

Review of Joost Kalker's Wheel-Rail Contact Theories and Their Implementation in Multibody Codes

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1 INTRODUCTION

During the past decades Kalker developed a number of wheel-rail contact theories that can be used to determine the tangential forces and spin moment between the wheel and the rail [Kalker, 1990]. These theories are: *Linear Theory*, *Simplified Theory*, *Empirical Theory*, *Strip Theory* and *Exact Three Dimensional Rolling Contact Theory*. These theories assume that the contact between the two bodies is non-conformal. Recently, Li and Kalker [Li and Kalker, 1998] introduced an approach for numerical solution of the conformal contact between the wheel and the rail. In this paper, Kalker's wheel-rail contact theories are presented. The paper provides an overview for each theory and its restriction or error as was reported by Kalker. In addition, a systematic procedure for implementing Kalkers's wheel-rail contact theories in multibody codes is briefly presented.

2 SIMPLIFIED THEORY

During the period of 1973-1982, Kalker developed the *Simplified Theory*. The theory is based on approximating the relation between the tangential surface traction and the tangential surface displacement by using compliant (flexibility) parameters. In the simplified theory, the traction-displacement constitutive law takes a simple linear form [Kalker, 1973]

The simplified theory can be used to investigate the influence of the surface layers that cover the bodies. In reality, the wheel and rail are contaminated. In this case, due to the difference in the layers, the coefficient of friction may be reduced. This leads to variation in the saturation level of the creep forces.

This theory is used in the most known program FASTSIM that was developed by Kalker in 1982 [Kalker, 1982]. FASTSIM is widely used in computer programs to determine the wheel-rail creep contact forces.

3 LINEAR THEORY

In this theory, the contact patch is divided into an adhesion and sliding area and the effect of the spin moment is included. The theory is based on the assumption that the traction distribution is continuous at the leading edge of the contact. That is the traction must vanish at the leading edge where the particles enter the contact area. On the other hand within the contact area, the traction builds up until the trailing edge. In addition, Kalker introduced the table of creepage and spin coefficients that are known as Kalker's coefficients [Kalker, 1967]. Kalker's coefficients

are used in several wheel-rail contact theories to determine the tangential forces and spin moment. To this day, the linear theory is commonly used to investigate railroad vehicle dynamics.

4 EXACT THREE-DIMENSIONAL ROLLING CONTACT THEORY

The exact three-dimensional rolling contact theory is based on the principle of virtual work. In this case, the solution of the contact problem is determined by maximizing the complementary work over all possible functions that satisfy the constraints. In addition, the displacements of the surface in the contact area are expressed as integrals of the surface tractions by using influence functions [Kalker, 1990]. The influence functions can be determined analytically for the homogenous, isotropic half-space. Therefore, half-space assumption is used in this theory. The exact three dimensional rolling contact theory is used in the well known program CONTACT developed by Kalker.

5 CONFORMAL CONTACT (LI-KALKER THEORY)

The methods described in the preceding sections assume that the contact area is non-conformal, and the half-space approximation is utilized. In the case of conformal contact, the half-space approximation is no longer valid as the size of the contact area is not small compared to the size of the contacting bodies. In addition, the creepages and spin are not constant within the contact area. Li and Kalker used two quasi-quarter spaces for solving the conformal contact problem [Li and Kalker, 1998]. In their approach, the variation of spin throughout the contact area is considered.

6 IMPLEMENTATION OF KALKER'S WHEEL-RAIL CONTACT THEORIES IN MULTIBODY CODES

A systematic approach for implementing Kalker's wheel-rail contact theories in multibody codes is described. The procedure uses non-generalized surface parameters to represent the wheel and the rail surfaces [Shabana et al., 2008]. Some results that are obtained from a multibody code are presented in this paper.

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