ON THE BENEFITS OF RAIL MAINTENANCE GRINDING

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Introduction

Rail grinding is the process of removal of metal from the top surface of the rail head through the use of abrasive grinding materials. Rail grinding has been used by freight railroads and transit systems since the late 1930's for the elimination of rail surface defects. Those early applications used relatively unsophisticated rail grinding cars for the elimination of corrugations, engine burns, and batter at rail ends.

During the next 4+ decades, grinding techniques improved, using primarily rotating grinding stones mounted on dedicated rail grinding cars or sets of cars, referred to as grinding trains. During this period, the application of rail grinding was extended to numerous types of rail surface defects to include; corrugations, joint batter, weld batter, engine burns, flaking and shelling, as well as for the grinding of mill scale from new rail [1][1]. This mode of grinding for defect elimination, often referred to as “rail rectification”, remained the primary use of rail grinding from the early applications in the 1930's until the 1980's. [2].

During the period starting in early 1980, however, this defect elimination or rectification approach started to give way to the rail "maintenance" or "preventive" grinding approach. This latter approach does not allow surface defects to develop to any significant extent, but rather attempts to eliminate the development of these surface defects before they emerge on the rail head. It also makes extensive use of rail profile grinding techniques to control the shape of the rail head and the wheel/rail contact zones. A key driver to the development and implementation of this new approach was the development of a new generation of higher speed fully automatic rail grinding equipment that allowed for use of multiple grinding patterns and the real time variation of those patterns while grinding.

This evolution from traditional grinding to maintenance grinding and the concurrent use of profile control has resulted in a significant broadening of the use of rail maintenance grinding techniques to increasing the service life and reduce the overall cost of rail in track. It has also led to improvements in wheel/rail dynamic interaction and the reduction of wheel/rail forces in both the vertical and horizontal plane (depending on specific profiles used). This reduction in dynamic interaction (and forces) results in improved rail life, noise reduction, and reduced damage to both the track structure and the rolling stock.

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[1] [ ] refer to references at end of paper

Rail Grinding Applications

Rail grinding, as noted above, can be divided into two broad categories, based on the specific objective and method of achieving that objective. These will be described in the following sections.

Control of Surface Defects

Control and/or elimination of defects on the top surface of the rail head represents the traditional area of rail grinding [1,2] often referred to as rail rectification. Since these surface defects represent locations where vertical wheel/rail dynamic activity is initiated, control of these surface defects results in a reduction in vertical dynamics, noise, vibration, and vertical impact forces. While this type of grinding has traditionally been one of the remedial type actions, i.e. elimination of defects after they appear on the rail head, earlier and more aggressive grinding standards have led to better control of this class of defects and the consequential reduction of their adverse impact on overall operations and costs. In some cases, the initiation of certain classes of surface defects, e.g. low rail freight corrugations, have been completely forestalled by the use of profile grinding techniques.

Surface defects normally manifested themselves on the top surface of the rail head. These surface defect grinding applications include grinding of the following classes of rail surface defects (For a complete set of definitions refer to Chapter 2 of the Manual of Recommended Practices of the American Railway Engineering Association [3].):

<u>Corrugations</u>

<u>Discrete Anomalies</u>
- Engine or Wheel Burns
- Battered and/or Mismatched Joints
- Weld Irregularities
- Rail Head Damage
- Spalling or Flaking (Shelly Spots)
- Shelling (Gage Corner Shelling)
- Surface Batter / Crushed Head
- Plastic Flow (Lip, Flowed Rail)
- Rail Surface Roughness
- Mill Defects

In current practice, grinding for the control of surface defects is frequently combined with profile grinding in a consolidated rail grinding activity.

Profile Grinding

Rail profile grinding refers to the method of controlling and maintaining the shape of the rail head (hence the term “profile”) through the grinding of the head of the rail [2, 4]. Profile grinding goes beyond the basic defect removal approach of conventional grinding and addresses the control of the shape of the rail, and the associated interaction between the wheel and the rail, to include wheel/rail contact.

This “shaping” of the rail head and the influencing of the wheel/rail interaction is a major difference between traditional defect grinding and profile grinding. Traditional defect elimination tends to "flatten" the rail, as illustrated in Figure 1(a) [5]. Profile grinding, on the other hand, grinds a specific contour or profile into the rail head (Figure 1.b). It should be noted that contour grinding is used to restore the original shape or profile of the rail head, while profile grinding is used to give the rail head a special profile other than its original rail profile. Through the control of the rail head shape by means of profile grinding, the locations of wheel/rail contact, and thus the interaction between the wheels and the rail head, can be controlled.

Elimination of surface defects, if present, is the necessary first step in profile grinding. Thus, for rail with surface defects and plastic flow, profile grinding can be a three step process, as illustrated in Figure 2. The initial step consists of one or more grinding passes which eliminate any surface defects present. The second step also consists of one or more grinding passes which effectively reshape the deformed rail head. The third and final step (if necessary) grinds the final rail head profile. However, as maintenance grinding becomes an ongoing process with frequent grinding passes to maintain the desired rail head profile, surface defects generally do not have sufficient time to form, and profile maintenance can become a “one pass” process.

Rail profile grinding encompasses three broad areas of rail maintenance:

1. Control of gage face wear and lateral wheel/rail curving forces.

2. Control of rail surface fatigue.

3. Control of corrugations.

While profile grinding can address all three of these maintenance areas, they cannot usually be addressed simultaneously [2,6,7]. Thus, the profile that is best suited for the control of one of these maintenance areas may not be (and in fact is usually not) the best for the other two problem areas. It is therefore necessary to define the specific

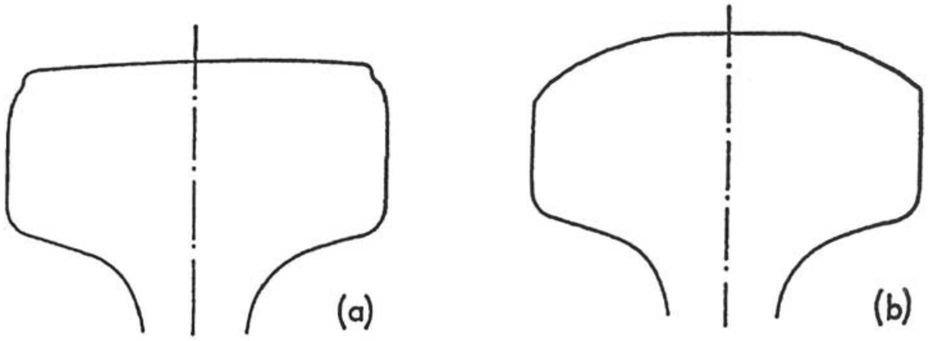


Figure 1. Ground Rail Profile
(a) "Flat" Profile after defect elimination grinding
(b) "Contour" profile after profile grinding

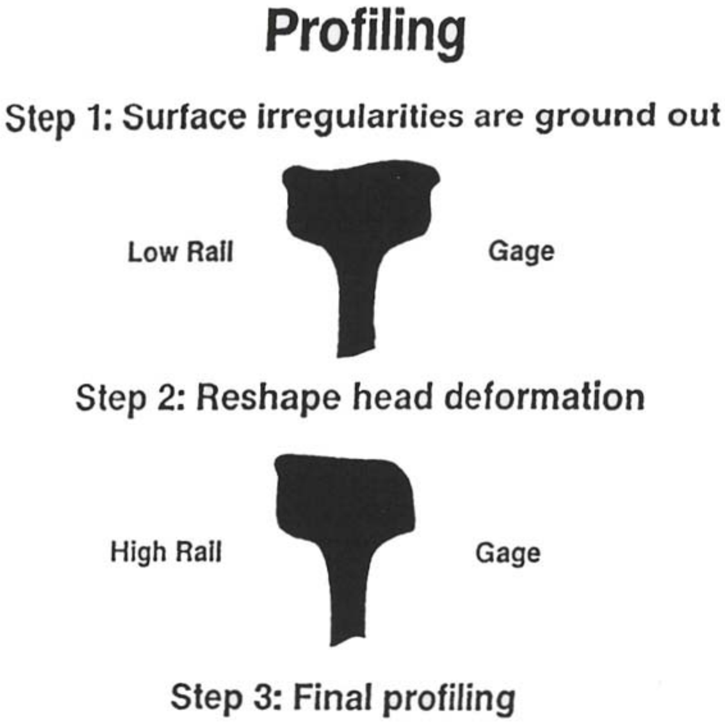


Figure 2. Three Steps of Profile Grinding

problem or class of problems to be addressed prior to the selection of a grinding profile and initiation of profile grinding.

