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INVESTIGATION OF VERTICAL DYNAMICS OF A HYDROGEN FUEL BUS

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Abstract: *The paper deals with two approaches to the creation of hydrogen fuel bus multibody models intended for the investigation of the bus dynamic response. The basic dynamic model for vertical dynamics was derived in the form of an ordinary differential equation system and was implemented in the MATLAB system. In order to study more complex behaviour the bus multibody model was also created using the alaska simulation tool based on a relative coordinate multibody formalism. Both models were used for the studying of the bus vertical dynamics. A very important issue of missing or inaccurate model data caused by the lack of a design documentation is discussed in the paper.*

Keywords: ***Multibody dynamics, suspension, vertical dynamics, air spring, shock absorber.***

1. Introduction

As new and progressive fuel systems are designed for the means of public transport, dynamic properties of these new vehicles should be tested and verified. The paper deals with the approaches to the creation of TriHyBus multibody models intended for the investigation of the bus dynamic response.

Fig. 1: Front view of TriHyBus and a fuel cell in the back of TriHyBus.

The TriHyBus project, which has been coordinated by Nuclear Research Institute Rez plc (the Czech Republic) for several years, comprises R&D, implementation and a test operation of a 12 m city bus (see figure 1) with a hybrid electric propulsion using hydrogen fuel cells. The bus was manufactured by ŠKODA ELECTRIC Inc. using the chassis of the Irisbus Citelis 12M bus (produced by Iveco Czech Republic, Inc.) and operates in the city of Neratovice, where the first Czech Hydrogen filling station was built in the Veolia Transport bus park. The 48 kW Proton Motor Membrane fuel cell is used as a main power-source for the 120 kW electric traction motor. Additional 28 kWh traction accumulators and ultra-capacitors are used when the bus accelerates or ascends, working together the fuel cell, allowing the energy recuperation while decelerating. The bus equipped with a hybrid power unit has a higher efficiency of the propulsion system.

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The vehicle driveability is comparable with the characteristics of standard buses. However, the distribution and total bus mass are rather different. It is the reason of the verification of the bus skeleton strength (connected with vertical dynamics) and of investigating the bus stability. The approaches to the creation of a TriHyBus dynamic model in the MATLAB system and two types of TriHyBus multibody models are introduced in this paper.

2. Basic dynamic model of the bus

The basic dynamic model of the TriHyBus was prepared in order to simulate the bus vertical dynamic response with a relatively simple model, which is suitably parameterized. The simulation with the model is very fast (Zhu & Ishitobi, 2004) and the model can be used for the fast sensitivity analysis and optimization. It is characterized by four rigid bodies (see figure 2). The bus sprung body is represented by one rigid body with three degrees of freedom (two rotations φ and θ, one translation z). The divided front axle (two half-axles) is simplified and represented by two rigid bodies (each one with one degree of freedom, translations z_1, z_2). The rear axle is supposed to be rigid and is modelled using one rigid body with two degrees of freedom (one rotation φ_3 and one translation z_3). Air-springs, hydraulic shock absorbers and tires are represented by nonlinear spring-damper elements. The model was derived by the free body method in Hajžman & Polach (2004) and can be written in the form

$$\boldsymbol{M}\ddot{\boldsymbol{q}} = \boldsymbol{f}(\dot{\boldsymbol{q}}, \boldsymbol{q}, t), \qquad (1)$$

where $\boldsymbol{M}$ is the diagonal mass matrix, $\boldsymbol{q}$ is the vector of the model generalized coordinates and the right hand side function represents all linear and nonlinear forces in suspension and gravity forces in bodies' centers of mass.

