The Use Of Ground Based Radar To Monitor The Effect Of Increased Axle Loading On Rail Bridges

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ABSTRACT

With the critical role that iron ore rail infrastructure plays in maintaining consistently high mine productivity, it is necessary to find solutions that allow to monitor and analyse the status and the physical condition of this infrastructure, with the highest accuracy possible and with non-invasive monitoring techniques.

In this paper, the application of ground-based radar interferometry (IBIS-FS) to remotely monitor and evaluate the condition of twelve railway bridges from an iron ore mine in Australia, is reported. The analysis was conducted to assess the bridges dynamic response to varying axle loads.

The principal survey aims were to:

- Analyse the physical condition of the bridges by comparing the measured with the maximum allowable displacement
- Verify the effect of increased axle loading;
- Define a maintenance plan for the rail bridge network.

This paper shows how this highly accurate and innovative remote monitoring technique can be used to determine whether rail infrastructure is fit for purpose when moving to higher axle loading.

Keywords: radar interferometric sensor, bridge displacement, IBIS-FS, remote sensing, structural dynamic response, non-invasive monitoring techniques, structural monitoring and maintenance.

1. INTRODUCTION

In November of 2014, IDS (Ingegneria Dei Sistemi S.p.A.) was commissioned by a mining company to conduct an interferometry survey of bridges on its rail network in Western Australia. The primary objective of the survey was to measure the movement and vibration of twelve bridge structures under load to determine whether they are fit for purpose for current loads and for possible increasing load train.

Moreover, the objective of the survey was to understand if utilizing this technology, as part of standard visual inspection practices, will provide full and ongoing visibility of the condition of bridge structures on track, allowing more proactive rather than reactive maintenance. Cost benefits will accrue by:

- easy and rapid installation of the instrument compared to standard methods;
- no interruption on the railway traffic during the measurement activities;
- simultaneous multi-point measurement of deflection and vibration;
- reduced risks and improved safety for technicians.

2. BACKGROUND OF TECHNIQUES

2.1 Stepped Frequency Continuous Wave Technique (Taylor, 2001)

The principle of this technique is that the radar steps through a range of frequencies from low to high frequencies of the bandwidth at up to 200 times per second (200 Hz). The real and imaginary components of the signal are analysed in the frequency domain. The phase and amplitude information of the signal is retrieved by Inverse Discrete Fourier Transform (IDFT) (Palombo et al., 2011) and an amplitude versus range profile of the radio echoes is constructed for 0.5 m bins forming a one dimensional map called a range profile which shows reflected amplitudes with respect to the range from the radar sensor. Figure 1 demonstrates this concept.

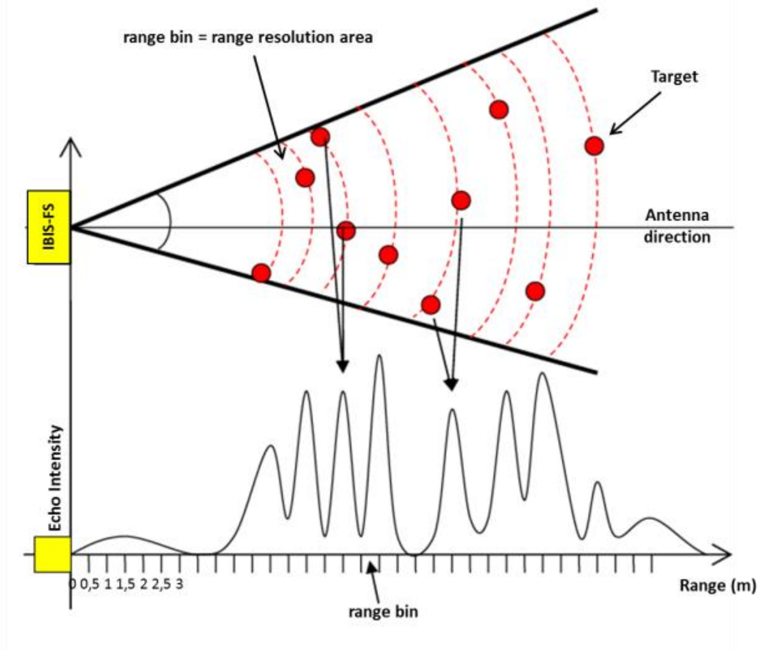


Figure 1. The range profile shows the intensity in dB of the signal reflected back from each object in the transmitted wave path back to the receiver of the radar as a function of each objects distance from the radar.

