Switch Geometry Modeling using ANCF

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In the analysis of multibody system (MBS) dynamics, contact between two arbitrary rigid bodies is a fundamental feature in a variety of models. Many procedures have been proposed to solve the rigid body contact problem, most of which belong to one of the two categories: offline and online contact search methods. This investigation will focus on the development of a contact surface model for the rigid body contact problem in the case where an online three-dimensional non-conformal contact evaluation procedure, such as the elastic contact formulation—algebraic equations (ECF-A), is used. It is shown that the contact surface must have continuity in the second-order spatial derivatives when used in conjunction with ECF-A. Many of the existing surface models rely on direct linear interpolation of profile curves, which leads to first-order spatial derivative discontinuities. This, in turn, leads to erroneous spikes in the prediction of contact forces. To this end, an absolute nodal coordinate formulation (ANCF) thin plate surface model is developed in order to ensure second-order spatial derivative continuity to satisfy the requirements of the contact formulation used. A simple example of a railroad vehicle negotiating a turnout, which includes a variable cross-section rail, is tested for the cases of the new ANCF thin plate element surface, an existing ANCF thin plate element surface with first order spatial derivative continuity, and the direct linear profile interpolation method. A comparison of the numerical results reveals the benefits of using the new ANCF surface geometry developed in this investigation.

Introduction

The objective of this work is to develop a new finite element based procedure for representing surface geometry in MBS contact problems. This procedure ensures a certain degree of continuity at the element interface, thereby allowing for more accurate predictions of kinetics results that include the contact forces. Specifically, the main contributions of this investigation can be summarized as follows:

(1) The investigation clearly identifies and explains the limitations of using curve representations in the description of surface geometry. It also identifies and explains the limitations of using low-order interpolations with contact formulations that demand a higher degree of continuity. These two geometric approaches for modeling surfaces can lead to fundamental kinematic and kinetic problems that cannot be ignored in the analysis of important engineering applications such as railroad vehicle systems.

(2) This communication proposes a new finite element-based surface geometry that ensures higher degree of continuity at the element interface. The new geometry, which is based on ANCF finite elements, is proposed in order to address the fundamental problems associated with the use of the curve representation or the use of lower-order interpolation. A biquintic interpolation is used in order to address the kinetic problems that result from the use of other existing geometric descriptions.

(3) This work presents for the first time a comparative analysis, both qualitative and quantitative, to demonstrate the value of using the proposed geometry approach. To this end, three different approaches are compared analytically and numerically. These three approaches are the curve representation for the surface, the low-order surface interpolation, and the proposed

higher-order surface interpolation. The results of this study demonstrate that the use of higher-order surface interpolation is feasible in many challenging problems.

(4) Finally, a numerical example of a rail vehicle negotiating a turnout is used to demonstrate the feasibility of using rail CAD geometry model that can be systematically integrated with complex MBS models. The example presented in this brief clearly demonstrates the need for the use of the new geometric approach to model important technological applications. The results also demonstrate clearly the limitations of other existing approaches.

This investigation has been published in an extended manner in [1].

Numerical Results

The numerical simulations are carried out for three different scenarios that correspond to the three surface types (curve representation, low-order interpolation, and high-order interpolation) discussed in this investigation. The results obtained using the three different surfaces are compared. The simulations are carried out using the online non-conformal elastic contact formulation (ECF-A) implemented in the general purpose multibody package SAMS/2000. Among the three models, the fastest is the linear interpolation method, which requires 5 min and 8 s of CPU time on a personal computer using serial computations, while the cubic ANCF method required 5 min and 27 s, and the quintic ANCF method required 6 min and 22 s. The simulations were performed using an Intel PC with i5-2400 CPU that has a clock speed of 3.10 GHz. While the linear interpolation is faster, the improved accuracy of the quintic ANCF method far overweighs the additional CPU time it requires as will be demonstrated by the numerical results. The best agreement in the results is found in the location of the contact point. In Fig. 1, it is shown that the difference in the computed lateral position of the contact point is negligible between the cubic and quintic ANCF thin plate models, while the discrepancies are more pronounced when compared to the linear profile interpolation method. Note that the large shift in the location of the contact point at 7.9502 m (313 in.) corresponds to time at which the contact point switches from the stock rail to the tongue rail. A similar phenomenon can be seen in the plot of the vertical position of the contact point shown in Fig. 2. As the contact point transitions from the stock rail to the tongue rail, there is a small vertical shift downward. Following this, the contact point shifts vertically by 6.35 10^{-3} m (0.25 in.) as per the design of the tongue rail, which includes this elevation increase. It is also important to note here the linear nature of the change in the vertical position of the contact point in the case of the direct profile interpolation method. Recall that linear interpolation is used in the longitudinal interpolation between any two profiles; consequently, this leads to a linear change in the height of the profile along the rail space curve. This phenomenon is less pronounced in the lateral shift as the individual profiles are described with cubic interpolation. Figure 3 shows the trace of the contact points along the left rail in the proximity of the tongue rail. Here, the cause for the lateral shift is more pronounced: the contact point shifts laterally to follow the stock rail until such a time that the primary contact point transitions from the stock rail to the tongue rail. The difference between the three examples is much more pronounced in the normal contact forces. In Fig. 4, a comparison is shown for the normal contact force at the left wheel/rail interface between the direct linear interpolation method and the quantic ANCF thin plate mesh. Here, it can be seen clearly that the linear interpolation method produces fictitious spikes in the forces, which is certainly an undesirable and unrealistic feature.

