MODELLING THE FLEXIBLE MULTIBODY SYSTEM OF A FREIGHT WAGON BOGIE USING COMPUTER TOOLS

Ján Dižo, Miroslav Blatnický[1]

Summary: As well as in every engineering sector also in the design of rail vehicles tools for computer modelling and simulation are nowadays the most often used. In this way static analyses of rail vehicle components and dynamic analyses of a completed rail vehicle multibody system are possible to perform. Static analyses are most commonly carried out using the finite element method. Abreast of it the multibody system dynamics is investigated in other specialized software and methods. If we combine these two approaches we can improve multibody system of a rail vehicle and therefore to evaluate its behaviour and properties closer to reality. This contribution is focused on the preparing and implementation of flexible body into the multibody system of rail vehicle bogie. For this purpose the freight wagon bogie was chosen.

Key words: rail vehicle, computational modelling, multibody system, flexible body

INTRODUCTION

The development process of a design new and also renovating the existing rail vehicle employs computer aided simulations. In this way costly experiments and prototypes can be reduced. Production of a rail vehicle is composed of several phases. There are the design phase, the development phase and the optimisation phase, the production of a rail vehicle, the verification and validation of a rail vehicle and in the end the commissioning of a rail vehicle. At this time computer software allow to perform complex simulations. Thus, shorter development periods and rising requirements like durability, efficiency or mass reduction which intensifies the usage of lightweight structures demand precise simulations.

1. FORMULATION AND APPROACH TO THE FLEXIBLE MULTIBODY SYSTEM

The properties of rail vehicles as mechanical systems can be designed (12, 13), studied, evaluated and verified by means of experimental methods and measurements, simulation calculations and optimization using computer software (5, 8) or also by special equipment in laboratories (2, 3).

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In investigating dynamic properties and behaviour of rail vehicles we model and describe these vehicles by means of multibody system dynamics.

A standard multibody system of a rail vehicle contains rigid bodies that are connected by ideal joints, coupling elements, contact elements, suspension and spring elements and force elements. Rail vehicle dynamics also involves the phenomena of wheel/rail contact (6, 7), which significantly influences the rail vehicle properties and wheel/rail contact stress conditions.

Rail vehicle analysis includes applications, where deformations of individual bodies have to be considered as well and taken into account in calculations. Therefore, the rail vehicle multibody system is extended with flexible bodies. Generally, the Finite Element Method is most often used for flexible bodies' implementation into the rail vehicle multibody system. Then the multibody system we call Flexible Multibody System (FMBS). This however means that a large number of degrees of freedom would be introduced into the rail vehicle model. Therefore we need the so-called reduction of linear degrees of freedom, which represents the principal step for efficient simulation of a rail vehicle multibody system with a flexible body in MBS software.

1.1 Principles of the flexible multibody dynamics

The formulation of the finite element method uses a coordinate system firmly fixed to the body to describe the deformation field of each body. Flexible bodies and rigid bodies of the rail vehicle multibody system are represented by a set of Cartesian coordinates and have their relative motion restrained by a set of kinematic constraints. There are also other formulations of multibody systems, such as natural coordinates, which can be used with the finite element description of the large motion of flexible bodies. Nevertheless, we need another set of coordinates to define the kinematic constraints between the rigid and flexible bodies of the multibody system. For kinematic description of the motion of a flexible body performing large displacements several methods have been developed. Among them the floating frame formulation method which is in one breath a most commonly used method in computer simulation of multibody systems with flexible bodies, and is implemented in commercial multibody computer software (9, 10).

In this formulation, the configuration of a flexible body is described by two set of coordinates (Fig. 1). One set of coordinates is used for location and orientation of the selected body coordinate system and the other set is used the body deformation with respect to its coordinate system. Using this approach, the global position vector of the flexible body B^i can be written as (4):

$$r_P = r_i + R_{iP} + u_P \qquad (1)$$

All vectors in eq. (1) are in Fig. 1; vectors represent the following: r_P – position vector of the point P, r_i – non-linear motion of the reference frame K_i, R_P – the position of the point P in the non-deformed state, u_P – superposed linear elastic deformation.

