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Nadal Critical and Ride Index Characteristics of Inspection Train Using Universal Mechanism Software on Different Back to Back

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Abstract

This research conducted dynamic simulations using the Universal Mechanism software with variations between back to back widths of 1000 mm and 990 mm, focusing on the relationship between train operating speed, vibration levels, and passenger comfort index during operation on a small curve on the PPI Madiun track with a radius of R42. The issue investigated in this study stems from PM No. 17 of 2011, which sets the standard back-to-back usage at 1000 mm. It is crucial to understand the characteristics of each back to back setting, as the operational track gauge used is 1067 mm. The simulation results indicate that the nadal criterion and ride index are more favorable with the 990 mm back to back setting. At a speed of 25 km/h, the nadal criterion for the 990 mm setting was 0.636, compared to 0.670 for the 1000 mm setting, and the ride index for the 990 mm setting at this speed was 1.315449, compared to 1.288552 for the 1000 mm setting. These results are considered valid as the error value in the data validation calculations was less than 10%, specifically 8.26%.

Keyword: Nadal, Ride Index, Back to Back, Universal Mechanism, Lateral Force.

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1. Introduction

In Indonesia, railways are currently one of the mainstay modes of transportation that are of interest to many people. Railroad facilities have various types that can be distinguished, namely locomotives, trains, carriages and special equipment [1]. Inspection trains are one of the special equipment types of railroad facilities, inspection trains are commonly used to inspect railways, maintenance and repair, maintenance testing, and many others.

A train certainly does not always run straight and gentle considering the geography in Indonesia has many mountains and hills scattered throughout the island. Therefore, a railroad track must have a rail geometry that helps the train run, such as slope, curve, railroad width, connection, and railroad elevation[2] [3]. In addition to railroad geometry, there are other factors that affect the running of the train, namely track irregularity / railroad irregularities that often occur on a line caused by the age of the

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railroad, improper railroad construction, receiving excessive loads, and so on. Track irregularity has several types including alignment, vertical, gauge, cant, twist [2], [4], [5], [6].

PPI Madiun Inspection Train

The use of the PPI Madiun inspection train is run on an internal track with a back to back width of 1000 mm and a track width of 1067 mm and the largest radius is at R149 and the smallest radius is at R42. The operation of a train in a small curve certainly has its own critical characteristics and ride index. The relationship of the curve radius to the wheelbase distance, wheel diameter, and the amount of back to back distance also affects the train to be able to turn in the curve or not [7].

In Indonesia, there are facilities that have different back to back distances, for example conventional trains operated by PT KAI use a back to back of 1000 mm which refers to PM. No. 17 of 2011 [1] regulates the “Standards, Procedures for Testing and Certification of Carriage Feasibility”, while the facilities operated by PT MRT Jakarta, and KRL facilities operated by PT KCI use a back to back of 990 mm with reference to international standards from Japan, namely JIS E 4502-1 Rolling Stock Axles Quality Requrements [8]. The difference in the distance from back to back has its own criteria for the facilities operated. The magnitude of the nadal and ride index criteria affects the level of safety and comfort of the facility when operated [9][10][11][12][13].

2. Research Method

The train design used for dynamic simulation is a design with one train unit consisting of one carbody, two bogie frames, and four wheelsets that are adjusted to existing specifications, including object mass, object size, and other parameters. The design of the train has several steps to go through, from the design of the lower frame to the carbody. Designing is done with Universal Mechanism software. The steps are as follows:

In the bogie frame design above, there are two separate parts, namely the bogie end frame and the bogie side frame. The end frame bogie is divided into two, namely the outer end frame and the inner end frame.

