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Multi-body contact in non-linear dynamics of real mechanical systems

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Abstract

The considerable number of real mechanical systems operates in conditions of multi-body contact. Very often, elastic properties in contact areas couldn't be neglected, so the elastic deformations exist in contact area of each two deformable bodies in contact. When there are two or more contacts at the same time and rotations and/or translations of contact bodies, these conditions cause the continuous changes of contact areas' geometry, friction, load distribution and other parameters. Therefore, the problem of non-linear dynamics of mechanical system becomes very complex.

In this paper, the new approach for analyzing the non-linear dynamics of mechanical systems with multi-body contacts will be presented. In this approach, the contact bodies in mechanical systems are simulated with basic geometric deformable bodies coupled with elements with time-varying stiffness and damping. The main principles of mathematical phenomenological mapping are used for multi-body contact reduction to simple single-degree of few-degrees of freedom systems with total stiffness as main characteristic. The cases of two and three basic geometric bodies in contact are modeled to enable the investigation of influence of main parameters (stiffness, damping, external load, friction coefficient) in non-linear dynamics of multi-body contacts. The Finite Element Analysis is used to calculate the time-varying contact deformations, total stiffness and external load distribution.

A particular attention is paid to the presentation of new approach application on real mechanical systems with multi-body contacts, such as gears and ball bearings. The analyses of non-linear dynamics of a particular gear pair and a particular ball bearing will illustrate the capabilities and advantages of presented new approach for comfortable and qualitative analysis of non-linear dynamic behavior of real complex mechanical systems.

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Keywords: Nonlinear Dynamics; Contact; Stiffness; Gears; Ball bearings

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1. Introduction

The real mechanical systems, which are parts of complex machines and industrial installations and plants, very often have complex characteristics with respect to geometry, kinematics, lubrications and interconnections. The contact with or without lubrication is one of the most common interconnection form in real mechanical systems for power transmissions. The basic contact characteristics of these multi-body contacts are: geometry of contact surfaces with and without irregularities, material deformability, and coefficient of friction and so on. It is obviously important to study all of contact features in multi-body contacts and to assess their influence on dynamics of this kind of mechanical systems. The complexity of this problem is actually higher due to variable basic characteristics of contact which exist in real systems. The characteristics of contact mainly depend of time, but also very often depend on each other. These postulates are the basis and the main motivation for developing a new approach for investigation and assessment of non-linear dynamics of multi-body contacts which is explain in main steps in this paper. This approach is dedicated only to non-linear dynamics caused by multiple nonlinear phenomena of contact and at this stage is not connected with the known theory of multi-body dynamics, [1-2].

A significant number of contemporary studies are dedicated to very complex and comprehensive research of non-linear dynamics of the particular mechanical systems with multi-body contacts, [3-7]. But, it is obviously that each of them is valid only for a particular case and required a lot of time and computational methods. In the same time, very often a trend to simplified the geometry and working conditions during these analysis is present in order to make a problem of system global motion (generally refers to the vibration) solvable. In accordance with these facts, the main target during the new approach definition was to develop the unique algorithm with as much as possible simplifications, which will not diminish the reliability of the results obtained as output. This algorithm could be used as a general guideline for non-linear analysis. However, the knowledge of researchers on each individual issue is still very important.

2. A new approach for non-linear dynamics of multi-body contacts

In the analyzing of the non-linear dynamics of complex mechanical systems with multi-body contacts, the unique solution and method couldn't be defined. But, the main strategic postulates and goals should be set up in order to make the future analysis shorter, cost reducing and enough accurate at the same time. In this framework, the flow chart of the algorithm of a new approach for non-linear dynamics of multi-body contacts is developed and shown in Fig.1.

The first step in the developed procedure is analysis of the mechanics of multi-body contacts. Often, the analyzed systems are very complex and incorporate the variables which shouldn't be neglected. In almost all real systems, contact deformation of contact zones causes the time-varying stiffness and damping. In this point of discussion, the difference between contact stiffness and damping in differential part of contact surfaces and stiffness and damping of whole mechanical systems consists of few or more deformable bodies should be highlight. The calculation of functions which define the system stiffness and damping allows the simplifications in non-linear dynamics of very complex machines and industrial plants and installations where the mentioned multi-body contacts exist as parts, usually in power transmission elements and systems. During the next steps of discussed procedure, Fig.1, the general tendency should be to reduce the multi-body contacts to connection between the bigger machine and installation parts to element with neglected mass and time-dependent stiffness and damping. In Fig.2 a simple example of multi-body contacts is presented with three spheres. In this case the external force direction determined very simple problem with deformations in contact zones in only one direction. Therefore, this system could be very successfully reduced to a system with one degree of freedom. In the cases of real mechanical systems with few or more deformable bodies in contact, often the reducing of the number of degrees of freedom is not so simple, but is still possible without reducing the quality of final results of vibration characteristics. At this procedure level, the main principles of mathematical phenomenological mapping [8] are used for multi-body contacts reduction to the system with at last as possible degrees of freedom, with total (reduction) masses, stiffness coefficients and damping coefficients as main characteristics. This approach is particularly suitable in the case of standard machine elements with multi-body contacts, such as rolling bearings and CV joints, [7, 9, 10]. In other cases, for example for geared systems the masses of meshed gears couldn't be neglected, so the appropriate model has to be developed, [10-11]. In