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SELECTED PROBLEMS SOLVED IN PILSEN USING MULTIBODY DYNAMICS

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Abstract: The paper informs on some problems solved during approximately past twenty years in Pilsen using multibody simulations. Naturally, the list of activities is not comprehensive, it concerns activities of the authors in Výzkumný a zkušební ústav Plzeň s.r.o. and in the Department of Mechanics, Faculty of Applied Sciences, University of West Bohemia. Activities in the field of transport engineering, nuclear engineering, fibre modelling and robotics are mentioned in brief. Simulations with the Triple Hybrid Hydrogen Bus model and the problem of fibre modelling including the example of the application are presented slightly more in scope of the limited extent of the paper.

Keywords: multibody dynamics; computer simulations; means of transport; fibre; nuclear reactor

1 Introduction

Physical models of real objects based on the system of rigid and flexible bodies are the principle of multibody dynamics. Computational models based on the system of bodies allow introducing general force effects and thus they are suitable for considering a wide range of both internal and external effects of a different character (controls, feedbacks, fluid, wind, variable gravitation, etc.). In the worldwide extent, multibody dynamics started to develop significantly in the 70´s of the last century, viz. in connection with the development of hardware and software (e.g. [1], [2], [3]). In the course of the above mentioned period multibody dynamics developed from the classical mechanics of the systems of bodies to the independent branch of mechanics of a multidisciplinary character and of wide application possibilities. Multibody simulations are irreplaceable especially in developing industrial robots, road and rail vehicles, aerospace research objects and are applied in the case of live objects, especially in biomechanics. Since the multibody modelling is introduced in many branches of applied sciences it is not possible to refer to all the principal publications dealing with those problems.

The most complete survey concerning new approaches, methods and applications is given in the Journal of Multibody System Dynamics [4] and the Journal of Multi-Body Dynamics [5]. Thematic conferences organized by the European Community on Computational Methods in Applied Sciences (ECCOMAS) have become a tradition and are taken place every two years. The first of them, Multibody Dynamics 2003, took place in Lisbon, the last one (eighth) was held in Prague in 2017. Asian Conferences on Multibody Dynamics (the ninth one will be held in Xi´an in August 2018) and Joint International Conferences on Multibody System Dynamics (they started as late as 2010 in Lappeenranta, the fifth one will be held in Lisbon in June 2018) also are very popular.

2 Ten years of multibody simulations in ŠKODA VÝZKUM

In the paper of the same name as the title of this chapter [6] the selected problems solved during the years from 1996 to 2006 in ŠKODA VÝZKUM s.r.o. (Výzkumný a zkušební ústav Plzeň s.r.o. now) using multibody simulations were presented in brief.

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Due to ŠKODA VÝZKUM s.r.o. aiming at applied research and development the realization outputs in this sphere of dynamics are especially of the application character. The *alaska* simulation tool and the SIMPACK commercial program packages are used in ŠKODA VÝZKUM s.r.o. (note: the MSC.Adams software is at disposal in the Department of Mechanics, Faculty of Applied Sciences, University of West Bohemia) and in-house computer models are programmed in the MATLAB system. The activities in the field of multibody simulations were and are applied in transport engineering, in nuclear and power engineering and partly in biomechanics. The ŠKODA VÝZKUM s.r.o. advantage is the fact that it is possible to verify most computer models on the basis of service and sophisticated laboratory measurements on real structures mostly performed on experimental devices of the Institute.

Simulations with multibody models of means of public transport were introduced especially in [6]: simulations of a bus driving along an uneven road surface, simulations of a slow front impact of a bus against a concrete wall, design of the rear carriage stabilizer bar of an articulated trolleybus, simulations of the fall of a standing passenger against the trolleybus composite doors and design of characteristics of air pressure controlled hydraulic shock absorbers of an intercity bus.

Dynamic and strength properties of tank semitrailers with aluminium pressure vessels were investigated in cooperation with the company of ZVVZ a.s. Operational measurement with the real NCG 40 tank semitrailer connected to the Scania 124L truck and computer simulations with its virtual models verified driving properties of the semitrailer and to confirm its desired service lifetime.