Using the above-described dynamic description we can use the principle of virtual work in dynamics of Lagrange's equations of motion to symmetrically develop the dynamic equation of motion of the flexible body that is undergoing large reference displacements. In this formulation, the equations of motion are expressed in terms of a coupled sets of reference and elastic coordinates. The location and orientation of a selected body are defined by the reference coordinates, and the body deformation with respect to its reference state is defined by the elastic coordinates (4).

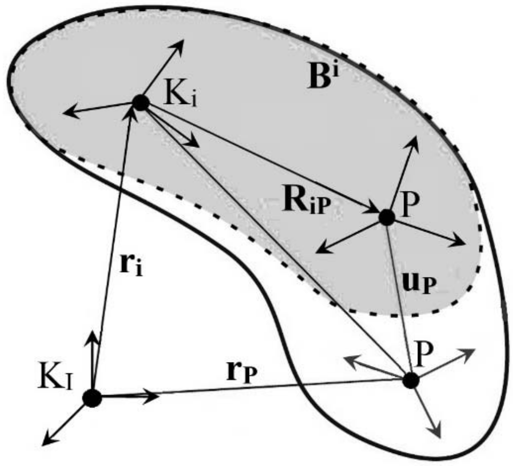

Fig. 1 - Flexible body – kinematics representation

The equations of motion of a flexible body in a rail vehicle multibody system can be written in a general form:

$$M^i \ddot{y}^i + K^i y^i = q_e^i + q_v^i + q_c^i \quad (2)$$

The subscript *i* indicates the number of bodies, M is the mass matrix, K is the stiffness matrix, y is the vector of the system of generalized coordinates, and vectors q_e, q_v, and q_c are vectors of externally applied forces, Coriolis and centrifugal forces and constraint forces, respectively. The vector q_c can also be rewritten as the vector of Lagrange multipliers λ:

$$q_c^i = -Q^{iT}\lambda \quad (3)$$

where Q represents the Jacobian matrix of the kinematic constraint equations defining the joint constraints and trajectories of the corresponding motion. The equations of motion (2) can also be expressed with a small modification as:

$$M\ddot{y} + Ky = q_e + q_v + q_c \quad (4)$$

If we write the coordinates vector ***y*** in the following form:

$$y = \left[y_r^T, y_f^T\right]^T \quad (5)$$

then the matrix form of the equations of motion of the flexible multibody system will be as follows:

$$\begin{bmatrix} M_{rr} & M_{rf} \\ M_{fr} & M_{ff} \end{bmatrix}\begin{bmatrix} \ddot{y}_r \\ \ddot{y}_f \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & K_{ff} \end{bmatrix} = \begin{bmatrix} (q_e)_r \\ (q_e)_f \end{bmatrix} + \begin{bmatrix} (q_v)_r \\ (q_v)_f \end{bmatrix} + \begin{bmatrix} (q_c)_r \\ (q_c)_f \end{bmatrix} \quad (6)$$

The subscript r and f indicate reference coordinates and elastic coordinates respectively (11).

Using the floating frame of reference method for the reduction of flexible bodies leads to a highly nonlinear mass matrix due to the inertia coupling between the reference motion and the elastic deformation, but the stiffness matrix remains the same as the stiffness matrix in structural dynamics. This is because the elastic coordinates are defined with respect to the coordinate system of the body.

2. MODELLING THE FLEXIBLE MULTIBODY SYSTEM OF A FREIGHT WAGON BOGIE

This chapter introduces modelling the flexible multibody system of the freight wagon Y25 bogie. The Y25 bogie is the most widely used freight wagon bogie in Central and Eastern Europe (1).

Flexible body creation and flexible body reduction includes three main operations:

- creating the FE model of a rail vehicle component,
- import the FE model into the MBS software,
- setting up the FMBS of a freight wagon bogie.

