Optimisation of Rolling Stock Wheel Machining

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Abstract

This study was conducted on behalf of a large Australian mining company. The company operates a rail system and has 48,560 ore car wheel sets in service. During service the ore car wheels experience deterioration and damage. The damaged material layer is machined out of the wheels at fixed maintenance intervals to prevent any damage to the track and/or ore car. Currently the company machines wheels to two different standards at two separate maintenance locations. The maintenance of the steel wheels represents a substantial cost for the company both from the machining process and the associated operational disturbances.

The purpose of this project was to make informed recommendations about the optimum depth of cut and machining interval to reduce overall wheel maintenance costs. The key objectives of the project were; to analyse wheel degradation rates and modes, find the optimal wheel maintenance interval, determine the optimal amount of steel that can be removed from the wheel and provide a cost analysis to determine the most cost effective wheel maintenance strategy. Wheel degradation rates and modes were determined through analysing wheel wear data from the Ore Car Condition Monitoring System (OCCM), while subsurface wheel defects were analysed in the laboratory using Scanning Electron Microscopy (SEM).

1. Introduction

During service heavy haul ore car wheels are subject to high mechanical loading, frictional forces, cyclic loading and rapid heating cycles that occur during braking. These factors all contribute to increased rates of wheel deterioration. Typically, damage is in the form of thermal and fatigue cracking, rolling contact fatigue, spalling, hollowing and scaling. The wheels are also subject to flange wear and subsurface defects that initiate from metallurgical defects in the wheel (Transport RailCorp 2013).

The re-profiling of wheels is a costly but essential process. Defective wheels may cause damage to both the track and the ore car and in severe cases have been known to cause train derailment (Transport RailCorp 2013). The high costs arise from not only the actual machining process but also the operational disturbances associated with the shunting of ore cars and the downtime of the ore cars during the wheel machining process.
Currently the company machines wheels to two different standards at two separate locations. At the first maintenance facility a standard 2.5 mm is taken off the rim of the wheel, where the wheel rim is measured from the centre of the wheel (70mm from the rim back). At the

second facility 2 mm is machined off the wheel rim from the same reference point. The depth of cut significantly impacts wheel life as wheels are scrapped based on rim size. The depth of cut taken at the machining facilities increases significantly with flange size, which corresponds to the thickness of the flange. A flange size 0 is a ‘good flange’ and larger flange numbers indicate a thinner flange.

The AAR standards (2012) provide a guideline for the amount of material to remove from heavy haul train wheels using a flange witness groove. The witness groove serves the purpose of showing that the lathe operator has not wasted service tread by turning more off the tread than necessary to restore the full flange contour. A wheel gauge is used to determine the depth of cut, the pointer circled in Figure 1a indicates the amount of metal to be machined off with a witness groove to restore full flange contour.

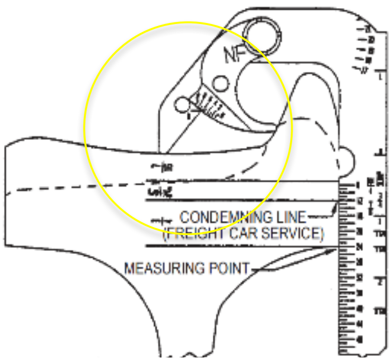

Figure 1a. Witness Groove Machining (AAR Standards 2012)

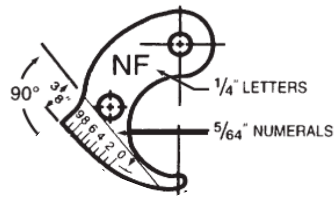

Figure 1b. Close up of NF pointer

The flange size indicated by the pointer is supposed to determine the amount of necessary metal to be removed from the rim in 1/16 inch increments to restore flange profile. However, much larger cuts are currently being taken than recommended by the standard. For example, a flange size 1 would indicate that 1/16 of an inch, or 1.6 mm needs to be machined off the rim to restore the flange; however, the company removes 3.5 mm. This approach was taken by the company to ensure all tread defects were removed from the wheel before the wheel was put back into service. However, the optimal amount of material to remove tread defects has not been investigated.

The mining sector is currently facing very challenging market conditions. At this point in time, the company is spending a large portion of their annual ore car maintenance budget on wheel maintenance. The optimisation of the machining process and maintenance intervals could result in greater efficiencies, a reduction in operating costs, an increase in returns and an improvement to the company’s competitiveness.

