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GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS
Research Designs And Standards Organisation
LUCKNOW -226011

INSTALLATION AND COMMISSIONING REPORT OF OPTICAL RAIL PROFILE MEASUREMENT AND ANALYSIS SYSTEM

TECHNICAL REPORT NO. TM-66

TRACK MACHINE & MONITORING DIRECTORATE

MARCH' 2004

This report is based on data collected during the field trials carried out by the Track machines and Monitoring Dte. of RDSO. Although, every care has been taken in analysing it objectively, the views expressed in this report are subject to modifications from time to time in the light of fresh data. Further, they do not necessarily represent the views of the Ministry of Railway (Railway Board), Government of India.

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Surendra Kumar
Exec. Director/TM

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LIST OF ABBREVIATIONS

S.NO.	Abbreviation	Stands for
1.	RPMS	Rail Profile Measurement System
2.	VME	Virtual Memory Extension
3.	CPU	Central Processing Unit
4.	I/O	Input/Output
5.	D/A	Digital to Analog
6.	LTC	Laser Temperature Card
7.	CCD	Charge Coupled device
8.	ALD	Automatic Location Detector
9.	LASER	Light Amplification by Stimulated Emission of Radiation.
10.	CSV	Comma separated values

1.0 INTRODUCTION

Indian Railway was not having any equipment or system for measurement of Rail Wear (Vertical & Lateral), Rail Inclination and lip. In the absence of any proper measuring system the rail wear assessment for planning rail renewal was being done manually by using some special gadgets manufactured locally in different railways. The rail wear is determined by actual weighment, taking rail profiles at ends after unfishing joints and taking rail profiles by locally manufactured profile measuring gadgets.

Indian Railway have a total route Kms of 46,338 and total track kilometer of 63,346. It was felt that the assessment of wear for rail renewal purpose for such a huge track is not possible manually. Thus the proposal for procurement of two sets of Optical Rail Profile Measurement and Analysis System capable of measuring, Vertical Wear, Lateral wear, Rail inclination, lip flow and gauge was included in the work progress of 1996-97 at total cost of 5.48 corers. The sanction for the work was communicated by Railway Board vide letter no. 94/ER/ 3400/12/ FWP(Pt) dated 05.8.96. In the sanction letter Board mentioned that it would be proper to procure one system first and repeat the order if field trial proves its accuracy and future savings can be identified. Accordingly a global tender was floated and finally the order was placed on M/s E.H. Reeves & Associates Inc., USA vide P.O. No. SP3/0002/TM/OIB/97/ 0004 dated 24.2.99.

In terms of para 6.1, 8.1 and 8.2 of technical specifications and clause 14 and 24 of the contract the training and lab inspection of the system was carried out in Feb/March 2001. Firm's engineers first visited RDSO in April'2002 and subsequently made few more visits for installation and commissioning of the system. Firm's engineers have completed the installation and commissioning of the system in their recent visit which started form 01.2.2004. The field validation of the system has been dealt in this report.

2.0 BRIEF SYSTEM DESCRIPTION

2.1 The RPMS is a rail cross-section measuring device. Its function is to provide accurate and reliable measurement of rail profiles in real time. The system is designed to function up to a speed of 160 kmph with a minimum of operator intervention. Differences between a standard reference profile and the measured rail profile can be determined from the profile data.

The RPMS consists of two major components: a VME bus based Computer System and a Non-Contact Measurement Assembly. The VME bus Computer System is mounted inside ICF all coil coach and the Non-contact sensor beam is mounted on the bogie of the ICF all coil coach.

2.2 VME bus computer system

The Computer System is based on the VME bus architecture. Functionally, the VME system uses one processor configuration. One processor (CPU), referred to as the I/O CPU, provides the operator interface, comparison of measured profiles to standard profile, data storage and reporting, file management, interface to other systems, system performance monitoring and error checking functions.

The complete system is contained in a standard 19-inch rack mounted 12 slot chassis. Power to the chassis is provided through a DC-DC converter. Cards are mounted vertically and forced filtered air is blown in the chassis for cooling of system. The following cards have been used in the chassis of the computer system

- I/O processor card – 1 no.
- LASER/Temperature Controller Card (LTC-3) – 1 no.
- Image Processor Cards- 4 nos.
- D/A card – 1 no.

2.3 Non-Contact Measurement Assembly

The RPMS uses four video cameras and four lasers for non-contact measurement of rail profiles. A pair of lasers projects a thin line of light across the surface of each rail while a pair of cameras acquire images of the laser lines. The raw video images of rails are sent to the VME bus computer system where they are processed to produce rail profiles.

Camera and laser positions are fixed relative to one another and are mounted in a closed beam assembly. One set camera and LASER measures the half of the rail profile.

2.4 Laser/Camera Beam Assembly

The beam assembly is mounted on the coach bogie, six inches above the rail and within in the clearance envelope of the vehicle. The mounting provides an operating position for profile measurement and recording and an upturned maintenance position for alignment and calibration of LASER & camera.

2.5 LASER

The RPMS lasers are equipped with a special beam-spreading lens, called line optic, that projects a very thin, uniform laser line (810-nm wavelength) from the foot of field side to the foot of gauge side of the rail. Only a small section of the web, shadowed by the railhead, is not illuminated. Each laser is temperature controlled by multiple thermoelectric coolers to produce a constant monochromatic beam. The laser power output is adjust is adjustable to a maximum of 80 milliwatts.

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2.6 Camera

A high shutter speed CCD array camera is used to measure the position of the laser line. Each camera is fitted with a optical lens and software controlled iris motor for exposure control.

A band pass optical interference filter, tuned to the wavelength of the laser light, is used to block ambient light. Though this filter provides high tolerance to sunlight, screening is necessary to prevent direct reflections of sunlight into the camera, for which sun shields have been installed on all sides of the sensor beam.

2.7 Tachometer

A 1000 pulse optical tacho generator of BEI Inc. USA make has been used for measurement of accurate distance traveled by the vehicle. It is directly mounted on the axle box, coupled with the axle using a specially designed mounting arrangement. For accurate measurement of distance it is necessary that the tachometer drive should be free from slippage and backlash. Tachometer is interfaced with Laser temperature controller card which provides a +5V DC power and signal conditioning to it.

2.8 Power Requirement

The RPMS requires 22 V, 50 Hz conditioned AC electric power. 1 KVA off line uninterruptible power supply (UPS) of 30-minute backup time has been installed to provide basic power conditioning required for the system. A transformer, which converts 220 V to 110 VAC is used to provide 110VAC power to the B&W Sony monitor used for viewing the raw images.

3.0 MEASUREMENT TECHNIQUE

3.1 General Principle

RPMS uses a technique called as "light sectioning". This technique employs a thin band of light to outline the surface of the object to be measured. A camera is used to acquire an image of the object. The camera sees the thin band of light as a sharp edge, and the position of this edge can be determined in the camera's field of view. This technique has been known since the 1950's, but was impractical before the development of modern CCD cameras and digital computers.

The RPMS uses infrared laser as the light source. The laser is equipped with a special beam spreading lens that spreads the laser spot into a thin line of light. The laser is mounted perpendicular to the rail and projects the line onto the railhead and base. A video camera is used to take a picture of the rail while it is illuminated with the laser. The resulting image shows the laser light as a thin band around the rail. Specialized computer software determines the location where the laser intersects the rail. Points on the intersection are the profile points that describe the rail shape.

The software for obtaining rail profiles analyses the digitized video images to locate the rail in the camera's field of view. An advanced image-tracking algorithm then locks onto the rail position, allowing objects such as switches and crossings to be detected while reducing interference from unwanted objects. Profile distortions due to variations in image intensity are minimized by the technique of dynamic threshold. This process reduces the need for an operator to constantly monitor and adjust the camera exposure.

Rail profile information is extracted and reduced to X-Y coordinate data, which is then geometrically corrected for perspective distortions. The resulting X-Y coordinate data set represents the profile section from each camera. The profile sections from two cameras (gauge side and field side) are merged together to form a single rail profile. The results are displayed, processed by ancillary equipment, and stored to disk.

3.2 Calibration Process

Each camera is individually calibrated for X-Y-Z rotations, perspective distortion, and X-Y scale factors. Calibration requires inserting a calibration fixture into the illumination plane of the laser. A dovetail mount and clamps secure the calibration fixture into the correct position. The standard profile calibration fixture has nine pegs, positioned in a precise rectangular array. The rectangle spans the camera's entire field of view, and provides a reference for correcting camera distortions. This array defines the coordinate axes for the system.

The calibration fixture is positioned so that the pegs intersect the plane of light projected by the laser. Perspective distortion makes objects that are further away appear to be smaller. As a result, pegs that are closer to the camera appear to be spaced further apart from each other. In addition, the camera's rotational position with respect to the calibration fixture results in an apparent rotation of the peg's position in the field of view. When viewed by the camera, the pegs appear as points of light against a black background.

For correction of these distortions, it is necessary to determine the camera angles with respect to the target and the distance between the target and the camera. The camera angles can be determined by nothing that perspective distortion results in the sides of the peg rectangle converging at two points called vanishing points. The vector cross product of the vanishing points can be used to determine the camera angles and the distance between the camera and the target.

The camera angles are used to correct X-Y-Z rotations and perspective distortion. The result is a geometrically correct image of the peg rectangle. However, it is still necessary to scale the rectangle to match the known dimensions. This is accomplished by calculating the ratio of the distance between the pegs in each direction with the known dimensions. These ratios are the X and Y scale factors.

The final step is to locate the origin of the camera's coordinate system with respect to the measuring system's coordinate frame. The center of the corrected peg rectangle is calculated in X and Y. This point will be defined to the origin of the camera's coordinate system and will be subtracted from each point. As a result, the center of the peg rectangle becomes (0,0). The distance from the measuring system's coordinate frame to the center of the peg array is a constant determined during assembly. This dimension is used to offset the origin of the corrected peg array thereby locating the camera's coordinate system with respect to the measuring system's coordinate frame.

When the calibration target is removed and the system is used to measure a rail, the same transformations are applied to each point as were used to correct the peg rectangle. This results in geometrically and dimensionally correct points.

The procedure requires that a technician mounts the calibration fixture on the measuring assembly. Automatic software then makes the required measurements and produces a calibration parameter file. The procedure requires approximately 10 minutes. The required calibration frequency depends on the mechanical stability of the measuring assembly, the cameras, and the lasers. New systems can require calibration at intervals of 20 to 30 hours of operation. Once a system has 'settled in', intervals of 100 to 200 hours of operation between calibrations are normal.

3.3 Coordinate System

For all measurements it is necessary to establish a coordinate system on the rail. This is accomplished by the following procedure:

- Using points from the web starting on the top of the left side, search to locate the nearest point across on the right side of the web. These two points then become a point pair. The entire web is processed in this way, resulting in a large number of point pairs (web overlapping zone). Each point pair defines a line segment across the web. The center point of each line segment is a point on the web centerline. These points are used in a least square fit calculation to determine the slope and Y intercept of the web centerline. The web centerline is called Ya.
- For each web, locate points that are in the base fillet region. The approximate center of this region of points is determined by calculating the slope of the tangent line at each point on lower half of the web. A slope of 1.0 indicates the center of the fillet region.
- From the standard definition of rail type currently being measured, the extent of the fillet region is known relative to the center of the region. These points are extracted from the web data set and used to calculate the center of the fillet (O_f) by curve fitting. The fillet center point is called O_f. The curve fitting procedure also produces a quality of fit factor. This procedure is performed for both sides of the web. The side that produces the best quality of fit is used as the vertical reference point. If neither side produces an acceptable quality of fit, the profile is rejected.
- Translate all profile points so that the O_f corresponds to the center of the fillet on the standard definition rail. The profile is now normalized.

