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Model–based Engineering – Fully Equipped City Bus Model – First Correlations Between Numerical and Experimental Data

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In this paper fully equipped city bus model and its correlations with experimental data is presented.This task is developed at AGH University of Science and Technology in the EU–founded project EURECA–CHASING, in which functional virtual prototyping has been applied. The model consists of multi–body suspension made in Virtual.Lab (LMS software) built from rigid elements connected with each other with kinematics joints and flexible superstructure (FEM made in HypeMesh–Altair software). Multibody models are used to simulate body dynamic behaviour. To make the realistic, all board systems such as ECAS or ABS have been modelled in AMESim (LMS software).

Fully equipped city bus model has been developed for the purpose of calculating kinematics of the suspension what can be use to optimize ride and handling performance.

However all models are useful if they are not corresponding to reality. For this reason experiments with real city bus have been carried out. The results of correlation numerical and experimental data have been presented and some interesting consideration have been derived.

Keywords: Transport, road transport, simulation, vehicle modelling, vehicle suspension

1. Introduction

Rising fuel prices, ever-increasing traffic jams but also more comfortable and faster public transport caused that people more and more often are choosing public transportation to reach a destination. The most popular among all types of public vehicles are buses because they can easily reach almost every place using normal streets. City buses have to serve people but also they are places of work for dozens of bus drivers.

Nowadays automotive word is focus on car design. Companies are trying to outrun each others with designing cheaper, better, quieter and safer cars using sophisticated modelling techniques, forgetting how important are city buses [8].

Normally to make virtual tests with buses, multibody model is created with superstructure that can be rigid or sometimes flexible to make model more realistic [1][5].

Evolution of on–board systems such as ABS[1], EBD[2], ECAS[3] for heavy vehicles that have an influence on ride requires evolution of simple bus models [2].

For this reason a virtual assessment of the fully equipped city bus has been developed. Such a model reflects real bus behaviour with on–board systems. With such a model in a very first phase of bus design some components can be optimized and some elements can be change to improve some performances in terms of passengers' and bus driver's comfort, safety and driving behaviour.

2. Fully equipped city bus model

Process of modelling fully equipped city bus model (developed at AGH UST) that can be use for different tasks (like simulations, optimization ect.) includes few basic steps:

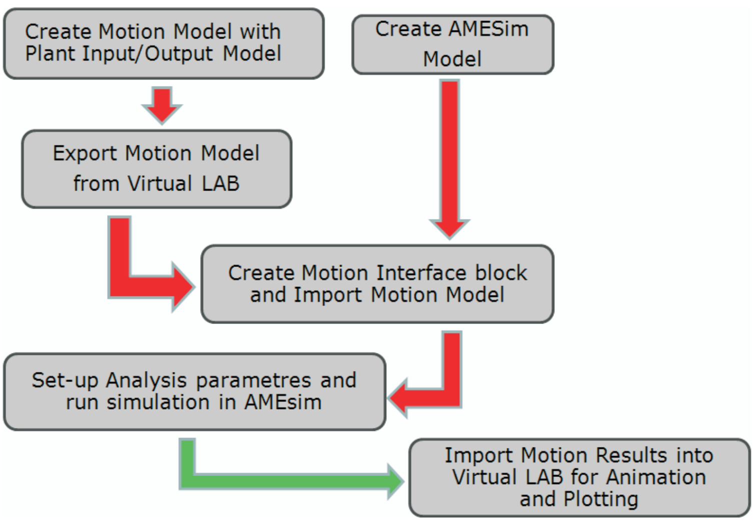

Figure 1 Process of creating fully equipped city bus model

[1]ABS (Anti–lock Braking System) – prevents lock–up during braking, no matter what the road surface conditions are [6]
[2]EBD (Electronic Break Distribution) [6]
[3]ECAS (electronically controlled air suspension) – the control system for air suspension that provides air to the air springs and facilitates automatic vehicle leveling and selectable ride height configurations [6]

2.1. *Multibody model [4]*

The multibody model is divided into the superstructure and suspension. Superstructure is being built from flexible elements and is described in next paragraph. Suspension instead is modelled from rigid elements with kinematics joints (revolute, spherical joints etc.) between elements which provides movements between different parts.