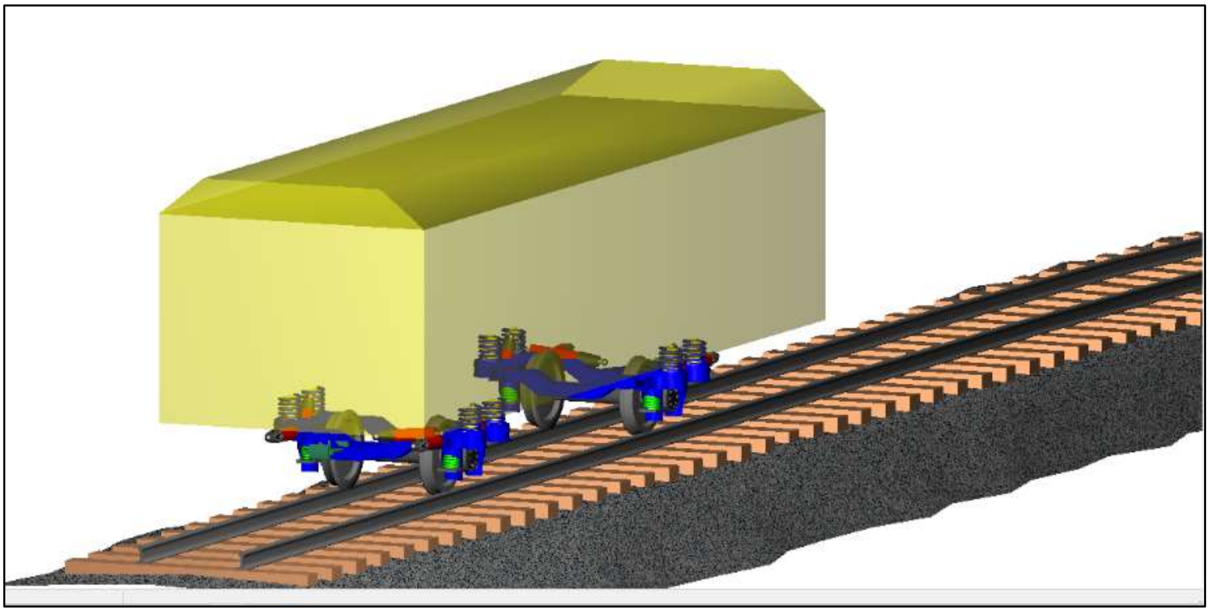

Figure 1 Design drawing of PPI Madiun Inspection Train

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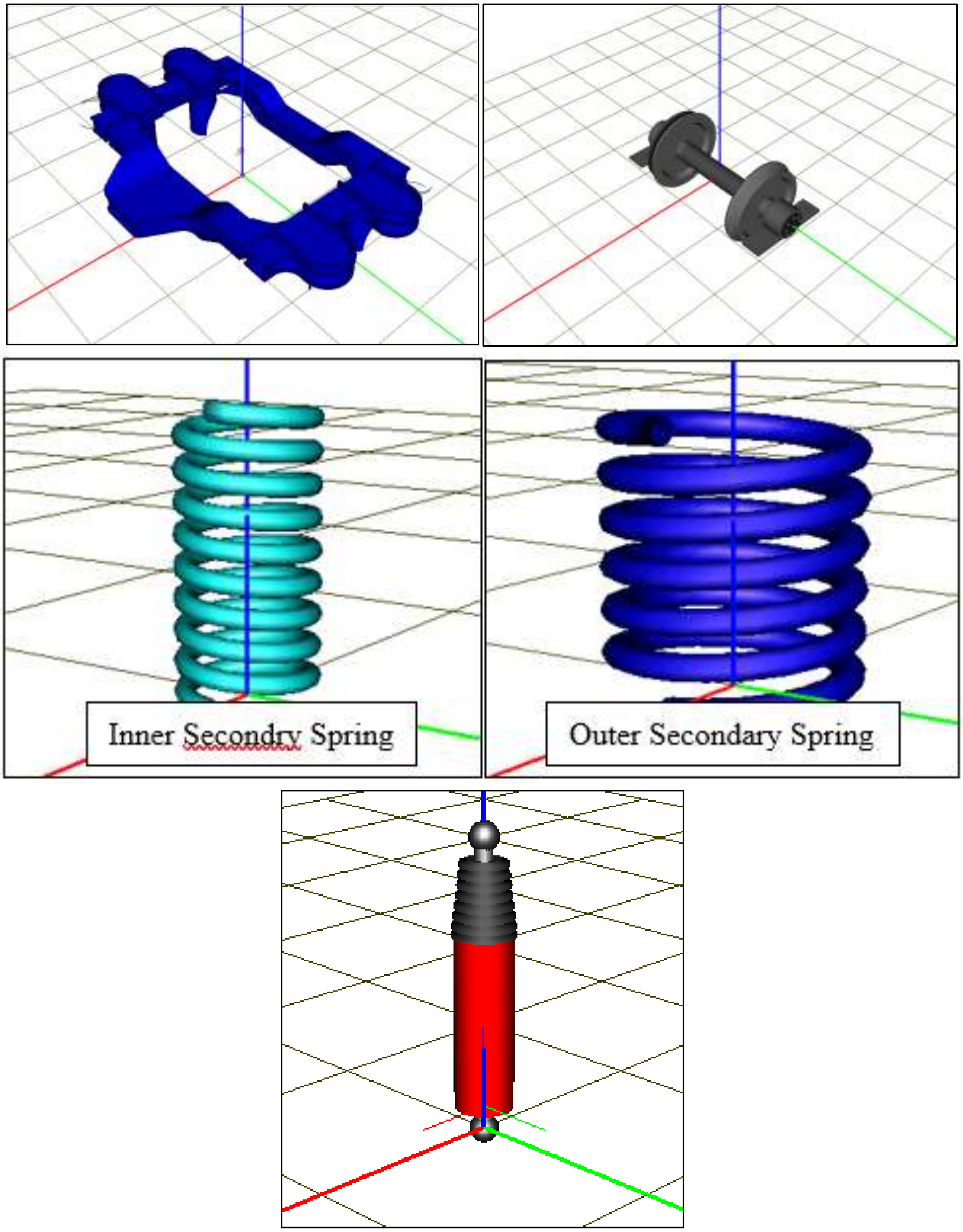

Figure 2. (a) Bogie Frame Design (b) Wheelset Design (c) Inner Secondary Spring (d) Outher Secondary Spring (e) Damper

The addition of wheelsets with sizes and dimensions adjusted to the provisions of the technical specifications where in this study using 2 wheelset designs, namely the distance between 2 wheels 1000 mm and 990 mm. The wheelset is included as a sub assembly in the Universal Mechanism. The addition of spring serves to reduce the vibration that occurs on the train when simulated. There are two

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kinds of spring that will be added, namely secondary spring and primary spring. The addition of a damper that functions to reduce vibrations that occur in all directions. The damper used in this Universal Mechanism uses components that already exist in the library, just adjusted to different field requirements such as damper coefficients, damper length, and the direction of the existing damper force. The addition of the wheel tread design to the universal mechanism application in accordance with the variations used, namely the back to back 990 mm using a radius of 1:20 and back to back 1000 mm using a radius of 1:40.

