Railway wheel wear predictions with adams/rail

R. Lewis[1]*, M. Cavalletti[2], R.S. Dwyer-Joyce[1], A. Ward[1], S. Bruni[3], K. Bel Knani[4], P. Bologna[4]

[1]Department of Mechanical Engineering, The University of Sheffield, Mappin Street, Sheffield, S1 3JD, UK
[2]Mechanical Dynamics Italy, MSC Software, Via Palladio 93, 33010, Tavagnacco (UD), Italy
[3]Department of Mechanical Engineering, Politecnico di Milano, Via La Masa 34, 20158, Milano, Italy
[4]Fiat Research Centre, Strada Torino 50, 10043, Orbassano (TO), Italy
*Corresponding author

ABSTRACT

A model has been developed to predict the wear of railway wheels incorporating the dynamic behaviour of the vehicle wheelset. The wear modelling approach is based on a wear index commonly used in rail wear predictions. This assumes wear is proportional to $T\gamma$, where T is tractive force and γ is slip at the wheel/rail interface. Twin disc testing of rail and wheel materials was carried out to generate wear coefficients for use in the model.

The modelling code is interfaced with an ADAMS/Rail multi-body dynamics simulation of the railway wheelset to give contact conditions at the wheel/rail interface. Simplified theory of rolling contact is used to discretise the contact patches produced by ADAMS/Rail and calculate local traction and slip.

The wear model combines the simplified theory of rolling contact, ADAMS/Rail output and the wear coefficients to predict the wear and hence the change of wheel profile as the vehicle passes over given track layouts.

1 INTRODUCTION

New specifications are being imposed on railway wheel wear and reliability to increase the time between wheel reprofiling operations, improve safety and reduce total wheelset lifecycle costs. In parallel with these requirements, changes in railway vehicle missions are also occurring. These have led to the need to: operate rolling stock on track with low as well as high radius curves; increase speeds and axle loads and contend with a decrease in track quality due to a reduction in maintenance. These changes are leading to an increase in the severity of the wheel/rail contact conditions (Stanca et al., 2001) which will increase the likelihood of wear occurring.

In order to deal with these demands new design methodologies are required that integrate advanced numerical tools for modelling of railway vehicle dynamics and suitable models to predict damage sustained by wheels under typical operating conditions.

The aim of the work described was to develop a wear model for integration with ADAMS/Rail multi-body dynamics simulations of a railway wheelset to develop an engineering design tool for predicting wheel profile evolution. This will help in designing wheels for minimum wear, optimising railway vehicle suspensions and wheel profiles and in evaluating new wheel materials.

This work was carried out as part of the European Community funded project HIPERWheel. One aspect of this project was the development of an integrated CAE procedure for assessing wheelset durability taking into account damage mechanisms such as metal fatigue, rolling contact fatigue, wear and fretting.

2 MODELLING METHODOLOGY

The modelling methodology for predicting the evolution of a railway wheel profile consists of four main elements:

(i) *ADAMS/Rail Multi-Body. Simulation of the Wheelset*. Used to obtain, as a function of time, position, force and slip for the wheel/rail contact as the wheelset passes around a pre-defined track layout.

(ii) *Local Contact Analysis*. Used to derive the pressure, traction and slip distributions within the wheel/rail contact. The inputs for these calculations are taken directly from ADAMS/Rail multi-body simulations.

(iii) *Wear Determination*. Based on wear constants derived from twin disc wear testing and used to relate the local contact conditions to the amount of material removed from the wheel.

(iv) *Wheel Profile Evolution Prediction*. The wheel is discretised and wear caused by each set of contact conditions generated in ADAMS/Rail is summed to determine the change in profile. The worn profile is then fed back to ADAMS/Rail for a new set of input conditions to update the contact analysis.

The complete procedure is schematically represented in Figure 1.

