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Structure-preserving Analysis on Folding and Unfolding Process of Undercarriage**

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ABSTRACT The main idea of the structure-preserving method is to preserve the intrinsic geometric properties of the continuous system as much as possible in numerical algorithm design. The geometric constraint in the multi-body systems, one of the difficulties in the numerical methods that are proposed for the multi-body systems, can also be regarded as a geometric property of the multi-body systems. Based on this idea, the symplectic precise integration method is applied in this paper to analyze the kinematics problem of folding and unfolding process of nose undercarriage. The Lagrange governing equation is established for the folding and unfolding process of nose undercarriage with the generalized defined displacements firstly. And then, the constrained Hamiltonian canonical form is derived from the Lagrange governing equation based on the Hamiltonian variational principle. Finally, the symplectic precise integration scheme is used to simulate the kinematics process of nose undercarriage during folding and unfolding described by the constrained Hamiltonian canonical formulation. From the numerical results, it can be concluded that the geometric constraint of the undercarriage system can be preserved well during the numerical simulation on the folding and unfolding process of undercarriage using the symplectic precise integration method.

KEY WORDS structure-preserving, symplectic precise integration, nose undercarriage, constraint default

I. Introduction

Undercarriage is an important structural component that plays a role during the taking off and landing process of planes, because its reliability and dynamical properties may affect the safety performance of plane. Thus, many studies on the dynamical analysis of undercarriages have been reported in the past

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several decades. By considering the undercarriage as a multi rigid body system, Veaux[1] studied the kinematics problems between different parts of the undercarriage; Yadav and Ramamoorthy[2] analyzed the landing gear dynamics of an aircraft with a heave-pitch model that contains telescopic main gear and articulated nose gear using oleopneumatic shock absorber; Kruger and his colleagues[3] used three software packages to simulate the dynamic response of landing gear and discussed the possible application of controlled landing gears; Lyle, Jackson and Fasanella[4] simulated the energy absorbed by the gear with a nonlinear dynamic finite element code; Plakhtienko and Shifrin[5] presented a nonlinear model describing vibration of the landing gear relative to the fuselage, which was intended to analyze the dynamic stability of no-swiveling main-gear wheels; Thota and his colleagues[6] developed and studied a mathematical model with torsional and lateral bending modes that were coupled through a wheel-mounted elastic tyre; and recently, Han and his participators[7] presented a highly accurate numerical method to analyze the dynamic stress in the main landing gear of certain light aircraft during the landing process, the results of which agreed with the experimental results well.

The dynamical analyses of undercarriage in the above references were mainly on the precision of the analysis method and neglected the geometric constraints between different parts of the undercarriage. Actually, the geometric constraints between different parts of the undercarriage are very important factors that affect the kinematics as well as the dynamical response of undercarriage. Thus, the geometric constraints should be contained in the dynamical governing equation of undercarriage as a series of pure algebraic equations. And the integrated dynamical governing equation of undercarriage is a typical differential algebraic equation (DAE) that is a bottleneck problem in the numerical analysis of multi-body dynamic systems.

For DAE, several representative contributions to the numerical methods should be mentioned. Gear[8] discussed a unified method for handling the mixed differential and algebraic equations of the types commonly occurring in the transient analysis of large networks or in the continuous system simulation, which initiated the numerical study on the DAE; Hairer and Wanner[9] proposed several numerical methods for differential-algebraic problems, including the multistep methods, the Runge-Kutta methods and the half-explicit methods for index-2 systems, and discovered the stiff problem in applications to constrained mechanical systems, especially to multi-body systems; Nedialkov and Pryce[10–12] presented a series by underpinning the authors' DAETS code to solve DAE initial value problems using Taylor series expansion, which gave a new way to solve DAE.

All ideas of these classical numerical methods for DAE are applied in the algorithms of current business software for multi-body systems, the most popular one of which is the Automatic Dynamic Analysis of Mechanical Systems (ADAMS). The core idea of handling the geometric constraint in ADAMS is that, the acceleration constraint equation is obtained from the second-order differential of the displacement constraint; and the numerical discrete method is applied to the combined ordinary differential equations consisting of the dynamic governing equation and the acceleration constraint equation. This idea causes two problems in the algorithm: one is the complexity of the algorithm due to the increased workload from acquisition of the second-order differential of the displacement constraint and the numerical discrete process of the acceleration constraint equation; the other is the constraint default problem in the numerical results. The origin of these two problems is the unnecessary computation of the second-order differential of the displacement constraint and the numerical discrete process of the acceleration constraint equation. Thus, Zhong and Gao[13] proposed the analytical structural mechanics integration method to deal with the constrained dynamical systems, in which the independent displacements at the integration points were treated as primary variables to be solved, and the constraint conditions were strictly satisfied at the integration points.

Referring to the idea of the analytical structural mechanics integration method[13], the symplectic precise integration method[14] is used in this paper to analyze the dynamical properties of undercarriage during the folding and unfolding process. In the numerical experiments, the constraint default situations and the time-dependent generalized displacements are obtained. In addition, considering the shorter folding time and the smaller impact on the fuselage, an appropriate active force scheme is obtained.

II. Dynamic Model of Nose Undercarriage during Folding and Unfolding Process

Ignoring the structural details of the undercarriage, the structure of a typical telescopic main nose undercarriage is shown in Fig.1.

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