THE RELATIONSHIP BETWEEN RAIL GRINDING AND RAIL LUBRICATION

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ABSTRACT:

This paper examines some of the issues relating to the interrelation between rail lubrication and rail grinding. The relationship between rail lubrication and rail surface fatigue is discussed together with the loss of the wear mechanism that removes the surface damaged material from the gage corner of the railhead. The concept of using rail profile grinding to replace this wear mechanism, and thus delay the development of rail surface fatigue damage is presented, together with its growing acceptance and use in the heavy axle load railroad environment.

INTRODUCTION

In recent years, the benefits of effective lubrication of the railhead, specifically the gage face of the railhead and the wheel/rail contact area at this gage face, have been shown to be quite significant and dramatic. This includes benefits in improved rail wear life and in improved vehicle track interaction, and correspondingly increased fuel efficiency (1,2). The result has been a concentrated effort by freight railroads, to improve their lubrication effectiveness, as well as to explore new means to increase their overall system lubrication.

One of the results of this increase in lubrication effectiveness has been a continuing change in the dominant mechanisms of rail degradation, in track with the advent of Continuously Welded Rail (CWR) and the consequential elimination of rail joints, rail wear, both at the top of rail head in tangent track and at the gage face in curves, emerged as the dominant rail replacement mechanism for mainline track. However, as axle loads increased, this mechanism started to shift towards internal fatigue defects in tangent tracks (3) with the advent of the 100 Ton cars, these fatigue defects became the dominant mechanism in tangent track, with gage face wear remaining dominant in curves. However, as the level and effectiveness of rail lubrication increases, this mechanism likewise begins to shift away from rail wear. Instead, in well lubricated track, where gage face wear has been significantly decreased, rail fatigue defects, in the form of surface fatigue, such-as rail spalling and internal fatigue, such as in rail shelling, have begun to emerge as the dominant failure mechanism (3,4).

This paper will examine some of the issues relating to the interrelation between rail lubrication and rail grinding. Specifically, it will examine the effect of rail grinding, and in particular rail profile grinding, on rail life, in a well lubricated environment. The relationship between rail lubrication and rail surface fatigue is discussed together with the loss of the wear mechanism that removes the surface damaged material from the gage corner of the railhead. The concept of using rail profile grinding to replace this wear mechanism, and thus delay the development of rail surface fatigue damage is presented, together with its growing acceptance and use in the heavy axle load railroad environment. The results of this type of rail profile grinding in reducing the occurrence of rail fatigue defects will be presented together with an analysis of the economics of rail profile grinding as a means of extending the life of rail, in track.

RAIL DEGRADATION AND LUBRICATION

As has already been noted, with the use of Continuously Welded Rail (CWR) in track, the dominant rail failure modes, and correspondingly the criterion for the removal of rail for high tonnage, heavy axle load, mainline track are as follows:

Tangent and Light Curvature Track:

Rail fatigue (internal) tends to be the dominant criterion. This takes the form of the more common internal defects such as transverse defects, detail fractures, vertical split heads, horizontal split heads, etc. However, in some cases, railhead wear (top of railhead) often in conjunction with extensive remedial grinding can be a criterion.

Moderate and Heavy Curvature Track (See Figure l):

