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WILMA–Managing continuously welded rails the elegant way

A new intelligent rail stress monitoring system has been developed by Transnet Freight Rail (Technology Management). The system uses strain gauges to measure longitudinal rail forces as well as rail temperature. The system is used to manage CWR, but can also predict rail breaks and buckling, functions as a maintenance tool and can do predictions based on historical measurements and weather forecasts, thereby reducing train delays and derailments. The system comprises a valuable contribution to the high-tech world of heavy haul

THE ADVANTAGES of continuously welded rails (CWR) over conventional non-welded rails are well known and the substantial reduction in total rail life-cycle cost is certainly its most attractive benefit. However, CWR has to be managed in such a way that the potential track failures that accompany it do not relegate the safety of the track.

Statistics of the coal export line in South Africa revealed that some 50–60 % of all train delays are stress related. Track stress is responsible or contributes to the occurrence of rail breaks, track buckling, block joint failures, certain track geometry deviations and component failures in turnouts.

This article describes an intelligent system that has been developed to manage CWR on a heavy-haul line and which has already been implemented on a track section of 200 km.

THE WILMA SYSTEM

WILMA is the acronym for Wayside Intelligent Longstress Management and is the name that has been chosen for the Transnet Freight Rail system to monitor and manage CWR. The system was developed with the following aims:

- To develop a wayside system that will monitor longitudinal rail stress in real time to enable better management of CWR
- To warn against possible track buckling and rail breaks
- To be a tool for planning and executing CWR maintenance
- To prevent derailments

CWR MANAGEMENT

Theory

Tracks with continuously welded rails have to be managed for the occurrence of residual rail stresses and bending stresses caused by train loads as well as temperature stresses which are responsible for rail breaks and lateral stability problems such as track buckling.

The rail force (N) due to a temperature increase is calculated with the following formula (from Esveld[2]):

$$N = EA\alpha\Delta T$$

In which:

E = Young's modulus for the rail, (N/mm^2)

A = total cross-sectional area of the rail (mm^2)

α = coefficient of expansion (/°C)

$\Delta T = T_{neutral} - T_{actual}$ (°C)

The neutral (or stress free) rail temperature ($T_{neutral}$) is the temperature at which the track is neither in compression nor tension. The rail force will then be approximately 0. If the rail temperature rises above $T_{neutral}$, the track will be in compression while a decrease in rail temperature below $T_{neutral}$ will result in overall tension forces in the track.

The neutral temperature of the track can be measured by a number of methods.

Measurement methods

CWR measurements are usually carried out on Transnet Freight Rail lines by using one of the following methods:

- Cutting the rail combined with hand measurements
- The lifting frame method
- Strain gauge-based measurements

Cutting the rail combined with measuring the rail movement is accurate if measurements are done correctly, but it requires track occupation, the welding of a closure rail and it weakens the track structure.

The *lifting frame* method is also a time-consuming procedure which requires track occupation to loosen and fasten the rail fasteners and is only useable in tension conditions. The lifting frame used by Transnet Freight Rail has however been upgraded to enhance accuracy and performance.

Strain gauging is extremely accurate and usable in any stress condition. It however requires a high skill level for initial installation and is expensive.

A critical evaluation of the methods mentioned above has been carried out to develop the WILMA system that will be described below.

SYSTEM DESCRIPTION

The system is made up of the following components:

- Encapsulated strain gauges
- HBM MGC-Plus amplifier system
- HBM CP22 communication card
- RS232-GPRS communication interface unit
- Siemens Class10 GPRS Modem

All the strain and temperature gauges are encapsulated for ease of application and re-usage and are manufactured by trained Transnet Freight Rail technicians adhering to strict quality control measures.

Applied instrumentation is covered by cover plates to protect against vandalism and damage due to on-track maintenance procedures. The cover plates are manufactured from mild steel and are galvanised to prevent rust. Two matching cover plates are bolted onto each other from both sides of the rail to protect the rail bound instrumentation (see figure 1).

The measurement hardware is

1 Cover plates to protect instrumentation against vandalism and on-track maintenance

2 Hardware for CWR measurement

3 System layout and concrete enclosure

installed in a steel cabinet placed in a concrete enclosure next to the track, which is either a concrete cubicle or a relay room.

Figure 2 shows the hardware chosen to amplify the rail stress and temperature measurements and which remotely sends the data to a central file server. A standalone amplifier with a plug-in display unit is utilised and can be expanded to more than 20 measurement channels.

The communications processor has RS232 connectivity and is remotely configurable via SMS. It connects to a server via GPRS to send data. Approved lightning protection forms part of the hardware that is housed in the steel cabinet.

Figure 3 shows the concrete cubicle with a safe door that is placed next to

4 File server with monitoring software

5 Geographical Coalline map with measurement stations

6 Lifting frame for the calibration of the system

the track to house the measurement hardware. Strain gauge cables are separately threaded through steel reinforced hydraulic hosing which runs along the sleepers and then vertically down into the track formation where it is buried. From outside the track formation the cables are conveyed to the concrete cubicle in galvanised steel pipes.

