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Nonlinear Track-Railroad Vehicle Interaction

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This investigation describes a new nonlinear formulation based on the absolute nodal coordinate formulation (ANCF) for modeling the dynamic interaction between rigid wheels and flexible rails. The generalized forces and spin moments at the contact points are formulated in terms of the absolute coordinates and gradients of ANCF finite elements used to model the rail. To this end, a new procedure for formulating the generalized ANCF applied moment based on a continuum mechanics approach is introduced. In order to have an accurate definition of the creepages, the location and velocity of the contact points are updated online using the rail deformations. An elastic contact formulation that allows for wheel/rail separation is used to define the contact forces that enter into the dynamic formulation of the system equations of motion. An elastic line approach is used to define the rail stress forces, and the relative slip between the rigid wheel and the flexible rail is iteratively updated using the deformations of the ANCF finite elements. The formulation proposed in this investigation is demonstrated using a five-body railroad vehicle negotiating flexible rails. In order to validate the ANCF rail model, the obtained results are compared with previously published results obtained using the floating frame of reference (FFR) formulation that employs eigenmodes. The comparative study presented in this work shows that there is, in general, a good agreement between the results obtained using the two different formulations.

Introduction

Wheel/rail contact interaction forces have a significant effect on the dynamics and stability of railroad vehicle systems. These forces are a function of several variables such as the dimension of the contact area, creepages, material properties, and track flexibility. In the area of railroad vehicle dynamics, many investigations have been focused on the track flexibility, which influences the location of the contact points and the overall dynamic behavior of railroad vehicles. Consequently, it is important to consider track flexibility in order accurately predict the wheel/rail contact forces and examine the vehicle response in many simulation scenarios and loading conditions. Some reasons for the need to include the effect of track flexibility in multibody system (MBS) railroad vehicle simulations are given below.

- Including the effect of the track flexibility allows for more accurate modeling of the vehicle/track coupling.
- More accurate models for wheel and rail wear and fatigue can be developed by considering the effect of track motion and flexibility.
- The deformation of a track allows for an accurate prediction of the creepages, which are required in the formulation of the creep forces. These forces influence the dynamics and stability of railroad vehicle systems.
- Accurate studies of the effect of temperature, buckling, gage widening, loss of rail stiffness, etc. require the use of the more accurate flexible rail models.

This investigation uses the Floating Frame of Reference (FFR) formulation that allows for introducing the flexibility of linearly elastic railroad tracks, and the Absolute Nodal Coordinate Formulation (ANCF), which is a fully nonlinear method, to include the dynamics and flexibility of the tracks and the interaction with the vehicle. An extended version of this work is underway [1].

Models and Case Study

In this section, the vehicle and track models as well as various case studies discussed in the numerical results section are presented. A 5-body railroad vehicle model is simulated on three tangent track models: a rigid track and flexible ANCF and FFR tracks. In addition, the flexible tracks are analyzed considering a scenario characterized by the lack of attachment between sleepers and rail. The case study considers the original stiffness and damping properties, but it includes the effect of the loss of contact between two consecutive sleepers and the right rail.

Vehicle Model. The vehicle model used in this investigation consists of a 5-body suspended bogie running at a constant forward velocity over a tangent track. The model includes two wheelsets, two equalizers, and a frame. Sixteen bushings and four bearings elements connect the vehicle bodies. The velocity constraint is imposed on the pitch coordinate of the rear wheelset, with a value of $\dot{\theta}_y = 37.1$ rad/s, which yields an approximate forward velocity of 17 m/s.

Track Models. Two different flexible track models (ANCF and FFR) are developed using the formulations described in previous sections of this brief.

Case Studies. One case study is considered to compare ANCF and FFR flexible track models. In this case, standard track lateral and vertical damping and stiffness properties are used with the assumption that two consecutive sleepers lose contact with the right rail. This case is used to analyze the loss of contact between the rail and sleepers as a consequence of a gap between the ballast and the sleepers. These structural flaws may cause severe damage.

Numerical Results

This example represents a damaged track which has standard material. However, a loss of contact between two consecutive sleepers and the right flexible rail segment is assumed.

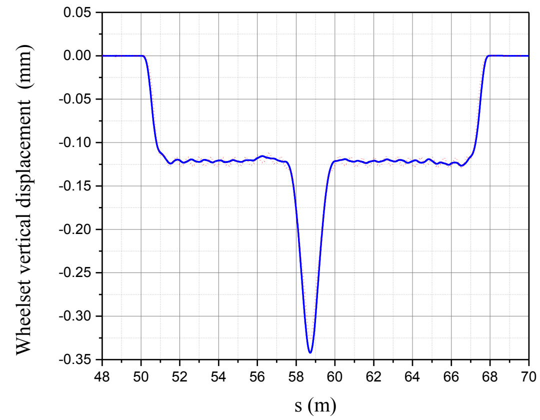

Figure 1. Rear wheelset vertical displacement with lack of sleepers. (FFR; ANCF)