In the field of rail vehicles only the MGR Coal Hopper two-axle open wagon multibody models were created. They were intended for the laboratory tests simulations performed in the Dynamic Testing Laboratory of ŠKODA VÝZKUM s.r.o. With multibody models it is possible to simulate the laboratory kinematic excitation of wagon wheels in vertical direction, which corresponds to the real loading states performed on the test stand. Evaluation of the impact of using two-leaf composite springs of the wagon suspension instead of five-leaf parabolic steel ones on the monitored kinematic and dynamic quantities was the aim of computer simulations and laboratory tests in particular.

The properties of control assemblies of nuclear reactors are investigated in cooperating with ŠKODA JS a.s. In the framework of the cooperation multibody models of the ARK control assembly of the VVER 440/V213 nuclear reactor, the LKP-M/3 control assembly of the VVER 1000 nuclear reactor and multibody model of the UR-70 control rod of the IRT-200 research nuclear reactor have been created so far. These multibody models serve especially for the simulation of the control assemblies behaviour during the fall of control rods without or with the seismic excitation. In multibody models the possible contacts of the “falling” bodies with the neighbouring inner reactor parts are considered and the presence of (flowing) fluid is taken into account. On the basis of the simulations results meeting requirements for the time of the control rods falls during seismic events in the nuclear reactor localities is especially evaluated.

3 Newer activities

In the field of means of public transport a multibody model of the Triple Hybrid Hydrogen Bus (TriHyBus) was created and using it simulations focused on the investigation of vertical and lateral vehicle dynamics were performed (e.g. [7]). In the framework of benchmark multibody models of the Segway personal transporter were created and using them selected types of simulations were performed [8].

In investigating the properties of the LKP-M/3 control assemblies of the VVER 1000 nuclear reactor the attention was paid to investigating the influence of deformations of fuel assembly guide tubes and to modelling the flexible control assemblies based on the absolute nodal coordinate formulation (ANCF) (e.g. [9]).

Attention was paid to a completely new field, which is the modelling of fibres and cables (e.g. [10]). The motivation is the development of a fibre model, which could be efficient for the usage in a mechatronic model of a manipulator consisting of fibres and an end-effector whose motion is driven by fibres – particularly for the usage in the QuadroSphere model (see Figure 1). The QuadroSphere is a tilting mechanism with a spherical motion of a platform and an accurate measurement of its position. The platform position is controlled by four fibres; each fibre is guided by a pulley from linear guidance to the platform. The QuadroSphere model serves for the investigation of different possible strategies of the control of the active structure superimposed to the end-effector of the cable-driven mechanism in order to improve the end-effector positioning accuracy and the operational speed.

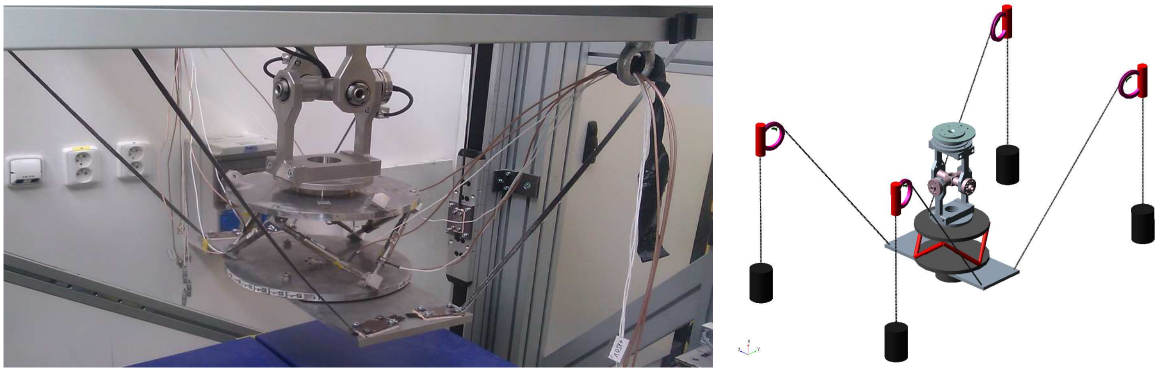

Figure 1: The QuadroSphere tilting mechanism and its visualization in the MSC.Adams software.

Apart of Investigation dynamic behaviour of the TriHyBus (Výzkumný a zkušební ústav Plzeň s.r.o. only) the above mentioned activities were performed both in Výzkumný a zkušební ústav Plzeň s.r.o. and in the Department of Mechanics, Faculty of Applied Sciences, University of West Bohemia.