3.4 Measured Parameters

Using the measuring principle discussed in para 3.0 the proprietary software developed by the firm acquires the profiles of left and right rail and calculates the following parameters by overlaying the acquired rail profiles on new rail profile already stored in system and generates on line print outs of analog report (strip chart), exception report and overlaid normalised print of new and acquired rail profile along with the calculated parameter values at that particular profile. The sample of these printouts are placed at Annexure I, II & III.

3.4.1 Rail Head Contour

This is the basic data set resulting from profile measurement. Data points begin at the bottom of the field side and continue around the head of the rail to the bottom of the gauge side. In addition, points are also measured on both webs starting from base to approximately 25 mm below the head. Point density is approximately 0.5 mm. This data set is used to calculate all other parameters. Point-to-point accuracy is better than 0.1 mm.

3.4.2 Lateral Wear

Lateral wear is measured across the profile head at the gauge point, which is at a distance of 14mm below the rail top. The difference between a new rail section and the measured rail section is calculated at this point. This measurement is not affected by the presence of a metal flow lip unless the lip extends down below the gauge point. As the measurement is defined to be along a line perpendicular to the rail centerline, the measurement is corrected for rail inclination.

3.4.3 Vertical Wear

Vertical wear is determined by overlaying the new rail profile and measured rail profile and taking the difference of height of new and measured rails. The heights of new and measured rails are defined as the distance between a vertical reference point and highest points on the rail top of the corresponding rail profiles.

Accuracy of the vertical wear calculation depends on the accuracy of the vertical reference point, which is derived from the base fillet radius on either side of web. The buildup of dirt or other material on the web affects the reference point. However, because the reference can be calculated from either side of the rail, dirt build up only sometimes becomes a problem.

3.4.4 Rail Inclination

Rail inclination is defined as the angle between the rail centerline and the track plane at that point. The track plane is a line between the highest points on each railhead. Thus for accurate measurement of rail inclination, profiles from both rails are measured at the exact same instance of time and completely rigid connection between the left and right side profile measuring units is provided. Rail inclination is a standard output from the RPMS.

3.4.5 Rail Lip (Burring)

Rail lip or burring is defined as the lateral flow of metal beyond the normal dimension of the railhead. The RPMS calculates rail lip by subtracting the X coordinate of new rail at the user defined gauge point (14mm from rail top) from the maximum X point of the measured rail. Rail Profile lip is a standard output from RPMS for both left and right sides of the rail.

3.4.6 Gauge

The gauge is defined as the distance between the user defined gauge point (14 mm from rail top) on the gauge face of each rail. The RPMS sums the difference in position of the gauge point in the field of view of each camera with the known distance between cameras. The resulting gauge measurement is the difference between the optimal gauge and the measured gauge.

4.0 FIELD TRIALS

4.1 Objective of Field Trials

The objective of the field trials of rail profile measurement and analysis system are summarized below-

- Testing of functionality of various sub systems/equipment e.g. Tachometer, ALD, Key Pad and D/A card out put of the system.
- Assessment of reliability of recorded data by comparing the same with data measured by a portable profile measurement system in static condition.
- Assessment of repeatability of results at various speed combinations.

4.2 Scope of the Report

The scope of the report is limited to ascertain the repeatability of the system at various speed combinations and accuracy comparison the parameter recorded by portable measurement system with in terms of the provision of para 3.1 and 3.4 of technical specifications.

4.3 Field Trial Scheme

4.3.1 Selection of Trial Sections

In terms of para 3.5 of the contract the repeatability tests are to be conducted on two sections, one for low speed routes and other for High speed routes and on each section the trial is to be conducted on minimum recording speed of the system i.e. 20 km/h and maximum permissible speed of the route. Considering the provision of technical specifications for low speed stretch Chunar – Churk section of North Cenrtral Railway (NCR) having a maximum booked speed of 50 kmph and for high speed stretch Kanpur – Fathepur section of NCR having a maximum permissible speed of 130 kmph has been selected for field trials.

4.3.2 Trial Speeds and their combinations

To ascertain the repeatability at same speed combinations and different speed combinations, trial section was divided into small stretches and trials at different speeds were conducted on these small stretches. The length of small stretches and speed of recording planned for these stretches of Chunar-Churk and Kanpur-Fathepur section in different runs are tabulated below:

Table -1.0 Section: Chunar – Churk

S.No.	Kilometer		Speed (kmph)	
	From	To	RUN-1	RUN-2
1.	240	230	20	20
2.	230	210	35	35
3.	210	180	50	50
4.	180	165	50	35

Table -2 Section: Churk – Chunar

S.No.	Kilometer		Speed (kmph)	
	From	To	RUN-1	RUN-2
1.	165	175	20	50
2.	175	195	35	50
3.	195	225	50	50
4.	225	240	35	20

Table -3 Section: Kanpur – Fathepur

S.No.	Kilometer		Speed (kmph)		
	From	To	RUN-1	RUN-2	RUN-3
1.	1015	1010	20	20	100
2.	1010	1003	50	50	100
3.	1003	990	75	75	100
4.	990	965	100	100	130
5.	965	948	130	130	130
6.	948	943	130	130	20

Table - 4 Section: Fathepur –Kanpur

S.No.	Kilometer		Speed (kmph)		
	From	To	RUN-1	RUN-2	RUN-3
1.	942	948	20	20	75
2.	948	955	50	50	75
3.	955	960	100	100	20
4.	960	980	100	100	100
5.	980	990	130	130	100
6.	990	997	130	130	75
7.	997	1003	75	75	50
8.	1003	1015	75	75	100

From the actual speed of recording achieved in various small stretches, stretches having common kilometer in two runs having different and same speed combinations were identified and are tabulated below for repeatability analysis.

Table - 5 Section: Chunar – Churk

S.No.	Speed Combination		Kilometer		Data file Name	
	1st run (Kmph)	2nd run (Kmph)	From	To	1st run	2nd run
1.	20	20	240	230	N3251245	N3271453
2.	35	35	231	215	N3251245	N3271453
3.	50	50	214	175	N3251245	N3271453
4.	35	50	216	210	N3251245	N3271453

Table - 6 Section: Churk – Chunar

S.No.	Speed Combination		Kilometer		Data file Name	
	1st run (Kmph)	2nd run (Kmph)	From	To	1st run	2nd run
1.	20	50	165	170	N3251559	N3271730
2.	35	50	176	195	N3251559	N3271730
3.	35	20	229	240	N3251559	N3271730
4.	50	50	195	226	N3251559	N3271730

Table –7 Section: Kanpur – Fathepur

S.No.	Speed Combination		Kilometer		Data file Name	
	1st run (Kmph)	2nd run (Kmph)	From	To	1st run	2nd run
1.	130	130	990	976	N3060938	N3051219
2.	100	100	990	967	N3060938	N3040754
3.	75	75	1003	990	O0530758	O0540758
4.	50	50	967	965	N3060938	N3040754
5.	75	100	1002	990	N3041449	N3060938
6.	100	130	990	976	N3041449	N3060938
7.	50	50	1010	1003	O0530758	O0540758
8.	75	20	956	960	O0531357	O0541154
9.	20	20	1018	1010	O0530758	O0540758

Table -8 Section: Fathepur - Kanpur

S.No.	Speed Combination		Kilometer		Data file Name	
	1st run (Kmph)	2nd run (Kmph)	From	To	1st run	2nd run
1.	130	130	992	995	N3061702	N3041112
2.	100	100	960	976	N3051707	N3041112
3.	75	75	993	1007	N3041112	N3041718
4.	20	75	944	953	N3061702	N3051707
5.	20	100	954	975	N3051707	N3041718
6.	50	75	993	1007	N3051707	N3041718
7.	75	100	989	992	N3051707	N3041718
8.	50	100	985	988	N3041112	N3051707
9.	75	130	1007	1011	N3041112	N3061702

4.3.3 Transponder location

The locations of the ground transponder in Chunar – Churk, Kanpur-Fathepur and Fathepur-Kanpur are tabulated below in table 9.

Table -9

Sr.No.	Chunar-Churk	Kanpur-Fathepur	Fathepur-Kanpur
1.	Km. 234.639	Km 1015.925	Km 955.700
2.	Km. 213.896	Km. 987.641	Km. 978.783
3.	Km. 210.881	Km. 958.700	Km. 1013.936
4.	Km. 182.951	-	-

4.3.4 Selection of curve for measurement by Portable Profile Measurement System

As per technical specification a curve of approximately 1 kilometer was to be selected for measurement by portable profile measurement system. Accordingly a 5^0 curve between kilometer 211-210 was selected at Chunar-Churk section of North Central Railway.

5.0 TOOLS USED FOR ASSESSING PERFORMANCE OF THE SYSTEM

For measurement of profile in static condition the EZ-2 portable profile measurement system provided by the firm was used. The details of the system are described below in para 5.1. The analysis tools used to compare the profiles taken under static conditions using portable profile measurement system and the profiles taken under dynamic condition using RPMS are described in para 5.2. This analysis tool is provided with the EZ-2 portable profile measurement system by the firm. The analysis tool used to verify the repeatability of measurement done at various same and different speeds using RPMS system is described in para 5.3.

5.1 Portable Profile Measurement System

The Portable Profile Measurement System is a compact laser-based non-contact portable instrument designed specifically for measuring rail profiles with high contour accuracy, and storing them for further off-line analysis. Powered by a single commercially available 12 VDC battery, this can be used in continuous operation for approximately one hour. A power saving standby mode conserves battery charge for extended operations without the need to power off. The system comes with two batteries, which allows up to two hours of continuous operation. The battery charger provided with the system, recharge the batteries in approximately 30 minutes.

This system measures the railhead profile from the under-head web-to-head fillet, up to the gauge side of the railhead, across the top of the railhead, and down the field side of the railhead up to bottom of the railhead field face. Measured railhead profiles are stored in files on a flash memory disk that is integrated with the system's custom image processing board. The total number of rail profiles that can be stored depends on the size of the flash memory disk. For this system standard 8 MB flash memory disk is provided which allows storing of approximately 1000 profiles.

A precision calibration verification target allows the operator to quickly verify and/or correct the system calibration. Typical time for calibration verification/ correction is approximately two minutes, including the time to install and remove the target.

Previous laboratory validation of the system's measured profile compared to independent third party measurements of a precision 136-RE (136 lb/yard) rail section indicate the system's profile contour accuracy to be ±0.03 mm. Such high accuracy makes it a preferred instrument for manually collecting reference rail profiles for comparison with the dynamic rail profiles collected by any other system.

5.2 EZ-2 Portable Desktop

EZ-2 Portable Desktop is a Windows software package supplied with the EZ-2 that provides off-line profile analysis and file management support for the EZ-2. This analysis tool has following capabilities-

- Compare measured rail profiles with reference rail section profiles and perform detailed profile analyses;
- Export measured rail profiles in a variety of formats for use by other software;
- Download measured rail profile files from the EZ-2, and provide over laying facility.
- Upload software updates and reference rail sections to the EZ-2; and
- Print the results of the various comparisons and analyses.

EZ-2 Portable Desktop automatically aligns the measured rail profile with the reference rail section using the web-to-head fillet under the gauge side of the railhead. As this alignment may not be perfect for a variety of reasons, EZ-2 Portable Desktop provides a facility for manually adjusting the alignment by rotating and translating the measured rail profile.