In all cases, it must be noted that the ground profiles deteriorate with traffic. In one set of tests, the profiles tested lasted only 10 MGT (in non-lubricated heavy axle load freight operations) and were completely gone after 20 MGT of traffic [8]. This indicates the profiles must be continuously maintained and that rail maintenance grinding is an ongoing activity that must be continued and maintained in a regular (and defined) basis.

Reduction in Rail Wear

The use of rail profile grinding to control wheel/rail interaction, wheel/rail contact, and (thus) rail wear was developed and introduced by the mining railroads of Western Australia during the late 1970's [3]. It was subsequently introduced in North America in the early 1980s, concurrent with the introduction of the first fully automated rail grinding train, RMS-1 [2, 9] The focus of this initial application of profile grinding was on the optimization of the "steering" of conventional three piece freight car trucks [4]. The results were the development of a set of asymmetric rail head profiles (i.e., asymmetric about the center line of the rail head), with a separate profile for the high and low rails of the same curve. In addition, for tangent track, where "hunting" wear was noted, special tangent profiles were develop to control this form of wheel/rail behavior, and the resulting rail head wear [2].

The initial profile grinding concept was designed to make use of the steering of the conventional three piece freight car truck generated by the conicity of the wheelset [6]. By making use of the difference between the wheel radii due to this conicity, which is known as the "rolling radius differential", it is possible to compensate for the difference in length, around the curve, between the high rail and the low rail (by having the outer wheel ride on the larger radius portion of its tread, and the inner wheel ride on the smaller radius portion of its tread, see Figure 3). This results in a shifting of the wheelset, which in conjunction with the longitudinal "creep" force generated by the rolling radius differential (which tends to align the axles into a radial position [4]) reduces flanging on relatively sharp curves, and has the potential for eliminating flanging on curves less than 3 degrees (based on a 1:20 wheel conicity) [4]. This has been the experience in Australia, as illustrated in Figure 4, where increased wear life of the order of 70 to 80% has been reported [2].

Recent research by the Association of American Railroads [10] suggests that introduction of a conformal, single point contact, between the wheel and the gage corner of the high rail (in curves) will generate a lower wheel set angle of attack and reduced lateral curving forces as compared to a “two point” contact configuration. This is illustrated in Figure 5 for a range of lubrication conditions.

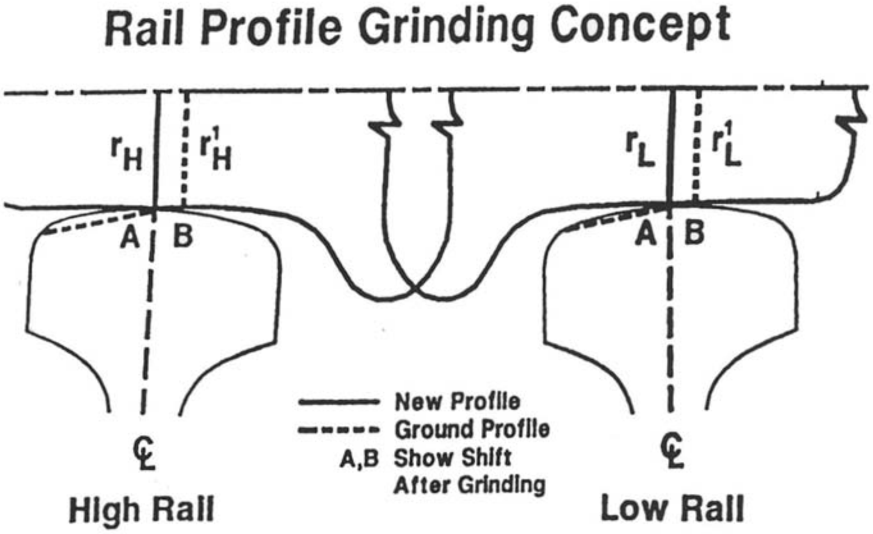


Figure 3. Profile Grinding to Improve Car Steering

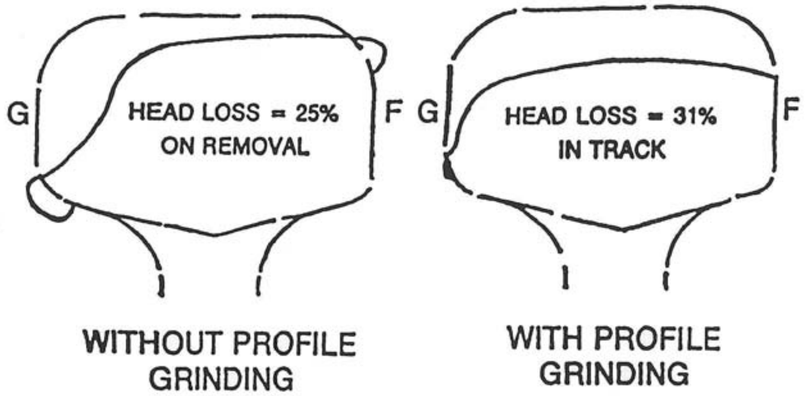


Figure 4. Worn Rail Sections, with and without Profile Grinding

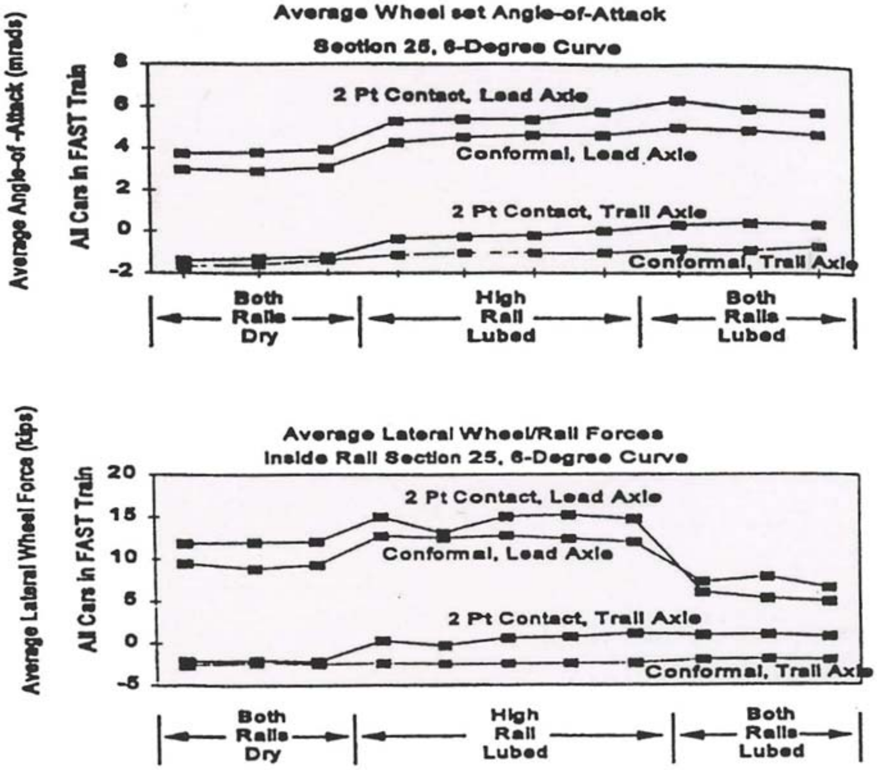


Figure 5. Angle-of-Attack and Lateral Forces before (Conformal) and after (2 point contact) High Rail Gage Corner Relief Grinding

Control of Gage Corner Fatigue

A second area of benefit associated with rail profile grinding is in the control of rail surface fatigue, and in particular fatigue defects at the gauge corner of the rail head. This includes both surface fatigue defects, such as spalling, and sub-surface fatigue defects, such as gage corner shelling, such as commonly found on heavy axle load freight operations. This is the area of benefit most frequently reported by North American heavy haul freight railroads [11,12].