This results in 98 degrees of freedom. All rigid elements have been characterized with the parameters such as mass, moment of inertia. In the mounting points between the structure and the suspension the rubber bushing has been modelled. The nonlinear force–deformation (axial, radial, Cardanic and torsional) characteristics have been taken from producer.

City bus suspension has been modelled as two axles (front – independent and rear dependent one). Front suspension contains rigid elements connect by kinematic joints two air springs and two shock absorbers. This suspension is mounted to the frame (also with rubber bushing). As in this type of suspension air springs are used instead of normal assembled at each corner of the vehicle, two air spring at front suspension and four air spring at rear suspension but rear suspension is modelled for only two air springs, six coordinate markers as air spring displacement sensors non linear force- height characteristics depends on different level of pressure have been taken from the producer. Shock absorbers also have been modelled in terms of dependence the damping force on the relative velocity of compression and rebound given by producer. [7].

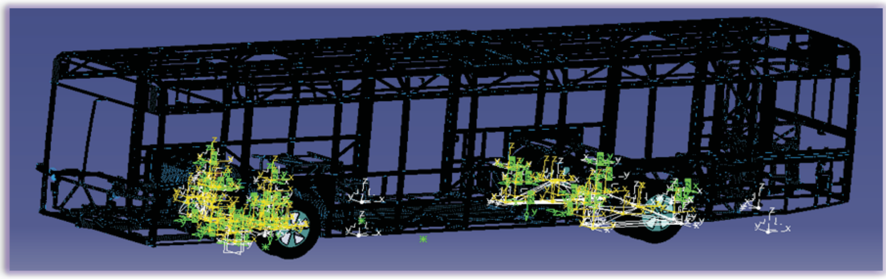

Figure 2 Multibody model of city bus

2.2. *Flexible superstructure*

Normally in multibody analysis it is assumed that all elements are structurally rigid. It means that there is no relative displacement between elements of the body (distance between two random points of the body remains constant). It is used because it makes a model more simple and equation easier to be solved.

However in some cases flexibility is important and analysis requires elements more complicated which can be deformed. The flexibility action of the superstructure of autobus has a big influence on the dynamics characteristic of whole suspension. To make a body flexible it is important to attached to this body modal data to describe flexure. Normal modes are used to represent natural vibrations of a body and static one are used to account for localized loading.

For this reason finite element model has been made in HyperMesh from Altair (one of the most powerful tool for FEA) [3]. Superstructure has been divided into 6 assemblies:

- roof
- floor
- front part
- rear part
- left wall
- rear wall

Each part has been meshed separately. for meshing 2D elements QUAD4 have been used mostly and TRIA3 (only few). Each component is been meshed as separate component and got its own material properties and thickness.

In each part, connections between beams have been simulated with rigid elements (RBE2 in Nastran). All construction (assemblies) has been connected with CBAR elements. Model contains 1055437 grid points (more than 6 million degrees of freedom). Mass of all model is 5131 kg.

To calculate flexible superstructure of this bus, Nastran SOL103 with Craig–Bampton reduction has been set. This reduction lets to reduce the size of a finite element model (combines motion of boundary points with modes of the structure assuming the boundary points are held fixed). Important is that C–B Mass and Stiffness Matrices fully define system [9].

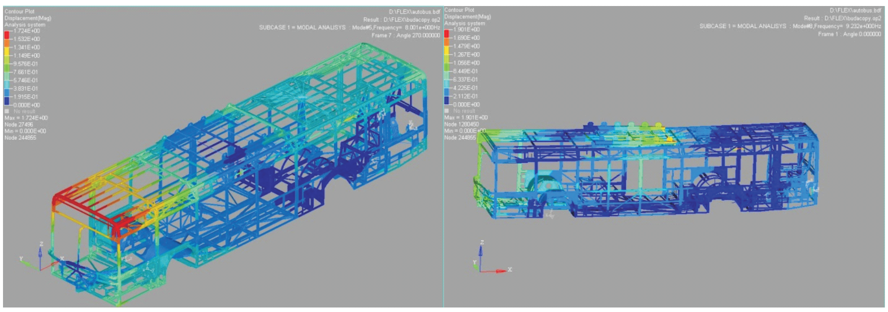

Figure 3 First torsion (8.001 Hz) and bending (9.232 Hz) modes

2.3. *On–board systems*

As it has been said in introduction, on–board systems are very important while driving and have an influence on bus ride. For this reason they have been modelled to achieve realistic model of a city bus.