The sampling frequency controls the maximum frequency measurable by the system with the Nyquist frequency, or maximum detectable frequency, being approximately half of the sampling frequency. The frequency that can be sampled is controlled by the distance from the structure, as for radar waves travelling further to a reflector, the sensor must wait longer to receive the return signal. In practice this means that reflectors at a range of 1 km can only be sampled at 30 Hz, whilst closer reflectors can be sampled at 200 Hz. The sampling rate does not affect the accuracy of measured deflections (up to 0.01 mm) as this is determined by the wavelength of the radar waves.

The IBIS-FS radar has a minimum range resolution of 0.5 meters meaning that only objects with separation greater than this can be resolved as separate objects i.e. they must be at least 1 range bin apart. Objects within the same range bin cannot be resolved as separate objects.

2.2 The Differential Interferometry Technique (Henderson and Lewis, 1998)

Once the measurement data has been assigned to range bins and the peaks selected for the targets of most interest, the deflection of the targets is measured using differential interferometry. The phase of the returned radar waves from each target is measured during consecutive samples with the phase of the return signal calculated using the formula:

d_(p)∝ λ/4π Δφ (1)

Where dp is the radial displacement, λ is the wave length, and φ the phase change. Figure 2 illustrates the concept.

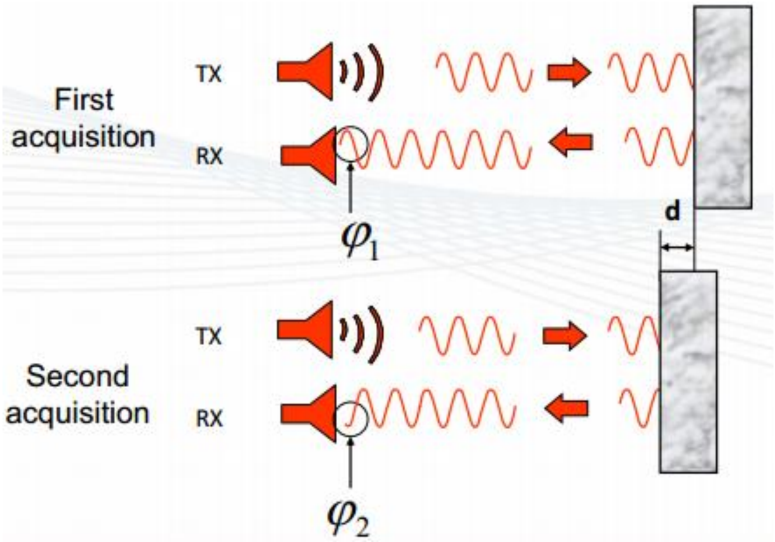


Figure 2. Interferometry concept

The displacement measured is along line of sight so to calculate vertical or horizontal deflection, the geometry of the scenario needs to be calculated. In the example shown in Figure 3, the vertical component of the deflection of the bridge is calculated as:

$$dp = d \sin(\alpha) \tag{2}$$

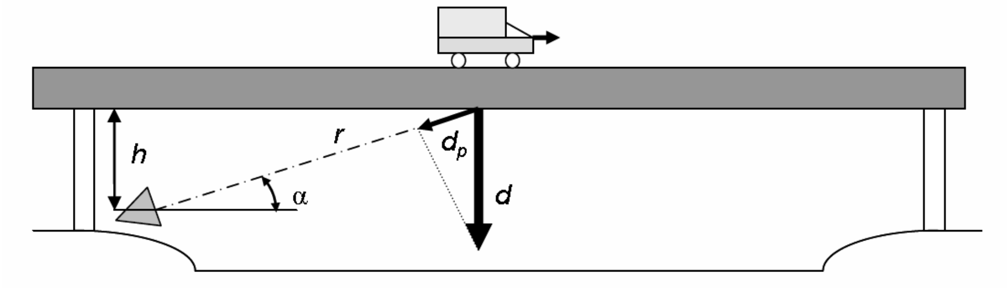


Figure 3. Vertical displacement calculation

In order to calculate deflections (i.e. vertical or horizontal) the alignment of the system to the structure is important. Where the vertical component is required, the alignment must be along the length of the structure and in most cases this would be from beneath the structure. To measure horizontal movement, the alignment would be from the side of the structure. Where both components are required, two systems would need to be synchronized wirelessly.

3 SYSTEM DESCRIPTION AND SPECIFICATION

The system consists of a sensor, power supply and control unit and has two horn antennas for transmission and reception of the radar signal (see Figure 4).

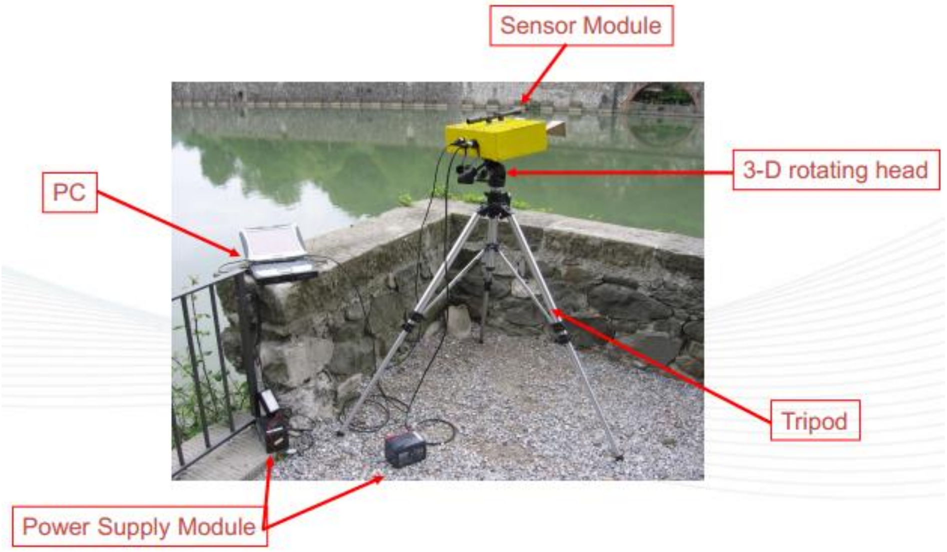


Figure 4. IBIS-FS system setup

The sensor generates a tune-able sine wave with central frequency of 17.2 GHz and with a bandwidth up to 300 MHz. The radar is classified as a Ku – band, according to standard radar-frequency letter band nomenclature from IEEE Standard 521-1984 (Bernardini et al., 2007).

The sensor is supported on a tripod with a fully rotatable head allowing it to be placed easily at any required angle. Communication between the radar sensor and the control unit is through a standard USB interface. The data logger is a standard laptop running Windows 7 with dedicated software to configure, store, process and view the data.
The power supply is a commercially available 12V battery which can power the system for 8 hours in the field.