EZ-2 Portable Desktop also allows comparison with rail grinding templates, which usually are a limited section of the top and gauge side of the railhead, and thus do not contain the web-to-head fillet normally used for alignment. For this type of comparison, EZ-2 Portable Desktop uses the highest point on both profiles for vertical alignment, and the gauge point on both profiles for horizontal alignment. This alignment also can be adjusted manually.

5.3 WinPALS Profile Editor

WinPALS Profile Editor is a Windows software package that provides editing and analysis tools for rail profiles captured by the RPMS. Using WinPALS Profile Editor, the user can:

- View and print measured rail profiles and rail wear measurement strip charts,
- Change the rail type of incorrectly typed measured rail profiles,
- Delete measured rail profiles distorted by high ballast and other obstructions,
- Recalculate measured rail profile alignment with respect to the reference rail section and determine the resulting rail wear measurements,
- Export rail wear measurements and measured rail profiles in a variety of formats for further analysis external to WinPALS Profile Editor.

WinPALS Profile Editor provides several different views of the measured rail profiles and rail wear measurements:

- The raw profile view displays the measured rail profiles in the orientation observed by the RPMS, allowing the user to see the rail's orientation in free space.
- The normalized rail profile view displays the measured rail profile aligned with the reference rail section, with indicators for the rail inclination angle, rail wear measurement points, and alignment sections.
- The wear view provides a strip chart display of user selected rail wear parameters.

These various views of the rail profiles, combined with its rail wear measurements and measured rail profile export capabilities, make WinPALS Profile Editor an useful tool for selecting and extracting rail wear measurements and measured rail profiles for the accuracy and repeatability analyses.

6.0 Methodology and Analysis of data

As per technical specification the dynamic performance of the RPMS is to be validated in field under two categories:

- Verification of Rail profile contour and wear accuracy in comparison with some portable equipment.
- Verification of repeatability of results for wears and gauge measurements.

The following subsections describe how these tools were used for data analysis.

6.1 Rail Profile Contour Accuracy

Portable Profile Measurement system described in para 5.1 was used for static measurement of profiles for 1 kilometer of curved track selected on Chunar-Churk section. The software tool described in para 5.2 was used to verify the accuracy of rail profile contours recorded by RPMS in comparison to rail profile contours recorded by portable rail profile measurement system.

The analysis technique for determining rail profile contour accuracy for selected curve track is described below:

- The profiles of both left and right rail were taken at every 4.0m interval on the selected one kilometer curved track selected on Chunar-Churk section (Km 211-210).
- The RPMS measured rail profiles of both left and right rail of the selected one kilometer curved track were exported in EZ-2 format using WinPALS Profile editor.
- Only those RPMS measured profiles, which were less than-1 meter apart with the EZ-2, were selected to be exported in EZ-2 format.
- The RPMS measured exported profiles were overlaid on the EZ-2 measured profiles using EZ-2 portable desktop, which aligns the two profiles automatically. The manual alignment facility provided in EZ-2 portable desktop was used to fine-tune the overlaid profiles.
- EZ-2 portable desktop was used to export the calculated differences between the selected RPMS profiles and EZ-2 profiles from the gauge measurement point to top or the railhead in the Microsoft excel spread sheet.
- Microsoft Excel was used to calculate the minimum, maximum and SD of the difference values.
- The analysed results of selected overlaid profiles are given in table-10

Section: Chunar-Churk Km. 211-210
Contour accuracy between EZ-2 and RPMS System

EZ-2	File Name: O0342215	Rail: Left/Right
RPMS	File Name: N3251559	Direction: UP

Table-10.

Km	Meter	MAX	MIN	AVG	STD
211	816	0.200	-0.170	0.007	0.111
211	824	0.170	-0.180	-0.048	0.092
211	828	0.160	-0.190	0.021	0.106
211	832	0.190	-0.170	0.028	0.108
211	836	0.130	-0.160	-0.011	0.082
211	840	0.210	-0.190	0.025	0.116
211	848	0.230	-0.200	-0.003	0.127
211	852	0.230	-0.210	-0.006	0.144
211	860	0.160	-0.180	-0.022	0.086
211	868	0.120	-0.180	-0.051	0.089
211	872	0.190	-0.230	-0.082	0.113
211	876	0.160	-0.180	-0.006	0.108
211	880	0.220	-0.180	0.008	0.131
211	884	0.190	-0.210	-0.015	0.126
211	888	0.160	-0.150	-0.045	0.080
211	892	0.180	-0.200	-0.037	0.122
211	896	0.180	-0.170	-0.010	0.107
211	904	0.190	-0.210	0.014	0.100
211	912	0.150	-0.190	-0.007	0.098
211	920	0.170	-0.090	0.028	0.057
211	924	0.150	-0.140	-0.039	0.090
211	928	0.190	-0.190	0.003	0.116
211	936	0.120	-0.110	0.010	0.064
211	944	0.180	-0.150	0.009	0.071
211	960	0.180	-0.170	0.003	0.073
211	972	0.180	-0.160	-0.020	0.085
211	976	0.210	-0.230	-0.020	0.145
211	980	0.190	-0.190	0.006	0.120

- The overlaid rail profile plots of some selected locations along with the plot of difference in contour measurement at various points of profiles are shown in fig. 1 to fig.32.

