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Wheel Wear and Rail Damage Prediction for Wheels Turned with Thin Flanges

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Abstract

Economic Tyre Turning (ETT) is the process of turning wheels to a profile that has the same tread shape but a thinner flange than the design case, allowing less material to be removed from the wheel diameter. ETT can allow maintainers to extend wheel life, particularly when the wheel is approaching its minimum diameter. Modern wheel lathes are typically capable of turning such profiles but GB railway group standards do not currently permit their use.

This paper investigates the effect of using ETT wheel profiles on the wheel-rail interface, in terms of wear and rolling contact fatigue (RCF) damage. It demonstrates how a Wheel Profile Damage Model (WPDM) can be used to accurately predict both the magnitude of wheel wear and the worn shape of the wheel for mileages exceeding 100,000 miles since turning. The paper presents results for one suburban and one inter-city train fleet. It discusses the validation of the wear prediction using data from the real fleets and the calibration methodology used to adjust the Archard wear model within the WPDM to improve the accuracy of the simulation results for specific routes. Having established that wear patterns can be predicted with a good degree of accuracy, the paper then examines how the predicted wear performance changes when wheel profiles with thin flanges (four different flange thicknesses at 1mm intervals from 28mm to 25mm) are used.

The analysis is extended to predict the effect of using ETT on rail RCF for typical routes and operating conditions using a series of vehicle dynamic simulations. The analysis considers new 56E1 and 60E2 rails together with a selection of worn wheel and rail profiles.

1. Introduction

The GB Railway Industry is seeking ways to extend the life of wheelsets in order to avoid significant cost caused by condition maintenance and periodic replacement of railway wheelsets. In general, the wheels tread wear relatively slowly, and could be expected to last for long periods based on wear considerations alone. However, they are also subject to tread damage caused by wheel slide events, rolling contact fatigue and flange wear[1]. Therefore wheels require regular re-profiling by machining on a wheel lathe, which can drastically reduce the expected life.

GB Railway Group Standard (RGS) GM/RT2466 [2] requires that the wheel profile is restored to a full design-case flange thickness. This may require a significant amount of material to be removed from the tread and in therefore a considerable reduction in wheel diameter. Hence turning a wheel with a thinner flange could help reducing the cut depth required during wheel re-profiling and therefore extend wheelset life.

The aim of this paper is to evaluate the effect of turning thin flanges on wheel wear and rail damage. This includes using real turned wheel profiles (P8 and P12 versions, both widely used profiles in the UK) running on two different Electrical Multiple Units EMU (one suburban and one inter-city train fleet).

The P12 profile (The profile developed was named WRISA2) is similar to the P8 profile but with two significant changes, an 'anti-RCF relief' in the flange root area and it has a lower initial conicity. The vehicles have different of primary yaw stiffnesses ranging from relatively soft for EMU1 to relatively stiff for EMU2. The wear behaviour of P8 and P12 wheels on these vehicles were well documented and measured data was available to support calibration of the wear models.

2. Methodology of the Wear Prediction

The WPDM [3] is a numerical simulation model developed to predict the wear pattern and rate for each wheelset type (motor or trailer) of a vehicle fleet for a chosen mileage. Based on the fleet's route diagram, the WPDM characterises the duty cycle of the vehicle in terms of curve radius, cant deficiency and traction/braking performance. A schematic of the WPDM analysis methodology is shown Figure 1.