In mentioned city bus four–channel four–sensor ABS is used. This system consists of speed sensors and a separate valve for each of four wheels. ECU (electronic control unit) is monitoring each wheel individually to make sure maximum braking force is achieved.

A co–simulation model for four-wheel vehicle has been established between 1D software like AMESim and multibody software like LMS Virtual.LAB. Co–simulation mode characterized by the fact that the AMESim equations of Motion and the Virtual.Lab Motion state equations solves separately.

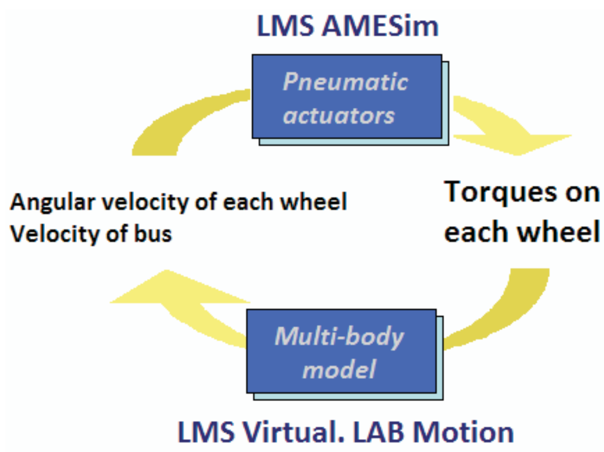

Figure 4 Idea of co–simulation between AMESim and Virtual.Lab

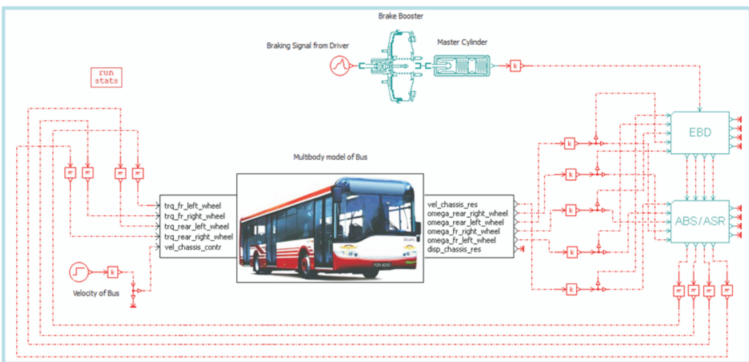

Figure 5 Fully equipped city bus model

The AMESim model receives signals of the angular velocity of each wheel, velocity and displacement of bus from Virtual.LAB model, then calculates and sends back for outputs signals responsible for torques for each wheel to multibody model. The idea co–simulation process is shown in Fig. 4 and implementation in Fig. 5 Another important on–board system is ECAS as it was mentioned before there are six coordinate markers as air spring displacement sensors. AMESim model of air suspension system developed in project CHASING consists of air springs valves regulating air flows, a compressor, two reversing valves deciding the air path, a reservoir storing the compressed air, a pressure sensor measuring the inlet pressure of the air spring valves, an air filter removing dirt in the circuit, and a air dryer (Fig. 6)

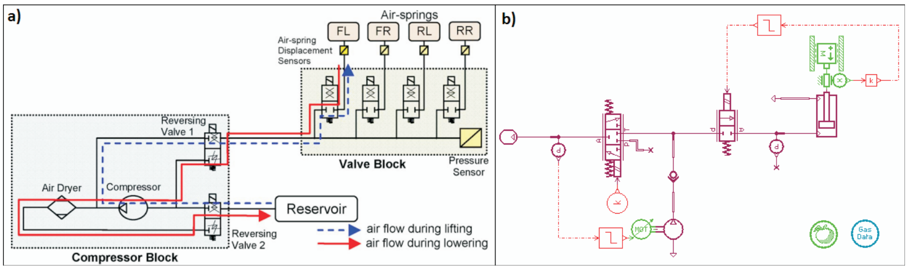

Figure 6 Air suspension system for height control and simulation model in AMESim

3. First correlations between numerical and experimental data

None model is useful if does not corresponds to real vehicle. For this reason some ride tests on real city bus have been done and results (experimental data) have been correlated with numerical data from virtual assesment simulations.