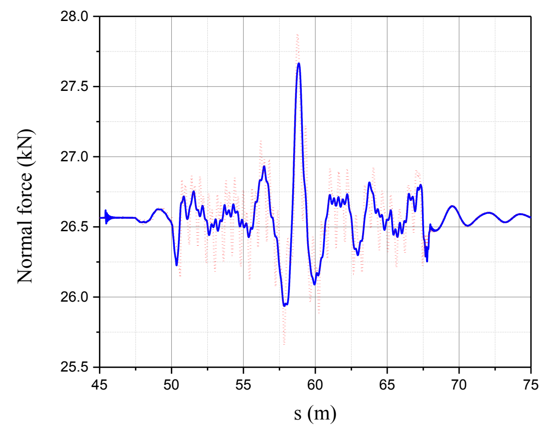

Figure 2. Rear wheelset normal force with standard stiffness and lack of sleepers.
(FFR, ANCF)

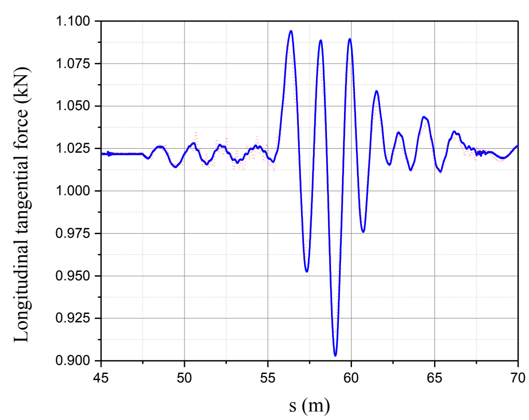

Figure 3. Rear wheelset longitudinal force with lack of sleepers. (FFR; ANCF)

This scenario is modeled by removing the damping and stiffness elements of two sleepers at locations $s = 58.4$ m and $s = 59$ m. Figure 1 shows the rear wheelset vertical displacement, where the peak value is caused by the lack of the sleeper stiffness. Figures 2-5 show the normal and tangential contact forces. The results of the normal contact force, shown in Figure 2, show change of approximately 4% when there is no contact between the rail and the sleepers. On the other hand, the results of the longitudinal tangential force of Figure 3 show oscillations of about 9%. The lack of sleepers clearly influences the value of the longitudinal creepage. The lateral tangential force and spin moment also show sudden changes as shown in Figures 4 and 5. The results presented in these figures are consistent with the results reported in previous investigations which considered the effect of the lack of sleeper contact.

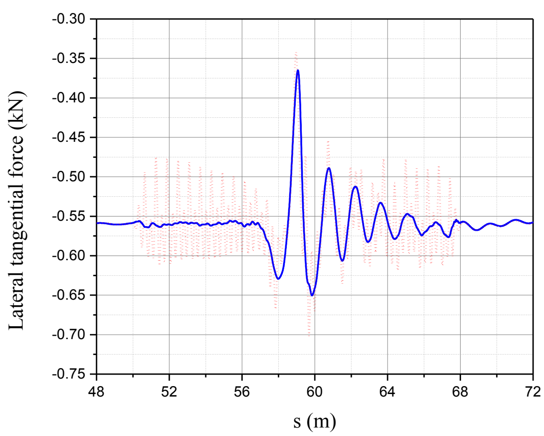

Fig 4 Rear wheelset lateral force with lack of sleepers.

(FFR, ANCF)

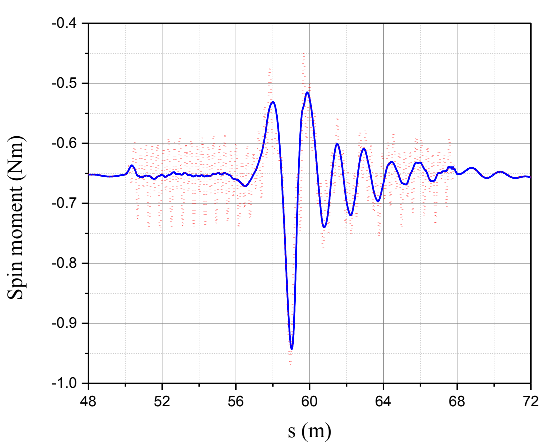

Fig. 5 Rear wheelset spin moment with lack of sleepers.

(FFR, ANCF)

Summary and Conclusions

In this investigation, ANCF finite elements are used to develop a new approach for the integration of geometry and analysis for railroad vehicle system dynamics. The same shape functions used to define the rail geometry are used to perform the FE/MBS analysis. The three-dimensional wheel/rail elastic contact formulation used in this study accounts for the rail deformations and allows updating systematically the rail geometry using ANCF finite elements. Such an online updating procedure is necessary in order to compute accurately the creepages required in the formulation of the creep forces. Good agreement with the FFR approach has been found. However, because of the moving load, a high number of eigenmodes is required to achieve convergence. Despite the fact that the examples considered in this investigation represent small deformation problems, the proposed ANCF formulation can be used for large deformation problems and allows for the use of different material constitutive equations. Large deformation rail problems that result from high temperature or rail buckling will be the subject of future investigations.

References

[1]. Recuero, A.M., J.F. Aceituno, , J.L. Escalona, , and A.A. Shabana, 2015, "A Nonlinear Approach for Modeling Rail Flexibility Using ANCF Finite Elements", Submitted for publication.

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