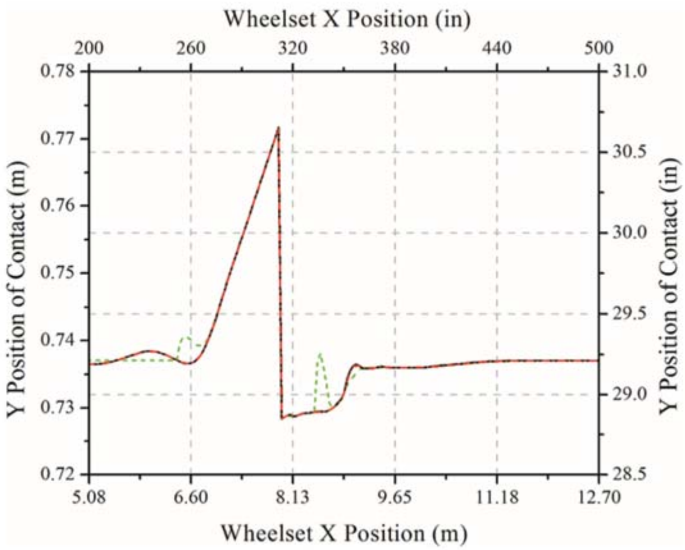

Fig. 1 Y Coordinate of contact point on left rail (green- linear interpolation; red-cubic plate; black-quintic plate)

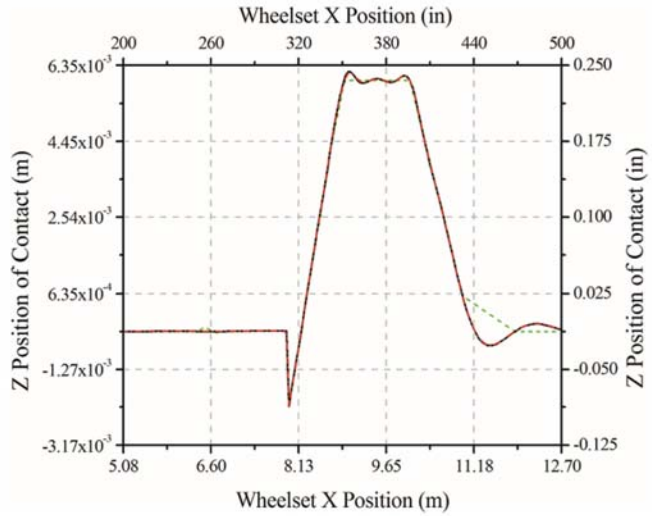

Fig. 2 Z Coordinate of contact point on left rail (green- linear interpolation; red-cubic plate; black-quintic plate)

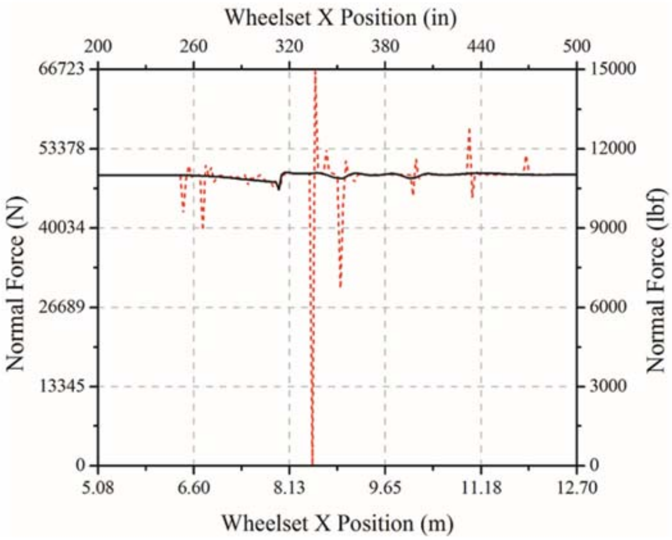

Fig. 4 Normal force at left contact linear interpolation (dashed red line) versus quintic plate (solid black line)

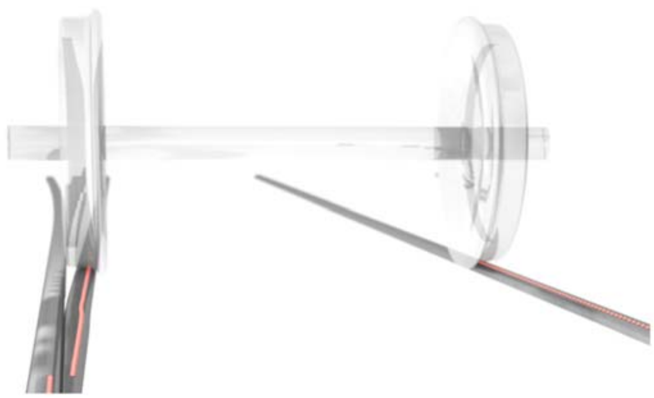

Fig. 3 Trace of contact point along quintic ANCF thin plate turnout

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References

[1]. Hamper, M.B., Wei, C., and Shabana, A.A., 2015, "Use of ANCF Surface Geometry in the Rigid Body Contact Problems: Application to Railroad Vehicle Dynamics", *Journal of Computational and Nonlinear Dynamics*, Vol. 10, 021008, pp. 1-12.