Before the FE model import of the freight wagon bogie component into the multibody software it is necessary to perform reducing degrees of freedom of the finite element model of it. Reduction of the finite element model consists of several phases:

- setting up location of the interface nodes; the interface nodes allow connecting the flexible body to each other in the multibody system of a rail vehicle,
- connecting the interface nodes with the flexible body structure; in FE software Ansys it is possible to perform using:
    - rigid body element,
    - force disturbing constraints,
- defining the coupling nodes as retained nodes,
- and finally defining the retained degrees of freedom.

When the finite element model of the rail vehicle component is reduced, it is possible generating the input files, which is required for multibody software. This file contains all necessary information about flexibility and properties of selected rail vehicle component. Once the input data of flexible body are imported into the multibody software, it is possible apply to the flexible body joints, constraints, force elements etc. Deformation of the flexible body are caused by these boundary conditions and loads

The procedure of the flexible body preparation includes several parts. First, we have to create a 3D model of the bogie frame using modern software existing for this purpose. This model can be imported into the FEM software, where we create a FEM mesh and perform modal analysis, which is necessary for evaluation of eigenfrequencies and eigenmodes, then we analyse the flexible body behaviour and finally reduce it. After that the FE model of the bogie frame can be implemented into the multibody dynamic model of the freight wagon bogie (1).

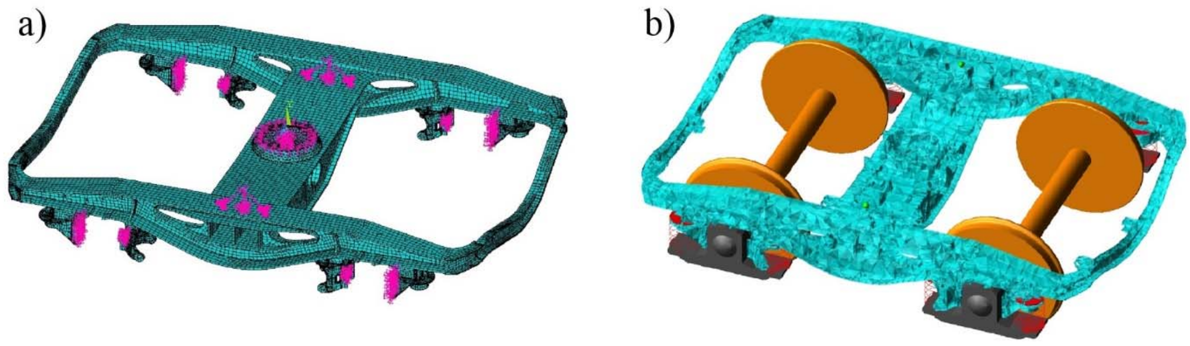

Fig. 2 - The FE model of the freight wagon bogie with interfaces nodes a) and the FMBS of the freight wagon bogie b)

As noted above, the flexible body reduction expects the interface nodes definition. These nodes have to appear in those locations where the other components of the freight wagon bogie (e.g. axle boxes, wheelsets, suspension, etc.) will be connected to the bogie frame. In our case, these locations are on axle guides, central pivots and side bearers. Interface nodes on axle guides serve for the interconnection with axle boxes and suspension elements, and interface nodes on the central pivot and side bearers allow connection of the bogie to wagon body. Figure 2a) shows the FE model of the freight wagon bogie frame created in Ansys FEM software. After definition of interface nodes we imported the model into the MBS software Adams/Rail and set up the FMBS of the freight wagon bogie Y25 (Fig. 2b).

CONCLUSION

The focus of this contribution is to present the FE model preparation of the rail vehicle part for the import into the MBS simulation. The computer simulation are nowadays an integral parts of the development process of rail vehicles. The multibody simulations with flexible bodies allow a more detailed analysis of the behaviour of the rail vehicle. The inclusion of the flexible body into MBS simulation allow better optimize design of rail vehicles and prevent potential problems during their long-term operation.

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