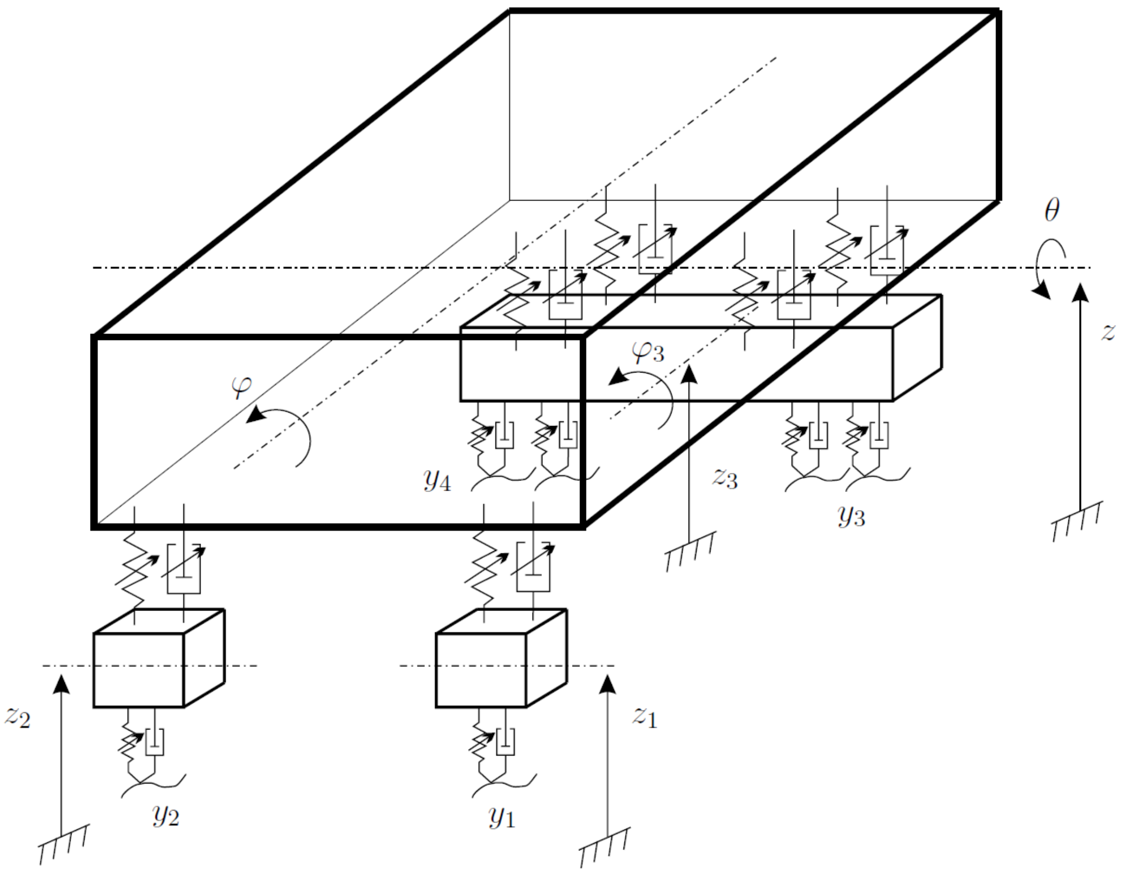

Fig. 2: Scheme of a basic dynamic model.

The model was implemented in the MATLAB system by means of real TriHyBus parameters (see the next chapter for more detail). The excitation of the bus is defined by functions $y_1(t)$ to $y_4(t)$ for each tire. The most direct way for the investigation of vertical dynamics problems is the numerical solution of the equations of motion (1).

3. Multibody models of the bus

In order to obtain a more comprehensive tool for dynamic analysis (e.g. Hegazy et al., 2000), multibody models of an empty and a fully loaded hydrogen bus were created. For the buses of the two weights a basic multibody model and a multibody model with more precise kinematics of axles´ suspension were created in the **alaska 2.3** simulation tool (Maißer et al., 1998). A creation of relatively simple multibody models (in this case of the basic multibody model) and an effort to improve them are important due to the significant shortening of the computational time.

