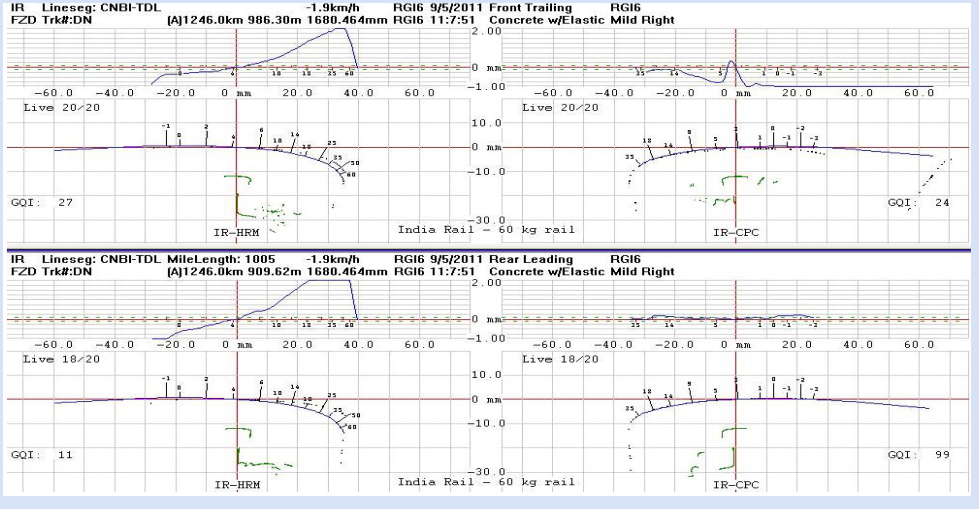
ज्ञान ज्योति से मार्गदर्शन
To Beam As A Beacon of Knowledge

Rail Grinding





November 2022
Indian Railways Institute of Civil Engineering
Pune - 411001

Published By
Indian Railways Institute of Civil Engg.
11-A, South Main Road, Koregaon Park, Pune 411 001.

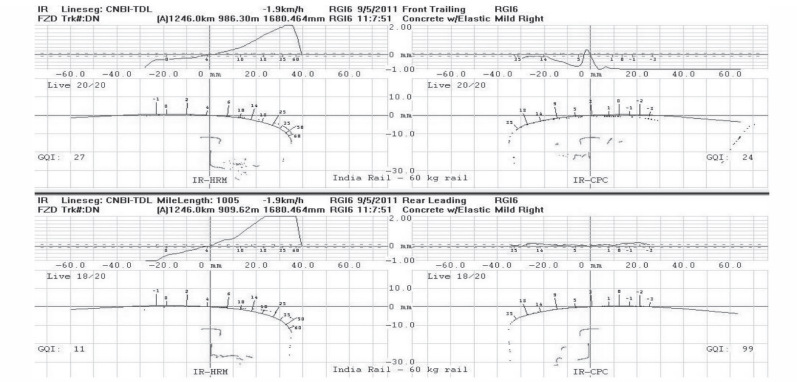
FIRST EDITION : NOVEMBER 2022

Price ₹ 150/-

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November 2022

INDIAN RAILWAYS INSTITUTE OF CIVIL ENGINEERING,
Pune 411001

FOREWORD

Railway, being safer and economical, has been the preferred mode of transportation for passengers as well as freight. The axle load and speed of freight trains and speed of passenger trains has been increasing world over and Indian Railways is no exception. Indian Railway has a mixed traffic with freight and passenger trains running on the same track. The axle load of freight trains was increased from 20.32 T in year 2006 to 25 T in year 2010 i.e. in a small span of 6 years. Dedicated Freight Corridor (DFC) has been designed to carry 32.5 T axle load, though initially trains will be running at 25 T axle load. The freight speed is proposed to be increased to 100 Kmph and that of passenger train to 160 Kmph. Increasing axle load and speed is a socio economic requirement. All this has an impact on rail, causing premature failures and impairing the safety of trains. Rail grinding and milling is a method to remove the surface flaws at initial stage itself and to re-profile the rail head making the profile more favorable to the wheel profile and thus control the stress on rail. This reduces these rail failures, controls the wear of rail, ensures safety of trains and even increases the life of rail.

Though rail grinding and milling started way back in 1950's, Indian Railways realized its importance much later. First 20 stone grinders was inducted in 1995 which was subsequently condemned in 2010. Then two 72 stone grinders were inducted in 2011. These grinders however are not sufficient for vast network of Indian Railways and are covering only limited selected routes with high axle load or GMT. Indian Railway is now planning to grind most of the routes by inducting more production rail grinding machines. Also Switch Rail Grinding Machine (SRGM) to cover points and crossing which is not ground by production grinders are also being inducted along with Rail Inspection Vehicle (RIV).

Hitherto there has been no comprehensive publication, available on working of RGM on Indian Railway, though it being one of the important area of work for the engineers vested with responsibility of track maintenance. The first of this kind of publication on "Rail Grinding" will help field engineers in understanding rail grinding and working of Rail Grinding Machine.

Pune
27th October, 2022

Ashok Kumar
Director General
IRICEN, Pune

PREFACE

I joined IRICEN as Professor/Track Machine in April 2017 where after promotion I am now working as Sr Professor/Track Machines. Before coming to IRICEN, I was posted at RDSO as Director/Track Machines,where I got the opportunity to deal with Rail Grinding Machine (RGM), though for a very brief period of six months. At IRICEN I have been imparting training on rail grinding for the last five years and in the process, interacting with manufacturer and suppliers of machines apart from trainees which has helped me in further understanding of the subject.

Rail grinding was started on Indian Railways in the year 2011 with the induction of two 72 stone grinders. Training to railway men were already being imparted at IRICEN on the subject. However no publication in the book format was available for the guidance of field people. Director General, IRICEN has now given me the opportunity to write a book on the subject. The book has been written, keeping in view the end user, that is the permanent way maintenance staff. The intention is to make them first understand different stresses to which rail is subjected and different failures caused by them. The book subsequently discusses benefit of grinding in reducing these failures and the proper method of grinding to get the best result. Brief on different grinders working or likely to work in future has been covered.

This book is not really an original work. This book owes its contents to all the faculty who have been teaching the subject in the past and have been updating the relevant contents at IRICEN. I would particularly like to mention the contribution of Sh. P.K.Garg, PCE/WR and Ex-faculty at IRICEN who apart from being the pioneer in introducing the subject at IRICEN, has compiled a very useful handbook in the form of "Guidelines for working of Rail Grinding Machine" for field users which I

have been regularly referring for better understanding of the subject. I owe this also to all the people who have participated in numerous discussions in different courses I conducted at IRICEN, officers and supervisors of RDSO and officers at Railway Board dealing with RGM with whom I regularly interacted on the subject. While writing this book I regularly interacted with Sri Yash Sehgal, Director, M/s Vandhana international, the Indian agent of M/s Loram, and with Sri Sidharth Sriniwas, India head of M/s Harsco and the information shared by them has been very helpful in writing this book.

In spite of all my sincerity, the book would not have been compiled in this form without sincere advice and edition by Shri Anil Kumar, SP/T1 and Shri Satya Prakash, Dean/IRICEN.

I also convey my sincere thanks to Shri Ashok Kumar, Director General, IRICEN for his guidance and support in publishing this book.

Any suggestion on further improvement of the book is most welcome.

Anil Choudhary
Sr Professor/IRICEN

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1
Introduction

1.0 General

Indian Railway has a mixed traffic with freight and passenger trains running on the same track. The axle load of freight trains has increased The freight speed is proposed to be increased to 100 Kmph and that of passenger train to 160 Kmph. In future it is proposed to be increased to 200 kmph & above. Increasing axle load and speed is a socio economic requirement. However, all this impacts rail life and the same is reflected in increasing rail fracture and more flaws being detected in USFD testing. Year 2017-18 saw an increase of 25% in rail and weld failure over Indian Railways.The rail & weld fracture comparative position for last 3 year is tabulated below:

FY	2016	2017	2018
Rail & weld failure (Nos)	3237	3546	4369

Various reports of RDSO indicates that the major cause of such failure is Rolling Contact Fatigue (RCF) defects. Since all this affects safety of passengers, it is important that all corrective action to ensure safety is taken. Track structure and maintenance standard of railway track has improved with time, but menace of rail fracture continues to be a matter of concern not only for Indian Railways but for railways world over. Rail grinding and milling has emerged as one of the effective maintenance tools to reduce the damage to the rail due to RCF.

1.1 Rail Profiling Method

Removal of metal is done to re-profile the railhead taking into consideration the profile of the wheel for optimization of the rail wheel contact band and thereby making rail wheel interaction favorable. In the process addresses the issue of removal of surface defects, reduction in the growth rate of internal defects and also the issue of rail wear. This is expected to increase the life of the rail and the wheel, apart from reducing the rate of generation of defects in the rails.

Different methods are used for this as listed below:

a. Rotational Grinding

Removal of metal to achieve the desired profile is generally achieved through rotating grinding wheels. The same can be understood from the below given figure:

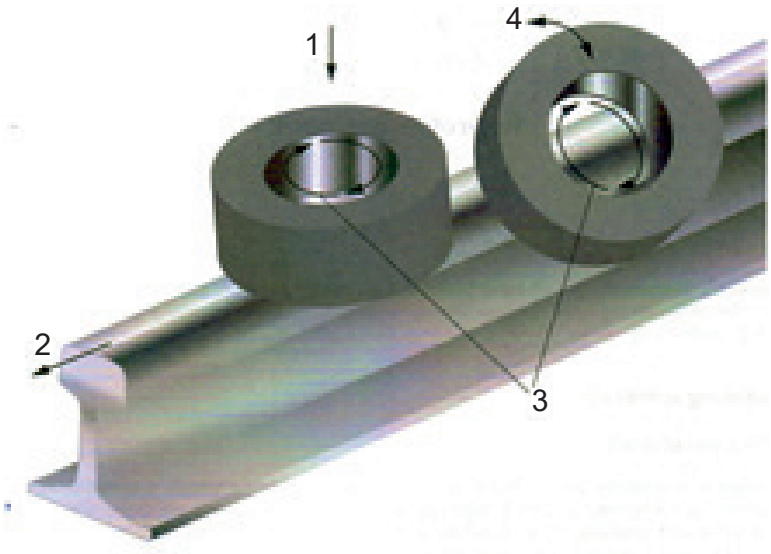


Fig 1.1: Rotational grinding

(1 Stone pressure, 2 Uniform forward and backward movement, 3 Stone rotation, 4 Stone inclination)

The metal removal depends on configuration and size of machine and the grinding speed. Normally the speed is between 3 to 25 Kmph.

b. Milling

It is a machining process whereby rail milling cutter heads, equipped with carbide tipped tools rotate in the longitudinal direction of the rail head. Metal chips are thereby cut out of rail head creating facet contour on the running surface and the rounded contour on the running edge to achieve the desired profile. The same can be understood from the figure below.

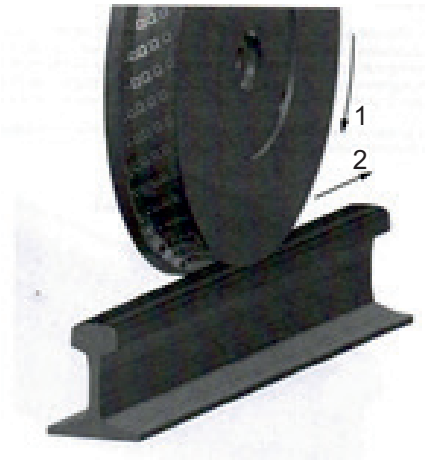


Fig 1.2 : Principle of milling

(1 is milling rotation and 2 is milling direction)

Rail milling is characterized by the large volume of metal removal. The machine is equipped with 2 to 6 milling units and are supplemented with a final finishing grinding unit. The working speed is 500m/h to 1500 m/h.

c. Oscillation grinding

Here material removal is achieved by two components, one grinding stone performs oscillating movements along the longitudinal direction of the rail and the machine moves forward at the same time. The same can be understood from the figure below:

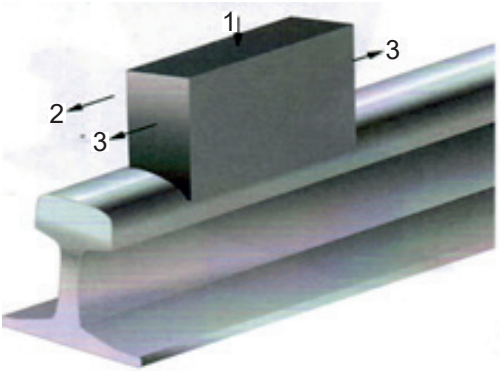


Fig 1.3 : Principle of oscillating grinding
(1 is stone pressure, 2 is uniform forward and backward movement and 3 is oscillating movement)

Volume of material being removed is determined by the number and size of grinding stones, the grinding pressure grinding speed and rail hardness. Normally 24 to 72 stones are provided. Several grinding passes are required to achieve the desired profile. The working speed with oscillation is 1200 m/h. without oscillation it can work at around 15 Kmph.

d. Planing

Rails are planed with a chip removing process by straight and radial cutting plates inserted in a cartridges that are adapted to rail profile. Any predetermined transverse profile can be manufactured. The arrangement can be understood from the figure below:

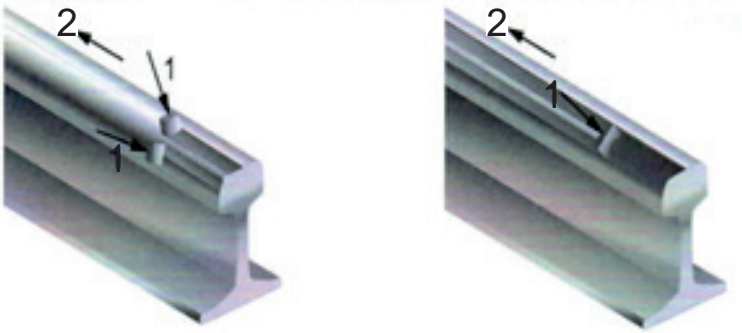


Fig 1.4 : Corner and Radius cut

(1 Pressure of the planning tool, 2 Uniform forward and backward movement)

Metal removal is from 0.2 to 2,5 mm and working speed is 4 to 5 Kmph

e. High speed grinding

High speed grinding is based on the principal of tangential grinding. The grinding stones are not driven by motors but are dragged and rolled along the rail. The angle-offset of the stones results in relative motion lateral to the rail head thus enables grinding. The same can be understood from the figure given below

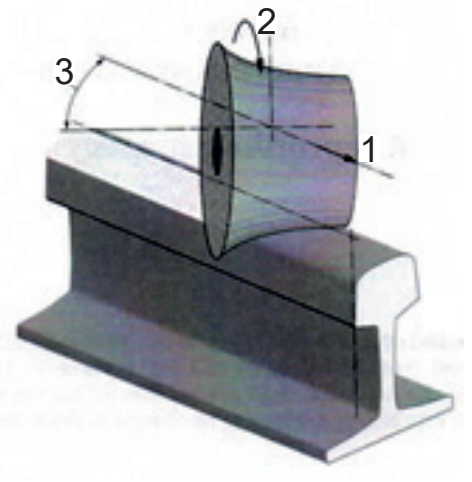


Fig 1.5 : Principle of High Speed Grinding

Grinding speed is between 50 to 80 Kmph. Limited profiles can be achieved and it is a preventive grinding technology.

1.2 Indian Railway and Rail Grinding

Indian Railway is primarily using grinders with rotational technology and will be called RGM for plain track or SRGM for one to be used at points and crossing. The machines using milling technology will be called milling machines. Though rail grinding and milling started way back in 1950's, Indian Railways realized its importance much later. First 20 stone grinders (RGM) was inducted in 1995 which was subsequently condemned in 2010. Then two 72 stone grinders (RGM) were inducted in 2011. These grinders however are not sufficient for vast routes of Indian Railways and are covering only limited selected routes with high axle load or GMT in NR, NCR, ER, SER, ECOR, SCR, SR & SWR. With the increase in axle loads over Indian Railways, it is important that grinding over all such routes are done. Also the existing grinders are not able to grind points and crossing and at some other special track structure locations with check rails like L-xing where special grinders called Specialty Rail Grinding Machine (SRGM) are proposed to be used. Recording rail profile in advance helps in planning the grinding system for achieving desired profile. Rail Inspection Vehicle (RIV) is used for the purpose.

Indian Railways has started inducting R260 rails and in future will be inducting high strength R350HT rails. On such routes with high strength rails, rail grinding becomes even more important and same has been discussed in the book in subsequent chapter. Accordingly Indian Railways has a master plan to procure following machines for meeting the rail grinding requirement.

Machine	Sanctioned	Master planning
Rail Grinding Machine (RGM)	10 Nos	20 Nos
Milling Machine	1 No	Nil
Speciality Rail Grinding Machine (SRGM)	10 Nos	20 Nos
Rail Inspection Vehicle (RIV)	10 Nos	20 Nos

1.3 About the book

The book covers, different stresses on rail, rail defects which can be prevented or creation of which can be avoided by properly using grinding technology. Grinding technology and other special features of grinding machine, milling machine and Rail Inspection Vehicle (RIV) proposed to be inducted in Indian Railways has been discussed in detail.

◆◆◆

2.0 Rail Stresses

Rail is subjected to many types of stresses during manufacturing, transport and service. These stresses are dependent upon manufacturing process, laying process, loading and speed of rolling stock, contact, interaction taking place between Rail and Wheel. These stresses have been classified as under –

A. Bulk stresses- These stresses define the requirement of yield capacity of Rail and includes-

   (i) Internal residual stress

   (ii) Thermal stresses due to temperature variation

   (iii) Bending stresses and torsional stress (Due to vertical and lateral load and its dynamic impact).

   (iv) Stresses due to miscellaneous factors

B. Cyclic stress – This stress defines the endurance requirement of Rail, which is subjected to Cyclic reversal of stress.

C. Contact Stresses – These stresses defines the shear strength and hardness requirement of Rail and includes –

   (i) Rail wheel contact stress

   (ii) Shear stress

The rail properties which are crucial for taking these stresses are:

   (i) Rail Section-The sectional properties like-sectional area, moment of inertia and sectional modulus

   (ii) Ultimate Tensile Strength of rail steel

   (iii) Yield Strength of rail steel

   (iv) Endurance Limit (Bending Fatigue strength)

   (v) Other properties important for rail design are:

   • Fracture toughness and fatigue crack growth rate

   • Hardness and Wear resistance

Table 2.1

Rail	Section	Ultimate Tensile Strength (UTS), Kg/ Sqmm (min)	Yield Strength Kg/ Sqmm	Hardness BHN
880 MPa	60 Kg UIC	90	46.8	260
R260	60 Kg UIC	90	56.07	260-300
1080 Cr	60 Kg UIC	110	57.1	320-360
1080 HH	60 Kg UIC	110	46.8	340-390
1175HT	60 Kg UIC	120	57.1	350-390

For finding the suitability of Rail to carry designed load, the suitability is checked w.r.t its

a. Yield strength to carry Bulk stress.

b. Endurance limit to carry cyclic reversal of stress.

c. Shear strength to carry contact stress.

In addition to that the hardness, fracture toughness should be adequate to reduce wear and to prevent rail fracture.

2.1 Rail Suitability in Yield Strength to carry Bulk Stress

The stresses in rail due to bulk stresses should not exceed the yield strength of rail material. The bulk stresses as calculated for 880 MPa rail and suitability of rails to take different stresses is discussed below

A. Stresses responsible for failure of rail in yielding

(i) **Internal Residual Stress :** Internal residual stresses are the stresses which gets locked in rail during its manufacturing and rolling. During cooling of rail material from molten state to solid state, the cooling is faster at edge than the central portion. This differential rate of cooling, results in locking of stress in the rail material. In addition, it also causes bending of rail which is subsequently straightened by passing these rails through a set of rollers which results in locking of additional stresses. i.e. residual stresses.

It has been found that locked internal residual stress on 60 Kg, 880 MPa, UIC rail manufactured by SAIL is maximum at foot center (tensile) and is around 24.5 Kg/ Sq mm. The same is 250 MPa in EN code.

(ii) **Thermal Stress:** Thermal stress is caused due to temperature variation. Rails are fixed to sleeper through elastic rail clips and these sleepers are embedded in ballast. The elastic clip should hold the rail in such a manner that there should not be any relative movement between rail and sleeper. Theoretically, rail has no thermal stress and is stress free at destressing temperature but is subjected to compressive or tensile stress when temperature increases or decreases respectively as it is restrained from expanding freely. ***Taking Zone-V temperature zone and td as tm+7.5, the maximum thermal stress (tensile) created in 60 Kg, 880 MPa, UIC rail is 11.32 Kg/Sq mm.***

For wider sleeper, the destressing temperature has been reduced by 5 degree in Zone V on trial basis for 2 years. This will reduce the thermal stress to 10.03 Km/Sqmm.

(iii) **Bending and Torsional Stress:** Bending stress and Torsional stress are generated in rails by train loads (axle load). While in straight track, vertical load is prominent, in curves rail is subjected to both vertical and lateral loads. These loads are not acting along the neutral axis of rails but are eccentric and are therefore also causing torsional stress, in addition to bending stress.

The bending and torsional stresses therefore acting can be broken into following

a. Stress due to vertical bending

b. Stresses due to twisting on account of eccentric vertical loading

c. Stresses due to twisting on account of lateral loading

d. Stresses due to deflection of rail on account of lateral load.

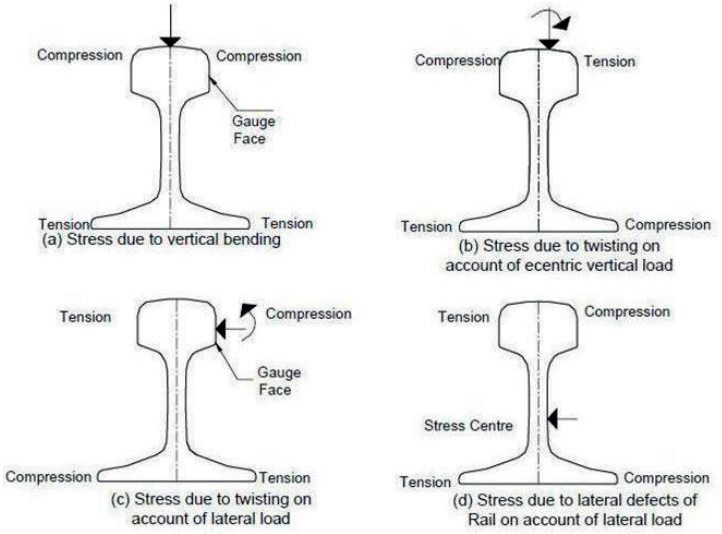


Fig. 2.1 : Bending and Torsional Stresses

Following parameters are required for calculating these stresses.

- Dynamic augmentation of the axle load - This dynamic augmentation of vertical load (axle load) at different speeds are taken from C-100 report of RDSO made for different type of vehicles.
- Adjacent wheel impact - RDSO has prepared a master diagram given in technical paper No 323 for finding the impact on bending stress under a particular wheel due to other wheels within a certain distance.
- Leading wheel impact - Leading wheel if beyond certain distance, increases vertical bending stress under a wheel load . This increase is taken as 10% of bending moment by RDSO.
- Lateral wheel load is calculated using Prud'Home's limit. Load on outer rail is half of Prud'Home's limit value.
- Track modulus-The bending stress depends on track modulus which is defined as load per unit length required for causing unit deflection in track. Track modulus depends on type of track structure, ballast cushion, ballast condition and formation condition etc. For representative track on Indian Railways, the same is taken from CT-12 report by RDSO as

135 kg/cm/cm for first 4t load and 540 kg/cm/cm for beyond 4t load for for 60 Kg rail with sleeper spacing as 1660/km.

- The sectional and material properties of rail- The sectional property of rail is taken for 5% worn out section. The properties used are sectional modulus, radius of gyration, moment of inertia, elastic modulus, the location of shear centre etc. These properties are defined for different type of rail section used over Indian Railways.

Using the above parameters, the bending stress has been calculated by RDSO for carrying 25 t axle load BOXN wagon at 100 Kmph on 60 kg, 880 MPa UIC rail with PSC track at 1660 No./ km sleeper spacing and 300 mm cushion. The critical locations of stress are F1,F2 and H3.

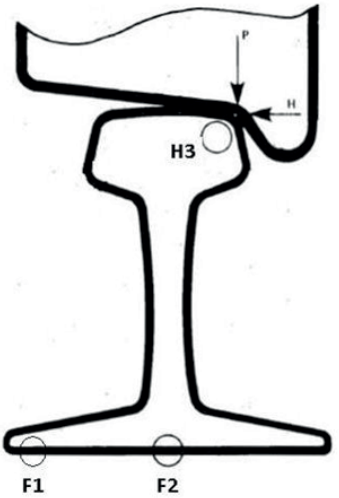


Fig. 2.2 : Critical location of stress

The tensile & compressive stress due to Bending and Torsion calculated at these locations are:

Table 2.2

Stress (Kg/ sqmm)	Head Corner H3 (Compression)	Foot Corner F1 (Tension)	Foot Centre F2 (Tension)
Vertical bending	-14.91	+12.51	+12.51
Eccentricity of vertical load	+4.66	+2.99	-
Twisting by Flange Force	-7.32	- 4.69	-
Lateral deflection under flange force	-4.20	+8.70	-
Total	-21.77	+19.51	+12.51

(iv) Unforeseen reasons: Some additional stresses taken as unforeseen for reasons like flexing of rail in curves etc equal to 10 % of Yield Strength (4.68 Kg/mm2 for 90 UTS) at the edges of rail foot and head and equal to 10% of calculated bending stress at foot center is taken. This therefore comes as 1.326 kg/sqmm in 60 Kg 90 UTS rail discussed above.

(B) Suitability of Rail to carry different axle load on Yield Strength based criteria

Out of the three critical locations i.e. H3, F1 and F2, the maximum stress (tensile) is generated at foot centre (F2), primarily because of high locked residual tensile stress (24.5 Kg/Sqmm)

(i) Suitability of existing 90 UTS (880 MPa), R260 and 1175HT rail for carrying 25 T axle load : Based on the above concept, the suitability of rail in yield for carrying heavier axle load calculated for most critical location i.e. rail foot centre is tabulated below:

Table 2.3

25T Axle load				
Speed & Dynamic Augmentation	**50 Kmph (DA-43%)**	**60 Kmph (DA-47%)**	**75 Kmph (DA-53.5%)**	**100 Kmph (DA-72%)**
Stresses (Kg/sqmm)				
Bending Stress*	10.51	10.79	11.23	12.51
Residual Stress	24.5	24.5	24.5	24.5
Thermal Stress	11.32	11.32	11.32	11.32
Unforeseen	1.05	1.08	1.12	1.25
Total	**47.38**	**47.69**	**48.17**	**49.58**
Yield Strength of 880 MPa rail	46.8	46.8	46.8	46.8
Yield Strength of R 260 rail	56.07	56.07	56.07	56.07
Yield Strength of 1175 HT rail	57.1	57.1	57.1	57.1
Yield Strength of 1175 HT rail	57.1	57.1	57.1	57.1

*Taken from table 2.6

From the above it can be seen that, on yield criteria, 880 MPa rail is not suitable for carrying 25 t axle load even at 50 Kmph. R260 and 1175 HT (350 HT) rails are suitable for carrying 25T axle load at 100 Kmph.

(ii) Suitability of 90 UTS (880 MPa), R260 and 1175HT (350 HT) rail for carrying 22.9 T axle load:

Based on the above concept, the suitability of rail in yield for carrying heavier axle load calculated for most critical location of rail foot Centre is tabulated below:

Table 2.4

22.9T Axle load				
Speed & Dynamic Augmentation	**50 Kmph (DA-43%)**	**60 Kmph (DA-47%)**	**75 Kmph (DA-53.5%)**	**100 Kmph (DA-72%)**
Stresses (Kg/sqmm)				
Bending Stress	9.68	9.93	10.34	11.51
Residual Stress	24.5	24.5	24.5	24.5
Thermal Stress (Zone-IV)	11.32	11.32	11.32	11.32
Unforeseen	0.97	0.99	1.03	1.15
Total	**46.47**	**46.74**	**47.19**	**48.48**
Yield Strength of 880 MPa rail	46.8	46.8	46.8	46.8
Yield Strength of R 260 rail	56.07	56.07	56.07	56.07
Yield Strength of 1175 HT rail (R350HT)	57.1	57.1	57.1	57.1

From the above it can be seen that, on yield criteria, 880 MPa rail is not suitable for carrying 22.9 t axle load for speed of vehicle more than 60 Kmph in temperature Zone IV. R260 and 1175 HT rails are suitable for running 22.9 T axle load at 100 Kmph.

However if the destressing temperature is reduced by 5 degree, the thermal stress reduces from 11.32 to 10.03 Km/Sq mm i.e. reduction by 1.29 Km/Sq mm. Total stress at 75 Kmph therefore reduces to 45.9 Kg/Sq mm (47.19- 1.29 Kg/Sq mm). 22.9 T axle load in that case be permitted at 75 Kmph on 880 Mpa rail. Similarly, the stress by 25T axle load at 50 Kmph in Zone IV with wider sleeper reduces to 46.09 Kg/Sqmm (47.38-1.29). Thus 25T axle load can be permitted at 50 Kmph.

C. Shortcomings of calculation methodology used

The calculation method used above for finding the suitability of Rail in yield strength criteria is having shortcomings as below:

(i) Actual dynamic wheel loads (vertical & lateral) is taken using CT-100 report of RDSO and are not known actually which may be higher/Lesser. Measuring wheel is required or else a better assessment method internationally accepted may be used.

(ii) A factor of 1.2 for extra vertical load on curves due to cant excess or deficiency is being considered in international literature which is not being considered in IR methodology.

(iii) Actual lateral force coming on one rail, particularly on the outer rail of a curve, is likely to be higher than half of the Prud'Home's limit inducing higher stresses in rail.

(iv) The sectional wear considered in calculation corresponds to less than the limiting value.

(v) Overloading of wagon not considered.

(vi) Track modulus being taken is from the study conducted in 1970's. Track structure and maintenance practice has changed with time. There is a need to recheck the track modulus for existing structure.

However, Indian Railway method of calculation has been verified by TTCI and it is found to be in line with international practice.

2.2 Rail Suitability under Cyclic Loading (Fatigue failure)

Any material subjected to cyclic loading, encountering cyclic variation of stress or cyclic reversal of stress between compression and tension fails in fatigue after some cycle of loading.

Endurance limit is the limit of cyclic stress which the material can endure without failure in infinite cycles of loading. It is a material property and defines the maximum limit of stress within which the reversal of stress can takes place. The checking is done by subjecting the sample made out of rail to around 2 million cycle of loading.

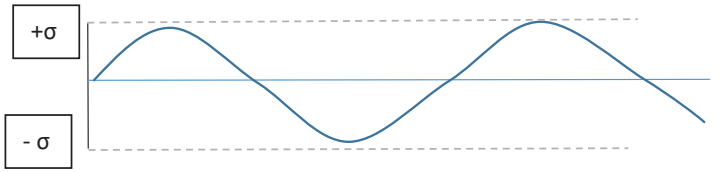


Fig. 2.3 : Cycle reversal of stress

For 90 UTS rail material, this endurance limit is 33.3 Kg/Sqmm,

that means if the cyclic loading is creating a reversal between +33.33 Kg/Sqmm (compressive) to -33.33 Kg/Sqmm (tensile), the material will not fail even after infinite cycle (taken 2 million for testing) of loading. This reversal is taking place about mean value of zero stress.

In rails, there is always a locked constant stress. If we take rail foot as the critical point, the constant locked tensile stress in 880 MPa is 11.32 Km/Sqmm (thermal in Zone IV) and 24.5 Kg/Sqmm (residual stress). Thus total constant locked tensile stress is 35.82 Kg/Sqmm. Due to train loading, reversal of bending stress takes place about this mean position and the limit within which reversal of stress can take place for infinite life is calculated by smith diagram.The limits for 880 MPa Rail and R260 Rail and the actual stress created by 25T axle load of 100 kmph is given below:

Table 2.5

Rail Type	Axle Load& Speed	Range of permitted stress as per smith diagram (Kg/Sqmm)	Actual stress* (Kg/Sqmm)
880 MPa	25T (Speed-100 Kmph)	35.5 to 46.8	32.75 to 49.58
R260	25T (Speed-100 Kmph)	25.63 to 56.07	32.11 to 49.59

** Calculation not shown here and taken from RDSO report.*

Thus on 880 MPa rail, the actual stress is beyond the range permitted for 25T axle load wagon at 100 Kmph and this rail will fail after some definite cycle of loading in cyclic fatigue. R260 rail however will not fail due to fatigue even after infinite cycle of loading as the stress is within the permissible range. Similarly 1175 HT (R350 HT) Rail is expected to have infinite life under cyclic loading for 25T axle load at 100 Kmph, however that can be ascertained after endurance limit of the material is found and smith diagram is made.

2.3 Rail Suitability to take Contact and Shear Stress

Rolling Contact Fatigue (RCF) defect refers to a range of defects that occur due to the development of excessive contact/shear stress at or close to the wheel/ rail contact surface which exceed the shear strength of rail material.

Following are the design considerations for ensuring adequacy of

rail with respect to the contact stresses

- Shear strength and shear stress generated
- Yield and shakedown

A. Shear Strength and Shear Stress

According to Hertz theory, the contact area between two curved elastic bodies such as wheel and rail head is generally ellipsoidal, and the contact stress distribution is semi-ellipsoidal.

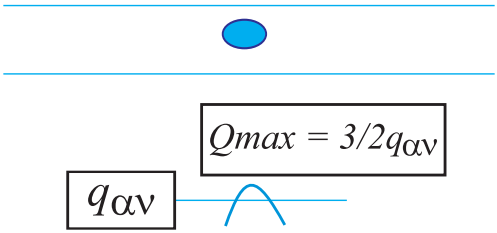


Fig. 2.4 : Maxm and average contact stress

The size of this elliptical contact is around 10-12 mm on major axis and 5-8 in minor axis. The contact however will depend on radius of the wheel and crown radius of the rail.

The shear stress distribution observed in the rail under static vertical load is shown below (Further discussed in chapter 3):

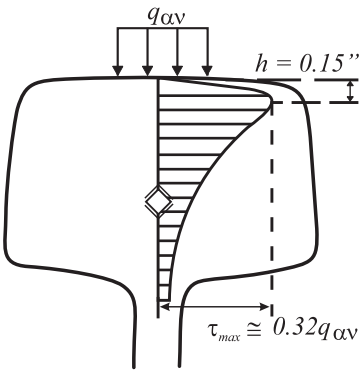


Fig. 2.5 : Shear Stress Distribution under rail

It is observed that the maximum shear stress is below the surface at a distance of 0.15” (3-4 mm) as shown.

$$\tau_{max} = 4.13 \sqrt{Q/R}$$

Where Q is wheel load in Kg and R is the radius of wheel in mm.

Wheel load is increased by 1000 Kg to account for constant extra load on one rail of curve due to cant excess or deficiency. It can be observed that lesser is the wheel radius, more is the the shear stress

The above calculation of maximum shear stress is applicable for tangent track having rail-wheel contact at the top of the rail head. However, this value can drastically change under the following conditions:

(i) Reduction in the area of the contact patch due to contact taking place near the gauge corner of rail in sharp curves

(ii) Tangential forces generated at the rail-wheel contact due to lateral/ longitudinal slippages in curves and tractive/ braking forces

(iii) Dynamic component of wheel load

The permissible stress in rail is:

$$\tau_{per} = \frac{\text{Yield Strength}}{\sqrt{3}}$$

As an approximation, yield strength is taken as 50% of UTS and thus shear strength of rail becomes 30% of UTS. The shear strength of 880 MPa rail and R260 rail both having UTS of 90 is taken as 27 Kg /Sqmm. and that of R350 HT will be 36 Kg/Sqmm.

However from yield strength criteria, the shear strength of different rails used over IR is

Table 2.6

Rail	UTS (kg/Sqmm) (IRS T-12)	Yield Strength (Kg/Sqmm) (IRS T-12)	Shear Strength (Kg/Sqmm)
880 MPa	90	46.8	27
R260	90	56.07	32.37
1175 HT*(R350 HT)	120	57.1	33

** The yield strength of R350 HT rails are found to be far more than the value specified in IRS specification. The shear strength is thus going to be higher.*

It is difficult to actually assess the stress generated in rail at rail wheel interaction point when negotiating a curve as it will depend

on rail and wheel profile at the contact point and the contact area generated.

As per C.Esvald, the actual shear stress is around 50% more in sharp curves. The required UTS of rail assuming shear strength is 30% of yield strength and yield strength as 50% of UTS is:

Table 2.7

Axle Load	New Wheel Diameter	Contact Stress (New wheel)		Required UTS (Kg/mm^2) (New Wheel)	
		Straight	Sharp Curve	Straight	Sharp Curve
22.9	1092	18.91	28.37	63.04	94.56
22.9	1000	19.76	29.64	65.88	98.82
22.9	840	21.56	32.34	71.88	107.82
25	1092	19.76	29.64	65.87	98.80
25	1000	20.65	30.98	68.83	103.25
25	840	22.53	33.8	75.10	112.60

It can be observed that for new wheel from shear strength criteria 880 MPa rail, R260 rail and 1175 HT rails are all suitable for straight track for 22.9T and 25T axle load. For sharp curve, only 1175HT is suitable. For worn out wheel, the stress is going to be even higher.

B. Yield and Shakedown:

The tractive force of locomotive, causes tearing of rail material (ratchetting) at the contact point. The material may be stretched beyond elastic yield limit causing permanent damage to the surface. However, beyond initial yield, the maximum contact load which can be sustained by a body in rolling contact, with limited plastic deformation, is known as the shakedown limit. Contact stress beyond this shakedown limit is responsible for formation of surface defects.

The typical mechanical behavior of any material when subjected to rolling contact and cyclic load is depicted below:

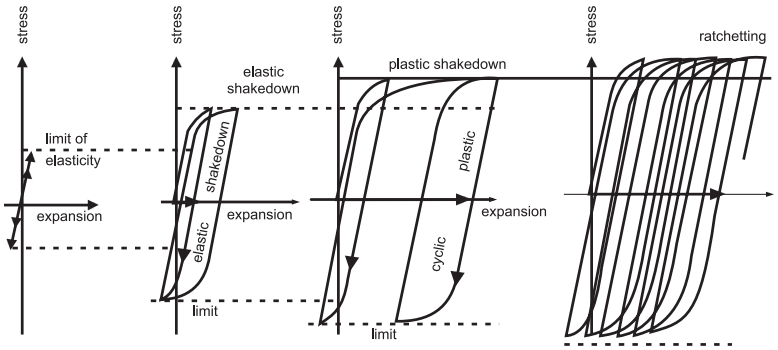


Fig: 2.6 Elastic and Plastic deformation under rolling contact and cyclic loading

If the stress remains lower than elastic limit, no plastic deformation takes place and material behaves elastically leading to high cyclic fatigue failure. When the stress increases initially, material hardening takes place such that the stress can be borne without structural deformations occurring. This limit is elastic shakedown limit. If stress goes beyond elastic shakedown limit, plastic deformation will take place which does not progress as the load is cyclic. This limit is plastic shakedown limit. If stress goes beyond this, each subsequent cyclic will cause further deformation eventually leading to cracking. This behaviour is called ratchetting.

The stress created at surface should be within plastic shakedown limit to prevent damage to the surface. The shakedown limit can be calculated from the below graph

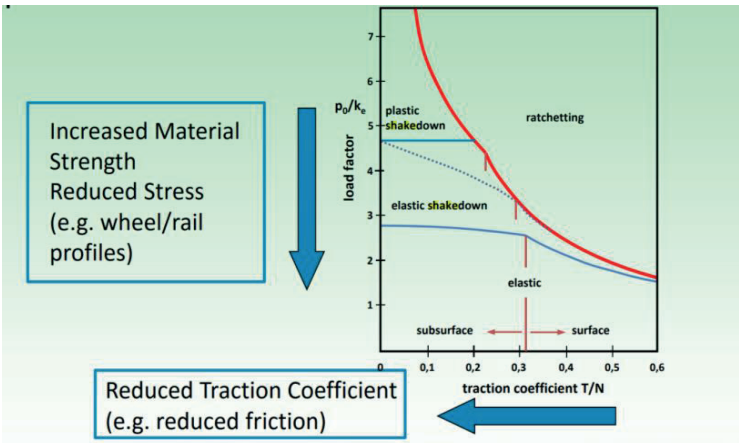


Fig 2.7 : Shakedown diagram

On the X-axis is coefficient of friction μ (Tangential force (T) / Vertical force (N)) and on the Y axis is the maximum normal surface stress (P_o) /shear strength K_e .The red line is the limiting line beyond which failure (ratchetting) takes place. If the value is close to red line subsurface defects are created.

