Efficient Computational Method for Multibody Dynamics of Supersonic Intermittent Contact System

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EXTENDED ABSTRACT

1 Introduction

A supersonic rocket sled is a large and high-precision ground test equipment. Supersonic rocket sled tests use a rocket engine to push the sled along a track at high speed. Meanwhile, the performance of the test specimen mounted on the sled can be tested. The component of the rocket sled that contacts the track is called *slipper*. The slipper wraps around the track, keeping the sled from flying off the track as it moves, which is shown in Figure 1. The slipper and the track contact intermittently with a series of impacts. Therefore, the slipper-track system is a supersonic intermittent contact system. Lots of studies showed that supersonic intermittent contact can cause severe vibration of the rocket sled and significantly affects its motion stability. Therefore, its study is very important.

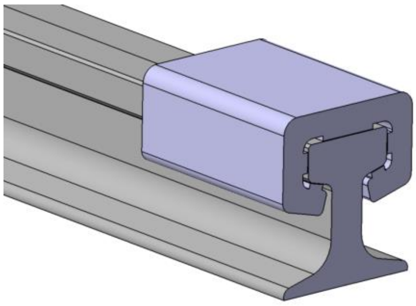

Figure 1: Slipper and track

Some studies have already been conducted on the multibody dynamics of supersonic intermittent contact system. Usually, the track is regarded as a rigid body, and the position constraints of the slipper are established according to the track irregularity; the dynamic response of the rocket sled is studied on this basis. The track is often regarded as a rigid body due to computational considerations, because it needs to be very long, owing to the high speed of the sled. However, this method ignores the influence of track vibration on the slipper. The slipper and the track are in intermittent contact and interact with each other, so it is more reasonable to regard the track as a flexible body. There are two ways to establish the flexible dynamic model of the rocket sled track in other studies. The first is to discretize the track using the finite element method (FEM). The second is to regard the track as a continuous beam model and use the modal analysis method based on the normal modes of the track. However, these two methods require a long time for computation.

To sum up, for the multibody dynamics simulation of supersonic intermittent contact system, the difficulty is how to balance the computational efficiency and accuracy of track model. Since the track is a typical beam structure, using the finite volume method (FVM) to discretize the track becomes an idea to solve the problem. Reference [1] proved the high efficiency of using FVM to discretize beam in multibody dynamics computations. In this method, internal forces of a beam are evaluated only at the boundaries of the volumes, thus simplifying their contribution to the equilibrium equations. In addition, Morandini established a method to make the constrained point move along a series of finite volume beams. Therefore, this study will propose a modeling and computational method for supersonic intermittent contact system based on finite volume beams and slider joints. This approach will improve the computational efficiency of the intermittently contacted long-distance flexible track.

2 Method

The study of the supersonic intermittent contact system has been implemented in the MBDyn. MBDyn is a multibody analysis program developed at the Department of Aerospace Engineering of the Politecnico di Milano [2]. The first is the modeling of the track. The track model used the finite volume beam element. Deformable beams can be interpreted as discrete elastic constraints that link independent rigid bodies. The three-node beam element is used to model the track. A piece of beam is divided in three parts that are related to three reference points, which includes the midpoint and the two endpoints. The beam element is divided in finite influence regions surrounding the nodes. The boundaries between the influence regions are the so-called *evaluation points*. At each evaluation point, a 6D constitutive law is defined. It defines the relationship between the generalized beam strains and their time derivatives and the internal forces and moments at the evaluation points.

To compare with the experimental natural frequencies of the track, 10 modules of track are first established. The track model includes tracks, blocks, joints, and the ground. Among them, there are 10 track modules and 11 blocks. Each module of track beam is connected by a common node. Different meshes with one, two and four beams for each track module are considered. Comparison of the results obtained with these three models with experimental modal test results shows that both the two-beam and the four-beam model have acceptable errors. Therefore, the two-beam model is chosen as the best compromise between accuracy and the computational requirements. A total of 100 track modules are considered for the supersonic intermittent contact system.

The slipper in the supersonic intermittent contact system is considered as a rigid body, since its stiffness is much larger than that of track. The beam-slider joint is used to connect the track and two sliders. The slider node is static without mass and inertia. There are 20 contact points between the slipper and the track. Therefore, using the offsets of the slipper and two sliders, the normal contact forces can be defined considering the gap between them. The normal contact force is defined by the contact stiffness and damping, with respect to the relative position and velocity. Besides, the frictional force in the sliding direction and vertical or lateral direction is also considered. The length of the track is equal to 100 m. The initial velocity of the slipper in the sliding direction is 500 m/s. The overall simulation time is 0.2 s, with a time step of 10^{-4} s. The integration algorithm is the backward differentiation formula (BDF), which is an implicit multi-step integration algorithm with variable order and variable step size.

