International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 3 Issue 4 ǁ April. 2015 ǁ PP.59-63

The Development of the Multi-body System Dynamics theory and the Absolute Nodal Coordinate Formulation

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Supported by Graduate Research and Innovation Funded Project of the Shanghai University of Engineering Science(Project number:E109031401019)

Abstract: *Elaborated the research background of multi-body system dynamics theory, points out the various systems of flexible system dynamics method. Systematically reviewed from four aspects of flexible multi body system dynamics is absolutely more than ten years since the birth of node coordinates method research progress, i.e., the system dynamics research progress of nonlinear multi-body system dynamics research progress, and the application of relevant research progress, finally put forward a series of research questions.*
Keywords: *The flexible multi-body system, Absolute node coordinates method, The numerical algorithm, Nonlinear material*

I. Introduction

After so many years of development, the multi-body system dynamics theory has quite mature. Many scholars in the theoretical and applied research projects have made a lot of achievements. For example, in 1989,Liu Yanzhu, a Professor of Shanghai Jiaotong University, wrote a book named "The Multi-body Dynamics". In 1999,Hong Jiazhen, wrote "Computing Multi-body System Dynamics", and in 2004,Professor Chen Liping of Huazhong University of Science and Technology wrote"Mechanical System Dynamics Analysis and Application of ADAMS" etc, and in recent years scholars have a high level of papers published in this area. These experts scholars has a comparatively deep research on dynamics, but with the progress of technology, Flexible multi-body system, especially the large deformation components of flexible multibody systems are widely used in aerospace, mechanical, biological and other fields. Such as space station large deformation of slender arm vibration problem , large deformation problems of electric locomotive traction power line in the process of movement ,the large deformation problems in the process of satellite solar panels , etc. The traditional modeling method based on dynamic model of small deformation hypothesis has been can't get accurate results of large deformation problem of flexible multi-body dynamics. In order to get accurate rigid coupling dynamics model of this kind of system and reveal the dynamic coupling mechanism, many scholars at home and abroad have done much research in this area, and a series of research achievements have been made.

II. The development of multibody system dynamics

In aviation, aerospace, vehicle, machinery， weapons, and many other engineering fields，system usually needs to solve many complex system problems such as kinematics, dynamics and control. This type of system is

characterized by system components exist a wide range of relative motion, these parts of mutual connection topology and constraint form varied, stress situation in addition to external forces interact with system components may also exist complex control links, Their commonness is: the system is composed of multiple objects in relative motion, so often referred to as multibody system.

In the 60's, because of the demand of high and new technology development, system components based on rigid body assumptions of multi-rigid-body system dynamics research has been rapid development. Research results are widely used in aerospace, vehicle, machinery industry, etc. Until the mid 70's, dynamics of multi-rigid-body systems research has made great progress, some of the multi-rigid-body system dynamics analysis software has achieved its commercialization. Up to now，study of multi-rigid-body system dynamics in the aspect of theory, numerical method and software development are already quite mature and perfect. Witenburg[1] laid a multi-rigid-body system dynamics Lagrange method, and the method of graph theory is introduced into the multibody system dynamics. Kane[2] using the generalized rate instead of the generalized coordinates describe system movement, directly using the d 'alembert principle resume dynamics equation, and will be in the form of a moderate amount of force and d 'alembert force directly to the specific direction of base vector projection to eliminate ideal binding, applicable to the complete system, also applies to nonholonomic system.Haug[3] put forward the suitable for multi-rigid-body system computer modeling and solving methods of Descartes. Garcia De Jalón and Bayo[4] proposed natural coordinates of multi-rigid-body system modeling method, which is also called the fully cartesian coordinates method, and presents a meet the requirements of real-time simulation of the effective solving method. Shabana[5] system introduced about the numerical solution algorithm of multiple rigid body systems.

