut spikes and tie plates. Also refers to mechanical methods of joining rail, such as joint bars, nuts and bolts.*
- **Field area of rail –** *the grinding area of the rail head defined by the intermediate radii towards the upper corner of the rail head on the outside of the track.*
- **Field flow –** *Metal at the field area that has flowed outward away from the track centre due to repeated high wheel/rail contact stress.*
- **Fire risk –** *The possibility of any brush or vegetation along the track catching fire due to the sparks that result from grinding operations. Fire risk may be*

expressed as none, low, medium, high or severe to schedule the requirement of fire prevention strategies.

- **Gage area of rail –** *the grinding area of the rail head defined by the short sharp radii towards the upper corner of the rail head on the inside of the track.*
- **Gage corner shelling –** *Pieces of rail metal that break away from the gage corner of the rail, due to repeated cycles of high contact on the gage corner.*
- **Gage face wear –** *The change in shape of the cross-sectional area on the gage face of the rail as a result of wear from wheel flange contact. Gage face wear is usually measured 0.625 inches vertically down from the highest point on the rail running surface.*
- **Gage flow –** *Metal at the gage area of the rail that has flowed in towards the track center, due to repeated high wheel/rail contact stress.*
- **Grinding budget –** *The yearly financial allocation required to support all aspects of the annual rail-grinding program. This can include labour, materials, the cost of buying/leasing a rail grinder, safety training for employees, traveling expenses, sub-contracts for fire support, etc.*
- **Grinding committee –** *The group of people who oversee the implementation and completion of the grinding program.*
- **Grinding cycle –** *See Cycle Times.*
- **Grinding machine –** *See Rail Grinder.*
- **Grinding motors –** *Hydraulically or electrically powered motors that operate at their rated capacity and having their spindle (axis of revolution) perpendicular to the ball of the rail. The movement of a grinding motor around the transverse profile of the rail is controlled either automatically or manually. There is a grinding stone at the end of the spindle, and the face of this stone comes into contact with the head of the rail with a controlled grinding pressure.*
- **Grinding pass –** *A section of track has sustained one grinding pass if the grinder has ground over the section in a single direction only.*
- **Grinding pattern –** *A description of the grinding motor settings on one rail, including: the number of grinding motors to be used, their order of configuration angles, and grinding pressures.*
- **Grinding pressure –** *A measure of the normal force with which the grinding stone contacts the rail, usually expressed in amps or psi of pressure.*
- **Grinding program –** *The annual/monthly/weekly plan that defines some of the following: areas of the rail system to be ground, cycle time (in terms of tonnage/time), the type/size of rail grinder that will be used, the path the rail grinder will follow in order to cover the specified areas, the number of grinding passes, the grinding pattern, the grinding speed, the type of rail in track, the current progress of the plan, etc.*
- **Grinding shift –** *The daily period when the rail grinder is available to perform grinding work.*
- **Grinding speed –** *The advance speed of a rail grinder as it moves along the track to grind the rails.*
- **Grinding Stone –** *an abrasive cutting tool brought into contact with the rail. Grinding stone physical dimensions are dependent on the requirement to clear*

track obstacles, generally from 4 (100mm) to 10 (250 mm) inches in diameter. Grinding stone performance is dependent on chemical ingredients of the grit, grit size and shape, type of resin bond and the manufacturing process (pressure to compact).

