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Vibration Characteristic of Difference Rail Crack Via 3-D Numerical Method

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Abstract: This research to analyze the vibration characteristic of several design of crack classification by using the numerical modelling method by developed a wheel/rail contact model that simulates a wheel rolling on a track. The harmonic response of the railway vehicle wheelset is investigated by using ANSYS software. From the findings and trends of the frequency response shows the more lines of crack occurs on rail, the highest value of amplitude changes. The influencing factors due to the exposure of the contact surface area that have been exposed.

Keywords: Frequency Response, Vibration Characteristic, Wheel/Rail Interaction.

1. Introduction

Malaysia's railway is a significant by-product of the industrial revolution. Malaysia now has the world's fifth-largest railway network, and development is underway to transform railway as the primary mode of transportation [1]. Track maintenance, on the other hand, is required on a regular basis to keep it in good operating order, especially when high-speed trains are involved, to avoid any accidents [2]. Manual inspection takes time, money, and can even be dangerous. Train operations will also be delayed and disrupted because of this [3]. The ultimate goal of this study is to develop an active detection system that can detect rail defects as the wheel rolls on the rail. To achieve the goal, preliminary study was conducted to investigate the vibration characteristic of various rail conditions using numerical modelling method [4]. By using 3-D numerical method (ANSYS), a wheel/rail contact model that resembles a rolling wheel on a rail was developed to investigate the vibration characteristic of rail containing artificial cracks with different depth, direction, and quantity of cracks.

2. FEM Rail Model

The harmonic response of a wheel/rail contact model that resembles a rolling wheel on a rail was developed to investigate the vibration characteristic used ANSYS software as seen in Figure 1. The other parameter used for the wheel/rail model were represented in Table 1.

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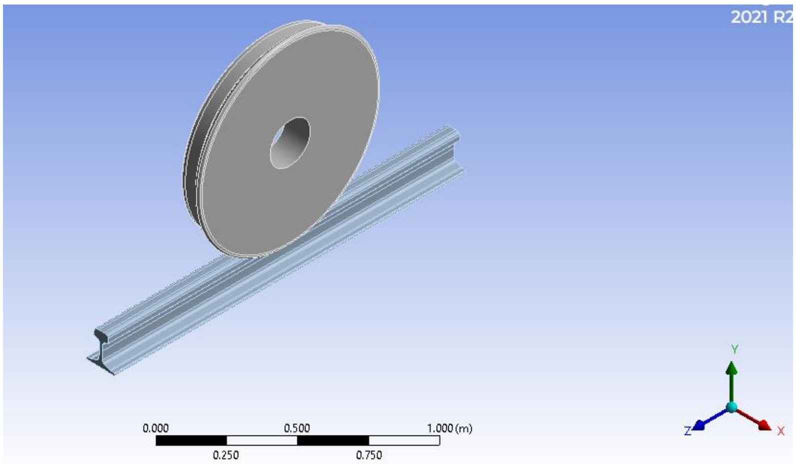

Figure 1: Model of Wheel and Rail

Table 1: Wheel/ rail parameters [5]

Parameter	Specification
Rail model	UIC 54
Wheel model	P8
Material	Structural Steel
Mass of wheel	3750 kg
Rail length	1750 mm

3. Crack Model

The critical size of a fracture should be defined as the size at which the structure can be predicted to fail. The effect of crack growth was simulated and varying the crack position and the length of the rail with three levels of crack depth. The model was developed as open crack with a "gap" across the rail head with 5mm length. A 1.5mm crack thickness was made at the top of the rail at the middle of the rail. Three different levels of crack depth were reproduced: Depth 1; 5mm, Depth 2; 10mm and Depth 3; 15mm. In this study, the 5 cases based on the condition of the rail were obtained to produced 13-frequency response.

- **First case:** The model was developed as free of flaws.
- **Second case:** The direction of the crack growth was at longitudinal (z-axis) with 1 line crack as seen in Figure 2. Three different levels of crack depth were reproduced: Depth 1; 5mm, Depth 2; 10mm and Depth 3; 15mm.
- **Third case:** The direction of the crack growth was at vertical (x-axis) with 1 line crack as seen in Figure 3. Three different levels of crack depth were reproduced: Depth 1; 5mm, Depth 2; 10mm and Depth 3; 15mm.

