International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Special Issue, Vol. 1, No. 1, January 2014
National Conference on "Recent Advances in Mechanical Engineering" RAME – 2014

Research Paper

ESTIMATION OF ROLLING CONTACT FATIGUE IN RAILWAY VEHICLES

Goutam Nayak[1] and Piyush Verma[2]

The aim of this analysis was to estimate the fatigue life of the rail wheels of LHB coaches used in luxury trains of Indian Railways. This paper first discusses the rolling contact fatigue phenomenon and mathematical models for different kind of fatigue failure modes on the basis of which different fatigue parameters are evaluated. The work carried out includes modeling of LHB coach in a multi-body dynamic solver package GENSYS and also designing of track considering irregularities according to local terrains. Time simulation was carried out to get the dynamic outputs of forces and different fatigue parameters. Fatigue life was calculated in terms of run distance of the rolling stock both for Indian and European track profiles and results were compared.

Keywords: Rolling contact fatigue, Railway wheels, Fatigue index, Damage estimation

INTRODUCTION

Railway wheels may fail in a number of different ways. Even though wear is the most frequent cause behind wheel re-profiling, this is a fairly harmless (although costly) form of deterioration. Fatigue failures, on the other hand, are more violent in nature and may lead to the break-off of a large part of the wheel. Consequences of such failures include damage to rails and sleepers and to train suspensions and bearings. In rare cases, even derailments may result (Marine Vidaud and Willem Jan, 2009).

Broadly rolling contact fatigue failure in rail wheels is divided into three categories: surface induced failure, subsurface induced failure and deep surface initiated failures (Ekberg, 2000). Surface induced failures are mainly due to gross plastic deformation of the wheel material close to the running surface. The plastic flow is mainly of high frictional loading and/or low yield material strength. The cracks normally grow some millimetres into the wheel before deviating to the surface and breaking off a piece of the wheel tread. Subsurface failures occur below the running

[1] Vikram Sarabhai Space Centre, Trivandrum.

[2] Reliance Industries Ltd., Jamnagar.

surface. After initiation, the cracks usually propagate at a depth of 10 to 30 mm below the wheel tread. If and when a crack finally branches towards the wheel surface, a large piece of the wheel tread will break loose. Consequently, these subsurface-induced failures are potentially more dangerous than surface-induced failures. The partition between subsurface initiated fatigue and fatigue initiated at deep defects is somewhat dim. Here, fatigue initiated at deep defects denotes cracks that are the result of high cycle fatigue stemming from a combination of high vertical loading and relatively large material inclusions (in the order of a mm). Fatigue cracks initiate at a depth of some 10-25 mm below the wheel treads.

In past three decades efforts have been made to understand Rolling contact fatigue but it is a complex phenomenon and mechanisms of the crack growth under multi-axial state of stress with cyclically varying loads are yet to be understood clearly. Under large compressive loading cracks propagate mainly in a mixed MODE II-MODE III. This type of propagation is normally not seen in cases other than rolling contact and there is a lack ofuniversal criteria to predict the crack growth direction. Again, it is complicated to simulate in physical experiments, making it difficult to verify and calibrate numerical models. Due to the compressive loading, friction between the two opposite crack faces also plays a vital role in determining the rate of crack propagation under rolling contact. The magnitude of the crack friction is, however, difficult to quantify. Majority of the fatigue research studies have been made on, and most of the predictive models have been developed for, tensile loading. In a predominantly compressive loading, the validity of such models may be questioned. For instance, it can be noted that traditional crack growth prediction methods, such as Paris' law, predict zero crack growth under compressive loading. All these factors complicate the study and understanding of rolling contact fatigue.

MATHEMATICAL MODELS FOR ROLLING CONTACT FATIGUE FAILURES

Mathematical models for three different types of rolling contact fatigue failures have been established by Anders Ekberg, Elena Kabo of Chalmers Institute of Technology and Hans Anderson of Swedish National Testing and Research Institute (Ekberg *et al.*, 2002). The multi-body dynamic solver package GENSYS used for current work calculates the Rolling Contact Fatigue indexes on the basis of the mathematical models briefly described below:

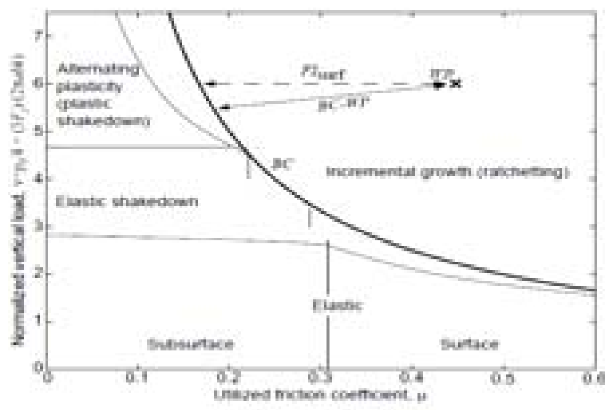
SURFACE INDUCED FAILURES

Initiation of surface cracks is the result of ratcheting and/or low-cycle fatigue of the surface material. A fast and reasonably accurate way of identifying load levels corresponding to surface fatigue in rolling contact is the use of shakedown maps as shown below:

Figure 1 Shakedown map with work point WP indicated by 'X' and boundary curve for plastic surface deformation denoted by 'BC'.

The vertical load magnitude (*Fz*), contact geometry (Semi-axes of Hertzian Contact, *a* and *b*) and the yield stress in shear (*k*) forms a normalized vertical load (υ) defined as:

Figure 1: Shakedown Map



$$\upsilon = \frac{3Fz}{2\pi abk}$$

This is combined with Utilized friction coefficient μ, which is defines as:

$$\mu = \frac{Flat}{Fz} = \frac{\sqrt{Fx^2 + Fy^2}}{Fz}$$

where, Fx and Fy are lateral loads in the wheel-axle and rail directions.

The equation of the boundary curve for surface flow in the shakedown map is

$$\upsilon = \frac{1}{\mu}$$

The fatigue index is given by;

$$FI_{surf} = \mu - \frac{1}{\upsilon} = \mu - \frac{2\pi abk}{3Fz}$$

Surface fatigue is predicted to occur if $FI_{surf} > 0$

SUBSURFACE INITIATED FAILURES

Subsurface initiated rolling contact fatigue behaviour is basically high cycle fatigue behaviour. Cracks initiate from the defect sites approximately around 3 mm below the wheel tread and it grows upto some depth of 10-25 mm and finally it fractures circumferentially. In a multi-axial varying stress condition an equivalent stress is evaluated based on Dang Van Criterion and the same represents the Subsurface fatigue index (FI_{sub}) as given below:

$$FI_{sub} = \frac{Fz(1 + \mu^2)}{4\pi ab} + a_{DV}\sigma_{h,res}$$

where, a_{DV} is a material parameter and $\sigma_{h,res}$ is the residual hydrostatic stress.

Subsurface fatigue is predicted to occur if $FI_{sub} > \sigma_e$

Here, σ_e is the equivalent fatigue limit (normally taken equal to the fatigue limit in pure shear).

DEEP SURFACE INITIATED FAILURES

The partition between 'subsurface initiated fatigue' and 'fatigue initiated at deep defects' is somewhat dim. Fatigue crack initiates approximately at a depth of 10-25 mm below the wheel and fatigue impact at the defect is fairly unaffected by the contact geometry at moderate vertical load magnitudes. This motivates adopting the vertical load magnitude as 'fatigue index'.

$$FI_{dep} = Fz$$

Deep surface fatigue is predicted to occur if, $FI_{dep} > F_{th}(z, d, H, ...)$

Currently, intensive research aiming at quantifying F_{th} is underway. It is, today, known that F this a function of the position of the defect below the wheel tread, z, the size of the defect, d and of load history, H. It is also likely that depends on shape and metallurgical composition of the defect.

MODELLING OF LHB COACH IN GENSYS

The rolling contact fatigue study was carried out on a model of LHB (Linke Hofmann Busch) coach currently used in the luxury trains of Indian Railways. A multi-body dynamics solver package GENSYS was used for the dynamic analysis. A model of the coach, bogie and track are shown in the figure below:

Figure 2: From Top to Bottom Shows a) LHB Coach, b) Bogie Isometric View, c) Model of Track, d) Side View of Bogie, Modeled in GENSYS