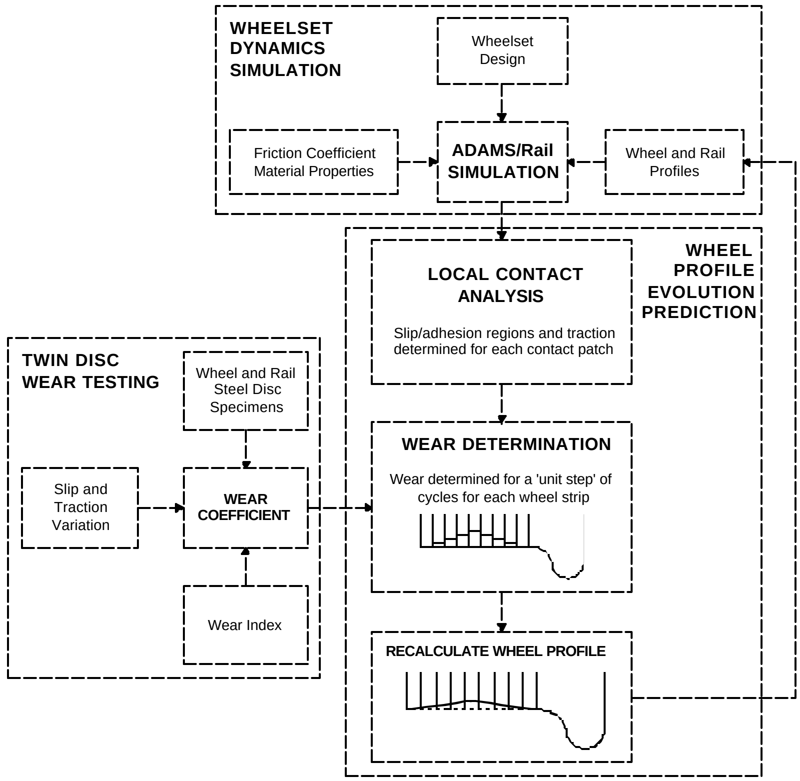

Figure 1. Railway Wheel Wear Modelling Scheme

This shows how the modelling scheme is integrated with the multi-body dynamics simulations generated by ADAMS/Rail to produce a complete CAE tool for predicting wheel profile evolution.

3 ADAMS/Rail MULTI-BODY DYNAMICS SIMULATION

The first step in wheel wear evaluation procedure, is the realisation of a multi-body model of the complete railway vehicle and track combination. This is performed to evaluate contact specific parameters, such as wheel/rail forces, relative positions and creepages.

The complete railway system (see Figure 2) in ADAMS/Rail consists of a vehicle model, a track model and contact elements.

