Static Analysis of Railway Axle using Finite Element Method and Monitoring of Railway Bearing Based on Vibration Analysis

B Asngali¹, A Susanto¹*, M F Subkhan², I Martinez³, K Yamada⁴, F Majedi⁵

1. Introduction

Railway-axles is one of the critical components in train car. They holds the car body’s weight and should transmit it to the wheels [1]. Besides, railway axles are related to passenger’s safety during the trip. The railway-axle is always supported by some bearings. Therefore, railway axles and supported bearing are important in this case.

In some researchers, we can found investigations and experiments using different methods. Regularly checked of railway-axle by inspection of magnetic particle and ultrasonic testing were often provided. Besides, railway bearings are often monitored through vibration analyses. Vibration signal measured through real phenomena, such as vibration measuring of railway, is really nonlinear and non-stationary caused by many factors; machine elements which compose in a structure, rail lines track, and dynamic load. Therefore, it is needed an appropriate signal processing for feature extraction to get important information. Hilbert-Huang transform (HHT) is one of the advanced signal processing which accommodates the nonlinear and non-stationary nature [3] and it has been employed to monitor the mechanical systems. The authors utilized HHT to monitor milling states [4]–[6]. In this work, they used HHT for analysing the acceleration and strain signals to monitor milling states in order to chatter and bumping avoidance. They also utilized the HHT to analyse transient signals for monitoring chatter...
in turning process [7], [8]. Besides, Kalvoda and Hwang used HHT to analyse vibration for end-mill condition monitoring [9], [10]. However, the use of HHT for monitoring the rolling bearing on the railway axle is still trying the feasibility. In this research, the HHT is utilized for analysing the non-stationary and non-linear vibration signals measured during railway operation in order to monitor the single outer race fault of railway roller bearing. The railway axle bearing test rig was developed in this research.

2. Method

In this research, both static and dynamic analyses were applied. Static analysis was formed by finite element method. Besides, dynamic analysis was done by vibration analysis.

2.1. Static Analysis Method For Railway Axle Design

The design of the railway axle is done by 3D computer design. And then analysis it by finite element analysis (FEA). The model of railway axle are generated as shown in Fig. 1. Meshing is taken assembled design as shown in Fig. 2. On the other hand, the boundary conditions are shown in Fig. 3. Material used for the model is high carbon steel, which chemical and mechanical properties are shown in following Tables 1 and 2.

![Fig. 1. Assembly model of railway wheel-set in 3D model](image1)

![Fig. 2. Meshed model in finite element analysis.](image2)
Fig. 3. Boundary conditions

Table 1. The chemical compositions of material

|   | C (%) | Si (%) | Su (%) | P (%) | Ni/Cu (%) |
|---|-------|--------|--------|-------|-----------|
|   | 0.37-1.2 | 0.15   | 0.04   | 0.04  | 0.3       |

Table 2. Mechanical Property of Materials

| Materials                              | Vol               |
|----------------------------------------|-------------------|
| Modulus of elasticity (GPa)            | 84 GPa            |
| Ratio of Poisson                       | 0.28              |
| Ultimate Tensile strength (N/mm²)      | 550-650 N/mm²     |
| Tensile strength Yield (N/mm²)         | 320 N/mm²         |
| Density (Kg/mm³)                       | 7.85 x 10⁶ Kg/mm³ |

2.2. Dynamic Analysis Method By Vibration Monitoring

After modelling and analysis it using FEA, the laboratory scale of test-rig as shown in Fig. 1 were then manufactured for conducting dynamic analysis. On the dynamic analysis, the vibration signal was analysis using FFT and HHT. The signal was obtained by laboratory experiment. Experimental tests were conducted on the railway axle-bearings test-rig. This experimental set-up is explained by the schematic diagram as shown in Fig. 4.

Fig. 4. Schematic diagram of experimental test in railway axle-bearing test-rig
The signal obtained in this experiment were then analyzed using Hilbert-Huang transform (HHT). HHT consists of two consecutive procedures and Empirical mode decomposition (EMD) is the first procedure. By using EMD, the raw data can be simplified into a series of signals which is called intrinsic mode functions (IMFs). In the second step, the Hilbert transform is applied toward all IMFs for creating the time-frequency spectrum, which is called as HHT spectrum. EMD procedure and Hilbert transform were summarized in the references mentioned in [4]–[8]:

3. Result and Discussion

3.1. Static Analysis Using Finite Element Analysis

In the first case, we applied 55947 N of load and speed 100 km/h. The results are shown in following Fig. 5. In this figures, the shear stress and total deformation are in the left and right hand, respectively. In the second and third cases, we applied 73549 N and speed 100 km/h, and 60000 N and 100 km/h. The results are shown in Figs. 6 and 7. Based on this results, the stress and the deformation are small enough. Therefore, the design can be applied.

3.2. Dynamic Analysis by Vibration Monitoring

The signal obtained in the laboratory experiment is shown in Fig. 8. It can be seen that the signal was disturbed by some noises. Let us investigate the frequency content of this vibration signal by FFT is shown the result. Here, the spectrum also consists of some frequency, namely; spindle rotational
frequency (20 Hz) which is associated with spindle rotation of 1200 rpm and its harmonic frequencies (40 and 60 Hz).

![Vibration signal](image1)

**Fig. 8.** Vibration signal; (left) time-domain of clear vibration signal, (right) frequency spectrum of noisy vibration signal

### 3.3. Vibration analysis using HHT

The vibration signal shown in **Fig. 8** was then preprocessed by EMD first to get a set of IMF components. EMD produces seven IMF components and a monotonic residue as shown in **Fig. 9**. C1 to C7 in this figure are IMF components. On the other hand, C8 is the monotonic residues of the EMD process. Now let us investigate the frequency content of each IMF by FFT.

![IMF signals](image2)

**Fig. 9.** IMF signals obtained by EMD process

The frequency spectra that correspond to all IMF components for each case are shown in **Fig. 9**. According to this figure, IMF 3 and IMF 4 have significant vibration of the observed signal because they contained characteristic frequencies. IMF 3 consists of harmonic frequencies (40, 60 Hz). IMF 4 consists of spindle rotational frequency (20 Hz) and others are harmonic frequencies. It needs to be noted that the EMD can separate the significant.
The second step, Hilbert transform is applying to generate the HHT spectrum. The HHT spectra of each vibration signal are shown in Fig. 10. As can be seen, the energy gathers in line with certain frequency components, namely, spindle rotational frequency and harmonic of tooth passing frequency. Therefore, we can analyze the signal both in time and frequency domain using HHT.

4. Conclusion
In this work, static and dynamic analysis are presented. Static analysis is presented by analysis the design of railway axle through finite element analysis (FEA). Dynamic analysis is presented by analysing the outer race fault of the railway axle bearing based on vibration analyses. The important points are concluded as:

a. The results show that the stress and the deformation are small enough. Therefore, the design can be applied.

b. Simplified signals can be produced by EMD process of HHT (called IMF signals).

c. EMD can be combined with FFT method.

d. The drawback of FFT can be addressed using EMD-FFT combination.

e. HHT spectra provided powerful result for analysing signal in time-frequency view.
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