- **Fourth case:** The direction of the crack growth was at longitudinal (z-axis) with 3 lines crack as seen in Figure 4. Three different levels of crack depth were reproduced: Depth 1; 5mm, Depth 2; 10mm and Depth 3; 15mm.
- **Fifth case:** The direction of the crack growth was at vertical (x-axis) with 3 lines crack as seen in Figure 5. Three different levels of crack depth were reproduced: Depth 1; 5mm, Depth 2; 10mm and Depth 3; 15mm.

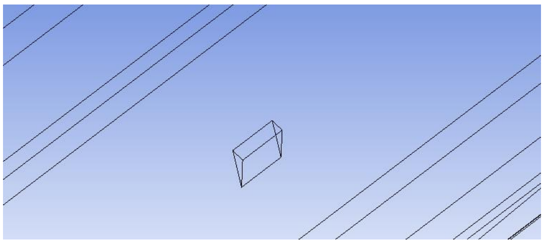

Figure 2: Case 2

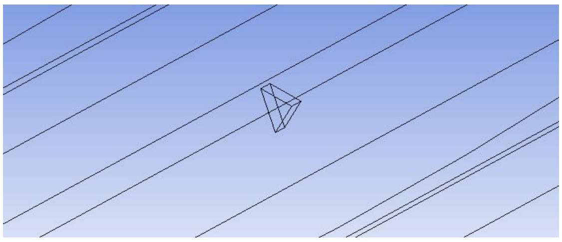

Figure 3: Case 3

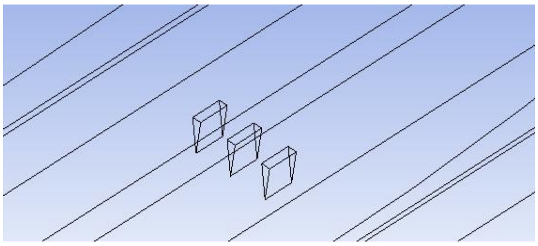

Figure 4: Case 4

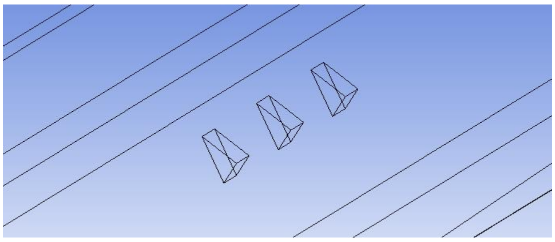

Figure 5: Case 5

4. Frequency Response Analysis

Frequency Response analysis is the process of determining the vibration characteristic for each rail condition by selected the harmonic response method [6]. All cases included free defect surface model were analysed by simulation using ANSYS version 2021 to obtain the difference of frequency response towards crack's pattern. In Figure 6 shows the result of frequency response for case 1 which had no defect along the rail. The comparison done based on the highest peak value of amplitude based on the condition of the rail as seen in Table 2.

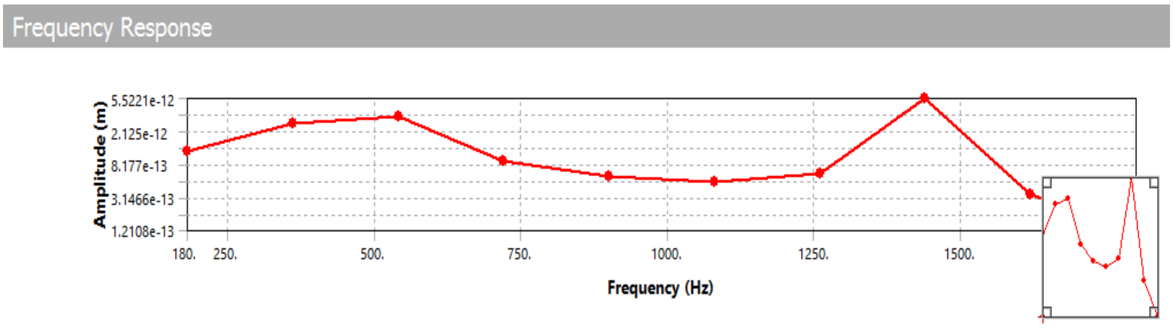

Figure 6: Frequency response for free defect rail

Table 2: The result obtains from frequency response categories by cases

Case	Length (mm)	Thickness (mm)	Depth (mm)	Frequency Range (Hz)	Highest Amplitude (x 10^{-11}) (m)
1st	[redacted]			1440	0.5522
2nd	5	1.5	5	180	1.4503
			10		1.4627
			15		1.4646
3rd			5	180	1.4843
			10		1.4708
			15		1.4566
4th			5	180	1.5860
			10		1.5721
			15		1.5521
5th			5	180	1.6546
			10		1.6300
			15		1.5655

