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# Study of Railway Wheel Service Period Prediction at Maximum Curved Distance Based on Flange Wear Level

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Abstract

The study aimed to comprehensively analyze the impact of curves on railway tracks on the wear level of train wheel flanges. The case study focused on the Yogyakarta-Kutoarjo line, which presented a unique track with several curves. Data collection involved meticulous measurements of wheel flange wear on regularly operating trains along the line, along with a thorough analysis of track geometry, train operating speeds, and wheel materials. This quantitative research employed the linear regression method to analyze the data. The findings revealed a notable correlation between wheel flanges A and B's wear levels and curves on the Yogyakarta-Kutoarjo railway line, with 1.036 mm and 1.495 mm of wear on wheels A and B, respectively. The R2 value falling within the range of 0.7521 to 0.9678 indicated a significant influence on wheel flange wear. The study also identified the furthest curved distances, 102,304.80 km for wheel A and 136,857.00 km for wheel B. This research is anticipated to make meaningful contributions to the advancement of railway track and wheel maintenance, ultimately enhancing railway systems' safety and operational efficiency.

Keywords: *Curve Distance, Wear, Wheel Flange*

Abstrak

Penelitian ini bertujuan untuk menganalisis secara komprehensif dampak tikungan pada jalur rel kereta api terhadap tingkat keausan flens roda kereta. Studi kasus difokuskan pada jalur Yogyakarta-Kutoarjo, yang memiliki karakteristik unik dengan beberapa tikungan. Pengumpulan data melibatkan pengukuran keausan flens roda pada kereta yang beroperasi secara rutin di jalur tersebut, serta analisis menyeluruh terhadap geometris jalur, kecepatan operasi kereta, dan material roda. Penelitian kuantitatif ini menggunakan metode regresi linier untuk menganalisis data. Hasil penelitian menunjukkan adanya korelasi yang signifikan antara tingkat keausan flens roda A dan B dengan tikungan pada jalur kereta api Yogyakarta-Kutoarjo, dengan tingkat keausan masing-masing sebesar 1,036 mm dan 1,495 mm pada roda A dan B. Nilai $R^2$ dalam rentang 0,7521 hingga 0,9678 mengindikasikan pengaruh yang signifikan terhadap keausan flens roda. Penelitian ini juga mengidentifikasi jarak tikungan terjauh, yaitu 102.304,80 km untuk roda A dan 136.857,00 km untuk roda B. Penelitian ini diharapkan memberikan kontribusi yang berarti bagi pengembangan pemeliharaan jalur rel dan roda kereta api, sehingga dapat meningkatkan keselamatan dan efisiensi operasional sistem perkeretaapian.
Kata Kunci: *Jarak Tikungan, Keausan, Flens Roda*

## INTRODUCTION

The railway system plays an important role in facilitating community mobility, and the condition of the facilities and infrastructure influences the performance of the railway system. One component of the railway facility that runs on rails is the wheel section. When the facility is running, friction will occur between the rail head and the wheels, where the friction does not always occur in the same position because the wheels always move left and right due to shifts in the width of the rail track and the condition of the rail surface (Sari et al., 2021). The railway track allows wear on the rails because they are often passed by the train itself (Yudistirani et al., 2021).According to PM number 175 of 2015 concerning the Technical Specification Standards for Normal Speed Trains with Self-Propellant, the hardness of the train wheels must be lower than the hardness of the railway track. The difference in hardness causes wheel wear to occur faster than wear on the train rails that are passed along with the number of kilometers traveled by the train. One of the problems with the facility is that wheel flange wear is a common problem, especially on rails with many bends, and can cause various problems such as reduced train stability, increased friction, and damage to wheel components(Rafsanjani & Rachmanto, 2021). Excessive wear can disrupt train movement and pose a safety risk to passengers. To better understand and address the factors that cause wheel flange wear is very important (Rudy

Santosa, 2023). One of the treatments carried out is on the wheel flange which is caused by wear from friction between the wheel and the rail. The thing that accelerates the wear process is the heat treatment on the curve (Prakasa, 2023).