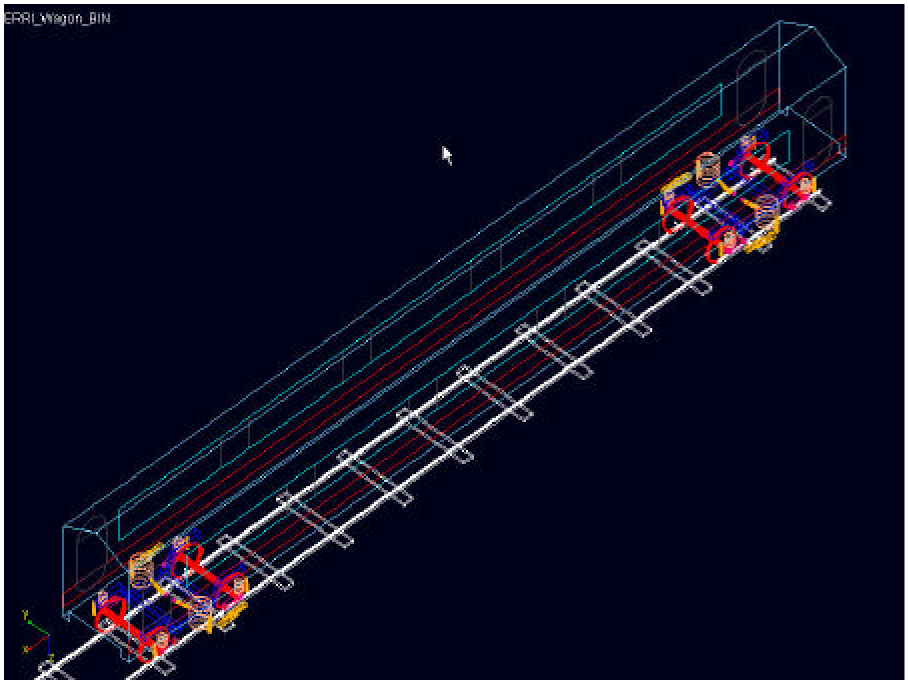

Figure 2. Complete Railway System Modelled in ADAMS/Rail

The vehicle model contains all information about the vehicle design: suspensions, dampers, bumpstops, etc. The track model includes the analytical description of the track layout (horizontal and vertical curvature, cant, gauge variations etc.) together with measured or analytically generated irregularities and the description of the rail profiles (constant or variable along the track). Contact elements are used to model the wheel/rail interactions. Three different models are available:

(i) WRQLT - Quasi-linear contact, using wheel and rail profiles defined by equivalent conicity parameters, used for stability analysis.

(ii) WRTAB - Tabular contact element. It uses a pre-calculated contact table to evaluate the contact geometry during the simulation.

(iii) WRGEN - General contact element. This is the more detailed contact element, it uses the actual wheel/rail profiles at each simulation step, and it allows multi-point contact.

The model can be analysed in three different ways:

- Linear analysis, for the evaluation of the vehicle model eigenvalues.
- Stability analysis, used for the evaluation of the critical speed of the vehicle.
- Dynamic analysis, to simulate the actual behaviour of the railway system in operating conditions.

The dynamic analysis method is used to calculate, as a function of time, all meaningful quantities related to the dynamic behaviour of the vehicle and the wheel/rail contact. In order to integrate the wheel wear calculation and dynamic analysis results these have been enhanced to include quantities such as contact patches dimensions and actual rolling radius, necessary for wear evaluation. Additionally, a specific toolkit has been created to export wear calculation data in ASCII format (*.wcd files). The quantities included in the file are shown in Table 1.

Quantity	Symbol	Units
Simulation time	t	s
Contact ellipse longitudinal semi-axis*	a	m
Contact ellipse lateral semi-axis*	b	m
Contact point position on wheel profile*	C_{pw}	m
Normal contact force*		N
Longitudinal creepage*		
Lateral creepage*		
Spin creepage*		
Rolling radius at contact point*	R	m
Longitudinal velocity	V	M/s
Actual friction coefficient at contact point*		

Table 1. Quantities Calculated during the Dynamic Analysis

Quantities identified by (*) are calculated for all contact points that may occur between the wheel and rail. They are stored in a separate file for each contact point (up to three for each wheel/rail time step).

4 WHEEL PROFILE EVOLUTION PREDICTION

4.1 Wear Modelling

The approach used in the model for predicting wear is based on the rail wear index proposed by Elkins & Eickhoff (1979). An energy approach is adopted in the analysis of the relationship between wear rate and contact conditions. This assumes that wear rate (μg/m rolled/mm^2 contact area) is related to work done at the wheel/rail contact (wear rate = KT/g, where T is tractive force and g is slip at the wheel/rail interface, K is a wear coefficient and A is the contact area).

In order to generate wear coefficients required for the model, twin disc testing was carried out. This allowed the close control of slip and load required to study the performance of the wheel material over a range of contact conditions.

Discs used in the testing were machined from R8T wheel rims and UIC60 900A rail sections. Contact stresses and slip were changed in order to vary the Tg parameter for the wear index analysis (for further details on the wear tests see Lewis et al. (2002)).

The results (see Figure 3) indicate that a number of wear regimes exist. The first of these was characterised by oxidation of the disc surfaces and very low wear rates. As contact conditions became more severe in the second regime the wheel disc appeared to be wearing by a delamination process. In the third regime this process worsened as catastrophic wear occurred. A wear constant has been defined for each regime as shown.