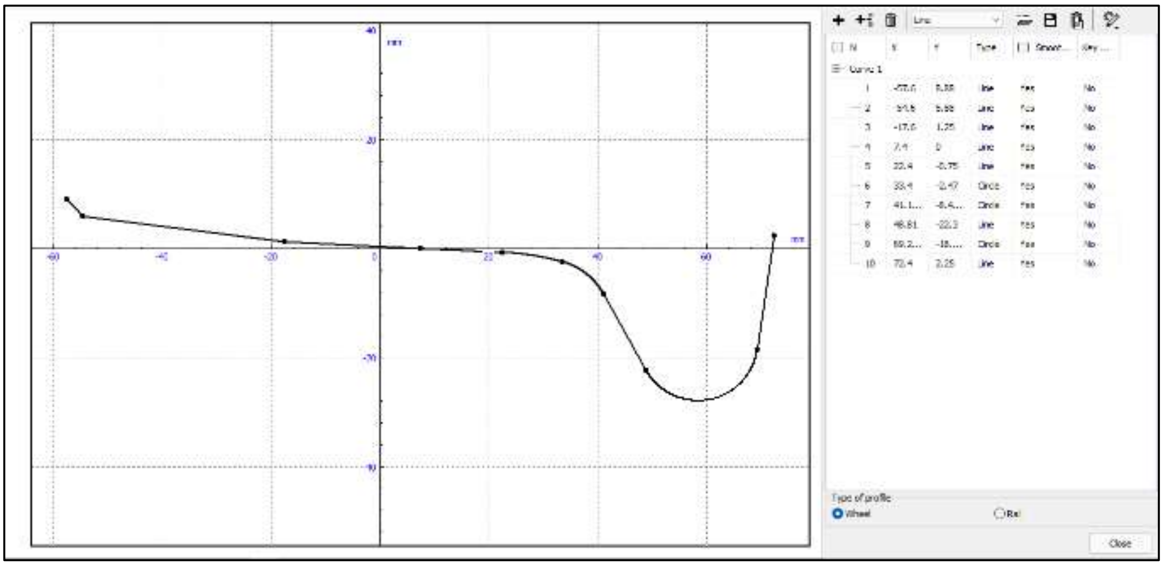

Figure 3. Wheel Tread Design Radius 1:20

Figure 12 shows the wheel design with a radius of 1:20 used on the 990 mm back to back, the center point of the wheel at coordinates (7,4), (0) with a clearance of 9 mm.

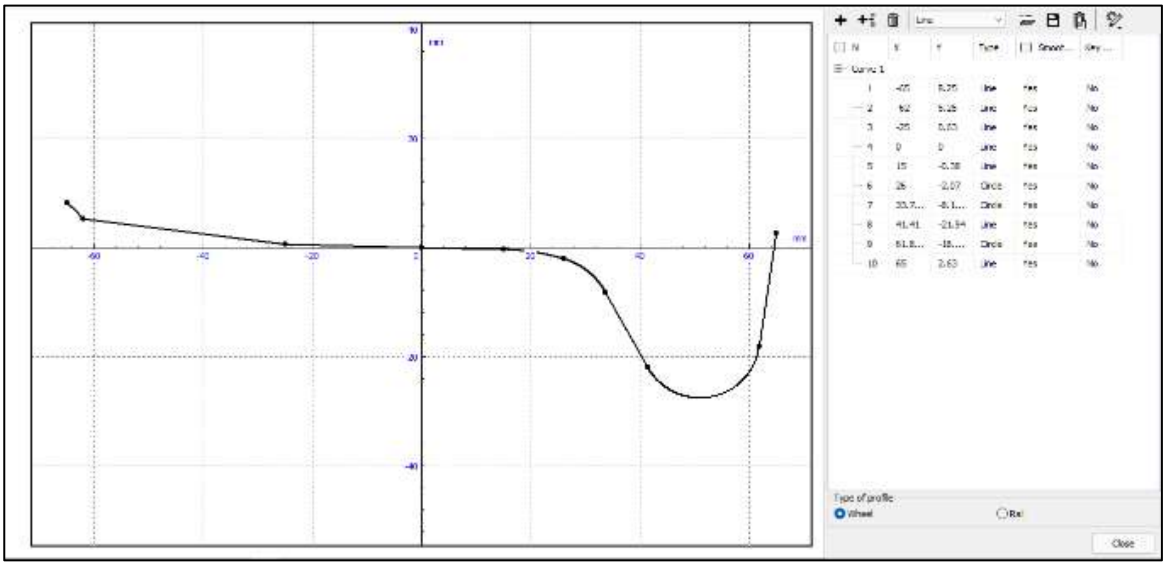

Figure 4. Wheel Tread Design Radius 1:40

Figure 4. shows the wheel design with a radius of 1:40 used on a 1000 mm back to back, the center point of the wheel at coordinates (0), (0) with a clearance of 4 mm. Validation of the train design is carried out by means of human calculations through Microsoft Exel software with the curving bogie