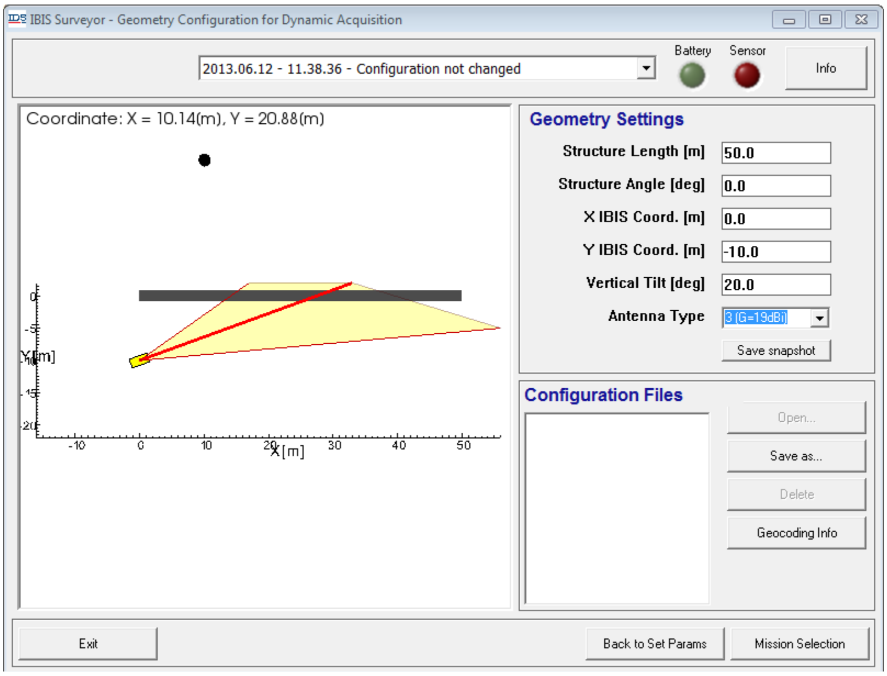
4 SURVEY METHODOLOGY AND DATA ANALYSIS

The bridge surveys were conducted with 2 x IDS IBIS-FS interferometry systems to increase the number of bridge spans that could be monitored over the survey period, with each unit set up under each bridge to monitor the structure. The instrument requires 20 minutes to install and the same time to dismantle. The instrument is specifically designed for outside use and is IP65 standard for all-weather use. A typical system setup from this survey can be seen in Figure 5.

Figure 5. IBIS-FS was set up directly under the bridge to maximize the power of the return signal to the receiver from each range bin

The cross beams shown in Figure 5 were typical and were excellent reflectors of the transmitted radar wave which resulted in excellent data quality for each of the bridges surveyed.

To ensure accurate geometry of the interferometer systems in relation to the bridge, IDS used laser distometers to measure angles and distances from the survey equipment to the underside of the bridge structure.


IBIS Surveyor - Geometry Configuration for Dynamic Acquisition

2013.06.12 - 11.38.36 - Configuration not changed

Coordinate: X = 10.14(m), Y = 20.88(m)

