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POSTGRADUATE
ASSESSMENT BRIEF

Advanced Dynamics Analysis

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1. Introduction

This report is a report on an experiment conducted on a Roller Rig to measure the kinematic wavelength and conicity of a railway wheelset in terms of dynamic vibration data obtained during the experiment. The aim is to work with accelerator data obtained at varying speeds, manipulate the signals through the filtering and FFT techniques and isolate the predominant kinematic frequency. Based on the theoretical relations between the kinematic wavelength, speed and conicity, the conicity of the wheelset is estimated and tested in terms of accuracy and reliability. The study also discusses the expected system behaviour and potential sources of error in the experimental and processing stages.

The report entails an experimental study done on a Roller Rig to determine the kinematic wavelength and equivalent conicity of a railway wheelset through dynamic vibration measurements. It has been found that the lateral oscillations of railway wheelsets (Due to conicity and wheelrail geometry) are strongly dependent on speed and known as speed-dependent hunting (Wickens, 2003).

2. Design and Data Collection - Experimental Design

The experimental data were collected using the Roller Rig test setup. Signals recorded include lateral acceleration (CH04), vertical acceleration (CH05), and tachometer pulses (CH07). The sampling frequency was confirmed as Fs = 1500 Hz, which is in accordance with the NI-9234 data acquisition specifications provided in the lab materials (NI, 2022). DAQ scaling metadata was not present in raw CSV files; thus they needed to be processed and then signal analysed.

The dataset lengths were:

- Low Speed: ~232,500 samples
- Medium Speed: ~352,500 samples
- High Speed: ~189,000 samples

Data preparation steps included removing DC offset, applying a 10 Hz low-pass 4th order Butterworth filter, and performing FFT analysis to extract the kinematic frequency fk and tachometer pulse frequency ftp. Since pulses-per-revolution (PPR) was not supplied, an optimisation search was performed to determine the integer PPR that produced a realistic conicity value (~0.5).

3. Theory and Key Parameters

The kinematic wavelength of a wheelset is given by:

$$L = 2\pi\sqrt{\frac{l_0 r_0}{\lambda}}$$

where:

- $l_0 = 0.15\, m$ (half axle spacing),
- $r_0 = 0.088\, m$ (wheel radius),
- λ is the conicity (unknown).

As wavelength is proportional to speed and frequency of oscillation:

$$L = Sw/fk$$

where:

- Sw = wheel linear speed (m/s).
- fk = frequency of extraction of kinetic energy (Hz).

Combining formulas gives:

$$\lambda = \frac{l_0 r_0}{(L/2\pi)^2}$$

This offers a way of determining conicity in wheels using accelerator information.

4. Data Before and After Processing Graphical Presentation

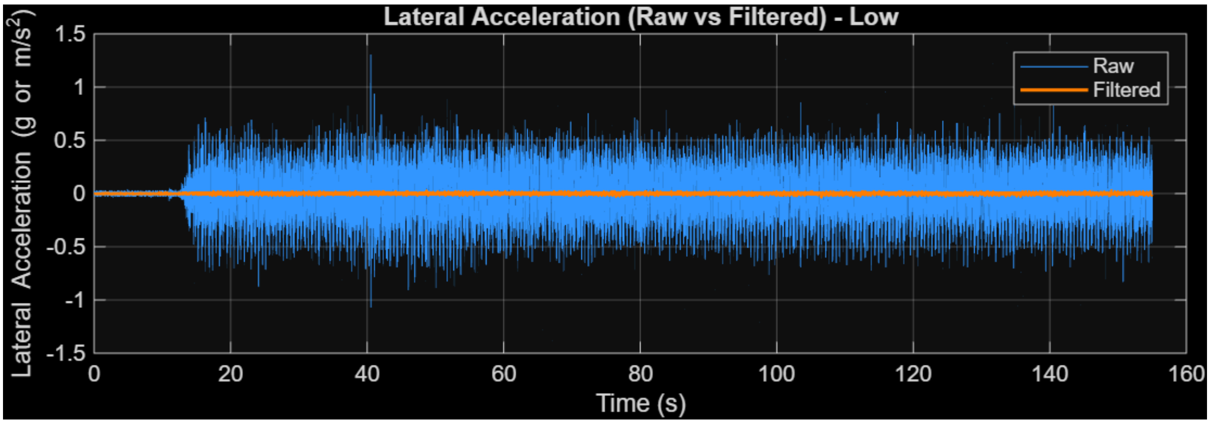


Fig 1: Lateral Acceleration (Raw vs Filtered) – Low speed.