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formula. Furthermore, the validation of design calculations will validate the results of simulations conducted with the Universal Mechanism application. In this step, the total lateral force simulation is carried out which aims to find out the total lateral force of the train that occurs when passing through an arch with a radius of 42 meters on the PPI Madiun track.

3. Results And Discussion

3.1 Design Validation

Validation is done by comparing the lateral force values on the wheels from the analytical calculation with the simulation results, when the train moves on a curved track with radius R42.

3.1.1 Simulation of Total *Lateral Force*

The simulation of total lateral forces aims to find out the total lateral force of the train that occurs when passing through an arch with a radius of 42 meters on the PPI Madiun track using Universal Mechanism software.

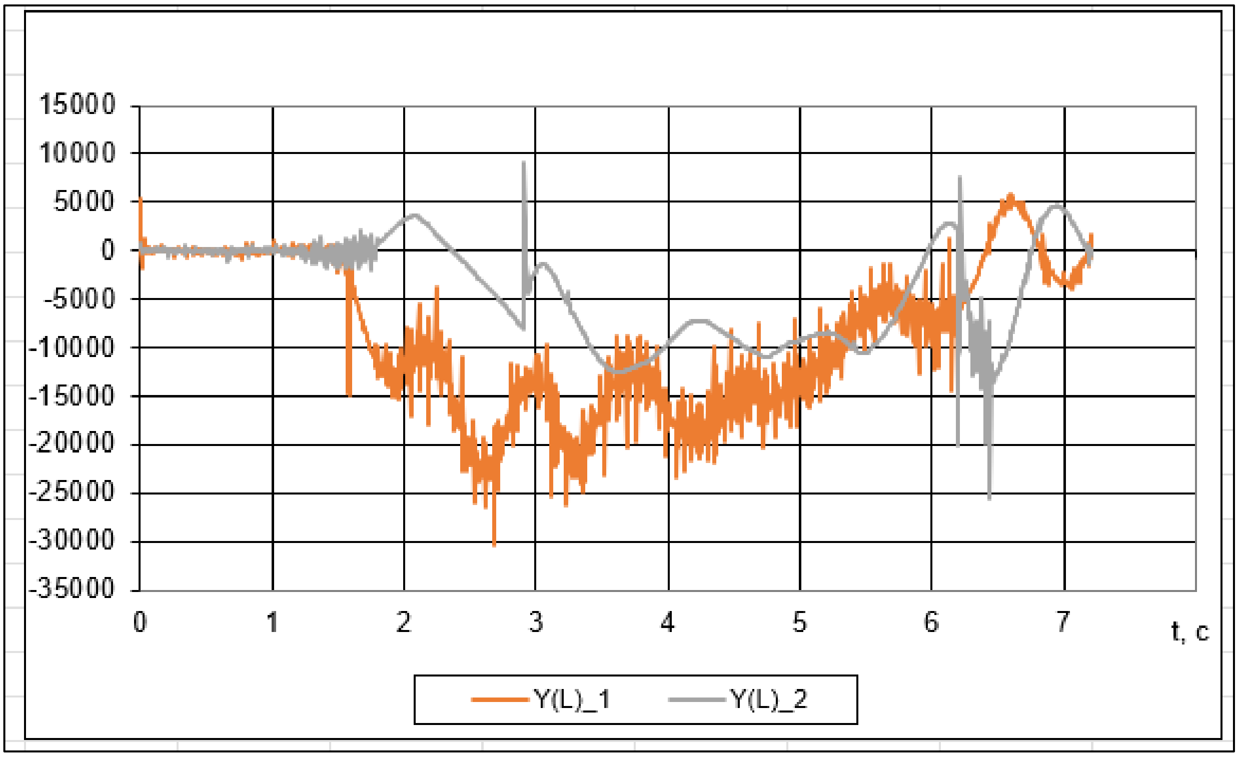

Figure 5. Simulation Results in the Form of Diagrams in Microsoft Excel

So the result obtained from the lateral force simulation is 30352 kg. This result is used for comparison with the curving bogie formula calculation in the data validation process.

3.1.2 Calculation of *Curving Bogie Formula*

In this analytical validation stage, the first step is to calculate, RM as the center of friction.