3.1. *Experiments on real city bus*

Experiments have been carried out in Czech Republic on bus test truck with CNG powered city bus (the same as a model). Bus has been stuck with accelerometers network to measure vibration of a bus structure and suspension (Fig. 7). Accelerometers have been put on front axel (on wheel upright) and rear axel (near upper control arm). Bus has been driven with constant velocity 30 [km/h].

Bus have been ridden on sinusoind type of road (Fig. 8).

Measured waveforms have been filtrated due to fact that there was a constant component and some noises which came from measurement stuff. The useful results are between 0 and 50 [Hz].

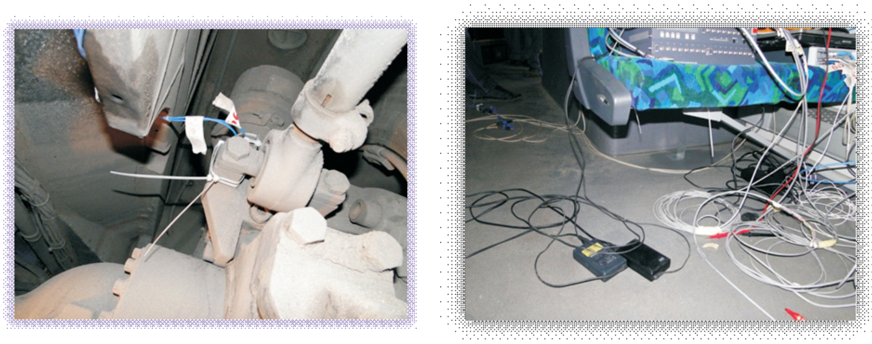

Figure 7 Accelerometers on a real bus

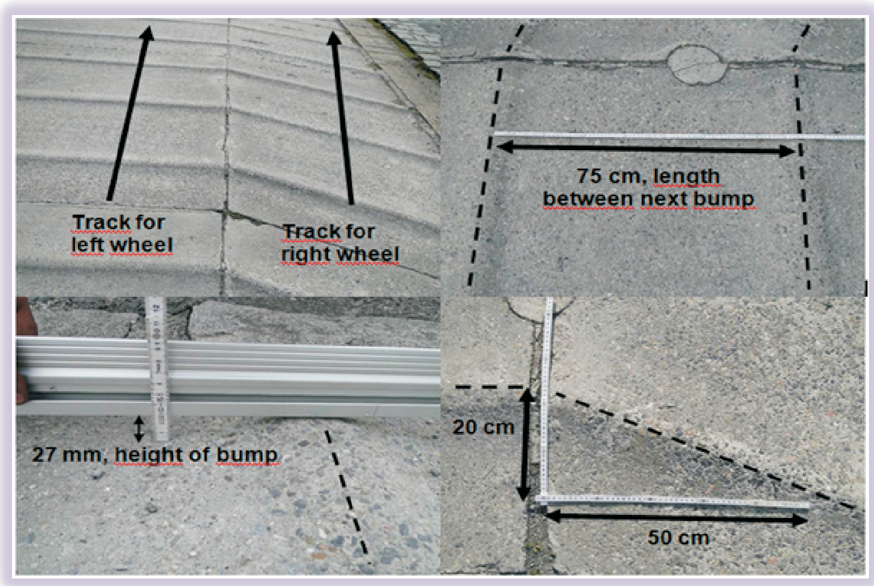

Figure 8 Sinusoid road profile

3.2. *Simulations of fully equipped model*

Simulations have been carried out in VirtualLab software with co-simulation with AMESim where (described in paragraph X) multibody model of city bus has been equipped with on–board systems. Simulations have been performed with constant velocity 30 [km/h] as it have been done in real measurements on test truck. Measurement markers have been put in the same place as in real bus to receive vibrations in the same areas.

To make simulation conditions very close to reality, also a ride truck (sinusoid road profile) has been simulated (Fig. 9).