It can be seen that the parameters that keeps the values on left side of red line are suitable for reducing shear failure of rails. Thus by reducing contact stress, by having compatible rail & wheel profile by reducing traction and by using high shear strength rail, the shear failure of rail can be reduced.

Taking coefficient of friction between rail and wheel i.e. steel and steel as 0.3, the maximum normal surface stress (P_o) by shear strength (K_e) i.e. P_o/K_e permitted will be 3 (approx.).

As P_o is the maximum normal load that can be taken, it will depend on contact area.

Taking contact patch of rail and wheel to be quasi elliptical of size around 13 mm (area- 132.665sq mm), the shear strength required for different axle load is tabulated below.

Table 2.8

Axle Load (t)	Po (Wheel load/ contact area) in Kg/ Sqmm	Required shear strength (K_e) for P_o/K_e to be less than 3 (Kg/ Sqmm)	Rail UTS required (Kg/ Sqmm)	Suitable Rail
22.9	86.3	> 28.77	95.66	1175HT(R350HT)
25	94.22	> 31.4	104.66	1175HT(R350HT)

This is a sample calculation and is dependent on coefficient of friction and also on rail and wheel contact patch. However it gives fairly good idea of the failure of rail in shear. Thus from (A) and (B) above, it is observed that 1175 HT (350HT) rail is required to meet with shear stress requirement in sharp curves. Also it keeps shear stress within elastic shakedown limit under tractive force for higher axle loads i.e. 22.9T/ 25T. A study in Australian Railway (Ref. “Railway Track Design – A review of current practice” by N.F.Doyle, a publication of Bureau of Transport Economics, Australian Govt. Publishing Service) on requirement of UTS & yield strength from shakedown criteriais given below:

Ultimate Tensile Strength Requirements

For 22.9t axle load, the Ultimate tensile strength required for tangent track is around 900MPa for 960mm wheel diameter and more than 900 MPa for 840mm wheel diameter. For curved track, it is more than 1080 MPa and is in the range of 1080-1100 MPa for 960mm wheel diameter and 1110-1130 MPa for 840mm wheel diameter.

For 25t axle load, the Ultimate tensile strength required for tangent track is more than 880 MPa. It is in the range of 920-930 MPa for 960mm wheel diameter and 940-960 MPa for 840mm wheel diameter. For curved track, it is in the range of 1100-1120 MPa for 960mm wheel diameter and 1140-1160 MPa for 840mm wheel diameter.

Yield Strength Requirement

For 22.9t axle load, the yield strength required is in the range of 450-460 MPa for tangent track and 640-660 MPa for curved track for 960mm wheel diameter.

For 25t axle load, the yield strength required is in the range of 460-480 MPa for tangent track and 660-680 MPa for curved track for 960mm wheel diameter. The requirement for 840mm wheel diameter is even higher.

2.4 Rail Hardness and Fracture Toughness

Hardness is a measure of a material's resistance to permanent deformation i.e. how much a material can withstand scratches, cuts, or other abrasions, as well as plastic deformation.

Toughness is a measure of how much deformation a solid material can undergo before fracturing and is measured by the amount of breaking energy they can withstand. Fracture Toughness is the ability of material with indigenous cracks to resist fracture by absorbing energy.

Therefore, it can be said that hardness and toughness have an inverse relationship. For a particular solid; hardness increases as toughness decreases.

A. Hardness of Rail

Harder rails normally will have more UTS. As mentioned hardness of 880 MPa and R260 Rail are same as 260 BHN minimum. Hardness of 1175 HT is 350 BHN and thus is very high.

B. Fracture Toughness & Rail Failure

The most common cause of failure of rail is the fatigue failure like kidney flaw caused by repeated higher contact stress. Fatigue failure almost always occurs in three stages:

(i) The initiation of Crack

(ii) The growth of Crack

(iii) Final fracture or collapse of structure.

Stages (i) and (ii) of the fatigue process are caused by repeated loading of rail by wheels. In rare cases where the structure already contains a crack like defect due to some reason including during manufacturing, the fatigue failure will start from stage (ii). Stage (iii) is caused by one loading event which may be abnormally severe or as is more likely the final occurrence of a normal load.

The initiation of crack may require millions cycle of loading and during this time there is no way of detecting the forth coming crack. The growth of crack at its initial stage also requires million cycle of loading and thus stage (i) and (ii) will take place many years and during this period there is no perceptible change in the rail shape or dimensions. The final failure will be sudden brittle failure caused by increasing load. Since no visible warning is available during stage (i) and (ii), USFD testing is the only existing method to detect these flaws before final failure takes place. Final fracture will take place when the fatigue crack length and applied stress (included locked residual stress, thermal stress) causes a critical and unstable condition and normally this causes a sudden brittle failure. The unstable condition is determined by the fracture toughness of the material sometimes described as its resistance to fracture in the presence of a sharp fatigue or fatigue like crack.

Fracture toughness governs the ability of rail steel to resist propagation of cracks from rolling contact fatigue and other defects. Good fracture toughness is particularly important in the prevention and propagation of transverse defects

The longer the flaw, the lower is the stress needed to cause fracture. Fatigue crack growth rate is defined as the crack extension per cycle of loading. i.e. $\Delta a/\Delta N$ where a is flaw size and N is cycle of loading.

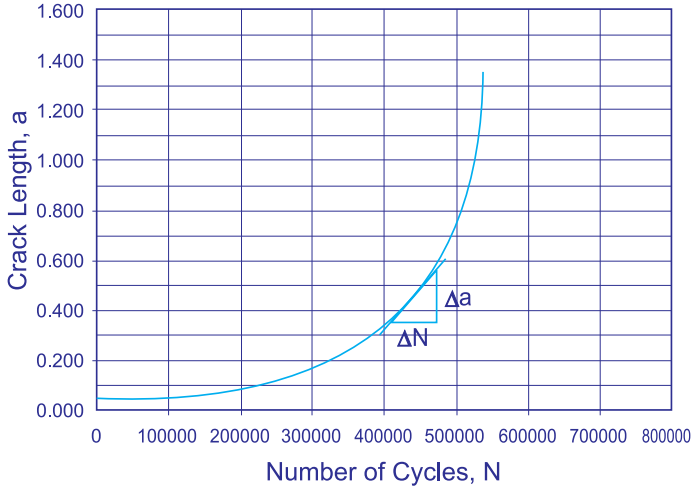


Fig: 2.8 Crack propagation rate

Thus if any internal flaw is generated, the higher fracture toughness of material will prevent that to be converted into fracture of Rail. Fracture toughness is measured in laboratory and of different rails are:

Table 2.9

Rail	Fracture Toughness (MPa m1/2)
880 MPa	29
R 260	29
1175 HT (R350HT)	32

R350HT rail has more fracture toughness and thus is best.

2.5 Rail Design Limitations and Griding Requirement

As discussed, the suitability of rail is checked for its capacity to take

- Bulk load and not fail in yield strength.
- Cyclic load and not fail due to cyclic variation or reversal of stress
- Contact load and not fail in shear and shake down

While rail may be designed for meeting the above condition but even these do not guarantee safety against failure. This is more

so applicable to contact stress failure as this stress can be very severe depending on how the rail and wheel profile interact with each other. These are normally surface and subsurface failure and can be controlled by regularly eliminating them at interaction & managing profile of rail and wheel both making rail and wheel interaction favourable. Such failures are discussed in Chapter-3

2.6 Criteria for Rail Renewal on Indian Railways

Para 202 (i) of Indian Railway Permanent Manual (IRPWM 2020) specifies following criteria for rail renewal which are primarily fatigue and wear based and are reproduced below in brief:

A. Incidence of rail fractures/failures

A spate of rail fractures on a particular section having 5 withdrawals of rails per 10 km in a year due to fracture and/ or rail flaws detected ultrasonically falling in the category of IMR will have priority while deciding rail renewal.

B. Wear on rails

(i) Loss of rail section:

Table 2.10

Rail Section	Loss in section as percentage
60 Kg/m	7
50 Kg/m	6

(ii) Vertical wear limit:

Table 2.11

Rail Section	Vertical Wear
60 Kg/m	13 mm
50 Kg/m	8 mm

(iii) Lateral wear limit:

Table 2.12

Section	Category of track	Lateral Wear
Curves	A and B Routes	8 mm
	C and D Routes	10 mm
Straight	A and B Routes	6 mm
	C and D Routes	8 mm

C. Expected service life in terms of Gross Million Tons (GMT) of traffic carried:

Table 2.13

Rail Section	Total GMT Carried for	
	72 UTS rails	90 UTS rails
60 Kg/m	550	800
52 Kg/m	350	525

Service life in terms of total GMT of traffic carried for considering through rail renewal of 60 kg 90 UTS rail would be 1000 GMT on the routes covered by rail grinding, provided condition of rail is satisfactory as per the other stipulated criteria mentioned in above on fracture/failure and wear.

The GMT based criteria specified in IRPWM for 72 UTS rails was existing since long time (this was wear based). For specifying the GMT based criteria for 90 UTS rails, RDSO carried out studies on rate of wear with respect to traffic density. It was noticed that GMT required for same level of vertical wear in 90 UTS rail was 1.57 times more than that for 72 UTS rails. This formed the basis for GMT based criteria for 90 UTS rails (800 GMT).

In addition, the criteria also mentions the failure on account of corrosion and maintainability as criteria for rail renewal. However these are not directly related to rail stresses and are maintenance issue.

Studies on failure in 90 UTS rail were undertaken by RDSO on Agra division of NCR in August 2002-September 2004 and results are contained in RDSO Report No. MC-82 of Sept. 2004. This report indicates that large no. of failures of 90UTS rails had occurred at cumulative GMT ranging from 14 to 497. Analysis of fractures indicated that about 40% of failures are on account of defect code 211 i.e. internal flaw in head, transverse breakage indicating that majority of rail failures were on account of Rolling Contact Fatigue (RCF).

The gauge face kidney flaws were more in 90 UTS Rails and is around 1.2 times more than 72 UTS rails.

RCF and wear of rail happens because of high value of contact stress at the rail wheel interaction location.

Rail however is subjected to many other stresses also in addition to contact stress.

◆◆◆

3.0 General

As discussed in chapter 2, the high value of contact stress causes surface and subsurface defects which may ultimately result in rail failure. Even if the rail has sufficient shear strength, still due to varying conditions depending on rail and wheel profile, track condition, wheel condition, vehicle suspension, axle load, speed of train etc the failure due to high contact stress is inevitable. The defects generation however can be controlled and the failure of rail can be avoided by reprofiling the rail head. This chapter deals with the rail wheel interaction at contact point.

3.1 Rail and Wheel Profile over Indian Railways

The unique property of steel to steel contact results in minimal deformation of both contacting bodies under load. This results in rolling contact with minimum energy loss across the contact patch and in minimum damping within material of the contacting bodies. That is why the rolling resistance associated with railroads is so low and permits the transport of vast tonnage at less energy consumption.

The different area of rail can be defined as below:

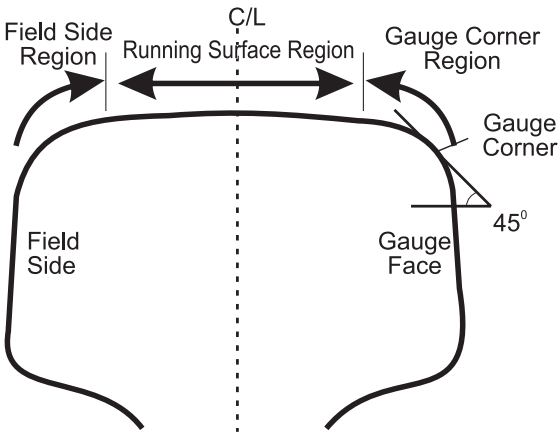


Figure 1 - Regions in 60 Kg/m Rail

Fig 3.1 Rail head surfaces

The profile of UIC 60 Kg rail used on IR is as given below

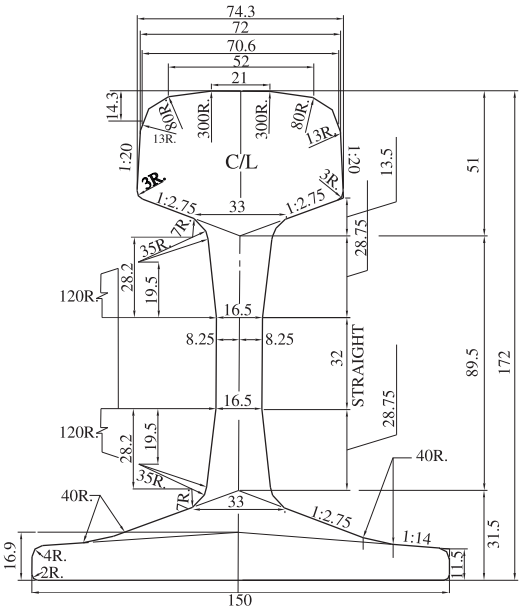


Fig 3.2: 60 E1 Rail Profile

The wheel profile of rolling stock over Indian Railways is worn out wheel profile. The worn wheel is not having a conical tread but is in the form of a hollow tyre matching with the average profile caused by wear. If a pure conical profile is given, the initial wear is going to be very high and wheel turning frequency will be more.

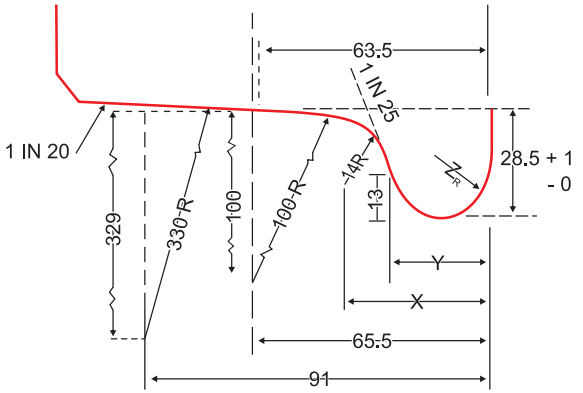


Fig 3.3 : Worn out wheel Profile as per RDSO Drg No.WD88021

3.2 Conicity of Wheel and Effective Conicity of Wheel Set

The rolling surface of wheel i.e. wheel treads are cut to a cone angle γ, For IR if provided with uniform slopes on tread, this is 0.05 (1/20).A pure conical wheel will be making contact on center of rail head.

Conicity of wheel is defined as

$$\gamma = \frac{\Delta r}{Y}$$

Where Y is the displacement of wheel and Δr is the rolling radius differential created due to this displacement.

True measure of the conicity is the function of both wheel on the wheel set and both rails in track. For any lateral position of the wheelset, the difference in radius between the two wheels at the contacting point is called the rolling radius difference or RRD as shown in figure below

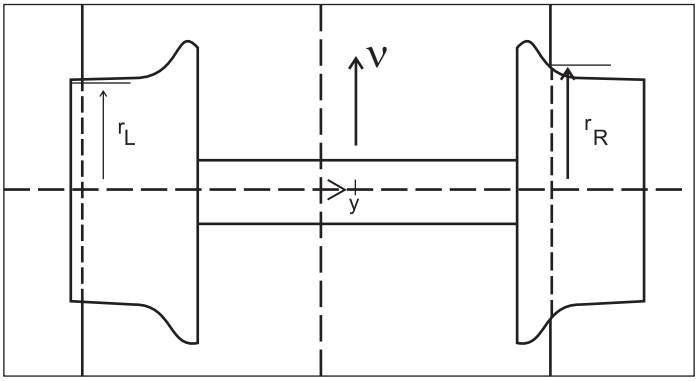


Fig 3.4 : Rolling Radius Difference (RRD)

The effective cone angle of the wheelset on the rails is referred to as the 'conicity' or "effective conicity" called Ye.

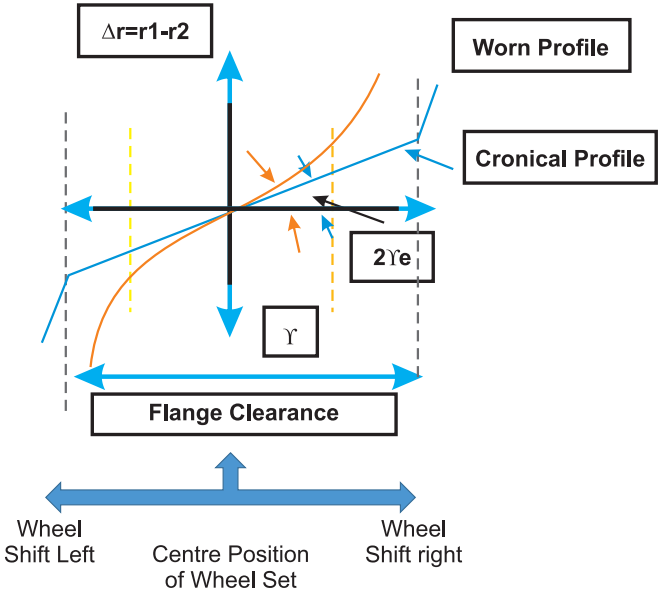


Fig 3.5 Conicity and effective conicity

The effective conicity (Δr /Y) is constant for conical tread. However for worn out wheel profile, the effective conicity increases with displacement. Also effective conicity of worn wheel is more than that for conical tread.

Mathematically, the effective conicity is calculated as one-half of the slope of the graph of rolling radius difference versus wheelset lateral shift:

- A wheel with a coned profile that has a slope of 1:20 that is sitting on rails with a convex head would be expected to have a conicity of 0.05 (i.e. one half of [1/20+1/20] = 1/20 = 0.05).
- For new wheels with a variable slope and for worn wheels, the conicity (ϒe) is defined as one-half of the rate of change of RRD with wheelset lateral shift when the wheels are in tread contact on the rails. In this case it is common to use the term effective conicity.

The wheel tread conicity results in change in rolling diameter of wheel in contact with rail table whenever the wheel moves laterally. Due to symmetry of the wheel set with respect to track, the rolling diameter of both left and right wheel are equal when wheel set is

central to track. If displaced to the right of the central position, right wheel rolling diameter ($2*r_R$) would be larger than left wheel rolling diameter ($2*r_L$)). As the railway wheel set consists of two wheels rigidly connected, both the wheel undergo equal rotation. Therefore, the right wheel would travel a longer distance than the left wheel, due to pure rolling movement. Differential movement of the wheels results in the wheel set (axle) acquiring an angular configuration with respect to track. This results in movement of the wheel set along a curved path, and towards the center of track. Due to the angular configuration, the wheel set continues moving to the left even after it becomes central to track (and rolling diameters become equal). As the wheel set moves further to the left of the central position , a similar mechanism sets in, whereby, due to the difference in rolling diameter of the wheels, the wheel set is gradually brought back towards the central position. The movement takes a sinusoidal path as shown below

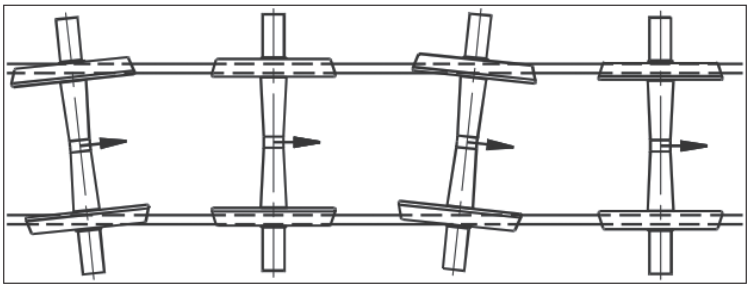


Fig 3.6: Sinusoidal motion of single wheel set

This is pure rolling and is defined as the zero force state of the wheel set.

The wavelength λo of the sinusoidal motion which a single wheelset with constant conicity (γ) would execute, is given by the formula (Klingel);

$$\lambda_0 = 2\pi\sqrt{\frac{rG}{2\gamma}}$$

Where r = wheel radius measured at a distance of 63.5 mm from inner face of wheel in case of B.G. wheel G = Dynamic gauge Dynamic gauge is the distance between the two wheel tread rail top contact points of a wheelset. It is approximately taken as the distance c/c of rail heads. The values of G adopted on Indian Railways Broad Gauge is, G = 1750 mm.

The frequency of oscillation is given by

$$f = \frac{v_o}{\lambda_o}$$

Where v_o is the speed of the vehicle. It can be seen that if conicity increases, the wavelength reduces and frequency of oscillation increases creating unstable situation.

The vehicles with a coned wheel profile i.e constant conicity will oscillate as shown below(Fig 3.7) making a contact in a band of x mm, causing wearing of wheel tread in this range. Since the conicity remains constant, the vehicle movement will be very stable with a constant frequency of oscillation at a particular speed on straight track

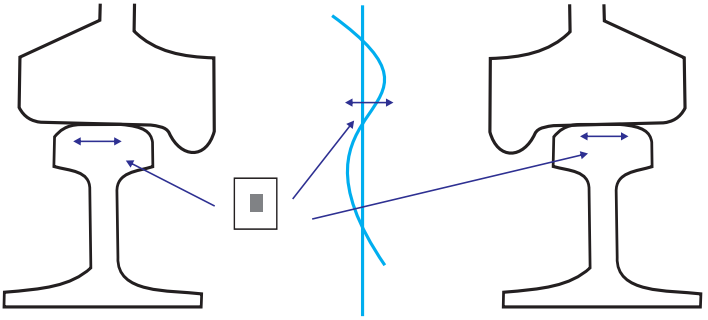


Fig 3.7 Contact band created on rail

This contact will always be at the crown with a very small contact patch causing high rail stress at the contact point. This will cause RCF failure and increased vertical wear of rail. Therefore, conical tread profile of wheel is good for stability of vehicle in tangent track but is not good for controlling RCF and wear of rail.

Therefore worn wheel profile is good for controlling wear and RCF of rail but is not good for stability of vehicle in tangent track.

For worn out wheel profile, the conicity is not constant but increase with lateral displacement causing following impact :-

a) Reduced wavelength of oscillation

b) Increased frequency of oscillation thus unstable movement

c) Reduced contact band (x) so localized wear of wheel causing hollowing of wheel

d) Reduced stress in rail & wheel due to matching wheel and rail

profile.

In general with time, the rail and wheel will wear to have a conformal type of profile which increases effective conicity thus reducing wear and RCF generation of rail but increases instability of vehicle on tangent track.

On curves of radius R, in pure rolling situation, the lateral displacement Y towards outside is given by Redtenbachers formula and is shown in the Fig 3.8

$$Y=\frac{Gr}{2R\gamma}$$

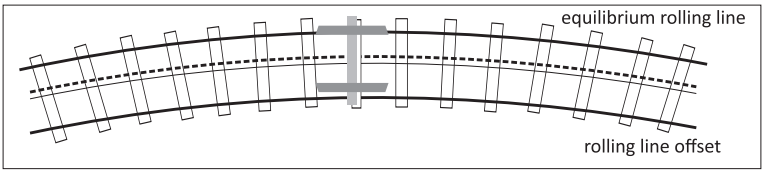


Fig 3.8 Lateral displacement of wheel set in curve

The equation shows that the wheelset will be able to move outward (Y) to achieve pure rolling only when sufficient flangeway clearance for a given radius of curvature and conicity of wheel is available. For a given curve radius, the amount of wheelset lateral shift needed to negotiate a curve reduces as effective conicity is increased. Higher conicity enables a vehicle to negotiate smaller radius curves before flange contact occurs. Otherwise, the flange will be guided by the flange contact.

The worn out wheel profile on curved rail encounters varying conicity with displacement. The equivalent conicity at any position is defined as

$$\gamma=\frac{R_w\,\delta}{R_w\text{-}R_R}=\frac{\Delta r}{Y}$$

Where R_w is wheel profile radius, R_R is rail profile radius and δ is the angle between plane of contact and track level. If the contact is at gauge corner, effective conicity is going to be high as δ will be more.

In worn profile of wheel R_w and R_R changes with position of contact. In pure conical tread, R_w is infinity and R_R is small, the equivalent conicity becomes equal to δ (0.05) i.e slope of wheel tread. As R_w and R_R become close to each other, the conicity increases thus reducing wavelength of oscillation and increasing frequency of

oscillation. i.e. instability

3.3 Critical Speed, Unstable Oscillation and Hunting

The conicity of wheel causes sinusoidal motion of wheel set as shown below. At low speed, this oscillation is a stable condition.

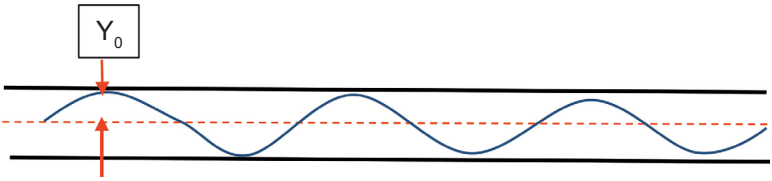


Fig 3.9: Cyclic movement of C/L of axle

With speed, the value of Y_0 increases generally due to slip and ultimately wheel may even start hitting the gauge face of the rails reducing stability and causing cyclic wear of rails. The vehicle movement changes in such situation from harmonic to Zig-Zag. This causes unstable motion called hunting motion. The wavelength reduces and frequency increases quickly as is shown in the below figure until it is in the critical range for the rolling stock and resonance occurs.

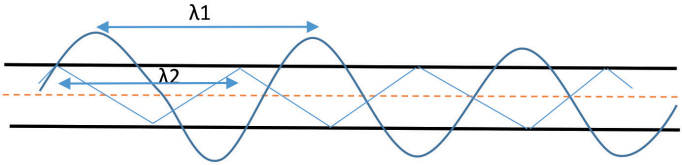


Fig 3.10 : Wheel hunting due to flange touching the rail

The unstable oscillation can occur even without flange touching the rail. The maximum lateral acceleration of this type of cyclic movement suggested by Kingel is given below;

$$\text{Acceleration (Max)} = 4\pi^2 Y_o (v^2/\lambda^2)$$

The lateral acceleration which is the measure of the forces, shows the adverse effect of high speed and/or small wavelength. A conicity of 1 in 40 in comparison to 1 in 20 gives greater wavelength and a lower lateral acceleration at the same speed. The progressively increasing conicity due to wear therefore has an adverse effect on the lateral forces which causes unstable motion.

The speed at which this harmonious movement is disturbed is called critical speed. For a particular conicity of the vehicle, there is one critical speed. High conicity increases the frequency of oscillation and creates the unstable situation at a lower critical

speed thus causing vehicle hunting. This results in sustained lateral motion of a wheelset or vehicle above a critical speed.

- Below the "critical speed" of the vehicle, the hunting amplitude decreases.
- Running exactly at the critical speed, the amplitude of the motion remains constant.
- If the critical speed is exceeded, the amplitude of the hunting motion increases.

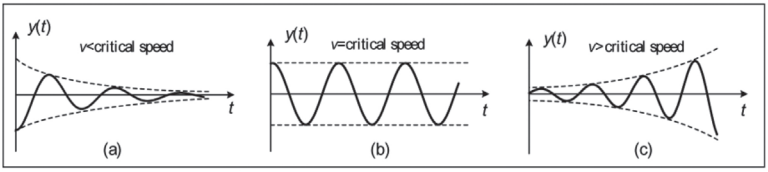


Fig: 3.11 Amplitude of oscillation w.r.t critical speed.

The vehicle movement changes in such situation from harmonic to Zig-Zag. This is called hunting motion. The wavelength reduces and frequency increases quickly until it is in the critical range for the rolling stock and resonance occurs.

Hunting is a function of the wheel/rail geometry, the suspension and the masses, and the inertia's of the vehicle. Since the mass and inertia (and in most cases, the suspension stiffness and damping of the freight wagons) will significantly change from empty to loaded wagon, the type of hunting motion observed usually differs between an empty and a loaded wagon. Since the stiffness values between axle box and bogie frame are lower in an unloaded vehicle, the risk for wheelset or bogie hunting is higher when vehicle is moving in empty condition.

The bogie design as far as conicity and flangeway clearance are concerned must be such that stable running is always guaranteed for the speed range in which the vehicle is to be used.

The variation of critical speed with conicity can be understood by the below representative figure:

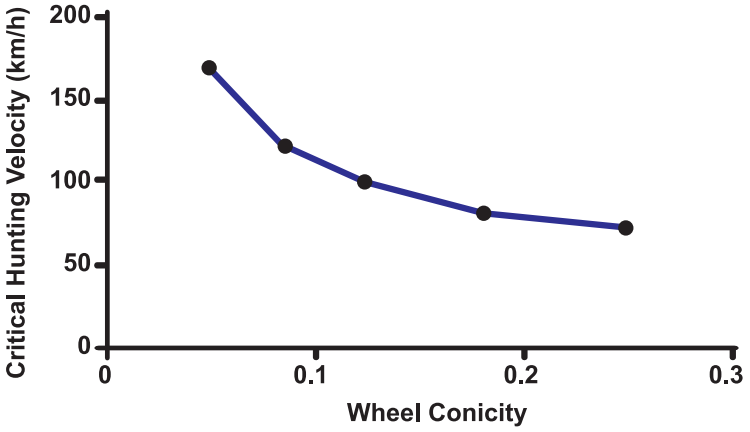


Fig 3.12 : Influence of wheel conicity on critical velocity on tangent track

Practically it is observed that with time rail and wheel profile stabilizes at an equivalent conicity of 0.2 to 0.3. For running stability this effective conicity should be less than 0.4 and for effective centering it should be greater than 0.1.

During profile design there is a trade off with respect to conicity. Low conicity favours stable running at higher speeds, high conicity gives better curving performance. In practice however, good vehicle suspension design can allow both stability at higher speed and good curving performance.

3.4 Creep and Creep Forces

Forces imposed on a wheelset as a result of constraints and/or forces applied at the journals cause the wheelset to deviate from a pure rolling position on the track. Partial sliding motions take place across the contact patch resulting in relative slip called creep or creepage. Creep results in the generation of forces across the contact patch to oppose this dynamic action.

The creep forces in the wheel/rail contact depend on the creep, the normal load in the contact, the friction coefficient, and the contact geometry. The relationship is nonlinear. Figure below shows a typical relationship between creep and creep force.

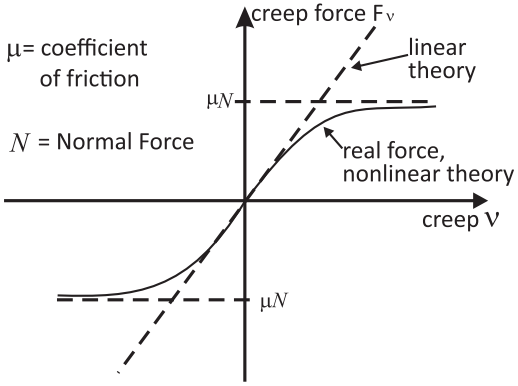


Fig 3.13: Creep Vs Creep force

The above graph shows that

- When creep is zero, the creep force is zero. In other words, to develop a creep force, creepage in the wheel/rail contact is needed. This means for example, to develop a traction or braking force, longitudinal creep in the wheel/rail contact is needed.
- For small creepages, the relationship is linear. The creep force, however, saturates at the value μN (i.e. this is the highest value of creep force possible to transfer in the contact).

The creepages and resulting forces acting across the contact patch can be divided into following components:

- Longitudinal creep and resulting force
- Lateral creep and resulting force
- Flange force
- Spin-Rotational creep

A. Longitudinal Creep and Creep Force

On straight track (Figure below), the pure rolling position is the centerline of the track. If the wheel set is shifted laterally from this position, the vehicle would try to take the dotted position shown in the same figure called the preferred position. However it is forced to actual final state by journal (Fj) and thus larger rolling radius wheel slips back and the smaller radius wheel slips forward which induces creep force Fs on the rail head opposing Fj. Thus Fs react against the constraining forces at the journals Fj. This creep force

created due to slippage is responsible for sinusoidal motion of the vehicle. At low speed this oscillation decays. At high speed, unstable oscillation i.e. hunting occurs. The amount of creepage and the creep force generated are directly proportional to the displacement y and the cone angle γ.

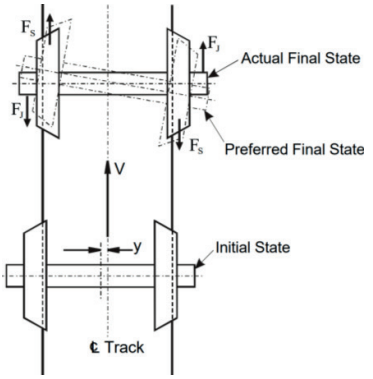


Fig 3.14: Longitudinal creep due to wheel negotiating a straight track

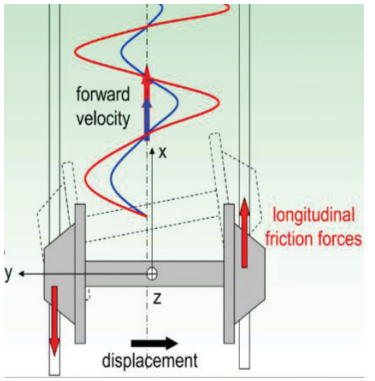


Fig 3.15 Sinusoidal motion generated by longitudinal creep

Railway vehicles use wheelsets comprising two wheels fixed to a common axle. The wheels tend to take the radial position as shown below:

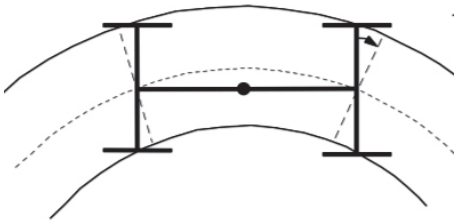
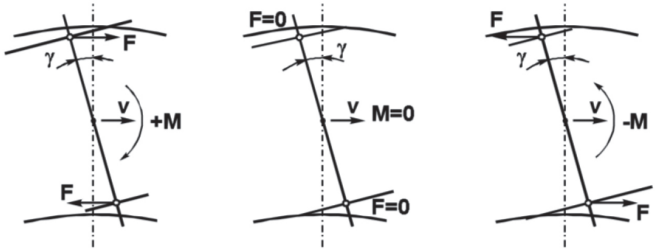


Fig 3.16: Vehicle negotiating a curve

In practice, rotation of the wheelsets into radial alignment is resisted by the vehicle suspension. The stiffer the primary yaw suspension, the larger the forces which will be required to achieve the required rotation. These forces are generated by the leading wheelset moving out beyond the equilibrium rolling line to give an excess of rolling radius difference that gives rise to creepage (or microslip), and consequently creep force, to steer the wheelset relative to the rail. Similarly, the required steering forces at the

trailing wheelset are generated by moving inwards from the equilibrium rolling line. (The creepage mechanism is further discussed in para 3.9)

Direction of wheel Longitudinal creepage would depend on the lateral position of the wheelset with respect to the pure rolling position as shown. The steering moment can be understood from the figure below



a. Lateral displacement larger than pure rolling condition, Slipping of outer wheel backward and inner wheel forward- Positive steering

b. Lateral displacement equal to pure rolling condition. No slippage

c. Lateral displacement smaller than pure rolling condition, Slipping of outer wheel forward and inner wheel backward.- Negative steering

Fig 3.17 Steering moment created by longitudinal creepage

If the curve radius is smaller i.e. the curve is sharper, or the bogie wheelbase is greater, the wheelset must rotate through a greater angle. Thus, larger steering forces must be generated, so the wheelsets must move further from the equilibrium rolling line. The forces that can be generated depend on the “effective conicity” of the wheelset on the rail. The larger the conicity, the greater the rolling radius difference for a given lateral shift. Conicity tends to increase with increasing wheel tread wear.

In the mild curves, the forces acting on the wheels are as shown below

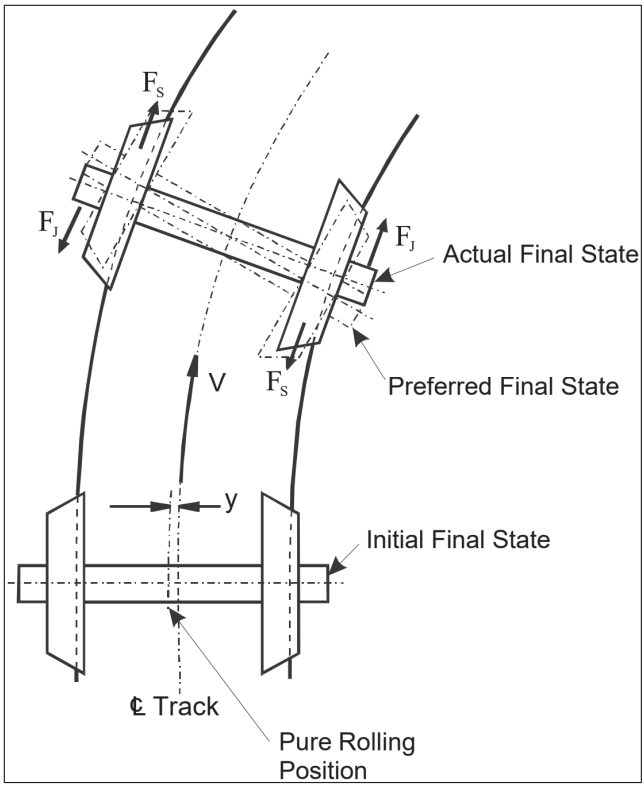


Fig 3.18: Lateral creep on mild curves track

Longitudinal creep force is also generated when the tractive or braking force is applied. During traction it works in forward direction while during brake application it assists in stopping the vehicle.

B. Lateral Creep

Lateral creep may be defined in the similar fashion. On rolling forward, the preferred final state of the wheelset is shown as chain-dotted in Fig below.

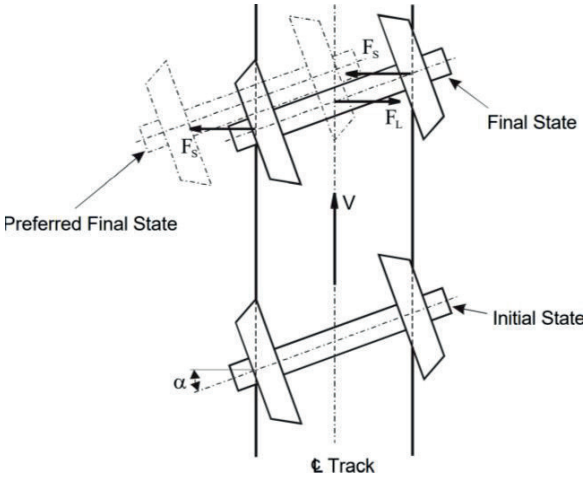


Fig 3.19: Lateral creep of wheel on straight track

The wheel is constrained by the vehicle suspension or a flange force shown as F_L. To be oriented to the track in a similar position to the initial state, the wheelset must have slipped laterally.

In curves also, the wheelset must slip laterally. This lateral creepage and the associated force are proportional to the angle of attack as can be understood from the figure below.

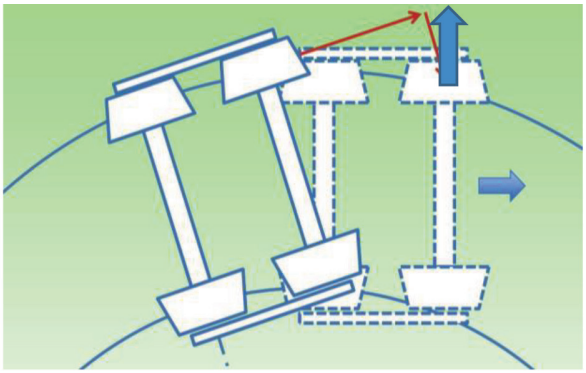


Fig 3.20: Lateral Creepage in sharp curve , guided by lateral creepage and flange force

C. Curving and Flange Forces in sharp curves

As discussed in para 3.4 (A) above, in sharp curves, the steering forces are ultimately limited by one of two mechanisms. The first limit is the available adhesion, causing creep force The second

limit is the flange, which limits the lateral shift of the wheelset, preventing the wheelset from generating sufficient rolling radius difference. Once the wheelset is unable to generate sufficient longitudinal creep forces to steer into the radial position, the wheelset will have an “angle of attack” to the track, and will run in flange contact, which must be resisted by the flange contact force. These forces are a major cause of wear. As the equilibrium rolling line is closer to the outer rail than the inner, the leading wheelset will always reach flange contact before the trailing wheelset.