The heat treatment testing process is carried out based on the type of composition contained in the steel which has different mechanical properties (Fistcar, 2021), so to obtain the desired results, retesting is needed by adding other elements to the composition (Leni, D., & Sumiati, 2022). Heat treatment of steel by adding chemical composition aims to optimize the mechanical and physical properties of steel to suit certain applications. The addition of chemical elements can affect the response of steel during heat treatment processes such as annealing, quenching, tempering, or normalizing (Corsetti Silva & Pitz, 2021). The hardness of the ordinary rail head must not be less than 240 Brinell. The hardness of the rail head can be increased by heat treatment, to achieve a hardness of 320 - 388 Brinell (Yudistirani et al., 2021). This can be determined by f-max by calculating through a graph taking f-max = 0.25 and n = 2 with a tensile strength of 90 kg / mm2 and a length of 10% (Rafsanjani & Rachmanto, 2021).

The complex topographic characteristics of the Yogyakarta-Kutoarjo railway line, many curves, pose significant challenges, which cause accelerated wear of the wheel flanges on the Diesel Electric Rail Train (KRDE) operating on this line. Components, especially train wheels, can experience wear on the wheel flanges, especially on curved tracks, which can cause reduced stability, increased friction, and damage to rail components(Khuluq & Pane, 2021). Impacts other than those caused by wear are noise and vibrations that need to be measured through Ride index tests carried out to measure the level of vibration and noise in the train while operating on the track (Amin & Prayogi, 2020). The purpose of noise testing is to determine the level of noise in the train. The maintenance that must be carried out in curved and straight maintenance has different maintenance times, of course on curved rail tracks it must be done routinely every 8 months with a high Track Quality Index (TQI) (Pamungkas, 2021). Maintenance needs to be carried out continuously to obtain optimal rail track conditions using 3 main aspects with a delay aspect of 81.49% in the infrastructure aspect if converted into units of time, the train was held up for 577.48 hours and obstructed for 104.18 hours, with a frequency of 62 times so that the number of disrupted trips was 257 trips (Andry Yuliyanto et al., 2024).

This study aims to investigate the impact of curvature on wheel flange wear, focusing on the Yogyakarta-Kutoarjo railway line. By conducting field observations and direct measurements, this study seeks to contribute in improving train performance and safety on curved railways. The results of this study are expected to improve our understanding of how curvature affects wheel flange wear on railways, which ultimately supports better maintenance practices and safety measures for train operations.

## METHODS

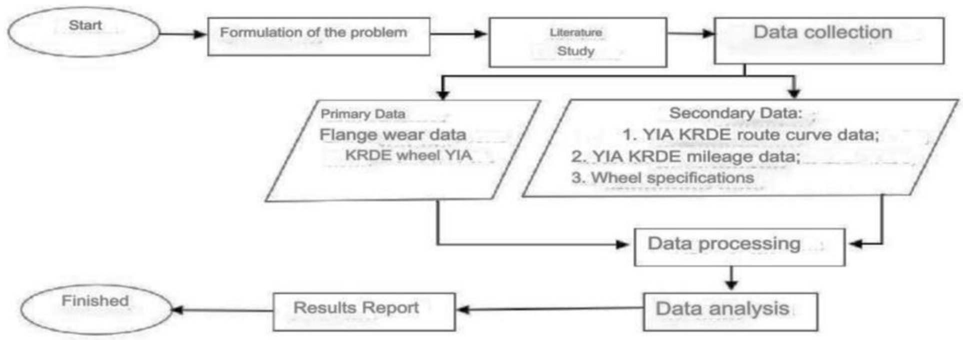


Figure 1 Research Flowchart

The study began by formulating the problem from this background to ensure the relevance and validation of the research carried out using a literature study method closely related to the analysis of wheel profile wear due to contact between the wheels and rails. The wear of the train wheel flanges mainly occurs when the train operates on a curve with a small radius, where the lateral force increases significantly.