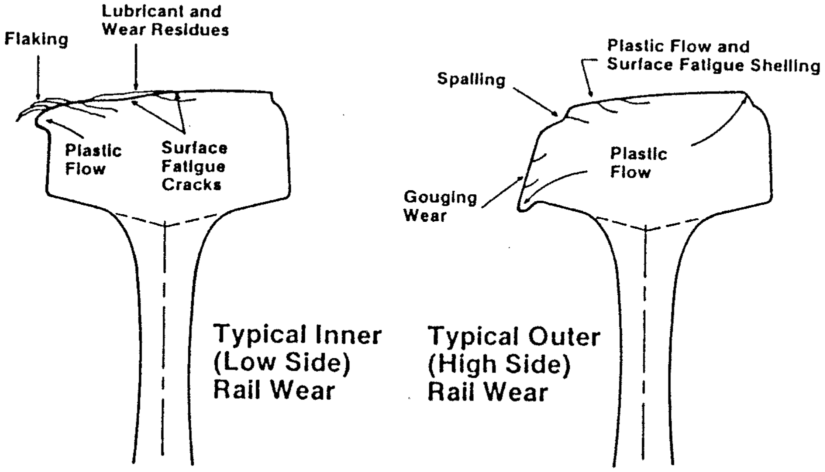


Figure 1. Wear of Rails in Curves Under Heavy Traffic Conditions.

In the absence of effective rail lubrication, gage face wear, either adhesive, fatigue or abrasive (5), is the predominant cause for rail removal with effective lubrication, and the corresponding dramatic reduction in rail wear (up to a factor of 100, but more commonly a factor of 5 to 10 (5)) this mechanism is significantly retarded so that fatigue emerges as a critical criterion (6). This can include both surface fatigue and internal fatigue. In addition, rail surface defects, which in turn are associated with surface fatigue at the top of the railhead (5), and which include corrugations, take on increased importance, and can result in rail removal.

In examining the relationship between wheel and rail contact, particularly in moderate to sharp curves, it can be readily seen (Figure 2) that high wheel/rail contact stresses can result in significant rail degradation (7). In unlubricated track, this degradation generally takes the form of severe adhesive wear. In lubricated track, it takes the form of surface fatigue development (spalling) at the gage corner of the railhead. This buildup 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 (7).

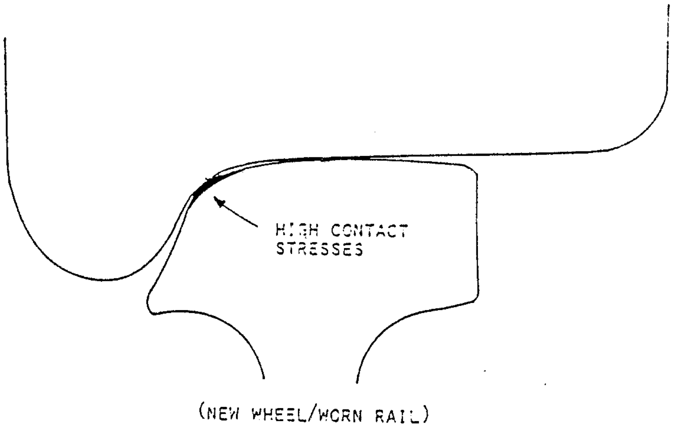
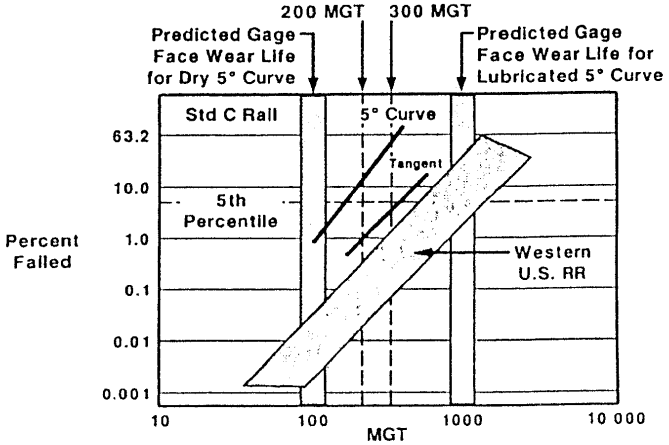


Figure 2

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 detects such as rail shells (8), which in turn can propagate (initially longitudinally but subsequently in the transverse plane) and turn into transverse separations or detail fractures of the railhead. These in turn represent a dangerous class of internal rail defects.

This relationship between rail life and rail lubrication is dramatically illustrated in Figure 3, which presents rail life data from a 5 degree curve at the Facility for Accelerated Service Testing, FAST (6). 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.)