The key project objectives are listed below:

1. Provide the Client with further insight into wheel degradation rates and modes.
2. Determine the depth of subsurface defects for wheels and the minimum amount of material that can be removed from the wheels to remove these defects
3. Determine the impact of maintenance interval on wheel life costs
4. Develop a cost analysis to draw conclusions about the optimal wheel maintenance strategy

To support conclusions regarding the optimal wheel maintenance strategy, the wheel degradation rates and modes had to be understood. Through understanding how the wheel was deteriorating over time, conclusions could be made about the optimal point to machine the wheels to maximise wheel life and minimise cost. Subsurface defects were analysed through microscopy and microanalysis techniques to determine the depth of tread damage for moderately damaged wheels with spalling. Furthermore, minimum cut trials were conducted to determine if a smaller depth of cut could remove all surface defects. The project also involved drawing conclusions about whether the current maintenance interval is optimal. A cost analysis was conducted to compare different maintenance regimes and guide the formulation of future machining procedures.

2. Methodology

2.1 Analysis of Wheel Degradation Rates

To be able to analyse the wear of wheels over time, data had to be extracted from the Ore Car Condition Monitoring System (OCCM). The OCCM system allows for the accurate measurement of ore car wheels, as each wheel passes by the system, optical sensors automatically trigger an asynchronous image grab. The wheel profile computer then processes the image and returns key outputs including; rim thickness, flange width, tread hollowness and flange height. The location of these feature points are shown below (Figure 2)

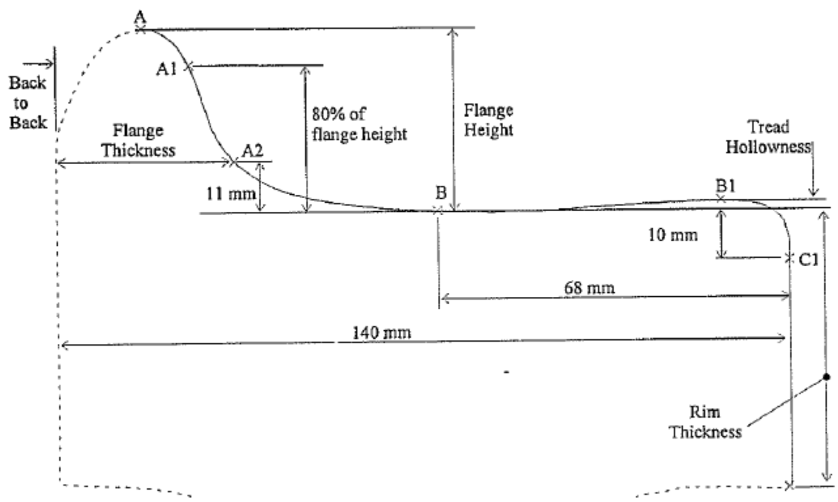

Figure 2. Location of feature points (MRX 2009)

The OCCM system is equipped with an automatic train identification system (ATI) that is able to detect the presence of a train and identify individual ore cars. There is no system that tracks what wheels are under what wagons at a given point in time. This means that a single wheel cannot be tracked over its lifetime. However, through analysing data for a particular wagon number, axle position (1-8) and side (L/R) the measurements for a single wheel can be analysed between machining cycles. Currently the wheel sets are machined on a two year planned maintenance period allowing for the analysis of two years of wheel data where measurements are taken several times each month. Wagon maintenance history was utilised to determine the date that a given wagon with freshly machined wheels left the workshop. This allowed for wheel wear over time to be analysed.

142 wheels were analysed, these wheels were evenly distributed with respect axle number (1-8) and ore car side (Left/Right). The sample was also evenly distributed across three rim size

categories, end of life wheels (29 – 42.24mm), midlife wheels (42.25 – 56.25mm) and new wheels (56.25 – 70mm). Linear regression techniques were then applied in R to draw conclusions about wheel degradation rates.

2.2 Analysis of Subsurface Wheel Defects

Scanning Electron Microscopy (SEM) and Electron Dispersive X-ray Spectrometry (EDS) training courses were completed at the UWA Centre for Microscopy, Characterisation and Analysis (CMCA). In order to analyse wheel defects and characterise the steel inclusions, entire wheelsets were transported from site to Gemco Rail where they were stored and cut into manageable sized sections for analysis.