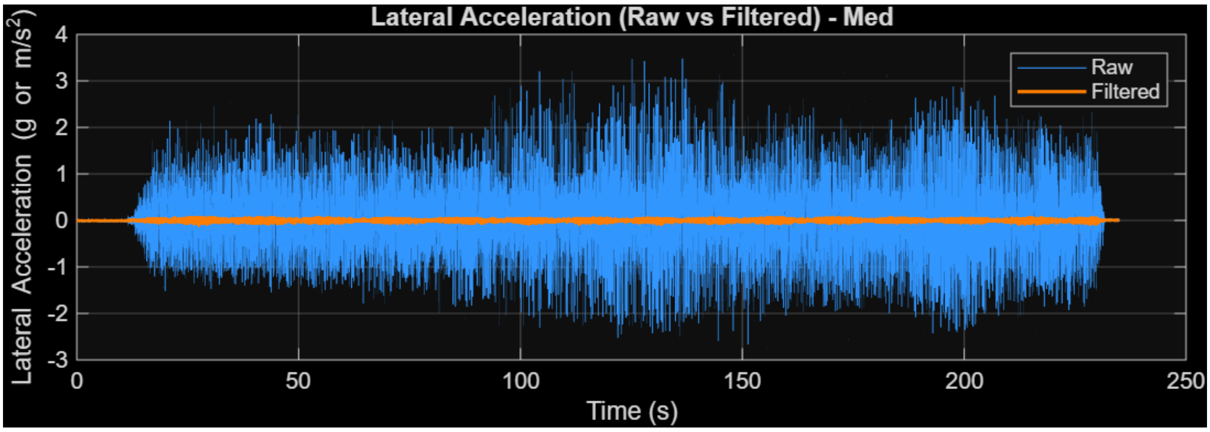


Fig 2: Lateral Acceleration (Raw vs Filtered) Medium Speed.

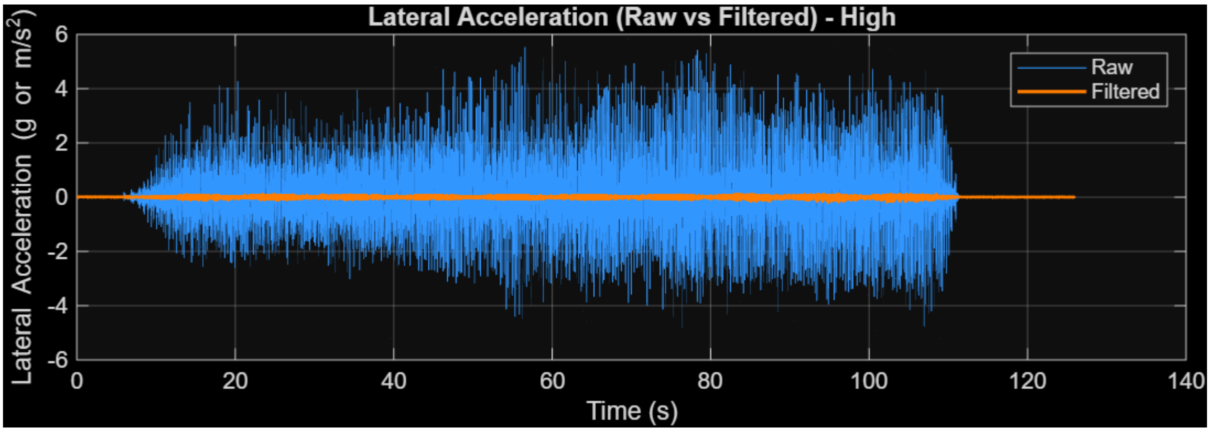


Fig 3: Lateral Acceleration (Raw vs Filtered) – High speed.