4 Experimental and computational investigation of handling behaviour of the TriHyBus

The TriHyBus project comprised research and development, implementation and a test operation of a city bus (see Figure 2 left) with hybrid electric propulsion using hydrogen fuel cells (e.g. [7]). The mass distribution and the total bus mass are rather different from common buses. This is the reason for investigating the bus driving stability. In order to obtain a tool for dynamic analysis, a multibody model of the bus was created (see Figure 2 right). The aim of the simulations with the verified bus multibody models is the calculation of kinematic and dynamic quantities giving information about the investigated properties of the vehicle at the selected operational situation. E.g. severe double lane-change manoeuvres according to ISO 3888-1 and moose tests were performed with a real vehicle.

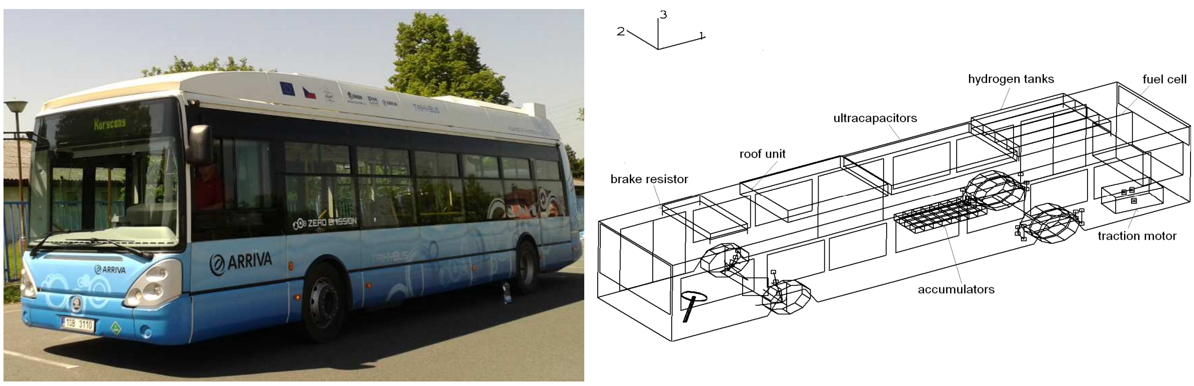

Figure 2: The TriHyBus – the real vehicle and the multibody model visualization in *alaska* 2.3 simulation tool.

In comparison with the previous experimental measurements on the similar vehicles much more utilizable data were recorded for performing simulations of driving manoeuvres with multibody models and their verification. From the point of view of simulations with the TriHyBus multibody model the measured bus speed and bus trajectory were the quantities for defining input data of the test drives. Selected quantities recorded during the test drives, viz. roll and yaw angles were monitored (see Figure 3). On the basis of comparing the simulations results and the results of experimental measurements it is evident that a certain coincidence of results exists. Not completely perfect coincidence of the results is influenced mostly by the ignorance of the actual air pressure in air springs of the bus suspension. In the case of further possible test drives with the real TriHyBus it will be necessary to measure the pressure in the air springs due to defining multibody models more precisely.

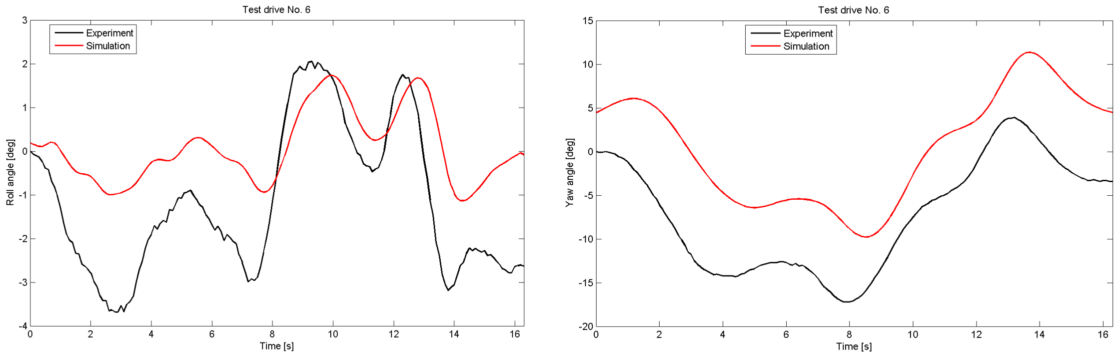

Figure 3: Time histories of the vehicle roll angle (left) and yaw angle (right) at the severe double lane-change manoeuvre according to ISO 3888-1 (at average vehicle speed approx. 35 km/h). (Taken from [7])

5 Modelling of fibres and cables in multibody dynamics and application

The fibre (cable, wire etc.) modelling should be based on considering the cable flexibility and suitable approaches can be based on the flexible multibody dynamics (e.g. [10]). There are many approaches to the modelling of flexible bodies in the framework of multibody systems. Comprehensive reviews of the approaches can be found e.g. in [11], [12].