3 Results and discussion

The simulation required 152.19 seconds of CPU time for a flexible track of 100 m, consisting of 502 nodes, 200 beam elements, and 202 viscoelastic supports. For the resulting model with 6000+ differential-algebraic equations, this computation time (about 0.076 s/time step, or a wall clock and simulated time ratio of about 760) is acceptable. Due to the length limit of the abstract, only the vertical positions of each middle node of track module are shown in Figure 2. It shows that when the slipper passes over the track, the track there vibrates significantly. In addition, this vibration can be transmitted to other positions of the track, which demonstrates the necessity of regarding track as flexible body.

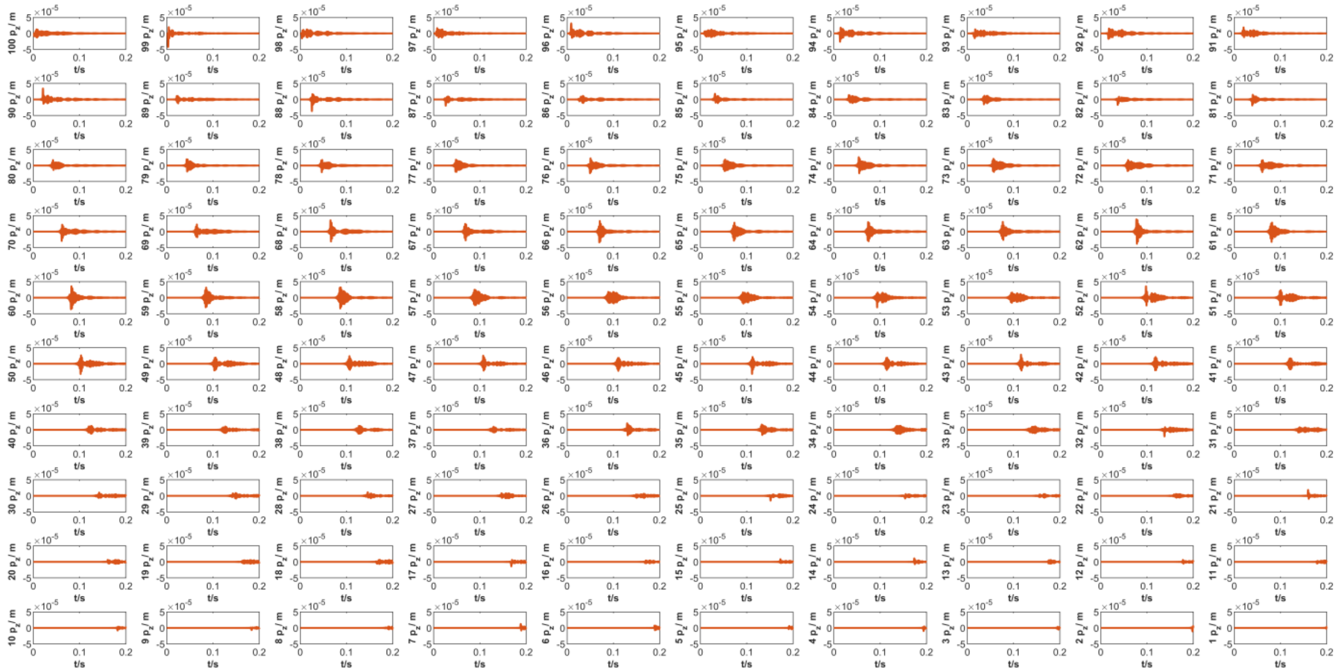

Figure 2: Vertical positions of each middle node of track module vs. time

This study discussed the modeling and simulation of a supersonic intermittent contact system based on finite volume beams and deformable slider joints. This modeling approach improved the computational efficiency of the intermittently contacted long-distance flexible track in consideration of accuracy. We will add detailed modeling methods and results in the paper. The results will contain positions, velocities, and accelerations of each track node and slipper, as well as strains and curvatures of the track beam and internal forces and moments. The normal contact forces and frictional forces will also be contained.

References

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