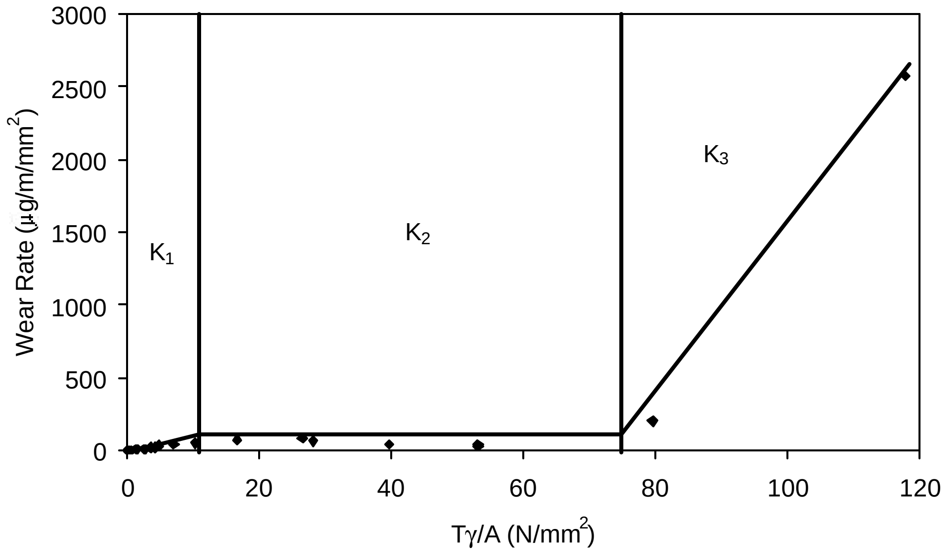

Figure 3. R8T Wheel Material Wear Rates and Regimes

4.2 Local Contact Analysis

ADAMS/Rail provides information about the load and tractions applied to the whole wheel/rail contact patch and its location. In this model it is assumed that the contact between the wheel and rail can be approximated by an elliptical contact patch. This allows the use of a faster solution method to determine the traction and slip distribution within the contact.

To enable the calculation of wear for each discretised strip of the wheel profile the contact ellipse is discretised into strips that correspond to the wheel strips. Each strip within the ellipse is then divided into equal sized cells.

ADAMS/Rail provides the total normal force, traction applied and the semi-axes a and b for each elliptical contact patch and it is from these values that local contact analysis is performed. The contact analysis calculates traction, T, pressure, p, and slip, g, for each cell (see Figure 4) from the leading edge of the contact, sequentially to the rear. The forces determined for each cell are compared to slip/adhesion criteria enabling slip and adhesion regions to be identified and the slip magnitude and direction to be determined. This approach is similar to the method employed in the FASTSIM algorithm (Kalker, 1982).

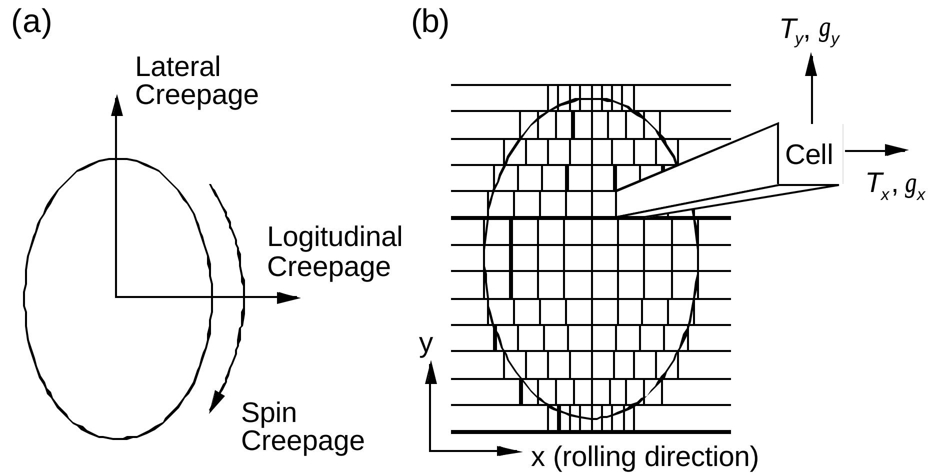

Figure 4. Output from: (a) ADAMS/Rail and (b) Local Contact Analysis

4.3 Wear Determination

To determine the evolution of the wheel profile as it wears, the wheel profile was discretised into circumferential strips. This enabled the elliptical contact patches to be located on the wheel circumference. The discretisation of the contact patches could then be made to coincide exactly with the strips of the wheel (see Figure 5). By aligning the discretisation strips in this way, wear calculated for each strip could be summed to calculate the wear depth for that region of the wheel profile.