Rail Life in MGT's

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

Figure 3. Fast Rail Failure Distribution

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, the point at which it is economically desirable to replace the rail due to fatigue) was reached after approximately 180 MGT.

Thus, lubrication of the rail in this case, extended the rail life from 80-100 MGT to 180 MGT, or approximately double the life. While this represents a significant extension of life, it is well below the potential wear life of 1000 MGT. In order to reach this level, it is necessary to control the rail fatigue build up. One such approach, rail profile grinding, offers the potential for extending the fatigue life of the rail in question, to that of an equivalent tangent section of track (9) or even longer. Noting the same FAST data (Figure 3), this could be 300 to 400 MGT, a further significant increase in rail life. In fact, it has been suggested by several authors (5,6,9) that controlled rail grinding, particularly profile grinding, can be used to artificially create controlled wear, in the well lubricated track environment, and correspondingly increase even further, the life of the rail in this lubricated environment.

RAIL PROFILE GRINDING

Rail grinding is the technique of removing metal from the running surface of the railhead using rotating grinding wheels (9). Traditional rail grinding was aimed at the removal of defects from the surface of the rail. These defects included corrugations, engine burns, battered joints (in bolted rail), high or battered welds (in CWR), etc. This was later extended to include grinding of rail surface fatigue defects, such as rail spalling, and the grinding of rail "lips". The primary thrust of traditional rail grinding was remedial, i.e., the correction of a problem in track, after it had become troublesome. If these defects were not corrected in time, the rail would have to be removed from track.

More recent rail grinding applications have shifted emphasis from remedial grinding, to maintenance grinding. In this latter application, rail defects are no longer permitted to grow to a significant (and troublesome) degree before they are addressed. Rather, the deterioration of the railhead is monitored more closely than before, and as soon as evidence of the degradation of the railhead appears, the rail is ground to avoid the development of significant defects. This has resulted in the early grinding of rail surface defects (often at a level historically considered to be "negligible"). In addition, this has resulted in the closer observation and control of the railhead shape itself, the profile of the railhead. Recent research has indicated that careful control and maintenance of the railhead profile can delay or eliminate the appearance of undesirable railhead defects (10, 11). This, in turn, has led to the growing practice of rail profile grinding.

Rail profile grinding is the technique of controlling the profile of the railhead, so as to achieve a desired wheel/rail interaction and control of the wheel/rail contact point(s). As applied to heavy haul railways, rail profile grinding usually involves the grinding of an "improved" profile (i.e., one that is different from the original railhead profile) onto the railhead. In addition, this profile is generally asymmetric, in that the high rail and low rail of curves (as well as the left and right rails on tangents) have different individual profiles.

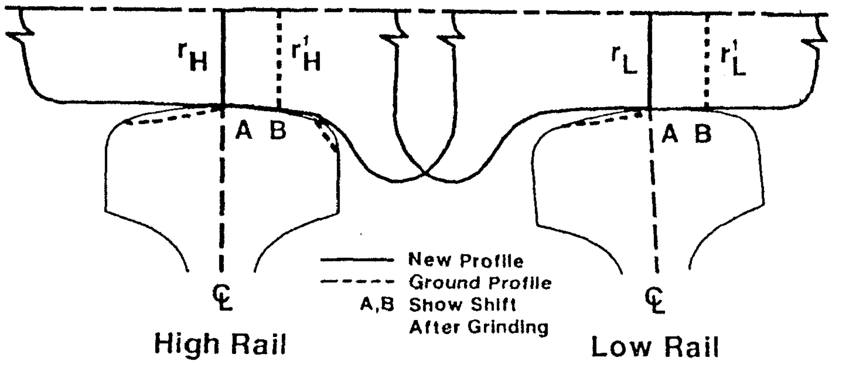
The rail profile grinding concept is illustrated in Figure 4. In general, profile grinding addresses three distinc1 wheel/rail interaction mechanisms, either individually (with a specific profile for each mechanism) or in combination (11).

