Non-Destructive Testing and Inspection of Rails at JSPL – Ensuring Safety and Reliability

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Abstract
Safety and reliability of a railway system primarily depends on the soundness of the critical components and their freedom from defects. With increased rail traffic carrying heavier loads at higher speeds, a quicker more efficient way of inspecting rails at manufacturing stage is now mandatory. At Jindal Steel and Power Ltd., India, a highly reliable and effective flaw detection method has been, therefore installed, for prevention against failures may originate from these defects. This paper describes the special features of on-line laser-based straightness measurement system, on-line eddy current testing and on-line ultrasonic testing system in details. A laser-based system inspects the straightness of rails using a unique mathematical algorithm, which computes the true horizontal and vertical longitudinal shape of the rail surface out from the measurement data. Typical defects, which are originating during manufacturing in rail is detected by On-line eddy current testing system with special probes and mechanics. On-line ultrasonic testing system detects internal imperfections, such as laminar defects, inclusion, tension cracks, etc. in the railhead, web and base.

Keywords : Rails, Ultrasonic testing, eddy current testing, manufacturing, Safety, Reliability.

1. Introduction
For over 150 years, railway infrastructure has continued to be one of the important backbones for passenger as well as freight transportation around the globe. Increases in train speed, pay load, reliability, and safety are the major thrust areas for railways, which necessitates stringent mechanical and functional properties such as wear and deformation resistance, fatigue life from the railway steel. These ever increasing performance targets have been successfully met by the manufacturers of rail steel [1]. The rapid evolution of transport systems and the need for more and more sophisticated materials have required the creation of safe and efficient products suitable for high speed use.

In this context of high technological demands, Jindal Steel and Power Ltd. (JSPL), India – three million tonnes integrated steel company with an annual turnover of over US $2.9 billion – is a part of about US $ 15 billion diversified O. P. Jindal Group, is one of the leading figures on an international level with a significant presence in sectors like steel, mining, power generation and infrastructure. Giving impetus to the significant rail sector, JSPL has pioneered the manufacturing of 121 metre long track rails in the Indian sub-continent. The world’s longest track rails are a testimony of JSPL’s manufacturing capabilities where continuous strategy technological innovation is a practice rather than an exception. What differentiates JSPL’s 121 m long rails from the others is that there is a drastic reduction in the welded joints, providing enhanced safety, cost reduction and travel comfort. JSPL products are subjected to stringent quality norms and can, therefore, match all international standards. JSPL is dedicated to transform the dream of operating high-speed trains into a reality. The continuous modernisation of JSPL rails production line has ensured that JSPL remains at the forefront of rail innovation, performance and value, always working in close partnership with their customers. By investing in research and technology and thus being able to use leading edge plants to deliver high quality and safe products, JSPL fulfils the steadily increasing requirements of the railway market. It does so in terms of standards, technique and quality.
and it facilitates cost reduction in direct Railway products and services intervention on the railway network.

2. Manufacturing process at JSPL

At JSPL, care and attention is paid from the selection of raw materials to the delivery of the finished product. An overview of the process at JSPL is depicted as Fig. 1.