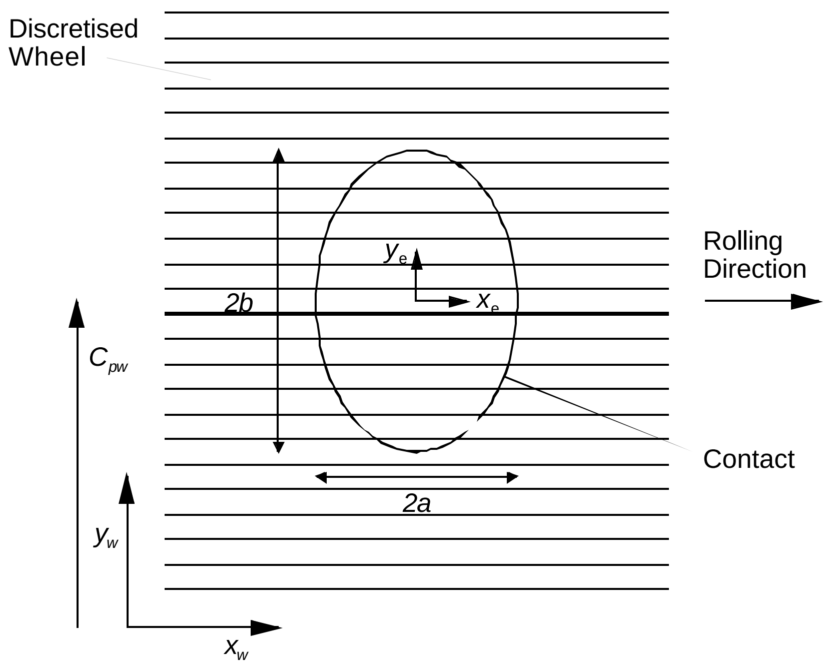

Figure 5. Discretised Wheel and Elliptical Contact Co-ordinate Systems

The positioning of the wheel strips was achieved by setting a co-ordinate system for the wheel and deciding on an interval width for discretisation. The strip width can be altered to improve resolution or increased to reduce computing time. For subsequent pressure, traction and slip calculations the contact is normalised giving the relationship between the wheel and ellipse co-ordinate systems as:

$$y_e = \frac{y_w - C_{pw}}{b} \qquad (1)$$

where y_e is the y value in the ellipse co-ordinate system, y_w is the y value in the wheel co-ordinate system, C_{pw} is the contact point on the wheel and b is the ellipse semi-axis.

A value for $T\gamma/A$ was calculated for each cell in the local contact analysis and compared to the wear regimes identified from wear test data (as shown in Figure 3 and Table 2). The corresponding wear coefficient, K, for each wear regime was used to calculate the wear volume per cell, WD_{cell}. The depth of wear per cell is then given by:

$$WD_{cell} = \frac{T\gamma}{A} K \frac{V\Delta t}{r} \qquad (2)$$

where V is the rolling velocity, r is the density of the wheel steel and Δt is the duration of the contact.

Regime	$T\gamma/A$ (N/mm^2)	Wear Rate (μg/m/mm^2)
K_1	$T\gamma/A < 10.4$	$5.3T\gamma/A$
K_2	$10.4 < T\gamma/A < 77.2$	55
K_3	$77.2 < T\gamma/A$	$61.9T\gamma/A$

Table 2. Wear Regimes and Coefficients

Each cell in the contact ellipse has an associated wear depth. The wear on each strip (in the rolling direction) is summed and that depth removed from the corresponding circumferential strip on the wheel. The contact time interval, Δt, in the output data from ADAMS/Rail is not necessarily equal to one revolution of the wheel. It is generally observed that wear occurs uniformly over a wheel circumference. Therefore it is reasonable to proportion the wear caused by a given patch location over the time, Δt, equally over the whole circumference of the wheel according to the ratio $V\Delta t/2\pi R$, where R is the wheel radius. This is carried out for each strip in the contact patch to determine the wear caused by that contact over the time, Δt. Each contact patch obtained from the ADAMS/Rail simulation is treated in the same way to obtain the worn wheel profile. This procedure is shown schematically in Figure 6.