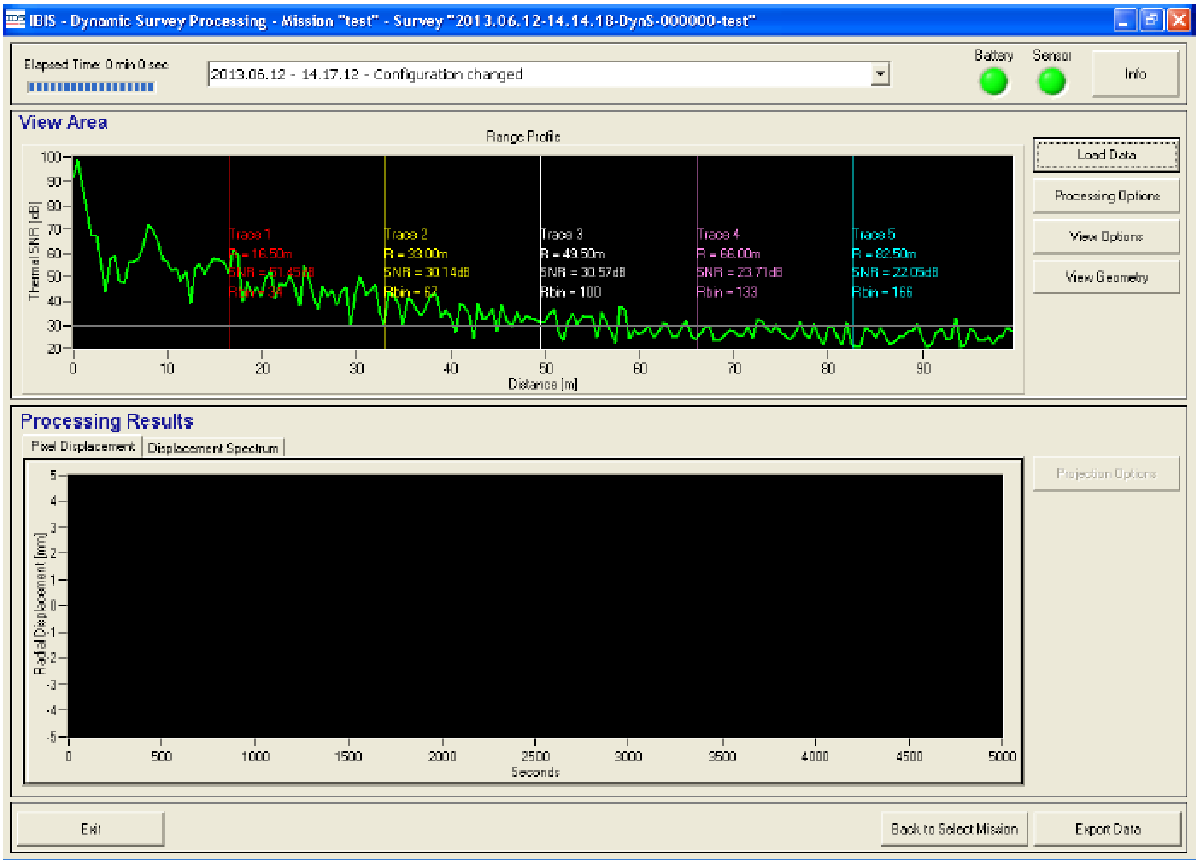
Geometry Settings

Structure Length [m]: 50.0
Structure Angle [deg]: 0.0
X IBIS Coord. [m]: 0.0
Y IBIS Coord. [m]: -10.0
Vertical Tilt [deg]: 20.0
Antenna Type: 3 (G=19dBi)

Configuration Files

Figure 6. Geometry setup of a bridge, during acquisition phase

Once data acquisition begins, the software showed the range profile (see Figure 7) of the illuminated area. It is important to identify points on the bridge structure that correspond with each of the high peaks within each range profile. These peaks are related to range bins that display an increased amplitude of the return signal and are often associated with good reflective points on bridge structures such as beams, girders and cross beam supports.



IBIS - Dynamic Survey Processing - Mission "test" - Survey "2013.06.12-14.14.18-DynS-000000-test"

Elapsed Time: 0 min 0 sec

2013.06.12 - 14.17.12 - Configuration changed

Figure 7. An example of a range profile of the area illuminated by the radar

To identify points on the bridge structure corresponding to peaks of reflected energy within the range profile, the laser distometer is used to determine the distance from the radar head to each of the cross beams under each bridge, which are known to be good reflectors of the transmitted radar wave. From this line of sight distance, the correct peaks associated with each cross beam can be identified, the geometry of the survey environment established (see Figure 8) and the vertical displacement and vibration characteristics of that range bin can be monitored over a specified time frame (see Figure 9 and Figure 10).