In this application, profile grinding is used to relieve the very high contact stresses in the region of the gage corner of the high rail associated with single point contact in a severe flanging condition (such as on a sharp curve) - see Figure 6. These high stresses can result in gage corner fatigue problems, including cracking and spalling. By grinding the gage corner of the high rail, the contact is shifted away from this corner and into a more central location on the rail head. In the case of sharper curves where flanging takes place, a second contact point between the flange of the wheel and the gage face of the rail can occur, thus generating "two-point" contact between the wheel and the rail. This dividing of the wheel/rail contact site into two points reduces the contact stresses at any one point and can result in a decrease in both surface fatigue "spalling" and sub-surface fatigue "shelling" [2,11]. In addition, it allows for a "wearing" away of the surface fatigue damaged rail steel, and a relocating of the (interior) point of maximum rail stress, before fatigue damage can initiate a failure defect. This is particularly important for well lubricated track or for premium hardness rail steels, where the rate of wear has been substantially reduced.

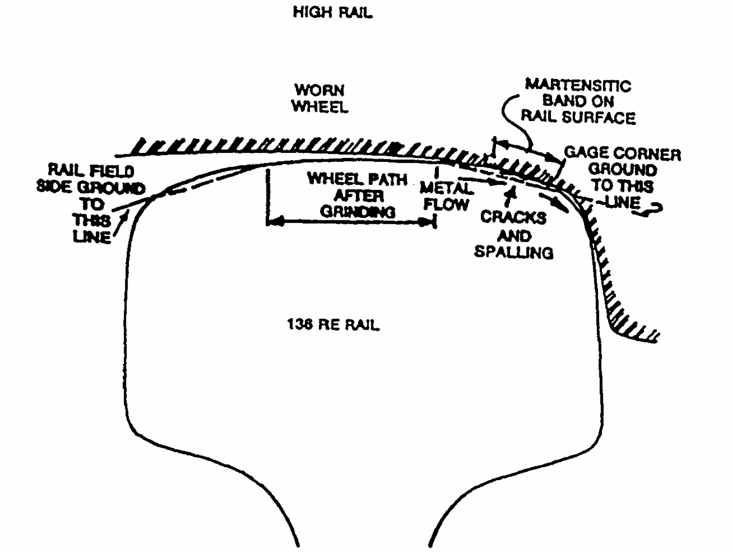


Figure 6. Gauge Corner Spalling and Profile Grinding to Relieve it

As was noted previously, this change in wheel rail contact, from one point to two-point contact, can result in a deterioration in truck curving performance [13], and a corresponding increase in the wheel/rail flanging forces(see Figure 7). The result of this can be an increase in gage face wear, if no other action is taken. Therefore, this type of gage corner profile grinding should be used primarily in those areas where rail fatigue and not rail wear is the dominant rail failure mode.

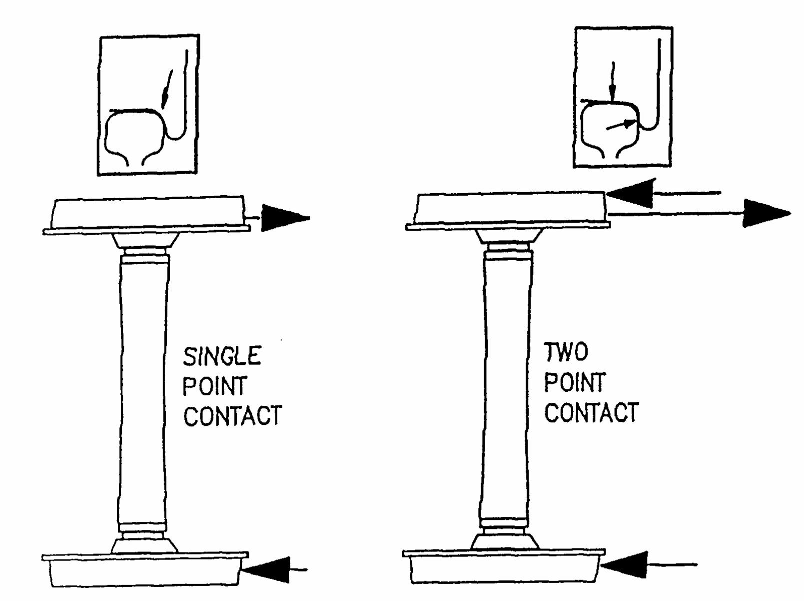


Figure 7. Single Point Versus Two Point Contact Steering Forces

Control of Corrugations

The third area where benefit has been derived from profile grinding is in the area of corrugation control; in particular, the control of the heavy axle load short wave corrugations found on the low rail of curves, as commonly observed on North American freight railroads. These corrugations generally have wavelengths in the range of 12 to 24 inches on wood tie track [14].

These corrugations are often associated with the high contact stresses generated when the false flange of a worn wheel runs on the field side of the low rail. This contact, which is counter-formal (i.e., the curvature of the two bodies in contact, are opposite to each other), causes significantly higher wheel/rail contact stresses than the other (conformal) wheel/rail contact configurations [6]. When this high contact stress is located near the field side of the low rail, severe plastic deformations and corresponding short wave corrugations can result.

Profile grinding has been used to control these short wave ("freight") corrugations on North American freight railroads. By grinding the field side of the low rail to shift the contact point towards the center of the rail head, the high stress producing false flange contact is avoided. In tests on North American freight railroads, the use of profile grinding to control the regrowth of corrugations was found to significantly reduce this regrowth rate as compared to conventional (defect elimination) grinding patterns [6,7].

While in general it is not possible to effectively combine profiles (i.e. wear and fatigue control profiles have significant differences which do not lend themselves to combination into one profile), it is possible to control corrugations in conjunction with another profiling activity. Thus, most railroad profiles include corrugation control in addition to control of either wear or fatigue. This has led to the significant reduction (and in some cases the elimination) of corrugations in an environment where frequent grinding passes are made to control and maintain the required rail head profiles.

Grinding vs. Lubrication

Rail maintenance grinding takes on increased importance in a overall effective rail maintenance program which includes effective lubrication, extensive defect testing, and the desire to obtain the maximum life of the rail in its first position.

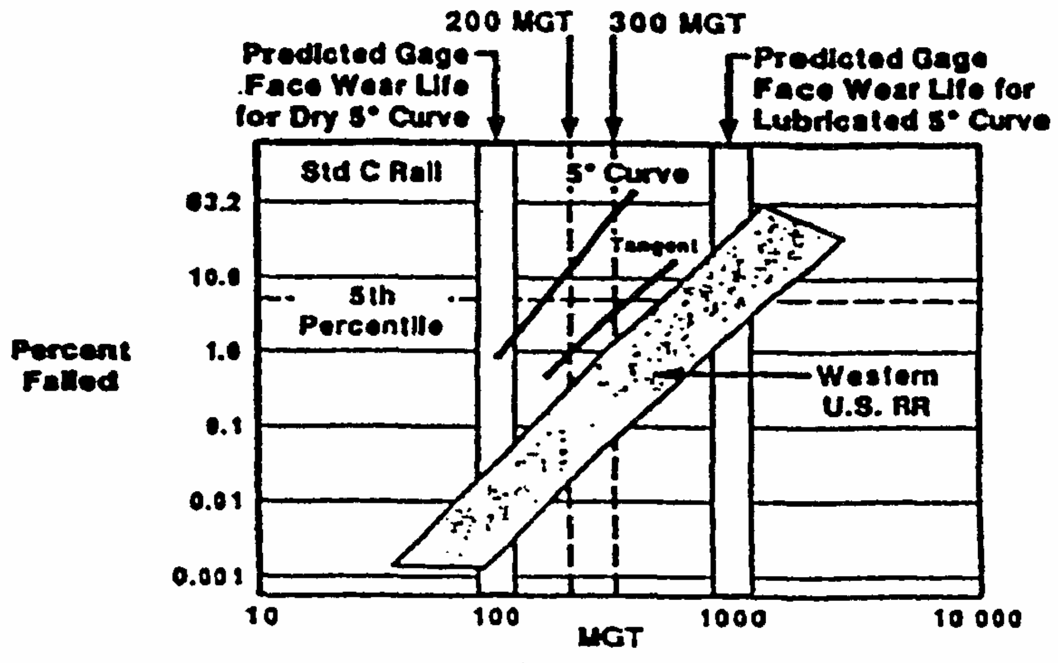
This becomes quite apparent in the rail degradation environment found on moderate and heavy curvature track under heavy freight loadings. If there is no effective rail lubrication, the result is a high rate of gage face wear, with rail (gage face) wear being the predominant cause for rail removal [15]. However, with the introduction of effective lubrication, and the corresponding dramatic reduction in rail wear, this wear mechanism is significantly reduced so that fatigue emerges as a critical criterion [16].