Data acquisition is obtained from primary and secondary data where the primary data is in the form of wheel flange wear data for the Yogyakarta International Airport Diesel Electric Rail Train (KRDE YIA), while the secondary data comes from track curve data in the form of distance traveled data and wheel specifications. The following step is data processing using the linear regression method and affiliating it to the Excel application to obtain the results of a more dominant curve comparison of wheel flange wear between the three trains with different tracks. To find out the value of the increase in wear that will occur on the KRDE YIA wheel flange to obtain the forecasting results that have been carried out.

## RESULTS AND DISCUSSION

Once primary and secondary data are collected, the focus shifts to the vital wear analysis of the wheel flange for KRDE YIA. By monitoring the wear each month over six months, we can uncover critical insights, identify potential issues early, and enhance both safety and efficiency. This proactive approach is essential for maintaining the integrity and performance of our system (Supriyana & Kholidin, 2016). The reading for wheel A is on the machinist's right side while plate B is on the machinist's left side.


Figure. 1 Wheel Pieces A and B.

KRDE YIA Wheel Flange Wear Analysis on the Yogyakarta – Kutoarjo Route using the linear regression method.

After collecting additional data on KRDE YIA wheel flange wear, the next step is to calculate the accumulated total arc distance every month for 6 months from October 2023 to March 2024. Then you can calculate the predicted maximum arc distance that can be covered by each KRDE wheel piece. YIA uses linear regression analysis to model the relationship between wheel wear levels and various factors such as distance traveled, carrying load, speed, track conditions and wheel specifications, as well as predicting future wear levels, so that timely maintenance can be carried out(Hidayat & Mahardiono, 2015). When a train travels along a curved track, it experiences an outward centrifugal force. This force increases with the train's weight and speed, emphasizing the need for effective engineering and safety measures. Understanding this relationship allows engineers to design trains and tracks that can safely accommodate high speeds while ensuring stability and preventing derailment(Nugroho Utomo, 2019). This approach enhances the overall performance and reliability of railway systems. (Rinaldi, 2022)

Table. 1 Calculation of the accumulated total curved distance on the KRDE YIA route in October – March.

| No. | Month | curved distance (km) | accumulated total curved distance (km) |
|---|---|---|---|
| 1 | Oktober | 1282,4 | |
| 2 | November | 1717,5 | 2999,9 |
| 3 | Desember | 2862,5 | 5862,4 |
| 4 | Januari | 4167,8 | 10030,2 |
| 5 | Februari | 2977 | 13007,2 |

| | | | |
|---|---|---|---|
| 6 | Maret | 2702,2 | 15709,4 |

To find the prediction of the maximum KRDE YIA bending distance for each wheel from wheel 1 to wheel 16. A simple linear regression model was used to find the relationship between mileage (χ) as the independent variable and wheel flange wear (ϒ) as the dependent variable.

The linear regression equation used is:

$$\boldsymbol{\gamma = m\chi + b}$$

Where:

y: Wheel flange wear (mm)

x: Train distance (km)

m: Gradien (rate of change of wear per kilometer traveled)

b: Intersep (initial wear over mileage = 0)

Analysis of the linear regression equation will determine the R2 of each wheel flange to determine the wear and tear from the distance traveled which can be seen from the data below :

Table. 2 Calculation of maximum KRDE YIA curved distance predictions on wheels 1 to 16.