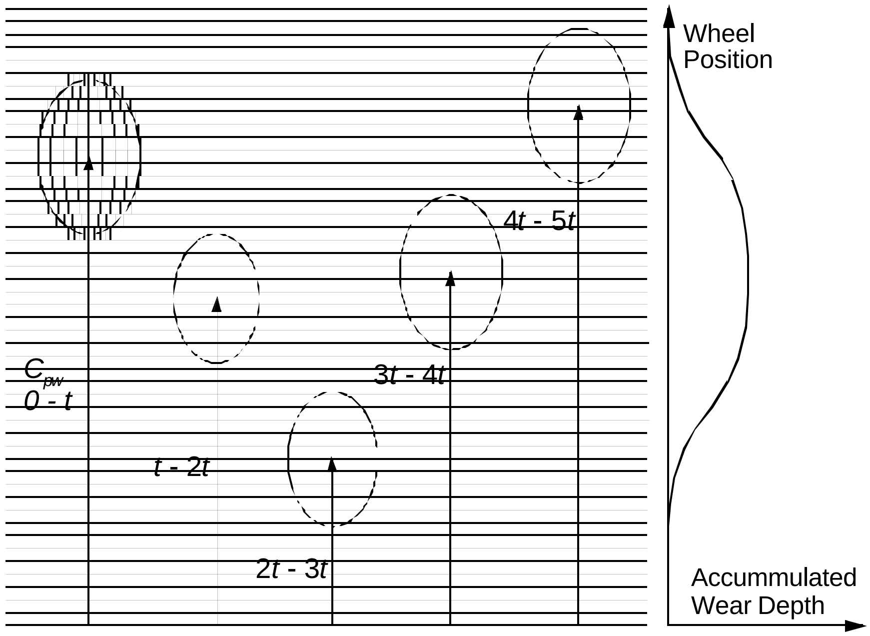

Figure 6. Summation of the Wear per Strip to give Total Wear Depth

5 INTEGRATION OF WEAR MODEL INTO ADAMS/Rail

The algorithm described in the previous section uses dynamic analysis results from ADAMS/Rail to evaluate wheel profile evolution due to wear. This algorithm has been introduced as built-in tool in ADAMS/Rail, and it is accessible through the graphic user interface. Figure 7a shows the dialog box used to “feed” the algorithm with the needed inputs. Results of “wear” evaluation are available in graphic format (for the overall amount of warn material), as shown in Figure 7b, and as an ASCII file for the evolution of wear during the simulation.

(a)