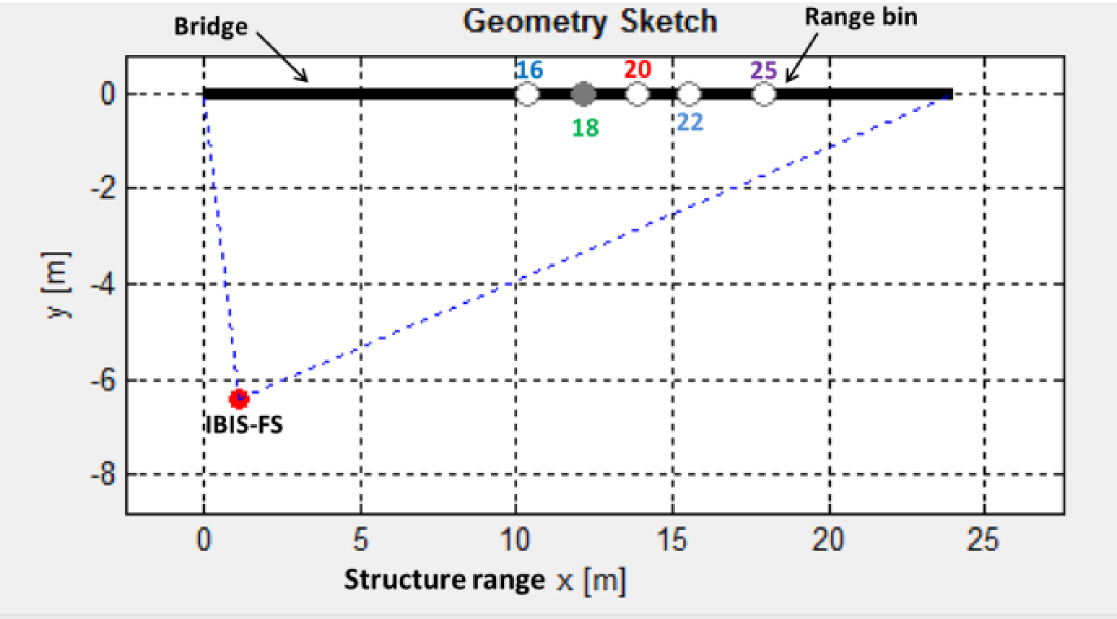


Figure 8. Geometry showing the range bin position that provide maximum power of the reflected radar