- **Intermediate Curve –** *Any curve having curvature sufficient to allow the leading wheelsets on the rail cars to develop both lateral and longitudinal creepage in the contact patch. This is dependent on truck type being used by the railroad.*
- **Intermodal traffic –** *Railroad traffic in which individual consists contain only cars which carry intermodal containers or trailers. These cars can be in stand-alone or articulated configurations.*
- **Key performance indicators (KPI)**: – *Any set of parameters that can be used to measure the results of a grinding program, over a fixed period of time. Abbreviated to KPI.*
  - **Total pass miles per year –** *the total number of grinding pass miles completed by the main line grinder(s) in one day (month, year).*
  - **Ratio of pass miles to track miles –** *the ratio of total pass miles ground divided by the total track miles ground.*
  - **Average shift hours per day –** *the average of the total time in hours that the grinder was scheduled to work each day.*
  - **Average pass miles per shift day –***the average of the total pass miles divided by the number of shifts worked.*
  - **Average grinder speed –** *the total pass miles divided by the total spark time in hours.*
  - **Average track time per day –** *the total time starting when the grinder leaves the siding switch travels to the work location, set up time, grinds rail, and returns to a siding switch. This time excludes planned "dead head" time to travel long distances from one work location to another.*
  - **Average train delay per day –** *the total time from the grinder lifting stones to clear for trains to the time when grinding resumes grinding.*
  - **Average per shift spark time –** *the total time the grinder spent actually grinding rail per day.*
  - **Average number of production grinders used during the year –** *the total number of grinders used per year, including a percentage for a portion of a year.*
  - **Stones per grinder –** *the total number of grinding stones on each grinder used on the railway during the year.*
- **Low rail surface wear –** *The change in shape of the cross-sectional area of the running surface of the low rail, as a result of wheel tread contact.*
- **Mainline grinding –** *Rail grinding performed over the major traffic areas of a railroad's mainline track.*
- **Maintenance grinding –** *A grinding strategy whereby the rail grinder has to remove rail surface cracks and reshape the rail. Generally, a large rail grinder completes 2 to 5 passes each cycle.*

- **Metal removed by grinding –** *The transverse area of metal that is removed from the running surface of one rail by a rail grinding pattern applied at a specific grinding speed.*
- **Mild Curve –** *A curve with sufficiently low curvature to permit the wheelset to steer through the curve by means of the rolling radius difference at the two tread contact patches. No longitudinal creepage is present, but some lateral creepage will exist.*
- **Mineral traffic –** *Rail traffic in which individual consists contain only cars (typically gondolas) which carry mined commodities, such as coal, iron ore, sulphur, potash, etc.*
- **Mixed freight traffic –** *Rail traffic in which individual consists contain a variety of car types, including intermodal cars and mineral cars.*
- **Passenger traffic –** *Rail traffic in which individual consists contain only passenger, business or tourist/observation cars. These cars generally have lower axle loads than loaded freight cars. Some passenger trains may have a boxcar at the end of the consist, which contains mail and courier parcels.*
- **Pass-miles –** *The length of a track segment (such as a curve or tangent) expressed in miles multiplied by the number of grinding passes completed during the grinding operation.*
- **Post-grinding inspections –** *Each rail segment recently ground is inspected to ensure that the desired surface finish (in terms of removal of surface damage) and the desired transverse profile is achieved.*
- **Pre-inspect the rail –** *Each rail segment on the grinding program is inspected by the grinding supervisor/ automated system shortly (a few days) before the grinder is scheduled to arrive. This allows the grinding plan to be formulated/updated for: grinding patterns, grinding pressures and grinding speeds required to achieve the desired results on both rails in each segment.*
- **Preventive grinding –** *A grinding strategy whereby each mile of track receives a light but frequent grinding pass. Generally, a large rail grinder completes one pass at high speed.*
- **Preventive-Gradual Grinding –** *a grinding strategy that embarks straight onto a preventive grinding cycle, however at slower grinding speeds or more aggressive grinding patterns to increase metal removal. The objective is to gradually transition the rail to the desired profile and crack free state.*
- **Rail grinder –** *A rail-mounted vehicle equipped with hydraulically or electrically powered grinding motors. Rail grinder machine size varies depending on the number of rail grinding motors under the machine. Generally the number of grinding motors ranges from 4 to 96.*
- **Rail grinding profile –** *The specified transverse profile of the rail head as defined by rail grinding templates or in electronic form in automated measurement systems. The shape is defined by curves of varying radii, and is approximated by the grinding stones in a series of short, straight facets. There may be several different profiles for high, low and tangent rails.*