2b = 5 m / 5000 mm
s = 40 mm
R = 42 m / 42000 mm

$$\text{ɿ}_{RM} = b + \frac{sR}{2b} \quad (1)$$

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$\text{ʅ}_{RM} \quad = 25000 + \frac{40.42000}{5000}$

$\text{ʅ}_{RM} \quad = 2836 \text{ mm}$

$\text{ʅ}_{RM} \quad = 2{,}83 \text{ m}$

From the above calculation, the value of the friction center *of* the ICDE train design is 2.83 m from the front axle. The next step is to calculate the total lateral force that occurs

$$H_2 - H_1 = T_{\eta 2L} + T_{\eta 2R} - T_{\eta 1L} - T_{\eta 1R} - (Q_{1L} + Q_{2R} + Q_{2L} + Q_{2R})\frac{ay}{g} \tag{2}$$

In completing the above calculations, there are several steps that must be completed first, namely

1) Calculating the amount of rear wheel lateal creep force

$$T_{\eta 2L,R} = \mu Q_{2L,R} cos\xi_{2L,R} \tag{3}$$

$$\begin{aligned} cos\xi_{2L,R} &= \frac{2b - \text{ʅ}_{RM}}{q2L,R} \\ &= \frac{5-2{,}83}{\sqrt{0{,}56^2+2{,}17^2}} \\ &= 0{,}968277 \\ &= 0.36 \text{ x } 6.875 \text{ x } 0.968277 \\ &= 2.3964864 \text{ (2.4 tons)} \end{aligned}$$

2) Calculating the lateral creep force of the front wheel

$$T_{\xi 1L,R} = \mu Q_{1L,R} cos\xi_{1L,R} \tag{4}$$

$$\begin{aligned} cos\xi_{1L,R} &= \frac{\text{ʅ}_{RM}}{q1L,R} \\ &= \frac{2{,}83}{\sqrt{0{,}56^2+2{,}83^2}} \\ &= 0{,}9809786 \\ &= 0.36 \text{ x } 6875 \text{ x } 0.6809786 \\ &= 2.4279220 \text{ (2.43 tons)} \end{aligned}$$

3) Calculating vertical force and centripetal force values

$$(Q_{1L} + Q_{1R} + Q_{2L} + Q_{2R})\frac{ay}{g} \tag{5}$$

$$Q_{iL,R} = 6{,}875\ ton$$

$$\begin{aligned} \frac{ay}{g} &= \frac{V^2/R}{g} \\ &= \frac{6{,}944444^2/42}{9{,}81} \\ &= \frac{1{,}148221}{9{,}81} \\ &= 0{,}117046 \end{aligned}$$

From all the above calculations that have been carried out, the calculation of the total lateral force can be completed.

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$$H_2 - H_1 = T_{\eta 2L} + T_{\eta 2R} - T_{\eta 1L} - T_{\eta 1R} - (Q_{1L} + Q_{2R} + Q_{2L} + Q_{2R})\frac{ay}{g} \quad (6)$$

$H_1 - H_2$ = 2,4 + 2,4 - 2,43 - 2,43 (6,875 + 6,875 + 6,875 + 6,875) 0,117046

$H_1 - H_2$ = 3.28164 (3.3 *tons*) (*V* 25 *km/h)*

So the value of the total lateral creep force from the above calculation is 3.28164 tons. These results are used for comparison with the simulation results.

3.1.3 Comparison of Simulation Results

$$\% \, error = \frac{Simulation\ results - Analytical\ Results}{Simulation\ results} \times 100\% \quad (7)$$

$$\% \, error = \frac{30.352 - 32.861{,}64}{30.352} \times 100\%$$

$$\% \, error = \frac{2509{,}64}{30352} \times 100\%$$

$$\% \, error = 8{,}26\,\%$$

From the calculation data of the comparison of analytical results with simulation results, it can be declared valid, because the results of the error value are still below 10%. In accordance with the statement of (Puji et al. 2009) The model is said to be valid enough if the absolute deviation (APD) is smaller than 10%.

3.2 Nadal's Criterial Simulation

The simulation results are in the form of critical values of radial (Y/Q) from back to back variations of 990 mm and 1000 mm presented in table form. This value is a comparison of the value between lateral (L) and vertical (V). This lateral and vertical value is in the form of a force that appears and can cause the wheels to come off the rail, so that the results of (Y/Q)/(L/V) are obtained as follows.

Table 1 Simulation Results of *Nadal's Criteria*

Velocity (km/h)	**Value (Y/Q)**	**Rel Tipe UIC 54**							
		back to back							
		990 (*mm*)				1000 (*mm*)			
		front wheel		Rear Wheel		Front Wheel		Rear Wheel	
		R1	L1	R2	L2	R1	L1	R2	L2
5	Y/Q	0.425	0.776	0.585	0.418	0.471	0.799	0.667	0.426
15	Y/Q	0.426	0.510	0.365	0.336	0.419	0.548	0.396	0.355
25	Y/Q	0.429	0.484	0.636	0.395	0.421	0.452	0.670	0.398

After the simulation is carried out, the results will be obtained in the form of a graph of each variation tested, namely at a back to back of 990 mm and also a back to back of 1000 mm. In each back to back there are 4 variables that have their own values, namely the right and left front wheels, and also the right and left rear wheels.