4.1 Vibration Characteristic Analysis Towards Crack Growth Condition

To investigate the behavior of vibration characteristic, a sensitivity analysis of frequency response due to the influence of the crack conditions. As know, in this study, the crack was applied at the middle of the surface rail. The direction was longitudinal and vertical. As state before, the depth of the crack was consisted of 3 levels of depth (5mm, 10mm and 15mm). The analysis had classified into depth, direction, and quantity of crack growth.

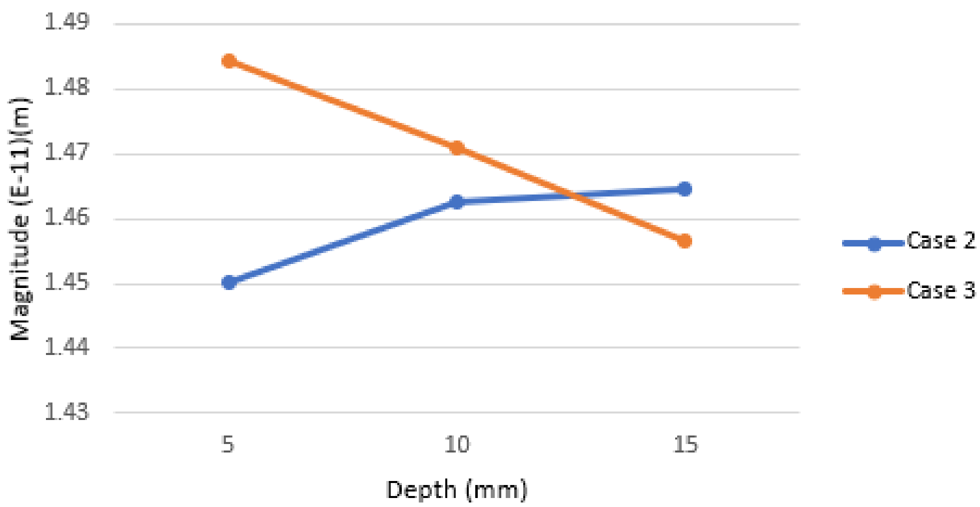

Figure 7: Crack Growth Direction

Table 3: Value of Amplitude Towards Crack Growth Direction

Depth (mm)	AMPLITUDE (m)	
	Crack Growth Direction	
	Longitudinal	Vertical
5	$1.4503 x 10^{-11}$	$1.4843 x 10^{-11}$
10	$1.4627 x 10^{-11}$	$1.4708 x 10^{-11}$
15	$1.4646 x 10^{-11}$	$1.4566 x 10^{-11}$

By identified the form the Figure 7 obtain, it shows that the value of amplitude for case 2 (horizontal direction) become higher when the depth become deeper. While for case 3 (vertical direction) shows that the deeper the crack, the lowest value of amplitude would be gotten. However, the most critical highest value of the amplitude signifies on vertical direction with the depth was 5mm as seen in Figure 7. By referred the values at Table 3, the percentage different between longitudinal and vertical with depth (5mm) was 2.29%. It proved that crack growth at vertical direction give the highest value compared to horizontal.

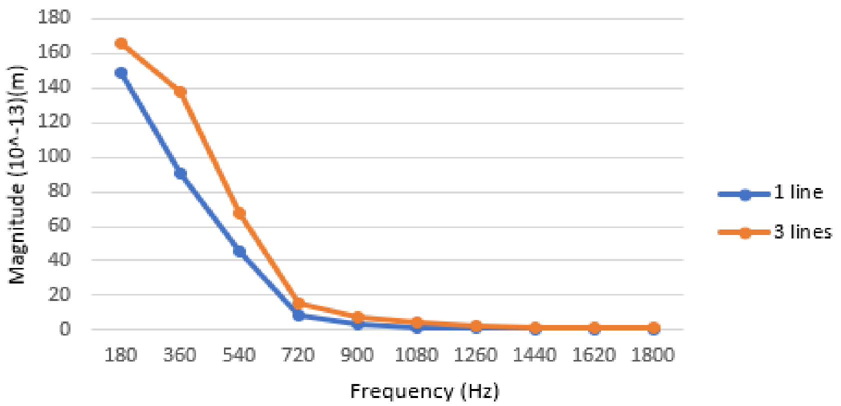

Figure 8: Quantity of Crack Growth

Table 4: Value of Amplitude Towards Quantity of Crack Growth

Depth (mm)	AMPLITUDE (m)	
	Quantity of Crack Growth with Depth; 5mm	
	1 line	3 lines
VERTICAL	$1.4843 x 10^{-11}$	$1.6546 x 10^{-11}$