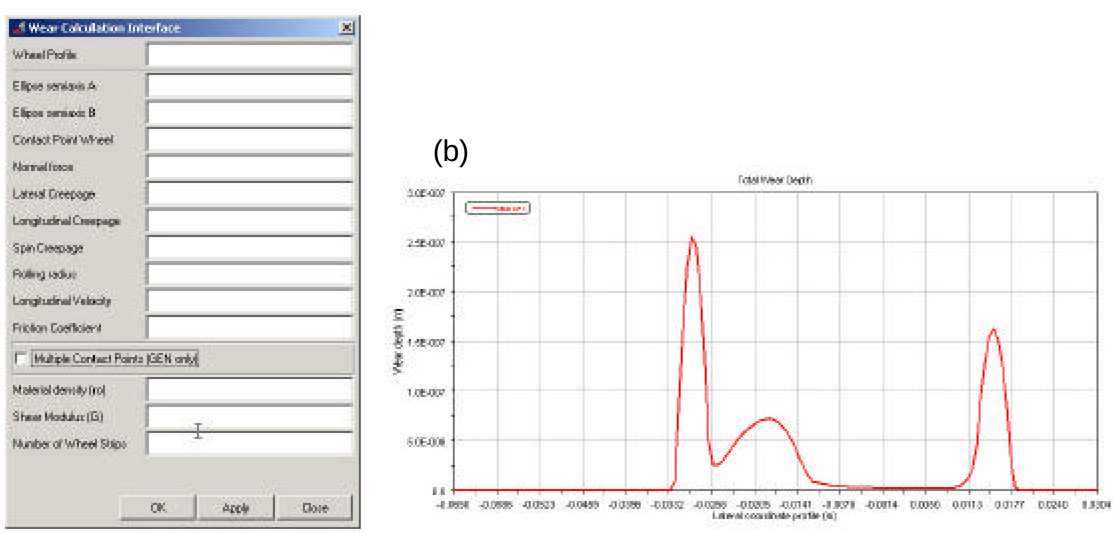

Figure 7. Wear Algorithm: (a) Input Dialogue Box and (b) Graphical Output

6 SAMPLE RUNS

A sample of ADAMS/Rail output data was run through the wear prediction programme. The data consisted of a vehicle running on a sample length of track as detailed below:

- 950 metres of straight track
- 240 metres of transition (straight to curve)
- 1440 metres of constant radius right hand curve
- 260 metres of transition (curve to straight)
- 1110 metres of straight track

The velocity of the vehicle was 220km/h and because of the large radius of curvature of the track, no flange contact occurred. The vehicle takes 65 seconds to cover the length of track.

The upper graph in Figure 8 shows the location of a contact patch on the right wheel of the leading bogie as the vehicle negotiates the curve. The lower graphs show the evolution of the wheel profile determined over 5 second intervals. The wear from the profile is shown both as that occurring just during the 5 second period and as a cumulative total.

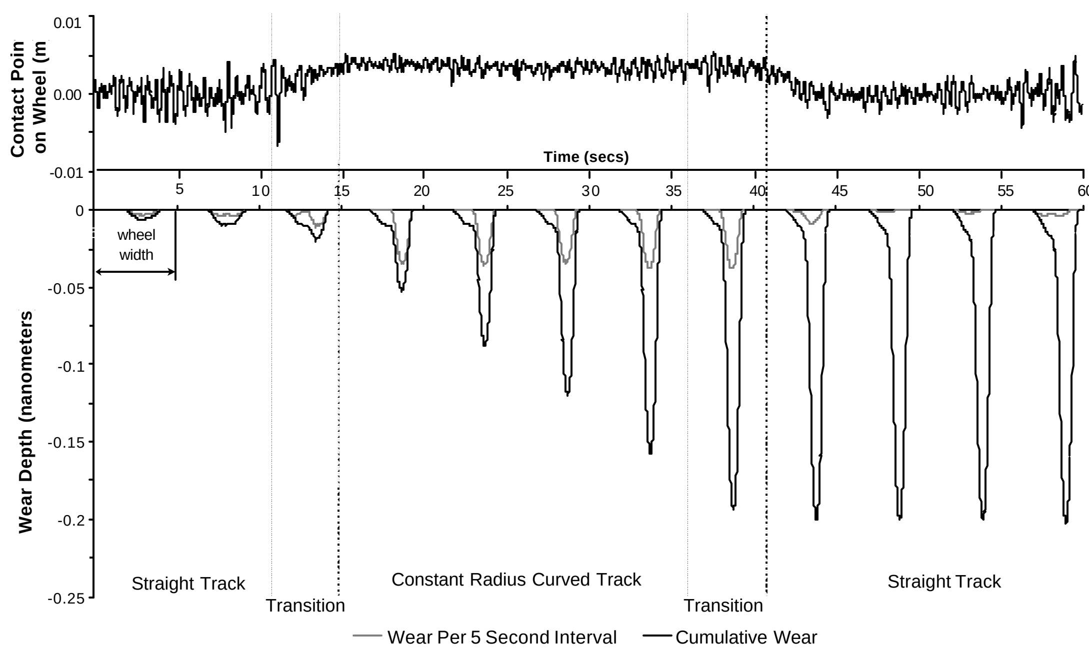

Figure 8. Wheel Wear per 5 Second Interval against Rail Position and Contact Point on the Wheel

The majority of wear on the tread of a wheel occurs around a curve. The straight track conditions produce little wear, although from the contact point on the wheel data it can be seen that the wheel moves most relative to the track in this region.