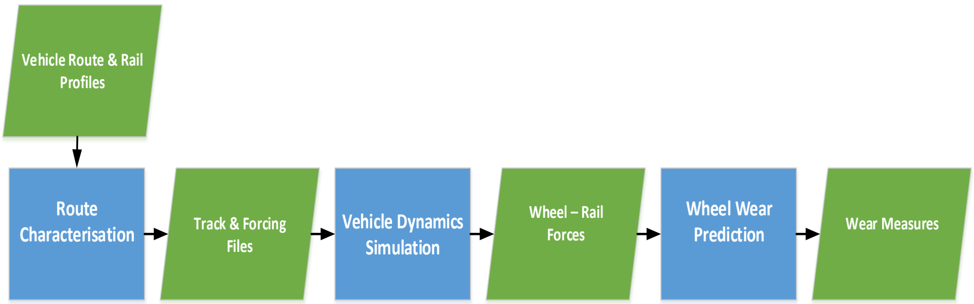


Figure 1: WPDM methodology Flowchart

Route characterisation was developed to represent the duty cycle of the vehicle with a series of short simulations without significantly compromising the results accuracy. The developed routine reads in one or more track geometry files (obtained from track recording vehicle) together with suitable vehicle speed to represent the different routes sections of a vehicle diagram. Later, the files are weighted in order to represent the frequency of operation of the vehicles running over the chosen routes. Based on that, the routine selects the appropriate curves radius and cant deficiency (typically 6-8 curve radii per route and 2-4 cant deficiencies per radii) bands based on their cumulative distributions. Using the route characteristic outputs, the WPDM runs the VAMPIRE [4] contact generation and transient analysis program using a specified wheel profile and vehicle model. The resulting wheel-rail contact forces and positions are then exported as binary output files (.out) for use in the wear model.

The WPDM uses the Archard wear model [5, 6] to determine the volume of material removed from the wheel profile. This Archard model assumes that the material loss (V_w) is proportional to the normal force (N) and sliding distance (s) divided by the material hardness (H) as shown below:

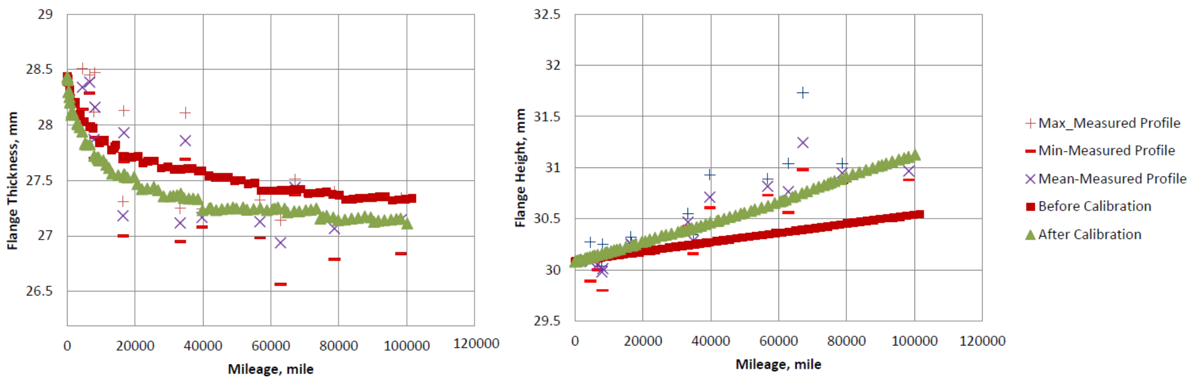
$$V_w = k\frac{N.s}{H} \qquad \text{Equation 1}$$

where k represent the wear coefficient which differs depending on the governing wear regime, the properties of the wheel steel and environmental conditions. The value of the wear coefficients were obtained by laboratory tests run on twin disc and pin-on-disc machines and field observation data. The wear coefficients k are a function of slip velocity and contact pressure.

The wear calculation uses the wheel-rail contact data and forces generated from the vehicle dynamic simulations. The vehicle dynamic simulations outputs typically include normal forces, size and location of the contact patch and creepages, which are used within the Archard wear model to predict the amount of material removal and how the wear is distributed across the wheel profile. An automated tool, which launches the VAMPIRE vehicle dynamics simulation, combines these steps to calculate the wear and controls the wear steps. A more detailed description of the WPDM construction and methodology can be found in [3, 7, 8]. The output from the wheel wear prediction routines includes the change in flange height (tread wear) and thickness (flange wear) with increasing running distance.

3. Calibration and Validation of the Wear Modelling

Whilst the WPDM gives good results in its standard version, the opportunity was taken to improve the accuracy of the predictions for the specific routes/fleets under consideration by calibrating the wear model against known wheel wear rates for these vehicles. The calibration methodology was based on adjusting the wear coefficients and comparing the simulated results to the real-life measured data. The wear coefficients were modified based on the position of the tread and flange contact on the wear chart. The calibration process shows that both wear rates and patterns are highly sensitive to changes in wear coefficients. Figure 2 shows the simulation results for P8 wheel profiles on EMU1 before and after calibration. The results were compared to the minimum, mean and maximum wheel profile measurements taken from vehicle operating on similar routes. It can be seen in that the calibration procedure managed to adjust the simulation results give good predictions of the average wear when compared to the real-life measured data.