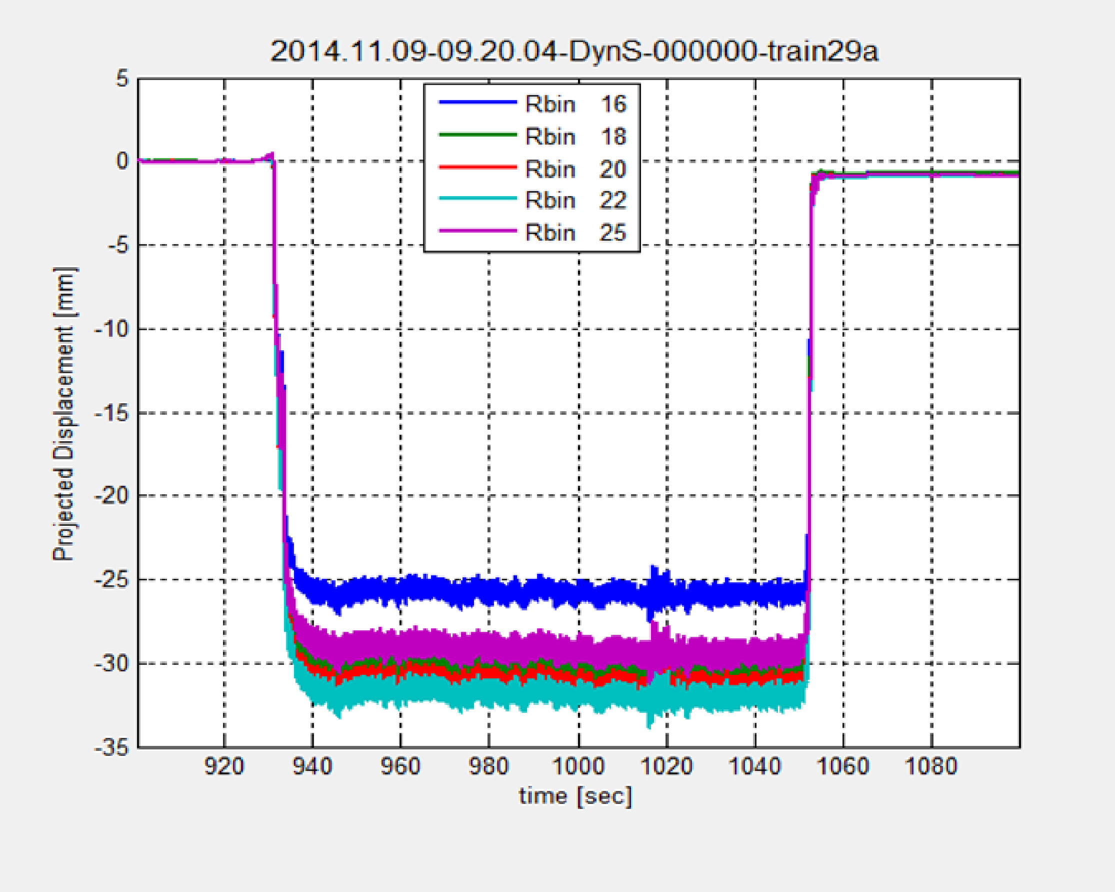


Figure 9. Displacement time graph of various range bins monitored. The time and date of acquisition is also shown on these graphs