As mentioned in previous analysis towards crack growth direction, the vertical direction (case 3) had the highest value of amplitude at depth 5mm. Based on Figure 8, it shows that the cracks with 3 lines give the highest value of amplitude compared to 1 line of crack. By referred the value of amplitude at Table 4, the percentage difference between the value for 1 line and 3 lines crack was 10.29%. It proved that the quantity of cracks was the biggest impacts towards vibration characteristic.

4.2 Discussion

This proves that the frequency response changes depending on the depth, direction, and quantity of crack growth – where quantity plays the biggest impact compared to direction factors as seen in Figure 9. It can be said that the greater the quantity of the crack's growth, the higher the value of amplitude will be.

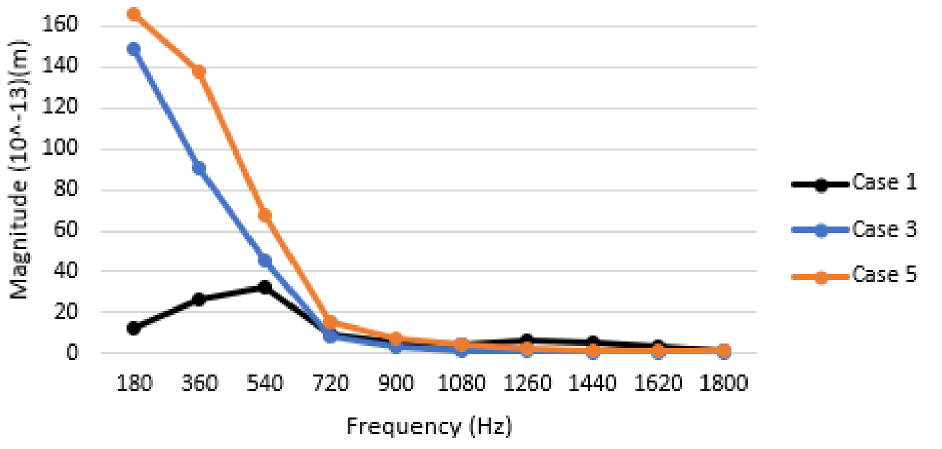

Figure 9: Graph of Critical Condition of Crack Growth Towards Vibration Characteristic

Based on all the analysis that has been made, the value of the magnitude changes due to the exposure of the contact surface area that is exposed to the crack surface area. . This is because, when the crack on the surface is in a vertical line, the surface traversed by the wheel on the crack is smaller and in a shorter period than the horizontal. Changes in surface flatness are instantaneous compared to the horizontal cracks. This will cause the tremors to occur more significantly. As for the crack depth, the wheel surface was not able to touch the inner surface of the crack if the crack has a deeper depth. In contrast, cracks with shallower depth are more likely to be touched by the surface of the wheel. In short, if it occurs in a vertical shape, the magnitude value will increase if the quantity of resulting crack line higher.

However, a horizontal crack with only 1 crack line will cause the wheel to traverse a longer distance than time compared to when the crack was vertical. This gives an opportunity for the wheel surface to touch the inside of the crack. Therefore, the deeper the crack was, the higher the value of the resulting amplitude. Nonetheless, the value will not be higher than the value produced by cracks that occur in a vertical line. The vibrations that occur are lesser than the vertical. In the situation where the cracks produced by the longitudinal line was more in number, the amplitude value will be higher than the value produced for a single line because there was more contact surface are that are exposed.

5. Conclusion

Simulation results were analysed where it was found that the frequency response changes depending on the depth, direction, and quantity of crack growth – where quantity plays the biggest impact among these three factors. It can be said that the greater the quantity of the crack's growth, the higher the value of amplitude will be. From the results, it can be concluded that it would be viable to develop an active rail defect detection system that able to differentiate whether the rail contain defects or not from the unique vibration response.

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