| Wheel number | Accumulated value of curved distance of piece A (km) | Accumulated value of curved distance of piece B (km) | Equation value (y) of chip flange wear A (left) | $R^2$ value | Equation value (y) of chip flange wear B (right) | $R^2$ value |
|---|---|---|---|---|---|---|
| 1 | 56.243,30 | 73.466,80 | 6558.4x +3776.1 | 0.8786 | 8611.3x +4560.4 | 0.7763 |
| 2 | 95.595,10 | 89.037,00 | 13117x - 9340.9 | 0.8786 | 13117x - 15899 | 0.8786 |
| 3 | 99.117,00 | 95.595,10 | 13818x - 11427 | 0.8288 | 13117x - 9340.9 | 0.8786 |
| 4 | 75.902,00 | 66.662,10 | 9239.1x +1989.2 | 0.959 | 9239.1x - 7249.9 | 0.959 |
| 5 | 59.338,90 | 68.236,80 | 6980.5x +3494.9 | 0.846 | 9364.4x - 6678.4 | 0.918 |
| 6 | 56.313,30 | 68.236,80 | 7810.5x - 6170.7 | 0.8722 | 9364.4x - 6678.4 | 0.918 |
| 7 | 72.919,00 | 67.130,00 | 9364.4x - 1996.2 | 0.918 | 10889x - 19982 | 0.878 |
| 8 | 60.686,90 | 87.559,00 | 8187.8x 48815.5 | 0.9072 | 12217x - 10177 | 0.9146 |
| 9 | 59.338,90 | 47.665,30 | 6980.5x +3494.9 | 0.846 | 6495.9x - 4301.9 | 0.9589 |
| 10 | 56.245,00 | 56.245,00 | 6558.6x +3776.2 | 0.8786 | 6558.6x +3776.2 | 0.8786 |
| 11 | 75.989,80 | 57.663,80 | 9045.5x +3625.8 | 0.7521 | 6909.1x - 2391 | 0.8288 |
| 12 | 83.262,34 | 95.595,10 | 10447x + 313.66 | 0.9195 | 13117x - 9340.9 | 0.8786 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 13 | 87.559,00 | 62.043,00 | 12217x - 10177 | 0.9146 | 9239.1x - 11869 | 0.959 |
| 14 | 54.590,30 | 71.467,08 | 7239.1x +3322.5 | 0.9098 | 9045.5x - 896.92 | 0.7521 |
| 15 | 87.559,00 | 55.038,40 | 12217x - 10177 | 0.9146 | 8154.8x - 10200 | 0.9678 |
| 16 | 102.304,80 | 136.857,00 | 13613x - 6599.2 | 0.8044 | 19068x - 15687 | 0.8355 |

So, to determine the wear of the wheel flange from the distance traveled based on the data above, it is done by calculating the accumulated mileage value of the curve of the A plate (km), which will be calculated into the equation so that you will get the equation value (y) of the wear of the A plate flange (left). Likewise, wear on wheel B flange is done in the same way. From the results of the R2 values, almost none of them exceed the value 1, meaning that the wear value is on a more reasonable scale(Syamsul Kamar, 2023).

Prediction of calculating the maximum arc distance for wheels A and B on the KRDE YIA Yogyakarta – Kutoarjo route.

This prediction aims to determine the maximum curved distance that can be traveled by wheels A and B on KRDE YIA during train operations on the Yogyakarta – Kutoarjo route. This is reinforced by the opinion of (Karyanto et al., 2020) Information regarding the maximum bend distance is very useful for preparing a maintenance schedule for the KRDE YIA Yogyakarta – Kutoarjo line. Complete prediction results can be seen in the table below:

Table. 3 Maximum arc distance for wheels A and B on KRDE YIA on the Yogyakarta – Kutoarjo route.