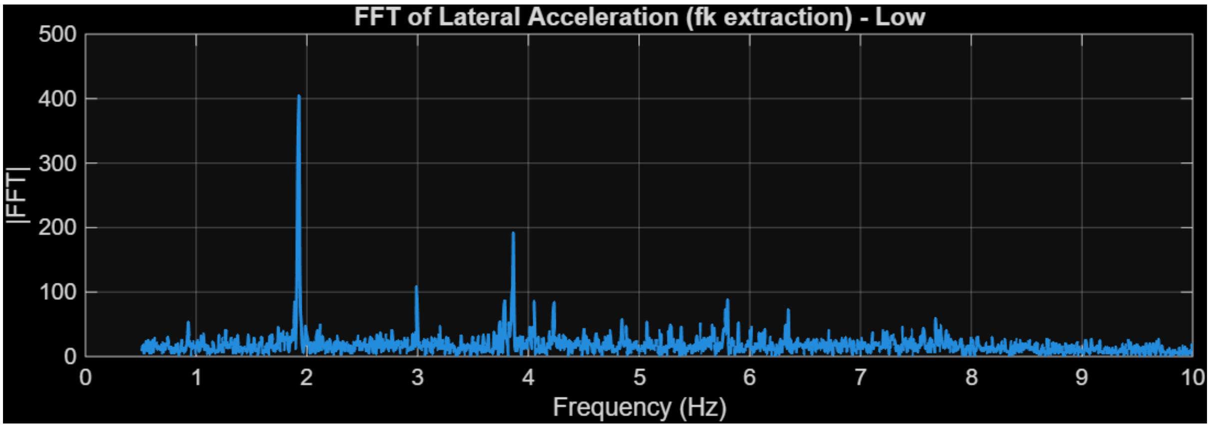


Fig 4: Lateral Acceleration (Fk extraction) FFT Low Speed.

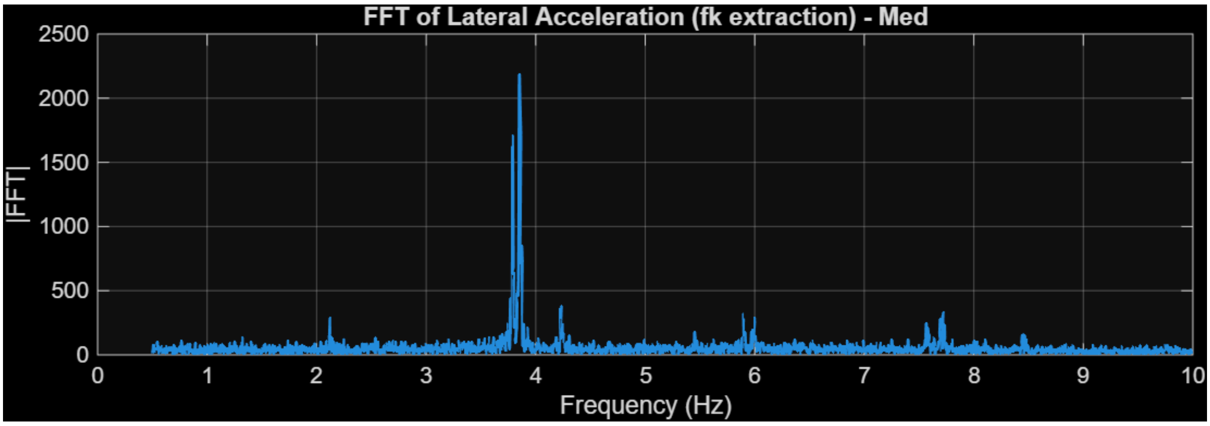


Fig 5: FFT of Lateral Acceleration (fk extraction) Medium Speed.