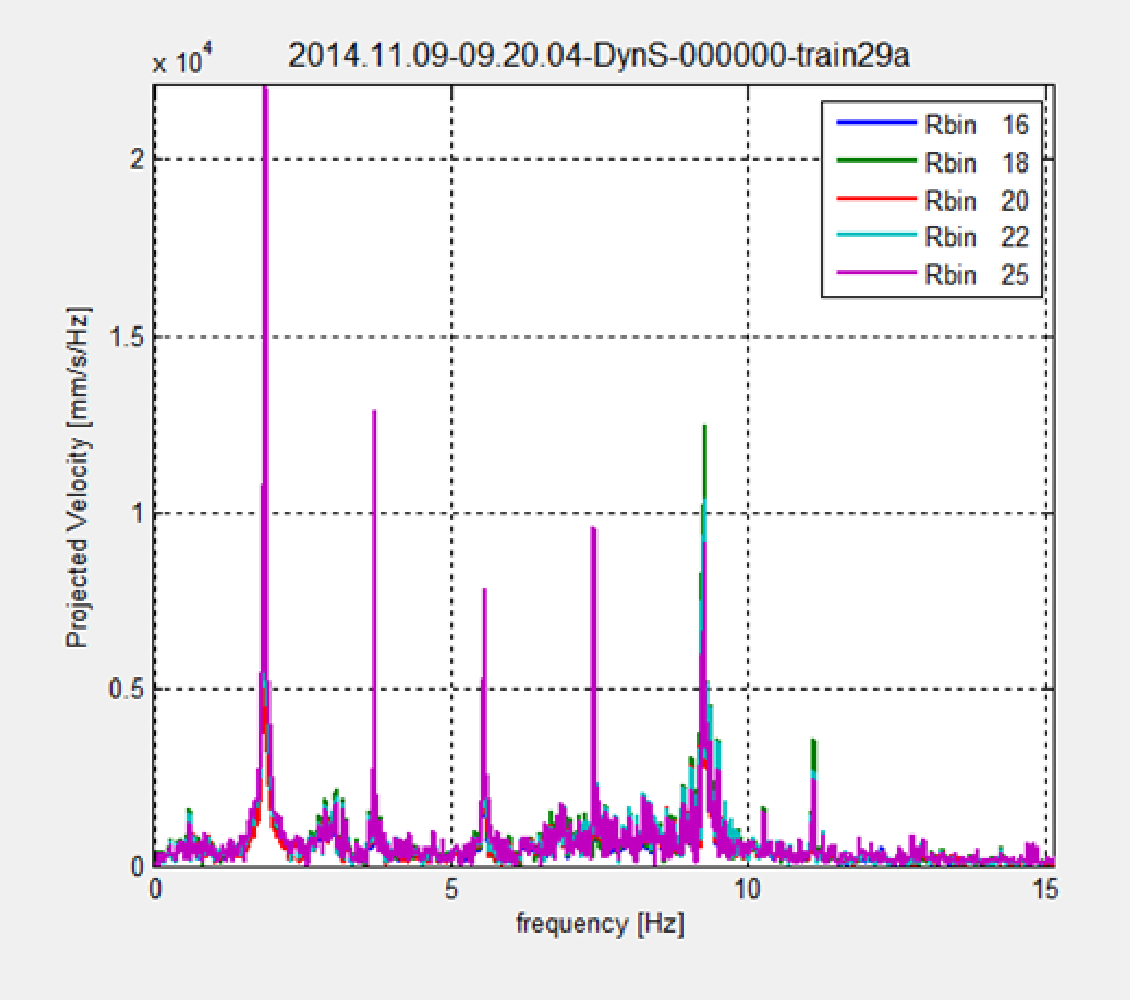


Figure 10. Vibration frequencies of each range bin monitored, with dominant frequency approximately 2 Hz

The vertical deflections over 40 mm and vibrational movement over 3 mm have been highlighted. The threshold for maximum vertical deflection has been guided by the average span of 26,500 mm divided by 640 = 41.41 mm, which is understood to be a maximum tolerance guide. The maximum vibration tolerance has been chosen to be 3 millimeters.

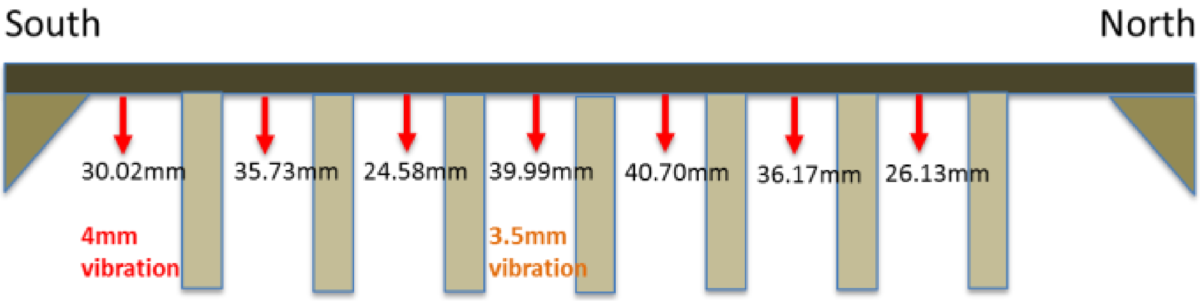


Figure 11. Example of results in one of the surveyed bridge

5 CONCLUSION

The survey provided detailed information on vertical deflections, vibration movement and vibration frequencies for multiple positions along each bridge structure surveyed, largely demonstrating the capabilities and accuracy of the system.

The data collected have given important information on the possibility to increase the trains load and demonstrate the full applicability of the system into the mining company bridge inspection program.

Furthermore, this field work is only the beginning for an ongoing monitoring and maintenance plan of the mining railway bridges, with the listed activities to be performed:

- periodical monitoring of bridge condition over time;
- regular scanning of areas which exhibit higher vertical deflections or vibration;
- an extended workshop or training program to garner more information from the data collected during the survey;
- continuous improvement of the use of interferometry for bridge monitoring through feedback from the visual inspection and maintenance group.

These information allow the IBIS-FS to be used as a SHM tool (Structural Health Monitoring) to predict damage and, especially, to plan maintenance actions to guarantee and increase the mining productivity.

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