The forces acting on the two axle bogie wheel set is shown below:

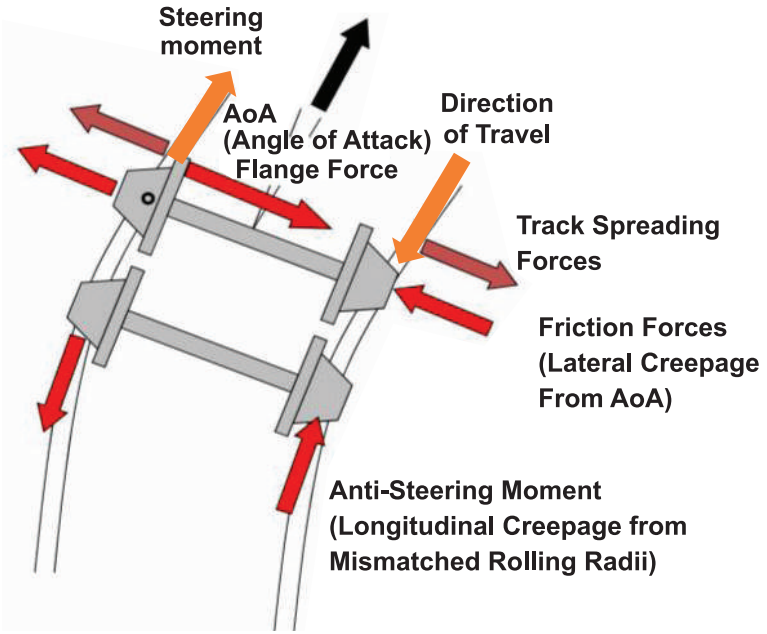


Fig 3.21 : Curving and Flange force in a bogie

The creep forces acting are:

a. Front axle outer wheel, as the lateral creep is inside the lateral creep force will be acting towards outside. (Fig. 3.20)

b. In the front wheelset, outer wheel will have larger rolling radius and will slip back as explained creating creep backward and thus creating forward longitudinal creep force. Similarly inner rail will have longitudinal creepage force acting backward.

c. In sharp curves of the rear wheelset the outer wheel will

have lesser rolling radius than equilibrium, hence will create longitudinal creep as shown. The inner wheel will have larger than equilibrium radius hence will slip back creating forward longitudinal creep. This force is normally very less. In mild curves however the position may be different

On the front axle, the longitudinal creep creates steering clockwise moment while lateral creepage creates anticlockwise moment.

If these are balanced as in case of mild curves, no flange contact is made. In sharp curves, since lateral creepage moment is more, flange force is inevitable and a balancing moment by flange force is created. This cause severe gauge face wear

Curving at high speeds with cant deficiency means that the wheelsets must generate additional lateral forces to overcome the centrifugal forces in the curve.

High lateral creepage is reflected in lateral material flows in the rail crown in sharp curves as well as material flows on the wheel as shown in Figure 3.22.

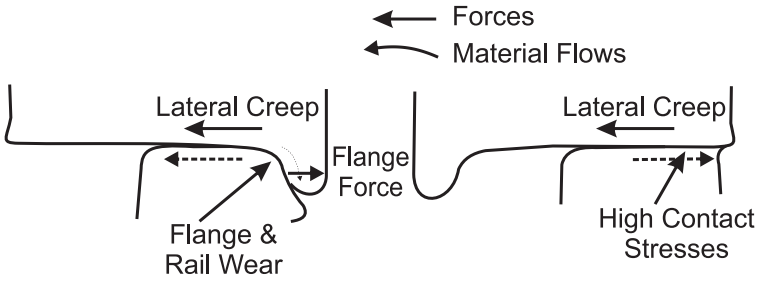


Fig 3.22: Wheel flange force due to lateral creep

Generally, the longitudinal and lateral creep forces play the most significant role in vehicle behavior. If controlled correctly, they provide effective guidance to the vehicle. If not, they can be the source of much track and wheel damage.

D. Spin

The magnitude of the spin creep generally depends on the contact angle γ. The dicone type shape of wheel set induces both the wheel to roll in opposite direction. However being connected a spin force is applied at contact patch. A spin torque is applied hence, a rotational “scrubbing” action occurs at high contact angles. This has been associated, together with high contact stresses, with the formation of head checks.

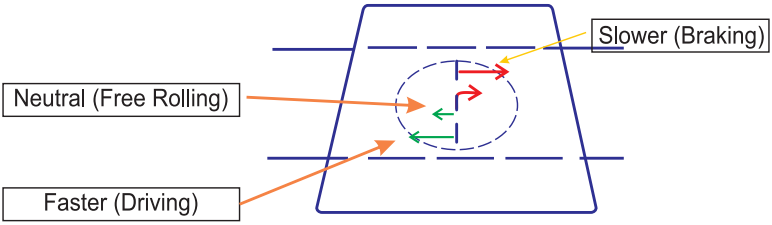


Fig 3.23: The spin in rail wheel contact patch

The same can be also understood by looking at different rolling radius at different contact points along wheel tread. More is the contact patch more is the spin forces though it reduces the contact stresses. So the contact patch can not be increased to a very large size, maintaining a balance between contact stress and spin forces to control RCF. The couple associated with spin is considered to have a minimal influence on rail/wheel forces.

The net creepage vector at the wheel/rail interface is (in general) a combination of longitudinal, lateral and spin.

3.5 Adhesion and Slip at Contact Patch

As discussed, there are three components of creep: longitudinal and lateral creep force and (spin) torque. Longitudinal creep and resultant forces arise because during traction in the direction of rolling, slip occurs in the trailing region of the contact patch (Figure below). The greater the value of traction force, the greater is the proportion of the slip region in the contact patch (Figure below) until the tractive force reaches its maximum level when the contact patch is not capable to absorb any additional tractive effort. Since creep is generated in lateral direction as well as due to spin, the area of slip and adhesion can be complex

Talking of longitudinal creep due to traction, the maximum level of tractive force between a locomotive driving wheel and rail depends on the capability of the contact patch to absorb traction. This is

expressed in the form of the adhesion coefficient or coefficient of friction (μ) which is a ratio of traction force (T) to normal load (N). As the traction forces becomes very high, the adhesion becomes zero and wheel slippage causing wheel burnt occurs.

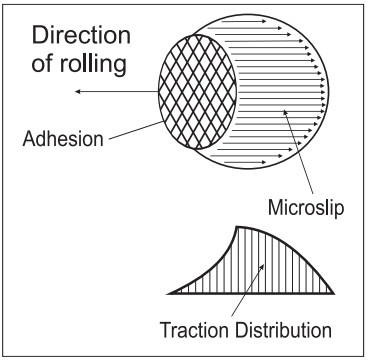


Fig 3.24: Adhesion and microslip in rail wheel contact patch

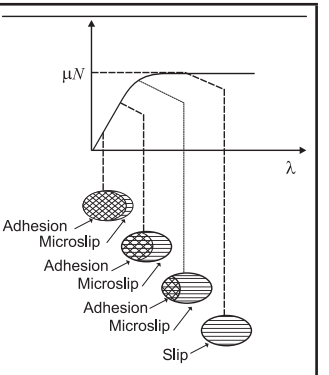


Fig 3.25: The change of adhesion area with increase of traction

The above behavior can also be understood from the below graphical representation

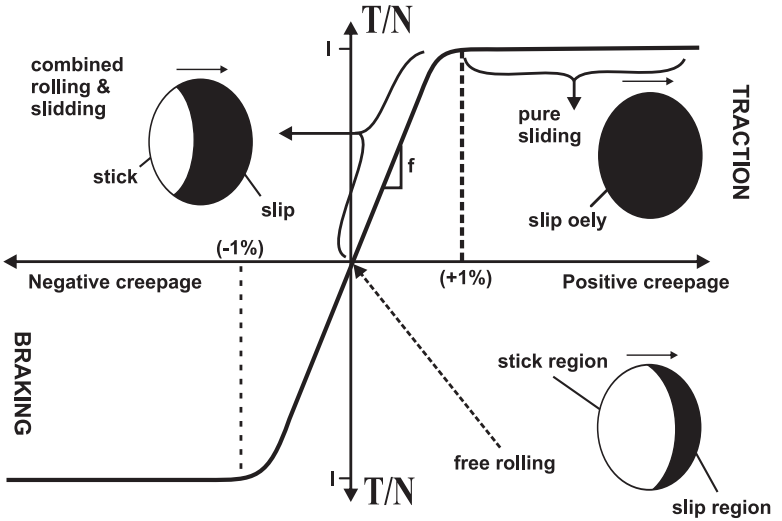


Fig 3.26 : Traction coefficient Vs slip at rail wheel contact point during Braking and Traction

While one of the wheel in a wheel set will be having positive creepage other will be having negative creepage as shown below:

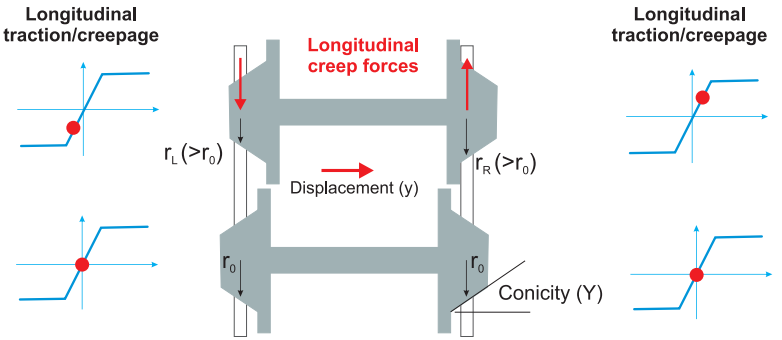


Fig 3.27 Steering forces on wheelset

Low adhesion between the wheel and rail is a long term challenge for the rail network. Reliable levels of adhesion at the wheel-rail interface are imperative for safe, efficient & reliable train operation.

3.6 Ratcheting

As discussed in previous chapter (para 2.4), shakedown diagram, describes the limits of material behavior in terms of non-dimensional normal contact pressure P_o / k_e as a function of non-dimensional traction coefficient (T/N), where P_o is the normal contact pressure, k_e is the shear yield strength, T is the tangential force which is primarily steering forces arising out of creepage but can also contain tractive and braking force, and N is normal load. At relatively low traction coefficient T/N, cumulative plastic flow occurs below the rail surface. If the traction coefficient is high (greater than about 0.3), plastic flow is greatest at the rail surface. The accumulation of a large number of unidirectional plastic strain increments “ratchets” (Fig below) the surface layer of material until its ductility is exhausted.

The ratchetting effect will depend on the friction coefficient, the maximum contact stress (which depends on the size of contact patch), and the shear strength of the steel as discussed before in para 2.3 B.

Cracks initiated by ratcheting grow perpendicular to the prevailing

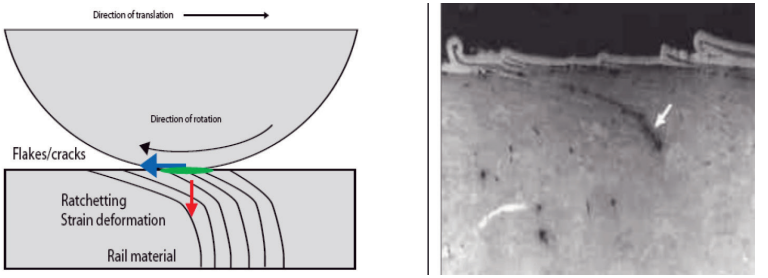


Fig 3.28: Ratchetting of Rail

direction of the traction force. In mild curves, longitudinal traction is dominant and cracks grow primarily perpendicular to the direction of travel. In sharp curves traction forces are primarily in the lateral direction and cracks are primarily parallel to the direction of travel. For mixed longitudinal and lateral traction, the cracks can grow at an angle about 45 degrees to the direction of travel.

3.7 Gravitational Forces

The wheel/rail contact also has to transfer the weight of the vehicle into the track structure. The sum of the vertical forces Q is equal to the axle load (figure 2-14). Because of the profiled wheels, the contact patches are inclined at a general contact angle γ. This results in the generation of a lateral component to the vertical load at each contact patch. The angle of the contact patches on each wheel can be different and result in a net force acting on the wheelset.

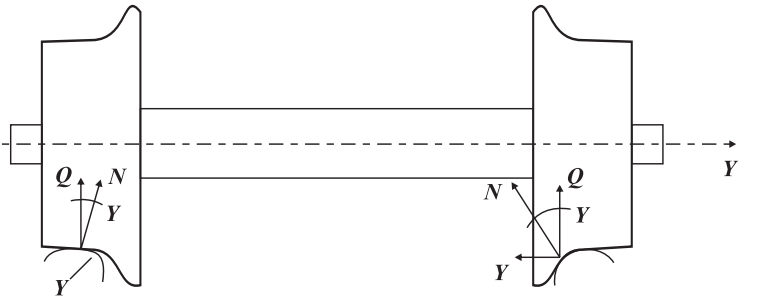


Fig 3.29: Gravitational force at rail wheel contact

Lateral components of normal forces on the wheelset generally, gravitational forces can assist in vehicle guidance although this effect is not of great significance and is not identified as being the cause of significant track or vehicle damage.

3.8 Shear Stress

The contact patch is surprisingly small with correspondingly high-contact stresses. Typically, contact is made over a quasi-elliptical contact patch the size of 10-12 mm major and 5-8 mm minor axis which implies that a 20,000- 25000 ton train is supported over a very small patch causing high value of contact stress.

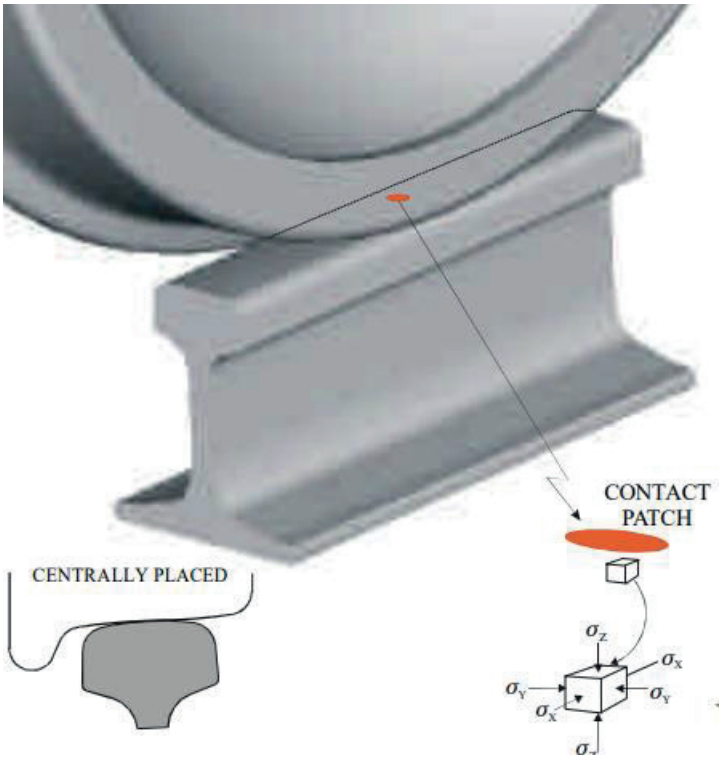


Fig 3.30: Pressure at the contact patch

Immediately beneath the contact patch in either the wheel or rail, the steel is under tremendous pressure from all directions as the contact pressure is “supported” by reaction pressures from the surrounding material of either wheel or rail. This is termed a triaxial state of stress. Each of the “stress arrows” as shown presses almost equally on the steel, which has no direction in which to move or “flow” and can withstand the load. Under these conditions, and using high strength steels, axle loads beyond present day applications (up to perhaps 60 t or beyond) should

be possible.

The shear stress on rail top as discussed in previous chapter is less or close to zero due to triaxial balance under static axle load as discussed. However as we go deeper inside, the σx and σy reduces faster as compared to σz thus creating maximum shear stress at around 3 mm below the surface. The contact stress on surface of rail and shear stress distribution as one goes deeper is discussed in chapter 2 (Para 2.3)

There are two significant volumes of material that exhibit deformation. One is a very thin layer on the surface of the contact patch and the other is the subsurface layer in the region of the maximum shear stresses. When the traction force is applied, these areas became closer and may form one area of potential failure. In actual therefore, there will be shear stress at the top surface also. The depth and value of maximum shear stress depends on axle load and crown radius as below.

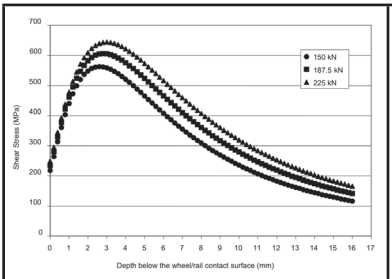


Fig 3.31: Shear stress distribution with depth for different axle load

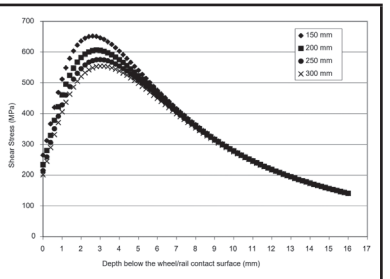


Fig 3.32: Shear stress distribution with depth for different rail crown radius

It can be concluded from the above figure:

- As axle load increases, the maximum shear stress increases and the location of maximum shear becomes deeper.
- As crown radius of rail becomes flatter i.e. radius is increased, the shear stress reduces and the location of maximum shear gets deeper into the rail.

This tractive force changes the stress distribution as shown below:

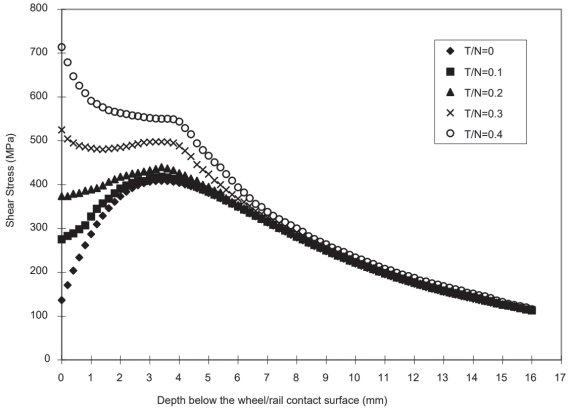


Fig 3.33: Shear stress distribution with depth for different tractive force

It can be seen that with increased tractive force, the shear at the surface increases and a time comes when maximum shear shifts close to surface.

3.9 Rail Wheel Contact Patterns

The rail wheel contact can be considered to be taking place in following region:

Region A: Contact between the central region of the rail crown and wheel tread

Region B: Contact between the gauge corner of the rail and the flange fillet

Region C: Contact between the field sides of both rail and wheel.

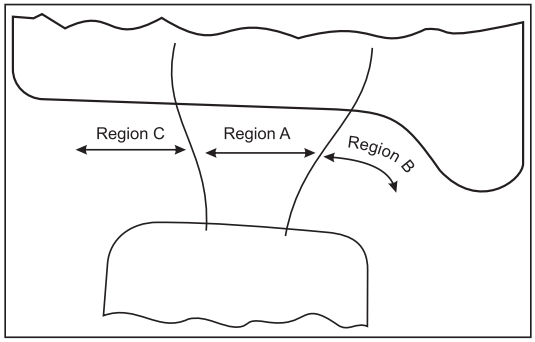


Fig 3.34: Contact zone on wheel tread

Contact in region A normally takes place on both the wheels in tangent/mild curve. The contact in B region normally takes place on outer wheel of sharp curves. The contact in region C normally takes place on inner wheel of curve. The contact pattern at these locations are discussed in detail in chapter 6.

3.10 Wear of Rail

The two main areas of Rail wear are:

- Top of the rail
- Gauge face wear mainly in curves

The amount of wear for a particular Rail and Wheel material will depend on the pressure (P) at the contact patch and the relative slippage (λ) between rail and wheel. P and λ are dependent on dynamic parameters of wheel/rail interaction. Also wear will depend on third body between Rail and Wheel like sand, lubricant, water etc.

It is found that value of pressure (P) x Relative slippage (λ) , defines the extant of wear that is going to take place.Wear occurring can be broadly classified as:

a. Mild

b. Severe

c. Catastrophic

As an approximation if P x λ is less than 40, it is mild wear case, if between 40 to 120, it is severe and if greater than 120 then it is catastrophic wear. The mild wear is characterized by bright surface of wear. Severe wear is characterized by rougher surface and in catastrophic wear, the surface is rough and shows score marks.

In tangent track, normally top of the rail is subjected to high contact stress and relatively low level of relative slippage (if there is no slip of the locomotive or car wheels as a result of low adhesion between wheel and rail or excessive tractive or braking effort.) In this case, P x λ is about 20 and the mild wear takes place. However with time the wheel tyre takes a profile creating false flange. The shear stress increases and contact point changes. The wear pattern also changes.

When negotiating a curve the wear at rail gauge face becomes more prominent, though it may occur for a short time on tangent track, especially if cars are hunting. In sharp curves under dry

conditions, conventional three-piece truck negotiation lead to the catastrophic wear mode of high intensity, resulting in a large amount of wear and quick change of the railhead profile. Depending on whether the wheels and rail have new or worn profiles there may be different contact pressure and different relative slippage distribution on the contact patches that will lead to different wear modes and rate of wear. Wear of Rail is found to be dependent on:

- Axle load: Both gauge face and Rail top wear increases with axle load.
- Gauge face clearance: Lesser clearance than certain value increases the wear
- Hardness: It is the most important factor which affects the wear of Rail. Increasing the hardness reduces the wear by very large value.
- Relative hardness of Rail and Wheel: It is found that increase in hardness of either rail or wheel, reduces the wear rate.
- Lubrication: It reduces the gauge face wear.

The method to reduce wear includes:

- Use of fully heat treated, head hardened rail
- Lubrication of gauge face particularly in curves.
- Wheel and rail profile preferably a conformal profile to reduce contact pressure
- Extra flange way clearance in curves i.e. wider gauge.
- Proper bogie design to reduce angle of attack preferable self-steering to reduce slippage.

3.11 Work Hardening

After multiple wheel/rail interactions in operation, the hardness of the interacting surfaces increases in comparison to the initial surface hardness. This introduces compressive residual stresses in the rail head surface zone. These stresses protect the rail by decreasing the local stresses generated by contact fatigue loading and inhibits ratcheting and wear. Work hardening has been observed on the running surfaces in both standard and head hardened rails. The considerable depth of the hardened layer (about 4-8 mm depending on the rail type) develops rather quickly, but the maximum hardness, which is achieved near the surface, increases gradually with passed tonnage. Since the

work hardening depends on the degree of material deformation, standard rails will work harden more than head hardened rails. The increase in hardness after different GMT (Million Gross Ton of Traffic) is shown in the Fig below.

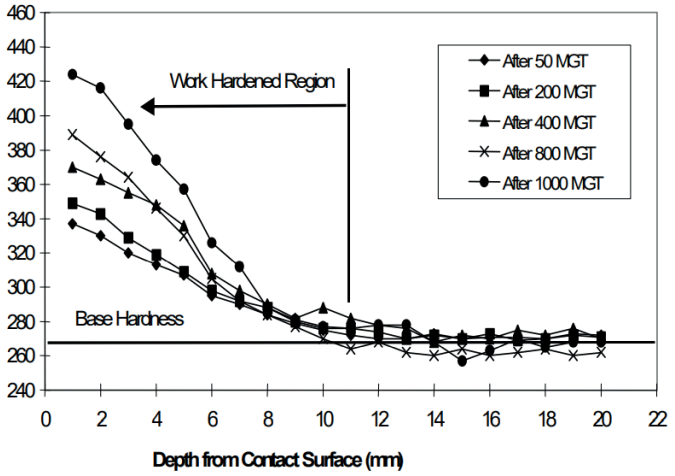


Fig 3.35 : Work hardening of rail with increasing GMT

Though work hardening always takes place in operation, it is very difficult to control this phenomenon and to use it decrease wear because the work hardened layer is not stable.

◆◆◆

4.0 General

The Rail wheel contact stresses causes failure at the contact patch if the stress value exceeds the shear strength of rail as discussed in previous chapter. Such failures are normally called Rolling Contact Fatigue (RCF) and is the most prominent reason for rail failure. In this chapter, different defects caused in rail due to rail wheel interaction is discussed.

4.1 Rolling Contact Fatigue (RCF) Defects

The term rolling contact fatigue is generic in nature and used to describe a range of defects that are due, basically, to the development of excessive shear stresses at the wheel/rail contact interface. RCF defects that occur in the gauge corner region of the rails, and which are of most concern. Some of the RCF defects are:

A. Gauge corner checking and spalling

This is a surface condition that occurs mainly on the high rails in sharper curves, and can be described as being like “fish scales”. As illustrated in Figure below, the cracks are initiated at or very close to the rail surface, typically occur at about 2-5 mm intervals along the rail, and can grow to 2-5 mm in depth, at a downward angle of about 10º-30º to the rail surface, gradually spreading across the rail head. Once this occurs they usually break out as small “wedges or spalls”.

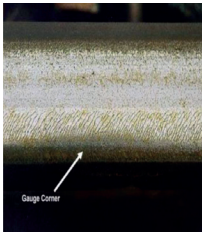


Fig 4.1: Initial stage of development of gauge corner checking cracks

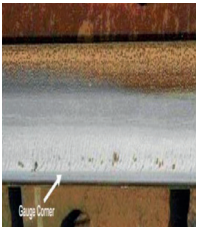


Fig 4.2: Intermediate stage of development of gauge corner checking cracks and spalls

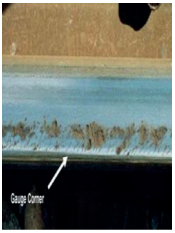


Fig 4.3: Severe stage of development of gauge corner checking cracks and spalls

Gauge corner checking can also occur in shallower curves and tangent track, where wheelsets/bogies/vehicles tend to exhibit hunting behavior.

B. Shelling

This is an internal defect (subsurface) that initiates at a depth of 2-8mm below the gauge corner of, generally, the high rails in curved track. In the initial stages of development, shelling defects become noticeable as dark spots in the gauge corner region of the rails. Shelling defects do not form as regularly along the rail as gauge corner checking defects. Shelling cracks develop on a horizontal or longitudinal plane consistent with the shape of the rail on the gauge corner. The cracks can continue to grow in a longitudinal direction on that plane for some distance at an angle of about 10º-30º to the rail surface, and then either spall out into a shell or turn down and form transverse defects which can continue to grow on a transverse plane and, if not detected in time, eventually lead to rail failure. It should be noted that sometimes transverse defects may also directly initiate from irregularities in the steel (inclusions) and grow in a transverse plane, without the need for a prior shelling defect. Because of their internal nature, transverse defects cannot be visually detected, and hence must rely on regular ultrasonic rail inspection.



Fig 4.4: Initial stage of shell development (dark spots)



Fig 4.5: Intermediate stage of shell development

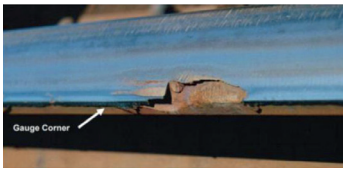


Fig 4.6: Severe stage of shell development



Fig 4.7: Small Transverse defect in the rail head initiated from shelling

C. Running surface or head checks and spalling

The other type of RCF defect is known as flaking, or running surface checking. This is also a surface condition that occurs on the running surface of the low and/or high rails. Initially, the defects appear as a mosaic or snakeskin like pattern on the rail head. In the latter stages of growth the cracks produce “spalls” that can be up to about 10-15 mm wide, up to 3 mm deep, and can be continuous along the rail length. Head checks occur at the rail surface due to large unidirectional plastic strains which ultimately may lead to rachetting.



Fig 4.8: Head checks with minor spalling

4.2 Cause of RCF and its growth rate

Both checking (gauge corner and running surface) and shelling defects are initiated by the high shear stresses that can develop at the wheel/rail contact region when such stresses exceed the allowable limits for the rail material. RCF is generated after multiple times the allowable stress is excadet (Para 2.3B). A number of factors can influence the shear stresses, including:

a. The nominal, dynamic and impact wheel loadings , and the range of factors that influence such loadings, including: track geometry, bogie characteristics, wheel and rail vertical irregularities, track superelevation etc.

b. The respective radii of the wheels and rails at their contact region and consequently the wheel and rail profile characteristics.

c. The diameter of the wheels (smaller diameters result in higher stresses).

d. The traction/creep forces.

Tangential force (T) and Normal Load (N) at the contact surface defines if shelling or checking will take place. At lower T/N values the maximum shear stresses are obtained at some depth from the rail contact surface, which corresponds to the region in which shelling generally develops. Higher axle loads increase the normal forces and hence may also reduce the T/N values, which in turn would enhance sub-surface crack initiation.

On the other hand, the higher T/N values which are obtained in relatively sharp curves (due to wheelset steering forces), or relatively shallow curves and tangent track (due to adverse vehicle dynamics, such as hunting) or at lower axle loads, lead to both considerable increases in the resultant maximum shear stress and a shift in the location of the maximum shear stress closer to the rail surface, where the checking cracks initiate.

Growth characteristics of the checking and shelling cracks is dependent on the work hardening of the rail steel which occurs due to the plastic deformation of the rail material, particularly at the higher axle loads. The plastically deformed material in the work hardened layer exhibits high compressive residual stresses. Such stresses inhibit fatigue crack growth, and therefore generally prevent the growth of the much shallower checking cracks into the rail head. On the other hand, the deeper shelling cracks may be able to penetrate through the compressive work hardened layer and continue growing on a transverse plane, thus developing into transverse defects, under the action of other stress environments, including rail bending, thermal stresses, and residual stresses.

For the same reason, it is possible that the checking cracks have been able to advance into the rail head, and sometimes lead to rail failures, under lower axle load, high speed passenger train, since such conditions would lead to a very limited (if any) work hardened compressive layer, particularly in newer rails that are subjected to adverse wheel/rail contact conditions.

It is also of interest to note that under poor wheel/rail contact conditions (resulting in excessive shear stresses), new higher strength rails may actually be more susceptible to the growth of checking cracks into the rail head, since the material would be more resistant to plastic flow and hence work hardening as it will not develop a considerable compressive residual stress layer.

4.3 Problems with RCF Defects

RCF defects are of particular concern for two main reasons:

a. They may lead to rail failures if not detected in time, particularly in the case of transverse defects.

b. They can mask the ultrasonic signal during routine inspection and hence prevent the detection of larger and deeper defects that may be present within the rail head, including any such defects that may have developed from the shallower initial cracks.

The removal of severe RCF defects, and in particular gauge corner and running surface checking, also entails extensive and expensive rail maintenance (grinding).

4.4 Different ways to Control RCF Defects

a. Use of Higher strength rail steels

- Install higher strength rail steels in the more critical track locations, to increase the allowable shear stress limits.
- The hardened rails not only exhibit reduced wear, but also reduced plastic deformation. Consequently, if the wheel/ rail contact conditions are not favourable, such conditions will be retained for a very long time. Standard rails, on the other hand, will tend to wear and/or deform plastically to accommodate non-conforming wheels.

Consequently, when hardened rails are used, it is essential that the appropriate (low stress) profiles are implemented soon after their installation, and that regular preventive maintenance i.e. rail grinding is applied.

b. Improvements in the cleanliness of the rail steels

This will reduce the number of inclusions that can act as initiation sites for the defects. This aspect is of particular relevance to shelling and transverse defects, rather than to gauge corner and running surface checking defects.

c. Improvements in the wheel/rail lubrication procedures

This will reduce the risk of rail contamination and hence the enhancement of fatigue crack growth.

d. Rail Grinding

This is the most important aspect of RCF removal and control.

4.5 Other Surface Defects

A. Squat Defects (Sometimes also taken as RCF defect)

Squats are subsurface laminations which initiate at small cracks, thought to be at the rail surface. These cracks extend diagonally downwards, at an angle of about 20°-30° from the horizontal, until they reach approximately 4-6mm below the surface, then spread laterally and longitudinally across and along the running surface.

There are 2 broad categories of squats which commonly occur:

(i) Running surface squats, thought to be initiated by thermal traction effects associated with some form of wheel microslip/ slip, and can occur anywhere in the contact band.

(ii) Gauge corner squats, which appear to initiate from preexisting cracks, usually rolling contact fatigue (RCF) and are usually, but not always, near the gauge corner, on the high rail of curves and in turnouts.

Squats are indicated by a darkened area in the contact band, which results from a depression in the rail surface and reduced polishing by train wheels. There is often a double sided kidney shape, notably running surface squats. A triangular surface crack is often seen on the gauge side of both gauge corner and running surface squats. Squats can occur in irregular patterns on one rail only or in both rails. In some cases on tangent track, the same pattern of squats is repeated on both rails, suggesting initiation associated with a particular wheelset.



Fig 4.9: Small size squats



Fig 4.10: Medium size squats



Fig 4.11: large size Squats

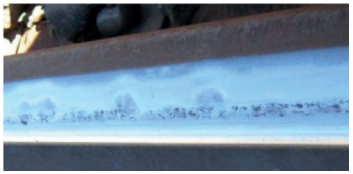


Fig 4.12: Example of multiple running surface squats from wheel slip

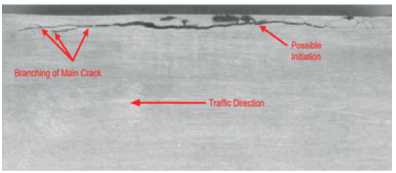


Fig 4.13: Sub-surface cracking associated with squat defect

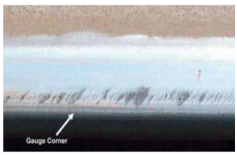


Fig 4.14: Example of gauge corner checking initiated squats - Small



Fig 4.15 : Examples of gauge corner checking initiated squats - Large



Fig 4.16 : Examples of gauge corner checking initiated squats – multiples



Fig 4.17: Squats in tongue rail

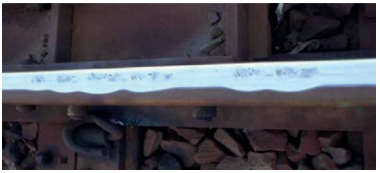


Fig 4.18: Squats in stock rail

Squats are taken as RCF defect and are normally initiated by microslip at the rail wheel contact patch. Generally squats are formed around 4 years or even later of formation of this microslip.

(b) Wheel Burns

Wheel burn defects are caused by the continuous slipping of the locomotive wheels on the rails. This occurs when the longitudinal creepage reaches saturation. The slipping action of the wheels increases the temperature near the surface of the rails to very high values. The subsequent fast cooling cause the rail material to transform in to a hard and brittle martensite phase, which in severe cases can extend to depths of 4-6mm from the running

surface.

The main factors that enhance wheel slip are:

(i) Excessive track grades.

(ii) Poor train driving procedures, such as rapid acceleration.

(iii) Insufficient locomotive power.

(iv) Contamination of the running surface of the rails, which can reduce the friction to undesirable levels.

The major concerns associated with the larger wheel burn defects are:

- The depression and/or spalling that occur at the wheel burns lead to very high impact loadings on the rail, and consequently exacerbate the deterioration of both track and some vehicle components, in a similar way to dipped welds, squats, rail corrugations, rail joints and wheel flats.
- The cracking that occurs within brittle martensitic layer may initiate transverse defects in the rails, particularly if the martensitic layer is relatively deep. In their early stages of development, such defects cannot be detected visually. Their detection therefore relies on the ultrasonic inspection of the rails.
- As for normal transverse defects, if the defects from wheel burns are not detected in time, a complete vertical failure of the rail head may occur.
- Because of the high impact loads, the defects from wheel burns can propagate at much faster rates, and are therefore potentially lead to rail failure.

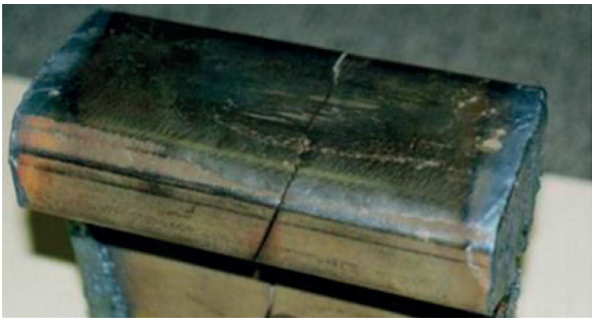


Fig 4.19: Transverse crack occurring at wheel burnt locations.

Squats are sometimes confused with wheel burnt. However the cause of the two are to some extent same i.e slipaage of locomotive wheels, the squats are because of microslip while wheel burns are because of complete slippage of wheel. Wheel burn will therefore appear on both the rails at a place while squats can be on one rail only.

(c) Tache-Ovale or shatter cracking (Not an RCF):

Tache-Ovale or shatter cracks (also known as transverse fissures) are due to internal defects that initiate within the rail head, and grow transversely. Their growth plane is therefore similar to transverse defects, however they initiate deeper in rail head and not in the gauge corner region. As for transverse defects, because of their internal nature, Tache Ovales cannot be visually detected, and hence must rely on regular ultrasonic rail inspection.

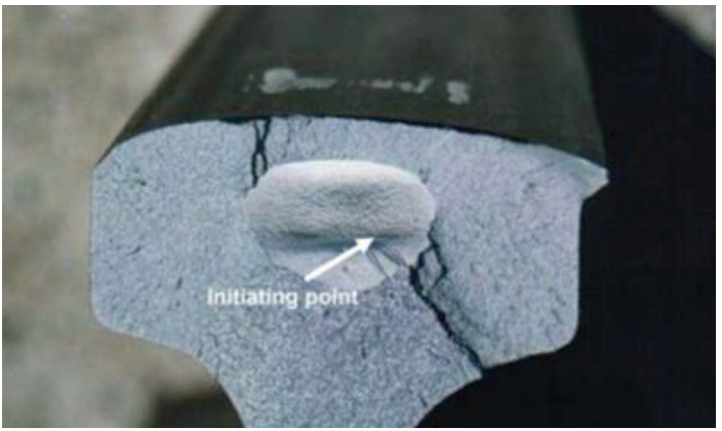


Fig 4.20 : Tache Ovale Crack

The initiation of Tache Ovale defects may also be due to the presence of hydrogen in rail steel (or welds).

(d) Corrugations:

Rail corrugations are cyclic (wave-like), generally vertical, irregularities on the running surface of the rails.

Corrugations are of two main types:

- Short pitch - from about 30mm to 90mm in wavelength or
- Long pitch - above about 300mm in wavelength.



Fig 4.21: Short Pitch Corrugations



Fig 4.22: Long Pitch Corrugations

Short pitch corrugations generally develop under lighter nominal axle load (< 20 tonnes) passenger operations. The depth of these corrugations is usually less than 0.2-0.3mm. Long pitch corrugations generally develop under higher nominal axle load (> 20 tonnes) mixed freight and passanger train operations. The depth of these corrugations can range from 0.1mm to above 2.0mm, and can be variable.

Short pitch corrugations are thought to form from the differential wear caused by a repetitious longitudinal sliding action of the wheel on the rail, whether through acceleration, braking or lateral motion across the rail. The longitudinal oscillations can develop due to the excitation of the torsional resonance of the wheelset. This may be enhanced by the stick-slip phenomenon that may occur at the wheel/rail contact patch in tight curves.

Long pitch corrugations, on the other hand, develop because of the plastic flow of the rail material that is due to excessive wheel/rail contact stresses and the combined vertical resonance of the wheelset unsprung mass and the track. The phenomenon is therefore exacerbated by all of those factors which lead to higher dynamic loadings and hence contact stresses, and plastic flow of the rail material, including:

- Higher nominal wheel loads.
- Higher vehicle speeds, which increase the dynamic loads.
- Larger vertical dips at welds/joints, which increase the impact loads.
- Higher track stiffnesses (concrete sleepers are much stiffer than timber sleepers), which increase the dynamic/impact loads.
- Higher rail pad stiffnesses, which increase the dynamic/impact loads.

- Higher bogie suspension stiffnesses, which increase the dynamic/impact loads.
- Smaller wheel radii, which increase the wheel/rail contact stresses.
- Higher friction/creep at the wheel/rail contact.
- Softer rails, which increase the propensity for plastic flow of the material.
- Poor matching of wheel and rail profiles, which leads to narrow wheel/rail contact and hence higher contact stresses.