These mechanisms included:

a. Improvement of the self-steering of the wheelsets (of three piece trucks) by enhancing the rolling radius differential and thus reducing any curving forces. This is accomplished by grinding of the field side of the high rail and the gage side of the low rail (see Figure 4).

b. Elimination of the false flange (of the wheel) contact on the field side of the low rail. This eliminates the very high local stress zones that are associated with the formation of short wave corrugations. This is accomplished by grinding of the field side of the low rail (see Figure 4).

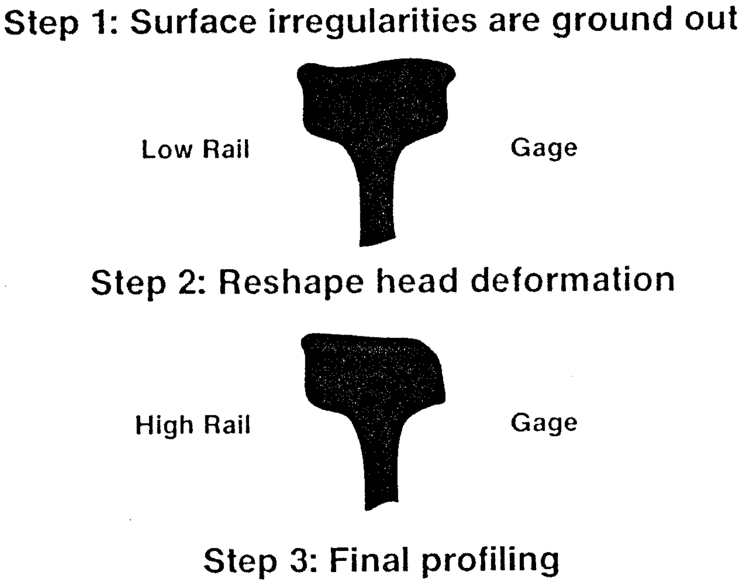
c. Elimination of the one point contact between the gage corner of the high rail and the throat of the wheel flange (Figure 2). This eliminates the high gage corner stress concentration that, in the absence of wear (i.e., for well lubricated track), results in surface fatigue. This is accomplished by grinding of the gage corner of the high rail (see Figure 4).



Ground Contours of High and Low Rails Shift Point of Wheel Contact from A to B, Increasing Differential Rolling Radius to an Extent Making Wheelset Self-Steering on Curves Up to Somewhat Over Two Degrees of Curvature. Gage Corner of High Rail is also Relieved Slightly to Avoid Contact with Flange Throat.

Figure 4. Rail Profile Grinding Concept.

Rail profiling is usually accomplished as part of a series of steps as illustrated in Figure 5. The initial step is the elimination of any surface irregularities or defects from the railhead. If this is not accomplished then the surface defects will grow and dominate the surface degradation mechanisms. In the case of ongoing profile grinding, this step can be eliminated, if the grinding is carried out on a frequent enough interval so as to avoid the development of any surface defects.



The second step involves the reshaping of the railhead, particularly if there is any significant deformation, such as due to plastic flow. Once again, this step can likewise be avoided if an active, ongoing profile grinding activity is being carried out, one that does not allow for the development of any significant railhead deformation. Finally, the third step, that of grinding the desired railhead profile, to control the actual location of the wheel/rail contact, is carried out.

In order to carry out this multiplicity of grinding activities, which in turn require a large number of specialized grinding patterns, anew generation of grinding machines, with the ability to pre-program a large number of different patterns, and change to these patterns while grinding, has been developed. These machines posses the capability to store and quickly utilize, a large number of patterns, such as illustrated in Figure 6, which makes the application of rail profile grinding, much more effective, than through the use of the older generation grinders with manually controlled motors. Note, the relatively small, but defined differences between the profile patterns used for high rail, low rail, and tangent profile grinding (Figure 6). More dramatic differences are evident when comparing profile patterns with contour or defect elimination (Center concentration) patterns.