The simplest way how to incorporate cables in the equations of motion of a mechanism is the force representation of a cable. It is supposed that the mass of cables is small to such an extent comparing to the other moving parts that the inertia of cables is negligible with respect to the other parts. The cable is represented by the force dependent on the cable deformation and its stiffness and damping properties. This way of the cable modelling is probably the most frequently used in the cable-driven robot dynamics and control.

A more accurate approach is based on the representation of the cable using a point-mass model. Point masses can be connected by forces or constraints. In the case of the manipulator mechatronic model consisting of cables and an end-effector, whose motion is driven by cables (e.g. in the case of the QuadroSphere), utilization of the point-mass model of a cable is very prospective.

A very promising approach usable for the cable modelling is the ANCF, which is based on the discretization of a cable or a fibre to nonlinear finite elements (e.g. [9], [12]). Absolute nodal positions and slopes are considered to be nodal coordinates of the ANCF elements. The formulation leads to a constant mass matrix and a highly nonlinear stiffness matrix. The model can be efficiently used for the investigation of various contact problems related to cables and fibres.

In order to represent bending behaviour of cables their discretization using the finite segment method or so-called rigid finite elements is possible. Other more complex approaches can utilize nonlinear three-dimensional finite elements.

Another approach used for the creation of a general model involving cables with distributed mass and time-varying length is based on Hamilton's principle, which serves for achieving a system of partial differential equations describing the cable dynamics. This approach is suitable for the modelling of cable-driven manipulators with flexible cables with distributed mass.

Experimental measurements focused on the investigation of the fibre behaviour were performed on an assembled weight-fibre-pulley-drive mechanical system (see Figure 4), which was described e.g. in [9], [10] (the weight can be considered to be the end-effector). A carbon fibre with a silicone coating is driven with one drive and is led over a pulley. The fibre length is 1.8 meters, the fibre weight is 5 grams. At the drive the fibre is fixed on a force gauge. At the other end of the fibre there is a prism-shaped steel weight (weight of 8 kilograms in this case), which moves in a prismatic linkage on an inclined plane. The angle of inclination of the inclined plane can be changed (in this case $\alpha = 30$ degrees). Drive periodic exciting signals can be of a rectangular, a trapezoidal and a quasi-sinusoidal shape and there is a possibility of variation of a signal rate. Time histories of weight position u, of drive position x and of the force acting in the fibre were recorded using a sample rate of 2 kHz.

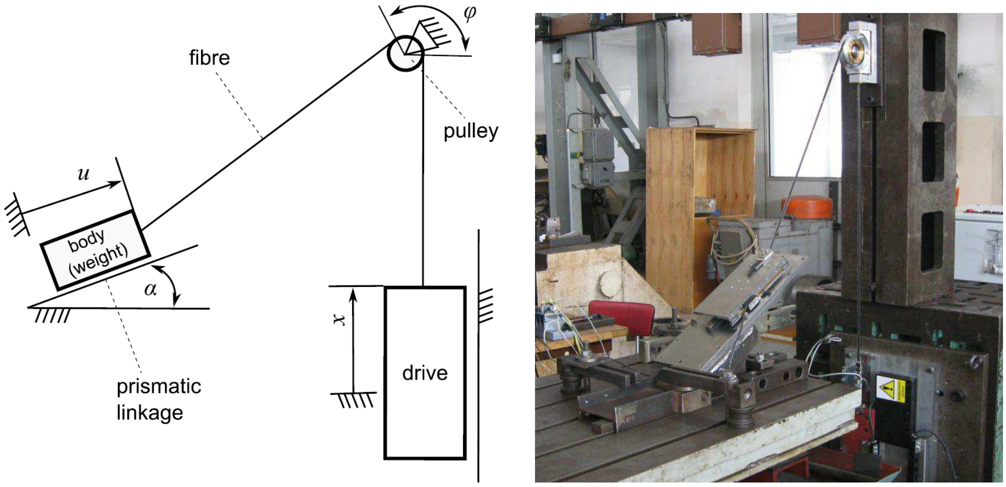

Figure 4: A scheme and a real weight-fibre-pulley-drive mechanical system. (Taken from [9])

The same system was numerically investigated using the force representation of the fibre and the ANCF fibre model [9].