However, it is still not certain why in a particular track or even section, different corrugation pitches may occur. The long pitch corrugations are sometimes observed on the low rails of curves, sometimes on the high rails, and sometimes on both. This is mainly a function of the superelevation of the track, which may lead to the loading of one rail more than the other.

Some of the method of reducing corrugation are:

- Use of higher strength (mainly heat treated) rail steels, particularly in sharper curves that are more sensitive to corrugation development
- Application of improved wheel and rail profiles, which reduce the wheel/rail contact stresses
- Application of regular rail maintenance in the form of grinding, to control the growth of corrugations. Rail grinding is also required to implement the improved profiles
- Reducing the track stiffness characteristics, with the implementation of softer and thicker rail pads, may also inhibit corrugation development

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Rail Grinding and its Strategy

5.0 General :

Rail grinding can be defined as the process of metal removal from the top surface of the rail head through the use of abrasive grinding materials, especially grinding stones or wheels.

Three primary function of rail grinding are to:

a. Remove already cracked and damaged surface metal. There are three reasons for this

(i) To remove cracks before they propagate deep into the head and cause more damage (e.g., shelling and broken rails)

(ii) To improve reliability of USFD testing

(iii) Cracked materials has poor strength and permits continued detoriation of the profile

In the preventive mode of grinding discussed subsequently in this chapter, the objective is to remove a thin layer of deformed surface material that may not have cracked but is likely to do so in near future.

b. Re-profile the rail back to a desired transverse profile. This shape is required to control and manage the performance of the wheel-rail contact (e.g., contact stress, steering and stability) and also control rail wear.

c. Correct (minor) surface defects such as minor squats and wheel burns, rail corrugation and dipped welds.

In this chapter the different aspects of grinding strategy will be discussed.

5.1 Rail Grinding Procedure

Most of the rail grinding is done by using rotating grinding stones. The removal of metal takes place through abrasion and gauging action of the rotating wheels cutting grains. The amount of metal removal will depend on

- Condition and characteristics of abrasive material
- Pressure on the grinding wheels
- Grind speed

- Angle between the grinding stone and the surface being ground

A facet is created by every grind stone and this facet size depends on the location on the rail head where grinding is being done apart from pressure being applied.

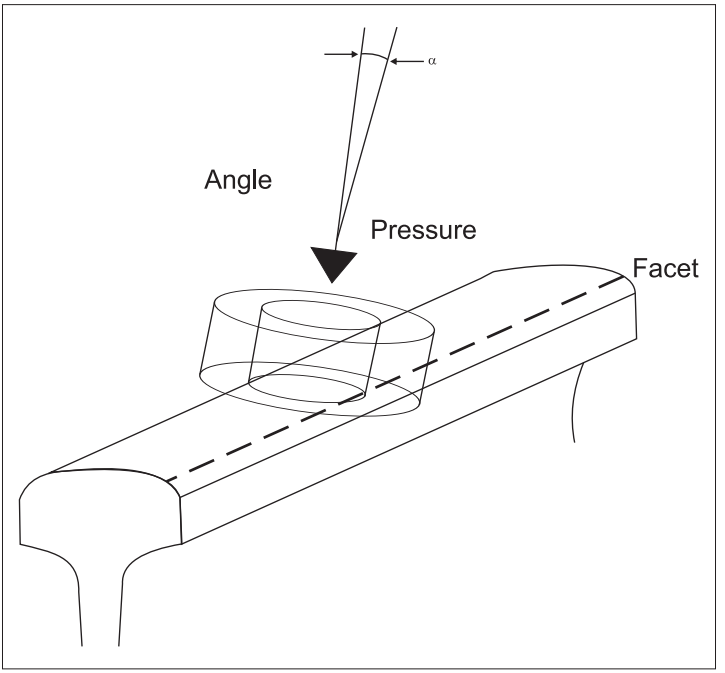


Fig 5.1: Grinding metal removal depends on pressure and angular orientation of stone

The facet created is shown in figure below

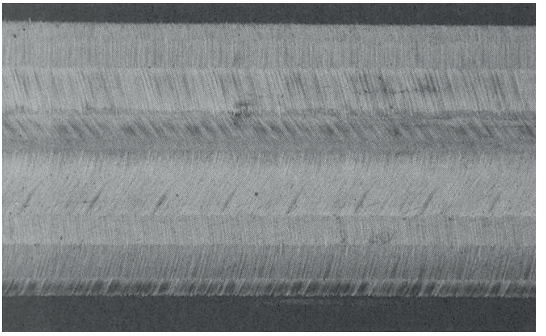


Fig 5.2: Facets created by grinding stones

The profile correction is done in both longitudinal and in transverse direction

a) Longitudinal rail profile correction:

The removal of rail corrugations and other longitudinal irregularities in the rail surface occurs through:

- Ensuring that the stone bears down on the peaks of the corrugations in preference to the valleys.
- Surging power and pressure on the stone to produce a differential cut when encountering a corrugation peak.

The diameter of the stone itself acts as a baseline that ensures that corrugation peaks of shorter wavelength are bridged by the stone and are thus subject to preferential grinding. The usual stone diameter is 250 mm, so that the grinding stone easily works to establish a level plane over this span.

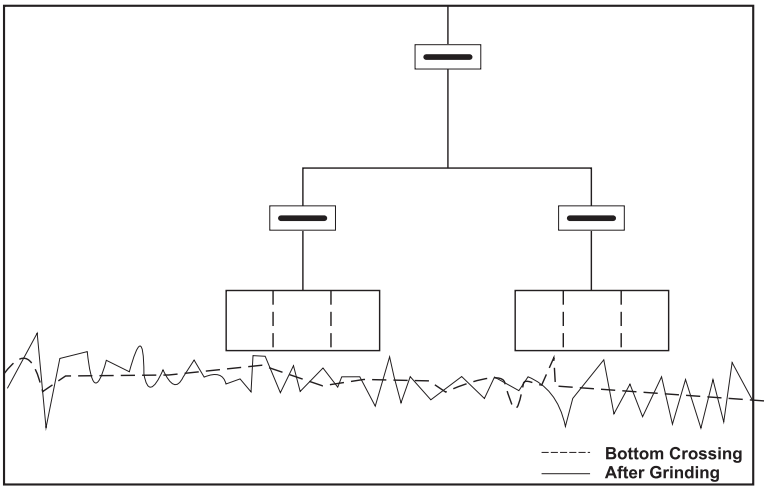


Fig 5.3 : Longitudinal profile correction

For corrugation wavelengths longer than the wheel diameter, it is very important that the individual grinding motor is not permitted to follow the profile of the corrugation, that would result in the same amount of metal removal from the valleys of the corrugation as from the peaks. One way of extending the baseline is to block two motors together so that they will rise and fall in unison. This causes them to bridge over all irregularities in rail surface over a longer rail length. Another method is to control the rate at which the grinding stone will be permitted to rise and fall in following the

rail surface using a hydraulic cylinder or active feedback based upon changes in motor torque.

b) Transverse rail profile correction:

This is done to make contact geometry between rail and wheel favourable. This will reduce the wheel/rail contact stresses and improve the wheelset steering characteristics and hence reduce the lateral creep at the rail surface. The more conformal contact would increase the contact area and reduce the wear.

Transverse profiles suitable at different locations are covered in detail in chapter 6

5.2 Rail Grinding Strategies

There are three strategies of grinding being followed over railways:

- Corrective grinding
- Preventive grinding
- Preventive gradual grinding.

a. Corrective grinding

Grinding is done for complete removal of corrugations and surface defects in one cycle (with required number of passes in same or continuous blocks) to achieve the engineered rail profile is called corrective grinding. Since this is normally done after flaw has gone deep, the number of passes required can be very high and in the process, the head hardened surface of rail top which otherwise is beneficial in controlling wear is eliminated completely.

b. Preventive grinding

Grinding done in the initial stages of defect generation and done at a pre-decided frequency so that RCF is eliminated before it goes deep inside the rail is called preventive grinding. Preventive grinding is considered to be a better approach since the grinding can be done in a single pass at higher speed and the head hardened layer on the rail top is not removed.

c. Preventive gradual grinding (IR Strategy)

Metal removal to be done is more than that required in case of preventive grinding but less than that required for corrective grinding. Since grinding started on IR in 2011 in limited manner, the flaws in rail particularly in curves were deep so the strategy decided is to go for corrective grinding (multiple pass) grinding in curve and preventive grinding in tangent track. Ultimately, to shift

to preventive grinding even on curves.

5.3 RCF Control

This aspect has been recognized as the most essential control procedure, particularly for gauge corner and running surface checking defects. It should be noted that the design of such maintenance strategies, is based on the balance required between rail wear and fatigue.

The RCF (Cracks initiated in the thin surface layer) growth rate with GMT/Loading cycle is initially slow and the rate increases with GMT. The growth can be broken into three phases

Phase-I Initial stage of flaw generation (ratchetting)

Phase-II Fast growth (Supposed to be through the depth of maximum shear stress)

Phase-III Slower rate and the crack branches (more based on combined bending and residual stresses etc.).

The three phases same is represented below:

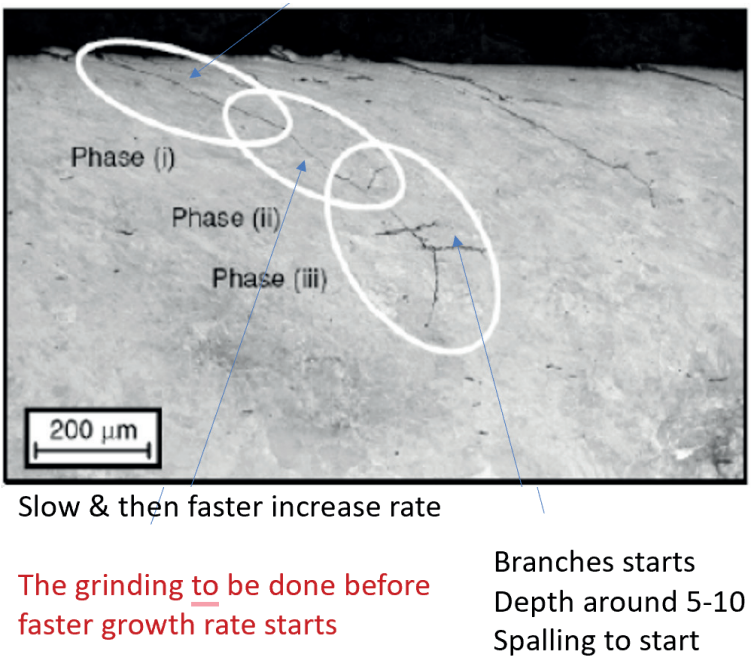


Fig 5.4 : Phases of Crack Growth

The flaw growth rate is initially slow in Phase-I but becomes high in Phase-II (where shear stress is relatively high) which slowly flattens (again slows down) due to reduced shear stress with depth as shown below. The flaw should be removed before it enters into phase II as shown above.

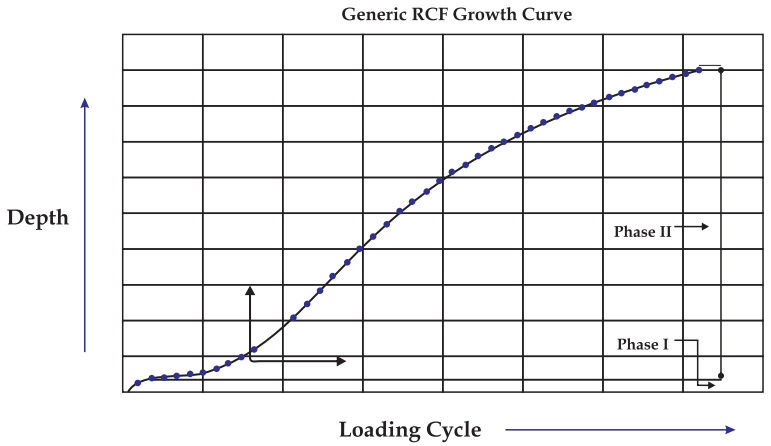


Fig 5.5 : Flaw depth with Loading Cycle

(representative graph)

The flaw rate increase depends on degree of curve as shown below:

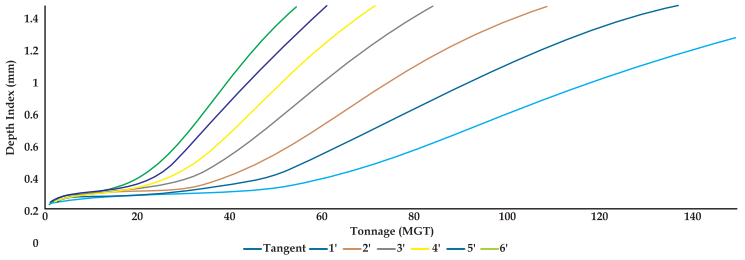


Fig 5.6 : Flaw depth increase with GMT for different degree curve

(representative graph)

From the above graph it can be seen that depth of flaw of 0.2 mm is reached at 20 GMT in 6 Degree curve while in tangent curve the same depth of flaw is reached after 60 GMT. Thus grinding interval for sharp curve needs to be at lesser GMT.

5.4 Optimum wear/Grinding to remove RCF- Magic Wear rate

Rail may be required to be replaced because of excessive wear or because of RCF causing rail failure. Some amount of wear is an advantage and helps in eliminating RCF before it culminates into transverse failure of rail. It is widely accepted that excessive wear should be prevented because it wastes the wheel and rail material, but insufficient wear which allows fatigue cracks to initiate and propagate, also reduces component life and increases the risk of rail failures. The wear required to optimize rail life can be understood from the graph given below.

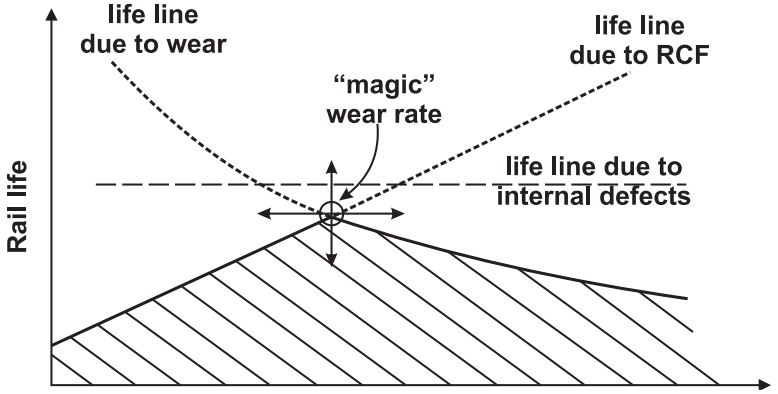


Fig 5.7 : Wear for getting maximum life of rail

From figure it is seen that, at very small wear rate, though the life due to wear is very high, the life due to RCF is very less as metal removal rate is insufficient to remove RCF and rail will fail early on account of RCF . At very high wear rate, the life due to RCF is high but that due to wear is less. The net result is overall, the life of rail is less in both the situations. Maximum life is obtained when life due to both RCF and wear are same i.e. material is being removed or is wearing at the rate required to just remove RCF. Wear more or less than this is going to reduce the rail life.

This wear is called "magic" wear rate, the wear rate at which maximum rail life is achieved. This occurs when the surface material wears (or is removed by grinding) just enough to prevent small fatigue cracks from propagating at an accelerated rate (Phase-II) in the rail and causing fatigue failures.

The achievement of the "magic" wear rate is of course the basis for

preventive or cyclic rail grinding, which aims to remove relatively small amounts of metal at more frequent intervals, and in so doing prevent the fatigue cracks from propagating at accelerated rates.

The concept is further illustrated in the graph below , which shows how the grinding cycles (25 GMT in this case) are applied to prevent the rapid growth of the cracks.

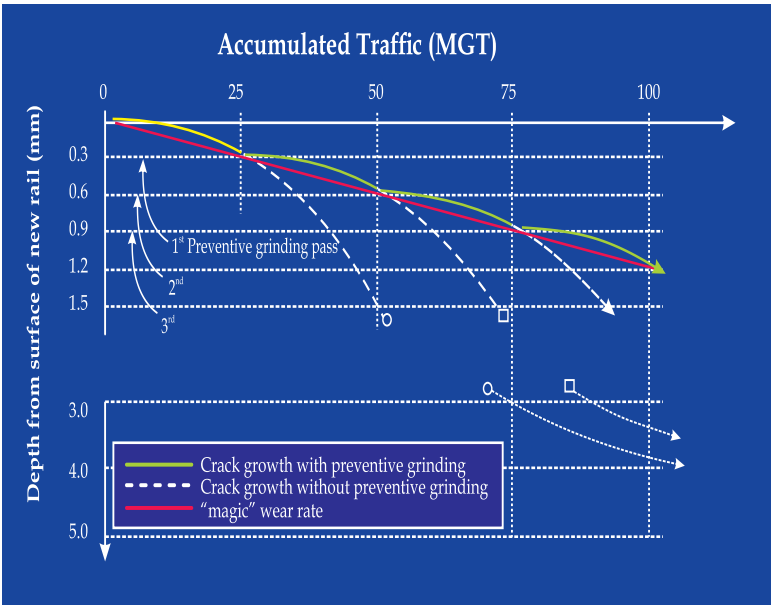


Fig 5.8 : Rail Grinding Strategy-Magic Wear Rate

The magic wear rate is thus the rate at which the total material should wear which includes wear under traffic and artificial wear caused by RGM so that the flaws are eliminated before they enters deep inside causing rail failure.

Rail grinding is thus a tool for preventive rail maintenance, not merely a means for correcting severe rail damage once it has occurred.

5.5 Reliable USFD result

For detection of sub surface defects, the grinding procedure has been successful in improving the ultrasonic testing by removing layer having cracks masking ultrasonic signal, without the need for removing large amounts of material. Following steps needs to be followed for that:

- Remove a minimum of 0.2 mm (and usually more than 0.4-

0.5mm) of metal from all contact surfaces including the gauge region.

- Ensure that all gauge corner checking cracks have been removed from the running surface Figure below (Fig 5.6) illustrates how the presence of the gauge corner checking cracks may inhibit the detection of small transverse defects.
- Establishing the recommended profiles, but allowing a gauge corner relief generally of 0.2 mm but in some cases up to 0.5 mm in the high rails.

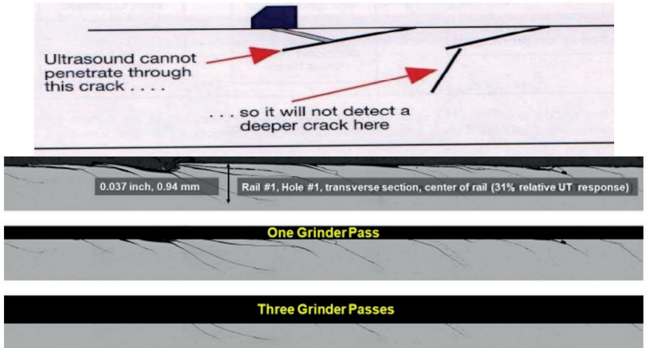


Fig 5.9: Flaw not detected by USFD which can be detected after grinding

In the figure above, it can be seen that deeper flaw is not being detected as ultrasonic waves are not able to reach to that level because of surface defect. It is only after one/two/three grinding passes that the surface defect is removed and the detection of subsurface flaw is possible.

5.6 Profile Correction for reducing RCF, Wear and for Stability of vehicle

With respect to profiles, both wheel and rail profiles have an effect on wear and RCF in three ways. First, how they interact to spread contact relatively evenly over the wheel and rail surfaces. Second, how they interact to control contact stress. Third, how they interact to influence the energy dissipated in normal running.

For this reason it is generally advisable to

- Aim for wheel and rail profile designs that give reasonably conformal contact to reduce contact stress.
- However the designed wheel/rail contact should not lead to equivalent conicity values that lead to unstable running. The

requirement of profile in curve and straight track is discussed in para 3.2 and 3.3.

- For situations where RCF can occur on the rail gauge corner, it may be necessary to develop wheel/rail profiles that reduce contact in this area.
- To reduce the rolling resistance which is responsible for energy dissipation, creepage needs to be reduced. Creepage can be reduced by having proper wheel and rail profile improving steering and reducing creepage and creepage forces.

5.7 Surface Correction

Proper rail surface is required to prevent further deterioration under traffic. Grinding done for correcting surface can be called:

- **Preparative:** Cleaning mill scale or dents introduced in construction from newly laid rail and smoothing high welds.
- **Preventative:** Removing layers of fatigued metal before micro cracking leads to more serious damage.
- **Curative:** Recovering rail that has been damaged by engine burns, ballast pressed into the rail surface.

5.8 Factors affecting preventive grinding interval

The optimal depth of material to remove from the rail to control RCF defects is the point on the RCF curve (Para 5.3 and 5.4) where the growth rate starts to accelerate. Following factors are going to effect the preventing grinding cycle:

a) The RCF crack growth curves will be different for high rails, low rails, and tangent rails. The grinding interval therefore should be different for tangent and for curved track.

b) Optimized rail profiles will minimize wheel/rail contact stresses and distribute the wear across the wheel tread, as well as improve train stability and curving performance. One objective of preventive grinding is to indirectly control the natural wear rate by implementing low-stress profiles. Better profile will reduce grinding frequency.

c) Harder and cleaner rail steels will significantly reduce the wear rate and the initiation and propagation RCF defects. Premium steels (R350HT)with high hardness have a magic wear rate that is roughly one-third that of standard R260 rails. This can be understood from the figure below:

Using harder and cleaner steels will thus increase the tonnage interval at which the RCF initiates and grows to a depth up to which machine can remove the same in one pass i.e. one of the important criteria deciding preventive grinding frequency. BS EN 13231-5-2018 mentions that some of the railways doing preventing grinding on R260 BHN rail at a frequency of 15GMT for curves and 45 GMT for tangent has double GMT interval for R350 HT rail depending on track and traffic characteristic.

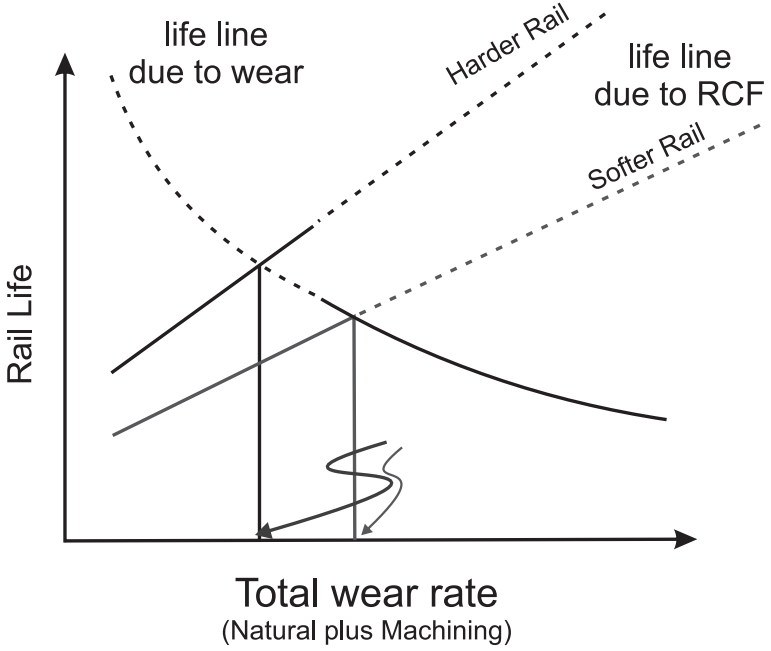


Fig 5.10 : Magic Wear Rate (MWR) of harder rail w.r.t less harder rail

d. New rail should be ground immediately to remove the surface defects caused during handling, weld alignment defects, milling defects and to achieve the desired profile required at that location to reduce contact stress and wear.

e. By proper friction management and Top of the rail lubrication discussed in chapter 10, the RCF generation and wear can be controlled, reducing grinding requirement.

◆◆◆

6.0 General

Different interactions that can be take place between wheel and rail is tabulated below:

Table 6.1

Wheel	Rail
New	New
New	Different level of worn rails
Different level of worn wheels	New
Different level of worn wheels	Different level of worn rails
New	Ground rail
Different level of worn wheels	Ground rail

The ground rail profile is so designed, that minimum stresses and wear of rail takes place. This chapter deals with these contacts and the profiles that should be strived to be achieved for best rail wheel interaction.

6.1 Rail Wheel Contact and its Impact

The different contacts that can take place between Rail and wheel are

A. Straight and Mild curve: Single point contact at Rail Crown area

The contact is made most often in the crown region of rails and occurs as vehicle negotiates tangent track and mild curves (non-steering bogies)

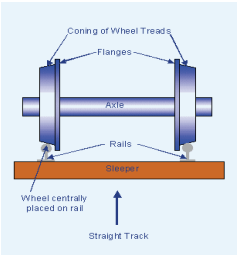


Fig 6.1: Wheel position in straight track

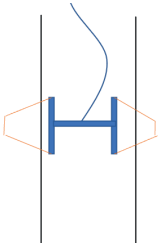


Fig 6.2: Sinusoidal motion of wheel set

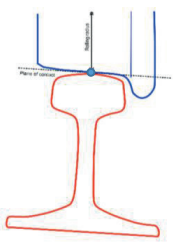


Fig 6.3: Single Point Contact

This contact region is primarily designed to optimize vehicle stability while providing a radius differential to negotiate curve with non-steering bogies in mild curves.

As discussed in para 3.2, less conicity has following impact:

- Reduces self-centering tendency
- Increases wavelength of oscillation
- Reduces frequency of oscillation
- Increases vehicle stability

Rail Crown has a radius over crown and for such wheel, contact is always at the same location on rail crown and thus damage to the rail crown takes place.

A profiled wheel which creates a wider contact is therefore preferred to reduce contact stress. However this causes increased Equivalent conicity and reduces the contact band (Y) on the wheel tread and also increases oscillation frequency i.e. vehicle instability .

Thus a balance should be drawn between lower contact stress resulting from more conformal contact (equal wheel and rail profile curvature) and resulting high conicity causing vehicle instability.

In straight alignment two point contact should be avoided at all costs because of the high resultant conicities and because of the wear associated with it.

B. Sharp Curve-High Rail

As the contact patch in this region is small, contact is often made under the most arduous stress conditions. In sharp curves, the

wheels on the high rail are generally in flange contact to achieve the required Δr. Depending on the shape of the wheel/rail profiles, four types of contact can take place (figure Fig 6.4 to 6.7) :

(a) Strong, two-point contact.

(b) Strong one-point contact

(c) Conformal contact

(d) Near-conformal contact



Fig 6.4: Strong Two point contact



Fig 6.5 : Strong One Point contact

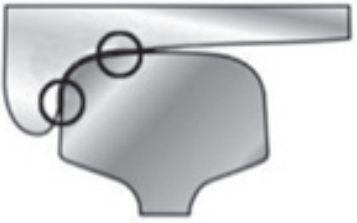


Fig 6.6: Near Conformal Contact

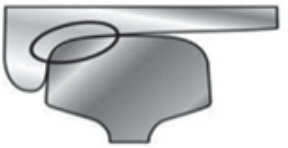


Fig 6.7 : Conformal Contact

Of these, strong two point and strong one point contact are not desirable. Conformal or near conformal profile is preferred.

(i) Strong Two Point Contact

Strong, two-point contact has one contact point on the wheel tread and another on the flange with large distance between these contact points and a gap between wheel flange throat and rail gauge corner greater than approximately 0.4 mm. A large rolling radius difference is developed between these two points. This type of situation is evident in very sharp curve and the lateral force generated at the rail wheel contact is very high. This results in:

- Longitudinal creep forces on rail top and force on flange acting in opposite directions. Wheelset steering moment is

reduced.

- Relative slip between these contact points and resulting high rate of wear and material flow on the flange tip

If two-point contact occurs, high wear rates and material flows are present. Under these conditions, wheel flange/rail wear is accelerated until the flange shape conforms to that of the rail.

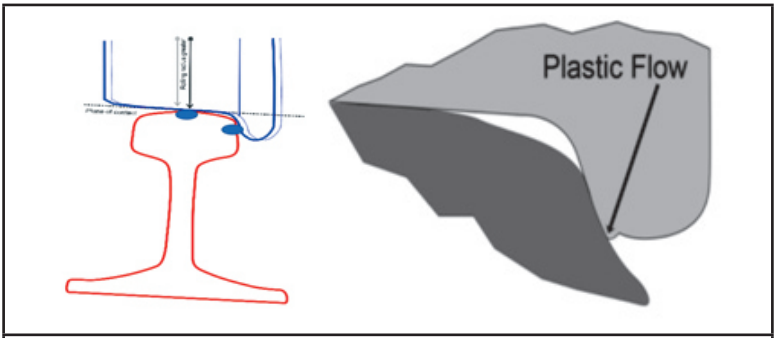


Fig 6.8: Plastic flow/wear at Flange tip contact in strong two point contact

Experience shows that under this condition, the flange often cuts under any lubricating film applied to the contact zone.

Strong two point contact are generally created when

- Rail and Wheel flange design are incompatible
- New wheel contacting worn high rail
- Deep flanged wheel contacting excessively worn rail.
- Over grinding of gauge corner

(ii) Strong One Point contact

Single-point contact generally results in a small contact area at the high rail gauge corner and lower lateral forces because of a high rolling radius difference between the wheels on the high and low rails.

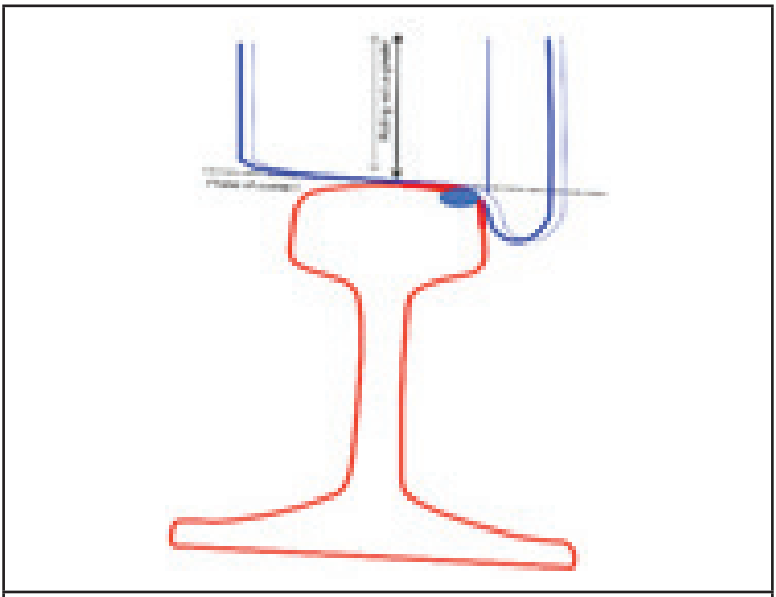


Fig 6.9: Single point contact on high rail of curve

However, high longitudinal creepages developed as a result of the high radius differential Δr, in conjunction with high-contact stress areas, can cause either, or both, a high rate of wear or surface cracks due to rolling contact fatigue. Also, in single point contact both vertical and lateral forces act at the same contact area making resultant force very high. Also, the radii of curvature of the wheel throat and the rail gauge corner, while of the same orientation, are small, so that any mismatch has a large relative effect on the size of the contact area. This amplifies contact stresses.

(iii) Conformal Contact.

Conformal flange contact is observed as the gauge-corner and flange wear to a common profile under arduous flange contact in curves.Conformal profiles tend to result in larger contact patch having decreased levels of contact stress as compared with non-conformal (counter-formal) profiles. The advantage of using this profile type is:

- It retains its shape.
- Gauge corner fatigue is controlled under prevailing axle loads.
- Lubricating films are supported due to low specific pressures.

- Conicity is “neutral” as it would seem that the wheelset does not experience the high conicities associated with single-point contact.

(iv) Near Conformal Contact

These are two point contacts with minimum distance between contacting points with small rolling radius difference between them two points and very less gap between wheel and rail at gauge corner and is taken as a conformal contact. This has reduced stresses and gauge corner is also relieved. These are normally the desired profiles as it produces lower lateral forces, rolling resistance and contact stress. They can be achieved by:

- Designing compatible wheel and rail profiles
- Regular rail grinding and wheel/rail natural wear

Under heavy haul operation conditions, wheel and rail profiles that are designed for near-conformal contact soon wear into full-conformal contact (not single point contact) with reduced level of stresses, resulting in extended wheel and rail reprofiling intervals.

The rail profile is conformal (and Near conformal) if it follows the profile of wheel and is non conformal otherwise. There can be following situations

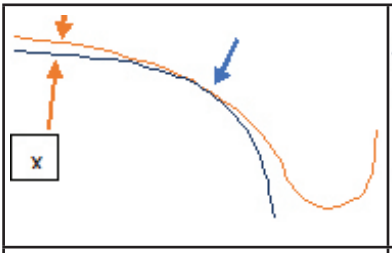


Fig 6.10: Single Point Non Conformal

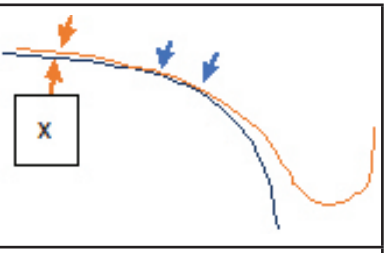


Fig 6.11: Single Point Conformal

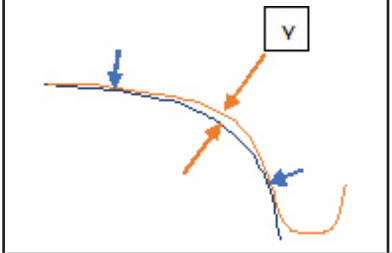


Fig 6.12: Two point non conformal

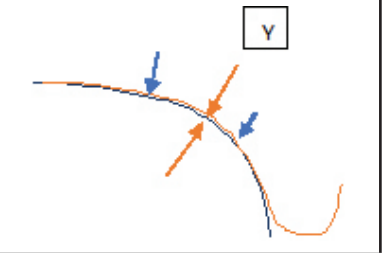


Fig 6.13: Two point conformal

If X and Y is less than say 0.1 mm, it becomes Near conformal contact. Under load, the material deforms elastically and gap closes and profile matches resulting in wide contact area extending to almost full wear band. If gap is more than 0.4 mm, both the contact point acts independently and advantage of reduced stress is not available.

Contact too close to gauge corner of outer rail has an advantage of improving steering of wheel. However, this produces stress situation at gauge corner that is difficult to manage under conditions of heavy axle load or high curvature. Thus as a guideline, where axle load is less, it should normally be single point conformal profile which should be preferred. Where axle load is high, it should be two point conformal contact which should be preferred.

(v) Sharp Curve-Low rail

The tread of the wheel should ideally contact the low rail in the center crown region.

Following situation may however arise

- Contact at low rail gage corner- It can reduce the rolling radius difference Δr on the wheelset, resulting in flange contact and higher lateral forces.This type of contact can occur when excessive material is removed from the field side of the low rail.
- Contact on the field side of the low rail- This will increase rolling radius differential and improve self-centering tendency reducing lateral force on rail.. However, in case of hollow tyre, such contact normally takes place and can cause reduced, rolling radius differential Δr on the wheelset, depending on the (worn) shapes of the wheels and result in high-contact stress due to small contact area and cause metal flow on the field side of both wheel and rail.In this type of contact either high contact stresses are generated as the outer edge of the wheel profile bears on the rail ,or contact ends before the edge of the wheel giving rise to the development of a false flange on the field side of the rail.

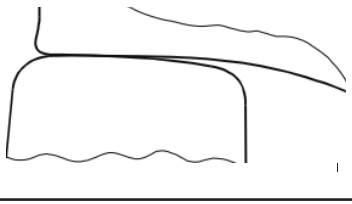


Fig 6.14: Field side contact on low rail

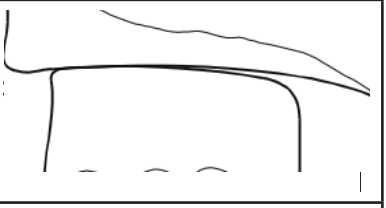


Fig 6.15: Field side contact on low rail and false flange created

6.2 Rail Profiling Purpose

The grinding strategy has been discussed in chapter 5. In general, rail profile to be achived after grinding encompasses three broad areas of rail maintenance namely:

- Control of Gauge face wear and improving lateral curving forces
- Control of corrugations
- Control of gauge corner fatigue

a. Control of gauge face wear and improving lateral curving forces

The grinding done to improve curving and controlling gauge face wear is explained in the figure below:

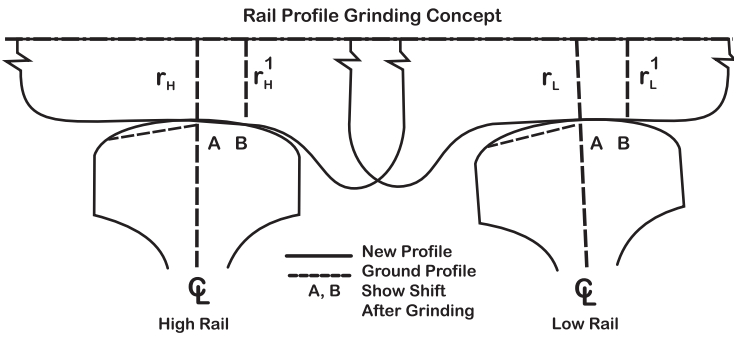


Fig 6.16: Grinding in curve to improve steering and relieve gauge corner

Here r (H) and r (L) is initial rolling radius over high rail and low rail respectively and r' (H) and r' (L) is rolling radius after grinding. It can be seen that by grinding on field side of high rail and gauge

side of low rail, the rolling radius on outer rail has been increased and on lower rail reduced, thus increasing rolling radius differential. This will try to steer the vehicle towards centre reducing force on outer rail. Even gauge corner of high rail has been relieved to control RCF at gauge corner. However these profiles should not create eccentric loading and loading reaction should be through the web of rail.

As discussed, a hollow tyre can cause material flow on field side due to high contact stress. In addition this contact on field side produces eccentric loading condition which causes torsion and may result vertical rail split particularly if rail is highly worn out. Removing this field side metal controls eccentric loading.

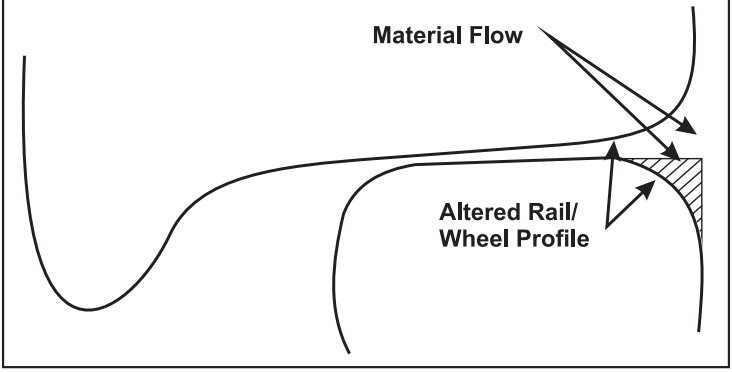


Fig 6.17: Field side metal removal to control eccentric loading

b. Control of corrugations

Corrugations are often associated with the high contact stresses generated when the false flange of a worn wheel runs on the field side of low rail. This causes very high value of contact stresses near the field side of rail causing severe plastic deformations and corresponding short wave corrugations.

These can be controlled by grinding on field side of low rail shifting the contact band towards the center of rail head, thus the high stress caused by false flange can be avoided as shown in figure above. It creates a low stress conformal contact condition near the center of rail head and reduces stress. Frequent grinding can prevent the formation of corrugation defect.

c. Control of gauge corner fatigue

The gauge corner is relieved by removing material from gauge corner thus making the contact two point as shown below.