2.3 Comparison of Wheel Maintenance Strategies

A cost analysis was completed and wheel machining strategies were compared. Discounted cash flow analysis was used to discount future cash flows and arrive at a present value estimate.

3. Results and Discussion

3.1 Statistical Analysis of Wheel Degradation Rates and Modes

A strong negative linear relationship was found between rim thickness (mm) and time in service (years). A scatter plot of all the rim thickness data over time is shown in Figure 3. The data for several individual wheels are highlighted to demonstrate the negative linear correlation between rim thickness and years in service.

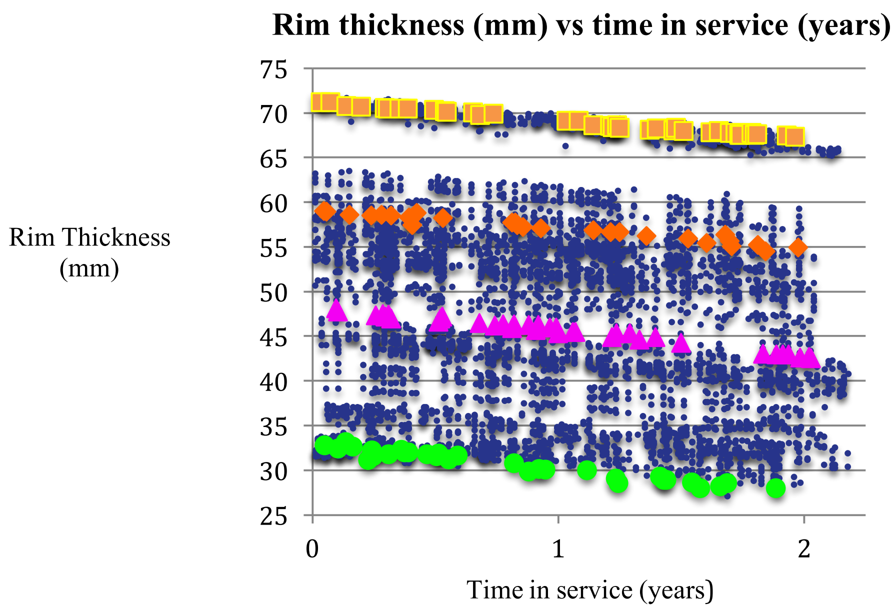

Figure 3. Scatter plot demonstrating rim wear

Each wheel in the sample starts with a discrete rim thickness that decreases linearly with time in service. The linear regression found a wear rate of -2.39 mm/year, the r-squared value (R^2)

found was high (0.98) showing low variability in the data. No significant difference between the wear rate was found based on vehicle side (left/right) and axle position (1-8).

Hollowness was found to occur in 43% of wheels and had a mean initiation time of 1.43 years. The maximum hollowness found after two years was 1.5 mm, this is below the 3 mm upper limit proposed by the RailCorp Standard (2013) suggesting this hollow does not negatively affect performance or rail life. Hollowness does not increase the amount of material to machine off a wheel, so this high percentage of wheels with hollowness may not be a concern for the Client (Frohling & Hettasch 2010).

Flange thickness is an important wheel parameter to consider as it determines the amount of material that must be removed from the wheel to restore the profile. Only 1.4% of the wheels were found to have flange wear that would require a deeper cut to restore rim profile.

3.2 Electron Microscopy Analysis

For microscopy analysis, the sample was mounted such that the damaged tread surface was perpendicular to the microscope. This allowed the microscope to capture the depth of damage into the wheel tread. Cracking can be seen propagating into the wheel rim with a maximum cracking distance of 1.7 mm from the surface of the tread in sample 1 (Figure 4). More electron microscopy analysis must be completed to determine the depth of damage for other defects.