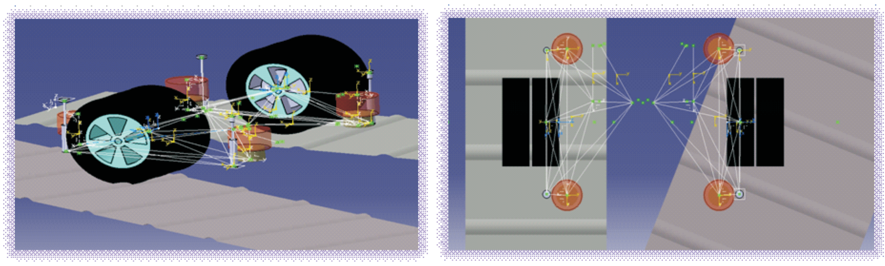

Figure 9 Model of sinusoid road profile

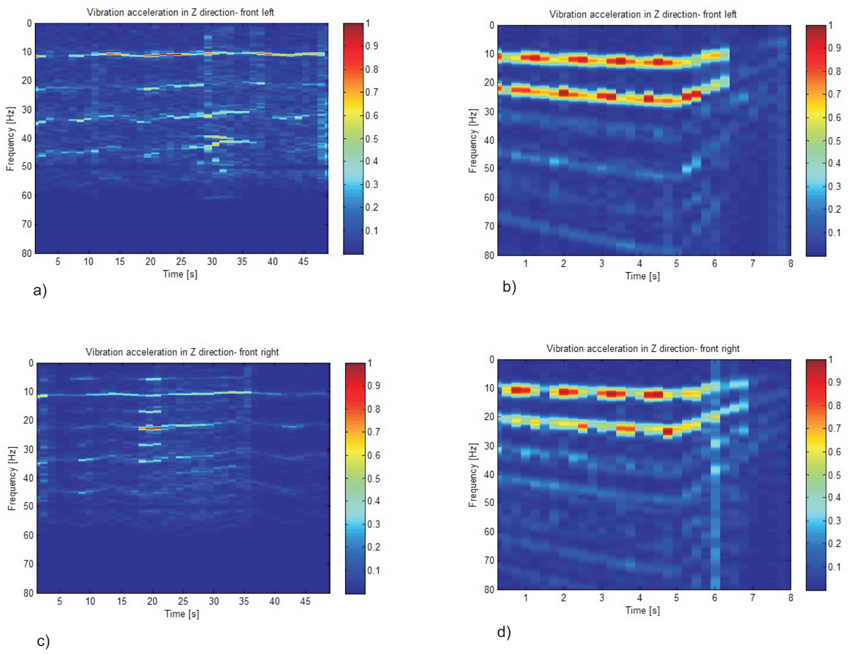

Figure 10 Correlation spectrograms between experimental and numerical data of vibration ac – celerations of measured points on suspension elements: a) front left suspension misured point – experiment, b) front left suspension misured point – simulation, c) front right suspension measured point – experiment, d) front right suspension measured point – simulation

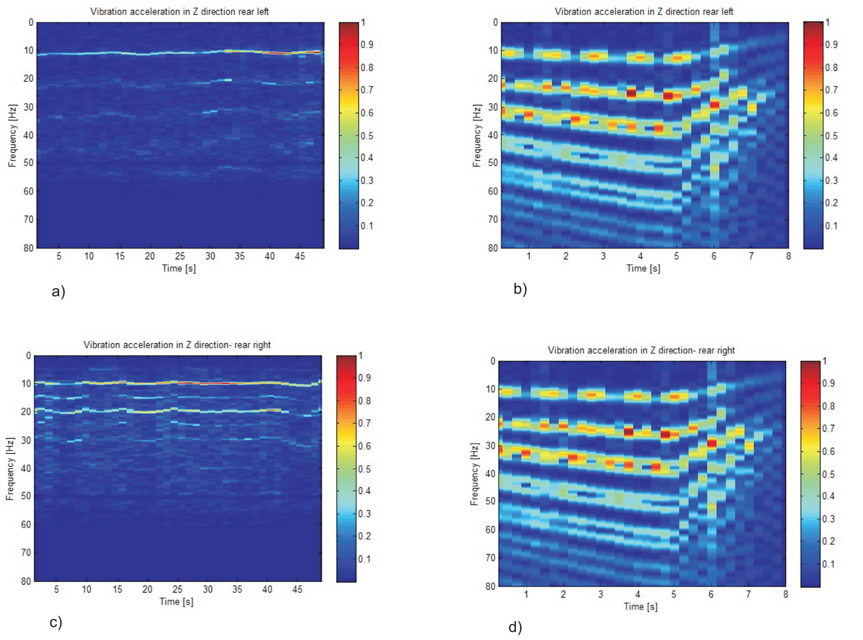

Figure 11 Correlation spectrograms between experimental and numerical data of vibration ac – celerations of measured points on suspension elements: a) rear left suspen- sion misured point – experiment, b) rear left suspension misured point - simulation, c) rear right suspension measured point – experiment, d) rear right suspension measured point – simulation