This behavior can be seen in examining the relationship between wheel and rail contact in moderate to sharp curves. In unlubricated track, rail degradation generally takes the form of severe adhesive wear on the high rail of the curve. In lubricated track, it takes the form of surface fatigue development (spalling) at the gage corner of the railhead. This build up of surface fatigue is aggravated in the case of well lubricated track, where no wear is allowed to occur. Without any significant railhead wear, this surface fatigue is allowed to cumulate, with the result that it can cause removal of the rail from track, if no corrective action is taken [11]. In addition, in the presence of a high level of lubrication, and the corresponding significant reduction in rail wear, fatigue can cumulate below the surface of the railhead, such as the point of maximum shear stress in the railhead. This can result in the development of subsurface defects such as rail shells.

The relationship between rail life and rail lubrication is dramatically illustrated in Figure 8, which presents rail life data from a 5 degree curve at the Facility for Accelerated Service Testing, FAST [16]. In the unlubricated environment, i.e., in a dry condition, the rail in this curve required replacement after 80 to 100 MGT of traffic. (Note, traffic was primarily heavy axle load, 100 Ton car traffic.) When the rail was "fully lubricated" the wear rate was reduced by a factor of 10, such that the projected wear life of the rail, under the same traffic conditions, was 1000 MGT. This was based on gage face wear. However, well before this extended wear life was realized, the rail began to experience significant fatigue defects. In fact, the 5 percent defect level (i.e. the 5th percentile which corresponds to the point where many railroads replace rails due to excessive fatigue defects) was reached after approximately 180 MGT.

Thus, using standard railroad criterion for the replacement of rail in main line tracks, it was found that lubrication of the rail (in this case) extended the rail life from 80-100 MGT (dry) to 180 MGT (due to fatigue), or approximately double the life. While this represents a significant extension of life, it can be seen that the development of fatigue defects resulted in the “failure” of the rail well before the rail’s potential wear life of 1000 MGT. Further, it can be observed that there was a change in failure mechanism, from wear in the dry environment, to fatigue in the lubricated environment.

In order to allow the rail to more closely approach its wear life potential, it is necessary to control the rail fatigue build up. Rail profile grinding offers the potential for extending the fatigue life of the rail through the reduction of maximum wheel/rail contact stresses (by shifting point of maximum contact) and the removal of fatigue damaged metal prior to the development of fatigue defects (by artificially creating controlled wear in the well lubricated track environment, and allowing for the removal, by wear, of fatigue damage rail metal [15,16]). Noting that profile grinding has the potential of extending the fatigue life of the curve rail to that of rail in tangent track [17], this could translate into a rail life of 300 to 400 MGT (based on the same FAST data as presented in Figure 8). This would represent a further doubling of the life of the rail, with a corresponding major economic benefit to the railroad. **This benefit has been shown to yield a ROI benefit of rail grinding of the order of 50 to 90%** [17].



Wear		Fatigue	
Dry	Lub'd	5th Percentile	10th Percentile
80-100	1000+	~180	~200

Figure 8. Fast Rail Failure Distribution

Benefits of Profile Grinding

The benefits of rail maintenance grinding in general and rail profile grinding in particular are primarily associated with improvements in rail performance and corresponding extension of rail life. These improvements/life extensions, which are presented herein, are generally associated with the above-defined mechanisms; i.e. wear, fatigue, and/or corrugation control, though in some cases there is a combination of effects which contribute to an overall extension of rail life. This rail life extension is often seen in conjunction with other improvements, such as improvements in rail metallurgy, steel cleanliness, lubrication practices, etc. Since these other improvements can be incremental in nature, and continuously ongoing (e.g. improved steel cleanliness), it is often difficult to isolate the benefits associated with rail grinding alone. However, as will be noted in this section, rail grinding has been shown to generate measurable extensions of rail life and improvements in rail performance.

Rail grinding also generates secondary benefits associated with reduced dynamic wheel/rail loading, such as reduced vertical impact loadings. These reduced levels of loadings (and associated improved wheel/rail dynamic interaction) produce benefits in terms of extended component lives (wheels as well as rails [18]), reduced maintenance cycles (e.g. surfacing cycles) [19], and reduced fuel consumption [20]. In addition, by controlling and eliminating such surface defects as corrugations, rail grinding has been shown to reduce noise and vibrations, and improve rider comfort (for passenger operations).

Wear

As noted above, rail profile grinding was originally developed by the mining railroads of Western Australia to control rail wear, particularly on shallow curves, under heavy axle load operations [4]. The result was a reported dramatic decrease in wear for curves of less than 3 degrees and a corresponding increase in rail life of the order of 70 to 80% for these curves [4]. This increased life is presented in Figure 9 which shows projected system rail requirements for one Western Australian railroad (without profile grinding) as compared to actual rail life experienced after the introduction of profile grinding [4].

This improvement in rail wear behavior was also reported in early FAST data, where field tests of the effect of profile grinding measured the reduction in both lateral flanging forces and in gage face wear, for several different rail head profiles [8]. In these tests, under 100 Ton car traffic, lateral force measurements were taken on a four degree test curve, with three different profiles and a control (non-profiled) rail head. In all cases, profile grinding significantly reduced the measured lateral forces. This reduction in lateral force translated into a measurable reduction in gage face wear as illustrated in Figure 10 [8]. While, recent testing at FAST has raised questions regarding proper rail profiles (i.e. one point vs. two point contact) as well as the effect of grinding on rail wear [10], those results clearly highlight the importance of defining the proper interaction between the wheel and the rail and the corresponding wheel and rail profiles. However, it must be noted that this definition of proper rail (and wheel) profile can have a major influence on the level of improvement in (or degradation of) rail wear behavior [10]. This effect must be considered in light of any other life limiting failure mechanisms that must be addressed by profile grinding.