Location : Km –211, M-512
Side: Left rail

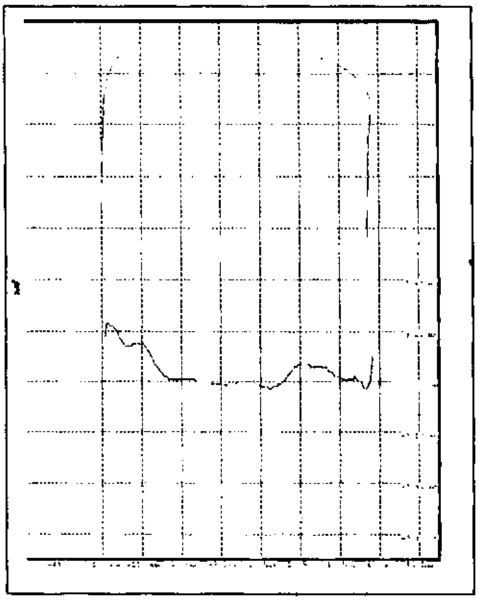


Fig. 1

Location : Km –211, M-688
Side: Left rail

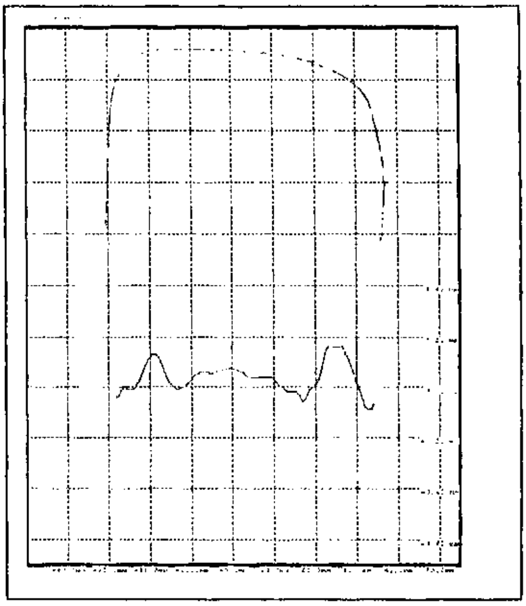


Fig. 2

Location : Km –211, M-696
Side: Right rail

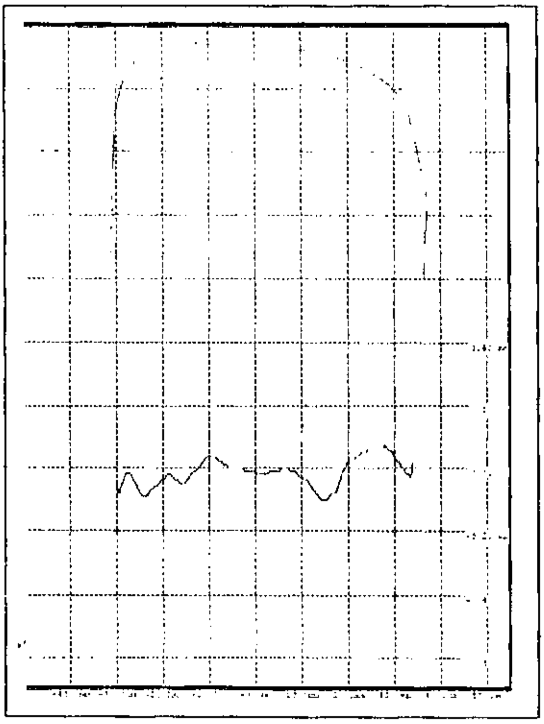


Fig.3

Location : Km –211, M-796
Side: Left rail

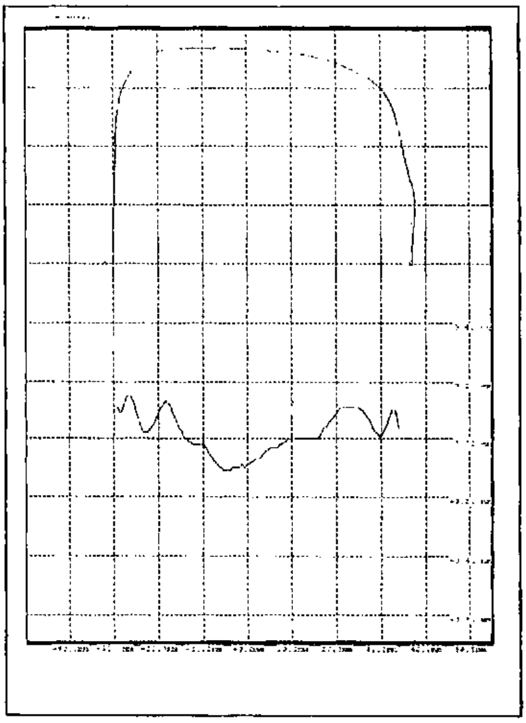


Fig.4

Location : Km –211, M-800
Side: Right rail

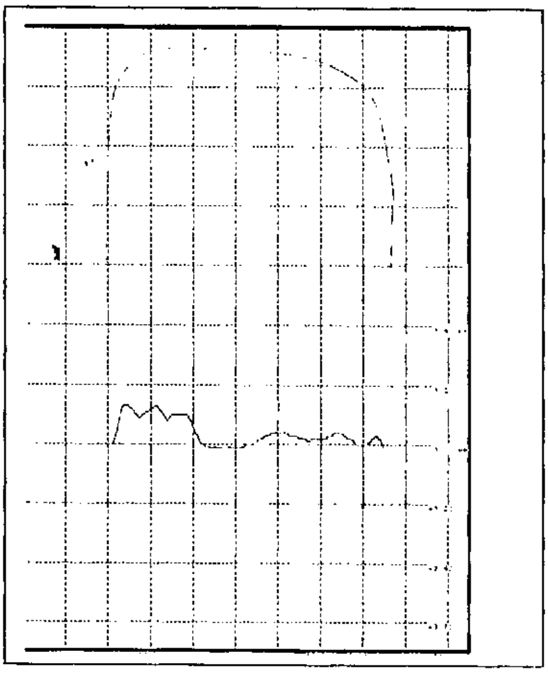


Fig. 5

Location : Km –211, M-816
Side: Left rail

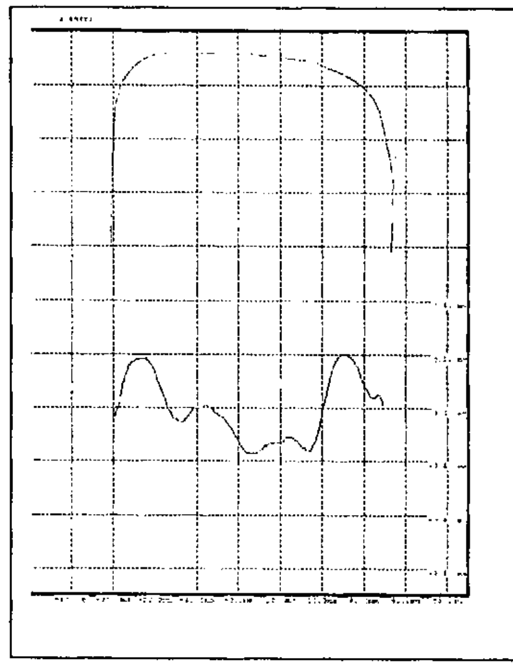


Fig.6

Location : Km –211, M-824
Side: Left rail

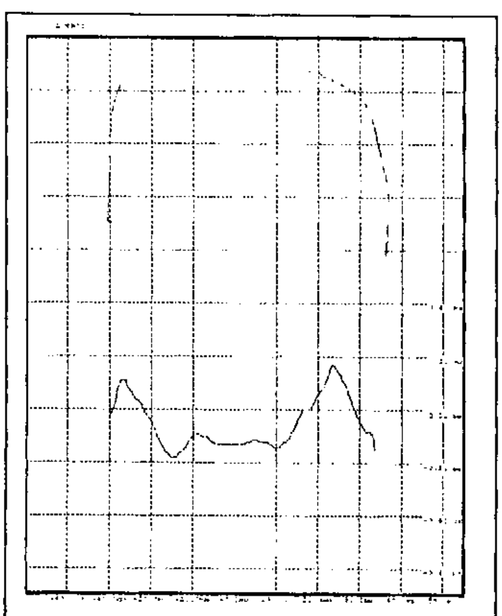


Fig.7

Location : Km –211, M-828
Side: Right rail

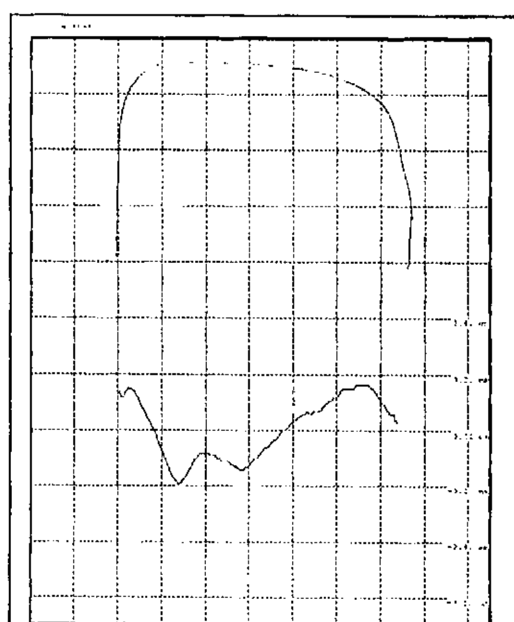


Fig.8

Location : Km –211, M-832
Side: Left rail

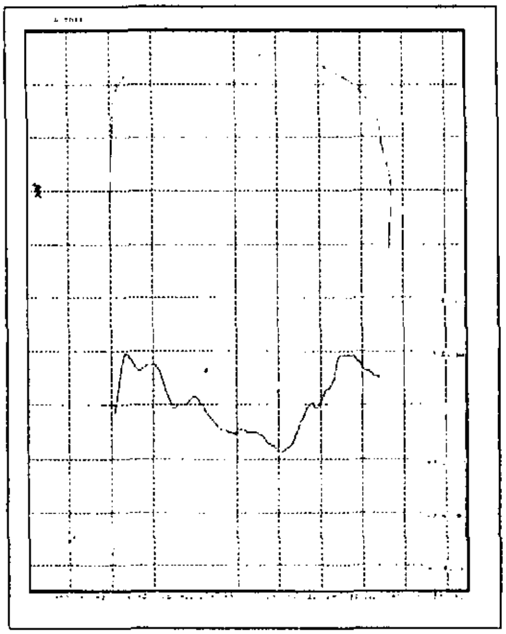


Fig. 9

Location : Km –211, M-836
Side: Right rail

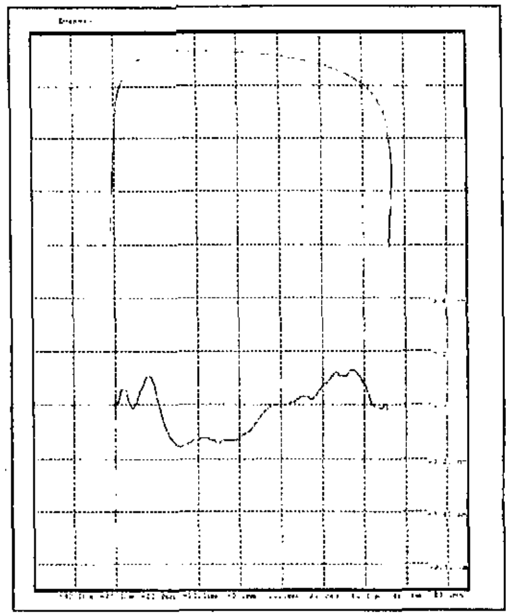


Fig.10

Location : Km –211, M-840
Side: Left rail

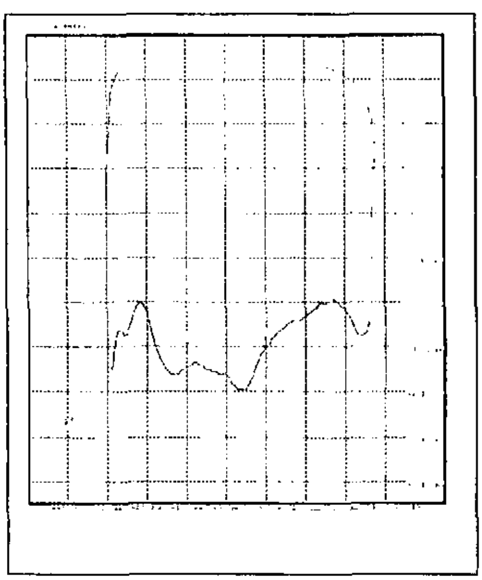


Fig. 11

Location : Km –211, M-848
Side: Right rail

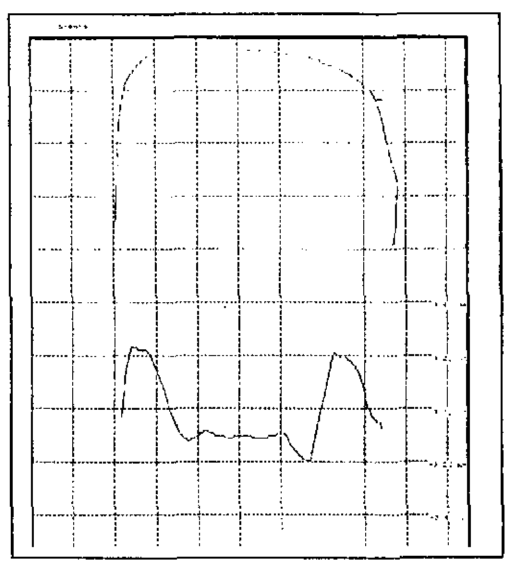


Fig.12

Location : Km –211,   M-852
Side: Left rail

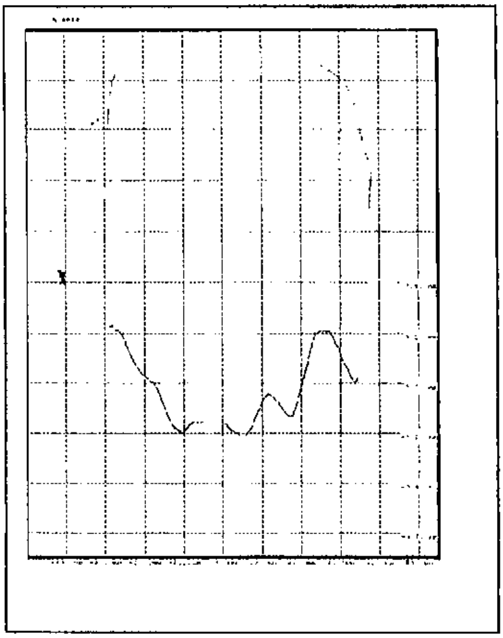


Fig. 13

Location : Km –211,   M-860
Side: Right rail

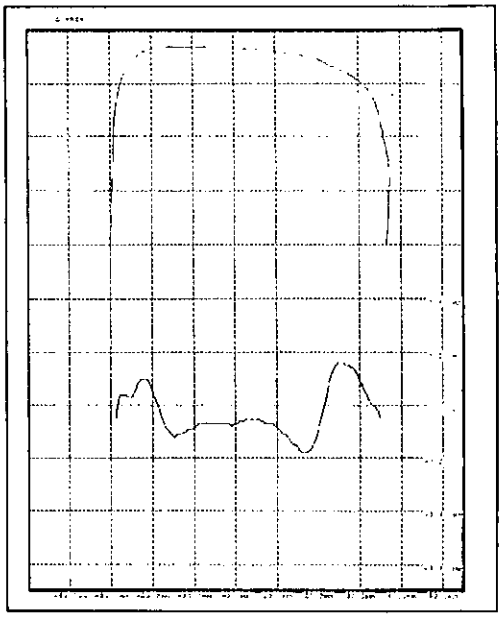


Fig. 14

Location : Km –211,   M-868
Side: Left rail

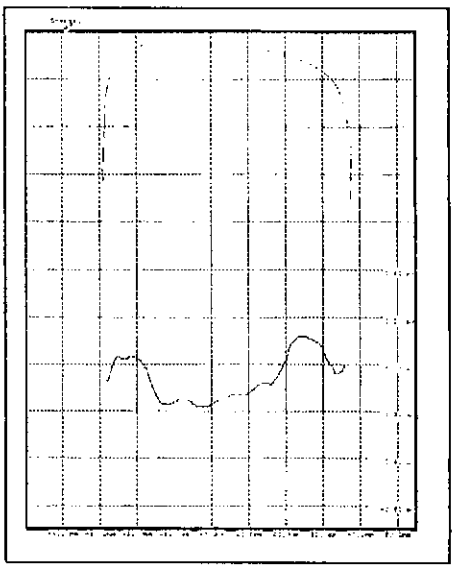


Fig. 15

Location : Km –211,   M-872
Side: Right rail

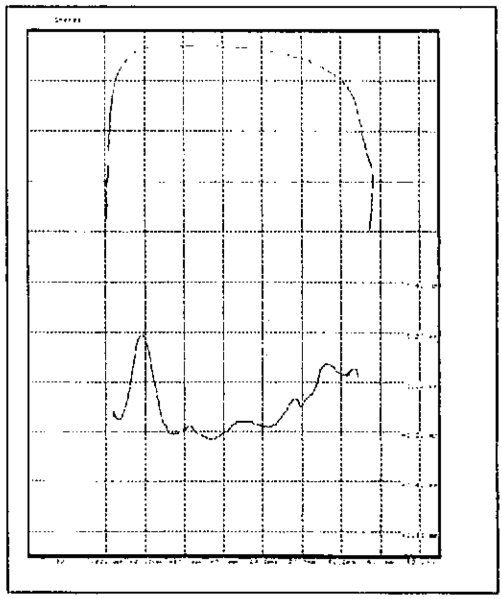


Fig. 16

06497

Location : Km –211, M-876
Side: Left rail

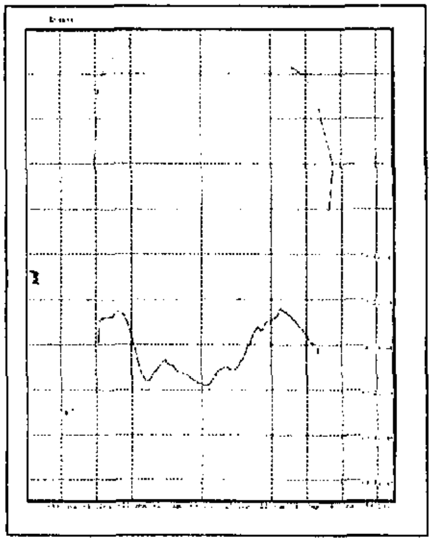


Fig. 17

Location : Km –211, M-880
Side: Right rail

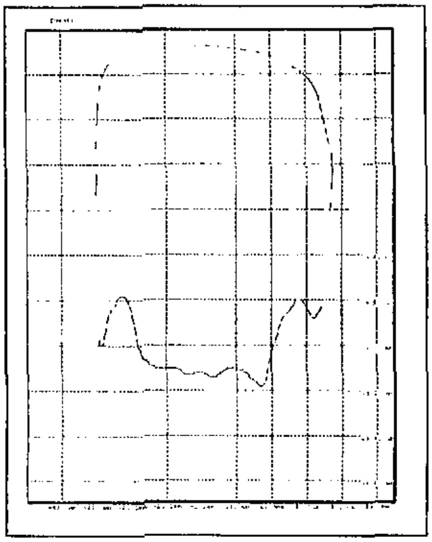


Fig. 18

Location : Km –211, M-884
Side: Left rail

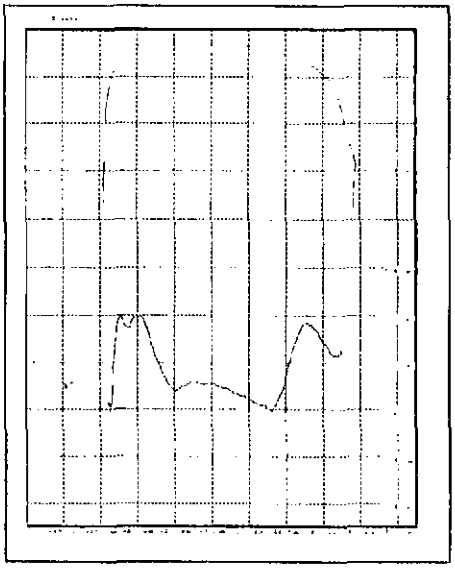


Fig. 19

Location : Km –211, M-888
Side: Right rail

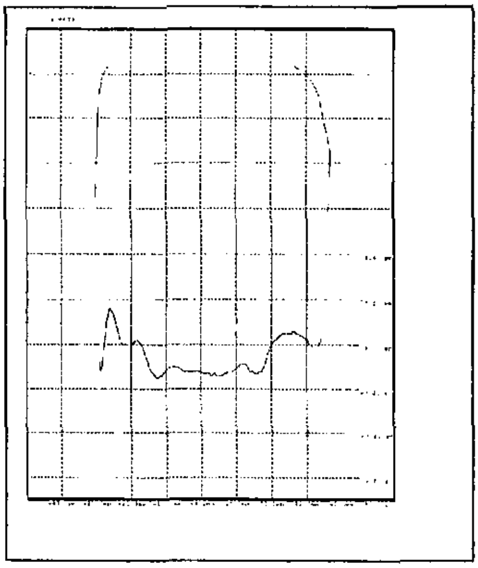


Fig. 20

0C498

Location : Km –211, M-892
Side: Left rail

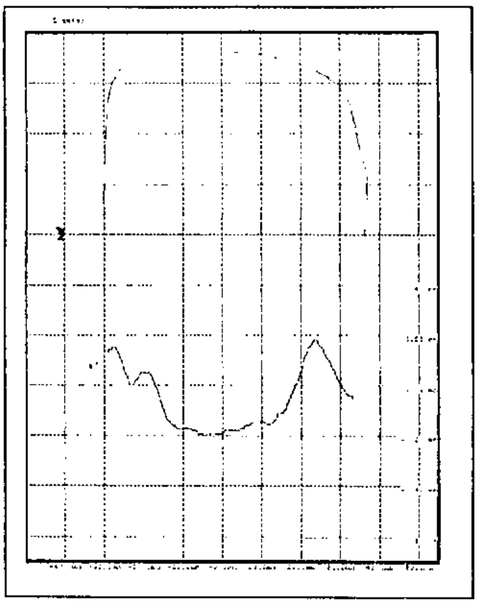


Fig. 21

Location : Km –211, M-896
Side: Right rail

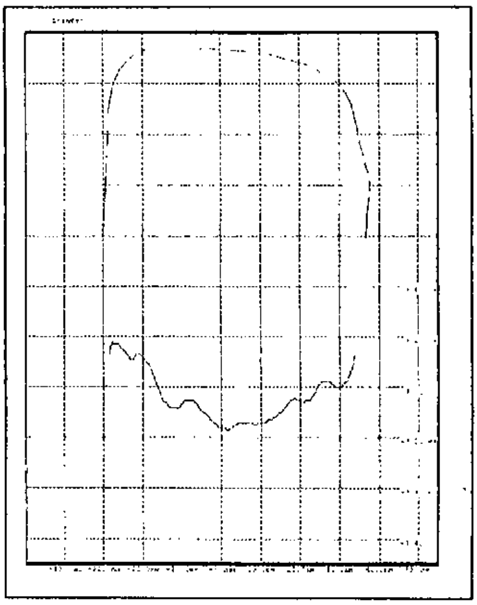


Fig. 22

Location : Km –211, M-904
Side: Left rail

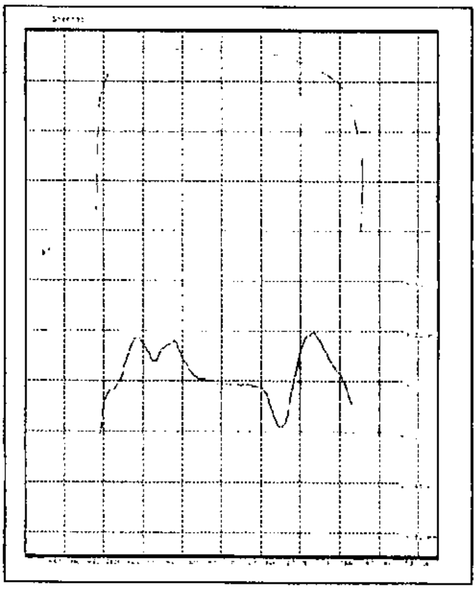


Fig. 23

Location : Km –211, M-912
Side: Right rail

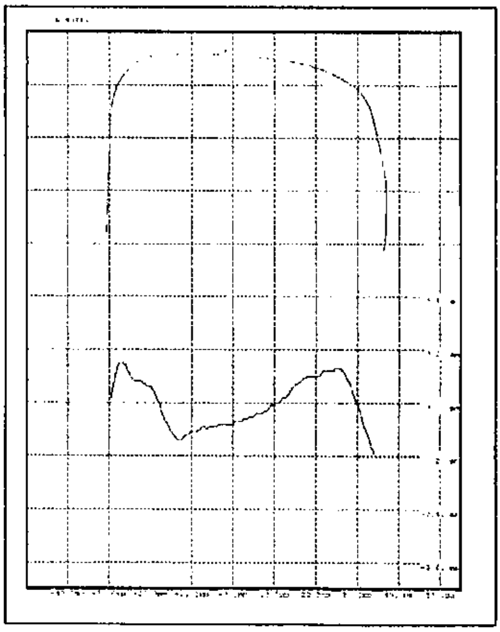