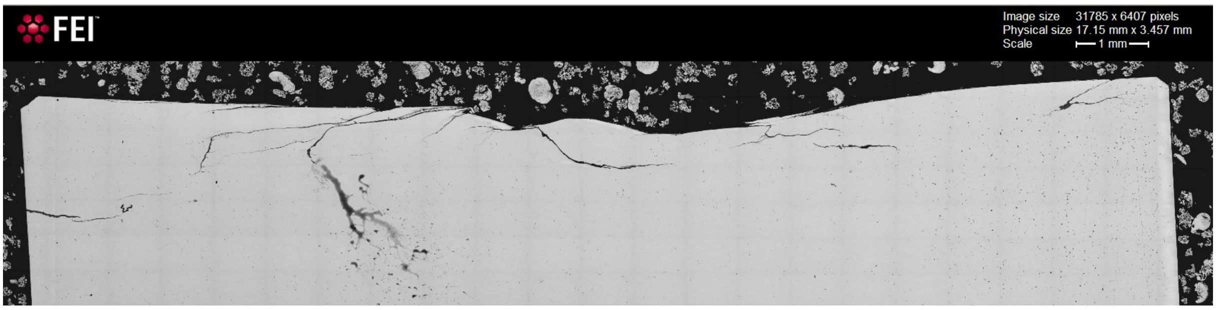

Figure 4: Image of Wheel Tread

3.3 Comparison of Wheel Maintenance Strategies

Wheel maintenance strategies were then compared to determine the strategy that maximised wheel life. Any increase in wheel life has the potential to lead to significant cost savings. Under the current practice, wheels start at a size 44 (970 mm diameter) and are scrapped if they are less than a size 18 after machining (888 mm diameter). This leaves 82 mm of tread to be used before the wheel has to be scrapped.

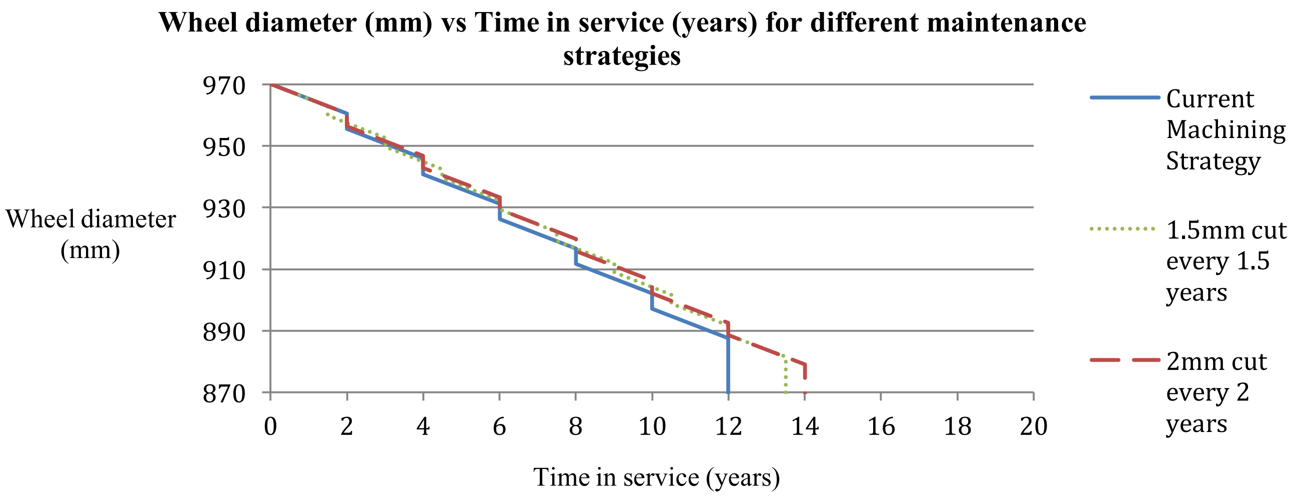

Figure 5: Comparison of Wheel Maintenance Strategies

A comparison of all feasible maintenance strategies is represented in Figure 5. A 2mm cut every two years is seen to maximise wheel life.

4. Conclusions and Future Work

Under the current strategy, rim wear occurs at a rate of approximately 2.39 mm/year. Rim wear was determined to be independent of wagon side (left/right), axle number (1-8) and wheel age. No acceleration in rim wear was observed over time, suggesting that the two-year wheel maintenance strategy is viable. Hollowness was found to occur in 42% of wheels and had a mean initiation time of 1.43 years. Only 1.4% of the wheels were found to have flange wear that would require a deeper cut to restore rim profile. The electron microscopy analysis found that the maximum damage depth was 1.7 mm for a moderately damaged wheel with spalling. However, only two samples were taken to conduct this analysis.

The wear rates and modes were examined for a sample of 142 wheels with two years of data. This sample size could be increased to more accurately reflect the wear rates of the population. The electron microscopy analysis found that the maximum damage depth was 1.7 mm for a moderately damaged wheel with spalling. In order to determine the maximum depth of damage for wheels with spalling more samples should be analysed using SEM.

5. Acknowledgements

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6. References

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