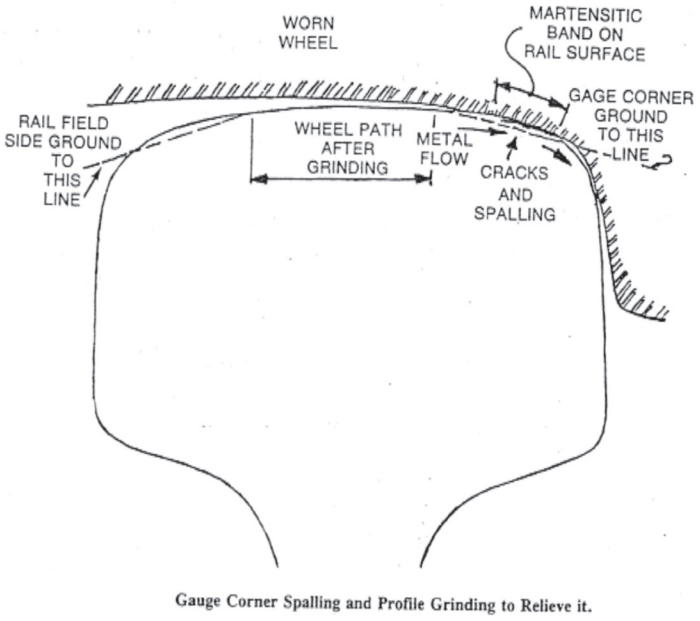


Fig 6.18: Gauge corner relieving converting single point contact to two point contact

It should be noted that by decreasing the separation between two contact points on top and side of rail head, the increased truck turning moment and increased wheel flanging forces can be reduced. This reduces the negative impact of two point contact while giving relief to contact stress at gauge corner.

While all three purpose can be achieved by grinding but usually all three cannot be addressed simultaneously. Thus one profile which is best for one may not be best for other two. Thus problem has to be prioritized.

6.3 Ground Profile Design

On the background of above discussion, different profiles that are achieved after grinding can be grouped as:

a. CPC- Contact Point Central (Single Point Contact)- The contact of wheel on rail is at centre of rail head

b. CPG- Contact Point Gauge (Single Point Contact)- The contact of wheel is towards gauge side but close to rail centre

c. CPF-Contact Point Field (Single Point Contact)- The contact is towards field side of rail but close to rail centre

d. HRS-High Rail Sharp Curve (Two Point Conformal Contact)- The contact is near gauge corner with inter-distance between contact points more and more clearance at gauge corner.

e. HRM-High Rail Mild Curve (Two Point Conformal Contact)- The contact is near gauge corner with inter-distance between contact less and less clearance at gauge corner.

The region of contact is highlighted in the sketch given below;

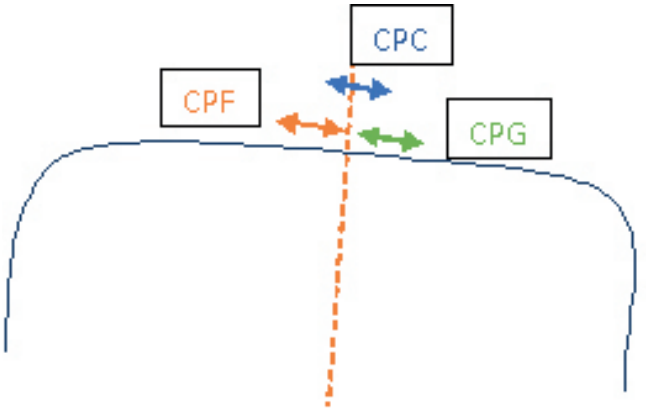


Fig 6.19: Region of CPC,CPF and CPG contact

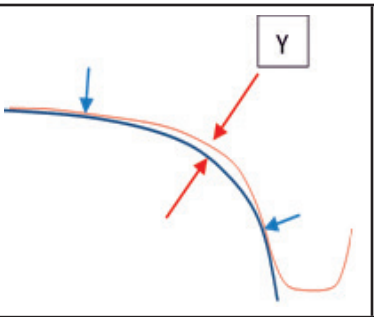


Fig 6.20: High Rail Sharp (HRS) Curve contact

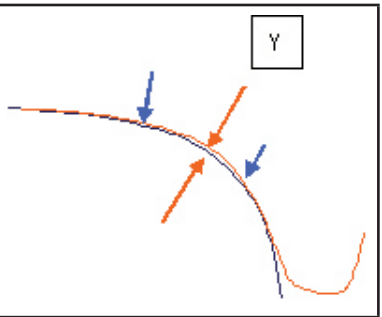


Fig 6.21: High Rail Mild (HRM) Curve contact contact

The profiles at different locations can be designed as explained below:

A. Profile-tangent track

As discussed in para 6.1 (A), a general rule, the focus on tangent track should be to promote stability, sometimes to prevent crushed heads or gauge corner defects. To promote stability, the contact should be close to crown and effective conicity should be less.

Most railways conscientiously apply a central 250-300 mm radius running band to all tangent rail. This promotes centralized wheel rail contact zone. A worn wheel profile creates a conformal or near conformal profile, widening contact patch and thus reducing stress in both rail and wheel, however, the contact band on wheel is restricted as explained in 6.1(A). The contact band width is normally limited to 20-30 mm. Thismeans that more and more wheels are running continuously at the same contact band on the wheel tread, a practice that promotes wheel hollowing.

It is therefore preferred to have templates that provide three distinct running bands, separated by about some distance (about 12 mm) with one at center (CPC), other biased towards the gauge (CPG) and the third biased towards the field (CPF). This distributes the contact on wheel tread and control wheel hallowing. CPG or CPF may not be used if there is RCF on Gauge or on Field side.

A hallow wheel when contacting flat worn out rail may cause strong two point contact as shown below causing RCF in both wheel and rails

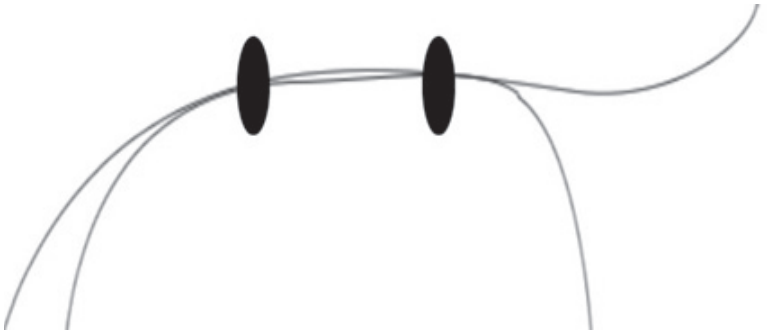


Fig 6.22: Two point contact on rail crown

The limited gauge corner relief is also given (as shown in Fig 6.24) to restrict the contact in central zone, however this results in very strong two point contact when wheel is flanging. This is

not a desirable contact and occurs during hunting and should be avoided.

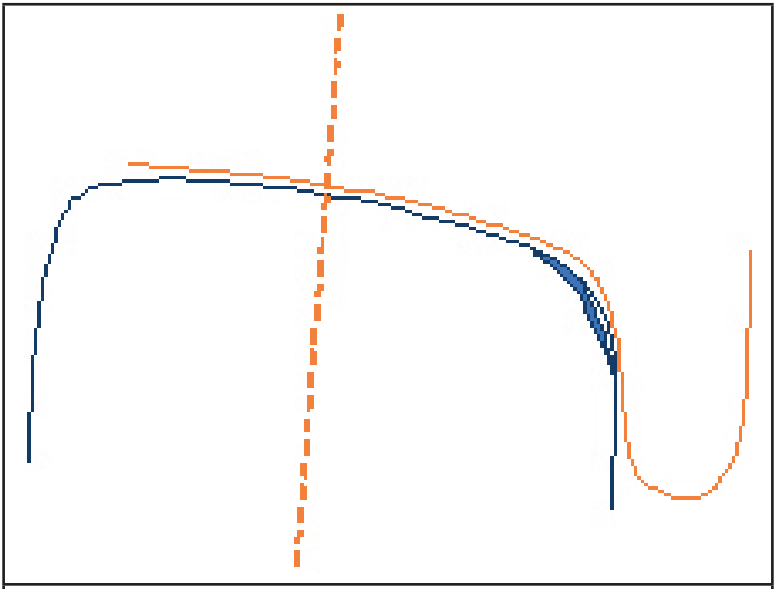


Fig 6.23 : Gauge corner relief to shift contact to center

The proper contact can be understood from the below given figure



Fig 6.24 : Proper Contact of new wheel on new rail

B. Profile- Curves

Optimal high rail profiles must avoid concentrations of stress and fatigue at gauge corner but also maximize the vehicle curving performance.

For good curving performance, the rolling radius on outer rail to be maximum and on inner rail to be minimum. Therfore, the contact zone on high rail of curve should be towards gauge face side and on low rail should be on field side as shown in figure below.

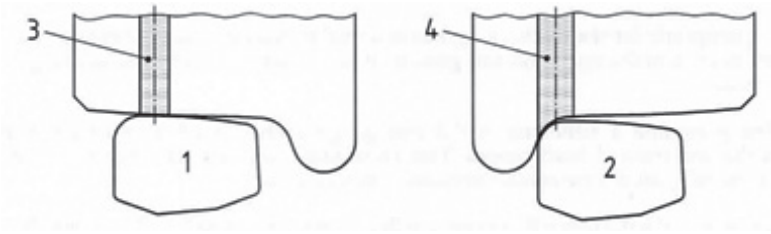


Fig 6.25: Asymmetrical profile for good curving on sharp curve (1 Low rail; 2 High rail; 3 & 4 are contact bands defining rolling radius.)

This profile is also called asymmetrical profile and is used to reduce gauge face wear of high rail. The contact on high rail has to be HRM or HRS and on low rail is shown as CPF. CPF on low rail gives the best rolling radius differential however, in case of hollow tyre, the same create very high contact stress on field side and therefore CPC profile is many times preferred for lower rail.

As far as possible and unless unavoidable, the contact should be planned to be at or close to crown.

Therefore, following contacts should be planned for curves:

- The contact zone on high rail of sharp curve to be at gauge corner and on lower rail near crown on field side.
- The same on high rail of shallow curve to be near rail crown on gauge face side and on low rail to be near crown on field side as shown in sketch below (Fig 2.7).

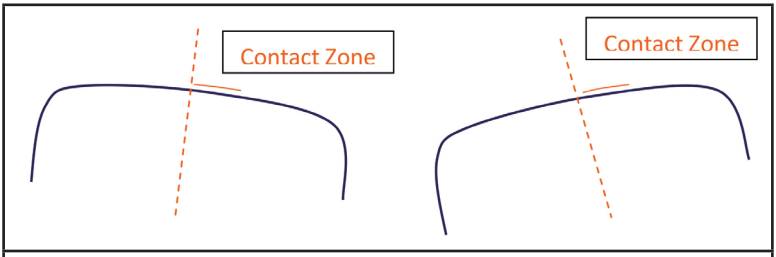


Fig 6.26: Sample High rail(Gauge side contact) and Low rail (Field side contact) profiles for mild curve

To avoid concentration of stress on gauge corner of high rail on sharp curve and on mild curve, the material at gauge corner needs to be removed as shown below. Similarly to have a contact near crown on lower rail, the gauge corner and field side is also relieved.

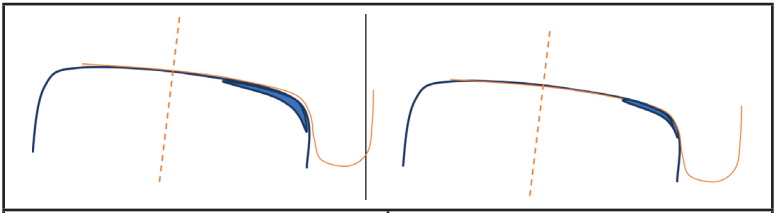


Fig 6.27: High rail on sharp curve and more relief at gauge corner

Fig 6.28 : High rail on mild curve Requiring lesser relief at gauge corner

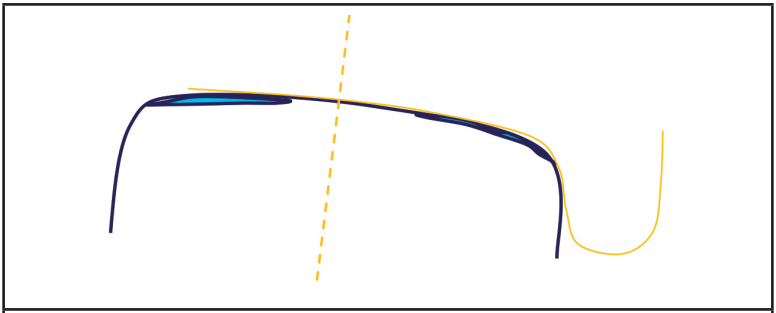


Fig 6.29 : Low rail on mild and sharp curve and relief at gauge and field side to have contact near crown

Actual profile to be achieved will be decided on the overall grinding objective and the rail wheel interface relationship. This will depend on

1. The type of track
2. The rail condition
3. The distribution of traffic
4. The distribution of wheel conditions

Since large number of different wheel profiles are moving on rail, the rail profile should be designed to meet the desired requirement for the profile which is in majority. Depending on the objective of grinding as discussed like reducing stress on high rail to control RCF by means of providing two point contact to improving steering and controlling wear by providing one point contact, the rail profile to be achieved is planned. One profile therefore cannot meet all requirement, and in fact some of the profile required for meeting one objective can be contradictory to other requirement. It is necessary to prioritize the requirement and design the ground profile accordingly

Also profiles achieved will continuously wear out and will have to restored after certain interval of time.

6.4 Grinding New Rail

New rails are normally subjected to strong Single point contact when negotiated by worn out wheel initially and even lubricating film is ineffective thus generating RCF failure and high wear until the rail and wheel stabilizes to some conformal profile.

Initial profiling of rail to conformal profile with proper greasing would reduce wear of both rail and wheel.

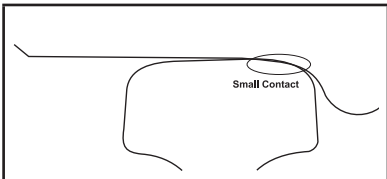


Fig 6.30 : New 60 Kg rail and New Wheel

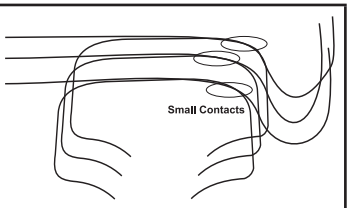


Fig 6.31 : New 60 Kg rail and different worn wheel

Rail grinding procedures have been successfully applied to control the gauge corner checking defects, which produces slight gauge corner relief of 0.5-0.8mm below the profile template to reduce the gauge corner contact for a limited time.

New rail grinding which is also called “Initial grinding” is done to

remove mill scales a procedure designed to control formation of short pitch corrugations and head checks. It also corrects any inclination defects left during laying. The target profile should be achieved and simultaneously welding defects should be smoothened at the initial stage itself.

6.5 Grind Pattern

A grinding pattern refers to a combination of grinding motor angle settings and accompanying pressures, which enable the sequence of grinding stones passing over the rail to produce a given net reshaping of the rail.

Grinding patterns can be described by the relative percentage of grinding motors deployed in each of the six key grinding zones shown below:

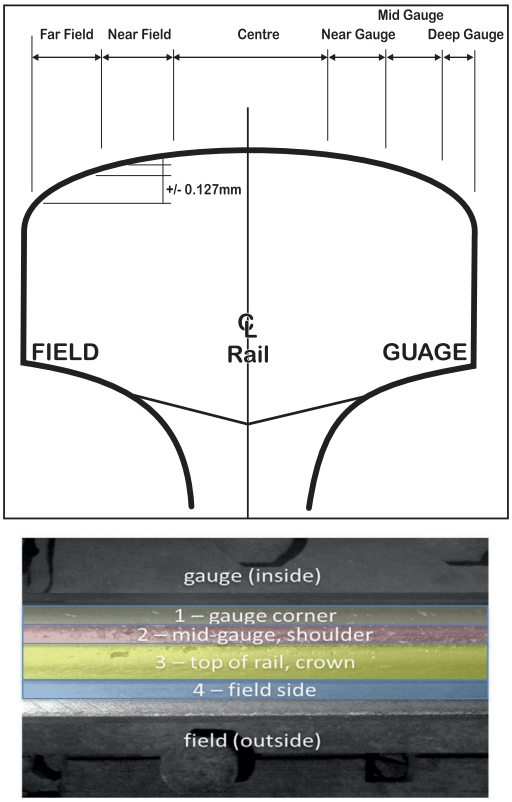


Fig 6.32 : Grind zones on Rail head

The arrangements of stones are shown below:

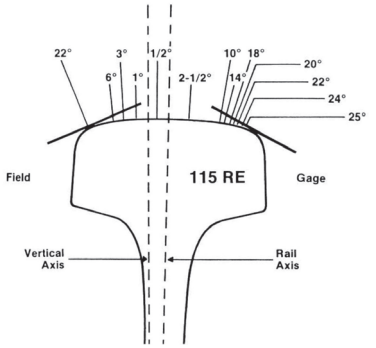


Fig 6.33: Angle of stone shown w.r.t vertical axis.

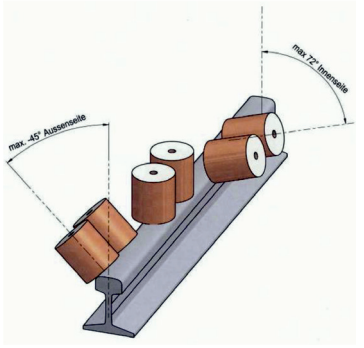


Fig 6.34: Arrangement of stones across X- section and along the rail

The pattern decides the profile that is going to be achieved after grinding. The rails are provided at 1 in 20 cant. For achieving any desired profile, if the position of stone is decided w.r.t rail kept flat on foot, the stone will actually be acting at a different angle on canted rail. For 60 Kg UIC rail with height of 172 mm, the angle to be modified by 2.86 degree .

The machine accepts the angle w.r.t vertical axis and not w.r.t rail axis therefore the position of stones to be given for canted rail by modifying the position by 2.86 degree (60 Kg UIC) for one decided by keeping rail flat on foot w.r.t rail axis. It thus implies that if stone (motor) while working is at (+) 20 degree on higher rail of curve means it is actually working at (+) 17.14 degree (w.r.t rail axis). Similarly if is at (–) 20 degree on higher rail is actually working at (-) 22.86 degree (w.r.t with rail axis).

6.6 Grind Passes and Grind cycle

A grinding pass is a single movement of a full grinding machine or train. Multiple grinding passes are given to remove additional metal. Since most of the grinding machines can grind in both directions, normally second pass is in backward and third pass is again in forward direction. Normally odd number of passes are deployed so that the last movement is in forward direction. Also first pass is more aggressive and removes more metal than the second and subsequent passes.

In preventive grinding, grinding is repeated after pre-decided GMT, assessed on the basis of rate of growth of flaw and the magic

wear rate discussed in chapter 5 required to prevent these flaws from getting converted into transverse failure of Rail. This grind cycle will therefore also depend on cutting capability of Grinding machine. More is the cutting ability of the machine more can be the GMT after which next grinding can be done. The capability of 96 stone grinder being more than 72 stone grinder, the gring cycle will change

6.7 Pummeling for Rail Profile

For deciding the profile, modeling software has proven valuable. The NRC for example has developed a Profile Optimization (Pummeling) Model that applies measured worn wheel profiles to a truck characteristic of that fleet and derives distributions of contact stress, fatigue damage, stability and curving performance. Through an iterative process, the model is used to engineer rail profiles that optimize the wheel/rail interaction in tangent and curved track. All wheels negotiating a track are not having same profiles. The wheels provided in new wagons are having worn out profile with flange thickness of 28.5 mm as discussed earlier. Before these wheels reaches condemnation limit of flange thickness 16 mm, there are intermediate profiles to which these wheels are turned in between. For Indian Railways wagon, there are total eight intermediate profiles (of which two entermediate profiles are shown in fig 6.43 & fig 6.44). Each train load containing large number wheels can have profile at different stages or somewhere in between. Similarly locomotives wheels which has a different condemnation limit will have different profiles in a train load

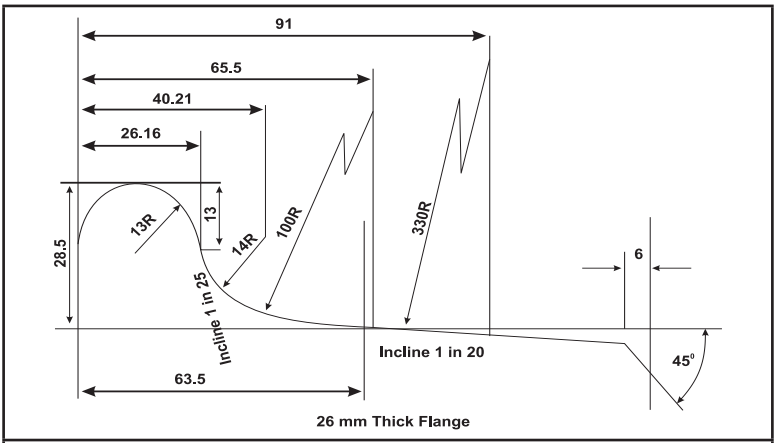


Fig 6.35 : Intermediate profile with flange thickness of 26 mm

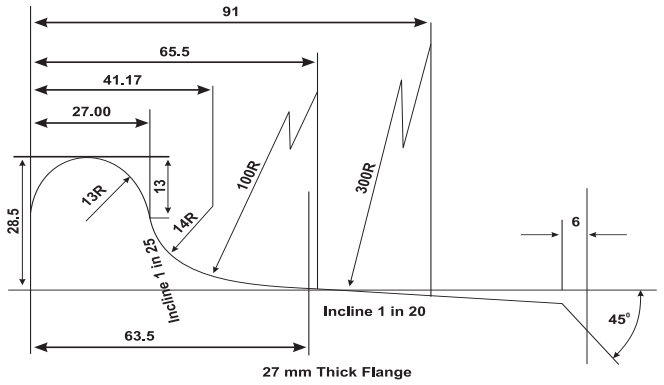


Fig 6.36: One of the intermediate Profiles with flange thickness of 27 mm

Trains running in a section, therefore will have different profiles and will be interacting with the rail differently. This interaction will depend on track alignment like interaction in straight and in curves of different curvature will be different. Since at a particular location, only one profile is possible, so best suitable profile for getting most favorable interaction will have to be found.

Pummeling is an analysis done to examine the distribution of wheel-rail contact locations on the rail head , in order to help define the required ground profile. The contact distribution is evaluated through a computer model that superimposes a set of measured wheel profiles on a given pair of rail profiles and performs a quasi-static curving balance. Information on the vehicle's weight, axle load, speed and truck characteristics, along with track parameters such as gauge, curvature and super-elevation, are used to model the wheel/rail interaction.

The information generated by the pummeling analysis provides a practical method for identifying the position and severity of the wheel/rail contacts. The contact points are shown in the figure below:

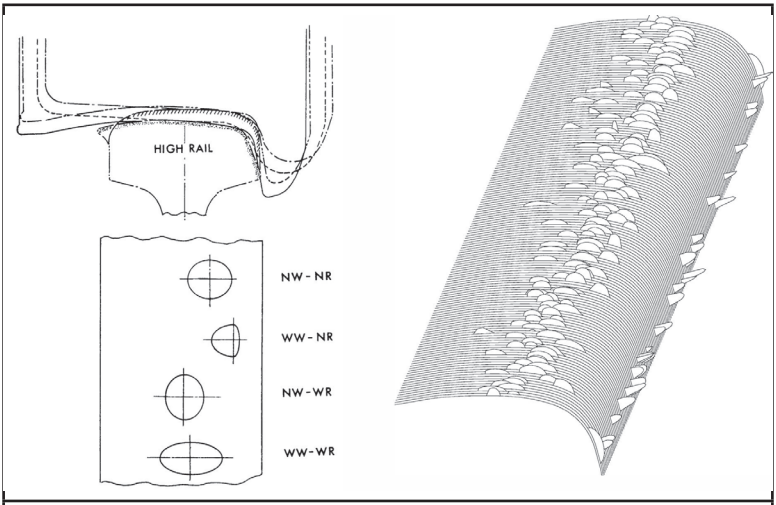


Fig 6.37 : The position, size and shape of contact patch of different wheels dictating the severity of damage on different locations of rail head.

The relative position depends on the wheel/rail profiles and lateral position of the wheelset. To find out the most suitable profile, the profiles of wheels running in the section are measured and the same are run on different rail profiles in computerized model. The location and severity of contact stress generated are plotted and the rail profile which creates least stress/damage is taken as the best suitable profile. The same is indicated the figure below:

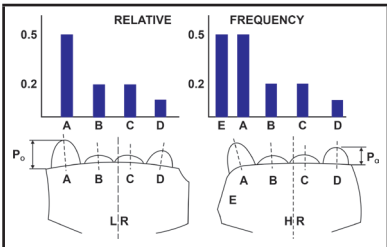


Fig 6.38: Contact location and severity of contact over High rail and Low rail in curve.



Fig 6.39: The stresses generated at different locations over different rail profiles.

In the present case, the profile highlighted in red gives the minimum stress and should be taken as the profile to be achieved

for that location.

6.8 Grinding of High Strength Rail (R350HT)

As the strength and hardness of the rail is more, the RCF generation is reduced, the propagation of RCF is reduced and wear of rail is reduced. Since wear is reduced, the removal of RCF simply by wear taking place in softer rail will not happen. Artificial wear by grinding will become necessary. Another advantage will be that profile designed will be retained for long duration. But it is necessary that the profile is properly designed as incorrect profile will also be retained creating undue high shears causing more RCF.

In general, grinding interval is going to be more in harder and high strength rail i.e. R350HT compared to 880MPa or R260 rail as generation of RCF & rate of propagation of RCF inside rail is reduced. (The magic wear rate of harder rail and its impact on grinding frequency discussed in para 5.8 of chapter 5)

◆◆◆

7.0 General

World over grinding machines are being manufactured by different manufacturers with slightly different technology and different grinding capacity. Functionally these grinders can be used for rail grinding on plain track which we will be referring as Rail Grinding Machines (RGM) or over points and crossing and some other specialized locations which we will be referring as Specialty Rail Grinding Machines (SRGM) covered in chapter 11. Different type of grinders used world on covered in Para 1.1 of Chapter 1.

Indian railway is using two 72 stone conventional production grinders of M/s Loram, USA and in future (work awarded) additional 96 stone conventional production grinders of M/s Loram, USA and SRGM of M/s Loram, USA and of M/s Harsco, USA make will be inducted for covering entire Indain Railways network. Also Rail Inspection Vehicles (RIV) of M/s Harsco, USA, which will be assisting users of RGM and SRGM in deciding pattern and profiles is proposed to be inducted. Milling machine is also likely being inducted.

In this chapter, the information on 72 stone and 96 stone conventional grinder of M/s Loram, USA has been covered.

7.1 72 Stone RGM, M/s Loram make:

These Rail Grinding Machines procured on Indian Railways in 2011 are high productivity conventional grinders using 72 stones, i.e. 36 stones for the left side and 36 stones for the right side rail. Each stone is rotated by an independent electric motor of 30 HP. Each motor can be tilted at a desired angle independantly from $+70^{O}$ (towards gauge face side) to -30^{O} (towards field side). Typical layout of the grinder is given below:

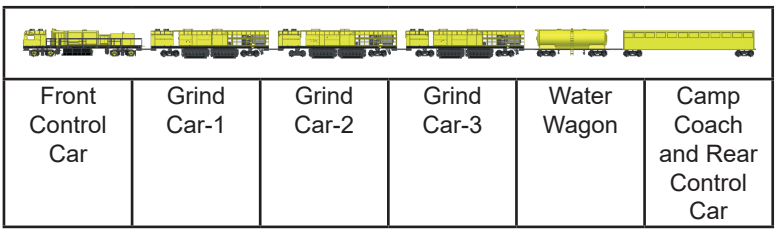


Fig 7.1 : 72 stone RGM layout

The grinding machine comprises of one Control Car, three Grind Cars, Water Wagon and Camp Coach. The dimension of these components are:

Car	Weight (Kg)	Length (m)
Control Car	91000	19.3
Grind Car	78000	19.3 (3 nos)
Water wagon	83200	12.5
Camp Coach	50000	21.3
Inter connections		9.1
Total		**120.1**

This machine can work in both the directions, while front control car has all the control and monitoring system, the camp coach is modified to have wind screen at the end and provided with driving facility for driving, when working in reverse direction. Thus Front control Car (FCC) has driving as well as grind controls while Rear Control Car (RCC) has only driving control system.

A. Front Control Car (FCC) The inside of front control car (FCC) is shown in fig 7.2 below



Fig 7.2 : Front Control Car Cab

In the front cab, the machine is having 2 touch screen consoles known as HMI (Human Machine Interface) consoles. These consoles are used for various settings, selection of patterns, viewing machine working, etc. The consoles display various menu

options. The operator can select one option by touch and this will display the sub-menu for the selected option.



Fig 7.3 : HMI Console

In addition the grind car has belly tank and water cannon as shown below:

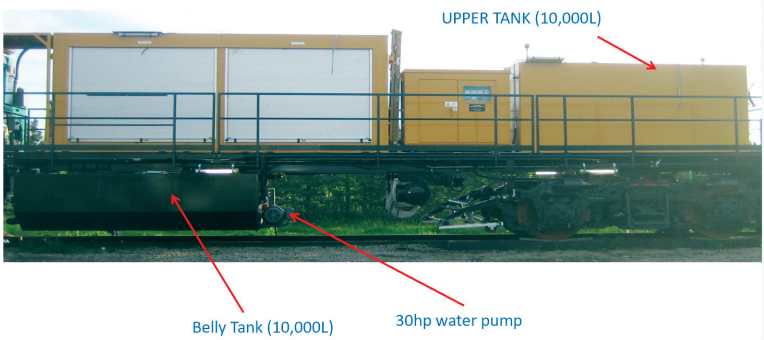


Fig 7.4 : Water storage and Pumping in FCC

In addition FCC has one KLD (Rail Profile Measurment System) attached for taking the rail profile. One KLD is attached to water wagon:

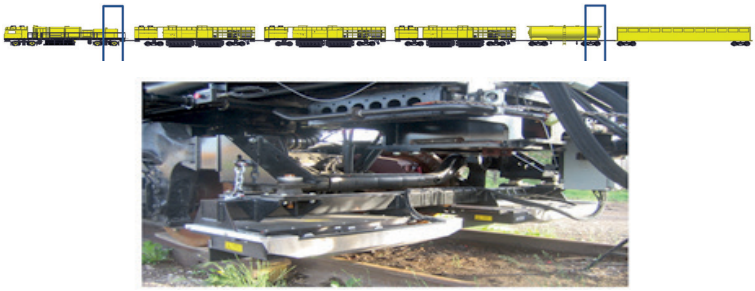


Fig 7.5 : KLD for rail profile measurement

The KLD takes rail profile before and after grinding, thus comparing the profile with the desired profile and check if the desired profile has been achieved or not.

B. Grinding Cars and Grinding Carriages

Each grind car has grinding stones placed on grind carriages as shown below. Each grind car has 24 stones, 12 on each rail and each grind carriage having six stones.

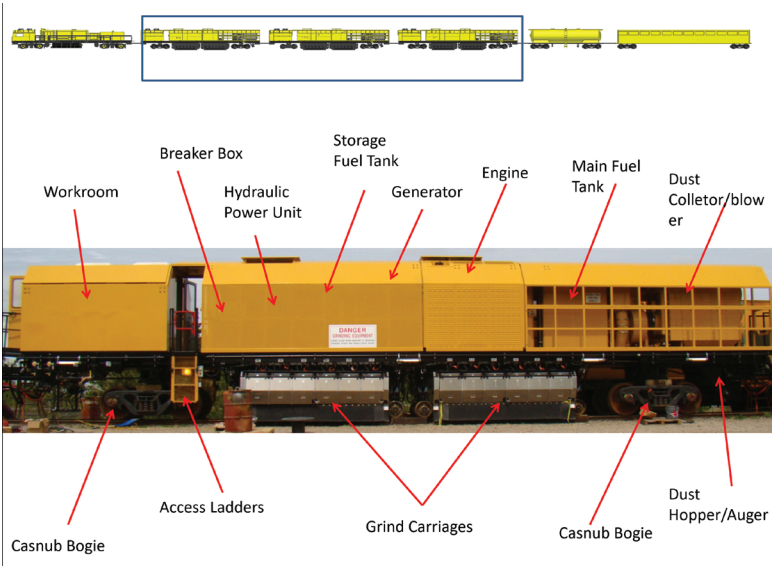


Fig 7.6 : Grind Carriage

Each grind stones is powered by one separate motors as shown below:

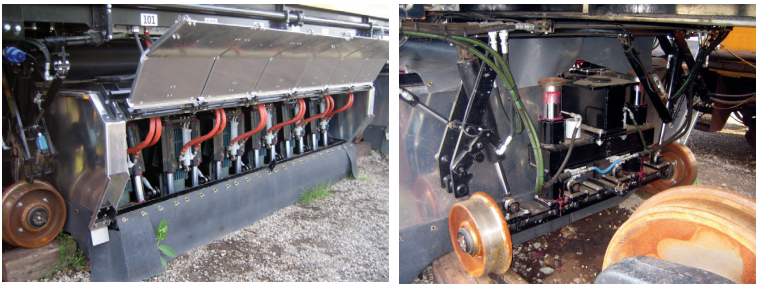


Fig 7.7 : Grind stones with motors (6 nos)

The carriage is supported on a buggy wheel as shown in the figure

above. The buggy is raised during running and is lowered during working.

Iron dust created during grinding is collected by dust collection system.

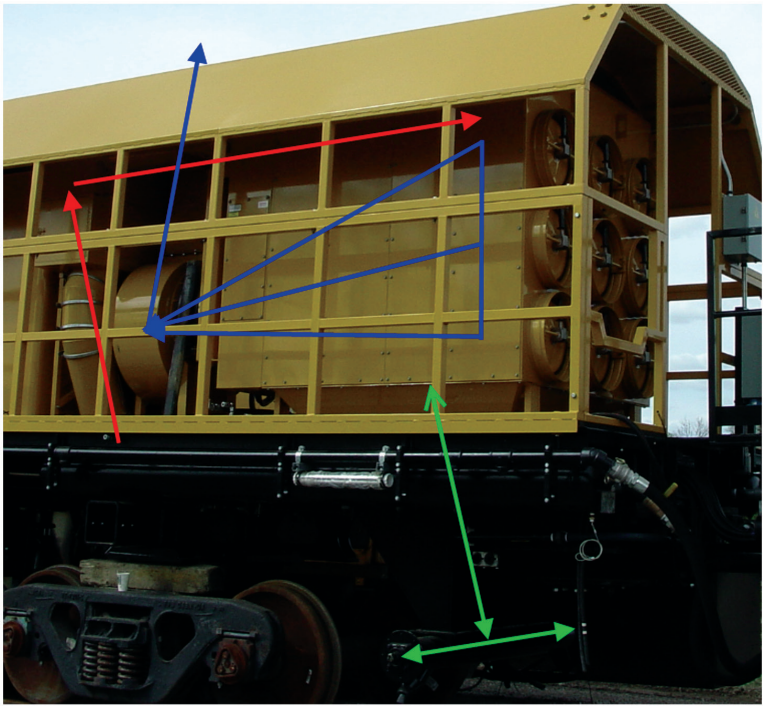


Fig 7.8 : Iron dust suction process

Dust/Hot air comes from carriages (red arrows), Air goes or through filters (blue arrows), Clean air go through blower and out of roof (blue arrow), Dust is collected in hopper and can be discharged to either side of the machine (green arrows). The iron dust if not removed will be deposited on rail as below:



Fig 7.9 : Iron dust on track

Iron duct falling on track may result in track circuit failure, if not lifted.

C. Grinding Stone:

Proper rail grinding stone is the key to effective and productive rail grinding. Grinding stones are specifically engineered to perform within a given range of contact pressures, revolutions per minute and heat inputs. In effect they 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.

Production grinding wheels consist of a disc of varying thickness, starting between 50 and 75 mm in thickness. These discs are made up of a matrix of thousands of abrasive grains held together in a synthetic resin-bonding agent as shown below:

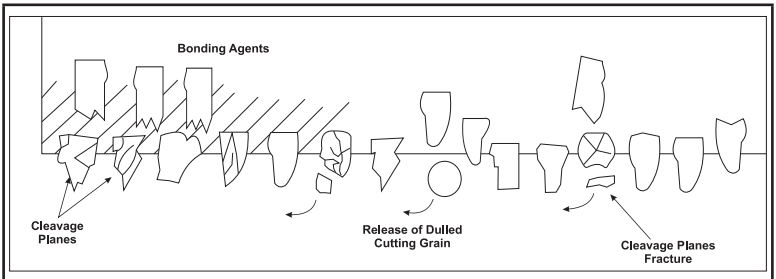


Fig 7.10 : Grinding stone showing fracture of cutting grains

Each grain acts as a cutting tool and the bond material is the "tool post." A good abrasive is one which fractures along many different cleavage lines, each fracture producing a sharp cutting surface. Also it is resistant to abrasive wear for long life and has a moderate to high fracture toughness to prevent premature fracture.

As the wheel rotates at around 3600 RPM, the cutting grain gradually dulls. A good abrasive will then continue to fracture along its cleavage planes to expose new cutting edges.

At some point in its life, the grain becomes too small to regenerate a cutting surface and will remain dull. As this continues, the friction on the grain builds up and it absorbs heat. The bond is formulated to respond by ultimately permitting the entire grain to dislodge from the matrix, exposing a fresh grain beneath. And in fact the abrasive grains are spaced in the stone's structure to specifically permit this without clogging the grinding interface. Hence the process starts again.

The grind stone is of 250 mm outer diameter and is placed on grind carriage. Each grinding stone has seperate 30 HP motor.

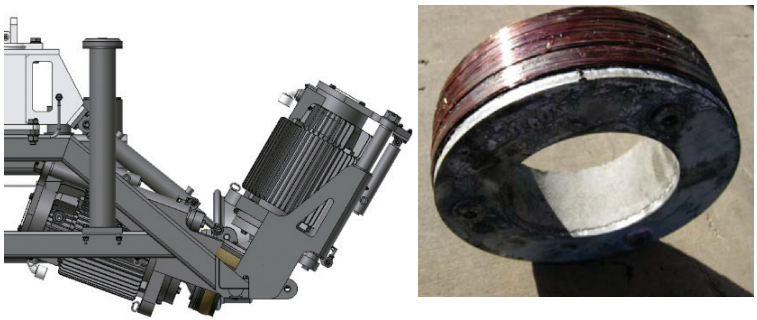


Fig 7.11 : Grind motor (having 30 hp motor tiltable between -30 to + 70 degree)

Life of stone is 8 to 10 hours of grinding.

Spark shield are provided to prevent the spark from spreading sideways which otherwise may result in fire catching up in dry grass or objects nearby.

D. Water Tanker and other fire control measures

The BTPN wagon attached has 75,000 liters of water. Wooden sleepers in track, dry grass and garbage in track/ on cess is susceptible to catch fire due to heavy sparks generated during grinding operation. Water is sprinkled through 'Tie Sprays' (set of nozzles spraying water at sleeper level) and 'Ditch Sprays' (set of sprinklers spraying water on cess area) before the grinding operation to make the area wet and reduce the chances of fire. These are provided on Grind car no. 1 & 3 as shown in figure below:



Fig 7.12: BTPN Wagons



Fig 7.13 : Tie Sray and Ditch Spray

The machine is equipped with 30 HP pump, water cannons, fire hoses, fire extinguishers and fire detection system to take care of fire hazards. Thus there are elaborate arrangements for prevention as well as quenching of fire on rail grinding machines since fire is a major hazard in operation of this machine.

E. Rear Control Car (RCC)

The machine is having a well-furnished air-conditioned camp coach known as Rear Control Car. The coach is also having driving controls for the machine on rear end. The coach can accommodate 14 people. The coach is provided with a kitchen, dining area, bathrooms, etc.

F. Rail Corrugation Analyser

Rail Corrugation Analyzer (RCA) is mounted on front axle of rear drive truck . This measures the rail corrugation while running of the machine and helps the operator in deciding the depth of cut

thus changing pattern as per requirement.