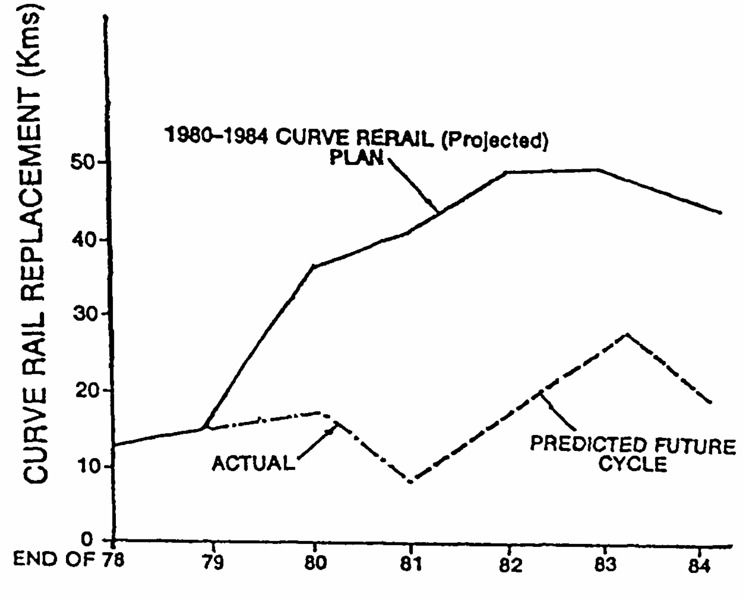


Figure 9. Effect of Profile Grinding on Curve Relay Requirements (5)

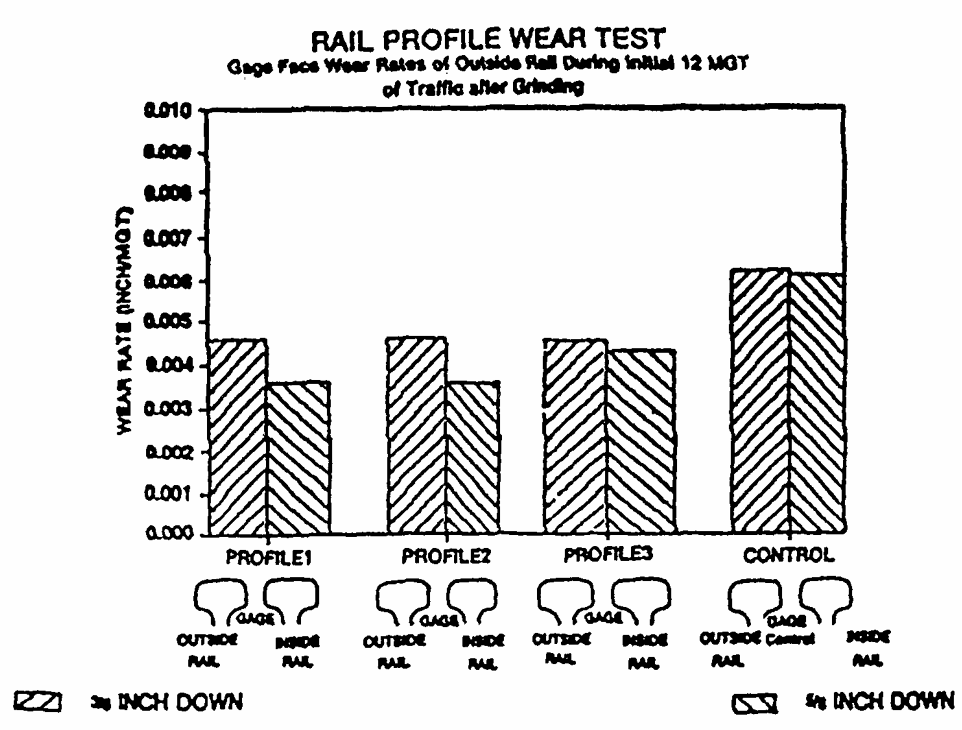


Figure 10. Outside Rail Gage Faceweare – 12 MGT

Fatigue

Use of profile grinding, and in particular two point profile grinding, to control rail fatigue defects has emerged as a key application for profile grinding in North America, particularly under heavy axle load operations. Early applications of profile grinding to control fatigue have been reported by Canadian National Railways [11], Canadian Pacific Railway [6,7], BC Rail [21], and others. In the case of one major North American railroad, profile grinding has been reported to have effected a systemwide reduction in fatigue related defects, particularly transverse defects (TDs), which in this case includes the detail fracture class of defects (which is most affected by profile grinding). This reduction in defects is illustrated in Figure 11 [17]. Similar effects on defect reduction have been reported in Australia where fatigue defects (as detected by ultrasonic rail testing) have been reduced by more than half, as illustrated in Figure 12 [18].

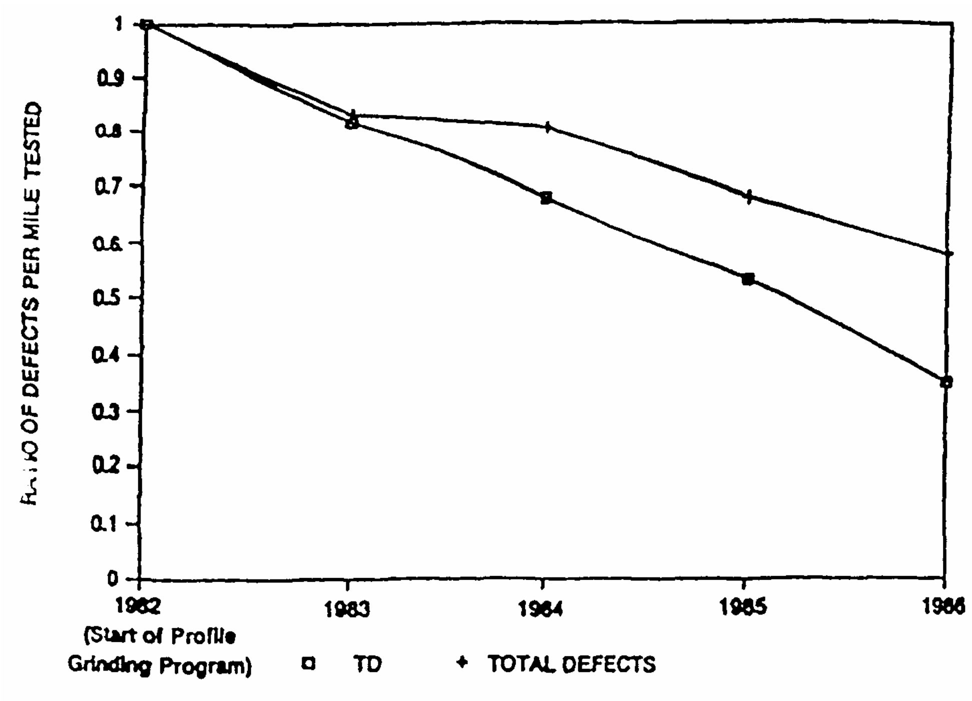


Figure 11. Rail Defects on Major North American Railroad (defects normalized by actual miles tested)

More recent North American experiences have confirmed this effect. This includes recent experience on Canadian Pacific [23, 23] and Burlington Northern [24, 25].

The relationship between effective profile grinding and control of fatigue defects is clearly illustrated in Figure 13 [25] which shows the number of detail fracture type fatigue defects experienced by the Burlington Northern Railroad during the period 1984 through 1995. Between 1983 and 1988, Burlington Northern performed profile grinding, generating a basic “two point” contact configuration on their rail [25]. As can be seen from Figure 13, the number of detail fractures were controlled and kept at a relatively low rate. In the period of 1988 through 1990, Burlington Northern changed to a lighter “conformal” (one point) grinding pattern with a resulting surge in detail fracture defects (see Figure 13) as well as a “rash” of defect related broken rail derailments (with a cost in excess of $6.5 million) [25]. By 1990 through 1991, Burlington Northern switched back to a more aggressive “two point” profile grinding and again experienced a reduction in detail fracture type fatigue defects, as illustrated in Figure 13 [25]. Thus, BN reports a strong correlation between effective profile grinding and the control of rail fatigue defects.