2.1 Steelmaking

Steel production in JSPL Works is based on integrated cycle. JSPL is having their own coal and iron ore mines which is a pre requisite in today’s competitive market. Besides this JSPL also having a full fledged pelletisation and sinter plant for effective use of the iron ore fines generated from mines. JSPL is having two Blast furnaces with a daily production capacity of 5,200 tonnes as the major metallic input material for the steel melting shop. Besides this, JSPL also crowned as the largest producer of the sponge iron in world with a capacity of producing 1.37 million tonne per annum. Sponge iron is also being used as the major input raw material for the steel melting shops (SMS). Steel with low levels of sulphur and other residual elements is the essential feedstock for heavy-duty rail steel. The hot metal with very low residuals is transferred to the SMS in torpedo cars with an average capacity of 300 tons. Hot metal and sponge iron are used as the main feed stock for electric arc furnaces (EAF) of steel melting shops. The primary refining operation of steel is being carried out in EAF followed by secondary refining and degassing of the steel through RH degasser. The entire steelmaking operation is precisely controlled using advanced computer software and intelligent process control systems. The desired steel chemistry is achieved by the careful addition of alloying elements to the molten steel in secondary refining units. The stringent hydrogen requirement of 1.6 ppm in liquid steel for rail steel is an indicator of clean steel. This is being achieved through RH degasser with process optimization at every stage of steel making process. The state of the art Combination caster is equipped with electro-magnetic
stirring (EMS) facility, auto mould level controller and dynamic spray control system, which facilitate high quality of cast blooms with minimal segregation and free from surface defect. JSPL integrated steelmaking plant produces feedstock for a diverse range of steel products. The plant produces rectangular section blooms of 285x390 mm designed for rolling of rails with high quality metallurgical characteristics. Quality of blooms are assured by close monitoring of process at every stage of steel making and casting. The internal soundness and surface quality of blooms are ensured through strict inspection norms before rolling.

2.2 Rolling

The recently reconstructed Rail and Universal Beam Mill (RUBM) at the JSPL (Figure 2) is based on the most modern technologies available in the field of rolling. It is possible to produce rails as finished products up to 121 metres long with very strict and uniform tolerances that satisfy all international standards and technical specifications. This guarantees maximum production flexibility and the satisfaction of the highest customer quality standards.

Figure 2. Overview of the process route at RUBM, JSPL for rail manufacturing including NDT testing and inspection (enclosed with a box).

Blooms are re-heated in dual fired walking beam type furnace. Consistent product dimensions and surface quality are assured by tight control of rolling temperatures. High-pressure descaling before and during rolling ensures a high standard of surface finish. Rolling begins in an accurately controlled roughing stand (Breakdown mill) followed by intermediate stands and then through a multi-stand universal tandem mill. Four rollers are positioned on all four sides of the steel feedstock, rather than the conventional pair of rollers in a two-high rolling stand—delivering exceptional dimensional accuracy and strengthening of the rail head. A universal rougher and universal finisher roll configuration has been shown in Figure 3.
The reduction ratio of continuous cast blooms through a series of rolling processes is higher than the ratio required by the standards. In this way the internal structure and homogeneity of the finished product are improved, as well as the mechanical characteristics (rails heavier than 50 kg/m are produced from a square 320 mm bloom). The use of high definition video cameras and of laser sources during the rolling phase allows the constant measuring and monitoring process parameters. Sophisticated automation using hot metal detector (HMD) sensors, pyrometers and other instruments like tachometer, load cells, etc. keep track of all the process data such as product temperature, rolling load, rolling speed, efficiency of equipment and ID-tracking. Furthermore, a 6-camera laser profile measurement device constantly monitors the dimensional quality of the rails during rolling.

During the final rolling pass, rails are relief-branded with the rail profile, steel grade, manufacturer name, rail section and year of manufacturing. After leaving the finishing stand, the rails are hot stamped with a unique identification mark – for permanent traceability.

3. Non-Destructive Testing and Inspection

The challenge for rail manufacturers is to provide consistency in long, straight and flat rails, combined with dimensional accuracy and steel integrity to deliver defect-free, trouble-free and decades-long service life. The increasing requirement for products with fewer surface defects derives from a variety of different reasons such as: safety in use, operational reliability, extension of life cycle, travel comfort, track geometry, increased speed, increased axial loads, increased railway traffic.

For the above mentioned reasons and for the many requirements of product quality control, the rails produced in the JSPL, are analysed in an integrated “system” of non-destructive testing and inspection (see the Figure 4).

An array of technically advanced testing and inspection equipment ensures that every rail meets customer specifications and is free from any internal or surface imperfections that could impede performance or reduce service life.