The last component of the system is the file server with monitoring software and large screen display (see figure 4). Data is received by the server and stored in a database from where the monitoring software can access the real time measurements. (The software is described in detail later in the article.)

The next section deals with the systematic approach that was followed to select the measurement sites.

SITE SELECTION

Sites were selected by interaction with track engineers and maintenance managers, by a desktop study of the call-out history of the line (including ultrasonic measuring car (UMC) faults and incidents that caused train delays) and by studying the general topography and layout of the line.

Sites were selected on a priority basis and the following list gives an indication of how sites were prioritised:

- Tunnel entrances and exits
- Track buckling and rail break areas
- Turnouts before and after deviations
- Long bridges
- Inside long tunnels
- Additional sites to bring about an even distribution of measurement sites along the track section

Approximately 100 measurement sites were chosen along the 200 km track section from Vryheid to Richards Bay. Sites were chosen in such a way that the spacing between the stations was not more than approximately 3 km.

CALIBRATION

A lifting frame developed by Van Tonder[3] is used to calibrate the strain gauges that measure the longitudinal rail forces at each of the measurement stations. An example of such a frame is shown in figure 6.

The lifting frame works on the basic principle that if a piece of string is tensioned on both ends and then displaced at the centre of the string, a specific force is needed to displace it. The higher the tension in the string, the higher the force needed to displace it at its centre. The frame is pre-calibrated for each type of rail it will be used on.

The track fastenings are loosened over a distance of 20 m after which the lifting frame is used to lift the rail a distance of 70 mm. The force required to do this is then measured accurately and used to calculate the stress-free (neutral) rail temperature. The theory used implies that the frame can only be used when the rail is in tension.

This section completes the description, installation and calibration of the WILMA system. The next section describes the software that was developed to receive and interpret the data in an intelligent manner.

SOFTWARE

Infrastructure condition monitoring software (iCOMS) was developed for the following purposes:

- To configure a group of measuring stations in such a way that they will function as a system with specific infrastructure condition monitoring characteristics
- To receive data sent from GPRS modems at remote measuring stations and to store the different measurements in a database
- To visually present the data in a simple format
- To carry out elementary mathematical functions to the data
- To do trending and forecasting analyses on the accumulated data
- To present the results of the analyses in such a way that intelligent maintenance decisions can be deduced from it
- To apply specific maintenance and alarm conditions to the data and results
- To generate user-defined reports on infrastructure condition

The software comprises four components, namely a database module, calculation and modelling (trending and forecasting) modules, a graphical presentation module with maintenance and alarm conditions (the viewer) and a report generation module.

The database module stores all data received from the remote measuring stations in a structured way. A unique station ID is used to link the data to pre-configured measurement stations on the database. Currently, datasets are received from the 100 measuring stations at an interval of three minutes.

The main purpose of the calculation module is to convert the strain measurements to forces and to calculate the stress free temperature ($T_{neutral}$) at each specific measuring station. When longitudinal strain in the rail is measured, $T_{neutral}$ can be calculated with the following equation:[4]

$$T_{neutral} = T_{actual} + \frac{\varepsilon}{\alpha}$$

In which:

ε = the measured longitudinal strain in the rail

The rail crown and side wear, which affect the cross-sectional area of the rail, are also taken into account when longitudinal rail forces are calculated.

The *forecasting module* estimates the expected rail temperature from forecasted air temperatures. In South Africa, the following relationship has been determined after extensive monitoring:[4]

$$Y = 1{,}64X - 8$$

In which:

Y = rail temperature (°C)

X = air temperature (°C)

As these equations do not make provision for factors such as wind and shadow, the following relationships were established for the maximum and minimum expected rail temperatures:[3]

$$Y_{max} = X_{max} + 23$$

$$Y_{min} = X_{min} + 23$$

Using the above equations, it is possible to predict which of the measurement stations might trigger the specified alarm limits in the near future.

The viewer can be installed on any PC connected to the Transnet Freight Rail intranet to view real time as well as historic data of the different measuring stations.

The *report generation module* generates three types of monthly reports from the accumulated data and the condition of the system. These reports include the following information:

Condition report

- Stations online
- Stations in normal/safe condition
- Stations requiring maintenance
- Stations with alarm conditions

It is envisaged that, once fully operational, the system will be widely used within Transnet Freight Rail by infrastructure managers, maintenance managers, the Coalline Operations Centre, production managers and finally by technology management for further research

Maintenance report

- Monthly maintenance advisor
- Suggested sections for de-stressing
- Suggested temperature ranges
- Guidelines for de-stressing

Historical data report

- Monthly longitudinal rail force and temperature plots
- Monthly maintenance requirements
- Monthly alarm conditions
- Overall system health

SYSTEM INTEGRATION

Figure 7 gives a schematic representation of the WILMA system. A number of measurement devices are configured to form a measurement station. The measurement stations are then grouped together to form the WILMA system. The iCOMS software controls the WILMA system (amongst other systems) and sends reports to Transnet Freight Rail's I²CMS (Integrated Infrastructure Condition Monitoring System – under development). The I²CMS is the twin brother of Transnet Freight Rail's ITCMS (Integrated Train Condition Monitoring System) which monitors all condition aspects related to the rolling stock on the line.