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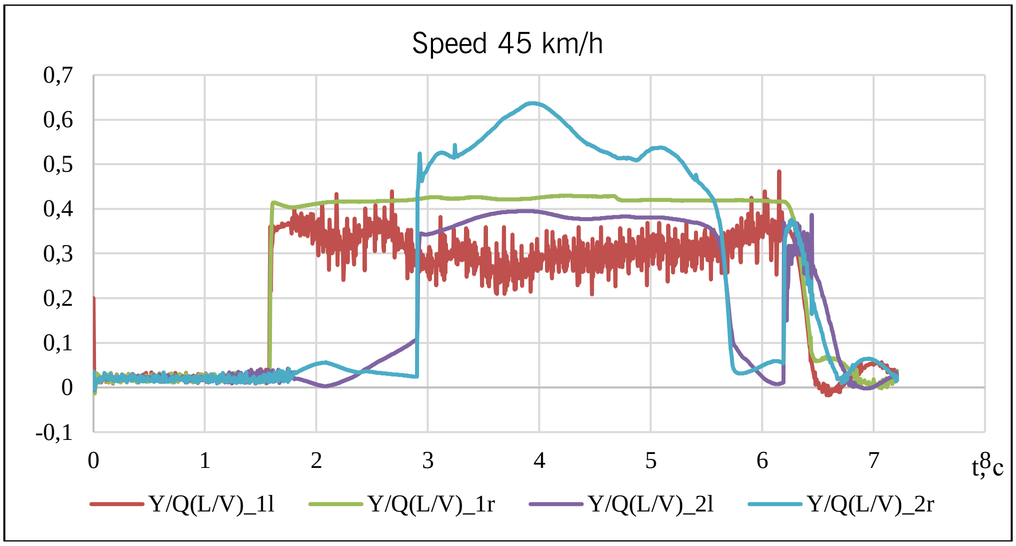

Figure 6. 990 mm Nadal Back to Back Criterial Chart 25 km/h Speed

Figure 6. shows the value of the nadal criterion when a dynamic simulation is carried out at a speed of 25 km / h, with the largest value in the rear right wheel 0.636 and the lowest in the rear left wheel 0.395.

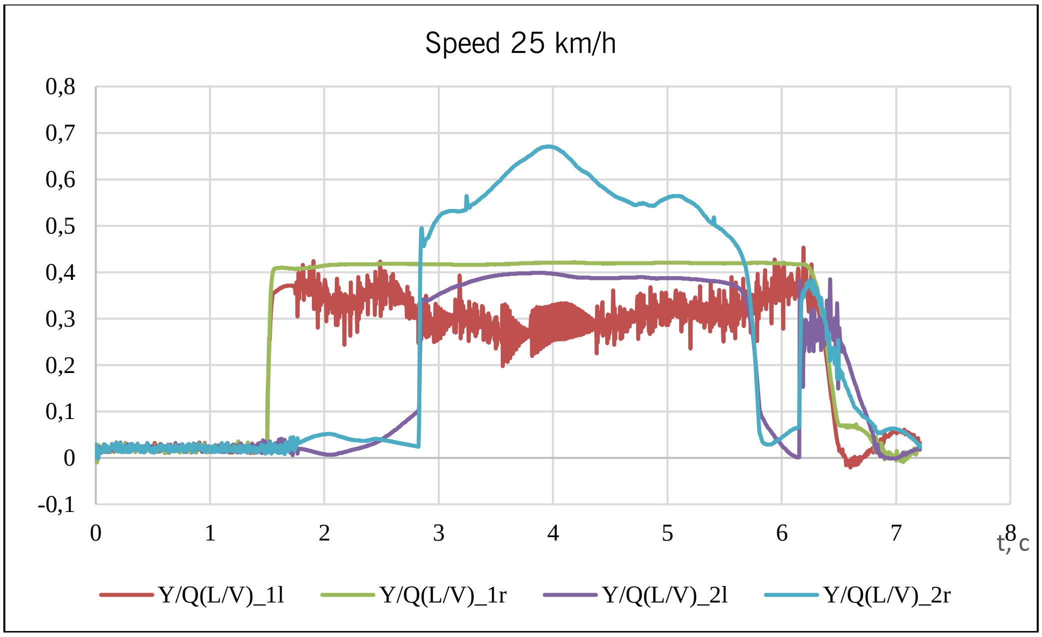

Figure 7. 1000 mm Nadal Back to Back Criterial Chart 25 km/h Speed

Figure 7. shows the value of the nadal criterion when a dynamic simulation is carried out at a speed of 25 km / h, with the largest value in the rear right wheel 0.670 and the lowest in the rear left wheel 0.398.

3.3 Ride Index Simulation

The *ride* index value is obtained by reviewing the vibration value of the train body, so from the two test variations using back to back 990 mm and 1000 mm, the following results are obtained.

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Table 2 *Ride Index* Simulation Results

Speed (km/h)	Ride index Maximum			
	Back to back 990 mm	Description	Back to back 1000 mm	Description
5	0.378	special	0.382	special
15	0.485	special	0.468	special
25	1.31	special	1.288	special

3.4 Graph of Ride Index Simulation Results

After the simulation is carried out, the results will be obtained in the form of a graph of each variation tested, namely at a back to back of 990 mm and also a back to back of 1000 mm. The graph will be presented separately according to the variations made.

