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Particle image velocimetry for strain measurement on a railway line

BACKGROUND

Deformation of the railway superstructure can be observed when loads are applied by passing trains. Deflections due to these loads can be measured using various measuring techniques, e.g. linear variable differential transducers (LVDTs), remote video monitoring (RVM) and multi-depth deflectometers (MDDs). Strain gauges are often used to measure the locomotive and wagon wheel loads on the track by calibrating the resulting strains in the bending rail, as measured by strain gauges installed on the flange of the rail. Strain gauges are relatively expensive and specimen preparation is time-consuming and requires some special skills. Figure 1 shows a typical strain gauge setup for wheel load measurement with a calibration frame positioned between two sleepers. Despite the disadvantage of using strain gauges, they are commonly used to determine strains experienced by a rail because of their accuracy.

In this study, particle image velocimetry (PIV) testing was done on a rail under different dynamic load frequencies in a laboratory to investigate the use of PIV to perform the same function as strain gauges to measure wheel load. A typical field setup using PIV would entail the painting of the rail, firstly with black paint and then with a random spray of white speckles, as shown in Figure 2. This is done to enable the software to trace particle movements with digital algorithms.

The PIV results were compared with strain gauge results to determine whether PIV analysis could be used to obtain accurate strain measurements on a rail. These results are presented in this short article.

OBJECTIVE

The objectives of the study were as follows:

- To determine the accuracy of strain gauge measurements as dynamic load frequency increases.

Figure 1 Typical strain gauge setup for wheel load measurement with a calibration frame positioned between two sleepers

Figure 2 Typical field setup using PIV where the rail is painted with black paint first and then with a random spray of white speckles

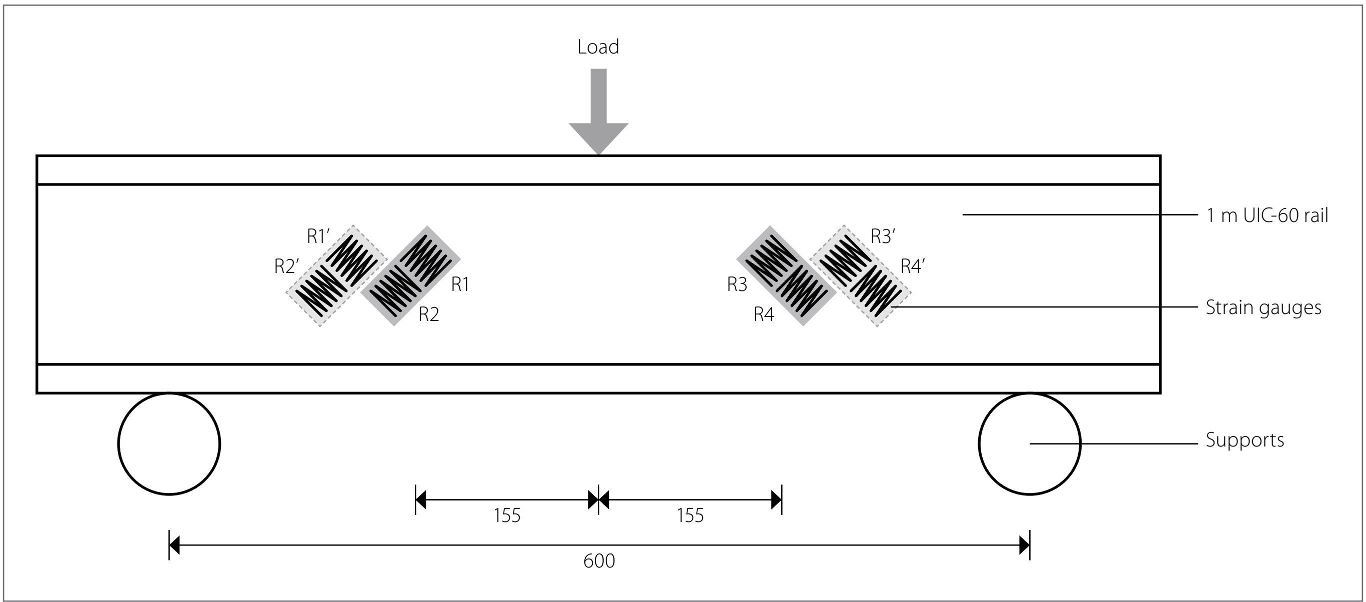

Figure 3 Schematic representation of strain gauges in a full-bridge configuration

- To compare the accuracy of PIV to strain gauge measuring techniques to determine the value of PIV as an accurate and possible replacement technique for strain gauges.

PROJECT DESCRIPTION

The experiment was conducted on a section of UIC-60 rail using an MTS dynamic actuator to simulate a train's load and movement, with supports similar to those of a conventional railway track. Strain gauges in a full-bridge configuration (see Figure 3) and PIV measuring equipment were used to measure rail deformation and strain. A DSLR camera was set up on a tripod to reduce movement. LED lights were set up behind the camera to improve the image quality of the rail surface (see Figure 4).