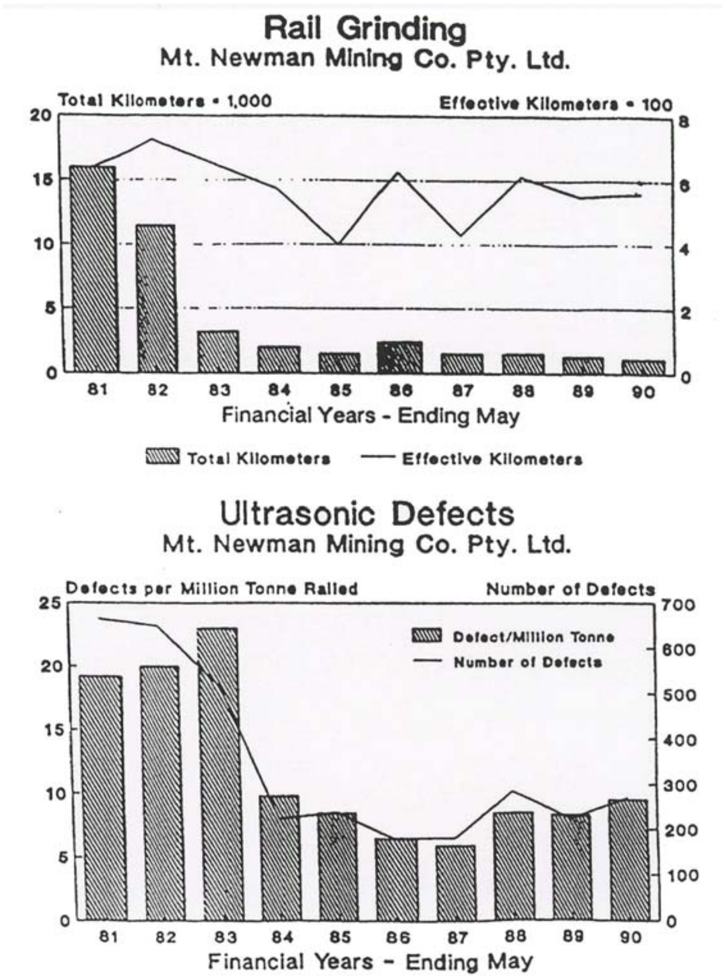


Figure 12. Rail-Grinding and Rail-Defect Experience

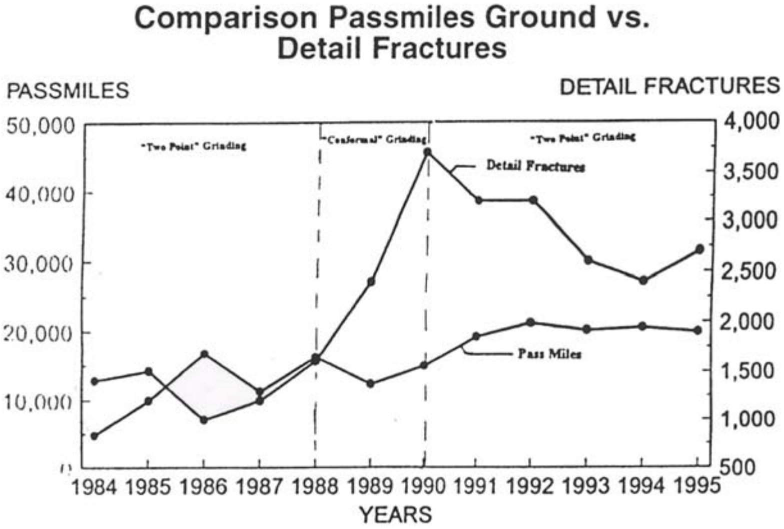


Figure 13. Detail Fracture History on Burlington Northern Railroad

Corrugations

Control of rail corrugations was one of the original priorities in North American profile grinding practices. In fact, one of the earliest controlled tests of rail grinding carefully examined the effect of profile grinding on corrugation development and recurrence [6,7]. The results of these tests, which are presented in Figure 14, show that corrugation regrowth was significantly slower using profile grinding techniques than it had been using conventional (defect elimination) grinding patterns. This reduced growth rate was equivalent to an extension of the grinding cycle from the previous 6 month interval to a 8 month interval, an extension of 33%. In addition, it was observed during that more frequent maintenance grinding, could reduce the overall amount of grinding by eliminating the corrugations while they were relatively shallow (or even before they begin to emerge).

More recent testing on CP Rail and BC Rail [21,26] confirmed this benefit and further showed that preventive maintenance grinding using appropriate grinding profiles can forestall the development of corrugations and provide for a rail "free of corrugations and service defects" [26]

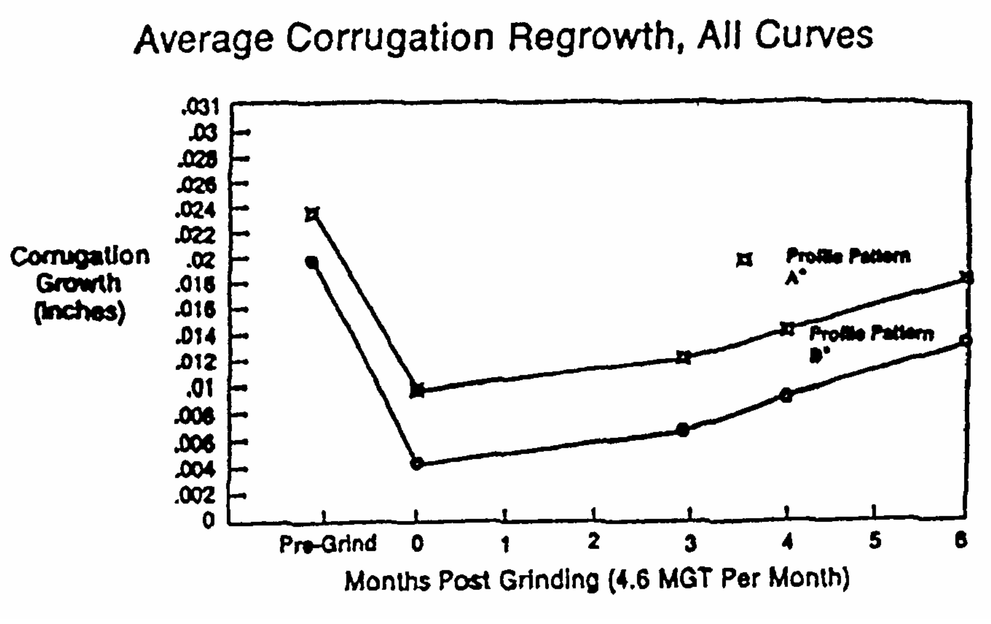


Figure 14. Corrugation Regrowth After Profile Grinding

Vertical Impact Dynamics

Corrugations and other rail service defects represent a source of dynamic wheel/rail excitation and corresponding impact loading which has the potential for generating significant damage not only to the rail, but also to the track structure and vehicles [27, 28]. This behavior is illustrated in Figure 15 which shows a more than doubling of the dynamic wheel/rail forces associated with corrugations of the order of 0.050 inches.

In addition to generating dynamic impact forces, corrugations generate noise and vibration, and can cause significant discomfort to passengers on rail vehicles [29]. Effective rail grinding can eliminate the growth and recurrence of corrugations (see Corrugations above) with a corresponding elimination of wheel/rail dynamic forces, noise and vibration. Noise reduction of the order of 7 dB and greater have been reported in conjunction with the elimination of rail corrugations by grinding.