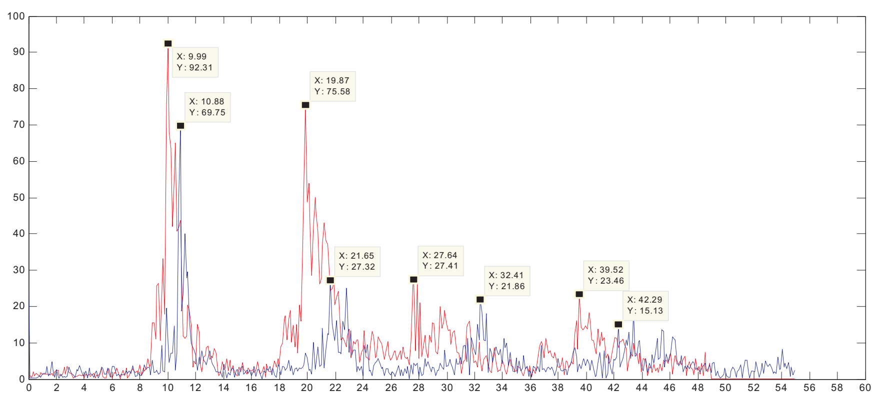

Figure 12 Spectrum of vibrations acceleration misured on front left suspension point

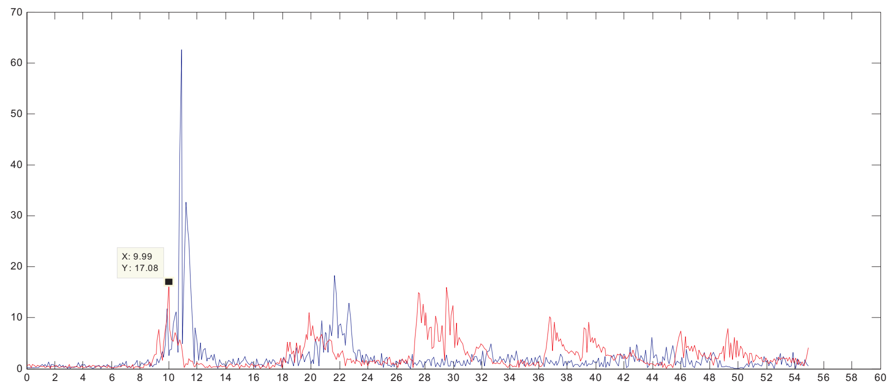

Figure 13 Spectrum of vibrations acceleration misured on rear left suspension point

3.3. *Correlation between experimental and numerical data*

Both numerical and experimental data have been filtrated (as it was said before) and time interval has been chosen to hold inequalities roadway in real tests and simulations in the same places. During the tests (both: experimental end virtual) vibrations acceleration have been measured. As an excitation, truck irregularities have been used.

The resulting curves for experiment and numerical simulation have been correlated to see if model corresponds to real city bus. Correlations have been done using spectrograms.

In the Figs 10–11 spectrograms of vibrations acceleration measured on suspension elements on real structure and fully equipped model. As it can be noticed frequency of vibrations for simulated model is almost the same as for real city bus structure. The difference oscitates around 1 [Hz] what is realy good result for the firs correlations. Amplitude of vibrations acceleration instead differs. However this can be solve easly by proper scale factor. To see a difference better spectra of front and rear left suspension part (Fig. 12, Fig. 13) have been shown (spectra of right part have the same trend as left one). For this reason the next step for making model more realistic will be updanig a model. It can be solve by minimizing error between this two curves.

4. Conclusions

In this work fully equipped city bus model developed at AGH UST has been shown. This model has been tested and correlated with measurements made during experiment with real city bus. First correlations shows that model is very close to reality. Both spectrograms and spectra show that frequencies of vibrations acceleration excited with road profile irregularities are for experimental and numerical measurements almost the same. There is a difference between peaks amplitude. Next step will be model updating using optimization techniques to decrease error between numerical and experimental curves.

Such a model can be use for different task. Starting with simple ride simulation, finishing with advanced multi–objective optimization of suspension kinematic parameters and also topology or topography of a structure.

Acknowledgements

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