Digital images were taken throughout the tests for analysing using GeoPIV software. PIV analysis was done using MATLAB 2017a with an image processing toolbox and GeoPIV.

To determine the accuracy of the strain measurements, dynamic loading for both the strain gauges and the PIV measurements were compared to static loading conditions of the strain gauges. Dynamic loading was applied to the rail at a single point at various frequencies (1 Hz and 5 Hz), and strain measurements were taken. PIV deformation measurements were obtained and used to calculate strain. These measurements were compared to strain gauge measurements to determine the accuracy of the PIV analysis and whether or not it is a viable alternative to strain gauges.

Both static and dynamic loading were carried out to a maximum load of between 130 kN and 150 kN.

The influence of higher frequency dynamic load application was investigated by comparing results for both 1 Hz and 5 Hz dynamic loading. The comparisons were made between the static load measured by the strain gauges and the dynamic load measured by the strain gauges and the PIV equipment. The accuracy of the two measurement techniques therefore refers to their deviation from the static load measurements.

Strain gauge measurements at a load application of 1 Hz showed a small variation from static measurements. A 99% accuracy was calculated for strain gauge measurements, while the accuracy of PIV measurements at the same frequency resulted in a slightly lower accuracy of 94%. Figure 5 shows that, by increasing the frequency to 5 Hz, both the strain gauges and PIV measurements deviated further from the calibrated strain. Strain gauge measurements were 98% accurate, while PIV measurements were 88% accurate.

CONCLUSION

Strain measurements from both techniques were compared under different loading conditions. As the frequency increased, both the accuracy of the strain gauges and the PIV measurements reduced. Figure 5 shows the accuracy of both the strain gauge and PIV measurements at 1 Hz and 5 Hz.

Conclusions from the study indicate that an inexpensive digital single lens reflex (DSLR) camera can be used together with

Figure 4 LED lights were set up behind the camera to improve the image quality of the rail surface

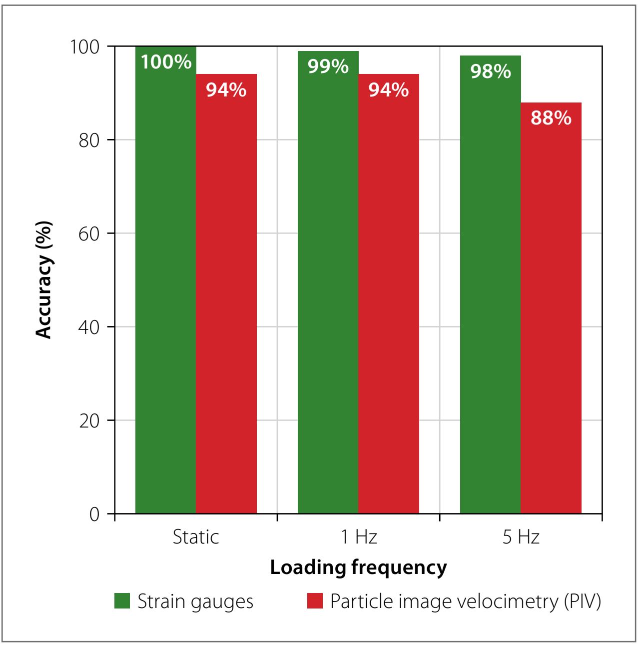

Figure 5 Results of both the strain gauge and PIV measurements at 1 Hz and 5 Hz

GeoPIV software to obtain strain measurements in a rail. These measurements were, however, calculated to be less accurate than strain measurements obtained from strain gauge measuring techniques, but still obtained results of 88% accuracy at the highest loading frequency. It can therefore be concluded that PIV measuring techniques can be considered as an alternative to strain gauge measuring techniques.

The laboratory experiment yielded positive results, but it is acknowledged that field conditions will probably add complexity and other difficulties to the PIV measurement technique.

RECOMMENDATIONS

The experiment, as executed, had certain limitations that could be improved on in future experiments. To eliminate factors that result in inaccurate measurements, the following recommendations and improvements should be considered:

- Only increasing lighting conditions will not have enough of an influence on the resolution of the images obtained. The texture created on the rail specimen should be as fine as possible.
- Dark spots should be further reduced by using a background colour on the specimen other than black. The black background caused the shade from the railhead to fade into the image and darken the area.
- To place the strain gauges on the rail, the rail needs to be prepared by grinding and sanding the uneven surface to a smooth texture. When the matt paint is applied to this surface, and light is used to illuminate the surface, the sanded areas are glossy which causes the PIV analysis to measure inaccurately. Care should be taken to ensure that the entire rail surface has the same matt finish to improve PIV analysis.
- Faster and more advanced camera or video equipment could be used to increase the accuracy of the PIV measurement technique. □

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