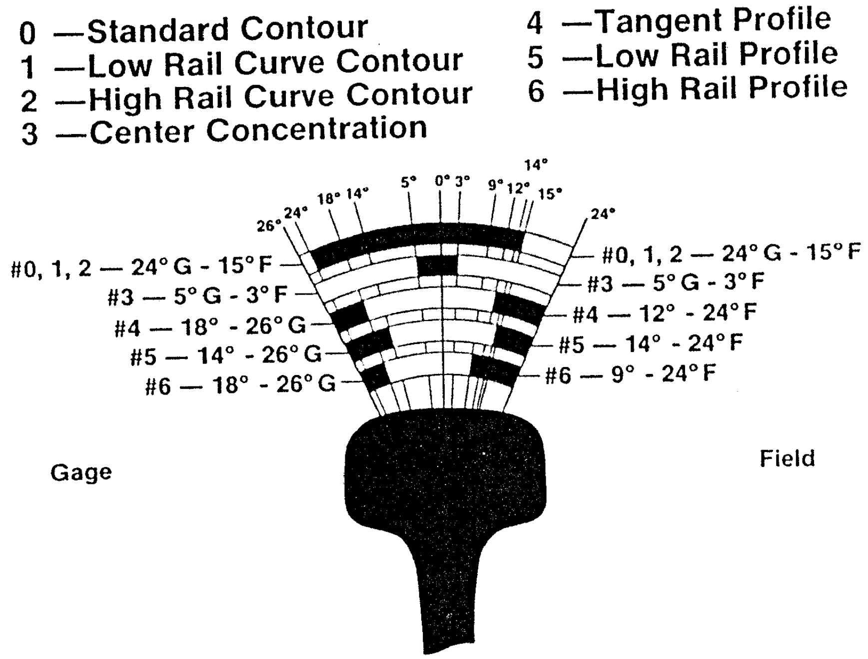


Figure 6. RMS 1 Patterns.

This type of fine control of grinding patterns, coupled with the ability to vary the depth of metal removal (which is readily carried out by varying the grinding speed of these new generation machines), in turn, lends itself to the application of profile grinding to simulate rail wear. This is the use of grinding, in a well-lubricated rail environment, to introduce a controlled amount of metal removal, i.e., controlled “wear”, at only those locations where it is needed to reduce the development of rail fatigue.

As noted earlier, the use of rail profile grinding to control rail surface defects has been active on several North American railroads since the early 1980's (7,11). At least one major North American railroad has reported (12) a reduction in fatigue related defects, since the use of rail profile grinding. This is shown in Figure 7 and 8, which present the relative number of rail defects (with respect to the base year of 1982) following the active use of rail profile grinding in 1982. As can be seen in Figure 7, the number of transverse defects (TDs), which in this case includes the detail fracture class of defects (which would be most affected by profile grinding), decreased significantly since 1982. The total number of reported defects, which includes all classes of defects, also shows a limited overall reduction.

