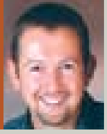

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# Track deflection measurement

A new optical track deflection measurement device was developed for Transnet Freight Rail (Track Technology) to be used for track research carried out in both field and laboratory investigations. The functioning and calibration of the system are demonstrated and examples are given of measurements taken on the South African rail network. The article discusses the advantages of the system, further developments and the implications for design and analysis

## INTRODUCTION

Repeated (cyclic) loading on a track structure causes resilient (recoverable) and permanent (non-recoverable) deformation (Brown 1996). In the case of elastic track formation design, the permanent deformation is relatively small compared with the resilient deformation component. Track engineers measure resilient and permanent deformation as these parameters enable them to derive track stiffness values, as well as to calculate the expected design life based on cumulative plastic strain (Li & Selig 1998). The measurement, or prediction, of track deflection therefore forms the basis of track performance and design. Over the years, various instruments have been developed and used for the measurement of track deflection. This article covers existing instrumentation, as well as the development of a novel technique for the measurement of resilient track deflection.

## BACKGROUND

Deflection measurement devices are commonly used in field and laboratory testing. A mechanical device was developed to measure the deflection of a sleeper relative to the ballast bed. This device, shown in Figure 1, enabled engineers to measure the size of a "blind slack", the hidden gap between the sleeper and the ballast that only becomes apparent when a seating load acts on the sleeper. Although crude in its design, this instrument provided reliable and immediate measurement of relative sleeper movements.

The instrument that is probably most widely used for measuring track deflection is the LVDT (Linear Variable Differential Transducer). Figure 2 demonstrates the use of LVDTs for measuring absolute horizontal rail and sleeper deflections. The

# using particle image velocimetry

LVDTs are attached to anchor rods embedded into the track formation below the ballast.

The challenge with accurate field deflection measurement is to find a non-movable reference in the area of the track structure, which usually extends a couple of metres in all directions from the track centreline. To overcome this difficulty, absolute measurements are often purposefully avoided by concentrating on relative measurements only, e.g. horizontal rail movement relative to the sleeper. Nevertheless, LVDTs are extremely useful and accurate in measuring dynamic track displacements.

Certainly the most advanced and sophisticated instrumentation in the field of substructure deflection measurement is the Multi-Depth Deflectometer (MDD) developed by the CSIR for use in the Heavy Vehicle Simulator (HVS). This technology uses specially manufactured LVDTs to measure the deflection of individual formation layers and enables the calculation of resilient and permanent strains at different depths. MDDs are anchored in rock at depths of 3 to 5 m and measurements can be referenced to the rock or relative to the MDD directly below the one under consideration. Figure 3 shows a cross-section model

1 Mechanical device for measuring sleeper deflection (Design: S van der Linde)
2 LVDTs for measuring horizontal rail and sleeper deflections
3 Multi-Depth Deflectometers (MDDs) installed into the track formation
4 The Transnet Freight Rail PIV system
5 PIV target attached to the rail (Centurion Station)

with MDDs installed at different depths in the track formation.

MDDs deliver extremely accurate formation deflection measurements, but their use is limited due to the complexity of the instrumentation and its installation. Total track occupation is also required for the installation of the equipment. This involves the drilling of a vertical hole, lining of the hole with a flexible tube and the placement of the MDD modules at the different layer interfaces. MDDs can be used to measure the permanent deformation of track (and pavement) formation layers over extended periods. A research site on the Coal Line (Bloubank – between Vryheid and Ulundi) has 54 MDDs in nine holes, of which 53 are still functioning after 5 years of permanent installation in the track formation. The value of these measurements supersedes that of most other deflection measurement devices.


## PARTICLE IMAGE VELOCIMETRY (PIV)

Particle Image Velocimetry (PIV) is a measuring technique that originated in the field of experimental fluid mechanics (Adrian 1991). It has recently been used to measure soil deformation in soil laboratory testing (White et al 2003 and White & Bolton 2004), as well as for measuring landfill settlement (White et al 2003). This research is based on work by Bowness et al (2006) who used PIV to monitor railway track displacements by employing a webcam attached to a telescope, which was used to monitor a target attached to the side of the rail. The telescope magnifies the video images that are captured by the webcam and these are analysed by a computer to calculate horizontal and vertical displacement.

A similar system was developed for Transnet Freight Rail (Track Technology) to be used for a variety of track research projects in the laboratory and in the field. This system uses a high-specification video recording camera to capture video images of the movement of a target fixed to the track component under consideration. Software is then used to calculate the horizontal and vertical displacements of the target in real time or afterwards in the office. The system is shown in Figure 4.

The target comprises a black square on a white background, 2 cm x 2 cm, but it could be any size depending on the accuracy and resolution required (see Figure 5). For track deflection applications, a white area with a width of 2 cm around the black target is adequate for the optical recognition software to calculate the horizontal and vertical displacements successfully.

The resolution of the system is approximately 0,001 mm and the accuracy is between 0,010 mm (in the laboratory) and 0,050 mm (in the field). The optical measurement is sensitive to changes in the light exposure and the target should preferably be in the shade during measurement to prevent shadows from falling onto it. Special covers have subsequently been developed to ensure that the target is in the shade at all times. Trial measurements during the night using a spotlight to illuminate the target proved to be even more successful than the daytime measurements.

Figure 6 shows an example of a PIV measurement where multiple targets were placed on a Tubular Track module. The four targets were placed in the rail, in the concrete beam, in the grout filling layer and in the formation respectively. With only one camera, multiple passages of the same train at the same speed have to be measured to obtain results of the type presented in Figure 7.