The massless fibre model is considered to be phenomenological and is modelled by the forces that comprise e.g. influences of fibre transversal vibration, jumping from the pulley etc. The number of degrees of freedom in kinematic joints of multibody model of the weight-fibre-pulley-drive system is 5. The weight, the pulley and the drive are considered to be rigid bodies. A planar joint between the weight and the base (prismatic linkage), a revolute joint between the pulley and the base and a prismatic joint between the drive and the base (the movement of the drive is kinematically prescribed) are considered. Behaviour of this nonlinear system is investigated using the *alaska* simulation tool.

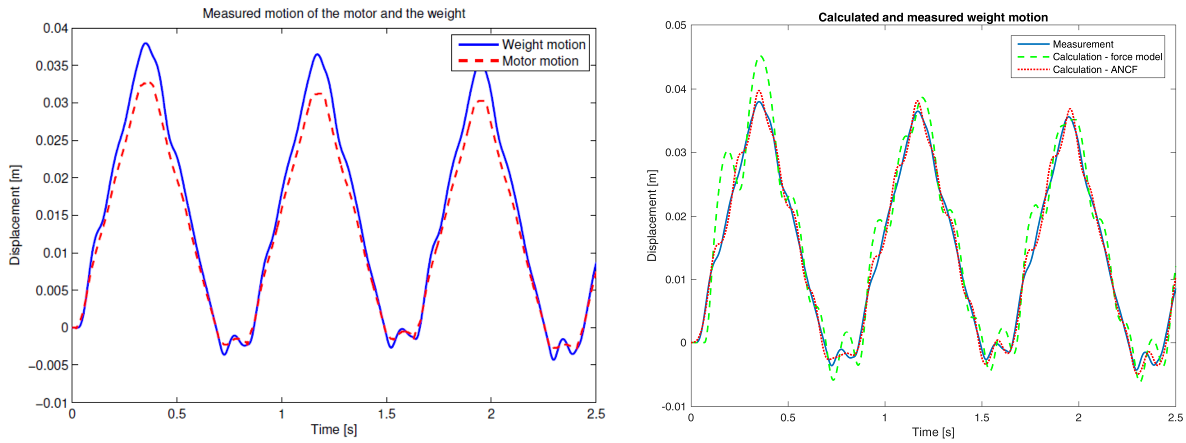

Figure 5: Examples of the measured motion of the drive and the weight (left) and the measured and calculated displacement of the weight (right). (Taken from [9])

In the multibody model of the weight-fibre-pulley-drive using the ANCF fibre model, the pulley is modelled as a rigid body with one degree of freedom (rotation), the fibre is modelled as a deformable body and is discretized to elements using the ANCF method. During the interaction of these two bodies, contact forces arise not only in the element nodes but they are distributed along the length of the contact arc. An in-house modelling tool in the MATLAB system based on the proposed modelling methodology was created.

A particular signal defining the motion of the drive and a time history of the measured position of the weight are in Figure 5. The measured motion of the drive serves as an input signal (kinematic excitation) for the numerical simulations. It is evident from the obtained results that at using the ANCF method the coincidence with the experimental results is better than at using the force representation of the fibre in the computational model. It is evident from the mathematical formulation that the ANCF method must be more precise than the force representation of the fibre (in the advanced approach).

The main advantage of using the force representation of the fibre consists in a very short computational time.

6 Conclusion

Information on some problems solved at using multibody simulations approximately past twenty years in Výzkumný a zkušební ústav Plzeň s.r.o. and in the Department of Mechanics, Faculty of Applied Sciences, University of West Bohemia are presented in this paper. Activities in the field of transport engineering, nuclear engineering, fibre modelling and robotics are mentioned.

Further development in varied fields of multibody dynamics is planned. Further challenges are in the field of nuclear engineering (the continuation in modelling the flexible control assemblies based on the ANCF), in the field of robotics (investigation of serial robots with fibres) and in rotor dynamics considering the journal bearings (modelling the problems of rotor instabilities incorporating multibody approaches).

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