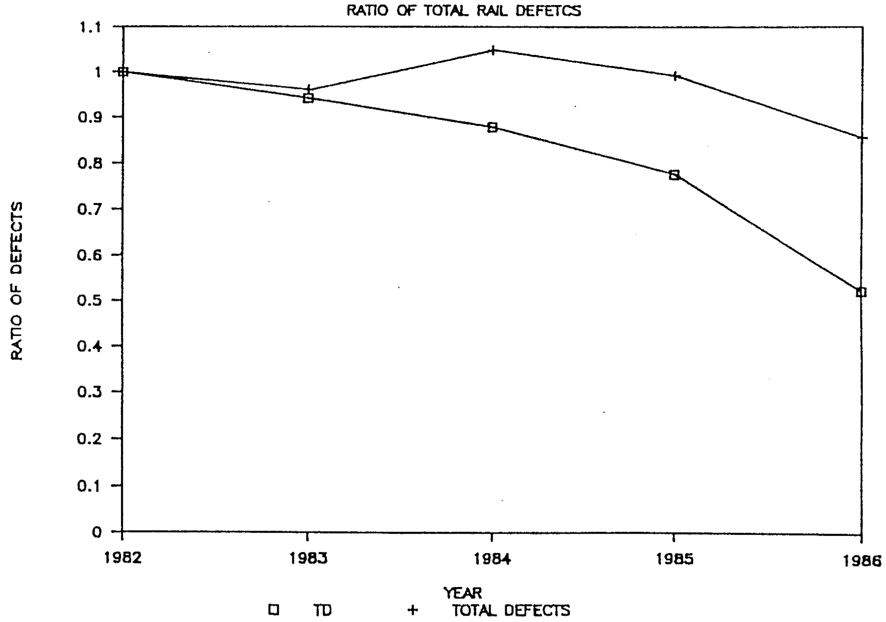


Figure 7. Rail Defects On Major Railroads

However, this is somewhat deceiving in that the total miles of track tested using ultrasonic inspection techniques, increased significantly during the same period. If these defects are normalized by the miles tested, as presented in Figure 8, the downward trend is more pronounced.

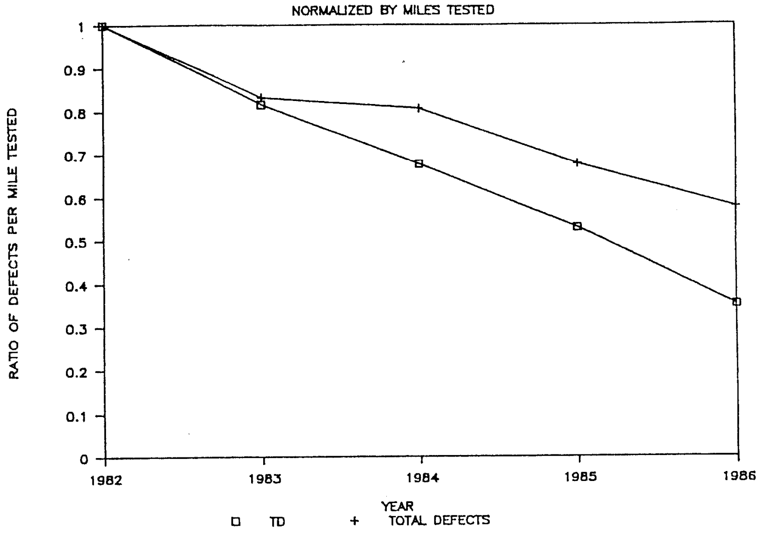


Figure 8. Rail Defects On Major Railroads.

While other changes in rail maintenance policy, such as an increased use for premium rail steel, and an improvement in overall rail steel quality, may have taken place during this period, the use of profile grinding was a "significant" factor in the railroad's overall rail maintenance policy. The decrease in defect occurrence, coincident with the increased use of profile grinding, strongly suggests a relationship, in accordance with the theory noted earlier.

ECONOMICS OF PROFILE GRINDING IN LUBRICATED ENVIRONMENT

While techniques such as rail profile grinding may be able to extend the life of the rail, in track, it is necessary to compare the relative savings associated with this grinding to the cost of the grinding itself. In order to examine this, an economic analysis of rail profile grinding in well lubricated environment, will be presented. This analysis is based on an earlier economic analysis, presented in Reference 9. However, in this case, the frequency of the rail profile grinding has been increased to allow for the use of rail grinding as a surrogate for rail wear.

Figure 9 presents the base case under analysis. The track consists of a five degree curve with well lubricated standard carbon rail and 100 ton unit train traffic. Two cases will be examined, with 25 MGT and 50 MGT annual traffic respectively. Noting the earlier rail life values (Figure 3), unlubricated rail has a wear life of 80 MGT (3.2 and 1.6 years respectively), while lubricated rail has a life (fatigue) of 200 MGT (8 and 4 years respectively). Further noting the life extension due to profile grinding to be at least 100 MGT (9) with frequent profile grindings (every 15 MGTI, the associated costs and benefits of. profile grinding are presented in Figure 10.