Beside our internal quality assurance mechanism, JSPL also ensure that a comprehensive third-party inspection is conducted before the final dispatch of the products to the customers.
The NDT system has been supplied and commissioned in 2003 by M/s Knorr Technik GmbH, Austria. This system consists of five main units as given in the Table 1.

### Table 1. Details of different units of NDT system at JSPL

<table>
<thead>
<tr>
<th>Unit</th>
<th>Make</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brushing Machine</td>
<td>Knorr Technik, Austria</td>
</tr>
<tr>
<td>Flatness Measurement Gauge</td>
<td>Joanneum Research, Austria</td>
</tr>
<tr>
<td>Eddy Current Testing Device</td>
<td>Institute of Dr. Forester, Germany</td>
</tr>
<tr>
<td>Ultrasonic Testing Device</td>
<td>Krautkramer, Germany</td>
</tr>
<tr>
<td>Paint Marking Unit</td>
<td>Krautzberger, Germany</td>
</tr>
</tbody>
</table>

#### 3.1 Brushing machine

The main function of brushing machine is to descale the rail. The rails are online descaled by 4 pot brushes. The running surface, base and head of the rails is treated by an electrically driven pot brush. The movement of the brush towards the rails surface is performed pneumatically, the speed and pressure are continuously adjustable.

#### 3.2 Flatness Measurement Gauge

This is an optoelectronic flatness measurement instrument. It is designated to perform contactless. It does fully automated measurement of rails in nearly real time.

The measurement is performed by the use of five measurement heads. After the system is configured to the actual rail type, it is ready for measurement. Acquisition of the measurement data is started by a light barrier and triggered by two incremental encoders. The measurement heads consist of a laser diode, which generates a light-section on the rails head. This section is monitored by a camera (part of the head), which passes the read information to the evaluation unit. Each of the five measurement heads delivers data for head shape and position of the rail. From this data, the relevant measurement points (e.g. center of rail head, etc.) are calculated which guarantees correct measurement results even for lateral movements of the rails.

A unique mathematical algorithm computes the true horizontal and vertical longitudinal shape of the rail surface out from the measurement data and gives guarantee of a correct calculation of the rail surface up to the ends.

#### 3.3 Eddy Current Testing Device
The Eddy Current test allows the continuous and automatic control of the head and of the feet of the rail at a speed of 1m/sec. The method is based on the uses the magnetic permeability of steel. All the probes transmit information concerning the number of detected defects, their distance from the ends and their position within the section (Figure 5).

Figure 5. A photograph of the eddy current testing device (left) and a schematic diagram of the probes arrangement (right).

The base of the rails to be tested is inspected by a four-channel rotating probe system, and the lower edges with two LMD segment coils. The base of the rail is also tested by two flat-coils for transverse defects. All probes are installed on pneumatically activated KT-Probe Moving Units, which are designed to follow the horizontal and vertical deviations in straightness of the rails to be tested. The distance between the probes and the surface as well as the test-track of the rail passing is kept constant by using adjustable guiding rollers, which are installed besides the probes. Rail head is tested by four rotating probes (two for side head and two for top head) to detect longitudinal defects. Head is also tested by 2 LMD coils to detect transverse flaws.

The rail passing the area of testing is supported by a non-driven supporting roller and a pair of vertical centering rollers. The frame structure will be designed to take-up also two probes moving devices for segment coils for testing the upper edge of the base of the rail (these two units including coils are not subject of this contract).

3.3.1 Testing Electronics
- Eddy Current test equipment CIRCOGRAPH DS for testing of longitudinal orientated flaws on the outer surface of rails base.
- CIRCOSCAN H rotating head, stationary (4x 5.0 mm probes), with diameter 250 mm
- Two LMD-flat coils, for the base of the rail 60 kg/m
- Two LMD-edge coils, for base (corner), special design for Rail type 60.

3.3.2 Calibration
The calibration of the eddy current system is carried out with a sample rail with a length of 12 metres in which defects of known position and dimensions are artificially produced.