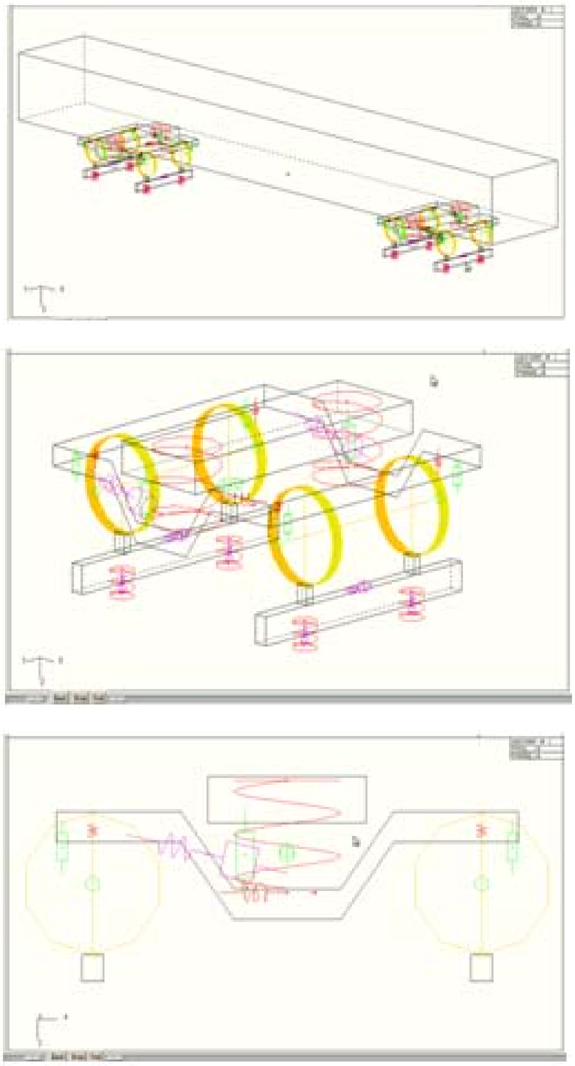
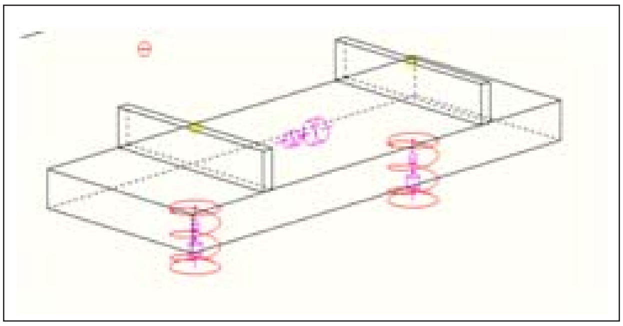


Figure 2 (Cont.)



Time simulation was carried out on a 1000 km S shaped curved track with varying track irregularities. Vertical force distributions and rolling contact fatigue indexes were obtained from the results of dynamic analysis. Time simulations were run for 3 types of Indian and European track profiles and the results obtained were analyzed in the following section.

RESULTS AND COMPARISON

In the present study estimation of fatigue life was made on the basis of sub surface fatigue criteria as the surface fatigue is not so dangerous and research is still going on about the deep surface fatigue criteria. The damage per cycle according to the Palmgren-Miner linear damage accumulation rule is given by:

$$D = 10^{\frac{5(\sigma_e - \sigma_{eq})}{\sigma_e - \sigma_u} - 6}$$

where, D is damage per cycle

σ_e, fatigue strength in pure sheer for 10^6 cycles = 261 MPa

$\sigma_{eq} = FPb$

σ_u, fatigue strength in pure sheer for 10^1 cycles = 469.8 MPa

Fatigue failure is then assumed to occur at a material point when the total accumulated damage D attains the value 1.

The fatigue life in terms of distance travelled can be written as

$$d = \frac{\pi D_w}{sD}$$

where D_w,diameter of wheel = 915 mm and s is the probability fraction of the load (Anders Ekberg, 1996) taken between 0.1 to 0.2.

Figure 3: From Top to Bottom Shows a) The Vertical Force Distribution on Both Left and Right Wheels Connected to an Axle, b) Surface Induced Fatigue Index, c) Deep Surface Induced Fatigue Index, and d) Subsurface Induced Fatigue Index