| maximum curved distance | | |
|---|---|---|
| wheels | wheel A (km) | wheel B (km) |
| 1 | 56.243,3 | 73.466,8 |
| 2 | 95.595,1 | 89.037,0 |
| 3 | 99.117,0 | 95.595,1 |
| 4 | 75.902,0 | 66.662,1 |
| 5 | 59.338,9 | 68.236,8 |
| 6 | 56.313,3 | 68.236,8 |
| 7 | 85.213,0 | 67.130,0 |
| 8 | 60.686,9 | 87.559,0 |
| 9 | 59.338,9 | 47.665,3 |
| 10 | 56.245,0 | 56.245,0 |
| 11 | 75.989,8 | 57.663,8 |

| | | |
|---|---|---|
| 12 | 83.262,3 | 95.595,1 |
| 13 | 87.559,0 | 62.043,0 |
| 14 | 54.590,3 | 71.467,1 |
| 15 | 87.559,0 | 55.038,4 |
| 16 | 102.304,8 | 136.857,0 |
| Jumlah Total | 74.703,7 | 74.906,1 |

Then the maximum curved distance that can be traveled by wheels A and B on KRDE YIA during train operation on the Yogyakarta - Kutoarjo route is compared to find out whether there is a correlation (Wahyu Adi Pratama et al., 2022). The correlation coefficient was obtained through correlation analysis using Microsoft Excel and compared with the correlation category.

Table 4. Correlation Coefficient.

| | Left | Right |
|---|---|---|
| Left (km) | 1 | |
| Right (km) | 0,54202058 | 1 |

Table 5. Correlation Category.

| Correlation Category | |
|---|---|
| 0,00 – 0,199 | Very Low |
| 0,20 – 0,399 | Low |
| 0,40 – 0,599 | Currently |
| 0,60 – 0,799 | Strong |
| 0,80 – 1,00 | Very strong |

From the table above, the correlation coefficient value between pieces A and B of the KRDE YIA wheel on the Yogyakarta - Kutoarjo route is 0.54202058, so it is included in the medium category, which means that the left curve and the right curve on the Yogyakarta - Kutoarjo route are almost the same distance apart.

Table 6. The R2 value is based on the KRDE YIA wheel flange wear addition equation.

| R2 value | | |
|---|---|---|
| wheel | left | right |
| 1 | 0,8786 | 0,7763 |
| 2 | 0,8786 | 0,8786 |
| 3 | 0,8288 | 0,8786 |
| 4 | 0,959 | 0,959 |

| | | |
|---|---|---|
| 5 | 0,846 | 0,918 |
| 6 | 0,8722 | 0,918 |
| 7 | 0,918 | 0,878 |
| 8 | 0,9072 | 0,9146 |
| 9 | 0,846 | 0,9589 |
| 10 | 0,8786 | 0,8786 |
| 11 | 0,7521 | 0,8288 |
| 12 | 0,9195 | 0,8786 |
| 13 | 0,9146 | 0,959 |
| 14 | 0,9098 | 0,7521 |
| 15 | 0,9146 | 0,9678 |
| 16 | 0,8044 | 0,8355 |
| Maks | 0,9590 | 0,9678 |
| Min | 0,7521 | 0,7521 |

From the table above, the R2 value is obtained based on the equation for the addition of KRDE YIA wheel flange wear on piece A, which is a maximum of 0.9590 and a minimum of 0.7521, on piece B, a maximum of 0.9678 and a minimum of 0.7521, so it is included in the strong category. which means that KRDE YIA wheel flange wear has a strong influence on the curve distance on the Yogyakarta – Kutoarjo Line(Widyaningsih & Ayuningtyas, 2022).

## CONCLUSION

The bend distance traveled by KRDE YIA greatly influences the level of wheel flange wear, meaning, the longer the distance traveled, the greater the potential for wear on the wheel flange, which can be estimated quite accurately because statistically an $R^2$ value above 0.75 has a strong relationship. between the variables tested (wheel flange wear and arch clearance).

The maximum service distance for KRDE wheels on the Yogyakarta-Kutoarjo route, namely that they can cover the furthest curved distance, is the 16 wheel A (left) 102,304.80 km and B (right) 136,857.00 km, so replacing wheel A will be more faster than wheel B. This could be due to differences in load distribution or other operational conditions on the track.

Based on the conclusions of this research, further research needs to be carried out to prove the influence of the wheel flange wear rate on the position of the train car configuration.

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