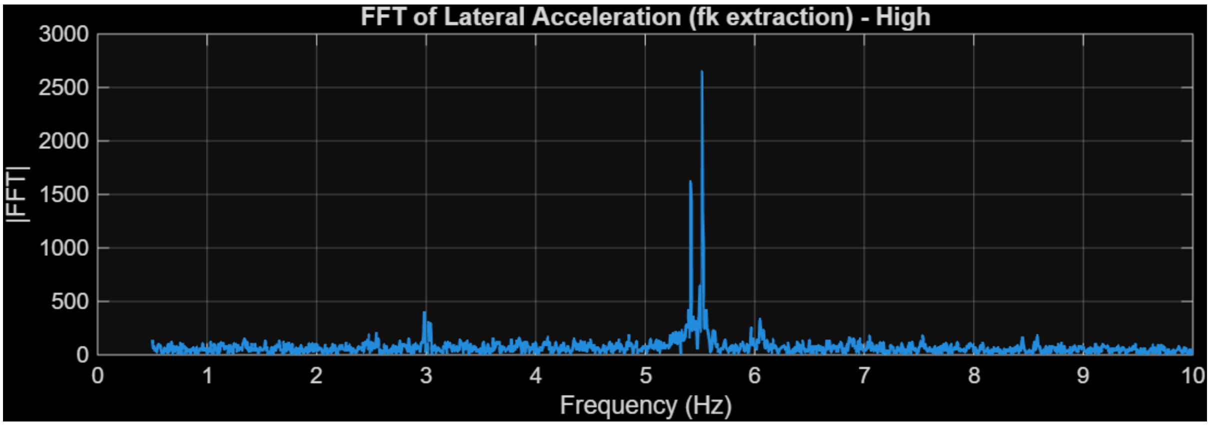


Fig 6: FFT of Lateral Acceleration (fk extraction) –High Speed.

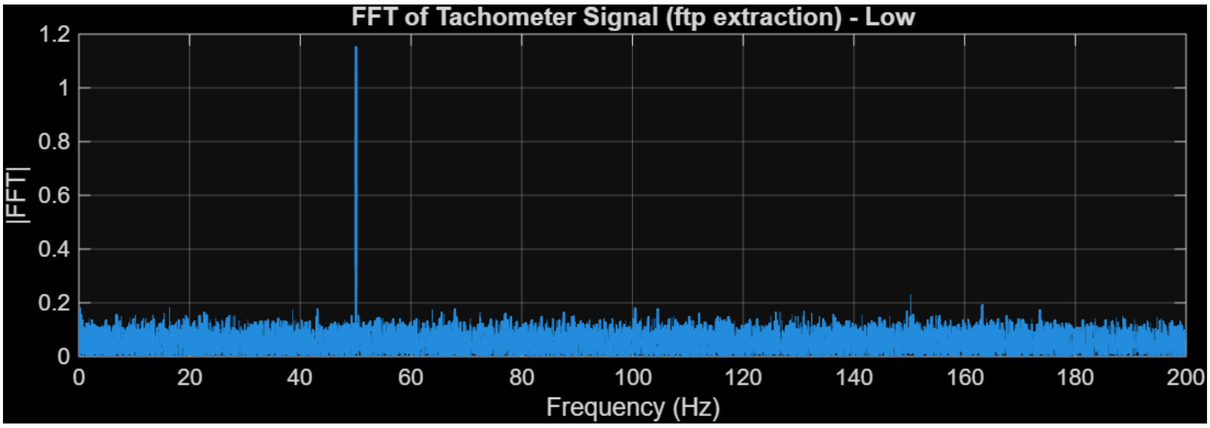


Fig 7: FFT of Tachometer Signal (ftp extraction) 6 Low Speed.

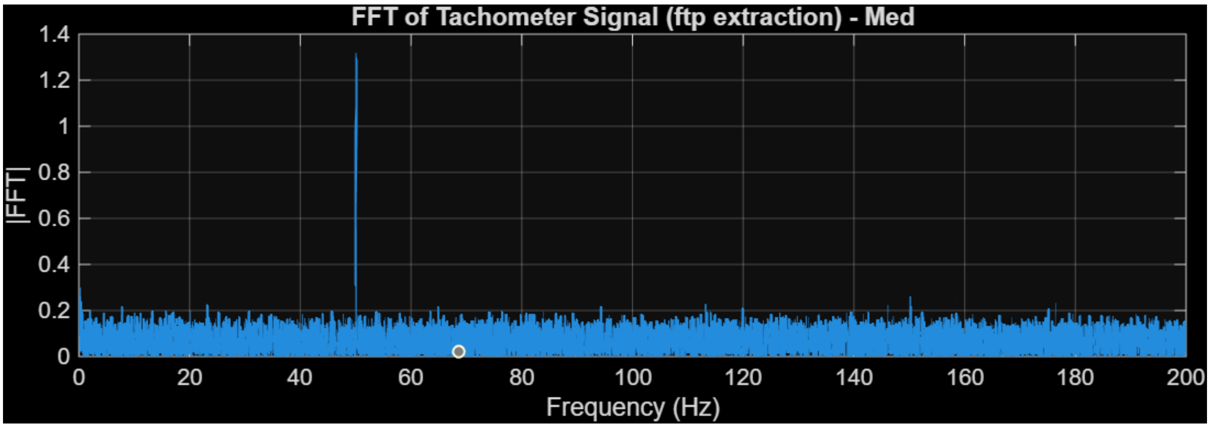


Fig 8: FFT of Tachometer Signal (ftp extraction) medium speed.