Roberson[6]Nikravesh[7],Schiehlen[8],Huston[9],in the early stage of the multi-rigid-body dynamics theory research also has important contribution. At home, Liu Tingzhu [10],Hong Jiazhen[11] in the research fields also started earlier and published many influential academic papers. Chen Liping[12] done deeper research combined with MSC. ADAMS software in engineering application of multi-rigid-body dynamics theory . Witenburg[13] comprehensive and systematic introduces the multibody system modeling method of graph theory, and introduces the multi-rigid-body contact between impact dynamics problems. Featherstone[14] comprehensively introduces the open loop and closed loop forward dynamics of multi-rigid-body systems, reverse mechanics problems and contact with the algorithm of collision problem.

Flexible multi-body system dynamics in the 1970's gradually aroused people's attention, some systems such as high speed vehicle, a robot with a slender manipulator, spacecraft, high-speed institutions, precision machinery, the deformation of flexible body will produce a great impact on the dynamic behavior of system. Flexible multi-body system dynamics research of deformable objects as well as the rigid body system in large space motion dynamics behavior[15,16] ,in fact, the dynamic equations of flexible multi-body system is multi-rigid-body system dynamics equation of structure dynamics equation and comprehensive and promotion. When the system do not experience a wide range of space movement, it is degraded for structural dynamics equation,and when components of deformation can be ignored, it will degenerate for multiple rigid body system dynamics equation. The integration of these two types of equations which leads to the new dynamic problems. From the perspective of the logic structure of the theoretical system，Direct solution of flexible multibody system dynamics is the multi-rigid-body system dynamics and structural dynamics，but it shows its theory must be based on the characteristics of the further back analysis of mechanics and continuum mechanics. and it also closely related disciplines with numerical calculation method and control theory, etc. In the 1980's, Haug[3] established a new discipline called "computational multibody system dynamics''. Multibody system dynamics research from multiple rigid body systems to more soft body system, flexible multi-body system dynamics become the important content of multibody system dynamics. So far, flexible multi-body system dynamics

research has made many achievements, but far away from the research level of multi-rigid-body system dynamics, the main reason is the object the understanding of the large global motion and elastic deformation coupling problem and meet with difficulties in processing method.

III. Absolute node coordinates method research

In 1996, Shabana[5] presented Absolute Node Coordinate Method . Absolute node coordinates method is the theoretical basis of finite element and continuum mechanics theory， it defines the coordinates of the method of unit nodes in the global coordinate system, using slope vector instead of traditional finite element method (fem) coordinates of the nodes in the corner. It have multibody system differential algebraic equation is derived by inertia matrix, there is no coriolis force and centrifugal force, etc, these characteristics make absolute node coordinates method to build dynamic model than traditional floating coordinate method, large rotating vector method is more accurately described the flexible multibody system. Absolute node coordinate method has been considered in the history of the multibody system dynamics is an important one of progress, its birth to the flexible multi-body system dynamics theory and finite element theory further integration, since it appears, has always been a multi-body system dynamics researchers focus on one of the hot issues.

In element research, Shabana[5] first derivation based on absolute one-dimension- al beam element model of node coordinates method, as shown in figure 1. Any point in the global position of the unit:

$$\boldsymbol{r} = \begin{bmatrix} a_0 + a_1 x + a_2 x^2 + a_3 x^3 \\ b_0 + b_1 x + b_2 x^2 + b_3 x^3 \end{bmatrix} = \boldsymbol{Se}$$

