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Finite Element Analysis of Wheel, Rail and Joints: A Review

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ABSTRACT

The aim of this review paper is to investigate stresses developed at wheel, rail and joints in order to improve their performance. Railway has various mechanical components such as wheel; rail, joints, axle etc. and they are considered as highly stressed components. Failure of these components caused accidents and disaster consequences for properties as well as human life. For reducing these chances of failure it is necessary to analyze the behavior of the wheel/rail and their joint which is subjected to various types of loads, which is completely unknown from the ancient time. This paper is an attempt to summarize the study of laboratory experiments and their comparison with FE analysis of wheel/rail and their joint.

Key words: Wheel/Rail, Rail-Joints, Stress, Wear, FEA

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INTRODUCTION

Railway plays a tremendous role in connectivity. There are various mechanical components of railway i.e. wheels, rail, rail-joint, axle etc. and they are subjected to various types of loading during the running conditions. Wheel consists of different kinds of functional parts such as rim, flange and hub. Different materials are used in wheels such as unalloyed or low alloyed steel which have contained high degree of purity. Wheels are subjected to various kinds of loads, stresses when they come in contact with track.

A steel rail has a flat bottom and its cross section is derived from an I-profile. The upper flanges of the I-profile have been converted to form the rail head. In India most commonly used rail profile is the UIC 60 rail, where 60 refer to the mass of the rail in kg per meter [12]. The rails should provide smooth running surfaces for the wheels and they should also guide the wheels in the direction of the track. The rails carry the vertical load of the train and distribute the load over the sleepers.

Two joint bars or fishplates and six bolts are used to connect the ends of adjoining rails. This joint assembly is to line-up rail ends horizontally and vertically and to create smooth running surface for rolling contact of wheel and rail [16]. The rail joints are weakest part of rail and also they are subjected to large stresses causing failure.

LITERATURE REVIEW

The contact pressures from service loads gradually change the residual stresses in the heads of rails and the rims of wheels from their initial distributions as permanent plastic deformation accumulates. The resultant state has a near-surface compressive component, aligned with the major live stress, which protects the contact surface against fatigue propagation of shallow surface cracks unit wear removes them. If the contact pressures are high enough, internal residual tension may develop and promote subsurface fatigue cracking. The fatigue environment can also be exacerbated by high traction/braking shear loads or by local heating and thermal stress if the interface is subjected to high power dissipation. The goal is to establish rational criteria for load or life limits [11].

The mechanism of effects of structure elastic deformations of bodies in rolling contact on rolling contact performance is briefly analyzed in this paper. Effects of structure deformations of wheel set and track on the creep forces of wheel and rail are investigated in detail. General structure elastic deformations of wheel set and track are previously analyzed with finite element method, and the relations, which express the structure elastic deformations and the corresponding loads in the rolling direction and the lateral direction of wheel set, respectively, are obtained. In the analysis of the creep forces, the modified theory of Kalker is employed [19].

A two dimensional finite element study is carried out to investigate a small part (micro-region) of a wheel pressed onto a rail. The wheel is assumed to be smooth or is given a certain surface roughness, and the rail is given a measured surface roughness. The wheel is loaded according to the average value of the contact pressure and its time history over the area which is found in a three-dimensional finite element analysis of a wheel–rail contact. The present paper also deals with understanding the wear mechanisms acting during wheel–rail contact [15].

The finite element method was used to make two-dimensional thermo-mechanical analyses of the rail cooling and roller straightening processes. The results became the initial conditions in a three-dimensional elastic-plastic rail model; the model is part of an FE tool developed for rolling contact fatigue analysis of rails. The results from this tool were analyzed for fatigue, for eight wheel passages, according to a method which incorporates a critical plane approach that evaluates fatigue damage on a cycle-by-cycle basis. A heavy-haul train was studied in this paper with respect to subsurface fatigue crack initiation in straight track. FE tool calculations were made to show the axle load at which rail manufacturing stresses reduce the fatigue life to crack initiation [6].

Method for the computation of the wheel–rail surface degradation in a curve where the major surface degradation phenomenon is a combination of wear and plastic deformation.

Thenormal contact problem is analyzed using the modified Winkler method and calibrated using the results from FEM modeling of the wheel–rail contact with elastic–plastic material model. A piecewise approach and stick-slip analysis of the rolling–sliding contact solves the tangential problem. A linear wear law is used in the wear computation. The form change for a typical two-point contact in a low radius curve was analyzed [13].

An overview of rolling contact fatigue phenomena occurring at wheels and rails. The paper outlines mechanisms behind the various phenomena, means of prediction, influencing parameters and possible means of prevention [3].

This paper gives a general introduction to fracture mechanics application to railway components. A brief discussion of various fracture control concepts such as safe-life, fail-safe and damage tolerance [14].

Research into the influence of interacting wheel and rail profiles on the distribution of contact zones and stresses is presented. The influence of contact forces on the deformation of rolling car load wheels and rails and the influence of this deformation on the redistribution of the contact stresses is also investigated. With the help of quasi-Hertz method as well as a finite element method, distributions of contact zones for different angles of attack of the wheel sets were defined. The offered technique to solve the contact problem has been used for the improvement of operating wheels [2].

The finite element code ANSYS/LS-DYNA is used to simulate the wheel/rail contact-impact behavior at rail joint region. The implicit and explicit finite element methods have been coupled to analyze wheel/rail impact process. In the FE simulation, a material model with linear kinematic hardening was used. The influences of axle load and train speed on contact forces, the stresses and strains in the railhead are investigated in detail [21].