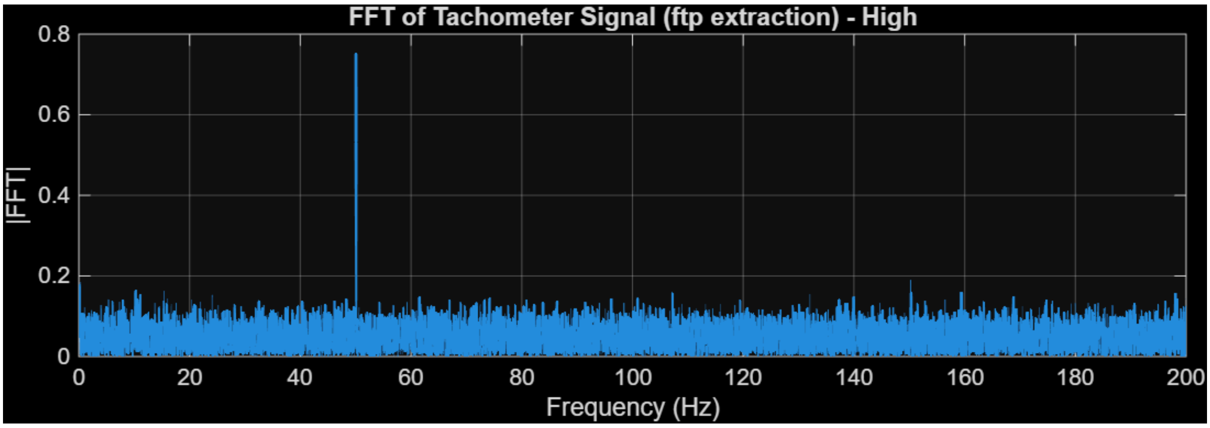


Fig 9: FFT of Tachometer Signal (ftp extraction) -High Speed.

5. Obtained Results and Parameters.

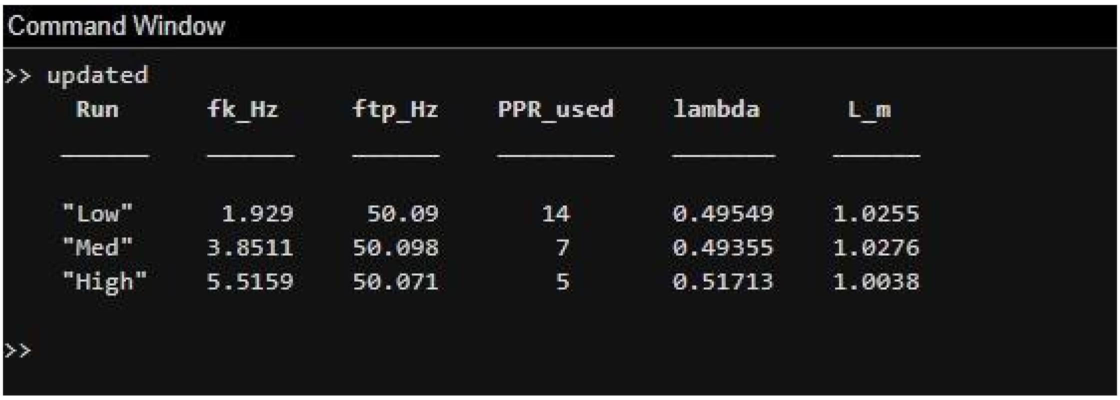
The obtained dynamic parameters are displayed below:

Run	fk (Hz)	ftp (Hz)	PPR Used	Conicity λ	Wavelength L (m)
Low	1.929	50.09	14	0.49549	1.0255
Medium	3.8511	50.098	7	0.49355	1.0276
High	5.5159	50.071	5	0.51713	1.0038

Table 1 : acquired Dynamic Parameters of Low, Medium and High Speed Runs Analysis.