Fig. 24

Location : Km –211, M-920
Side: Left rail

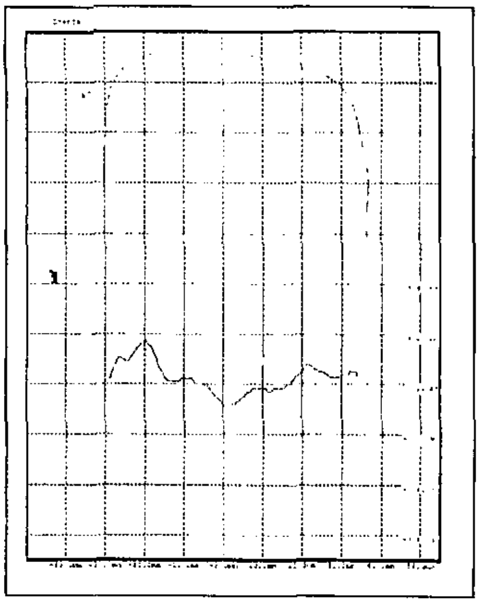


Fig. 25

Location : Km –211, M-924
Side: Right rail

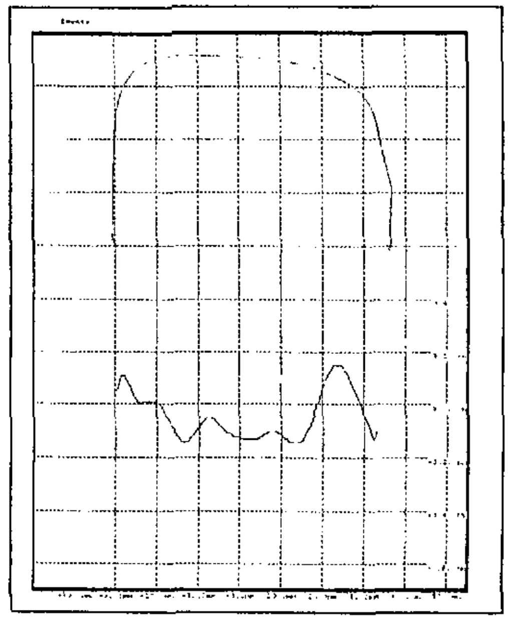


Fig. 26

Location : Km –211, M-928
Side: Left rail

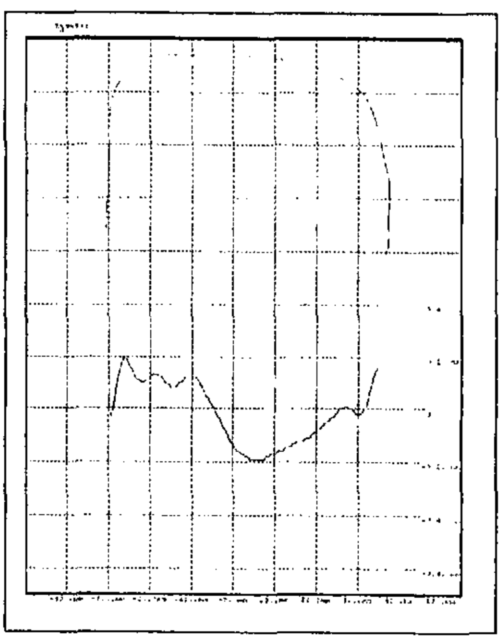


Fig. 27

Location : Km –211, M-936
Side: Left rail

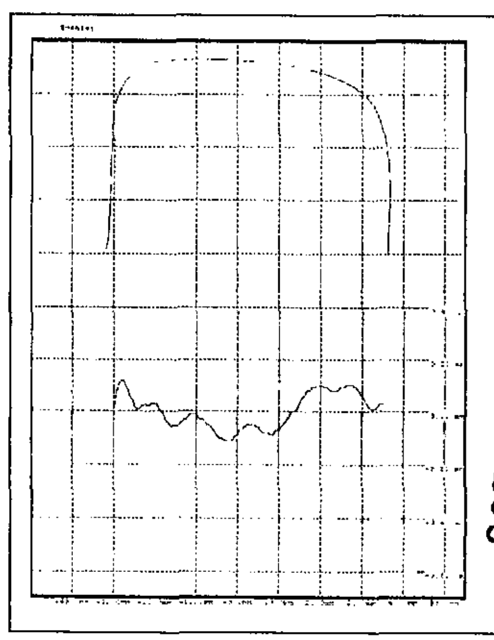


Fig. 28

06500

Location : Km –211, M-944
Side: Left rail

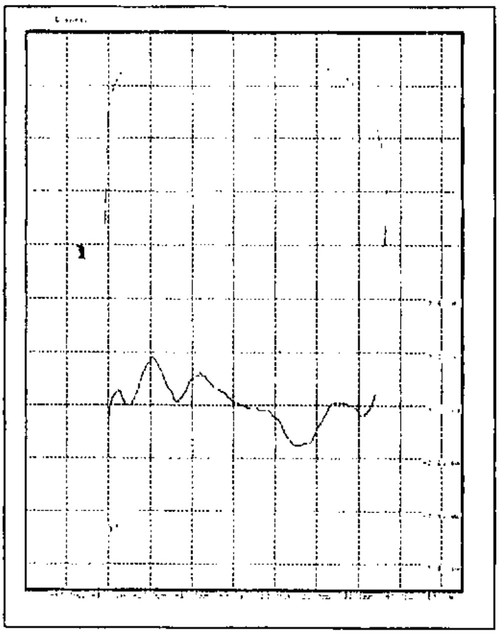


Fig. 29

Location : Km –211, M-960
Side: Left rail

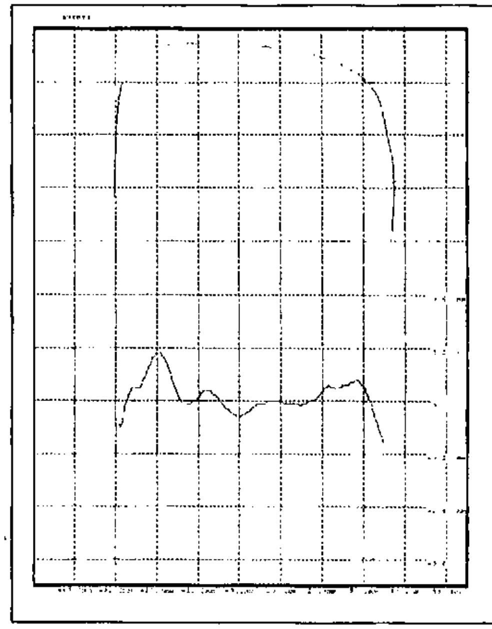


Fig. 30

Location : Km –211, M-972
Side: Left rail

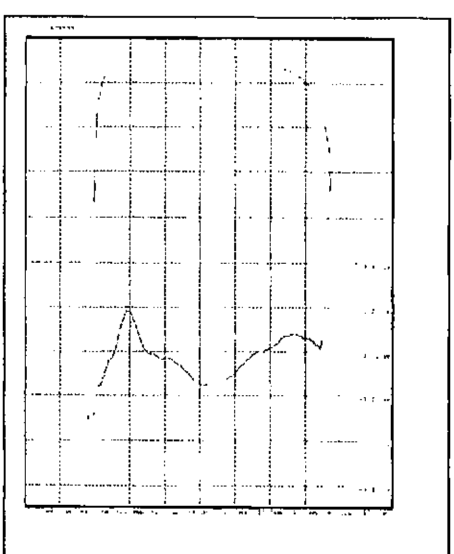


Fig. 31

Location : Km –211, M-976
Side: Left rail

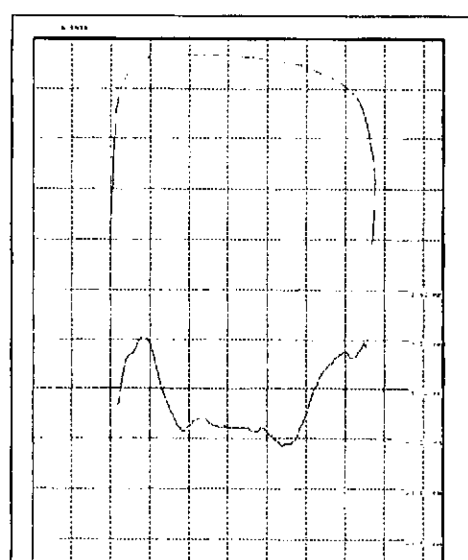


Fig.32

06501

- The contour accuracy plots and tabulated results indicate that the contour accuracy of the RPMS system is with in the limits laid down in the specifications. Limited number of EZ-2 measured profiles could be accurately overlaid over the RPMS measured profiles due to the various reasons described below:

Track Location Alignment

For the meaningful comparison of the rail profile measurements done by RPMS and EZ-2 the location of two measurements should be at or very near to the same location. To achieve this ground transponder was fixed at the start of the curve. RPMS captures the profiles @ 60 profile per minute and accurately captured profile between the previous and current sampling point is stored in the data file. Thus many of the profiles may be more than one meter distance apart from the EZ-2 measured profile and can not be used for comparison.

Rail profile measurement technique of the EZ-2 and RPMS system

Both the RPMS and the EZ-2 use lasers and digital cameras to capture the rail profile, and the basic measurement technique is same for both systems. However, there are some differences, which contribute to non alignment of two over laid profiles measured by EZ-2 & RPMS. The EZ-2 uses three lasers and cameras to capture a very high resolution profile of the railhead in three segments: the under head web-to-head fillet, the gauge side and the top of the railhead, and the field side of the railhead. The EZ-2 scans the railhead at steadily increasing laser illumination intensities over a period of approximately 30 seconds (10 seconds per profile section) to capture a very precise railhead profile. During the profile scanning process, the EZ-2 must remain stationary over the railhead.

