Symposium of Advances in Contact Mechanics: a tribute to Prof. J.J. Kalker
22 - 24 October 2008, Delft, The Netherlands

Survey of Programs on Contact Mechanics by Prof. J.J. Kalker

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Keywords: rolling contact, three-dimensional, contact mechanical software

1 INTRODUCTION

In his extensive career Joost Kalker worked on many contact phenomena. For this he developed various theories, which were accompanied by algorithms and computer programs. Most notably these are the FASTSIM algorithm for quickly evaluating the non-linear creep-force law in vehicle dynamic simulations, the CONTACT program for the exact theory of rolling contact in three-dimensional elastic half-spaces, and the USETAB program that uses a large table calculated with CONTACT in order to improve over the FASTSIM algorithm in speed, accuracy and versatility as well. In this presentation we survey these programs and present some new results.

2 CONTACT: THE 3D ROLLING CONTACT PROBLEM

The program CONTACT [1] is meant for three-dimensional, elastic and visco-elastic, concentrated contact problems. The program solves solves shifts as well as rolling, and transient as well as steady state problems. The program works using an influence function method. The partial differential equations used are those for homogeneous, isotropic elasticity. These equations for the interiors of the two contacting bodies are converted to equations for the boundaries alone using the influence function. In this way the primary unknowns are the surface tractions p_n, p_τ, the resulting displacements u_n, u_τ and the resulting slip s_τ. The analytically known influence functions for the 3D elastic half-space are used.

In CONTACT a calculation starts by defining a potential contact area that encompasses the true contact area. The potential contact area is discretised into rectangular elements. The surface tractions are approximated by functions that are constant within each element. CONTACT uses a quasi-static approach in which inertial effects are ignored. This allows for using a variational principle of maximum complementary virtual work, by which the contact conditions may be reformulated as a optimisation problem. However, time still plays a role in the definition of the slip. The slip at the surface of the contacting bodies is discretized using the “displacements at a previous time instance”' u'. For this a discretisation parameter is introduced, the traversed distance per time step dq.

The resulting minimisation problem is solved using an “active set” algorithm, in which the proper subdivision of the elements into “exterior”, “adhesion” and “slip” regions is iteratively solved. For the normal problem this yields a set of linear equations that is solved using the Conjugate Gradients method. The tangential problem with slip results in a set of non-linear equations that are solved using a specific Gauss-Seidel type approach in which the element division is determined along the way. Recent extensions concern matrix-free implementations of the solvers, which allow for much larger problems being solved, and parallellisation of the main computations using OpenMP.

3 ROLLEN AND USETAB: SPIN-CREEP-FORCE LAWS

A key element in the dynamic simulation of rail vehicles is the interaction between wheels and rails. For this many separate contact problems must be solved within each time step of a dynamic simulation, thus speed of computation is most important in this case. The speed of CONTACT is not sufficient for these type of simulations (2007: about 50 problems with in the order of 100 elements per second). Therefore alternative algorithms have been devised.

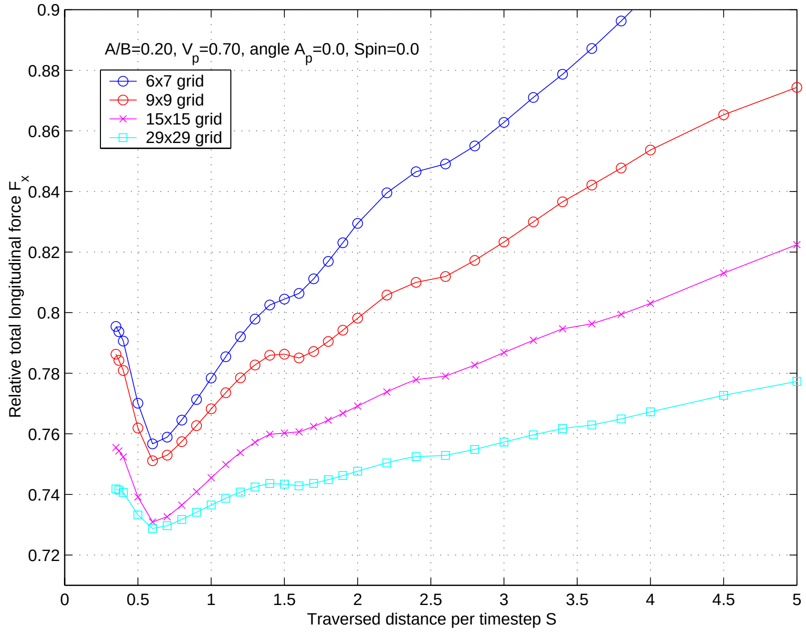

Figure 1: Dependency of (relative) total force F_x on discretisation grid and discretisation parameter *dq*.

Approximate linear and non-linear formulae may be used, yet with restricted accuracy in case of slip or when there is a significant amount of spin. In the FASTSIM algorithm, encoded in the computer program ROLLEN, model calculations using the simplified theory are used. The simplified theory is approximate by nature. Kalker reports a maximum error of 15% for rare cases using the FASTSIM algorithm [1].

An alternative to using FASTSIM is to pre-calculate a large number of cases beforehand, and then interpolating between these cases in an actual simulation. This is done in the USETAB program, using a general table for the creep-force-moment law. This table is set up for steel bodies

υ=0.28 and assumes an elliptical contact area. The principal unknowns are the ratio of the contact semi-axes *a/b* and the creepages ξ, η and φ. The table uses a smart lay-out exploiting all kinds of symmetries. In total 115,000 entries are used.

4 SOME NEW RESULTS

In 2005 we created a new table for the creep-force-moment law for use in the VAMPIRE analysis program. During this work we noted that the computed total forces depend critically on the discretisation parameter *dq*, the traversed distance per time step, see Figure 1. This raises questions on the appropriate setting of the input parameter *dq*.

These questions will be resolved using calculations on very fine grids. This will give insight in the speed and computational complexity of CONTACT as well. Finally we will elaborate on the accuracy and rate of convergence of the computed results.

5 REFERENCES

[1] J.J. Kalker. *Three-Dimensional Elastic Bodies in Rolling Contact*. Solid Mechanics and its Applications. Kluwer Academic Publishers, 1990.