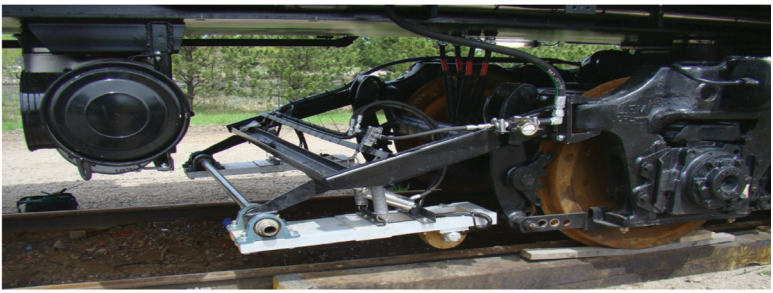


Fig 7.14 : Rail Corrugation Analyser

The RCA recording before and after grinding is shown below:

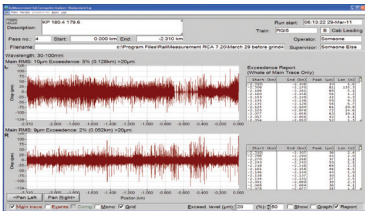


Fig 7.15 : Corrugation recorded before grinding

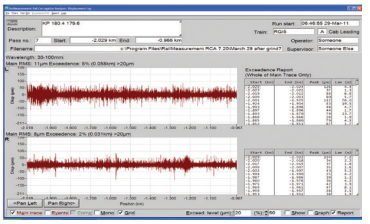


Fig 7.16 : Corrugation after grinding

G. Obstruction Detection Device:

These are mounted on front of front truck and at rear of Camping Coach. During travel these are locked up and lowered for working during grinding. It gives audio and visual warning if any obstruction over the rail is there and operators has to decide on the action to be taken depending on weather it is going to affect grinding or not.





Fig 7.17 : Obstruction Detection Device

H. Travel Cameras & Sequencing Monitor

These cameras are provided in RCC and FCC for overlooking the track in rear. They transmit the image of track and obstruction on rare side to the monitor in FCC and RCC respectively. This helps in sequencing the motors up and down as well as looking for any obstructions on the rear side of the train while carrying out grinding in reverse direction.

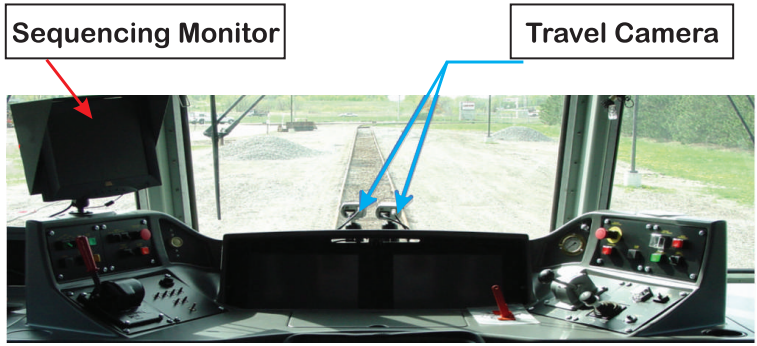


Fig 7.18 : Travel Cameras

I. Safety Systems

The grind car is provided with fire alarm system as shown below

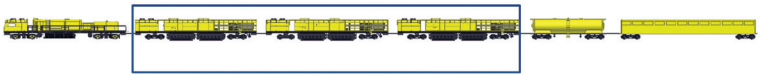




Fig 7.19 : Fire alarm system

This detects flame and alerts operator in cab of fire in engine room for taking requisite action. In addition, the machine is provided with safety devices to bring all machine operations to a halt by pressing one emergency stop button. “Hot Rail” switches are provided on each console and near each ladder in the train. On pressing this

switch, a loud hooter is blown and flashes blue strobes to warn the personnel on the machine of a passing train on the adjacent track.

J. Grind Data Management System (Rail-Pro in new machines of M/s Ioram)

The Grind Data Management System (GDMS) is an integrated automatic system for

- Data acquisition.
- Data management
- Quality control
- Reporting and planning tool for Rail Grinding.

GDMS is software-based system, which is fed with track data, different pre-decided patterns and proposed target profiles for different track geometry and structure. By taking a measuring run in advance, GDMS is having the facility of recommending one of the pre-fed patterns to get target rail profile from the existing rail profile. Thus it is used to suggest patterns to be followed for grinding at different locations.

It uses laser based rail profile management system (KLD) available in the front as well as on the rear of the grinding machine to record the pre and post grinding rail profile and gives how close we are to the proposed profile by giving Grind Quality Index (GQI).

K. Grind Quality Index (GQI)

Grinding Quality Index (GQI) is estimated by comparing the measured rail profile with the target rail profile template for the area of material to be removed for a particular grinding pass. The KLD provided in front measures the pre grind rail profile and compares the same with the desired profile giving pre-grind GQI. The measurement is taken at every 1m interval. The KLD at the rear similarly measures the profile post grinding and compares the same with the desired profile giving post grind GQI and the result is displayed on screen in the front cab as shown below

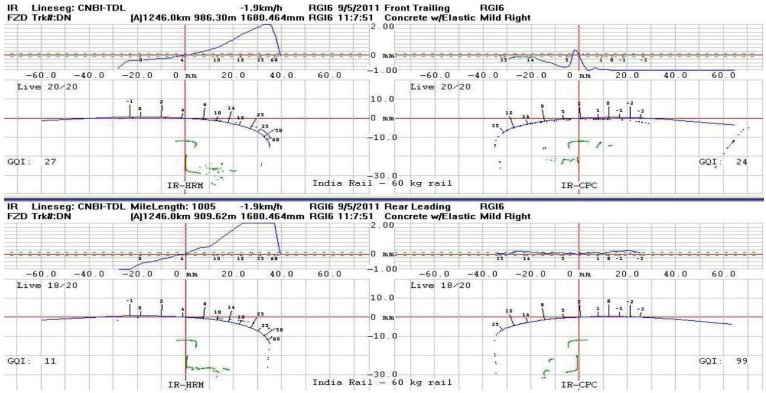


Fig 7.20 : Recording as shown done by KLD and displayed on Screen

While the upper two graph shows the recording by front KLD (Pre-Grind profile), the bottom two by the rear KLD (Post-Grind Profile). In the above graph following may be seen

- GQI at front left rail and right rail location (Pre-grind). In this case it is 27 and 24. The GQI at post grind location at rear left rail and right rail (Post Grind). In this case it is 11 and 99. However, it should be noted that these values are at two different locations and does not give the comparative pre and post grind GQI at same location.
- The rail profile proposed to be achieved at these four locations are also shown which in this case is HRM & CPC at front KLD location and HRM & CPC at rear KLD location.
- The metal cut depth required at different location corresponding to degrees shown over rail profile is shown slightly above the rail profile.

The GQI of 100 means no cutting of material is required and the profile matches completely to the desired profile.

In the report generated after grinding, the GQI is given as an average of 1 km length of grinding in tangent track in curves if it is less than 1 km, one GQI is given for complete curve.

L. Capability of the machine:

The capability of the machines are listed below:

(i) The machine is capable of grinding through 10^{O} curves(after removal of check rails) and up to 3% gradients.

(ii) Grinding can be done in either direction without the need for reversing the machine.

(iii) The machine can grind plain as well as curved track (without check rails), track in tunnels, track on bridges (guard rails on bridges are not an obstruction), glued joints and fish-plated joints.

(iv) Level crossings, points & crossings, SEJs and axle counters create obstructions and are to be skipped by raising the grinding stones while grinding. Check rail on sharp curve also creates obstruction and needs to be removed for grinding. It has also been observed that joggled fish plates provided on high rail of sharp curves also create an obstruction and should be removed before grinding.

(v) The machine is capable of grinding at a speed ranging from 2.4 km/h to 24 km/h. However the speed is kept between 8 and 20 km/h during grinding. The traveling speed of the machine without grinding is 80 km/h by design.

(vi) The machine will work in traffic block, but no power block is required during the grinding operation.

(vii) There is no need of any speed restriction on the track after grinding or on the adjacent track during grinding. However, as a precaution, trains carrying inflammable materials like Naphtha etc. should not be run on the adjacent track during grinding operation.

(viii) During the grinding operation, it is ensured that metal deformation does not take place and the temperature should not rise beyond 350 degree centigrade so that there are no metallurgical changes in the rail.

(ix) Water is not required for grinding operation but water is sprinkled on to the sleepers and on cess with the help of tie sprays and ditch sprays respectively to make the area wet to avoid cases of fire due to sparks generated while grinding. Water consumption is around 1100 l/km

(x) The machine can remove 0.2mm of metal on an average while grinding at 10 kmph.

(xi) The buggies should be lowered on straight track only to ensure that the buggy wheels sit properly on rails. In case of curve, due to different wheelbase of the buggy as compared to the wagon, the wheels may go off the rail on lowering. For

the same reason, the raising of the buggies is also done on straight track only.

(xii) The grinding motors are raised in case of obstruction while the buggies keep running on track.

7.2 96 Stone Rail Grinding Machine- M/s Loram Make

The 96 stone RGM is same as 72 stone grinder with following difference

a. Instead of three grind cars in 72 stone grinder, one additional grind car (24 stones) is provided thus improving the grinding capability of the machine to remove more metal at 10 Kmph. Also instead of one camp coach in 72 stone grinder, this has two camp coach. All this increases the machine length. These changes will have following implications:

- The requirement of stabling line length is more
- The grinding speed is increased, that means same amount of metal removal is now possible at higher working speed.



Fig 7.21 : 96 stone RGM M/s Loram make

b. The software Grind Data Management System(GDMS) has been replaced by a new software called Rail-Pro.

◆◆◆

Rail Grinding over Indian Railways

8.0 General:

Rail grinding was started scientifically and systematically on Indian railways in 2011 with induction of two 72 stone grinder of M/s Loram make namely RGI-5 and RGI-6. Since these two grinders were insufficient to cover complete network of Indian railways, the routes to be ground was prioritized. In this chapter, we will be covering the grinding being done by 72 stone grinder by RGI-5 and RGI-6 over Indian railways. For operation purpose, RGI-5 was allotted to South Central Railway and RGI-6 was allotted to North Central Railway. The Grinding strategy, the profiles and frequency of grinding for Indian Railways was suggested by National Research Council (NRC), Canada. The routes to be ground was prioritized by a high level committee in line with grinding strategy suggested by NRC Canada. NRC also suggested reviewing the existing worn out profile of wheels (RDSO Drg No WD 88021) and suggested new wheel profile (IR2010-WHL) for better rail-wheel interaction. However the same was not agreed.

8.1 Grinding Strategy :

NRC-CSTT recommended starting with a single pass Preventive-Gradual grinding strategy for tangent track (estimated to be 90% of the track) which involves embarking straight onto preventive grinding cycles without first undertaking the expensive task of cleaning the rail surface of fatigue damage and producing the NRC-CSTT Optimal rail profile. For curves where the flaw had already gone deep into the rail, a 3 pass corrective grinding strategy was suggested to start with and subsequently shift to single pass Preventive grinding.

The rail is transitioned to the desired profile and crack-free state on a gradual basis. Preventive-Gradual grinding reduces the wheel contact on existing mild or medium RCF and eventually catches up to the deep RCF over several grinding cycles.

The advantages of implementing a Preventive-Gradual strategy instead of a Corrective strategy are as follows:

- The amount of metal removed from the rail per gross million tonne (GMT) is reduced by 50%.

- Less metal removed at each track kilometre with increased productivity of the grinder by up to 60%; that is, more kilometres of track can be ground each shift and each year.
- The work hardened layer on the rail head is maintained and the softer steel does not begin to plastically deform after grinding, therefore the NRC-CSTT Optimal rail profile is maintained for longer tonnage intervals

8.2 Selection of routes-Criteria

Since only two grinders were procured, the grinding could be done over limited routes and for limited length. The routes selected was based on following consideration:

a. Importance/Utilisation of route

b. Axle Load and GMT of route

c. Failures in route and renewal due

To priorities the routes to be covered, following critical routes were identified:

a. High density routes

b. High utilized routes

c. High axle load routes

These important routes over Indian Railways are:

(i) Heave Density Routes (HDN)

There are 7 identified routes which carry 60% of Indian railway traffic as listed below:

Table 8.1

S. No	HDN No	Name of HDN Route	Length
1	HDN 1	Delhi-Howrah	1454 Km
2	HDN 2	Howrah-Mumbai	1968 Km
3	HDN 3	Mumbai-Delhi	1387 Km
4	HDN 4	Delhi-Guwahati	1827 Km
5	HDN 5	Delhi-Chennai	2180 Km
6	HDN 6	Chennai-Howrah	1218 Km
7	HDN 7	Chennai-Mumbai	1261 Km

(ii) Heavy Utility Route (HUN)

11 HUN routes on IR of total route length 23,347Km are listed below\

Table 8.2

S. No	HUN No	Name of HUN Route	Length
1	HUN 1	Amritsar-Andal	3049 Km
2	HUN 2	Kharagpur-Udhna	3035 Km
3	HUN 3	Chandigarh-Rajkot	1685 Km
4	HUN 4	Firozpur-Mundra Port	1529 Km
5	HUN 5	Jhansi-Muzaffarpur-Katni	2151 Km
6	HUN 6	Bandel-Dibrugarh	1490 Km
7	HUN 7	Vizianagram/Paradeep-Kota	2737 Km
8	HUN 8	Vasco-Machlipatnam	1501 Km
9	HUN 9	Ajmer-Dindigul	2803 Km
10	HUN 10	Manmad-Kanyakumari	2232 Km
11	HUN 11	Mangalore-Kanyakumari	1134 Km

(iii) High axle load routes

The feeder routes of DFC

a. Western Corridor

Table 8.3

SN	Rly	Route	Route Km	Track Km	Length of 60 Kg rail patch (In Track Km)
1	NR	Ludhiana-Hissar-Rewari	205.44	205.44	72.27
	NWR	Ludhiana-Hissar-Rewari	142.56	211.58	211.58

2	WR	Pipavav-Surendranagar-Viramgram-Mehsana	396	461	83
3	WR	Kandia Port-Gandhidham-Samakhiali-Palanpur	354	377	47
4	WR	Mundra Port-Gandhidham	66	132	57
5	WR	Viramgram-Samakhiali	235	384	394
6	WR	Hazira-Surat	40	40	40
7	WR	Dahej-Bharuch	62	62	62
		Total	**1501**	**1873.02**	**966.85**

b. Eastern Corridor

Table 8.4

S N	Rly	Route	Route Km	Track Km	Length of 60 Kg patch (In Track Km)
1	ER	Pradhankhunta-Ansol-Andal Including coal branch lines	73.2	278.0	221.0
2	ER	Andal-Santhia-Pakur	154.6	309.0	286.0
3	ER	Dankuni-Dumdum jn - Ballygung jn-Diamond Harbour, Ballygung jn-Budge-budge	100.7	201.0	35.0
4	ER & SER	Dankuni-Andul-Panskura-Haldia	141.2	304.0	295.1

5	ECR	Sonnagar-Garwa road-Barkakana	310.9	610.0	550.5
6	ECR	Patraru-Gomoh including PD Branch line	127.6	205.0	144.2
7	ECR	Sonnagar-Gaya-Gomoh	248.9	498.0	497.5
8	ECR	Gomoh-Pradhankhunta including Kusunda-Tetulmari, Katrasgarh - Nichitpur, Pradhankhunta-Patherdin link	66.3	106.0	98.1
9	ECR	Dhanbad-Katrasgarh-Jamuniatanr-chandrapura	33.3	58.0	11.5
10	ECR & SER	Gomoh-Chandrapura-Bokard-Muri-Chandil-Sini-Chakradharpur	200.5	347.0	348.9
11	ECR & SER	Chandil-Bhojidih-Mohuda-Gomoh	144.4	239.0	234.0
12	NR	Mughalsarai-Unchahar via Janghai, Phaphamau	208.4	299.0	177.2
13	NR	Varanasi-Sultanpur-Utratia-Rosa	439.4	879.0	635.2
14	NR	Zafrabad-Tanda	100.3	100.0	46.7
15	NR	Ludhiana-Beas-Goindwal Sahib	121.6	215.0	145.9

16	NR	Rajpura-Dhuri-Bhatinda (Lehra Mohabbat)	148.2	148.0	2.9
17	NR	Sirhind-Rupnagar-Nagal Dam	104.0	104.0	41.5
18	NCR	Kanpur-Paricha	191.1	266.0	245.4
19	NCR	Aligarh-Harduaganj	13.9	13.9	0.0
20	NWR	Hissar-Bhatinda-Suratgarh	296.6	296.6	147.9
21	NWR	Suratgarh-Biradhwal	17.8	17.8	15.2
22	SER	Tatanagar-Chandil	36.3	73.0	71.4
		Total	**3279.2**	**5567.3**	**4251.0**

c. 25T Axle Load Routes

Table 8.5

S N	Rly	Route	Route Km	Track Km
1	SER	Banspani-Daitari-Jakhpura-Paradeep	25.74	25.74
	ECoR	Banspani-Daitari-Jakhpura-Paradeep	318.2	597.9
2	ECoR	Kirandul-Kottavalasa-Vishakhapatnam	446.0	573.8
3	SER	Kiriburu-Bondamunda-Hatia-Bokaro Steel City	397.0	531.0
4	ECoR	Koraput-Rayagada-Vijaynagaram-Vishakhapatnam	379.0	767.7
5	SER	Noamundi-Banspani-Tata	155.0	431.0
6	SWR	Torangullu-Ranjitpura	23.0	23.0
7	SECR	Marauda-Dallirajhara	76.3	76.3

8	SER	Sini-Chandil-Damodar-Bunpur-Asansol, Damodar-Kalipahari-Durgapur	161.0	311.0
9	SER	Barsuan-Bimalarh-Rourkela steel plant	51.0	96.0
10	SER	Gua/Bolanikhadan-Barajamda-Noamundi	37.8	61.1
		Total	**2070.04**	**3494.4**

8.3 RGM 72 Stone Grind Routes

In preventive grinding, a cycle of grinding is to be followed, therefore only that much length to be chosen where machine can return after pre-decided GMT. Following routes therefore were selected for these two RGM. (RGI-5 & RGI-6)



Fig 8.1 : RGI-6 GRIND ROUTES (Base-NCR)



Fig 8.2 : RGI-5 GRIND ROUTES BASE-SCR

8.4 Ground Profiles :

The ground profiles suggested for Indian Railways by NRC are:

Table 8.6

Grinding Templates	Tangent	High	Low
UP Mild Curves (≤ 1.25°)		HM	CPC
UP Sharp Curves (> 1.25°)		HS	CPF
DOWN Mild Curves (≤ 1.25°)		HM	CPC
DOWN Sharp Curves (> 1.25°)		HS	CPF
UP tangent	CPF		
DOWN tangent	CPC		

Single Line Tangent*	CPF/CPC		
SINGLE Mild Curves (≤ 1.25°)		HM	CPC
NGLE Sharp Curves (> 1.25°)		HS	CPF
52 kg Tangent	CPC		
52 kg Curves		HS/HM	CPC
Tangent Track with Hunting	CPF		

*Single line will have 1 km CPC and next Km as CPF. Here HM stands for HRM and HS for HRS

As the name suggests, in CPF profile the contact of the wheel on the rail will shift towards the field side while in CPC the wheel will make the contact with the rail in the centre. HRM and HRS are two point contact profiles with different rail wheel contact location. CPG was not suggested even for straight track initially due to RCF observed on gauge side in existing rails. The profiles thus finally suggested to have contact at locations close to as shown in sketches below. However this is w.r t the suggested worn wheel profile of IR2010-WHL but can be taken as applicable for existing worn out wheel profile also.

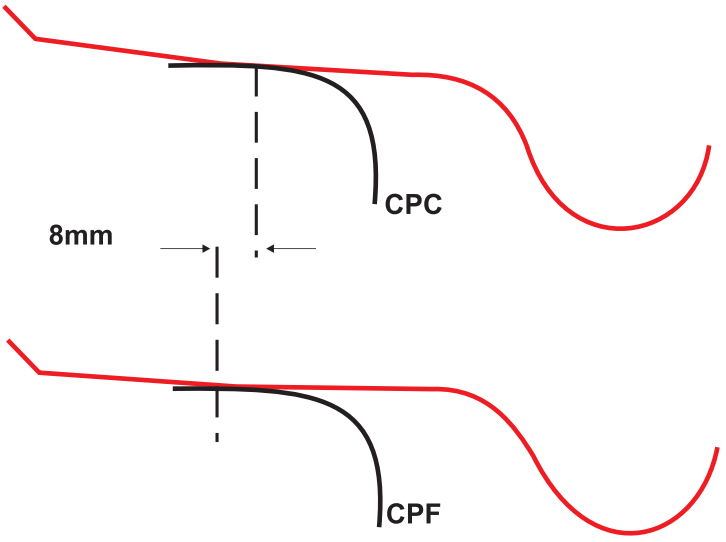


Fig 8.3 : CPC and CPF Profile

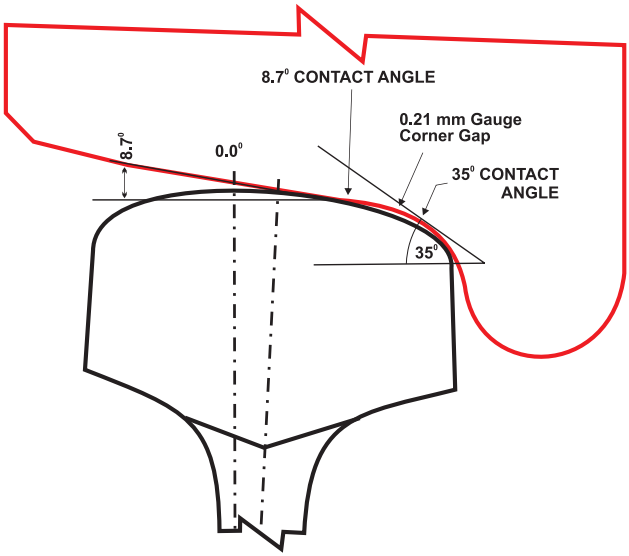


Fig 8.4 : Near Conformal 2 point contact (HRM)

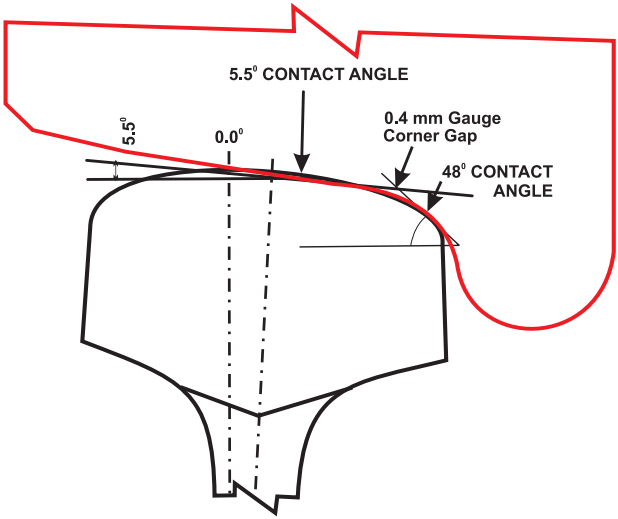


Fig 8.5 : Two Point Contact (HRS)

While CPC profile is designed to have contact at crown, CPF profile to have contact at 8mm on field side of crown. The HRM profile is a two point conformal contact to have contacts at around 8.7 degree and 35 degree with gap at gauge corner of around

0.21 mm. HRS profile is two point contact to have contact at around 5.5 degree and 48 degree with a gap of around 0.4 mm at gauge corner.

On Up and Down line CPC and CPF profile or in single line an alternate CPC and CPF profile is suggested to widen the contact zone on wheel tread to avoid it getting converted to hollow tyre.

8.5 Grind Frequency:

The grind frequency to be followed by Indian railway in routes selected is tabulated below:

Table 8.7

Comlative GMT in the section from start of grinding	Track Classification				
	Cycle #	Tangent (Straight) Track	Mild Curves	Sharp Curves	Test Sites
0	Grind 1	Single Pass at 15 Kmph	3 Passes at 18 Kmph	3 Passes at 18 Kmph	Monitor Profile
25 (Approx)	Grind 2	Single Pass at 15 Kmph	3 Passes at 18 Kmph	3 Passes at 18 Kmph	Monitor Profile and RCF
75 (Approx)	Grind 3	Single Pass at 15 Kmph	3 Passes at 18 Kmph	3 Passes at 18 Kmph	Monitor Profile and RCF
125 & so on (Approx)	Grind 4 & so on	Single Pass at 15 Kmph	3 Passes at 18 Kmph	3 Passes at 18 Kmph	Monitor Profile and RCF

As can be seen, the grinding after first pass (Grind-1) will be done after 25 GMT of traffic and subsequent grindings after every 50 GMT. While single pass grinding in tangent track to be done at 15 Kmph, three pass grinding in curve at 18Kmph to be done.

For KK line in Eco Railway, the frequency is recommended as 25 GMT instead of 50 GMT.

8.6 Track Data for Grind Data Management System (GDMS):

The track data is to be fed in GDMS in advance and it is important that following precautions are taken:

- Since, High rail and low rail are different for LH and RH curve, and profile decided for High Rail and Low Rail are also

different, it is important that, curves directions are correctly fed.

- Chainage of start of curve and end of curve and similarly other locations, is also to be correctly fed.

Track data should be collected from field in the format given in Table 8.8:

a. The required proforma to be filled is as shown on top. Some assumed data has been filled as example.

b. The data should be entered always in increasing Km irrespective of UP or DN line and direction of curve should be entered in the increasing Km accordingly.

c. Length measurement should be exact upto cm.

d. Each track Km starting point chainage should be taken as 0 and end chainage shall be the actual length of that track Km in meter and cm. These may not be exactly 1000 mtrs in each Tr Km, so the length should be exactly be measured in mtr and cm in each track Km. In above table Km 921 starts from 0 and ends at chainage 995.00 mtrs. Km 922 begins at 0 & ends at 1009.50 metres and so on.

e. All curves and level crossings of a Km are to be filled in successive rows repeating the same Km.

f. Railway station name in railway code and its centre line chainage to be filled in that row in which the station falls e.g. in above case stn RUB falls in Km 922

g. In the above shown chart there are two curves in Km 921 and three level crossings so there are three rows entries in Km 921.

h. TP1 is beginning of transition portion of curve i.e. start point of curve

CTP1 is beginning of circular portion of curve

CTP2 is end of circular portion of curve

In case there are two or more than two consecutive circular curves (compound) the chainage point of chainage of CTP3 and CTP4 to be recorded and degree of all curves to be recorded.

TTP2 is end of transition portion of curve i.e. last point of curve.

Table 8.8

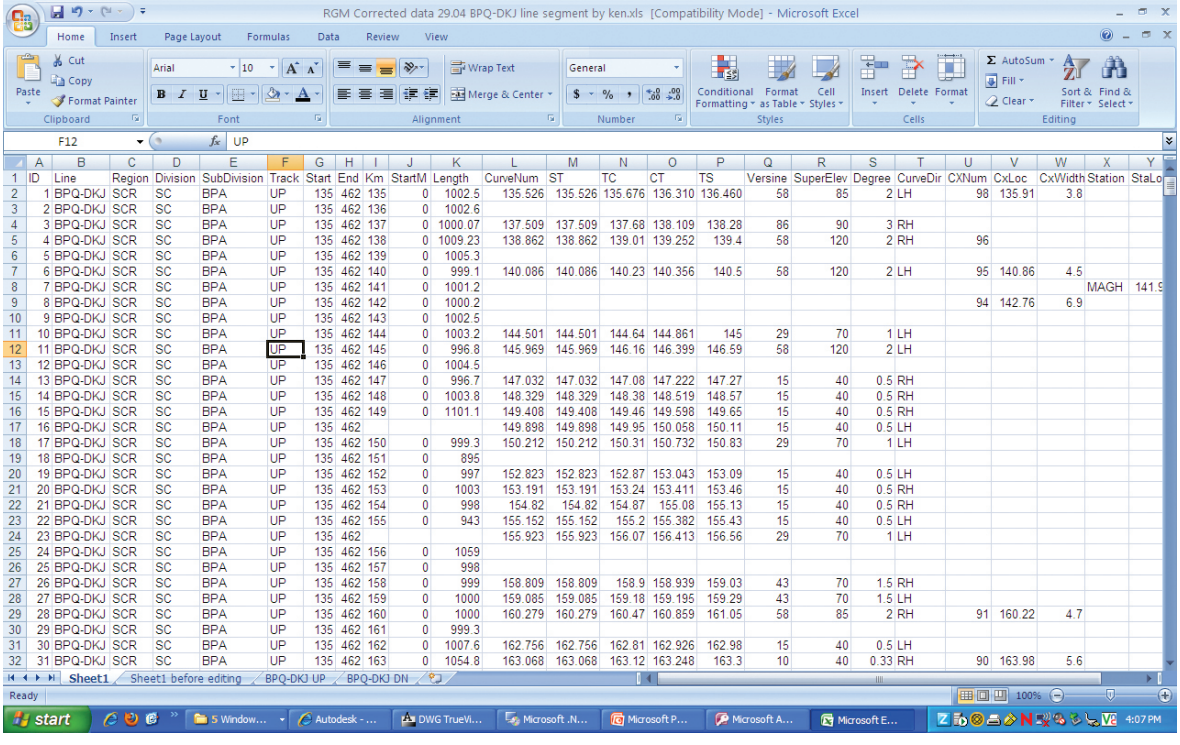
Profarma - Track Detail for feeding to GDMS of RGMS																								
Sr No	Rail-way	Divi-sion	ADEN HQ/ Stn	UP/ DN 3rd/4th	Section From Km	Section To Km	Length of each Km of Section			Curve Details									L-Xing Details			Station	
							Km	Start Ch. In Mtr	End Ch. In Mtrs	Curve No	TTP1	CTP1	CTP2	TTP2	Vers-ine in mm	S--Elev in mm	Degree of Curve	LH/ RH	LC No	Center Line Ch	Width of LC	Station Code	Center Line Ch

Profarma - Track Detail for feeding to GDMS of RGMS

Sr No	Rail-way	Divi-sion	ADEN HQ/ Stn	UP/ DN 3rd/4th	Section From Km	Section To Km	Length of each Km of Section			Curve Details									L-Xing Details			Station	
							Km	Start Ch. In Mtr	End Ch. In Mtrs	Curve No	TTP1	CTP1	CTP2	TTP2	Vers-ine in mm	S--Elev in mm	Degree of Curve	LH/ RH	LC No	Center Line Ch	Width of LC	Station Code	Center Line Ch
1	NCR	ALD	FTP	UP	921.200	1017.500	921	0.00	995.00	201	921.22550	921.24550	921.34550	921.36050	20	50	1.25	LH	51	921.58550	4.50		
				UP						202	921.3705	921.38045	921.43045	921.44045	15	35	1	RH	52	921.79050	5.50		
				UP															53	921.98050	6.78		
				UP			922	0.00	1009.50													RUB	922.58
				UP			923	0.00	987.00														

For filling these, following instructions to be followed

This data to be entered in Excel as shown below: (Fig. 8.5)



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	ID	Line	Region	Division	SubDivision	Track	Start	End	Km	StartM	Length	CurveNum	ST	TC	CT	TS	Versine	SuperElev	Degree	CurveDir	CXNum	CxLoc	CxWidth	Station	StaLo
2	1	BPQ-DKJ	SCR	SC	BPA	UP	135	462	135	0	1002.5	135.526	135.526	135.676	136.310	136.460	58	85	2	LH	98	135.91	3.8		
3	2	BPQ-DKJ	SCR	SC	BPA	UP	135	462	136	0	1002.6														
4	3	BPQ-DKJ	SCR	SC	BPA	UP	135	462	137	0	1000.07	137.509	137.509	137.68	138.109	138.28	86	90	3	RH					
5	4	BPQ-DKJ	SCR	SC	BPA	UP	135	462	138	0	1009.23	138.862	138.862	139.01	139.252	139.4	58	120	2	RH	96				
6	5	BPQ-DKJ	SCR	SC	BPA	UP	135	462	139	0	1005.3														
7	6	BPQ-DKJ	SCR	SC	BPA	UP	135	462	140	0	999.1	140.086	140.086	140.23	140.356	140.5	58	120	2	LH	95	140.86	4.5		
8	7	BPQ-DKJ	SCR	SC	BPA	UP	135	462	141	0	1001.2													MAGH	141.9
9	8	BPQ-DKJ	SCR	SC	BPA	UP	135	462	142	0	1000.2										94	142.76	6.9		
10	9	BPQ-DKJ	SCR	SC	BPA	UP	135	462	143	0	1002.5														
11	10	BPQ-DKJ	SCR	SC	BPA	UP	135	462	144	0	1003.2	144.501	144.501	144.64	144.861	145	29	70	1	LH					
12	11	BPQ-DKJ	SCR	SC	BPA	UP	135	462	145	0	996.8	145.969	145.969	146.16	146.399	146.59	58	120	2	LH					
13	12	BPQ-DKJ	SCR	SC	BPA	UP	135	462	146	0	1004.5														
14	13	BPQ-DKJ	SCR	SC	BPA	UP	135	462	147	0	996.7	147.032	147.032	147.08	147.222	147.27	15	40	0.5	RH					
15	14	BPQ-DKJ	SCR	SC	BPA	UP	135	462	148	0	1003.8	148.329	148.329	148.38	148.519	148.57	15	40	0.5	RH					
16	15	BPQ-DKJ	SCR	SC	BPA	UP	135	462	149	0	1101.1	149.408	149.408	149.46	149.598	149.65	15	40	0.5	RH					
17	16	BPQ-DKJ	SCR	SC	BPA	UP	135	462				149.898	149.898	149.95	150.058	150.11	15	40	0.5	LH					
18	17	BPQ-DKJ	SCR	SC	BPA	UP	135	462	150	0	999.3	150.212	150.212	150.31	150.732	150.83	29	70	1	LH					
19	18	BPQ-DKJ	SCR	SC	BPA	UP	135	462	151	0	895														
20	19	BPQ-DKJ	SCR	SC	BPA	UP	135	462	152	0	997	152.823	152.823	152.87	153.043	153.09	15	40	0.5	LH					
21	20	BPQ-DKJ	SCR	SC	BPA	UP	135	462	153	0	1003	153.191	153.191	153.24	153.411	153.46	15	40	0.5	RH					
22	21	BPQ-DKJ	SCR	SC	BPA	UP	135	462	154	0	998	154.82	154.82	154.87	155.08	155.13	15	40	0.5	RH					
23	22	BPQ-DKJ	SCR	SC	BPA	UP	135	462	155	0	943	155.152	155.152	155.2	155.382	155.43	15	40	0.5	LH					
24	23	BPQ-DKJ	SCR	SC	BPA	UP	135	462				155.923	155.923	156.07	156.413	156.56	29	70	1	LH					
25	24	BPQ-DKJ	SCR	SC	BPA	UP	135	462	156	0	1059														
26	25	BPQ-DKJ	SCR	SC	BPA	UP	135	462	157	0	998														
27	26	BPQ-DKJ	SCR	SC	BPA	UP	135	462	158	0	999	158.809	158.809	158.9	158.939	159.03	43	70	1.5	RH					
28	27	BPQ-DKJ	SCR	SC	BPA	UP	135	462	159	0	1000	159.085	159.085	159.18	159.195	159.29	43	70	1.5	LH					
29	28	BPQ-DKJ	SCR	SC	BPA	UP	135	462	160	0	1000	160.279	160.279	160.47	160.859	161.05	58	85	2	RH	91	160.22	4.7		
30	29	BPQ-DKJ	SCR	SC	BPA	UP	135	462	161	0	999.3														
31	30	BPQ-DKJ	SCR	SC	BPA	UP	135	462	162	0	1007.6	162.756	162.756	162.81	162.926	162.98	15	40	0.5	LH					
32	31	BPQ-DKJ	SCR	SC	BPA	UP	135	462	163	0	1054.8	163.068	163.068	163.12	163.248	163.3	10	40	0.33	RH	90	163.98	5.6		

Fig 8.5 : Data entered in Excel format

The columns should be as numbered in the sample and is reproduced below:

Table 8.9

Column	Name		Column	Name
1	ID – unique row # useful for finding errors		12	CurveDir – curve direction • Defined by ascending Kposts. Example: While travelling from Km 2 to Km 3 the Curve is a Left Hand
2	Line – Line segment name		13	CXNum – Crossing number
3	Region		14	CxLoc – crossing location
4	Division		15	CxWidth – Crossing width
5	Sub-Division		16	Station – station name
6	Track – name of this track; UP, DN, SL, 1, etc.		17	StaLoc – station location
7	Km – Kilometer post number		18	Start – Not used
8	Length – Length of this Kilometer (in meters)		19	End – Not used
9	ST, TC, CT, & TS – Curve points		20	StartM – Not used
10	Versine – used when calculating DOC		21	CurveNum – Not used
11	Degree – the Degree of Curvature		22	SuperElev – Not used

This excel data is converted to be usable GDMS format by using

software supplied by M/s Loram. However this data must be in sheet-1 of excel document and as shown to have 25 columns. Some of the information is not used by software as is not relevant for grind planning and are mentioned as “not used” in the above table.

The track information is displayed to the operator during grinding and he is aware of the track geometry when he is approaching that length & this helps him in feeding the grind pattern for left and right rails.

8.7 Grind Pattern:

Provision to feed 50 grind patterns i.e. arrangement of stones over different position on rails are available in the supplied machines. Accordingly to meet the requirement of achieving the desired profiles, following patterns were pre-fed by manufacturer.

The angle written below each pattern shows the area being covered in grinding. The height of the darkened portion indicates the amount of material to be removed. Thus some patterns designed to remove less material is mild patterns while the one designed to remove more material are aggressive patterns. Judicious selection of patterns become important. These patterns can be modified as per requirement.

The grinder has a facility to take the profile of existing rail using KLD attached. If the desired profile is fed in advance, the GDMS software of the machine will suggest the patterns required to achieve the desired profile from the measured existing profile. For Indian Railways however M/s Loram suggested patterns to be fed for single pass on tangent track for achieving CPC and CPF profile. For curved track, the pattern for first pass was given by M/s Loram, however for 2nd and 3rd pass, the pattern is suggested by the GDMS software which is used by the operator.

In case the track information in GDMS is not matching with track geometry, the operator needs to change to mild pattern so as not to damage the rail. NRC suggested following pattern for different passes (Table 8.10)

Pattern Sheet



Fig 8.6 : Patterns pre-fed in machines

Table 8.10

Template	Track	Patterns		Speed	Wrong Direction in GDMS			All Pass Speed
					3 Pass Patterns			
		First Pass Agres-sie	First Pass Generic	Kph	Pass 1	Pass 2	Pass 3	Kmph
High Rail Sharp Curve (HS)	UP/ Down	14	45	18	14	27	15	18
High Rail Sharp Curve on New Rail (HS NEW RAIL)	UP/ Down	2	45	18	2	47	23	18
High Rail on Mild Curve (HM)	UP/ Down	10	45	18	10	43	27	18
High Rail on Mild Curve - New Rail (HM NEW RAIL)	UP/ Down	2	45	18	2	47	X	18
Low Rail Shrp Curve (LS-CPF	UP/ Down	20	47	18	20	23	27	18
Low Rail Sharp Curve on New Rail (LS-CPF NEW RAIL)	UP/ Down	24	47	18	24	23	23	18
Low Rail on Mild Curve (LM-CPC)	UP/ Down	19	39	18	39	42	X	18
Low Rail on Mild Curve - New Rail (LM-CPC NEW RAIL)	UP/ Down	17	41	18	39	46	X	18
Tangent (TCPF)	UP	24	24	15				
Tangent New Rail (TCPF NEW RAIL)	UP	24	24	15				
Tangent (TCPC)	DN	39	39	15				
Tangent New Rail (TCPC NEW RAIL)	DN	39	39	15				
Tangent for 52 Kg Rail (TCPC 52 Kg RAIL)	UP/ Down	39	39	15				
Low Rail Sharp Curve 52 Kg (LS-CPC 52 Kg RAIL)	UP/ Down	39	39	18	39	42	X	18
Low Rail Mild Curve 52 Kg (LM-CPC 52 Kg RAIL)	UP/ Down	39	39	18	39	42	X	18

The grind cutting depth at different locations will be as given in table 8.11.