- **Rail internal defects**: – *Any type of crack or fissure with a point of origin inside the rail section. If not detected, the crack or fissure can progress to the surface of the rail section and result in failure of the section.*
- **Rail profile loss –** *The deviation of the rail profile from the rail grinding profile after the passage of traffic over the rail.*
- **Rail profile tolerances –** *The allowable, post grind, rail profile vertical deviation from the rail grinding profile as defined in tenths of a mm or thousandths of an inch..*
- **Rail wear –** *The change in shape of the cross-sectional area of the rail head due to the passage of rail traffic and grinding.*
- **Regional/Shortline railroad –** *Heavy haul freight railroads owning and operating relatively short distances of track. These railroads have very few interconnections with other railroads, and generally operate only one large rail yard.*
- **Road Crossings** – *a structure that allows road vehicles to cross over the track*
- **Rolling contact fatigue defects**: – *Visible and undesirable rail surface condition that requires treatment by rail grinding to prevent loss of rail life. Examples are corrugation, shells, spalls, and surface cracks.*
- **Seasonal traffic –** *Rail traffic that only occurs on a seasonal basis (for example seasonal grain shipments from silos).*
- **Sharp Curve –** *Any curve having curvature that is high enough to cause the leading wheelsets on the rail cars to take on an angle of attack that causes fully saturated lateral and longitudinal creepage in the contact patches. This is dependent on truck type being used by the railroad.*
- **Surface cracks (rolling contact fatigue cracks) –** *Cracks on the rail surface that arise from the repeated high contact stress cycles that occur in the wheel/rail contact patch.*
- **Surface spalling –** *Large flakes of rail metal that break away from the running surface of the rail as a result of surface cracks that have grown below the surface of the rail and joined together.*
- **Switch and crossing grinding –** *Grinding that is performed on switches and crossings to restore their profile. Usually performed by a small rail grinder known as a "switch and crossing grinder".*
- **Switch** – *a track structure used to divert rolling stock from one track to another.*
- **Tangent** – *any straight portion of a railway alignment.*
- **Ties -** *The lateral connection that supports the two rails in a track structure. Can be made from softwood or hardwood or concrete.*
- **Tonnage (MGT) –** *The cumulative sum of the gross rail load of every railcar and locomotive that travels over a given rail line. The tonnage is expressed in million gross tons (MGT). The tonnage does not include the gross rail load of track maintenance vehicles.*
- **Track elevation (of curves) –** *The vertical distance that the outer rail is above the inner rail.*
- **Track** – *an assembly of rails, ties and fastenings over which trains and railbound vehicles are moved.*

- **Train speed –** *The velocity of the locomotive and cars that comprise a train, as it moves along the track.*
- **Transit grinding –** *Grinding that is performed on rapid transit rail lines.*
- **Transit/passenger railroad –** *Railroads where the vehicles are used for the sole purpose of transporting passengers between stations. Transit railroads usually operate within a metropolitan area and use lightweight rail vehicles. Passenger railroads generally operate between metropolitan areas and use heavier rail vehicles.*
- **Transverse defects** – *a progressive crosswise fracture inside the head of the rail.*
- **Truck hunting –** *A low frequency, abrupt side-to-side motion of the rail vehicle, which usually results from wheelset lateral instability on tangent track. Hunting is characterized by the wheel flanges coming into hard contact with the gage face of the rails.*
- **Vertical split head –** *A large fissure originating inside the rail head and progressing down vertically through to the web of the section.*
- **Weld dipping –** *The metal in the heat affected zone (HAZ) on either side of thermite weld or at the join line of a flashbutt weld is softer than the original rail metal. Under the repeated action of contact stress from passing wheels, the metal in the HAZ can gradually dip below the surface of the adjacent rail.*
- **Wheel / Rail Noise –** *Any audible sounds that emanate from the contact patch of a moving wheel contacting a rail. These noises can range from low frequency sounds to high frequency squeals.*
- **Wide gage –** *Track gage that exceeds the nominal amount (56.5 inches for standard gage track).*