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Defining rail track input conditions using an instrumented revenue vehicle

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Abstract

To model the dynamic response of a train running over a given length of rail, the input conditions must be adequately defined. This paper explores the use of an instrumented rail vehicle to assist in the definition of this input condition. The benefits of using instrumented rail vehicle for condition assessment of track and rolling stock are gaining popularity. Railway track and rolling stock condition monitoring is essential in ensuring the safe and efficient function of railway systems. The ability to use an instrumented revenue vehicle for the condition assessment of rail tracks is particularly significant because this capability will not require track access during inspection. This instrumented vehicle can also provide useful data for the definition of the rail track input conditions for the assessment of the stability of a rail vehicle when traversing along the track. This information can be used to establish the wagon speed limits to ensure safe operation of the asset. To be able to predict the dynamic response of a rail vehicle, the dynamic input conditions imposed by the track will need to be identified. This paper will discuss some initial studies on the use of an instrumented rail vehicle to define the input conditions imposed by the rail track. The ability to define the rail input conditions is demonstrated by associating the results with features on the track that are identifiable.

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1. Introduction

Tracks are “continuous” linear assets that are distributed over a region [1]. They comprise several components including rails, sleepers, rail clips, ballast and sub-ballast. The maintenance of these assets is expensive given that this asset is expected to cover a large area. A well maintained ballast is crucial for the safe operation of trains [2]. Similarly,
the operating conditions of rail tracks is critical for safety. This has led to the development of on-board monitoring strategies [3-6]. These works lead to a very real practical solution for the monitoring of these continuous structures because they offer the potential of mounting monitoring equipment on board an operating vehicle or wagon [7-8]. The ability to relate the dynamics of the rail vehicle as it travels along a given length of track can facilitate the development of monitoring tools to assess track geometric irregularities [8-9] and the ballast conditions [10-11].

The stability of a rail vehicle when traversing along a track is dependent on the state of the rolling stock, the rail track and the ballast (subgrade). Information about the dynamic response of the rail vehicle can be used to determine the state of the vehicle/rail interaction. This information can be used to establish the wagon speed limits to ensure safe operation of the asset [12-13]. To be able to predict the dynamic response of a rail vehicle, the dynamic input conditions imposed by the track will need to be identified. Given the continuous nature of rail tracks, the idea of being able to classify this input using an instrumented rail vehicle is attractive. This is because data collection of this nature will not interrupt normal train operation and will have zero impact on the revenue of the rail car. Indeed, there now numerous efforts to achieve this [13] & [14]. The economic and engineering benefits of using an instrumented revenue car cannot be overstated.

Monash University (Australia) and the Institut Teknologi Sepuluh Nopember (Surabaya, Indonesia) is collaborating on a project for the management of rail assets. This project involves the Australian Rail Track Corporation, Indonesian Rail (PT KAI) and East Java Government Office for Land Transportation (Dinas Perhubungan). This paper will report on one of the foci of the collaboration. The aim of this paper is to demonstrate the use of an instrumented passenger vehicle to classify the input condition imposed by the rail track on the train. The results presented will show the sensitivity of this input conditions imposed by features of the track (i.e. level crossings and bridges). The ability to define the track input is compared with physical track features that are clearly identifiable.

2. Instrumented Rail Vehicle (IRV)

The IRV sensor package was installed onto a single passenger rail car scheduled to make repeated round trips between Surabaya and Lamongan. The IRV travelled on two separate tracks; North Track (towards Lamongan) and South Track (towards Surabaya) each track is about 40.8 km in length. The IRV was running normal operations including stopping and starting at stations (seven stations on each track) and taking on passengers. The rail vehicle was instrumented by engineers from the IRT. Figure 1 shows the rail vehicle that was instrumented for this work. The instrumentation was installed on the front vehicle. All cablings were routed into the driver cabin in the front and were connected to the SOMAT data collector.

![Fig. 1. Vehicle used in this project.](image)

The accelerometers, Acc1, Acc2, Acc3, and Acc4, were uni-axial accelerometers recording vertical (z-direction) acceleration only. These accelerometers were mounted on the unsprung mass of the vehicle and will be sensitive to varying track and wheel conditions. A GPS was also located on the rail vehicle to identify its position during the test-runs. The acceleration data along with its GPS location will be used to identify the location along the track associated with the vibration levels. When on the North Track, Acc1 and Acc4 will be on the leading section of the train. Whilst
when on the South Track, Acc1 and Acc4 will be on the trailing section of the train. All of the sensor measurements were recorded and stored onboard until the end of each trip where it transmitted its data to IRT’s servers in Australia. All channels were resampled to 100 Hz in this paper. A total of ten separate round trips were taken over the course of five days from the 20th to the 24th of August 2016.