(a) Flange Thickness **(b) Flange Height**

Figure 2: Simulated Flange Thickness and Flange Height Before and After WPDM Calibration – EMU1, P8 Profile

Examination of the measured wheel profile data from EMU1, shown in Figure 2, has demonstrated how the average flange thickness reduces significantly at first 20K mile, but thereafter tends to stabilise between 40k to 70k miles. Additionally, the measured data shows that the average amount of flange wear for EMU1 running through the examined routes was between 1 to 1.5 mm for P8 wheel profile. As shown in the Figure 2, the modelled flange height and thickness values compare well to the average values obtained in service for EMU1. These results represented a significant step in gaining confidence in wear predictions method.

The same simulation procedure was applied to P12 wheel profile and it was clear from the results that the simulated wear compares well to the measured values obtained in service for EMU1 and EMU2.

4. Modelling Results

Measured thin flange of P8 and P12 version profiles were provided by Network Rail as the starting point for each simulation cycle. These profiles were turned using the wheel lathe's economic wheel re-profiling option. Figure 3 shows the turned thin flange P8 and P12 wheel profiles. P8 wheel profiles were turned with four different flange thicknesses at 1mm intervals from 28mm to 25mm. While the P12 wheel profile was turned to 26mm flange thickness.

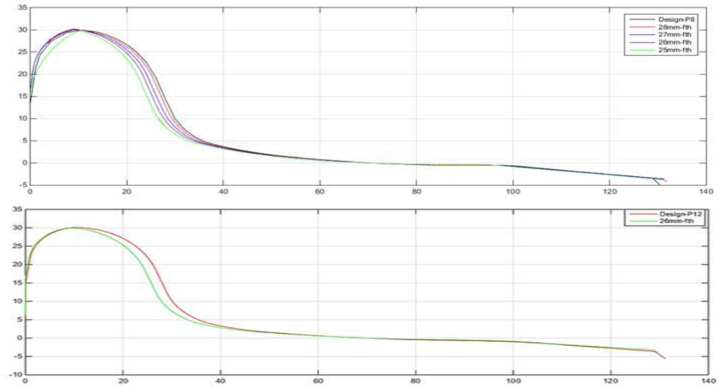
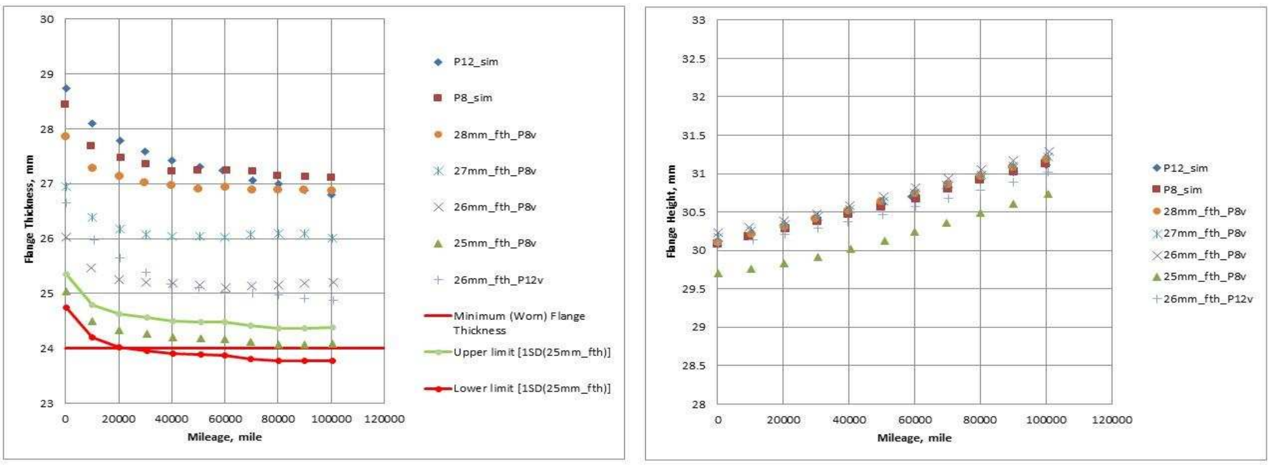


Figure 3: Turned Thin Flange P8 and P12 Wheel Profiles Compared with the Design Profile