The RPMS uses two lasers and cameras to capture a profile of the entire rail in four segments: gauge side web, gauge side railhead, field side web, and field side railhead. Each profile image is captured during the camera's 4 millisecond exposure, and is subsequently processed by the system to extract the rail profile. During the exposure time, the rail moves in the field of view of the cameras, as the RPMS moves along the track. This has the effect of "smearing" the image; essentially, the rail profile captured by the RPMS represents a sort of optical average of the rail profile over the small section of rail traversed during the exposure time. At the highest track measurement speed of 130 KMPH, the distance traveled during the exposure time is approximately 144 mm (less than 6 inches).

Absolute Reference Techniques

To make the rail wear measurements, each system has to reference the measured rail profile to an unworn reference rail profile.

The EZ-2 references its measured rail profile to the unworn reference rail profile using the under head web-to-railhead fillet. An automatic alignment algorithm in the EZ-2 software examines this area of the measured rail profile and compares it with the same area of the unworn reference rail profile, and rotates and translates the measured rail profile in such a way as to minimize the difference between the measured rail profile and the unworn reference rail profile in this area.

An example of an automatically aligned EZ-2 profile is shown below.

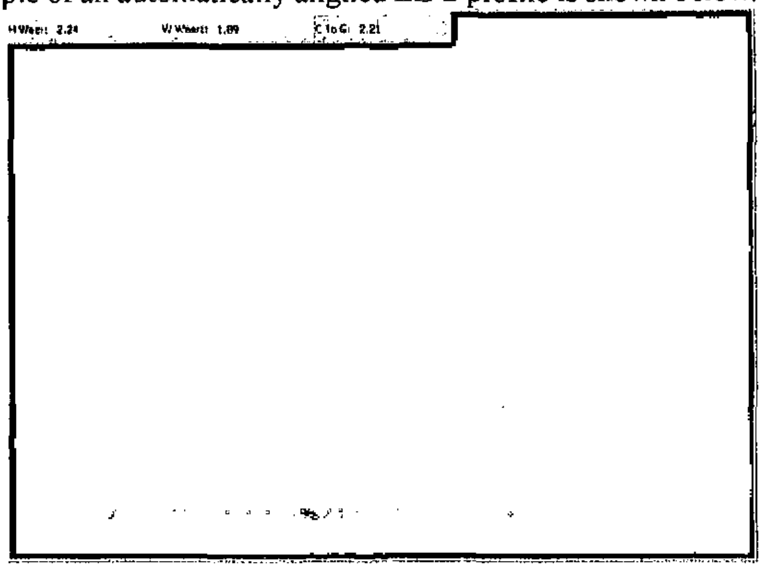
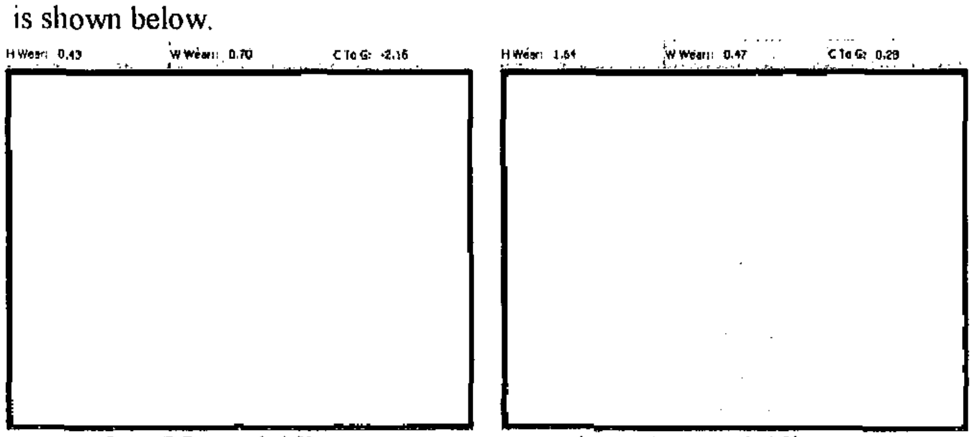


Fig. 33 Automatically Aligned EZ-2 Profile

Depending on the characteristics of the measured rail profile, the automatic alignment with the unworn reference overlay may or may not be correct. In cases where the automatic alignment is clearly incorrect, standard practice is to use the EZ-2 manual alignment feature to adjust the alignment of the measured rail profile to the unworn reference rail profile. An example of this is shown below.