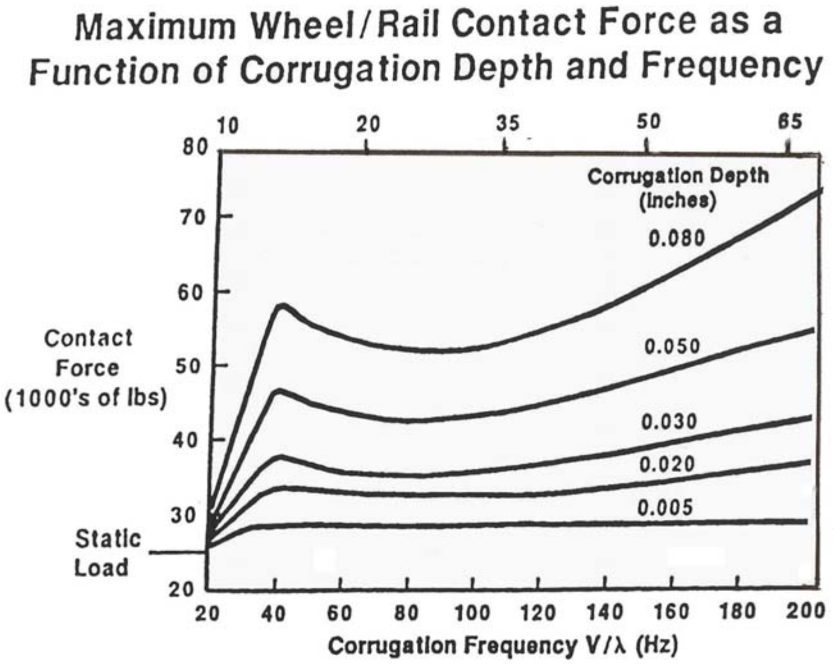


Figure 15

Overall Improvements in Rail Life

As has been noted previously, while significant increases in rail life have been reported in conjunction with rail grinding, actual field results often commingle several maintenance effects, so that the effect of rail grinding is masked somewhat by concurrent improvements in rail steels, in lubrication practices, and in inspection practices. In spite of this, railroads who have been able to document extensive increases in rail life, have attributed these extensions of rail life, in very large part, to rail profile grinding. Such is the case on the Burlington Northern Railroad, where improvements in average rail life of the order of 50 to 300+% have been reported (see Figure 16), with rail grinding being credited with being a key factor in this extension [12, 24].

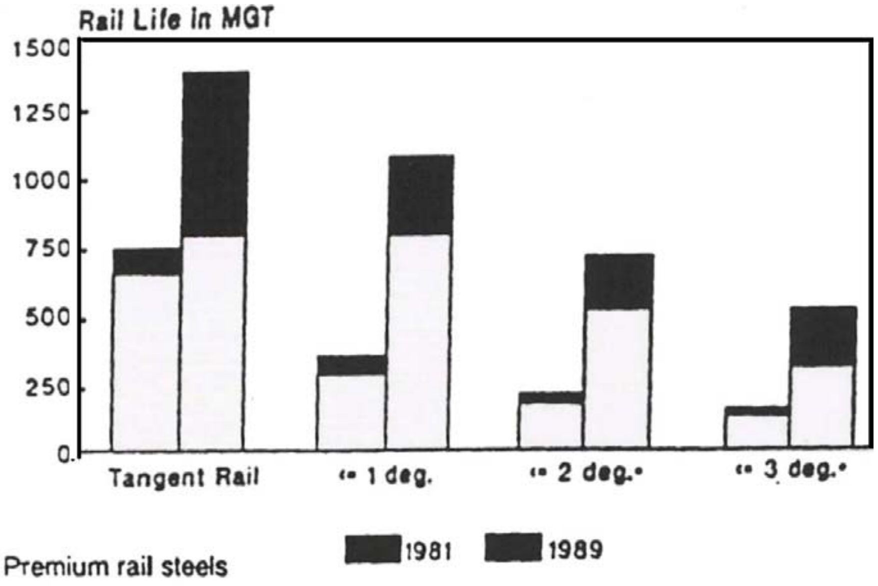


Figure 16. Average Expectations for Rail Life [12]

Canadian National Railways also reported significant increases in rail life associated with a combination of increased lubrication, improved rail steels, and rail profile grinding [11]. This overall increase was reported to be of the order of 500+%. CN further reported that if proper grinding was not performed on an ongoing basis, the rail could lose "95% of its potential service life" [11].

Likewise the case in Western Australia where rail profile grinding, in conjunction with improved wheel/rail interaction control has been credited with dramatic increases in rail life, with a current forecast rail life of the order of 2.4 Billion Gross Tons [18]. This represents a multi-fold increase in rail life from that experienced even a decade before.

Other North American Railroads have likewise reported increases in rail life associated with rail grinding to include CP Rail, CSX, and Conrail. In the case of CP Rail, the effect of rail grinding on rail life is clearly illustrated in Figures 17a and 17b. [23]. These figures show a dramatic reduction in miles of new rail laid during the period 1987 through 1995, which corresponds directly with the increase in miles of rail grinding for that same period. While other factors such as improved lubrication and metallurgy have contributed to the significant reduction in new rail requirements, CP credits rail grinding as being a key factor in this dramatic extension of rail service life [22, 23].

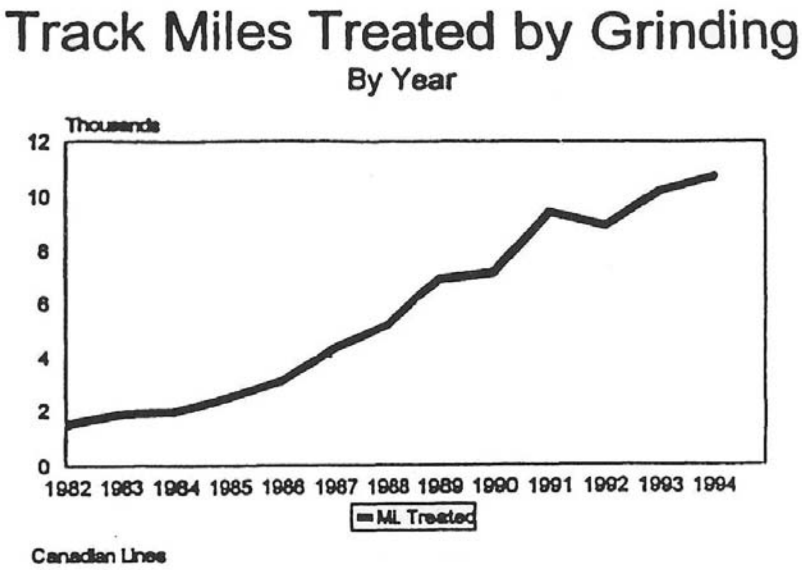


Figure 7a

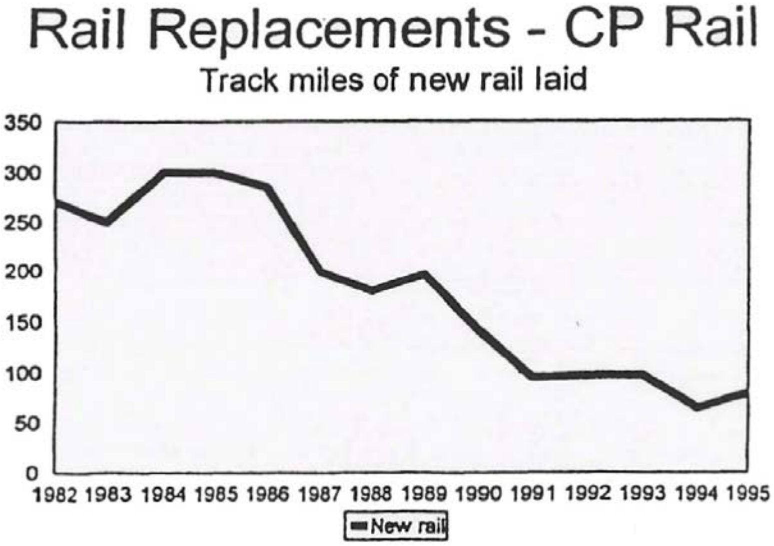


Figure 17a & b

Issues in Profile Grinding

While profile grinding has resulted in demonstrable benefits to railroads in terms of extended rail life and reduced damage to the track structure and rolling stock, profile grinding does change the wheel/rail contact environment with the resulting potential for undesirable behavior if not properly addressed.

The first such potential area of concern is the change in steering forces associated with the change in wheel/rail contact points. As noted previously, changing wheel rail contact from one point contact (wear control) to two-point contact (fatigue control) can result in a deterioration in truck curving performance, and a corresponding increase in the wheel/rail flanging forces (and associated rail gage face wear) [13]. This is illustrated in Figure 7 which shows a small increase in truck turning moments, associated with moving the contact point on the high rail towards the center of the rail head (and thus increasing the truck turning moment arm). This in turn generates an increase in lateral force as shown in Figure 5 which increases rail gage face wear [10] and also the potential for gage widening and rail overturning on curves [13]. This is of particular concern in environment where both the high and low rails are dry (such as immediately behind the rail grinder) or where the high rail is lubricated and the low rail is dry, which, as seen in Figure 5, generates the highest level of lateral loads.