Figure 9a shows the depth of wear after 33 000 wheel revolutions where the vehicle has been repeatedly running over the above sample of track. Figure 9b shows the location of this material removed with respect to the wheel profile. The wear from this short section of track is confined to a small section of the tread far from the flange. Using more severe curvature of the track, the contact area will significantly increase flange contact and profile wear.

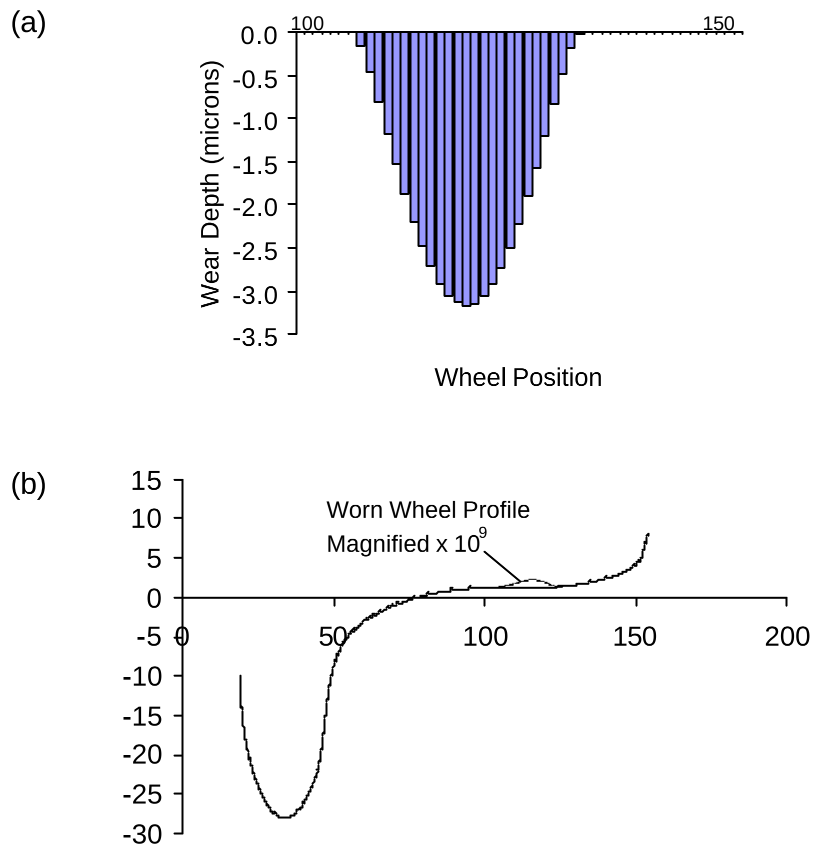

Figure 9. Wear Depth after 33 000 Wheel Revolutions (a) per Strip of Wheel and (b) with Respect to the Wheel Profile

Kalker (1991) observed that for a wheel rolling along a straight track for 33 000 cycles, approximately 1 micron of wear occurred. Whilst this data is for a different vehicle and track configuration, the amount of wear is of a similar order. Especially considering that for the sample result in the present case the contact patch position does not vary over a large region. The result of this is to concentrate the wear to a small region of the wheel.

7 CONCLUSIONS

A model has been developed to predict the wear of railway wheels. This assumes wear is related to $T\gamma$, where T is tractive force and γ is slip at the wheel/rail interface. Twin disc testing of rail and wheel materials was carried out to generate wear coefficients for use in the model.

The model has been incorporated into ADAMS/Rail, which produces multi-body dynamics simulation of a railway wheelset. The methodology for predicting the evolution of a railway wheel profile is made up of three stages: ADAMS/Rail outputs contact conditions at the wheel/rail interface; simplified theory of rolling contact is then used to discretise the contact patches and calculate traction and slip within each; finally the wear coefficients are used with the tractions and slips to predict the wear and hence the change of wheel profile.

This simulation routine will be used as part of a CAE package for assessing wheelset durability for the design of new wheelsets.

The model has been applied to a multi-body simulation of a passage around a sample track length. The worn profile is quantitatively similar to published data.

8 ACKNOWLEDGEMENTS

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