The graph in Figure 7 enables the calculation of the deflection of an elastic pad placed between the rail and the concrete beam, as well as the size of the gap between the concrete beam and the grout layer. These measurements are of considerable importance as they can be used for numerical analysis and design improvements to the track structure.

A test was carried out to determine the common error of a false reference, as shown in Figure 8. The LVDT attached to an anchor in the ground, ± 1,0 m from the rail, measured approximately 60% of the absolute vertical deflection of the concrete beam due to the vertical movement of the reference point itself. The PIV method as shown in the figure also enabled the determination of the pad's deflection (i.e. the compression of the continuous elastic pad between the rail and the concrete beam).

## FURTHER DEVELOPMENT OF THE SYSTEM

The software was modified to allow two modes of data capturing:

***Mode 1:*** Real-time deflection measurements allowing the user to observe the measured deflections in the horizontal and vertical directions as they are measured.

***Mode 2:*** Post-processing of the recorded video file which allows more flexibility and does not require the use of a computer in the field.

More sophisticated video cameras can be used to enhance the quality of the measurements by doing the following:

- Increase the resolution and accuracy of the measurements by increasing the optical zoom capability of the camera.
- Increase the number of measurement points by increasing the number of frames per second (currently limited to 25) or the frequency at which the video images are captured. LVDT and MDD data are normally captured at a frequency of 1 000 Hz or higher.

A method was also developed whereby two targets (one attached to the rail and another attached to a steel rod anchored in the top formation layer) can be captured by the same video camera. Post-processing of the data then allows the user to obtain two sets of measurements, synchronised and related to exactly the same loading case. Figure 9 shows the rail and formation deflection set-up, as well as

*Particle Image Velocimetry (PIV) is a measuring technique that originated in the field of experimental fluid mechanics. It has recently been used to measure soil deformation in soil laboratory testing, as well as for measuring landfill settlement. Figure 6 shows an example of a PIV measurement where multiple targets were placed on a Tubular Track module*

the strain gauges attached to the rail for measuring the accompanying wheel loads.

Improvements to the tripod on which the video camera is mounted also reduced the ground-borne vibrations originating from a passing train.

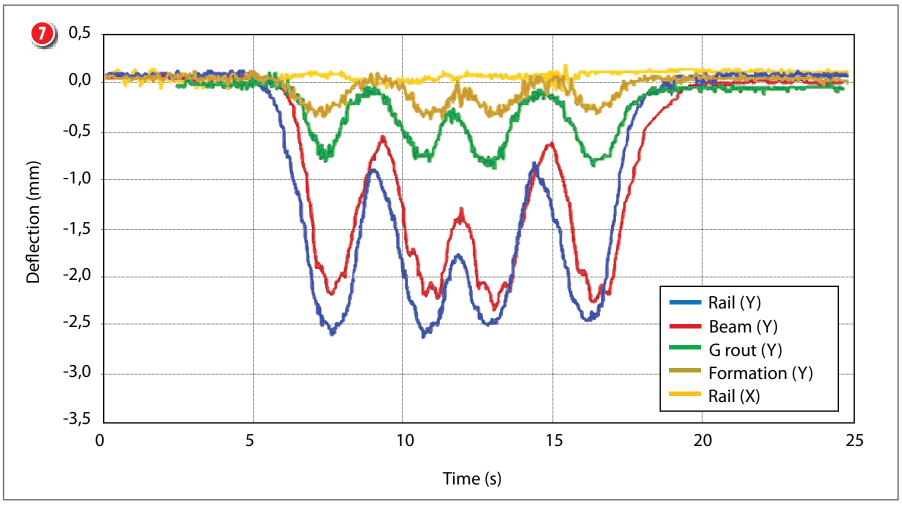
## ADVANTAGES

The advantages of PIV track deflection measurement can be summarised as follows:

- The measurement principle is optical – the most reliable type of instrumentation.
- No calibration is required and the accuracy of the instrument depends solely on the accuracy of the dimensions of the printed target.
- Deflections can be measured over a wide range, from 0,100 mm to 100 mm, to an accuracy of less than 1% of the full scale of the measurement.
- The equipment is relatively simple, available and affordable.
- Both horizontal and vertical displacements can be measured during a single test.
- Post-processing of the data can also be done in the office, reducing the set-up time in the field and allowing enhancement of the video images to eliminate invalid readings.
- Comparative analyses can be done in a quick and economical way.
- The instrumentation developed is an attractive alternative to other methods for evaluating slacks, track condition and transition areas.

## CONCLUSIONS

The PIV method has proved to be a successful alternative for measuring horizontal and vertical track deflection. A number of advantages make this method the preferred option over conventional instrumentation such as LVDTs and MDDs. Although it has some limitations, it constitutes a fast and cost-effective tool for measuring deflections over a wide range in the field and in the laboratory. The resolution and accuracy of the measurements depend on the optical characteristics of the video


6 Measurement example with targets placed on the rail, beam, grout and formation of a Tubular Track module (Ermelo yard)

7 Example of results showing the horizontal (X) and vertical (Y) deflection of the different track components

recording equipment, which are becoming more sophisticated and affordable as the technology advances. Although specific applications related to railways were demonstrated in this article, the equipment will undoubtedly be useful in other fields of engineering too.


## ACKNOWLEDGEMENTS

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8 Comparative measurements using the PIV method and an LVDT (Amandelbult Station – Northam/Thabazimbe)

9 Simultaneous measurement of rail and formation deflection (Bloubank – Vryheid/Ulundi)