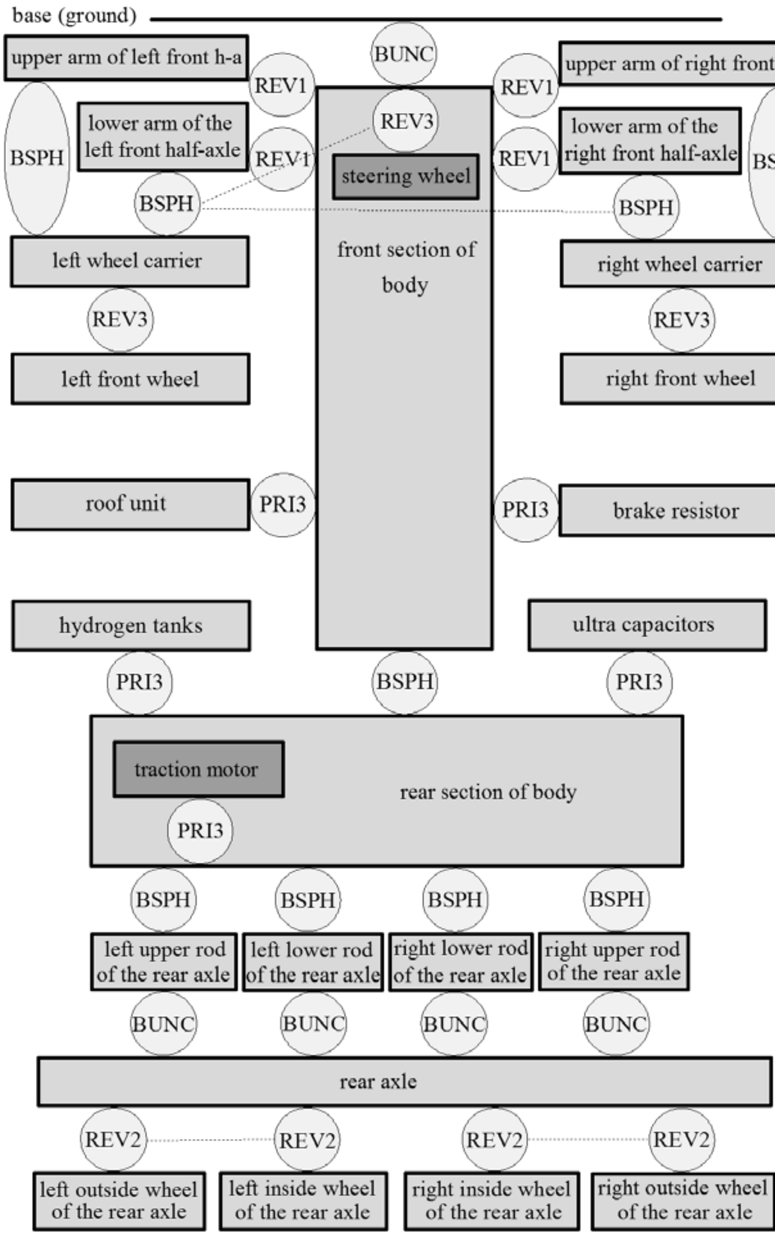

Fig. 3: Kinematic scheme of the multibody model with more precise kinematics of axles' suspension.

The basic multibody model of the hydrogen bus is formed by 21 rigid bodies mutually coupled by 24 kinematic joints. The number of degrees of freedom of multibody models in kinematic joints is 39. A kinematic scheme of the TriHyBus multibody model with more precise kinematics of the axles suspension is in figure 3. Rectangles designate the rigid bodies, circles (or ellipses) designate the kinematic joints (BUNC – unconstrained, BSPH – spherical, PRI3 – prismatic in vertical axis, REV1 – revolute around longitudinal axis, REV2 – revolute around lateral axis, REV3 – revolute around vertical axis). Dashed lines connect mutually dependent kinematic joints. The multibody model with more precise kinematics of the axles suspension (figure 3) is formed by 24 rigid bodies mutually coupled by 30 kinematic joints, the number of degrees of freedom of multibody models in kinematic joints is 73. The rigid bodies correspond to the bus individual structural parts and are defined by mass, centre of gravity coordinates and mass moments of inertia. Air springs and hydraulic shock absorbers in axles' suspension and bushings in the places of mounting certain bus structural parts are modelled by connecting the corresponding bodies by nonlinear spring-damper elements. When simulating driving on an uneven road surface the contact point model of tires is used in the multibody models; radial stiffness and radial damping properties of tires are modelled by linear spring-damper elements considering the possibility of a bounce of the tire from the road surface.

The basic dynamic model and both multibody models of the hydrogen bus are created especially on the basis of data (numerical data and technical documentation) provided by ŠKODA ELECTRIC Inc. Certain input data were derived or taken from the data used in the multibody models of the ŠKODA 21 Ab low-floor bus (Polach, 1997) and the SOR C 12 intercity bus (Polach & Hajžman, 2005). Characteristics of axles´ air springs are determined on the basis of static loadings of axles derived from the data provided by Iveco Czech Republic, Inc. Characteristics of shock absorbers in axles' suspension were derived from the shock absorbers characteristics of the SOR C 12 intercity bus. Stiffness data of bushings in assembly eyes for connecting radius rods to axles and chassis frame are taken from the documentation of the Lemförder Metallwaren and the Autófelszerelési Vállalat Sopron companies. Radial stiffness and radial damping characteristics of the public transport vehicle tires were experimentally measured in the Dynamic Testing Laboratory ŠKODA VÝZKUM Ltd. (Hajžman & Polach, 2006).

All multibody models can be used for the solution of the bus vertical dynamics with various types of excitation by uneven road surface as well as for the solution of horizontal dynamics problems (i.e. for handling and stability analyses).

4. Conclusions

Due to the need of studying the hydrogen fuel bus vertical dynamics several types of bus mathematical models were created. The basic dynamic model for vertical dynamics was derived in the form of an ordinary differential equation system and was implemented in the MATLAB system. In order to study a more complex behaviour two types of bus multibody models were created using the alaska simulation tool based on a relative coordinate multibody formalism. The described basic dynamic and multibody models can be used for the studying of the bus vertical dynamics. While the basic dynamic model is more suitable for fast analyses and optimization tasks the multibody models are efficient for a more accurate analysis of vertical and horizontal motion. The results from the vertical dynamics calculations are important inputs for the analysis of the strength and fatigue of the bus structure.

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