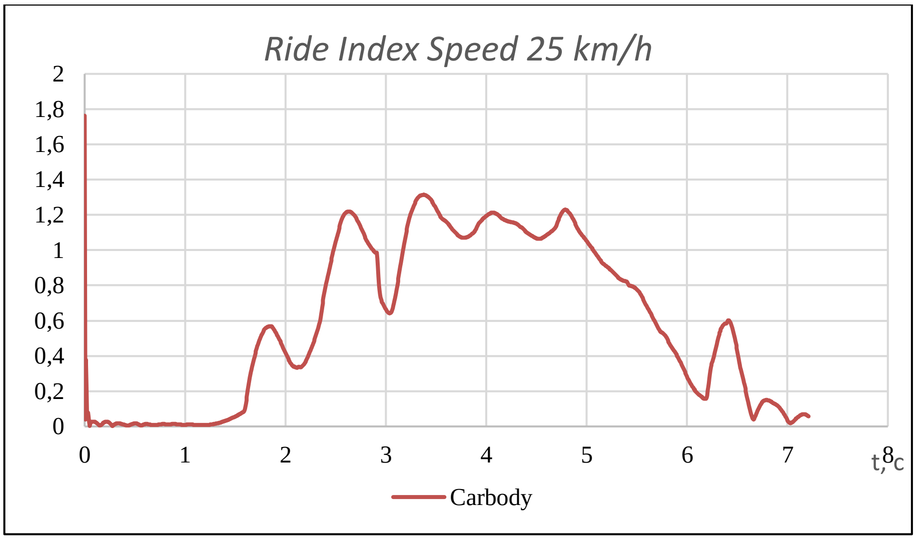

Figure 8. Graph of Ride Index Back to Back 990 mm 25 km/h Speed

Figure 8. shows the value of the ride index value when the dynamic simulation is carried out is 1.3. This value is for 990 mm back to back with a speed of 25 km / hour.

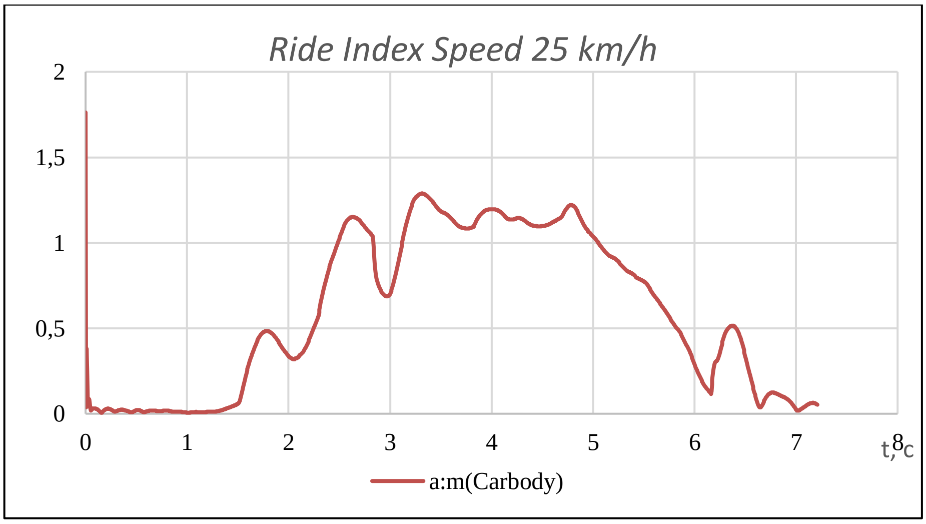

Figure 9. Graph of Ride Index Back to Back 1000 mm 25 km/h Speed

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Figure 9. shows the value of the ride index during dynamic simulation is 1.28. The value is for back to back 1000 mm with a speed of 25 km/hour.The simulation results obtained from the Longitudinal Train Dynamic simulation are carried out to find the comfort and safety index of the wheels when passing through a critical curve with a radius of 42 m. Each back to back variation used has its own characteristics at each different speed. The output of this simulation is the L/V graph. This L/V graph is a vibration in the Lateral (L) and Vertical (V) directions. Lateral vibration is vibration that occurs in the horizontal direction, while vertical vibration is a vibration perpendicular to the axis or in the vertical direction. The characteristics of the 990 mm back to back with the results obtained show the largest value when operating through the R42 curve at a speed of 25 km / h of 0.636, while the 1000 mm back to back gets a result of 0.670. Back to back 990 mm gets smaller nadal criterial simulation results than back to back 1000 mm. The greater the nadal criterial value the more dangerous the train is when operating [14][15][16].