Before Manual Alignment **After Manual Alignment**

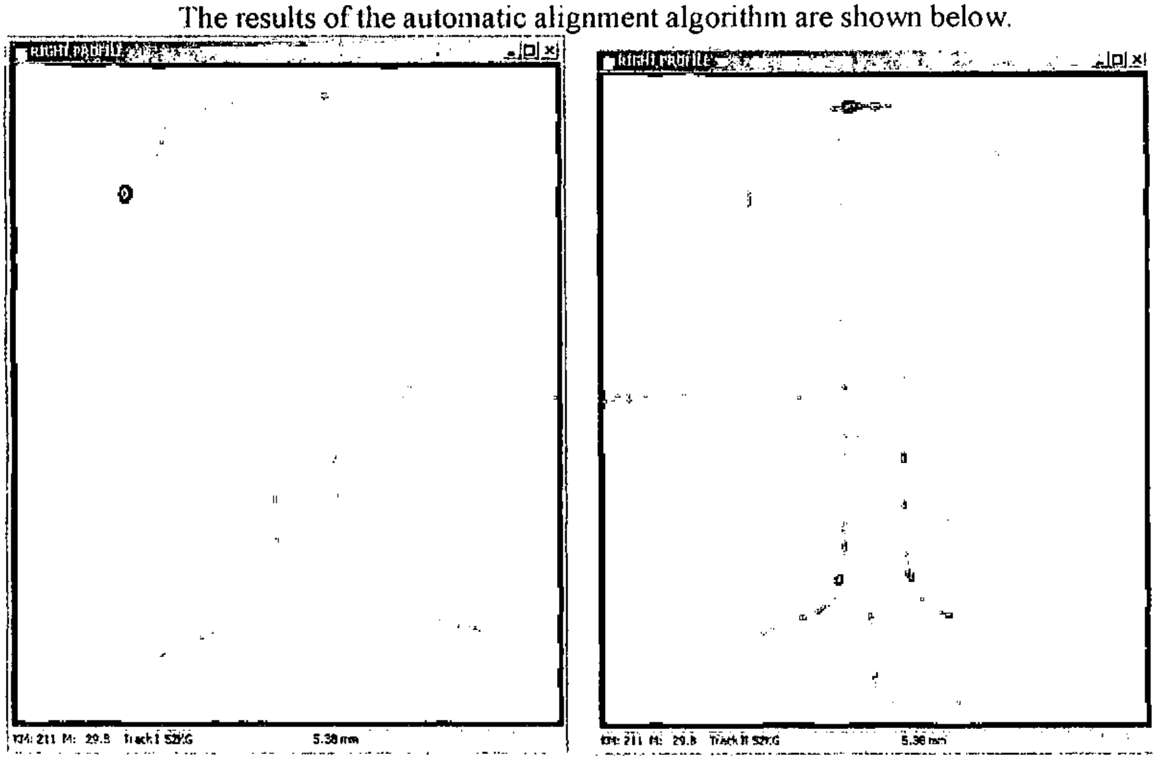
Fig. 34. EZ-2 Manual Profile Alignment Example

Rail wear measurements obtained from EZ-2 measured rail profile absolutely depend on the quality of the alignment between the measured rail profile and the unworn reference rail profile. For manually aligned profiles, the quality of the alignment is a subjective determination of the user – different users will probably obtain slightly different alignments of the same measured rail profile.

The RPMS references its measured rail profile to the unworn reference rail profile using the centerline of the web, and the web-to-foot fillet. The RPMS automatic alignment algorithm operates as follows:

- Determine the centerline of the web, and the angle of the centerline relative the centerline of the unworn reference rail profile.
- Rotate the measured rail profile so that the measured rail centerline is parallel to the unworn reference rail centerline. Translate the measured rail profile such that the measured rail profile centerline lies at the X axis origin.
- For each web-to-foot fillet, find the center of the web-to-foot fillet curve relative to the measured rail profile, and determine the quality of fit between the measured rail profile fillet and the unworn reference rail fillet.
- Using the measured rail profile fillet with the best quality of fit, translate the measured rail profile such that the Y coordinate of the measured rail profile fillet center of curvature is the same as the corresponding unworn reference rail profile fillet center of curvature Y coordinate.

The results of the automatic alignment algorithm are shown below.



Before Alignment **After Alignment**

Fig.35. RPMS Automatic Rail Alignment

The quality of the alignment depends on two factors: accurate determination of the rail centerline, and the quality of the measured rail profile web-to-foot fillet. Both of these are adversely affected by the accumulation of surface contaminants, such as dirt and heavy rust, which can lead to incorrect results.

06504

Incorrect web centerline can result in a slight rotation and/or horizontal translation of the measured rail profile relative to the unworn reference rail profile. When this problem occurs, it can be seen clearly in the aligned profile display. Although RPMS offers no facility for correcting web centerlines, it is possible to determine the effect of the error on the rail wear measurements, and to adjust the measurements by the application of an appropriate offset.

Incorrect web-to-foot fillet alignment also results in a slight vertical translation of the measured rail profile relative to the unworn reference rail profile. When this problem occurs, it can be seen clearly in the aligned profile display. Although RPMS offers no facility for correcting fillet alignment, it is possible to determine the effect of the error on the rail wear measurements, and to adjust the measurements by the application of an appropriate offset.

Thus the different absolute reference techniques for the two systems also contribute to non alignment of two overlaid profiles measured by EZ-2 and RPMS.

6.2 Rail Wear Measurements Accuracy

Rail wear is derived from the overlaid Rail Profile contours measured form the EZ-2 and RPMS system. If the difference at all contour points is with in the wear limit prescribed in the technical specification the lateral wear calculated at gauge point and vertical wear calculated at the top of head will also be with in the prescribed limits. The plots of contour accuracy clearly shows that the difference in the contours at vertical and lateral wear measurement points measured by the two system is well with in the prescribed wear limit. Further the table of contour accuracy shows that the maximum difference on the entire head contours is also less than the prescribed limit of wear. This confirms that system meets the wear accuracy limits mentioned in the technical specifications.

6.3 Measurements Repeatability

The analysis tool described in para 5.3 has been used for verification of repeatability of results in terms of provisions of technical specifications. The analysis technique for determining measurements repeatability for each selected speed combination is as follows:

- For each of the two RPMS profile data files selected for a specific speed combination, WinPALS Profile Editor was used to select a single kilometer randomly from the track stretch corresponding to the specified speed combination. The criteria used to select this kilometer were:
  - Proximity to a ground target location synchronization event
  - Presence of easily identifiable track features, such as a rail type change or a unique rail wear characteristic.
- The location misalignment between the two RPMS profile data files was determined as closely as possible by comparing the locations of the easily identifiable track features.

- WinPALS Profile Editor was used to edit measured rail profiles for the selected kilometer in both RPMS profile data files. The editing function was limited to deleting measured rail profiles that were not correctly aligned with the reference rail section because of interference from high ballast and other obstructions and to correct the reference rail section.
- WinPALS Profile Editor was used to export the vertical wear, lateral wear, and track gauge values along with locations from both RPMS profile data files to the spreadsheet-compatible CSV format
- A new Microsoft Excel spreadsheet was created by combining the exported rail wear and track gauge measurements from both RPMS profile data files for both left and right rails. The records from one file were manually aligned record by record with the records from the other file by shifting the records relative to each other such that the absolute value of the difference in distance between the track locations of corresponding records be less than or equal to 1.0 meter. Records from either set that did not have a matching record in the other set were discarded.
- For the remaining records, for each rail wear parameter and track gauge, the difference between the two RPMS measurements was calculated in the spreadsheet at each track location for both left and right rail
- The records in the spreadsheet were separated into blocks at 200 meter boundaries and the mean and standard deviation of the differences for each block were computed in the spreadsheet. The same process was repeated for the selected kilometer of Chunar-Churk, Kanpur-Fathepur (UP & DN lines) sections for various same and different speed combinations and the resultes are tabulated below in table 11 to 31.

Table -11

CHUNAR-CHURK KM 181 TO 180 (SPEED 50/50 Kmph)
DATE OF RUNS 21-11-03 AND 23-11-03 Data files - N3251245 & N3271453

BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	1.14	0.02	0.41	-0.03	0.56	-0.28	0.19	-0.11	0.27	0.11
2	1.08	0.15	0.56	0.09	0.60	-0.17	0.25	-0.02	0.28	0.00
3	0.94	0.23	0.32	-0.06	0.37	-0.23	0.22	-0.21	0.27	0.10
4	0.99	0.16	0.29	-0.13	0.43	-0.17	0.24	-0.18	0.23	0.05
5	0.98	0.19	0.43	0.11	0.49	-0.13	0.25	-0.08	0.48	0.09

Table –12

CHUNAR-CHURK KM 165 TO 164 (SPEED 50/50 Kmph) DATE OF RUNS 21-11-03 AND 23-11-03 Data files - N3251245 & N3271453										
BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	0.94	-0.04	0.57	0.01	0.36	0.07	0.19	-0.07	0.56	0.06
2	0.71	0.03	0.37	0.15	0.36	-0.13	0.22	-0.12	0.23	-0.03
3	0.97	0.03	0.46	0.10	0.51	-0.12	0.20	-0.08	0.41	0.06
4	1.10	0.07	0.71	0.22	0.40	-0.14	0.32	-0.13	0.49	0.06
5	1.49	0.09	0.31	0.30	0.60	-0.08	0.22	-0.08	0.96	0.24

Table-13

CHUNAR-CHURK KM 223 TO 222 (SPEED 35/35 Kmph) DATE OF RUNS 21-11-03 AND 23-11-03 Data files - N3251245 & N3271453										
BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	0.94	-0.13	0.24	0.06	0.23	0.27	0.27	0.25	0.18	-0.13
2	1.44	-0.28	0.32	0.09	0.38	0.19	0.19	0.22	0.31	-0.08
3	1.40	-0.43	0.37	0.01	0.47	0.33	0.25	0.18	0.51	-0.07
4	1.02	0.07	0.28	-0.01	0.42	0.19	0.26	0.23	0.23	-0.22
5	1.40	-0.26	0.26	-0.02	0.47	0.14	0.20	0.20	0.27	-0.11
6	1.07	-0.05	0.19	-0.03	0.29	0.20	0.24	0.20	0.29	-0.16

Table-14

CHUNAR-CHURK KM 237 TO 236 (SPEED 20/20 Kmph) DATE OF RUNS 21-11-03 AND 23-11-03 Data files - N3251245 & N3271453										
BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	1.30	0.03	0.46	-0.29	0.33	0.07	0.30	0.17	0.57	0.09
2	1.41	0.10	0.49	-0.23	0.36	0.16	0.32	0.11	0.54	-0.13
3	1.44	0.15	0.49	-0.17	0.39	0.15	0.41	0.10	0.61	-0.16
4	1.45	0.15	0.43	-0.29	0.49	-0.03	0.41	0.10	0.61	-0.16
5	1.42	-0.12	0.50	-0.09	0.41	0.13	0.38	0.17	0.33	-0.09

Table-15

CHUNAR-CHURK KM 211 TO 210 (SPEED 35/50 Kmph) DATE OF RUNS 21-11-03 AND 23-11-03 Data Files N3251245 & N3271453										
BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	1.26	-0.06	0.33	-0.13	0.43	-0.22	0.33	-0.15	0.14	-0.08
2	0.74	-0.03	0.33	-0.11	0.48	-0.25	0.26	-0.11	0.30	0.01
3	0.32	-0.01	0.20	0.02	0.31	-0.30	0.18	-0.21	0.39	-0.01
4	0.76	0.09	0.32	0.06	0.29	-0.20	0.28	-0.28	0.20	-0.01
5	0.24	0.09	0.19	0.09	0.27	-0.20	0.21	-0.25	0.18	0.05

Table -16

CHURK-CHUNAR KM 174 TO 175 (SPEED 20/50 Kmph) DATE OF RUNS 21-11-03 AND 23-11-03 Data Files - N3251559 & N3271730										
BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	0.781	0.282	0.33	0.15	0.29	-0.05	0.31	0.02	0.26	-0.04
2	0.453	0.260	0.20	0.06	0.37	-0.07	0.26	0.02	0.51	0.00
3	0.329	0.182	0.28	0.16	0.22	-0.04	0.22	0.12	0.16	0.00
4	0.952	0.218	0.34	-0.02	0.26	-0.11	0.21	0.11	0.19	-0.02
5	1.479	0.027	0.26	0.03	0.29	-0.04	0.38	0.07	0.33	0.00