A finite element analysis is conducted to study dynamic elastic–plastic stress. The ANSYS implicit code and LS-DYNA explicit code are coupled to simulate the process of the wheel contacting or impacting the rail joint. Contact elements are used to simulate the interactions between wheel and rails, between rails and joint bars, between joint bars and bolts and between bolts and rails. The effects of train speed, axle load and the height difference of rail joint on the contact forces, stresses and strains at rail head are investigated [16].

The effect of lubrication on vehicle/track and/or wheel/rail dynamic behavior was studied by vehicle running tests for track site measurements and vehicle dynamic simulations from the practical and theoretical aspects in this study [9].

The elastic-plastic contact problem with rolling friction of wheel-rail is solved using the FE parametric quadratic programming method. Complex elastic-plastic contact problem can be calculated with high accuracy and efficiency, while the Hertz's hypothesis and the elastic semi-space assumption are avoided. Based on the 'one-point' contact calculation of wheel-rail, the computational models of 'two-point' contact are established and calculated when the wheel flange is close to the rail. In the case of 'two-point' contact, the changing laws ofwheel-rail contact are introduced and contact forces in various load cases are carefully analyzed [7].

Utilizes a numerical method to analyze the effect of railway vehicle curving on the wear and contact stresses of wheel/rail. The numerical method considers a combination of Kalker's non-Hertzian rolling contact theory, a material wear model and a vertical and lateral coupling dynamics model of the vehicle/track [18].

A wheel/rail profile wear prediction methodology is developed and applied to the wheel/rail disc test about the wear of flange and gauge. Three-dimensional nonlinear finite element dynamic analysis code ABAQUS is used in the simulation of wheel/rail disc rolling contact process. The implicit and explicit finite element methods have been coupled to analyze wheel/rail disc rolling contact process. In the FEM simulation, a material model with bilinear kinematic hardening property was used. The wear model is based on Archard's wear model. A cubic spline interpolation algorithm was applied on wear distribution and the updated wheel/rail profiles. The simulation results are compared with measurements of laboratory wear test and the effectiveness of the wear prediction methodology was verified [4].

Experimental method based on the measurement of ultrasonic reflection is used to solve the contact problem, together with a FASTSIM (simplified theory of rolling contact) algorithm. Wear is estimated by means of the energy dissipation approach (T•gamma). Two different contacts are investigated, using wheel and rail profiles coming from unused and worn specimens [1].

The interaction of an interfacial fluid model for combined boundary and mixed lubrication of rough surfaces with a wheel–rail contact model that additionally accounts for frictional heating. Emphasis is placed on the qualitative behavior of the model with respect to the measurements and good agreement is found. The dependence of the maximum traction coefficient on rolling velocity, surface roughness and normal load is studied under dry and water lubricated conditions [5].

The experimental research on the wears of wheel and rail has been carried out using a large rolling-sliding contact test machine with the actual profiles of wheel and rail. Primarily, the effects of axle load, the angle of attack, rail hardness and lubrication on wear behaviors of wheel flange and rail gauge corner have been particularly focused in research. Based on those experimental results, the Archard wear coefficients of Japanese track were calculated under various conditions. A wear prediction model of rail profile taking into consideration contact stress, slip ratio at contact patch and material hardness was established based on the experimental results and the wheel–rail contact analyses [20].

A finite element method is used to study thermal-elastic–plastic deformation and residual stress after wheel sliding on a rail. The consideration of sliding contact between the wheel and the rail is restricted to a two dimensional contact problem. The repeated sliding contact process is simulated by translating the normal contact pressure and the tangential traction across the rail surface. The normal contact pressure is idealized as the Hertzian distribution and the tangential force is modeled by Coulomb model. The heat-convection and radiationbetween the rail and the ambient, the material mechanical and thermal coefficients changing with temperature are taken into account [8].

The model is first validated with Hertz theory and Kalker's computer program CONTACT for the normal solution and with CONTACT for the tangential solution, for the case of wheel tread–rail top contact. Subsequently, the influence of element size on solution accuracy is examined by comparing the results of different element sizes [17].

Numerical analysis of stress-strain characteristics of 3-D rail-wheel contact is successfully carried out using FEA. Analysis of three-dimensional half wheel, rail and axle assembly model is carried out in ANSYS [10].

A three-dimensional finite element model for rail joint bars is developed and dynamic load is applied to estimate the fatigue life of the joint bars. Different components of the rail joint bars are being created separately. The model consists of assembly of the rail, joint bars, bolts, nuts, washers, and wheel. A three-dimensional finite element analysis of rail joint bars is carried out in ANSYS. The static and dynamic loads are being applied to estimate fatigue life and endurance strength at the section. The material properties of the rail and wheel are assumed to be same. The material properties of the wheel and rail are considered to be bilinear kinematic hardening in ANSYS. All the material properties and boundary conditions are being applied strictly as per the guidelines made available by the Indian Railways in their manual [12].

CONCLUSION

According to the all above literature survey it may be concluded that the study on wheel/rail wear and stresses are mainly based on laboratory experiments and their comparison with FE analysis. All most FE model and wear model based on archard's wear model and material model. These models are adopted to investigate the problems of wheel /rail system under the wheel/rail frictional sliding contact. The thermal and mechanical properties are used in simulation. There are various types of method such as hertz's analytical method, kalkers's method, Fastsim method, FE method and winkler method is used for the analysis of wheel/rail and their contact. The FE method gives more efficient and accurate result then the hertz analytical method. Stress analysis of the wheel/rail and their joint with the help of above mentions method and models will help us to reduce the causes of hazards and safe human life and properties.

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