Table 8.11

Track Location (BHN) Work hardened rail	Preventive Gradual Metal Removal Depth mm	GRINDING ANGLE
New Rail (260-280)	0.3	
Curves High Rail (320-340)		
Guage	0.4	(+60 to +6 degrees)
Mid Guage	0.2	(+16 to +6 degrees)
Crown	0.1	(+6 to -2.5 degrees)
Field	0.2	(-2.5 to field degrees)
Curves Low Rail (320-340)		
Guage	0.25	(+45 to +16 degrees)
Mid Guage	0.2	(+16 to +4 degrees)
Crown	0.1	(+4 to -2.5 degrees)
Field	0.2	(-2.5 to field degrees)
Tangent (320-340)		
Guage	0.25	(+45 to +16 degrees)
Mid Guage	0.2	(+16 to +4 degrees)
Crown	0.1	(+4 to -2.5 degrees)
Field	0.2	(-2.5 to field degrees)

8.8 Advance Preparation

RGM machine operation and maintenance by railways required setting of facilities in advance for which following instructions were issued to railways vide letter no. 99/Track-III/MC/6 Vol.IV, dated 13.02.2009. Important instructions are reproduced below:

- Maintenance siding (@40-50 Km) with required facility
- Siding length as one spur of Length 300 m or two spurs of 150 m. These should be preferably unwired but if required to be wired then should be provided with OHE isolation arrangement.
- Rail level PF
- Resting and Toilet facility,
- Watering facility for RGM (water consumption is around 1100

l/km) and drinking water taps

- Oil Loading facility. (diesel consumption is around 85 l/km)
- Lighting arrangement.
- Approach road
- 3 Phase Power Point connection for welding.

Indian Railway is now inducting 96 stone grinder and as the length of machine is increased by one Grind Car and one camp coach, the total length of machine is now going to be 175 m. In addition on SRGM, one RIV and one UTV shall also be accompanying RGM, Accordingly, each siding should be now planned for 350 m with 150 m unwired for maintenance of machines.

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Rail Grinding Monitoring and Benefits

9.0 General:

The grinding benefits are to be monitored regularly to ensure that the grind profiles, grind pattern chosen are appropriate in terms of increased safety and reduced wear. Any decision to modify the profiles and changing corresponding pattern has to be taken on regular basis based on observation. The rail surface should be observed for facet profile, roughness, any bluing or dents for any remedial action. The ultimate aim is to ensure that rail life is increased and safety of train is ensured. This chapter discusses the method of monitoring the benefits of RGM.

9.1 Items to be monitored

The benefits of rail grinding will accrue in the form of:

- Reduced wear of rails
- Reduction in USFD defects
- Reduction in Rail/Weld fractures in track
- Reduction in damage to rail surface including RCF
- Reduced in weld dip

All this will increase the rail life and safety of train operation. Thus before grinding profile is compared to after grinding profile and the ground rail is checked for following :

a. **Contact band width & its position -** to decide that proper contact is made and Hunting has reduced.

b. **Wear Pattern of rails -** to decide whether the profile has actually resulted in reduction of stresses. The rates of vertical wear i.e. W1 & the rate wear at gauge corner i.e. W3 and rate of lateral wear i.e. W2 is monitored.

c. **Extant of Rolling Contact Fatigue (RCF) -** to confirm that already prevalent RCF has been eliminated and cycle is adequate to remove new RCF defects.

d. **Target Rail Profile attainment -** the profile attained after each grinding cycle be compared with target rail profile

Since it is not possible to measure these parameters at every location, a representative test sites are made for a particular

section The whole section is however monitored for improvement in USFD result and reduction of rail fractures.

9.2 Test sites

Test site locations are established as a representative track in a traffic section where monitoring and measurement will be done before and after rail grinding to arrive at proper decisions regarding various RGM implementation issues like appropriateness of metal being removed from the rail surface vis a vis growth of RCF cracks, the effectiveness of the grinding pattern to achieve the target rail profile and to control the grinding cycles to optimum frequency. On these sites, studies regarding rail surface conditions are performed; data of rail profile is collected and analysed for rate of wear along with analysis of USFD defects and rail/weld fractures in the section to evaluate the efficacy of rail grinding

A typical test site is represented in the Fig below. It consists of stretch of track covering three sleeper spacing's divided into three parts – first for measuring rail profile by MiniProf (Marked as MP), The measurement should be taken at centre of w marked on non-gauge face, second for taking surface photographs and the third for doing Dye Penetration Test and taking DPT photographs.



Fig 9.1 : Test sites

The Criteria for selecting test sites for RGM working are:

a. Normally each traffic section between junction stations should be represented by one test site. Track at test site location shall have predominant rail type available in the section.

b. Separate test sites should be chosen for different track structures (52 kg/60kg) as far as possible.

c. Rail renewal should not be due at the location of test site.

d. Rails there should have preferably 50% of GMT life remaining and expected to remain in service for at least next 3-4 year periods.

e. Test location should be away from signals. Defective/damage rail, welds, glued joints, way side rail lubricators etc.

f. The site should have access by road preferably.

g. Test location should include one tangent, mild curve (upto 1.25 degree) and sharp curve location(curve above 1.25 degree) depending on their availability in that particular representative section.

h. Three such test sites (To be taken as one) are selected at an interval of 80-100 m apart to constitute one test site. Keeping multiple test location as one test site ensures better reliability as other locations remain available for data collection even if rails are replaced at one location on account of rail fracture etc.

i. For any major change in gradient or formation structure, separate test site should be selected.

9.3 Measuring Equipment's and measurements taken:

The equipment's used for taking different measurements are:

Table 9.1

S. No	S. No	Measure
A. Specific Measuring Equipment		
1	MiniProf or Similar Optical Rail Profile Measuring Equipment with Personal Digital Assistant (PDA) / Tablet	Rail profile, Rail wear
2	Laptop/Computer with analysis software	Analysis of the data
3	DPT Kit (Cleaner, Dye penetrant and developer)	RCF analysis

4	Yellow paint, Marker pen, Steel scale and Cotton	Marking rail details, RCF status & Contact Band details
5	Digital Camera	Photography at test location
6	Surface roughness measuring Equipment	Surface Roughness after Grinding
B. Other Measuring Equipment		
1	P.Way inspection kit	Alignment/versine and unevenness
2	Bar Gauge	Rail profile deviation from target profile
3	Star Gauge	Rail top radius
4	Surface Hardness Testing instrument	Surface hardness
5	Digital Inclinometer	Angle at a point on rail top
6	Tribometer	Effectiveness of rail lubricator

a. Monitoring Rail Profile: MiniProf or Similar Optical Rail Profile Measuring Equipment with PDA/Tablet for Rail profile measurement:

These equipment's are used to take the rail profile before and after grinding. Some of the Optical Rail Profile Measuring Equipment available in market are listed below:

Table 9.2

Manufacturer	Accuracy
MiniProf	0.01 mm (Approx)
Graw	0.1 mm (Approx)
Pie	0.1 mm (Approx)

The photo of MiniProf is given below, this is to be connected to PDA or Laptop for collecting data

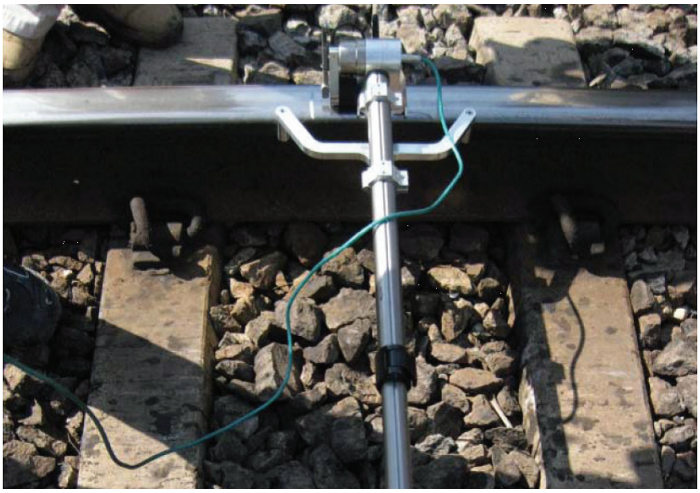


Fig 9.2 MiniProf

The measurement of such equipments are used to check

- If the desired profile is achieved or not
- The wear at different critical locations (W1, W2 and W3) shown below

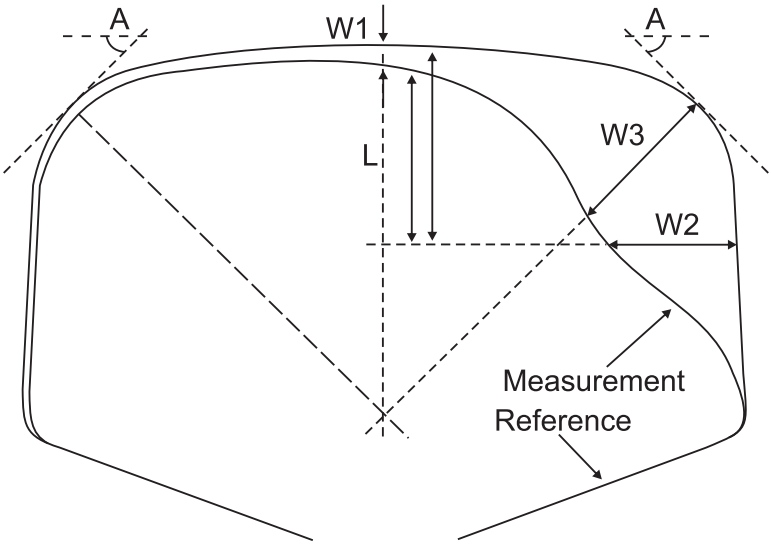


Fig 9.3 : Wear at different locations

The wear at rail top is W1, at gauge corner is W3 and at gauge face is W2. Miniprof software has a provision to overlap two profiles to get the wear at critical location. The underside of two profiles being compared should be overlapped to get correct measurement. A sample of MiniProf reading is enclosed below:

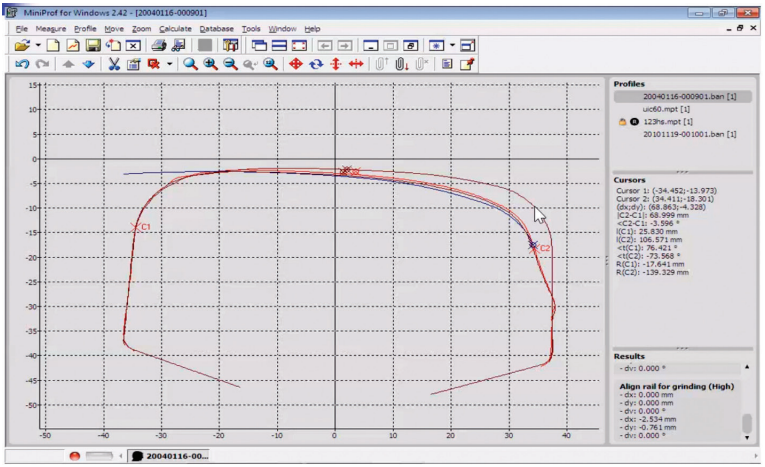


Fig 9.4 : Reading taken by MiniProf

In addition, rail profile can be checked by Bar gauge, which has template of all four profiles (CPC/CPF/HRS/HRM) and by overlapping these on rail head, how much it is close to the desired profiles can be quickly assessed after grinding.



Fig 9.5 : Bar Gauge for checking Rail Profile

b. Monitoring Contact Band: The location of contact of the wheel on the rail should change after the grinding. The rail-wheel contact band indicates this. Most of the wheels should make a contact on rail in a desired width on the railhead. Therefore, a

clear change in contact band location and size should be visible after the grinding. The contact band is to be monitored in curve and on straight track before and after grinding. Identification of contact band on railhead is done by spraying paint or making chalk marks on rail surface and allow a freight train pass over it. This will manifest in a form of erasing of the paint or chalk covered area in a band like formation. Details of location, date, width of contact band, distance from gauge face etc. should be written and a photograph showing contact band and details written on rail foot is taken for record.

c. Dye Penetration Test: At the second portion of the test site, dye penetration test is done, so that the damage on the rail surface including the cracks will become prominent. Dye penetration test is carried out before and after grinding. Extent of reduction in number and length of cracks indicates the efficacy of the grinding.

The dye penetration test uses 3 step process:

- Application of cleaner
- Application of dye penetrant
- And application of developer.

Procedure for doing DPT

- Having cleaned the surface, Dye is sprayed covering entire rail's top head surface.
- Then one has to wait for Two minutes to let the Dye spread deeply in the cracks.
- Then using a dry & clean cotton cloth the dye is wiped. Some clean water may also be used to clean the surface.
- After fully cleaning the surface, developer is sprayed, while spraying it has to be ensured that it is sprayed in one direction only and distance between nozzle and rail top is more than 20-30 cm so as to avoid localized excessive application of developer.

After the test, details such as date, location, tangent or curved track degree also, left/right rail or inner/outer rail, GMT carried, rolling year of rail, length of RCF cracks etc are written with a marker pen and a photograph is taken. The gauge face side and direction of traffic is marked by arrows on the rail.

Dye penetration test is carried out before and after grinding. After

the grinding, the test should be done only when the rail surface has become smooth, i.e. 10-15 days after grinding.



Fig 9.6 :Application of dye penetrant

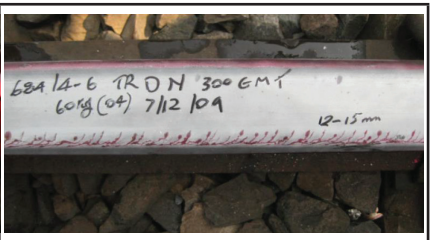


Fig 9.7 : Application of developer

9.4 Other Quality Checks:

a. Monitoring Rail Surface Finish – The condition of the rail top after grinding gives a lot of clues about the quality of grinding. A good finish should have regular grind marks of the grinding stones (these are known as facets) with silver finish. A bad finish will have irregular marks or skipped grinding at regular interval or blue colour on rails at certain locations (known as blueing defect) or irregular facet width etc. The facet width (the width of the marks left by grinding wheels) should be about 10 mm in the centre of the rail and 4 mm at the corners.At mid gauge it should be about 7 mm.

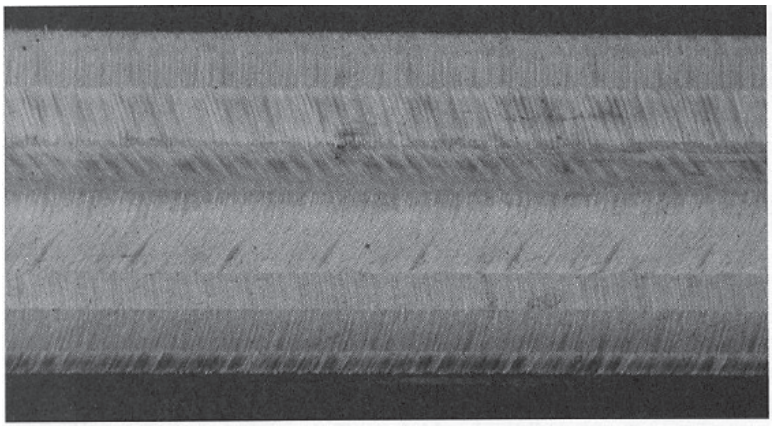


Fig 9.8 : Facet created after grinding

The inclination of any facet helps in identifying the grinding stone

creating that facet. The inclinometer should be used for the purpose.



Fig 9.9 : Inclinometer for measuring slope at particular position

b. Surface Roughness after Grinding – The rail surface should not become too rough after the grinding. The surface roughness level should not go beyond 12 microns after grinding.



Fig 9.10 : Surface roughness after grinding

c. GQI before & after Grinding – GQI stands for Grind Quality Index, which is a measure of the efficacy of the grinding with respect to the target rail profile. The GQI value 100 indicates that the target profile has been achieved fully. The lower the value, the more is the deviation from the target profile. During the run, GDMS screen displays GQI for both the rails before and after grinding separately. GQI of 80 and above is considered acceptable.

The post grind quality is summerised below-

Table 9.3

Surface Finish	Lower Gauge	Mid Gauge	Crown of
	Corner	Field	Rail
	+60 to + 16 deg	+16 to +6 deg &>-2.5	+6 to -2.5 deg
Facet Width	4 mm	7 mm	10 mm
Crown Radius			250 mm
Surface Roughness (Ra)	N/A	12 Microns	12 Microns

d. Crown radius – Crown radius of the railhead is measured before and after grinding by star gauge. The crown radius should be closer to 250 mm at centre of railhead after grinding. Crown radius is measured by star gauge. A template used to define the actual rail head crown's curvature. These are required to measure the rail top crown curvature. However the star gauge can measure radius only at crown



Fig 9.11 : Star gauge



Fig 9.12 : Measuring radius at crown

Template has four radius (150, 200, 250, 300 mm) curvature and by overlapping on crown, the approximate radius of crown is estimated.

e. Good surface finish after grinding - There are two aspects of the surface finish of the as-ground rail;

- Ridges left by the facets
- Surface roughness left by the grinding marks or scratches

Normally the facets created by last few stones in the series leaves the ridges. Pattern design should be such that the difference in the angles of subsequent cuts are within specified limits to avoid large ridges. This otherwise may become the sites of flow over or surface fatigue. The facets created on gauge corner should not be more that 4 mm and at other locations be more than 10 mm.

These grinding “scratch” marks trace the rotation and forward advance of the cutting grains. The rough nature of the as-ground rail surface is dependent upon the stone grit size and the grinding motor control. If a rougher surface finish can be tolerated, a considerably more aggressive grinding stone can be used. However this rough surface gets smoothened with passage of traffic.

The surface irregularities to be observed are:

- There shall be no sharp ridges especially at the interface of facets.
- There shall be no sharp “knife edge” on the outside edges of the rail that could cause a cutting injury.
- There shall be no gouging on the rail surface and sharp scratches.
- There shall be no indentations or longitudinal anomalies in the rail.
- There shall be no cyclic grinding scratch marks, as illustrated in Figure below. Such scratch marks have the potential to develop into short pitch corrugations.
- Short pitch and Long pitch corrugations shall be attended so that the remaining cyclic average longitudinal unevenness along the rail surface (peak to peak) shall be reduced.
- There shall be no overheating (bluing) of the rail surface.

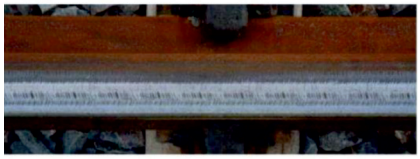


Fig 9.13: Cyclic Grinding Scratch mark



Fig 9.14: Unacceptable Grinding Scratches

- In noise sensitive regions the surface shall be smoother.
- In no case the roughness should be more than 12 micron.



Fig 9.15: Bluing of rail surface after grinding

f. Hardness of Rail- The hardness of rail after grinding should be checked to verify that the metal removal has not removed complete hardened layer. For 880 Mpa, 90 UTS rail, the hardness after grinding should be more than 300 BHN.

9.5 Monitoring at RDSO

Performa enclosed as Annexure 1 to 5 issued vide RDSO letter no CT/ML/RG Dated 18.05.21(shown below) is to be filled by field units and sent to RDSO every time before and after grinding. RDSO shall study the data received from different railways and decide on appropriate grinding parameters and grinding cycle.

RAIL GRINDING MONITORING PROFORMA

(Details of Test locations)

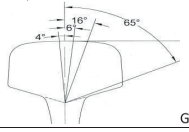
Rly..... Divn..... Route..... Section..... Km/TP.....

Rail Section/ UTS..... Type of sleeper..... Sleeper density..... Ballast cushion...

Tangent/Curved track..... Degree of curve..... Line(UP/DN)..... Axle Load.....

Total GMT carried..... GMT(Current)..... Date of Last Grinding..... Gauge(in mm)....

Engineered rail profile Template used ..... Rolling mark of rails.....

S.No.	Item Description	Observations on Left Rail * *		Observations on Right Rail * *		Remarks
		Before Grinding	After Grinding	Before Grinding	After Grinding	
A	Visual Inspection (severity be indicated)*					
	1.Gauge corner chipping (Y/N)					
	2.Metal Flow of rail top / Burring (Y/N)					
	3.Rolling Contact Fatigue Visual inspection & Dye Penetration test)					For a) to c)  Field Gauge
	a) Gauge face (65 to 16 deg.) (Y/N)					
	b) Shoulder of Rail (16 to 6 deg.) (Y/N)					
	c) Crown of Rail (6 to -4 deg.) (Y/N)					
	d)Pitch of fatigue cracks (mm)(Range)					
	e)Max. length of fatigue crack(mm)					
	4.Wheel burns and Scabbing (Y/N)					
	5.Any other defect observed					
B	Corrugation (Y/N)					
C	Hunting (Cyclic Wear) (Y/N)					
D	Track Geometry parameters					Parametersof the concerned blocks (SD & worst peak)of test site location should be taken from the records of TRC run just before grinding.
	1. Gauge					
	2. Twist					
	3. Unevenness (9.0 m chord)					
	4. Alignment (9.0 m chord)					

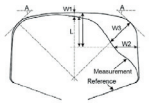
* Hard & soft copies of Photographs of the test locations before and after grinding, after Dye penetration test indicating condition of rail (size of defect, location in Km, Line, indication of gauge face, direction of traffic) be sent.

** Indicate Low or High Rail in case of curve.Left and Right rails shall be marked w.r.t direction of increasing kilometers in the section.

NOTE: 1. Details for each Tangent, Mild Curve($\leq 1.25^0$) and Sharp curve($>1.25^0$) test locations shall be submitted separately in the proforma.

2. Corrugation and Hunting should be observed in the block section containing the test sites (few kms on either side of test site).

Date: (Signature of Inspecting official with Name/Designation)

S. No.	Item Description	Observations on Left Rail		Observations on Right Rail		Remarks
		Before Grinding	After Grinding	Before Grinding	After Grinding	
E	Type of contact of wheel on Rail (One /Two/Multiple point contact)					
	1.One point contact					
	a) Contact Band Width (mm)					
	b) Distance from gauge face side* (mm)					
	c) Gauge Corner contact (Y/N)					
	2.Two point contact					
	a) Contact Band Width (mm)					
	(i)					
	(ii)					
	b) Distance from gauge face side (mm)					
	(i)					
	(ii)					
	3. Multiple point contact					
	a) Contact Band Width (mm)					
	(i)					
	(ii)					
	(iii)					
	b) Distance from gauge face side (mm)					
	(i)					
	(ii)					
	(iii)					
F	Wear of rail** (in mm) 1. Top Table (W1) 2. Gauge Face (W2) 3. Gauge Face Corner (W3)					
G	Weld dip at nearby location (Same weld to be measure every time)					
H	Post Grinding Roughness*** (Microns)					

*Distance measured upto center of contact band width.

** Measured by MiniProf and soft copies of rail profiles be sent.

*** To be measured with equipment available at RGM, otherwise general observation to be recorded.

Date:

(Signature of Inspecting official with Name/Designation)

Annexure- 2

RAIL GRINDING MONITORING PROFORMA
(Section Specific details)

Railway…….. Divn…….. Route……. Section……. From Km/TP…….. To Km/TP…….. Line (UP/DN/ Single)…….

Rail section and UTS…….. Type of sleeper……Sleeper density…….. Ballast cushion…….. Annual GMT…….. Cumulative GMT …….. Axle Load……..

Start Date of grinding cycle for major section…….. Date of last TRC run……..

Completion Date of Grinding cycle for major section……..

S. No.	Item Description		Straight Track		Mild Curve Track		Sharp Curve Track		Remarks
			Left Rail	Right Rail	High rail	Low rail	High rail	Low rail	
A	Full details of locations **before grinding***								
	1. Rolling Contact Fatigue (Head checks) (Y/N)								
	2. Corrugation (Y/N)								
	3. Hunting (cyclic wear) (Y/N)								
	4. Other defects (gauge corner chipping, flow of rail top, corrosion, wheel burns etc., specify type of any other defect)								
B	Effectiveness of Lubrication in sharp curves (Y/N)								
C	Track Geometry (TQI Value) - before grinding*	Composite							
		Short Chord							
		Long Chord							

* Details to be given for specific locations wherever significant defect is noticed.

Note : The above details shall be recordedevery time before grinding.

Date:

(Signature of Inspecting official with Name/Designation)

Annexure- 3

Analysis of Rail/Weld Fractures on the Section (To be generated through TMS)

Railway: Division: Subdivision:
Route: Section: Km From To UP/DN Total length Annual GMT
Track Structure- Rail: Sleeper:

S N	Cycle	Period From ..... To	Duration (Month)	Track Geometry	Length (Km)	Rail Fracture			Weld Fracture						Total Rail & Weld Fracture	Cumulative GMT for rail at end of cycle	Remarks of Rail renewal done with location	Any Other Remarks
									FB Welds			AT Welds						
						Internal flaw in head - Transverse break (Code 211)	Others	Total	Transverse crack (code 411)	Others	Total	Transverse crack (code 421)	Others	Total				
	2 Yr. prior to 1st Grinding			Straight														
				Mild Curve														
				Sharp Curve														
	1st to 2nd Grinding			Straight														
				Mild Curve														
				Sharp Curve														

Note: Position to be given w.e.f. 2 years preceding of Rail Grinding Introduction.

Date:

(Signature of Inspecting official with Name/Designation)

Annexure- 4

Analysis of Ultrasonic Defects -Normal Testing (To be generated through TMS)

Railway: Division: Subdivision: Route: Section: UP/DN
Km From To Length Annual GMT Track Structure – Rail ..... Sleeper .....
Stipulated Frequency of USFD Testing for section: For Normal Testing ..... (Month)

SN	Cycle of USFD Testing	Period		Track Geometry	Length Tested (Km)	OBS Defect (Number)					IMR Defect (Number)					Remarks about Rail Renewal etc
						70^0 Probe			Normal Probe	Total	70^0 Probe			Normal Probe	Total	
		From ------- To -------	Dura-tion (Month)			G	C	NG			G	C	NG			
	Details (individually) of 5 Cycles of Normal Testing prior to introduction of Grinding			Straight												
				Mild Curve												
				Sharp Curve												
	Total			Straight												
				Mild Curve												
				Sharp Curve												
	Ist Grinding Period From ..... To															
	Details (individually) of Intermediate Cycles of USFD			Straight												
				Mild Curve												
				Sharp Curve												
	Total			Straight												
				Mild Curve												
				Sharp Curve												
	2^{nd} Grinding Period From ..... To															
	Details (individually) of Intermediate Cycles of USFD			Straight												
				Mild Curve												
				Sharp Curve												
	Total			Straight												
				Mild Curve												
				Sharp Curve												
	3^{rd} Grinding Period From ..... To															

Note: Details of additional defects arisen in the cycles shall be given.

Date: (Signature of Inspecting official with Name/Designation)

Proforma for Calculation of DGR

Annexure-5

Railway……., Division…… Subdivision ……. Route…….…… Section: …… UP/DN ……

From ……(Km) To ……(Km) Length …… Annual GMT …… Track Structure – Rail …… Sleeper ……..

			Prior to Grinding Cycle I							Grinding Cycle I to II							
			Interval (Month)	Total New Defects			DGR			Interval (Month)	Total New Defects			DGR			
				Straight	Mild Curve	Sharp Curve	Straight	Mild Curve	Sharp Curve		Straight	Mild Curve	Sharp Curve	Straight	Mild Curve	Sharp Curve	
Length (Km)																	Similar Analysis to be carried for Grinding Cycle II to III and so on
OBS	70^0 Probe	G															
		C															
		NG															
	Normal Probe																
	Total																
IMR	70^0 Probe	G															
		C															
		NG															
	Normal Probe																
	Total																
Cumulative GMT at the end of cycle																	
Remark about rail renewal etc.																	

DGR = $\frac{\text{Total New Defects in length having similar situation x 100}}{\text{(Total length having similar situation) x (GMT accumulated between two cycles)}}$ = ……. Per Km/100GMT

Note- While working out total length of comparison, the kilometers where rail renewal/replacement has been done shall be excluded for comparison. In Total, stretches (Kms) with similar situation shall be taken.

Date: (Signature of Inspecting official with Name/Designation)

9.6 Benefits reported over Indian railways:

RDSO has done analysis of benefits of Rail Grinding over Indian railways based on reports received from different railways and the same has been compiled in Report CT-33 and CT-43. One of the major benefit expected of RGM is to improve safety and to improve the life of rail by controlling wear and reducing rail failure by controlling RCF generation;

a. Data collected for assessing the benefit of Rail Grinding.

(i) Data at test Locations:

- Bandwidth & its position : To decide that proper contact is made and Hunting has reduced.
- Wear Pattern of rails:- To decide whether the profile has actually resulted in the reduction of stresses. The rates of vertical wear i.e. W1 & the rate of vertical wear at gauge face i.e. W3 and rate of lateral wear i.e. W2 is to be monitored.
- Extant of Rolling Contact Fatigue (RCF):- To confirm that already prevalent RCF has been eliminated and the cycle is adequate to remove new RCF defects. To observe the propagation as well as number of Rolling Contact Fatigue.
- Attainment of Target Rail Profile: The profile attained after each grinding cycle to be compared with the target rail profile and grinding pattern to be changed if required.

(ii) Based on data of complete section:

- Defect Generation Rate (DGR) : To confirm whether proper rail wheel contact has reduced the stresses, thus the formation of new defects.
- Incidences of Rail & Weld failure: - Whether the number of failures has increased or decreased.

b. The observation of RDSO in its C-33 and C-43 report is reproduced below:

(i) CT-33 report of RDSO (Year-2014)

- The extent of RCF defects has reduced at many locations but still is a major concern in overall perspective. There is need to decide a strategy that will take care of RCF defects arising between cycles. The reduced interval between the second and third cycles can be one such measure, which can be taken immediately.

- The defect generation rate as observed from USFD result for the majority of sections has shown decreasing trend. The reduction was prominent after introduction of Rail Grinding.
- The target rail profile has not been achieved at various test locations. Thus, the grinding strategy needs to be reviewed. Reducing the time period between the successive cycle to attain target profile should be considered.
- The analysis done indicates that there is a substantial reduction in defect generation rate and number of rail/weld failures in majority of sections, where rail grinding has been introduced. This has substantially reduced the maintenance requirement in such section.
- The benefits of rail grinding are not very pronounced where the rail has already carried more than 400 GMT at time of introduction of rail grinding. It will be prudent to introduce Rail grinding in new sections only where rail has carried less than 400 GMT.
- Based on limited data and on vertical wear as recorded during monitoring, it is considered that service life in excess of 800 GMT can be expected on 60 Kg 90 UTS rails. This will be established after further studies/ monitoring are done. The high rate of wear on high rails of curve and field experience about wear even on mild curves suggest that gauge face lubrication using automatic track based gauge face lubricators on all curves is required.

(ii) CT-43 report of RDSO (Year 2019)

Contact bandwidth

The analysis of the contact band indicates that there is reduction in width of contact band at almost all test locations and contact band has gradually moved away from gauge face as anticipated. The grinding has been able to provide controlled rail wheel interaction to a large extent. However, there is no distinct differentiation in position of contact band between CPC & CPF profiles. Also, after 5th round of grinding, two contact bands have been observed on tangent track at two test locations of SCR & one location of NR and NCR each, which is not on expected lines.

Rolling contact fatigue

The RCF defects have been eliminated after 5th and 6th grinding from all of the test locations, except first two locations in SCR.

Target profile

The target rail profile has been achieved after 5th and 6thgrinding cycles on all of the test locations except at two locations on N.C Railway, both of which are high rails of mild curve. This may be due to increased wear on high rails of curve.

Rail wear

The effect of grinding on the rate of lateral wear has not been possible to be worked out with reasonable degree of certainty as the MiniProf data collected from field was in-coherent. Rate of vertical wear however can be definitely said to have reduced. Also from reading the trend shows that the wear rate in curve could not be controlled to a very large extant.

Defect generation rate

The defect generation rate as observed from USFD result and rail fracture data for the majority of sections, where three or more rounds of grinding have been completed, has shown decreasing trend indicating that grinding has been able to contribute to reducing the generation of new RCF defects.

Rail/weld failures

The fractures which are controllable by Rail grinding have been considered for comparison. It is seen that fractures on account of fatigue are NIL in all three zonal railways. It indicates the effectiveness of grinding is now clearly visible.

(iii) Discussion

As per IRPWM para 702, the criteria for renewal of rails is as given below:

- Incidence of rail fractures/failures.
- Wear on rails.
- Maintainability of track to prescribed standards.
- Expected service life in terms of Gross Million Tonnes of traffic carried.
- Plan based renewals.

Therefore rail fracture/failures and wear of rails are the two prime criteria for renewal of rail. From the observation in CT-33 and Ct-43 report of RDSO it is clear that :

- The Defect generation is controlled and rail life can definitely

be increased on account of this .

- For vertical wear, benefit of RGM are crystal clear.
- The effect of grinding on lateral rate of wear is not been possible to be worked out with reasonable degree of certainty due to improper recording of data at test sites. However general observation is still that the rate of wear of gauge face is still very high.

Though further study is still required to definitely decide on correct life of rail. The IRPWM has increased the life vide IRPWM para 702 (1)(d) as given below:

- The rail shall be planned for through renewal after it has carried the minimum total traffic as shown below:

Table 9.4

Rail Section	Life in GMT	
	72 UTS rails	90 UTS rails
60 Kg/m	550	800
52 Kg/m	350	525

- Service life in terms of total GMT of traffic carried for considering through rail renewal of 60 kg 90 UTS rail would be 1000 GMT on the routes covered by Rail Grinding, provided condition of rail is satisfactory as per the other stipulated criteria mentioned in Para 702(1) (a), (b) and (c) above.

It is clear that, the wear on curve needs to be controlled and that the same is possible only if proper lubrication of gauge face is done. The same is discussed in next chapter.

◆◆◆

10

Rail Lubrication & Top of Rail Friction Management

10.0 General

Controlling wear of rail for increasing the service life of rail is an important maintenance activity. Rail lubrication of gauge face is one of the standard method of controlling gauge face wear. The primary function of rail lubrication is to minimize friction between the wheel flange and rail interface, especially in the curves where side cutting of rails often occurs. If sharp curves are left unlubricated, the rail will need to be replaced long before it carries the estimated tonnage of traffic it was originally designed for. The routine application of rail lubrication, however, will increase the life expectancy of these rails. A study discovered that lubricating rails can theoretically reduce rail wear by a factor of 100 as compared to unlubricated ones. Under realistic conditions, the lubricated rail is able to withstand almost double the tonnage of an unlubricated rail before needing replacement. It's clear, that rail lubrication is absolutely necessary component of any rail maintenance routine.

10.1 Friction and Lubrication

Friction plays a significant and often underappreciated role in wheel/rail processes, including wear and RCF, adhesion, braking, lateral forces, fuel/ energy usage, vehicle steering, and hunting behaviour, to name a few.Friction is a property of two surfaces and in the wheel/rail case is heavily dependent on the properties and composition of the thin intermediate layer between wheel and rail known as the Third Body (the First and Second Bodies being rail and wheel, respectively). Natural variations in Third Body layer composition caused by weather, contaminants, and wheel/ rail conditions lead to a wide natural variation in wheel/rail friction levels.The goal of an effective lubrication and friction modification program should be to provide sustainable optimum wheel/rail friction levels.

AREMA recommends following friction level at different locations which can serve as guideline for understanding friction management requirement

- Gauge face on curves: less than 0.20 μ.

- Gauge corner on curves: ideally less than 0.20 μ (but less than 0.25 μ is a practical alternative).
- Top of rail (curves and tangent): 0.30 μ - 0.40 μ.
- Differential: maximum difference between left and right top of rail: less than 0.1 μ difference.

10.2 Indian Railway P.Way Manual Provision

a. IRPWM Para 613 (3)

Reducing side wear on rails-(Gauge face of outer rails) –

On sharp curves where the tendency of wear on the outer rail is noticeable, lubricators should be installed or hand lubrication of gauge face should be done, care being taken not to apply the lubricant on the top of the table. In case of hand lubrication, the Divisional Engineer may decide frequency of lubrication duly considering local conditions and traffic on the line.

Turning of rail is not advisable as it completely changes the surface and subsurface stresses to which rail is subjected and may cause rail failure.

b. IRPWM Para 424

Wear on Outer Rail of Curves:-

i. The wear on the outer rail on the curve can be reduced effectively by-

- Lubricating the gauge face of outer rails on the curves.
- Maintaining correct curve geometry and Super-elevation.
- Provision of suitable checkrail.
- Adopting slack gauge PSC sleeper as per RDSO drawings depending on curvature of track.

ii. Track mounted automatic Gauge Face Lubricators should be provided on curves of radius 875 m (2°) and sharper to reduce rail gauge face wear. On routes where rail grinding is in practice, track mounted automatic Gauge Face lubricators should be provided on curves of radius 1400 m (1.25°) and sharper.

Lubrication should be done on new rails or on old rails, which do not have Gauge Corner Cracking or head checks. While deciding the location of lubricators, following should be considered:-

- It is located on tangent track at the beginning of transition

curve where wheel flanging is just beginning to occur.

- On single lines, the lubricator shall be located in the direction of heaviest traffic.
- Lubricators should be located away from switches, crossings and other areas where discontinuity in LWR track may exist.

The lubrication is mentioned to be done after eliminating gauge corner crack i.e. RCF. The grease otherwise will enter into these cracks. Under train load, these trapped grease will get confined and a hydrostatic pressure will get built up which will increase the crack size and may even result in rail failure. The same is clear from the below figure:

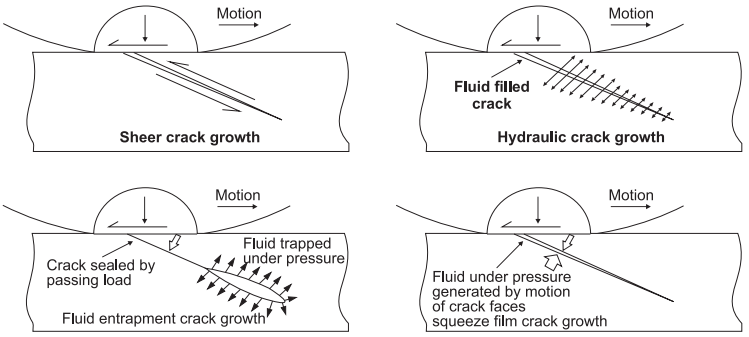


Fig 10.1 : Impact of lubricating cracked rail surface

10.3 Friction Management Advantages

Highly effective friction management in curves involves lubrication of the gauge corner/face of the high rail and friction management of the top of rail (TOR) for high and low rails to substantially reduce the tangential stress at the wheel/rail interface, therefore increasing the number of wheel contacts before RCF initiates. The friction is to be managed thus at following two locations

- Gauge face/Wheel flange (Friction to be reduced to less than 0.2μ)
- Top of rail (TOR) / Wheel tread (Friction to be managed between 0.3μ to 0.4μ)

A. Gauge face lubrication

High rail gauge corner/face lubrication has following impact:

- Significantly reduces wear of the high rail gauge face and

wheel flanges.

- With reduced wear on the high rail gauge face, the as-ground profiles are retained for longer tonnage intervals and RCF defects take longer to initiate, thereby extending the preventive grinding interval.

A gauge face lubricant needs to separate the contacting surfaces so that the roughness asperities do not contact each other, therefore, it should have following properties:

a. High compressive strength

b. Low shear strength

c. Should not break down under high temperature influence

Study shows that gauge face lubrication without proper TOR friction management increases lateral forces and therefore increases crack propagation which can be related from Fig 10.2.

Grease is used for lubrication and is defined by its viscosity. If there is wide variation of temperature, different grade for summer and winter may be required.

B. Top of Rail (TOR) friction management

On the top of rail, tangential forces for traction and braking as well as curving forces need to be transferred between wheel and rail. The friction level between wheel tread and top of rail consequently needs to be adjusted to an optimum, intermediate level. A very high friction level will damage the surface while a very low friction level will not be able to allow safe train operation like during braking. This is achieved by using thin-film friction modifiers (FM) that alter the composition of the naturally occurring Third Body layer between wheel and rail. The composition and the mechanical properties of this layer directly influence the friction characteristics between wheel and rail. The intermediate friction level allows safe and effective train operations, but reduces wear and RCF defects by reducing the acting tangential forces on wheel and rail.