Table –17

CHURK-CHUNAR KM 236 TO 237 (SPEED 35/20 Kmph) DATE OF RUNS 21-11-03 AND 23-11-03 Data Files - N3251559 & N3271730										
BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	1.479	-0.264	0.44	-0.10	0.35	-0.03	0.30	0.02	0.36	-0.02
2	1.406	-0.238	0.48	-0.16	0.20	-0.13	0.34	-0.07	0.45	-0.02
3	1.294	0.032	0.35	-0.03	0.30	-0.10	0.21	-0.09	0.49	0.07
4	0.841	0.195	0.37	0.03	0.18	-0.03	0.24	-0.08	0.29	0.03
5	0.944	0.207	0.22	-0.27	0.29	-0.09	0.13	-0.15	0.31	-0.06

Table -18

CHURK-CHUNAR KM 182 TO 183 (SPEED 35/50 Kmph) DATE OF RUNS 21-11-03 AND 23-11-03 Data Files - N3251559 & N3271730										
BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	0.341	0.240	0.21	0.01	0.35	0.19	0.23	-0.11	0.93	-0.08
2	0.711	0.283	0.30	-0.02	0.49	0.08	0.29	-0.03	0.23	0.09
3	0.951	0.039	0.32	-0.01	0.62	0.21	0.32	-0.18	0.24	0.08
4	1.434	0.092	0.56	0.00	1.02	0.22	0.42	-0.05	0.52	0.07
5	1.463	-0.154	0.52	-0.28	0.77	0.16	0.34	-0.26	0.20	0.04

Table.-19

CNB-FTP KM 1004 TO 1003 (SPEED 50/50 Kmph) DATE OF RUNS 22-02-04 AND 23-02-04 Data Files - O0530758 & O0540758										
BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	0.37	-0.03	0.22	-0.05	0.16	-0.13	0.25	-0.05	0.24	0.05
2	0.45	-0.04	0.26	0.04	0.16	-0.25	0.26	-0.03	0.25	-0.05
3	1.05	-0.25	0.33	-0.10	0.37	-0.18	0.25	-0.08	0.28	-0.04
4	0.48	-0.13	0.38	-0.11	0.13	-0.12	0.16	0.00	0.18	0.06
5	0.37	-0.12	0.15	-0.06	0.22	-0.15	0.15	-0.04	0.20	0.00

Table -20

CNB-FTP KM 997 TO 996 (SPEED 75/75 Kmph) DATE OF RUNS 22-02-04 AND 23-02-04 Data Files - O0530758 & O0540758										
BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	1.00	-0.13	0.27	-0.06	0.17	-0.03	0.26	0.01	0.19	0.02
2	0.47	-0.03	0.24	-0.08	0.16	-0.06	0.26	-0.04	0.18	-0.04
3	0.54	-0.14	0.27	-0.06	0.25	-0.11	0.29	-0.04	0.30	0.01
4	0.51	-0.04	0.36	0.00	0.18	-0.10	0.25	-0.05	0.24	0.06
5	0.43	-0.05	0.18	-0.07	0.33	-0.06	0.25	-0.08	0.21	-0.05

Table –21

CNB-FTP KM 976 TO 975 (SPEED 75/100 Kmph)
DATE OF RUNS 22-02-04 AND 23-02-04 Data Files - O0530758 & O0540758

BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	1.37	-0.42	0.64	0.01	0.51	-0.06	0.36	0.02	0.69	-0.02
2	1.32	-0.07	0.58	-0.03	0.39	-0.01	0.41	-0.07	0.78	0.06
3	1.41	-0.18	0.64	0.11	0.48	-0.05	0.44	-0.02	0.67	0.06
4	1.06	0.09	0.63	-0.21	0.37	-0.06	0.36	-0.13	0.46	0.01
5	1.31	-0.14	0.71	-0.10	0.27	-0.10	0.27	-0.05	0.49	0.01

Table-22

CNB-FTP KM 957 TO 956 (SPEED 100/120 Kmph)
DATE OF RUNS 22-02-04 AND 23-02-04 Data Files – O0530 758 & O0540758

BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	0.83	-0.11	0.61	-0.03	0.35	-0.10	0.26	-0.04	0.50	-0.09
2	0.86	-0.16	0.47	-0.04	0.33	-0.05	0.26	-0.03	0.52	0.01
3	0.41	-0.05	0.52	0.05	0.18	-0.09	0.26	0.01	0.36	0.01
4	0.41	-0.21	0.65	0.03	0.23	-0.06	0.23	-0.06	0.34	-0.02
5	0.28	-0.11	0.61	0.03	0.29	-0.10	0.23	-0.06	0.27	-0.05

Table-23

CNB-FTP KM 1004 TO 1003 (SPEED 50/50 Kmph)
DATE OF RUNS 31-10-03 AND 02-11-03 Data Files – N3041449 & N3040754

BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	0.59	0.07	0.18	0.09	0.23	0.05	0.43	-0.13	0.21	0.18
2	0.51	0.04	0.54	-0.20	0.21	0.02	0.31	0.03	0.21	0.16
3	0.57	0.02	0.57	-0.23	0.27	0.04	0.59	-0.13	0.32	0.15
4	0.56	0.13	0.47	0.17	0.31	0.11	0.35	-0.11	0.26	0.10
5	0.52	0.12	0.40	0.23	0.33	0.10	0.32	0.11	0.18	0.14

Table-24

CNB-FTP KM 990 TO 989 (SPEED 130/130 Kmph) DATE OF RUNS 31-10-03 AND 02-11-03 Data Files – N3040754 & N3060938										
BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	1.32	0.22	0.31	0.19	0.59	0.14	0.29	0.04	0.43	-0.04
2	0.83	-0.45	0.26	0.17	0.38	0.22	0.43	0.30	0.33	0.05
3	0.68	-0.44	0.34	0.16	0.49	0.27	0.42	0.15	1.01	0.04
4	1.15	-0.37	0.35	0.11	0.45	0.24	0.41	0.30	0.74	0.08
5	1.02	-0.31	0.41	0.29	0.32	0.28	0.42	-0.04	0.39	0.02

Table-25

CNB-FTP KM 967 TO 966 (SPEED 50/50 Kmph) DATE OF RUNS 31-10-03 AND 02-11-03 Data Files – N3040754 & N3060938										
BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	0.54	-0.39	0.81	0.10	0.13	0.23	0.28	0.07	0.70	0.05
2	0.60	-0.39	0.81	0.08	0.18	0.16	0.29	0.05	1.13	-0.08
3	0.73	-0.39	0.54	0.27	0.24	0.14	0.27	0.02	0.99	-0.14
4	0.49	-0.40	0.48	0.24	0.19	0.18	0.31	-0.01	0.83	-0.02
5	0.99	-0.38	0.63	0.27	0.17	0.19	0.34	-0.01	0.55	0.00

Table -26

FTP-CNB KM 983 TO 984 (SPEED 50/50 Kmph) DATE OF RUNS 22-02-04 AND 23-02-04 Data Files - O0531357 & O0541154										
BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	1.08	0.11	0.36	0.03	0.64	-0.05	0.53	-0.20	0.79	0.04
2	1.14	0.15	0.36	0.03	0.73	0.05	0.35	-0.14	0.71	-0.01
3	1.18	0.05	0.47	0.08	0.52	-0.02	0.34	0.06	0.74	-0.05
4	1.22	0.09	0.57	-0.09	0.88	-0.03	0.54	-0.14	0.40	0.02
5	1.35	0.09	0.78	0.15	0.75	0.08	0.34	-0.04	0.74	-0.01

Table –27

FTP-CNB KM 972 TO 973 (SPEED 35/35 Kmph)

DATE OF RUNS 22-02-04 AND 23-02-04 Data Files - O0531357 & O0541154

BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	0.39	-0.25	0.64	0.09	0.25	0.00	0.34	0.02	0.33	0.13
2	0.37	-0.24	0.62	0.00	0.90	0.00	0.40	0.03	0.36	0.03
3	0.47	-0.31	0.56	0.01	0.93	0.05	0.36	-0.10	0.31	0.01
4	0.35	-0.20	0.59	-0.02	1.00	-0.02	0.27	-0.05	0.34	-0.02
5	0.22	-0.14	0.80	-0.16	0.92	0.05	0.28	-0.02	0.18	0.02

Table –28

FTP-CNB KM 956 TO 957 (SPEED 75/20 Kmph)

DATE OF RUNS 22-02-04 AND 23-02-04 Data Files - O0531357 & O0541154

BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	0.94	-0.25	0.71	0.04	0.64	-0.09	0.30	-0.11	0.72	-0.07
2	0.64	-0.20	0.68	0.04	0.40	-0.06	0.34	-0.17	0.45	0.01
3	0.23	-0.19	0.80	0.04	0.27	-0.04	0.44	0.02	0.23	0.02
4	0.48	-0.26	0.86	0.12	0.98	-0.30	0.35	-0.12	0.77	-0.02
5	0.87	-0.37	0.74	0.03	0.85	-0.08	0.48	-0.04	0.90	0.01

Table –29

FTP-CNB KM 953 TO 954 (SPEED 50/75 Kmph)

DATE OF RUNS 22-02-04 AND 23-02-04 Data Files - O0531357 & O0541154

BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	0.83	-0.21	0.56	0.00	0.90	-0.04	0.30	0.00	0.55	0.04
2	0.43	-0.18	0.47	0.07	0.26	-0.07	0.30	-0.13	0.39	-0.01
3	0.27	-0.19	0.31	-0.01	0.29	0.00	0.22	0.00	0.17	0.01
4	0.93	-0.20	0.55	0.02	0.87	-0.06	0.27	-0.02	0.93	-0.02
5	1.28	-0.26	0.60	0.07	1.00	-0.09	0.31	0.00	0.79	-0.02

06512

Table -30

FTP-CNB KM 959 TO 960 (SPEED 20/75 Kmph)										
DATE OF RUNS 22-02-04 AND 23-02-04 Data Files - O0531357 & O0541154										
BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	1.01	-0.20	0.37	-0.01	0.43	0.01	0.32	-0.04	0.89	0.02
2	0.36	-0.23	0.62	0.04	0.30	-0.02	0.25	-0.05	0.18	0.00
3	0.67	-0.25	0.64	0.11	0.51	-0.04	0.27	-0.08	0.31	-0.03
4	1.38	-0.15	0.59	0.05	0.56	-0.02	0.43	-0.07	0.60	-0.03
5	0.52	-0.20	0.55	0.09	0.54	-0.07	0.26	-0.08	0.29	-0.02

Table -31

FTP-CNB KM 963 TO 964 (SPEED 35/75 Kmph) DATE OF RUNS 22-02-04 AND 23-02-04 Data Files - O0541154 & O0531357										
BLOCK NO.	GAUGE		LEFT RAIL				RIGHT RAIL			
			Vert-Wear		Lat-wear		Vert-Wear		Lat-wear	
	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG
1	1.39	-0.19	0.34	0.02	0.96	-0.12	0.28	-0.05	0.69	-0.05
2	1.43	-0.13	0.37	0.01	0.98	0.00	0.32	-0.04	0.73	0.03
3	1.17	-0.07	0.41	-0.04	0.59	0.01	0.45	-0.11	0.77	0.09
4	0.76	-0.12	0.27	0.03	0.42	-0.04	0.37	-0.04	0.70	0.04
5	0.50	-0.09	0.25	0.04	0.38	-0.02	0.26	-0.07	0.39	-0.04

- The result of the analysis tabulated in the table given above were compared against the specified measurement repeatability limits and it was observed that the analysed results fall well within the limits specified in the technical specifications.

7.0 CONCLUSION

From the analysis it is concluded that the system confirms to the accuracy and repeatability requirements mentioned in the technical specifications of the contract and commissioning certificate may be issued subject to fulfillment of other contractual requirements. 06513

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