3.3.3 Flaw Sensitivity and noise level
Flaw sensitivity depends on surface conditions and the noise level. The noise level is affected by the surface conditions, the magnetic inhomogeneity and guidance and conveying of the test material.

The signal to noise ratio shall be 3:1 for automatic testing. In areas with burrs, over- and under fills, scabs, spicules and similar the flaw sensitivity may not be reliably reproducible or may be restricted to a larger or smaller extent. Pseudo signals is depending on type of protruding parts cannot be excluded (Figure 6).

![Figure 6](image)

Figure 6. A typical display of the Eddy current system indication unsound rail (left image) and a sound rail (top right image)

### 3.4 Ultrasonic Testing Device

The Ultrasonic examination is carried out in a continuous and automatic mode soon after the Eddy current test. The system is equipped with 18+1 probe arrangement of the “squirter” type (with water jet) without direct contact with the rail that allow to check the whole section of the rail for its entire length. All the technical data of the ultrasonic testing machine (Figure 7) for the rails at JSPL has been tabulated in Table 2.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Scanning Tracks</td>
<td>18 flaw evaluation cycles plus 1 stamp recognition</td>
</tr>
<tr>
<td>Test System</td>
<td>NSP-VIS</td>
</tr>
<tr>
<td>Untested Ends</td>
<td>Smaller than 150 mm for testing rail at a test speed 2 m/s. It is required to keep the allowable deformation tolerances and a burr smaller than 3 mm. For burrs exceeding this limit, a longer untested end has to be adjusted.</td>
</tr>
<tr>
<td>Probe Frequency</td>
<td>5 MHz when using TR probes, 4 MHz when using angle beam probes, 2 MHz for stamp recognition</td>
</tr>
<tr>
<td>Gates</td>
<td>3 flaw gates and 1 back-wall gate per test cycle, individually adjustable</td>
</tr>
<tr>
<td>Gate Tracking</td>
<td>Automatic control of the gate width of gate &quot;C&quot;</td>
</tr>
</tbody>
</table>
Steel Vignol rails are to be tested for internal imperfections, such as laminar defects, inclusions as well as tension cracks in the rail head, web and base.

The rail head is to be tested from the rail head side and from the tread of the rail. The rail base area is tested from underneath of the rail and from the top of the base of the rail. The rail web is tested from the side. Detected flaws are to be marked true-to-location in the longitudinal direction of the rail. All flaws are subjected to an evaluation by an adjustable threshold value. A sorting signal is provided for each rail.

3.4.1 Test Technique
The test employs the pulse reflection method with TR probes which are coupled to the test piece by means of a water gap. For testing the head of the rail two probes are positioned from each side. Moreover, the rail head is tested by three probes beaming from the tread of the rail. The rail web is tested by six TR probes located in two housings. The rail base is tested by two angle beam probes from underneath and by a TR probe beaming in the center axis of the rail,
as well as by two angle beam probes from the top of the base of the rail. To avoid disturbances in the range of the rail stamps affecting the web test, a special angle probe is detecting the stamp area. The test machine is equipped with an evaluation system operating in multiplex mode for rail head, base and web testing. Within the system the probes are controlled in sequence according to a fixed pulse program.

The flaw results are marked true-to-length with paint on the rail surface at the end of the testing line. The test results are recorded after the test and can be printed.

3.4.3 Calibration

*Test Flaw for Rail Head*: 4 x 2 mm flat-bottomed holes. One side drilled hole. 2 mm dia.

*Test Flaw for Rail Web*: 6 x 2 mm flat-bottomed hole. The test flaws lie in the middle of the receiver crystal of the probe. The bottom faces of the flat-bottomed holes lie in the vertical center line of the rail web perpendicularly to the sound beam of the probe.

*Stamp Recognition*: The stamp recognition requires a reflector corresponding to a vertical groove min. 0.75 mm depth, 2 mm width and 25 mm height. (less than 0.75 mm depth do not influence the testing).

*Base with Normal Beaming Probes*: 1 x side drilled hole, 2 mm dia.