As discussed in chapter 3, the creep (Longitudinal, Lateral) is inevitable in the rail and wheel interaction. This creep creates damage to the rail and the damage depends on friction and adhesion between rail and wheel. By controlling friction the creep forces can be reduced (Ref: Fig: 3.20)

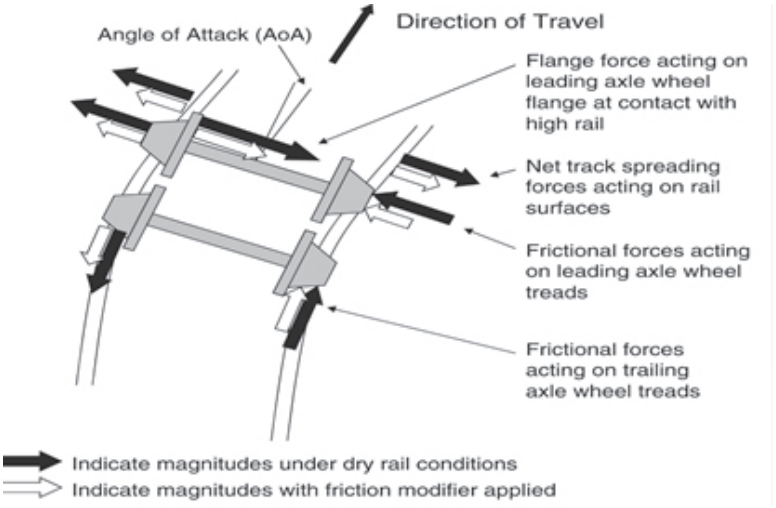


Fig 10.2: Reduced Creep forces due to Top of Rail friction management

TOR friction management has following impact:

- Controls vertical wear of rail
- Reduces lateral forces on outer rail thus gauge face wear.
- Reduces traction stress on the top of the rails on both the high rail and the low rail of curves, which results in reduced lateral creep forces, ratcheting, and plastic flow.
- By reducing friction on top of rail, the rolling resistance and lateral forces are controlled reducing fuel consumption by rolling stock.

This reduced stress will increase the tonnage interval until RCF initiates, thereby extending the preventive grinding interval.

Most of the proven benefits and safety assessments have been based on the use of water-based friction modifiers. These materials provide a thin dry film that control the wheel/rail friction coefficient in the range specified, kept normally between 0.3-0.4. These materials also provide a so-called “positive friction” at the wheel/rail interface, meaning that the shape of the traction creepage curve is modified to provide continuously increasing traction with increasing creepage. This also improves vehicle characteristics through a curve, as well as mitigating phenomena related to “stick-slip” such as corrugation and curve squeal.

Proper friction management allows the rail surface to work-harden. This harder rail surface can withstand higher normal loads and traction stresses. Retaining the work-hardened surface layer on the rail is an important part of increasing the preventive grinding intervals.

Impact of lubrications are summarized in below figure:

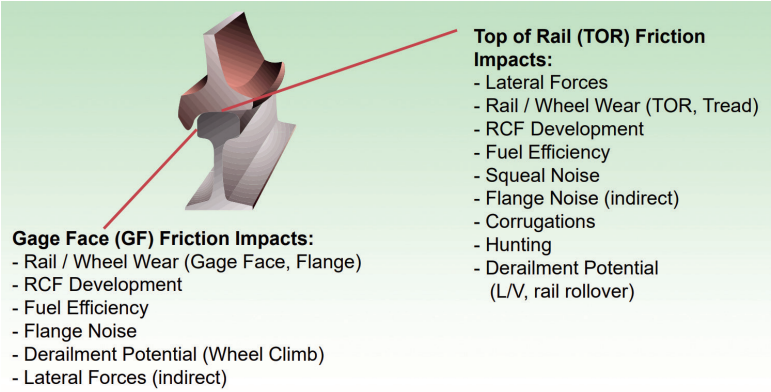


Fig 10.3 : Impact of gauge face and Top of Rail Friction management

To reduce lateral wear, the gauge face friction should be minimum i.e. as close to zero, while to reduce vertical wear, the TOR friction should be above some minimum value to achieve the adhesion required for haulage of vehicle. The steel to steel friction is around 0.6 micron. The friction requirement on different rail of curve will be as shown below.

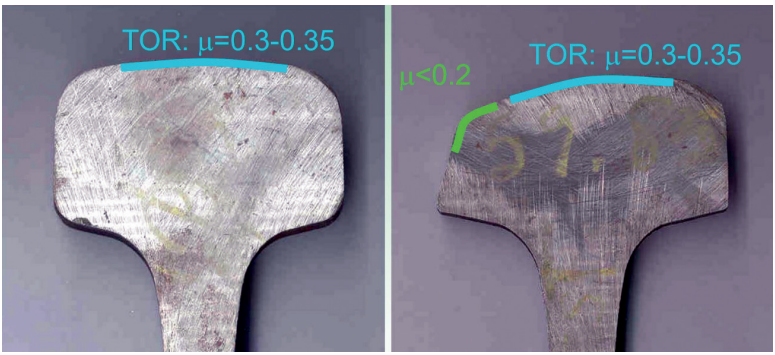


Fig 10.4 : Coefficient of friction required at different locations on rail surface

Highly effective lubrication of the high rail gauge corner/face and management of friction at the top of the high and low rails (using a friction modifier), coupled with metallurgies having improved hardness and cleanliness, substantially reduce rail wear and increase the preventive rail grinding interval required to manage RCF.

10.4 RDSO specification IRST-48 on Lubrication

On Indian Railways only Gauge face lubrication is done. RDSO specification IRS T-48 deals with "Technical specification for Track based Lubricators" both Electronic and Hydraulic type. The salient feature of that specification is produced here:

- This specification covers the description, functional and performance parameters of electronic track based lubricators for gauge face lubrication.
- The applicator system should be an electrically powered pumping system for delivering an adjustable quantity of lubricating material to the rails in a manner such that passing wheels, either all or nominated would carry the designed amount of lubricant along the gauge face of rails.
- The control circuit should be designed to accept voltage signals for speeds as low as 10 kmph and should be able to function properly up to speed of 200 kmph
- Gauge face lubrication applicators should be mounted such that gauge face lubricant is deposited onto the upper portion of the rail's gauge face so as to come in contact with wheel flange.
- It should have coverage of minimum 1 Km or 2 Km as the case may be with the recommended high quality rail-road lubricant.
- Carry down effect of 1 Km category would be made use of only where there is no other curve of similar flexure requiring lubrication in the adjoining 1 Km in the intended direction.
- A suitable lubricant for heavy rail road traffic should be used which is compatible with the system. Its lubricity should be such that it should provide friction value of 0.25 μ or below on gauge face corner.
- To ascertain the efficacy of the application system, coefficient of friction shall essentially be measured at the farthest point

of the carry down effect.

- Coefficient of friction and carry down effect of lubricator shall be measured at a frequency of one month or higher
- The supplier will give detailed specifications of lubricant to comply the above requirement and scrutiny of the offer.
- For fixing lubricator at the start of curve, it is the traffic direction in case of double line whereas it is heaviest traffic direction for Single line.

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Switch and Specialty Rail Grinding and its Strategy

11.0 General

The grinding of rails at certain locations like points and crossing, level crossing etc. is difficult by production grinders due to limited space for grinding stones to operate between running rail and check rails or running rails and switch or at nose of crossing etc. Switch and Specialty grinders(SRGM) are smaller grinders and has facility to place and operate stones in such limited spaces. In this chapter, the grinding strategy for grinding of points and crossing and other such special locations are discussed. Normally smaller (8-24) stone grinders are used for covering these special locations. Indian Railway is currently procuring SRGM's from M/s Loram and M/s Harsco. The working principle of both these machines are same with the difference of softwares and slight difference in layout. Here working of SRGM described is based on M/s Loram machine. Layout of M/s Harco machine is also discussed at the end.

11.1 Rail Wheel Interaction at Points and Crossing

A typical layout of turnout is given below:

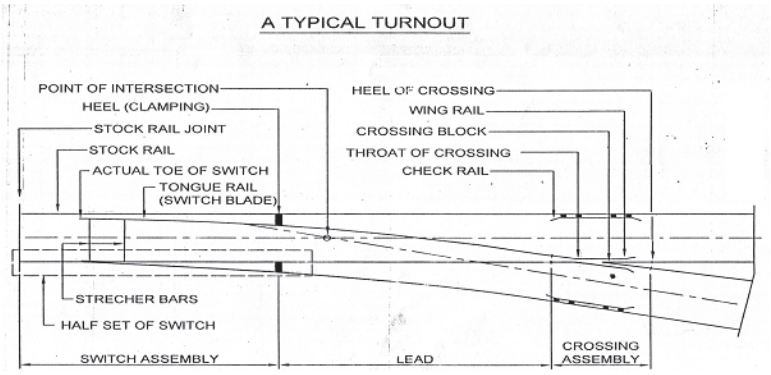


Fig 11.1 : Typical layout of Turnout

Because of the complex geometry of the turnout including changed stiffness in the turnout portion, the rail wheel interaction is very different and rail vehicle normally imposes loading more severe than the plain track. This normally leads to:

- Degrading of running surface of turnout
- Degradation of geometry of turnout
- Degradation of the key turnout components

Since the stiffness of turnout is high, the degradation is multiplied further. Such type of situation arises at all special locations where stiffness changes or where the vehicle has to jump a gap.

In addition, the rail wheel contact point also changes abruptly at following locations:

- In the figure above (RH turnout), the contact over the right stock rail changes from center of crown to field side in case of hollow tyre and then suddenly to gauge corner of right tongue rail within a very short distance and in a very short time span.
- The wheel on left stock rail however continues to move at the same contact point (Crown) but due to stock rail being vertical in non-canted turnout, the contact shifts towards gauge corner.
- Any contact at gauge corner or wear of stock rail may create a situation shown below



Fig 11.2 : Damage to switch because of excessive wear of stock rail

- At certain locations of transition in switch and in crossing portion, the wheel may contact two rails (stock rail and

tongue rail or wing rail and nose of crossing) simultaneously thus creating two rolling radius at the same time.

Stability of the vehicle is also compromised due to contact of worn wheel shifting to gauge corner in turnout due to non canted rail resulting in increase in effective conicity and also reduction in value of effective dynamic gauge (para 3.2). This reduces wavelength and increases frequency of oscillation as shown below:

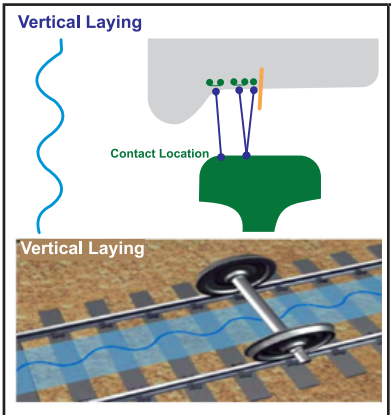


Fig11.3 : Contact on M/L of vertical rail of Points and Crossing and oscillatory motion of wheel

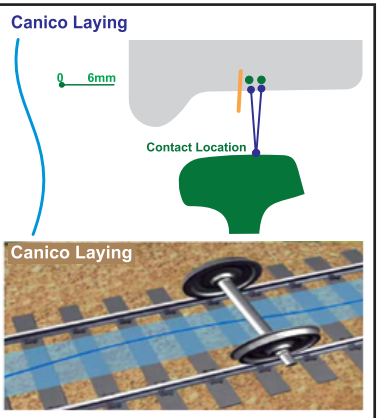


Fig 11.4 : Contact on M/L of canted rail of Points and Crossing and oscillatory motion of wheel

All this causes damage to the rail and compromises on the stability of vehicle. The impact increases with increase in speed, axle load, bad wheels and badly maintained track.

Such combination causes following type of rail failures on switches:

- Battering of surface in crossing area and in switches
- Corrugations particularly on inner curved lead rail primarily because of hollow tyre contacting on the field side of rail.
- Plastic flow and lip formation at different locations depending on rail wheel contact taking place

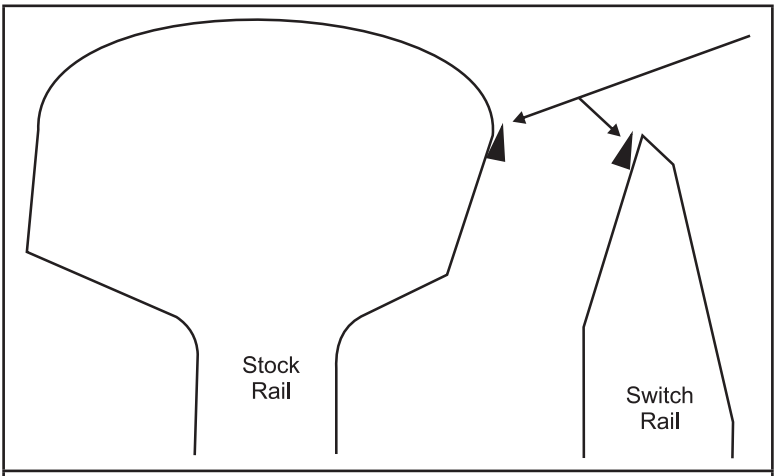


Fig 11.5 : Lipping which obstructs proper setting of point

The defect once created increases the rate of deterioration even further with time.

11.2 Objective of Grinding Points and Crossing

Normally switches and crossings are being attended only at tongue rail tip and nose of crossing by manually operated grinding wheel. Metals are deposited is these portion and profile is achieved by hand grinders. However these have their own limitations.The grinding is over a very short distance (may be around 1 m) and neither longitudinal nor lateral desired profile can be properly achieved. The unavoidable irregularities may create additional dynamic forces and local irregular contact conditions.

The objective of grinding by switch grinding machine is thus:

- **Improve overall wheel-rail dynamics-** To provide effective contact path over turnout thus optimize the size and location of wheel rail contact zone.
- **Reduce impact forces-** By removing the surface defects, the impact forces is controlled.

By achieving the above, the advantage gained is

- Life of components are extended
- The frequency of welding and surfacing of switch and crossing is extended.
- Overall improvement in running over turnout

11.3 Special Feature of Specialty and Switch Grinders

The grinder used for grinding points and crossings are normally smaller for the following reasons:

- The smaller size allows better management over a short length of points and crossing and thus more time can be spent at one location. It enable applying multiple passes required at points and crossing
- It allows more flexibility and ability and control each grinding motors and location of each grinding stone for more effective optimization
- Since moving in the yard, the smaller grinder requirement of fuel and water is less thus managing their movement in yard is better.

The grinding done by such grinders normally does not cover the full head in one pass as done by production grinders. It is thus necessary to have multiple passes through both mainline and turnout side.

The grinding is being done in two ways

a. The grinding is performed on stock rail and lead rail and motors are lifted on tongue rail of switch and nose of crossing. The wing rail is also not ground in this portion. These are to be attended by welders using hand grinders. This is done to avoid potential damage at these locations. The left over portion in crossing area is shown below:

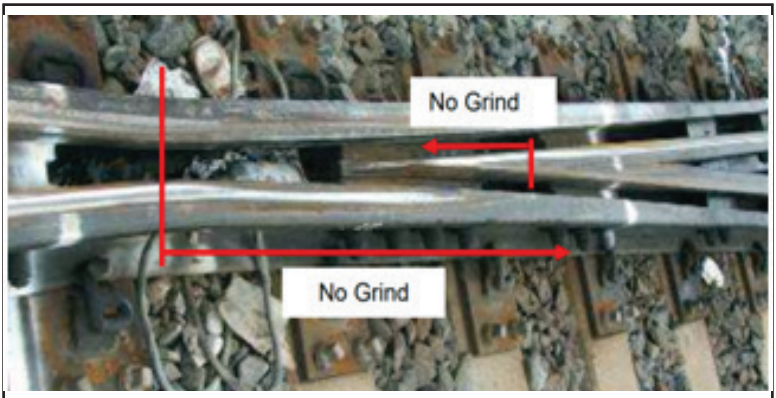


Fig 11.6 : Portion of crossing left by grinding machine

The grinding in this area should preferably be conducted in trailing

direction

Similarly the grinding of tongue rail is not done as it may damage the tongue rail as shown below:



Fig 11.7 : Damage to Tongue rail during grinding

b. The grinding of complete turnout including switch and crossing is done by SRGM. However special care to be taken that excessive metal is not removed from this area. The grinding on switch portion should be done with tongue rail and stock rail set properly so that tongue rail is fully supported by stock rail to get the profile as shown below:



Fig11.8 : Acceptable grinding of stock rail and tongue rail

However grinding starts at around 30 m ahead of switch and closes also at 30 m after the switch.

11.4 Profiles for Points and Crossing

Since, the rails are vertical, to avoid gauge corner contact, the metal from gauge corner is required to be removed for shifting the contact to CPC, CPF or CPG. Normally CPG contact to be avoided as the gauge side is already vulnerable to high stress.

One of the suggested contact can be as shown below:

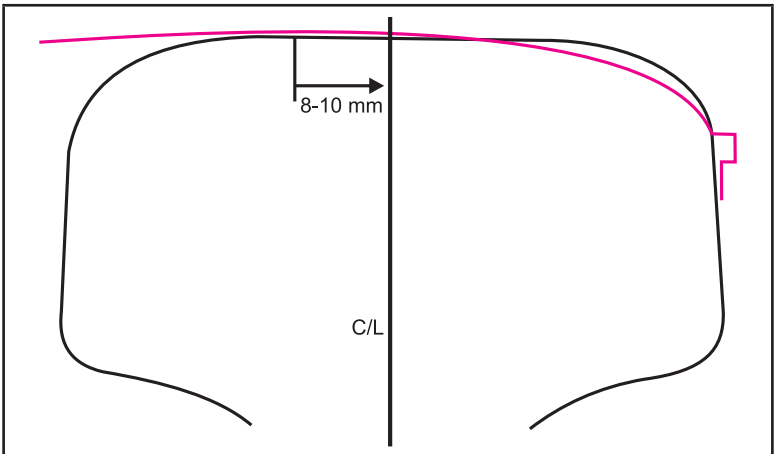


Fig 11.9 : Contact near crown for tangent track of T/o

However excessive cutting of material on gauge side near tip of tongue rail to be avoided as it may create a situation exposing tongue rail as shown below.



Fig 11.10 : Unacceptable excessive grinding of gauge corner of stock rail

Normally the profile designed is such that, the wheel continues to contact rail at the same location when entering into turnout and exiting from the turnout.

11.5 Working of 20 Stone Grinders on Indian Railways

For grinding of points and crossing, smaller 20 stone grinders are being used over Indian railways. Following are the important working parameters of the machine:

- **Working speed :** It is to be maintained at 8 to 10 Kmph

- **Number of passes:** Since, the number of stones are less (10 Nos for each rails), three passes of grinding will be required to cover full head and achieve the desired profile. While pattern for the first pass will be given by M/s Loram (M/s Harco for their machine), the pattern for next two passe will be suggested by the machine.
- **Profile:** The profile normally should be such that the contact over mainline and turnout remains along same alignment. However it is recommended to have a CPC type profile, the template of which is yet to be decided by both the manufacturers.
- **GQI:** GQI is not generated after each pass as full coverage of the railhead requires 3 passes and GQI is generated after the full rail head is ground. At the start of the griding program, the minimum value of GQI to be achieved should be 50. The eventual desirable value of GQI is 80.

11.6 Points and Crossings-Grinding Sequence

a. Area Covered and sequence of operation: For grinding turnout, the tongue rail is not ground, and crossing can be ground only in trailing direction as shown in the figure attached

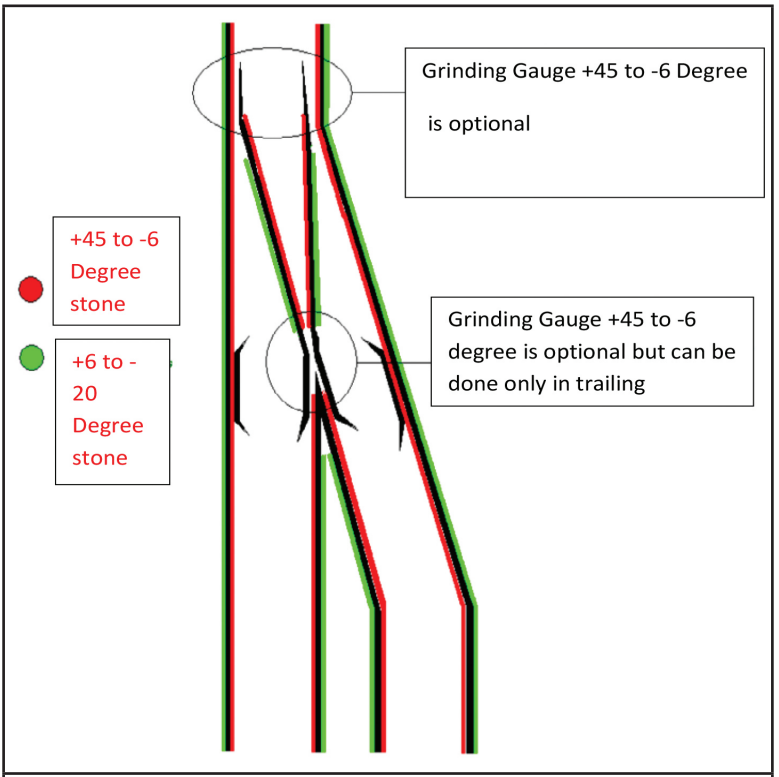


Fig 11.11: The portion covered during grinding

The gauge side stones are indicated as red and field side is indicated by Green in above figure. Normally mainline is first ground and then T/o side is covered. On crossing, the stones on crossing side are raised at around 300 mm ahead of crossing and again lowered 300 mm behind the crossing. On switch portion after heel block, initially field side stones are raised and then on reaching close to tip of tongue rail where the switch width is reduced to around half of rail width, the gauge side stones are also raised. The operation can be understood from the below figure where following locations are clearly marked:

- Rail Up/Down- Indicates all stones on that rail to be lifted or lowered
- Gauge Down- Gauge side stones to be lowered
- Field Down- Field side stones to be lifted
- Master Up- All stones both left rail and right rail to be lifted

Turnout:

(i) Working in Facing direction

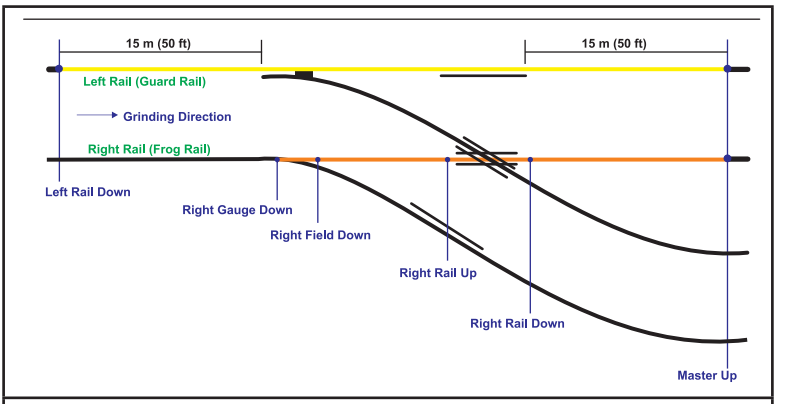


Fig11.12: Grinding on M/L track

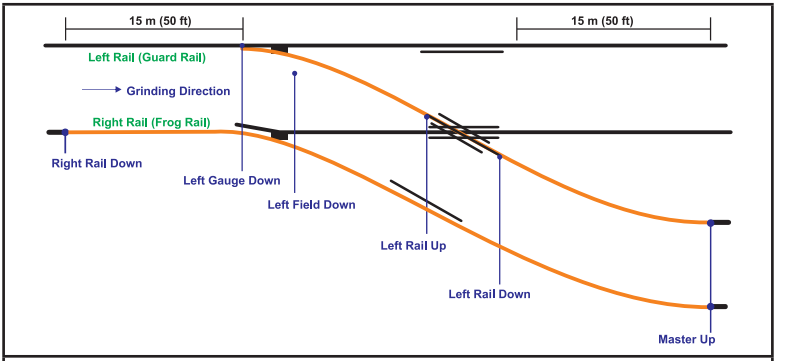


Fig11.13: Grinding on T/o side

(ii) Working on trailing direction:

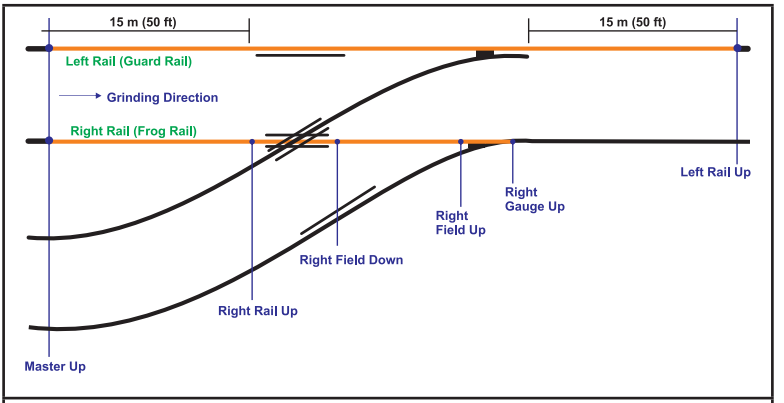


Fig11.14: Grinding on M/L side

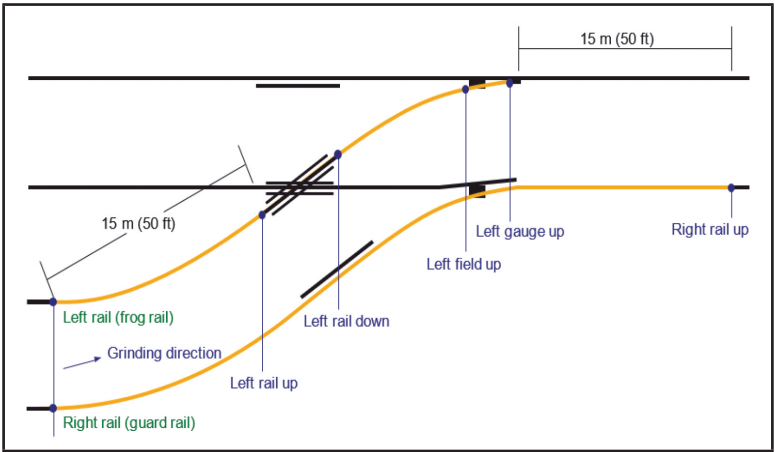


Fig11.15: Grinding on T/o side

(iii) Crossover connection:

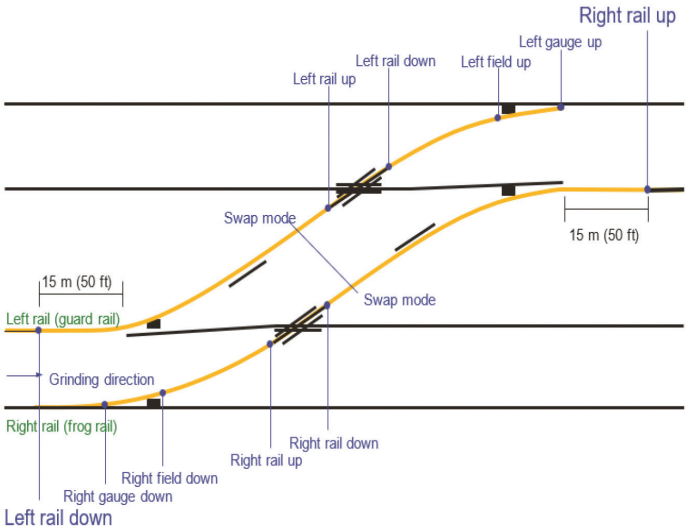


Fig11.16: Crossover connection grinding

The swap location shown is where, the LH turnout now becomes RH turnout.

(iv) Diamond Crossing:

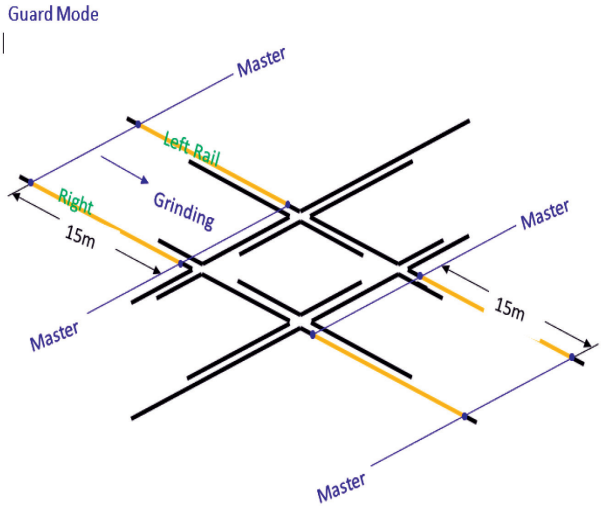


Fig 11.17 : Diamond crossing ground portion

11.7 Procedure of Grinding at other Special Locations:

The grinding procedure for other locations are:

Table 11.1

S. No	Locations	Number of passes and length	Working Speed	Profile	Pattern
1	Grinding a Glued Joint on turnout	3 passes and to cover 50 m on both side of joint	8-10 Kmph	CPC/CPF/HRM/ HRS as per location in T/o. For mainline it should be as decided for approach track for 72 stone grinder	First pass decided in advance and second and 3rd pass suggested by machine
2	Bridge with guard rails- Guard rails not required to be removed	3 passes and to cover 50 m on both side of joint	8-10 Kmph	CPC/CPF/HRM/ HRS as per location in T/o. For mainline it should be as decided for approach track for 72 stone grinder	First pass decided in advance and second and 3rd pass suggested by machine

3	Rails in Tunnel	3 passes and to cover 50 m on both side of joint	8-10 Kmph	CPC/CPF/HRM/ HRS as per location in T/o. For mainline it should be as decided for approach track for 72 stone grinder	First pass decided in advance and second and 3rd pass suggested by machine
4	Level Crossing- Can be ground without removing check rail	3 passes and to cover 50 m on both side of joint	8-10 Kmph	CPC/CPF/HRM/ HRS as per location in T/o. For mainline it should be as decided for approach track for 72 stone grinder	First pass decided in advance and second and 3rd pass suggested by machine
5	Switch Expansion Joint (SEJ)	Not Designed to grind SEJ			

11.8 Test site for Switch Rail Grind Monitoring

While selecting the turnout for developing test sites, the following precautions should be taken:

- Turnouts should be a mix of both new and old in a reasonable state of repair not near the end of their service life.
- Turnout should be in normal running line
- 4 turnouts should be selected per size of 1:8.5, 1:12 and 1:16.
- At least 1 turnout per size should be from railway lines of maximum annual tonnage / year

The turnout selected should be true representative of the general layout in the section for which test site is located.

The marking for measurement should be marked as shown in red box:

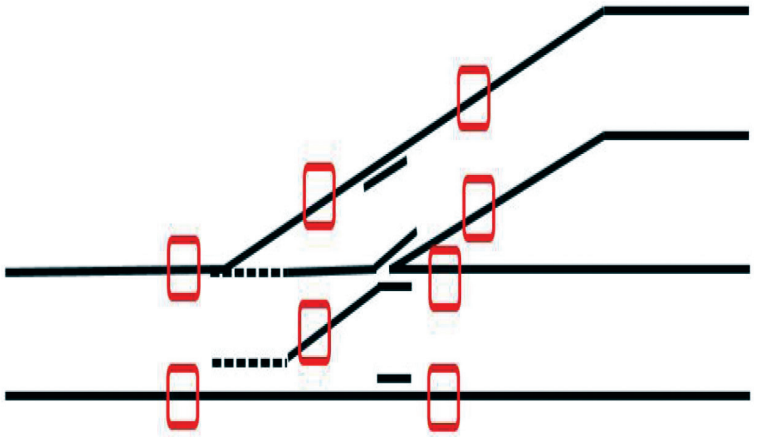


Fig11.18: Typical layout for marking test sites

The following data should be collected as abaseline at each of the red boxed location shown below each grind cycle

- MiniProf
- Establish a location on the rail between two sleepers and at least 3 meters from a joint or weld.
- Clearly label the exact location on the rail to perform measurement each grind cycle.

- Ensure rail is free of grease and debris
- Ensure MiniProf is placed squarely on the rail using rod and perpendicular device.
- Record detailed location parameters for each MiniProf file either in the file itself and on a data collection sheet. Clear well-lit and labelled photographs of the rail surface looking from above.
- Perform a dye penetrant or magnetic particle test directly adjacent to the location the MiniProf was taken.
- Clear well-lit and labelled photographs of the rail after dye penetrant/mag particle test (pre-grind only).

11.9 Switch and Specialty Grinder Machine-Description

- The working principle of SRGM is similar to production grinders. While M/s Loram make use Grind Data Management System (GDMS) or Rail Pro, M/s Harsco uses Smart Grind for management of grinding.
- The SRGM having 20 Stone Specialty Rail Grinding Machine is a typical “gap” grinder.
- The purpose of this machine is to typically cover sections that are left unground by a large mainline grinder.
- The machine can be strategically used in station areas to ensure grinding of all turnouts in and around the station along with other specialty areas of track.
- The traveling speed of the machine without grinding is 80 km/h by design. However, RDSO will pursue provisional speed certificate for these machines for 65km/h on submission of required company request.
- The machine is capable of grinding at a speed ranging from 2 km/h to 15 km/h. However the speed is kept between 8 and 15 km/h during grinding.
- The machine can remove 0.13 to 0.2 mm of metal on an average while grinding at 15 to 10 kmph.
- As per the experience gained so far, the average diesel consumption is found to be 200-275 liters/Hrs. and average water consumption is 1100 liters per km.



Fig 11.19 : SRGM (M/s Loram make)



Fig 11.20 : SRGM (M/s Harsco make)

- SRGM normally needs 3 passes on Points and crossing to complete thesequence.
- Fuel Tank Capacity - 5000 Liters, Water Tank Capacity – 6000Liters.
- SRGM has one Grind Car and one Camp Coach

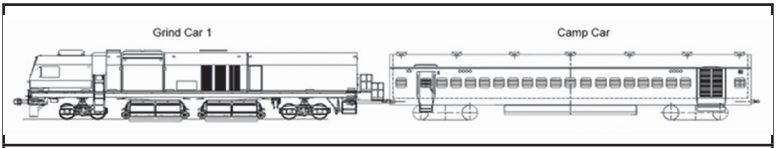


Fig 11.21 : SRGM (Loram Make) Layout with one Grind Car and one camp coach

- SRGM uses 250 mm grinding stones same as in production grinders. However it is able to cover the inaccessible areas between rails by its ability to laterally shift as shown below

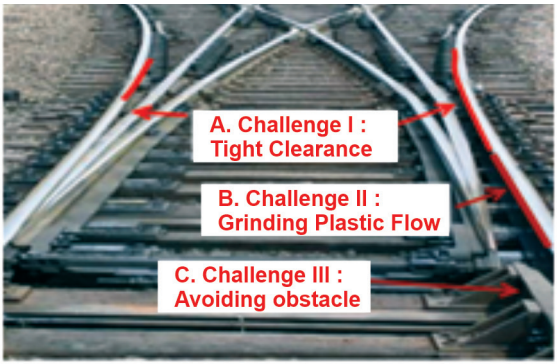


Fig 11.22 : Locations difficult to grind

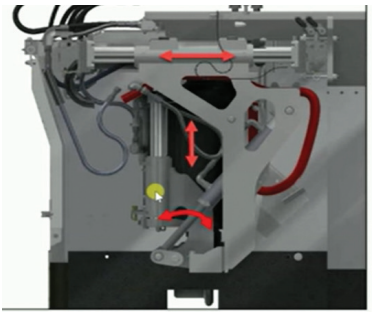


Fig 11.23 : Special arraggement for shifting grinding stones laterally in M/s Loram Machines.

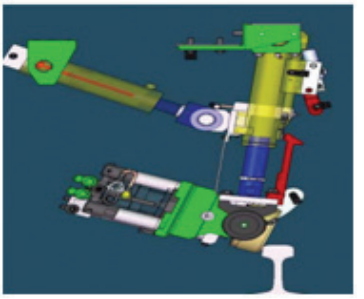


Fig 11.24 : Special arraggement for shifting grinding stones laterally in M/s Harsco Machines.

This improves the ability of the machine in following manner:

- The machine can grind curved track with check rails without removing check rails.
- Level crossings without removing check rails
- Points & crossings without removing check rails

Each Grind car has following components:

- Rail grinding equipment
- Dust collection
- Operator controls
- Power generation,
- Hydraulics
- Hydrostatic traction
- Tie and ditch sprays
- Rail inspection and profile measurement

The working of these are same as for production grinders.

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12.0 General

Rail Inspection Vehicle (RIV) are used for taking measurement of Rail profile in advance of Rail Grinding and helps in taking the managerial decision on profiles and patterns to be fed in Production Grinders and in SRGM for achieving the desired profile.

Indian Railway is procuring two RIV's from M/s Harsco which shall be used for taking advance measurement and suggesting grind plan even for M/s Loram's Production as well as SRGM apart from that for M/s Harsco SRGM.

12.1 Layout of RIV Supplied by M/s Harsco

The vehicle layout is as below:

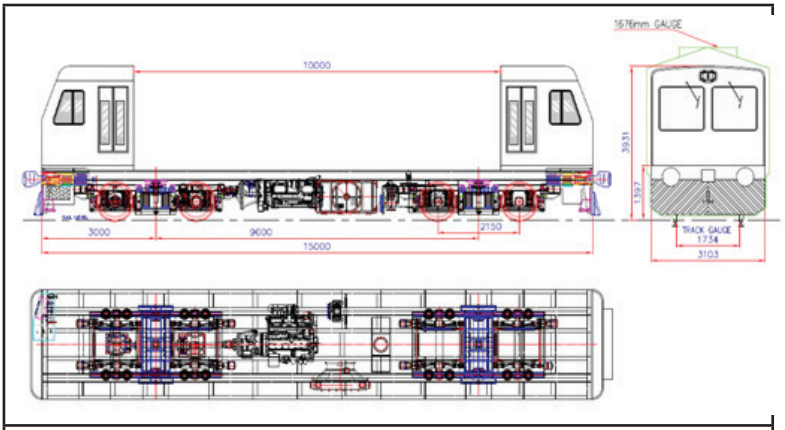


Fig 12.1 : Layout of RIV from M/s Harsco

The Rail Inspection Vehicle (RIV) is a self-propelled bi-directional bogie type (2 bogies/4 axles) vehicle with rapid acceleration to a speed of 80 km/h. The vehicle is provided with an air-conditioned cabin at both ends equipped with chairs for operator and inspection team.

12.2 Salient Feature of the M/s Harsco Make RIV

- It is installed with rail head profile measuring system, Corrugation system and High-Resolution Optical imaging system.

- Rail profile is collected using two optical units that are mounted on the vehicle frame.Each unit contains two lasers and two 3D-cameras that allow it to provide full rail profile.
- GPS and encoder system provides high-accuracy location
- The system consists of the acceleration sensors, which are installed on the axles of the rail-bound RIV. The accelerometers are used to monitor the vertical movements and to provide the signal data, sufficient for the assessment of the surface condition as it pertains to corrugation.
- Harsco SmartGrind software is used to record, localize and store the measurement data, and the configurable filters and processing patterns allow it to maximize corrugation detection process.Corrugation Severity Index (scale of 0-5) is established
- Advanced software algorithms provide calculation of multiple parameters, including rail wear as well as equivalent conicity in accordance with EN13231 and EN15302 standards.
- Given a current and target GQI, Harsco Smart Grind determines
- Number of passes
- Forecasted GQI
- Speed of grind etc
- Grind Plan
- The Grind Plan is only available for a specific machine. In this case Harsco 20-stone grinder. However Harsco RIV measures Rail Profile and Harsco Smart Grind converts the Rail Profile, Target Rail Template and Difference Curve into a .BAN file. This .BAN file exported to other OEM Grinders. Other OEM grinder utilize this to generate Grind Plan.

◆◆◆

S. No.	Name	Author/ Published by
1	Gudelines for working of Rail Grinding Machine	Sh. P.K. Garg, Sr Professor/ Track/IRICEN
2	Guidelines to Best Practices For Heavy Haul Railway Operations : Management of the Wheel and Rail Interface-2015	International Heavy Haul Association, USA
3	Guidelines to Best Practices For Heavy Haul Railway Operations: Management of the Wheel and Rail Interface-2001	International Heavy Haul Association, USA
4	TMC 226 -RAIL DEFECTS HANDBOOK Version 1.2 Issued June 2012 Reconfirmed 03 July 2019	RailCorp Engineering Manual
5	TMC 225 RAIL GRINDING Version 2.5 Issued April 2013 Reconfirmed 03 July 2019	RailCorp Engineering Manual
6	Rail Grinding Manual for Plain Track	Australian Rail Track Corporation Limited
7	Track Compendium	Bernhard Lichetberger
8	The Art and Science of Rail Grinding	Allan Mark Zarembski
9	Modern Railway Track	C.Esvald
10	RDSO Report CT-33 of 2014	RDSO, Indian Railways
11	RDSO Report CT-43 of 2019	RDSO, Indian Railways
12	Indian Railways Permanent Way Manual	Indian Railways
13	Chasing the magic wear rate	NRC Canada Publications

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Published by
Indian Railways Institute of Civil Engineering
11-A, South Main Road, Koregaon Park, Pune - 411001.