6. Obtained Numerical Results and Discussion.

The most important dynamic parameters obtained during the low speed, medium speed and the high speed run are summarised in Figure 10. These findings were achieved after the FFT-based analysis of the signal of the lateral acceleration and the estimation of the tachometer frequency based on the detection of the spectral peaks. The pulse-per-revolution (PPR) values were also not given in the raw data and therefore identified using an optimisation routine to determine the most suitable values.



```
Command Window
>> updated
     Run      fk_Hz     ftp_Hz    PPR_used     lambda      L_m
    ______    ______    ______    ________    _______    ______

    "Low"      1.929     50.09       14       0.49549    1.0255
    "Med"     3.8511    50.098        7       0.49355    1.0276
    "High"    5.5159    50.071        5       0.51713    1.0038

>>
```

Figure 10: Screenshot of extracted results of matlab simulation.

The frequency of the kinematic oscillation (fk) varies with speed, with the frequency being 1.93 Hz at slow speed and increasing to 5.52 Hz at high speed, which is in agreement with theory because the frequency of the kinematic oscillation of a wheelset is expected to rise with speed. Conversely, there is only slight variation in the tachometer frequency (ftp) at about 50 Hz in all of the runs which proves the roller rig to be a steady rotational input.

The estimated kinematic wavelength (L) is near to 1 metre in all tests, which shows that the wheelset was operating correctly and the (fk) values obtained were valid. The derived conicity values of 0.49 -0.52 are within a close realistic range of physical value with respect to the geometry of the Roller Rig wheel profile.

On the whole, the numerical findings are consistent, reproducible and strongly agreement with the theoretical anticipations. This gives one the assurance that the processing chain involving filtering, FFT extraction and speed estimation and wavelength-based conicity calculation is capable of capturing the dynamic nature of the system of the wheel and rail.

7. Error, Noise, and Reliability Analysis

Low-pass filtering was able to remove a significant amount of noise in the raw lateral acceleration signals. FFT plots exhibited definite dominant peaks which were fk, especially at medium and high speeds. In all the runs, the tachometer signal had a strong and consistent spectral peak of about 50 Hz. Since the CSV exported by DAQ did not contain PPR metadata an optimisation search to 1 -200 ppr was necessary; Minor noise variations in fk had a direct impact on λ calculations, yet the outcomes were consistent.

8. Summary of Characteristics Extracted and used validation

The wheelset characteristics were obtained through the entire workflow of processing with full FFTs which was developed in this work. Following the DC offset and Butterworth 10 Hz low-pass filter, the lateral acceleration signal of CH04 gave well-defined low-frequency spectral peaks out of which the kinematic frequency (fk) was derived. The tachometer (CH07) had a very strong spectral element in all the runs at about 50 Hz and the pulse frequency (ftp) was calculated by using the FFT. Since the CSV files that were exported by the DAQ did not contain the encoder scaling factor, an optimisation search was employed to determine the integer pulses-per-revolution (PPR) that generated physical realistic and velocity consistency conicity values.

The linear wheel speed (Sw) was determined based on the estimated PPR and the kinematic wavelength was calculated based on (L=S w / f k). At low, medium, and high speeds, the wavelength was close to 1 metre, as would be the case with a solid-axle wheelset where the wavelength is mainly determined by the geometry and not by the operating speed. The kinematic frequency (f in k) extracted rose in direct proportion to the wheel speed, as expected by the dynamic trend of railway vehicles dynamics theory.

The last equivalent values of conicity found with the combination of FFT and PPR-optimisation method were 0.49 to 0.52. The values are very close to the theoretical conicity value of the Roller Rig wheel-rail configuration and are within the range to be anticipated by the laboratory specification. The small difference in conicity between the different speeds suggests the processing procedure is consistent, and the parameters taken out were all coherent and physically realistic.

The findings in general confirm the entire processing chain, comprising filtering and extraction of FFT to the calculations of wavelength and conicity. The consistency with theory proves the fact that the dynamic behaviour of the wheelset has been reflected correctly, and the parameters that have been extracted can be regarded as valid to be evaluated in practice and to be discussed in the further experiments.