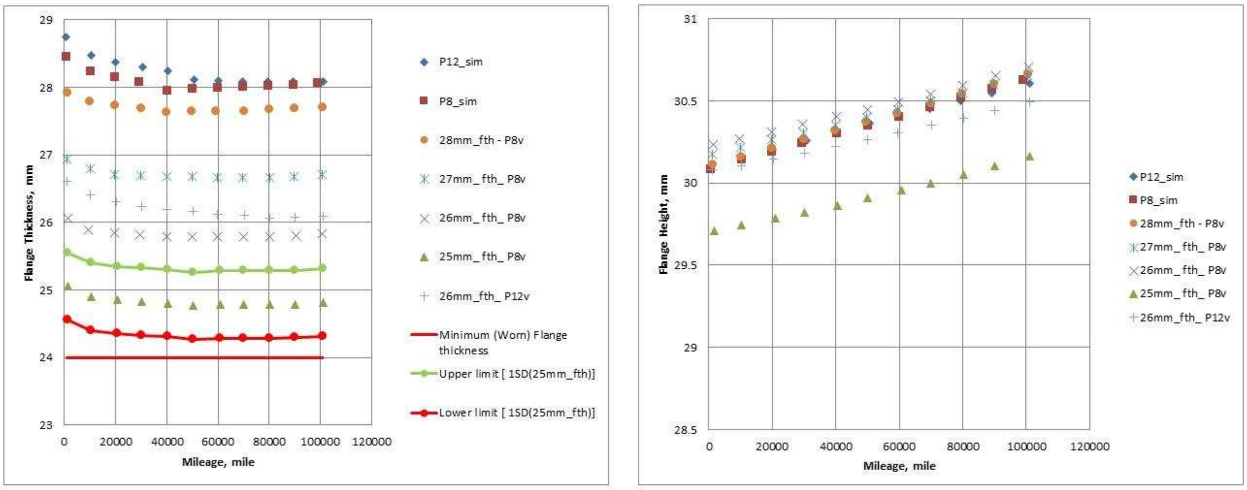
The results show that the thin flange profiles give an almost identical rolling radius difference at flange contact as the design case P8 and P12. However, thinner flanges inevitably result in a larger flangeway clearance than the full flange thickness P8 and P12 profiles. Figure 4 shows the predicted flange height and thickness for EMU1 up to 100,000 miles post turning. The results show that the flange height increases linearly with the mileage run whilst the flange thickness reduces significantly in the first 20,000 miles and then to stabilises between 40,000 and 60,000 miles.



(a) Flange Thickness **(b) Flange Height**

Figure 4: Simulated Flange Thickness and Flange Height- EMU1

Railway Group Standard GM/RT2466 defines the minimum worn flange thickness for P8 and P12 profiles as 24mm. The upper and lower worn limits in Figure 4 (a) represent the possible effect of the scatter observed in the measured data on the simulation flange thickness results. These limits were defined as: simulated flange thickness ± 1 standard deviation σ of the absolute error ε_i^{abs} (the absolute error between the measured data and simulated results of design P8). These limits represent the amount of variation could the flange wear has due to the considerable scatter in the measured data. These results suggest that if turning 25mm flanges is permitted, care should be taken to ensure that the accompanying inspection regime can identify wheels reaching their flange thickness limits at relatively low mileages. Figure 5 shows the simulated flange height and thickness for fleet EMU2 run up to 100,000 mile. The results show clearly that there is no excessive tread / flange wear in any of the cases considered and the flange wear for the considered cases remains less than the RGS 24mm limit.



(a) Flange Thickness **(b) Flange Height**

Figure 5: Simulated Flange Thickness and Flange Height- EMU2

A key concern with the possible use of economic tyre turning is that the resulting profiles could suffer higher wear rates than normally experienced or significant differences in the worn profile shape. The results of this study indicate that neither of these concerns will materialise for P8 and P12 profiles under typical operating conditions for modern MU stock.

5. Rolling Contact Fatigue Damage Prediction

A frictional energy based model (Tγ) was adopted in the current investigation to predict the RCF damage on the high rail. Figure 6 shows the relation between RCF damage and the Tγ[9]. Tγ is the frictional energy in the wheel-rail contact patch derived from the product of creepage and creep force.