*Base with Angle Beam Probes*: Notch of 2 mm depth, 3 mm width and 10 mm length. The test flaw is located in the transfer radius between web and base of the rail in a position of 45°.

3.4.4 Evaluation Method

According to type, the rails are tested with a pre-adjusted threshold determining the flaw size. Separate evaluation thresholds are assigned to the probes according to their physical characteristic, for head testing, web testing and base testing.

Following each test pulse the US hardware transmits a signal to the evaluation computer if the pre-selected flaw threshold is exceeded or remained below. These results are statistically checked before they are accepted as actual indications. Electrical interference from outside are thus effectively suppressed. Flaws which are larger than the preselected limit are marked true-to-location separately for the rail head, base and web areas. A coupling failure is acoustically signaled by a horn. Typical UT reports for an accepted and a rejected (conditional accepted) rail has been shown in Figure 8.
According to the test results, the evaluation computer classifies the rails as Accept / Reject / Untested. According to this sorting result a sorting is provided per rail the rail evaluated as "Reject" is paint-marked when leaving the machine.

All these preset values can be changed by the operator via the terminal. Moreover, the test parameters of the NSP-VIS can be recalled and represented via the monitor for checking purposes or printed out in the form of a list.

3.5 Paint marking unit

The defects detected by the Eddy current and ultrasonic control systems are processed in real time and signalled to the technicians both on monitors and on inspection reports. The defect detected is highlighted on the rail by means of an automatic paint spray.

This system consists of four channel (4-spray gun) making unit which is installed at the end of testing line. Each kind of defect (straightness, surface defect, interior defects, etc.) is marked in different colour. Additionally one colour is frozen to mark the rail as tested on end. The defects are marked (for ultrasonically detected defects only) in axial direction in their position. Figure depicts a photograph of the paint marking unit and a schematic diagram for colour guns arrangement.

3.6 Central Processing System

All results of the installed testing systems are transmitted to a central processing unit. This allows control and evaluation of data for quality assurance, product liability and for increasing production. The data output via screen-windows allows to combine and to visualize the generated results in many different ways.

CPS provides efficient tools for data acquisition and analysis of product and process information to report efficiency and quality of production. It includes easy-to-use functions for supervision and evaluation of the real-time and historical data.

Trend and analysis windows support the evaluation of real-time and historical data. The selected real-rime and historical product and process values as well as the results of data analysis can be shown in trend curves. The user defines the required select, sort and analysis criteria as well as the relevant data areas (date, time, name, measurement data, values etc.). The selected data and the resultant outputs from the analysis functions are ported to predefined tabular formats.

The signals from the main mill computer is available at a located process point and the CPS computer is be capable of taking required signals through tags.

4. Experience with use of automated testing system

Operational safety requires rails testing and monitoring during operation. Above mentioned automated system is being successfully used for couple of years for rail inspection in JSPL.
During that time, several serious defects, which could endanger operational fluency and safety, had been detected using this system and repaired or removed. Due to the accurate recording of indications positions, their finding and reevaluating by hand flaw detectors with contact probes and following repairs are much faster and reliable, which contributes to provision of operational fluency and safety on the track.

Conclusions

- Continuous investment in plant, technology, research and development, combined with the unrivalled metallurgical knowledge and track design expertise, ensure that JSPL Steel delivers the high-performance rail demanded by today’s rail operators.
- Process innovations and product development initiatives at JSPL are focused unwaveringly on delivering the high-performance rails required to support advances in train technology, as well as meeting the longer in-service product life and reduced maintenance costs demanded by rail network operators.
- The rolling mills at JSPL use the latest process technology, computer modelling, computer-controlled heating and cooling, and novel roll-pass design to produce exceptional quality rails.
- The advanced testing and finishing systems that complete the JSPL rail manufacturing process ensure that all rail products meet the high standards required for all rail applications – from high-speed and heavy-haul networks to urban and industrial railways.