The data were downloaded and analyzed using MATLAB. Given the nature of the data collected, it is appropriate to use the short-time Fast Fourier Transform (spectrogram) to isolate the frequency content of the data collected. In the analyses conducted, the spectrogram of the data was performed using 64 point wide bins with 63 point (98.4%) overlap to ensure a high resolution in the time scale at expense of resolution in the frequency scale. A Hanning window was chosen as the windowing function for its satisfactory frequency resolution and reduction in spectral leakage.

3. Results

Figures 2(a) and (b), and 3(a) and (b) show the spectrogram of the data from Acc1 and Acc4 along the North Track and South Track respectively. These figures show the vibration spectrum as a function of the track location. The main reason for presenting this is to demonstrate how the instrumented vehicle can be used to show the effects of the track conditions on the vibration response measured. The acceleration, deceleration and the cruising of the vehicle are shown in this figures. The speed dependence of the spectral is expected during run-up and run-down. It is also that the data collected on the North and the South track have quite different spectral content. When the train was running along the North Track, Acc1 and Acc4 are located on the leading wheel set and it is likely that it is more responsive to the prevailing track conditions. During the runs along the South Track, these sensors (Acc1 and Acc4) are located on the trailing wheel set. It is expected that the influence of the track conditions is more distinctly reflected in the response shown in Figure 2(a) and (b). Due to the location of the sensors with respect to the travel direction of the train, the response shown in Figure 3(a) and (b) is expected to comprise of the track conditions and vehicle responses. To substantiate this observation, a detailed look at the chainage from 216 km and 227 km will be discussed. Chainage is defined as the distance measured along the rail with reference to a fixed location in Surabaya. An attempt to associate the spectral response to the physical features along the track will be discussed. This has significant implications on the use of appropriately located sensors for the defining the track conditions for the definition of the dynamic response of a given train.

Figures 4(a) to (d) show the spectrogram of the acceleration recorded along the North Track. The first observation is that the spectrogram show clear peaks at some distinct chainage locations at 217.8, 218.3, 219 and 226. These features are shown in Figures 5(a) to (d). It is evident that the accelerometers on the leading wheel sets (Figures 4(a) and (b)) were sensitive to the presence of these features. It is also noted in the responses shown in Figures 4(c) and (d) associated did not display these distinct features. This can be attributed to the location of Acc2 and Acc3 where the coupled track-and-vehicle responses and the physical features of the track that gave rise to the distinct responses shown in Figures 4(a) and (b) are now immersed in the overall spectrum.
Fig. 2(b). Spectrogram from Acc4 (North Track) – Acc4 on leading section of train.

Fig. 2(c). Spectrogram from Acc4 (South Track) – Acc4 on trailing section of train.

Fig. 2(d). Spectrogram from Acc4 (South Track) – Acc4 on trailing section of train.
Fig. 3. Spectrogram of vibration response;
(a) Acc1 (North Track); (b) Acc4 (North Track);
(c) Acc2 (North Track); (d) Acc3 (North Track).

Fig. 5. Features identified:
(a): Bridge (5 m span) at chainage 217.8 km; (b) Level crossing at chainage 218.3 km;
(c) Level crossing at chainage 219 km; (d) Bridge (12.5 m span) at chainage 226 km.

The corresponding spectrograms for the same accelerometers from the South Track are shown in Figures 6(a) to (d). When the train is running along the South Track, the instrumented car was located at the trailing end of the train.
The physical features of the track are now immersed in the overall spectrum thereby making it difficult to properly define the presence of these features.

4. Discussions

The results presented above show that the instrumented rail vehicle is a very efficient method of collecting data for the assessment of rail track. When attempting to use these data to determine to define the track input conditions for the dynamic modelling of the train, it is evident that the sensors must be strategically located to mitigate the effects of the dynamic response of the train from overwhelming the desired response. It is evident from the results presented that a good understanding of the vibration response of the rail vehicle is required if the accelerometer data is to be used to identify the track conditions. The effects of accelerometer location is shown in the Figure 3 where the accelerometers Acc2 and Acc3 response showed the coupled response between the rail vehicle and that associated with the track condition. In contrast, Acc1 and Acc4 that are located on the leading section of the train show a clearer picture of the response due to track conditions.

5. Conclusions

This paper demonstrated the use of an instrumented passenger vehicle to classify the input condition imposed by the rail track on the train. The results show that the ability to define the track input is compared with physical track features that are clearly identifiable. This will help define the input conditions imposed by the rail track for future dynamic modelling of the train. The results presented will be provide invaluable insight into future research into the development of advanced asset management and maintenance tools for the safe operation of rail infrastructure.

![Fig. 6. Spectrogram of vibration response; (a) Acc1 (South Track); (b) Acc4 (South Track); (c) Acc2 (South Track); (d) Acc3 (South Track).](image-url)
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