This increase in force is of potential concern, and should be addressed in an overall system design, where the wheel and rail profiles must be optimized in order to achieve the optimum steering forces while maximizing the lives of the key components. Thus, it may be necessary to "trade-off" key track and vehicle performance parameters in order to optimize the overall system. Thus, if fatigue is the dominant replacement mode for the rails in curves (in a well lubricated environment), additional rail wear may not be an important factor, since the rail life is not limited by the wear. Similarly, it may be necessary to balance the strength of the track with the level of traffic loadings, such as by careful testing of the gage strength or by the use of high strength elastic fastening systems.

A second area of potential concern resulting from the shifting of the wheel/rail contact points is a change in the location of the applied vertical and lateral forces on the rail, and the corresponding overturning moment applied to the rail. This overturning moment is generally defined by an L/V ratio (ratio of lateral [L] and vertical [V] forces applied to the rail head) as illustrated in Figure 18. When the resultant of the applied lateral and vertical forces passes outside the base of the rail, the rail is no longer stable on its own base, but has a net overturning force applied to it. In these cases, the rail is restrained by its fastening system, and if this fastening system is weak or inadequate, the rail has the potential for rolling (rail head moves out laterally) and even potentially overturning.

By shifting the contact point of the vertical and lateral forces from the gage corner to the center or field side of the rail head, the overturning resistance is decreased. This is illustrated in Figure 19, which shows that if the lateral and vertical forces are applied to the gauge corner, the L/V ratio required to provide this potential instability is approximately 0.6. If these forces moved to the center of the rail head, such as would happen if contact was moved from the gage corner to the center of the high rail head, the overturning L/V ratio is reduced to approximately 0.4. If the forces are moved to the field side of the rail head, the overturning L/V ratio can be as low as 0.2. Such a case can occur if the false flange of the wheel is riding on the field side of the low.

In the case of the low rail, several of the ground profiles shift the contact point away from the field side of the rail head (and false flange contact) towards the center of the rail head. Thus, in these cases, profile grinding to alleviate false flange contact will also serve to increase the overturning stability of the low rail (from an L/V < 0.2 to an L/V > 0.4).

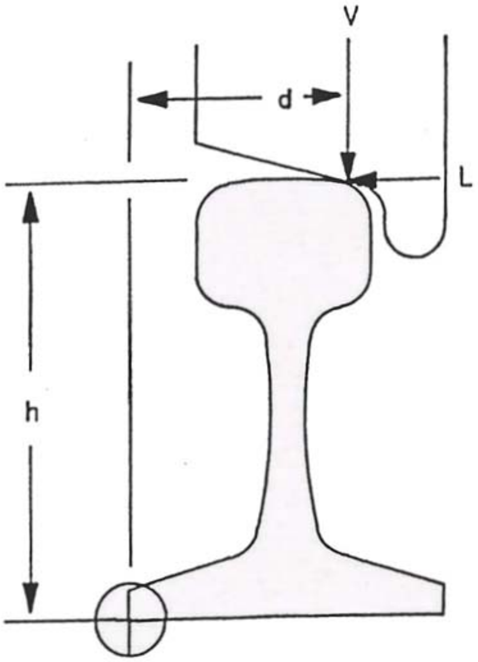


Figure 18. Rail Rollover Diagram

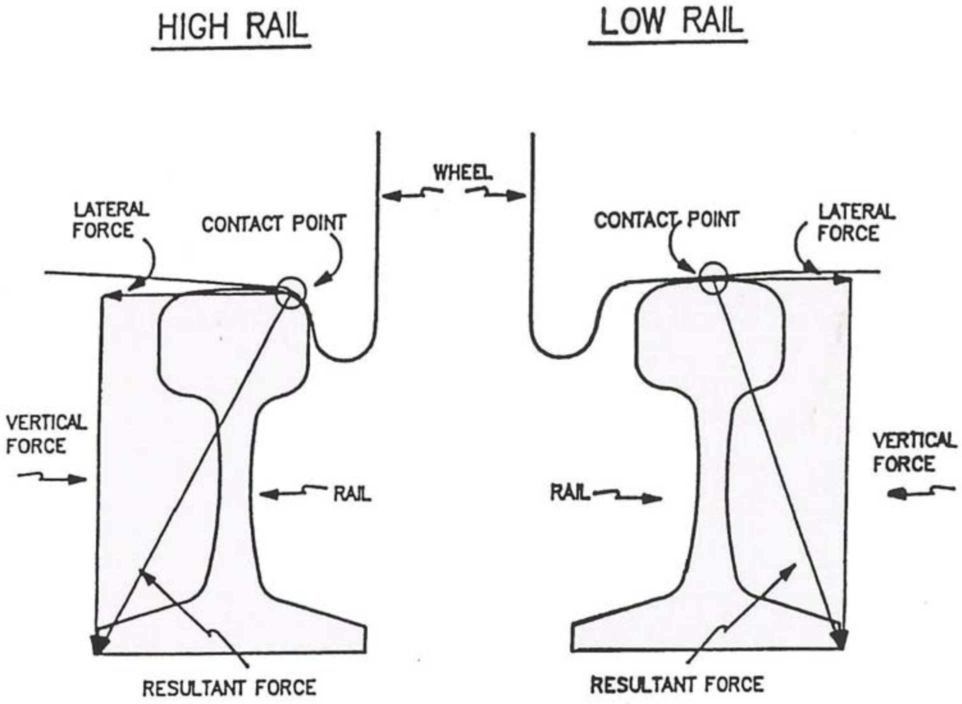


Figure 19. Rail Rollover Criterion

In the case of the high rail, shifting from one point contact on the gage corner of the rail to a two point contact, such as illustrated in Figure 7, will reduce the L/V ratio required to overturn the high rail from approximately 0.6 (gage corner contact) to approximately 0.5 for the two point contact normally introduced by current railroad grinding patterns (fatigue control). This reduction is diminished, if the separation between the two contact points is reduced, as is the case for several "new generation" grinding patterns [22]. This reduction in overturning resistance must likewise be accounted for by the maintenance of adequate track strength for the load environment on that curve.

Summary

Rail grinding has evolved over the past several decades from a relatively simplistic method of removing defects from the surface of the rail head to a more complex maintenance technique which controls not only the development of defects in the rail, but also the interaction and associated contact between the wheel and the rail. This latter technique, which controls the shape or profile of the rail head, allows for the extension of the life of the rail by addressing the dominant rail degradation mechanism(s), which can vary from location to location. By combining this profile maintenance technique with a preventive grinding philosophy, it is possible to achieve significant extensions in the life of the rail.

Rail profile grinding has been used to address three major modes of degradation; wear, fatigue and corrugations (surface defects). By selection of an appropriate rail head profile (or profiles since separate profiles are used on opposite rails in curves), reductions in the mode of degradation and its associated degradation rate can be achieved. This has been documented on railroads in the United States, Canada, and Australia, who have reported significant extensions of rail life. While grinding is usually only one of several simultaneous maintenance strategies employed to improve rail life, it has been demonstrated to be a key strategy, the absence of which can result in a rapid degradation in the rail condition and corresponding shortening of the rail life. Since rail represents the one of the largest (if not the single largest) maintenance of way cost area for most main line freight railroads, the control of rail degradation and extension of rail life represents a high priority for most maintenance of way departments.

Rail grinding, like many other technologies, must be used carefully and intelligently. When properly used it has been shown to contribute to a significant extension of rail life, reduction in rail (and other track maintenance) costs, and improvement in the dynamic wheel/rail loading environment. If not used properly, it has the potential for causing increased lateral wheel/rail forces, increased rail wear, and increased risk of rail overturning. Therefore, rail grinding must be used with a proper understanding of its benefits and limitations. When used effectively, rail grinding represents a valuable tool for the control of rail degradation, and for the reduction in overall track maintenance costs.

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