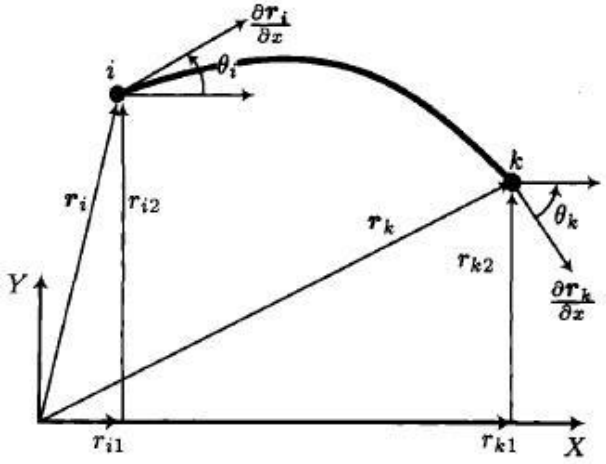

Fig.1 Two nodes, a one-dimensional beam element

Escalona first applied to the flexible large deformation such as system dynamics research,and berzeri for several based on different assumptions are put forward such as simplified model of one dimensional elastic force of beam and the comparative study. Berzeri based on one-dimensional beam element such as across floating coordinates and the absolute node coordinates, has carried on the comparative study, proved that the absolute coordinates for the large deformation and large rotation of flexible multibody system can obtain more accurate results. Omar and Shabana based on the continuum mechanics theory for the first time put forward a kind of classical plane strain shear beam element, but any point in the unit transverse slope coordinates is obtained by linear interpolation, thus cause the beam bending strain in the unit is constant,and at any point in the unit and the axial strain is obtained by quadratic polynomial interpolation, thus causing the bending strain and

axial strain are inconsistent, it will further cause shear locking problems. One way to solve this problem is to use the unit's partial tangential coordinates to redefine the bending strain, specific means is to change description unit displacement differential polynomial makes the strain field of kinematical characteristics of description. Subsequently, Kerkkanen change unit kinematics description way directly, such as a can effectively reduce the blocking problem of linear shear beam element, on the basis of his, Dufva with Sopanen further put forward a more accurate plane shear unit. Garcia - Vallejo removed the element node and the slope of the center line of the unit vector coordinates, at the same time to add a node at the point of the unit, He put forward a three-node plane shear beam element, and through the comparative study found that the calculation results to achieve the same precision, the number of the unit is only used for about half the number of previously proposed unit. Mikkola, relative to the Garicia - Vallejo etc etc is to remove node to express the direction of the beam section transverse slope vector coordinates, the new unit without introducing a new node coordinates or new nodes, less degrees of freedom. Shabana [5] and Yakoub was proposed based on absolute node coordinates method of three-dimensional beam element by using ANSYS software, and made a comparative study, Sopanen and Mikkola based on absolute node coordinates are studied for the first time unit of poisson locking problems, and points out that the most simple way to avoid the poisson atresia is assuming that material poisson's ratio is zero. the main reason of poisson locking phenomenon is the stress of the mutual coupling between different directions.This coupling effect will cause the beam incurring in the process of bending stress.Inaccurate results are achieved. They also set up a kind of can avoid blocking problem of simplified model for calculating the elastic force, change the describe the kinematic characteristics of the unit displacement differential polynomial. Dufva presents a description such as auxiliary variables more accurate three-dimensional beam element, another method is to solve the problem of unit shear locking directly use Hellinger - Reissner variational principle is introduced into shear stiffness, can be found in the literature. The above proposed unit node coordinates only contains the first-order gradient vector coordinates, Gerstmayr and Matikainen by introducing high-order gradient vector coordinates two nodes to construct a three dimensional high-order unit, and the unit is demonstrated by using ABAQUS software to solve the accuracy of the results, studies have shown that at the same time, the unit can effectively avoid poisson blocking problem. Shabana introduced by means of the deformation gradient matrix method to realize the absolute node coordinate transformation matrix of the gradient vector coordinates express and solving dynamic equation of discrete components. Sugiyama Suda and puts forward a method of nodes based on the absolute coordinates of the initial curve beam element, the Hellinger - Reissner variational principle to avoid the shear locking problems, assumes that the strain field method avoids the problem caused by the contact deformation atresia.