4. Conclusion

Based on the results of the research and discussion, the following conclusions can be drawn:

1. The characteristics of the nadal criterial using back to back 990 mm and 1000 mm can be known by simulating using universal mechanism software. The results of the data obtained during the simulation show differences in values/characteristics at speed variations in each back to back. At back to back 990 mm the L / V value obtained at a speed of 5 km / h is 0.776, at a speed of 15 km / h of 0.510, at a speed of 25 km / h of 0.636. While at back to back 1000 mm the L / V value obtained at a speed of 5 km / h is 0.799, at a speed of 15 km./ h is 0.548, at a speed of 25 km / h is 0.670.
2. The characteristics of the ride index using back to back 990 mm and 1000 mm can be known by simulating using universal mechanism software. The results of the data obtained during the simulation show differences in the value/characteristics of speed variations in each back to back. The ride index value is very linear with the speed variation used in each back to back, the faster the train travels the greater the ride index value, and vice versa. This is evidenced in the 990 mm back to back at a speed of 5 km / h resulting in a value of 0.378034, at a speed of 15 km / h of 0.485655, and at a speed of 25 km / h of 1.315449. While the back to back 1000 mm at a speed of 5 km/h produces a value of 0.382114, at a speed of 15 km/h it is 0.468952, and at a speed of 25 km/h it is 1.288552.

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References

[1] Peraturan Menteri 175 Tahun 2015 Tentang Standar Spesifikasi Teknis Kereta Kecepatan Normal Dengan Penggerak Sendiri.

[2] E. D. J. Putra, Y. A. Handoko, and I. Herman, “Pemodelan dan Simulasi Dinamik Kereta Tilting pada Lintas Kereta Api,” *Jurnal Penelitian Transportasi Darat*, vol. 24, no. 1, pp. 35–50, Jun. 2022, doi: 10.25104/jptd.v24i1.2024.

DOI: https://doi.org/10.71225/jstn.v1i4.66

[3] M. Kassner, “Fatigue strength analysis of a welded railway vehicle structure by different methods,” *Int J Fatigue*, vol. 34, no. 1, pp. 103–111, Jan. 2012, doi: 10.1016/j.ijfatigue.2011.01.020.
[4] G. Mikheev, E. Krugovova, and R. Kovalev, “Railway vehicle and bridge interaction: Some approaches and applications,” in *WIT Transactions on the Built Environment*, 2010, pp. 593–604. doi: 10.2495/CR100551.
[5] V. Petrenko, “Simulation of Railway Vehicle Dynamics in Universal Mechanism Software,” in *Procedia Engineering*, Elsevier Ltd, 2016, pp. 23–29. doi: 10.1016/j.proeng.2016.01.033.
[6] K. Knothe and S. Stichel, *Rail vehicle dynamics*. Springer International Publishing, 2016. doi: 10.1007/978-3-319-45376-7.
[7] Utomo, Atmaja, Tantra “Simulasi Pengaruh Diameter Roda 660 mm, 774 mm dan 860 mm Serta Variasi Kecepatan Terhadap Kriteria Nadal dan Ride Index Lintas R80 LRTPalembang”, Jurnal Perkeretaapian Indonesia Madiun. 2023.
[8] Y. Wang, X. Liu, Z. Li, X. Xu, J. Peng, and M. Zhu, “Research on evolution law of material comprehensive performance of S38C steel for high speed railway axle,” in *International Journal of Modern Physics B*, World Scientific Publishing Co. Pte Ltd, Jan. 2019. doi: 10.1142/S0217979219400125.
[9] T. Jendel, Prediction of wheel profile wear – comparisons with field measurements, Wear 253 (2002) 89–99, https://doi.org/10.1016/S0043-1648(02)00087-X.
[10] M. Podworna, Modelling of random vertical irregularities of railway tracks, Int. J. Appl. Mech. Eng. 20 (2015) 647–655, https://doi.org/10.1515/ijame-2015-0043.
[11] P.A.P. Pacheco, R.C. Esteves Júnior, T.J.P. Mendes, B. Meireles, I. Formigon, Tool wear analysis in milling of locomotives wheels, SN Appl. Sci. 3 (2021), https://doi.org/10.1007/s42452-020-04020-2.
[12] W. Zhu, D. Yang, Z. Guo, J. Huang, Y. Huang, Data-driven wheel wear modelling and reprofiling strategy optimization for metro systems, Transport. Res. Rec. 2476 (2015) 67–76, https://doi.org/10.3141/2476-10.
[13] N.F. Strey, A.B. Rezende, R.d.S. Miranda, S.T.d. Fonseca, P.R. Mei, C. Scandian, Comparison of rolling contact fatigue damage between railway wheels and twin- disc test specimens, Tribol. Int. 160 (2021), https://doi.org/10.1016/j.triboint.2021.107037.
[14] E. Magel, J. Kalousek, Designing and assessing wheel/rail profiles for improved rolling contact fatigue and wear performance, Proc IMechE Part F: J Rail and Rapid Transit. 231 (2017) 805–818, https://doi.org/10.1177/0954409717708079.
[15] M. Hiensch, M. Steenbergen, Rolling Contact Fatigue on premium rail grades: damage function development from field data, Wear 394–395 (2018) 187–194, https://doi.org/10.1016/j.wear.2017.10.018.
[16] J.P. Srivastava, M.V. Ravi Kiran, P.K. Sarkar, V. Ranjan, Numerical investigation of ratchetting behaviour in rail steel under cyclic rolling-sliding contact, Procedia Eng. 173 (2017) 1130–1137, https://doi.org/10.1016/j.proeng.2016.12.079.

DOI: https://doi.org/10.71225/jstn.v1i4.66