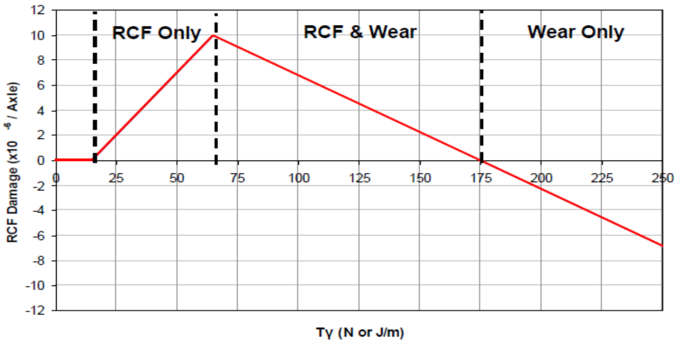


Figure 6: Whole Life Rail Model (WLRM) Damage Function

VAMPIRE dynamic simulations were used to identify the effect of flange thickness on vehicle curving at radii between 200 to 2000m. Tγ was calculated for each radii and the Whole Life Rail Model (WLRM) [9] damage function used to predict the RCF damage [9]. Two design case rail profiles (56E1 and CEN 60E2) together with a selection of worn wheel and rail profiles were used in these simulations. These profiles are commonly used within the UK network. Figure 7 shows that, in most cases, the various wheels share the same magnitude of the peak damage (occurring at between 400 and 600m radius), yet the results shows that there are detail differences depending on flange thickness and curving conditions.

The magnitudes and the range of radii where RCF damage occurs for EMU2 differs from EMU1 due to the differences in PYS. The RCF results show that thin flange versions of P8 and P12 profiles tend to generate similar RCF damage to full flange P8 and P12 profiles in the cases studied. However, the results indicated that 25mm flange thickness profiles are likely to generate some additional damage most notably for radii between 800-1400 m (more clearly observed 56E1).

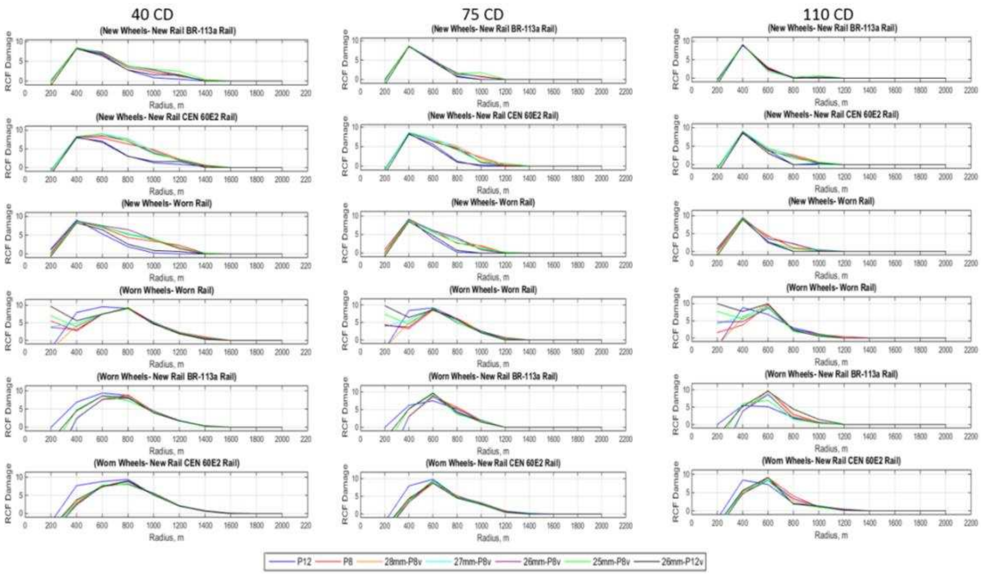


Figure 7: RCF Damage on High Rail – EMU1

6. Conclusions

Based on the simulation results, and considering the considerable scatter in the measured wheel wear data, the WPDM is considered to give accurate predictions of the wear rate and pattern for P8 and P12 profiles running on both EMU1 and EMU2 up to significant service mileage reached to 100k miles.

WPDM was calibrated by adjusting the wear coefficients, based on the position of the tread and flange contact on the wear chart, and comparing the simulated results against known wheel wear rates for these vehicles. This methodology succeeded to adjust simulation results give good predictions for the average flange and tread wear when compared to the real-life measured data.

The research provides valuable evidence to support the case that train operators should be allowed to implement ETT policies under certain specified conditions. This will provide the opportunity to exploit the cost savings associated with ETT without a significant detrimental effect on the infrastructure over which they operate.

7. Acknowledgements

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