The previous article has pointed out by adopting the method of floating coordinate research high-speed rotating flexible multi-body system dynamics problems must be introduced by the centrifugal players compensation technology, to get stable and correct results, absolute node coordinates is used to research this kind of problem, a large number of studies have shown that the absolute node coordinates method automatically consider system dynamic players don't need to introduce additional assistive technology can obtain accurate results. In 1997, Shabana and Christensen first plate unit based on absolute node coordinates method are presented, studies have shown that plate unit based on absolute coordinates system, can accurately describe the rigid motion of flexible plate. Worth pointing out here is that in solving large deformation and large rotation problem of flexible system dynamics, the traditional method usually USES the incremental iterative calculation, it must be linearized dynamics equations in incremental iteration, as a result of the node corner as degrees of freedom, after linearized dynamics equation and can't accurately express the rigid motion of the flexible body, eventually lead to inaccurate or even wrong results. Unit based on absolute node coordinates method is to define the node coordinates in the global coordinate system, including degree, solving the exact solutions can be

obtained by the incremental iteration.

In recent years, Chinese scholars of absolute node coordinates method is becoming more and more attention. Tian Jiang[3], for example, node into the absolute coordinate method, the research progress of the system description. Jin-yang liu[4-5] for mixed coordinates method and absolute node coordinates method of rigid flexible beams are studied. Tian Jiang[6-8] respectively studied by absolute node coordinates method described by fractional derivative constitutive relations of viscoelastic deformation of large multibody system dynamics problems and multi flexible body system containing kinematic pair clearance contact collision problem. In China, based on the absolute node coordinates method of multibody system dynamics research started relatively late. Li Bin[14] based on absolute node coordinate method and an approximate method of contrast study has found that the dynamics model based on absolute node coordinates method more accurate than a approximation model, better suited to describe the large deformation dynamic problems. Shen Lingjie etc. [15] based on absolute node coordinates method of one-dimensional beam element to study the flexible beam and oblique collision dynamics of rigid body. Jin-yang liu etc[16-17] use absolute node coordinates method to achieve the spatial 3 d rigid body dynamics analysis of flexible beam system, and puts forward a set of mixed coordinate system, the absolute node coordinates method to validate the correctness of the simulation results. Recent studies have shown that natural coordinates method can be used on the system of rigid component modeling, by the method of absolute node coordinate system of the flexible component modeling, which will also get constant mass matrix of the coupled system multibody system dynamics equation.

References

[1] Wittenburg J. Dynamics of System of Rigid Bodies.Teubner,Stuttgrt,1997

[2] Kane TR, Levinson DA. Dynamics theory and applications. McGraw-Hill, New York,1985

[3] Haug EJ. Computer-Aided Kinematics and Dynamics of Mechanical Systems. Ally -n and Bacon, Boston, 1989

[4] Garcia De Jalon J, Bayo E. Kinematics and Dynamics Simulation of Multibody Systems the Real-Time Challenge. Springer, New York,1994

[5] Shabana AA. Computational Dynamics .Wiley, New York,1994

[6] RobersonRE, Schwertassek R. Dynamics of Multibody System. Springer, Berlin, 1998

[7] Nikravesh PE. Computer-Aided Analysis of Mechanical Systems. Prentice Hall, Englewood Cliffs, New Jersey,1988

[8] Schiehlen W. Technical Dynamik.Teubner,Stuttgrt,1986

[9] Huston RL.Multibody Dynamics.Butterworths,Boston,1990

[10] 刘延柱,洪嘉振,杨海兴.多刚体系统动力学.北京：高等教育出版社,1989

[11] 洪嘉振.计算多体系统动力学.北京：高等教育出版社，1999

[12] 陈立平,张云清,任卫群等.机械系统动力学分析及 ADAMS 应用教程.北京：清华大学出版社, 2005

[13] Wittenburg J.Dynamics of Multibody Systems,Springer,Berlin,2008

[14] Featherstone R.Rigid Body Dynamics Algotithms.Springer,New York,2008

[15] 李彬, 刘锦阳.大变形柔性梁系统的绝对坐标方法.上海交通大学学报.2005.39(5):827-831

[16] 沈凌杰, 刘锦阳, 余征跃.柔性梁斜碰撞问题的非线性动力学建模和实验研究.力学季刊.2006.27(4):568-577

[17] Jin-Yang Liu,Hao Lu.Rigid-flexible coupling dynamics of three-dimensional hub-beams system.Multibody System Dynamics,2007,4:487-510