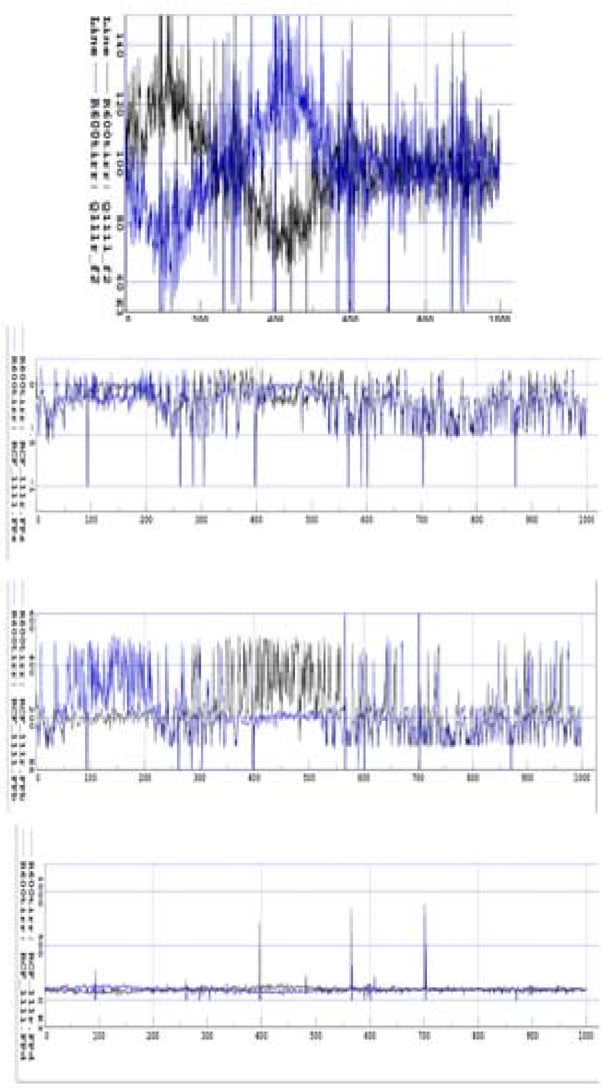


Table 1: Average Values of Different Fatigue Indexes and Estimated Fatigue Life

Track	FPs (10^-3)	FPb (10^6)	FPd (10^3)	s	D (10^)	D (10^5 km)
Indian	–179.903	215.366	97.004	0.149	–7.09	2.38
Indian (0.8)	–177.411	214.624	96.763	0.127	–7.11	2.91
Indian (1.2)	–178.125	216.359	97.849	0.174	–7.069	1.93
European	–202.747	206.5	94.923	0.135	–7.305	4.29
European (0.8)	–208.401	204.9	94.893	0.119	–7.343	5.31
European (1.2)	–196.589	208.109	94.933	0.152	–7.266	3.48

CONCLUSION

The results tabulated above show that value of sub-surface fatigue index increases with the magnitude of the track irregularities. Hence, fatigue life in terms of rolling distance decreases with an increase in magnitude of the track irregularities. Analysis also shows that the vehicle model running on European tracks have a greater Fatigue life as compared to the same vehicle model running on Indian tracks.

REFERENCES

1. Anders Ekberg (1996), "Rolling Contact Fatigue of Railway Wheels – Computer Modelling and in-Field Data", Proc. 2nd Mini-Conference on Contact Mechanics and Wear of Rail/Wheel Systems, pp. 154-163, Budapest, Hungary.

2. Anders Ekberg (1997), "Rolling Contact Fatigue of Railway Wheels—A Parametric Study", *Wear*, Vol. 211, pp. 280-288.

3. Anders Ekberg (2000), "Rolling Contact Fatigue of Railway Wheels – Towards Tread Life Prediction Through Numerical Modelling Considering Material Imperfections", Probabilistic Loading and

Operational Data, Ph.D. Thesis, Chalmers University of Technology, Department of Solid Mechanics, Göteborg, Sweden.

4. Anders Ekberg, Hans Bjarnehed and Roger Lundén (1995), "A Fatigue Life Model for General Rolling Contact with Application to Wheel/Rail Damage", *Fatigue & Fracture of Engineering Materials & Structures*, Vol. 18, No. 10, pp. 1189-1199.

5. Anders Ekberg, Kabo E and Andersson H (2002), "An Engineering Model for Prediction of Rolling Contact Fatigue of Railway Wheels".

6. Anders Ekberg, Reine Lindqvist and Martin Olofsson (1999), "Multiaxial Fatigue—A Probabilistic Analysis of Initiation in Cases of Defined Stress Cycles", Fatigue'99 – Proc. 7th International Fatigue Congress, pp. 923-928, Beijing, China.

7. Marine Vidaud and Willem Jan (2009), "Current Situation on Rolling Contact Fatigue—A Rail Wear Phenomenon", Presented in 9th Swiss Transport Research Conference.