Well Lubricated Curve

	25 MGT	50 MGT
Wear Life (Unlubricated)	3.2 Years	1.6 Years
Wear Life (Lubricated)	32	16
Fatigue Life (5%)	8	4
Fatigue Life (Profile Grind)	12	6
Rail Life Extension* (Grinding)	4 Years	2 Years

* Profile Grinding Every 15 MGT

Figure 9. Cost vs. Benefits for Rail Profile Grinding.

CONCLUSIONS

Rail lubrication, while having a significant benefit in extending the wear life of the rail, can result in a shift in failure (and hence replacement) mechanisms for rail from wear to fatigue. This *is* related to the dramatic reduction *in* wear rates associated with the use of lubrication, and the corresponding build up of rail fatigue. Thus, while rail life is indeed extended, the amount of this extension is limited not by the extended wear life, but by the fatigue life of the rail.

In order to allow for an extension of the fatigue life of the rail, rail grinding, and in particular rail profile grinding, has been used to introduce a controlled amount of wear, at those locations where the build up of fatigue is dominant. These include the gage corner of the high rail in moderate to sharp curvature track. Evidence to date strongly indicates that the use of an appropriate form of controlled profile grinding, can indeed artificially simulate rail wear, and in turn extend the fatigue life of the rail in track. Several North American railroads have already adopted an aggressive profile grinding activity.

Economic analysis of the costs and benefits associated with rail profile grinding under well lubricated conditions, similarly show a benefit. For the example of a five degree curve in heavy axle load unit train territory, the return on the grinding investment has been calculated to be 53% for 25 MGT annual traffic levels and 87% for 50 MGT traffic levels. Thus rail profile grinding has been shown to be an economically viable method of extending rail life in the well lubricated environment of moderate to heavy curvature and high track density.

ACKNOWLEDGMENT

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12. Private communication with North American railroad, (Additional details remain confidential at the request of the railroad).

Questions:

R. P. Agrawal: When head hardened rail is used, should grinding be continued at 15 MGT intervals? G. Brave similar question.

AMZ: The actual grinding interval should be a function of the rail wear rate and the rate of fatigue damage accumulation. This is dependent on several factors to include traffic, level of lubrication, type of steel, depth and effectiveness of grinding, rate of profile degradation, etc. The 15 MGT number appears to be a reasonable value for standard carbon rail. For the case of premium rails, this interval could be extended (or alternately a lighter grinding cut used). However, recent research seems to suggest that even more frequent "light" grinds can be very effective in delaying or eliminating certain classes of fatigue damage.

Nick Wilson: Reference Figures 7 and 8. Figures show a reduction in transverse defects and lesser reduction in total defects. This implies a 20% increase in other defects. What were the other kinds of defects?

AMZ: It is possible to reduce all defects as well as TDs without a corresponding increase in any defect category. This is because the absolute number of defects has decreased. Therefore, there is no corresponding increase in other categories required to "offset" the decrease in TDs. However, the rate of decrease in TDs is greater than many of the other categories, and thus the rate of decrease of all defects (which includes TDs) would be less than the TD rate alone.

Dave Davis: The defect data presented seems to indicate that defect occurrence rates are a function inspection frequency. Could you explain this? If the data shown is for detected defects only, what is the effect of grinding on service defects rates?

AMZ: First of all, the data shown includes service defects. Regarding the relationship between defect rate and inspection frequency, what appears to happen is that the number of defects increased as the miles tested increased. This could be due to a number of causes including the fact that the flaw detector cars are not 100% effective and thus can miss a percentage of the defects one time, while picking them upon a repeat run. In addition, increasing the inspection frequency can pick up those defects that have grown to detectable sizes in between inspections.

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