Maintenance warnings and alarms are sent to the relevant depot for action while stop train alarms are sent to the CTC (Centralised Train Control) and SOC (Satellite Operations Centre).

It is envisaged that, once fully operational, the system will be widely used within Transnet Freight Rail by infrastructure managers, maintenance managers, the Coalline Operations Centre, production managers and finally by technology management for further research.

DATA PRESENTATION

Longitudinal rail force (left and right), as well as rail temperature, is measured at each measuring station. The stress, free (neutral) rail temperature is then calculated from the field measurements.

Unique upper and lower alarm limits are defined for each measurement station for the measured forces as well as the temperature measurements. These are based on experience, the local track conditions of the site as well as the desired temperature ranges for the climatic region in which the site is situated. The desired temperature range within a specific geographical area is the rail temperature range at which forces in CWR should not cause buckling in extreme heat or a rail break during extreme cold weather.

Figure 8 shows an example of the longitudinal rail force and the rail and stress free rail temperature data respectively as presented in the iCOMS detail display.

The upper and lower alarm limits are configured in such a way that the following maintenance actions and train alarms are generated:

- The enforcement of a speed restriction to lower the risk of a derailment due to rail buckling or a rail break
- The stopping of all trains over the specific track section
- De-stressing of the track when conditions of extreme heat or cold demand this
- Offloading of ballast to increase the lateral and longitudinal stability of the track

ADVANTAGES AND DISADVANTAGES

Advantages

The advantages of the system can be summarised as follows:

- Intelligent maintenance at the right time and place
- Continuous CWR rail force measurements
- Assist in derailment prevention
- Possible rail break and rail buckling detection
- Maintenance management and cost savings
- Continuous research possibilities due to system expandability
- Advantages to other maintenance actions (for instance tamping and placing of closures)
- Better understanding of CWR and track behaviour
- Supporting data in the unfortunate event of a derailment
- Improved track safety, reliability and availability

Disadvantages

The disadvantages of the system can be summarised by the following points:

- The system requires a high level of maintenance. A dedicated team has to maintain the supply of electricity, the rail bound instrumentation and the data acquisition system at each of the numerous measuring stations
- Specialised removal and replacement of instrumentation for certain maintenance operations, that is, ballast screening and rail replacement
- Like most other wayside equipment, the system is prone to damage by lightning

INFLUENCE ON TRACK MAINTENANCE

Although the system was designed to have a minimal impact on track maintenance, special attention is required depending on the type of maintenance that is carried out in close proximity to the measuring stations.

On-track maintenance

In the cases of tamping and rail grinding, these actions can proceed with caution. Extreme caution is required when ballast profiling is carried out. The rail mounted strain gauges and cabling have to be removed when ballast screening is carried out. The system is unaffected by the passage of geometry cars, the UMC (ultrasonic measuring car), grease cars and other high-rail vehicles.

Off-track maintenance

All manual off-track maintenance actions close to the measuring stations need to be supervised with extreme caution. In the cases of rail and sleeper replacement as well as the placing of closure rails, prior notification is required for the temporary removal of the measuring devices and cables.

CONCLUSIONS

The WILMA system has been developed to manage CWR on a heavy haul line in South Africa. Rail force and temperature are measured at a substantial number of measuring stations on a 200 km track section. These measurements are remotely sent to a central file server running software that stores the data, calculates useful track parameters from it, applies alarm limits to the calculated parameters and carries out trending and forecasting routines. The system is a useful and elegant tool in the world of high tech heavy haul and contributes to the safe and efficient operation of a railway line.

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This article was adapted from a paper presented by the same authors at a conference of the International Heavy Haul Association (IHHA) in Kiruna, Sweden, and entitled 'An intelligent condition monitoring system for the management of continuously welded rails

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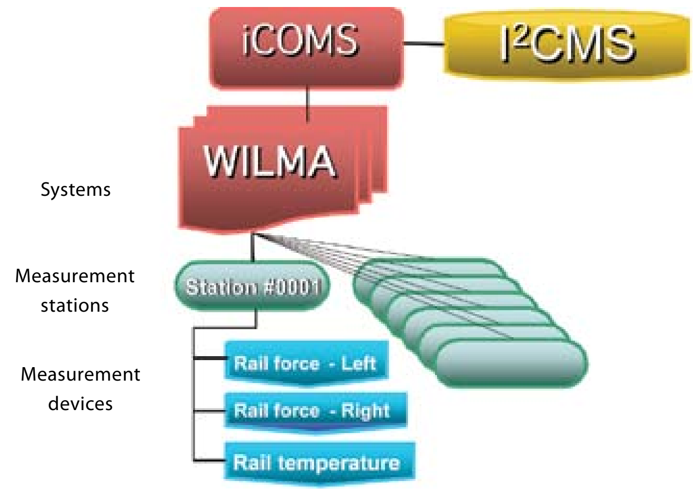

7 Schematic representation of the WILMA system

8 Example of longitudinal rail force data

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Source:
http://www.saice.org.za/downloads/monthly_publications/2008/CivilMay08/#/0