Vibration analysis of mechanical systems with utilisation of GRAFSIM and CATGEN software

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Analysis and modelling

ABSTRACT

Purpose: The paper describes the method and corresponding software used for modelling and vibration analysis of mechanical systems. A s an example the study on the modelling of a vibrating system in a form of a passenger car was discussed with determination of the characteristics describing its vibrations and resonance zones.

Design/methodology/approach: The software described in the article uses the matrix hybrid graphs method and matrix block diagrams method for making analysis of mechanical systems vibrations. For numerical calculations the system is represented in the form as a matrix block diagram, and is analysed in detailed way in the Matlab-SIMULINK environment.

Findings: Numerical software packages give possibility to analyse vibrations of mechanical systems or of their parts exposed to kinematic and dynamic excitations.

Research limitations/implications: Time responses of the vibrations of the passenger car system model evoked by various types of excitations are presented, as well as the amplitude –frequency –phase characteristics (a-f-p).

Originality/value: The paper constitutes the source of information into the theory and practice of mechanical vibrations as well as professional computer software as a tool enabling the determination of the time responses and the a-f-p characteristics of machine and equipment parts.

Keywords: CAD/CAM; Applied mechanics; Vibration analysis; Matrix hybrid graphs

1. Introduction

Modelling as being an important issue connected with the analysis and synthesis of technical objects [3-18], consists in selecting an idealized system giving the possibility to have necessary information on the modelled object itself. In order to create a physical and a mathematical model of the mechanical system, it is necessary to have a knowledge of its properties, correlations and processes that happens in that system [1]. In the most numbers of situations, models of mechanical systems are built of rigid elements, connected by kinematical couples. These kind of systems are commonly represented by physical models composed of inertial elements, that are under influence of proper constraints and forces from outside.

Presently for modelling and testing vibrations of mechanical systems computer-aided techniques are usually used. The utilisation of advanced analysis software constitutes a problem because of the economic means. There are a lot of specialised programs that are used by engineers for making analysis of mechanical systems.

At the Silesian University of Technology the GRAFSIM software has been developed, intended to perform a detailed analysis of 2D and 3D mechanical system vibrations [1, 3 - 7].

The software has been created in the environment of MATLAB-SIMULINK software and it enables, through the

system of proper windows, to insert all the necessary data of the system. The system is represented in the form of a matrix block diagram, that can be widely analysed in SIMULINK software.

In the GRAFSIM software the complex 2 and 3D mechanical systems with linear couplings subjected to dynamic and kinematical excitations, as well as every initial conditions can be simulated and analysed.

CATIA is a computer software intended to model 3D systems, therefore models of mechanical systems can be easily created in this program, and all the parameters of the mechanical system can be acquired by exporting them to GRAFSIM by utilisation of CATGEN interface. This software works between CATIA and GRAFSIM creating a proper input file. Thanks to this software engineers can easily build and perform analysis of the created in CATIA environment models (Fig. 1).

2. CATGEN software as the physical and geometrical data acquiring system from the CATIA application

As an example of modelling a vibrating system a passenger car (Skoda Fabia) was presented and the characteristics that describes its vibrations and resonance zones have been presented.

At the beginning a simple model of this system in CATIA software was created (Fig. 2).

The presented picture shows the coupling coordinates of elastic-damping elements (EDE) (shock absorbers and tyres) as well as coordinates of inertial elements.
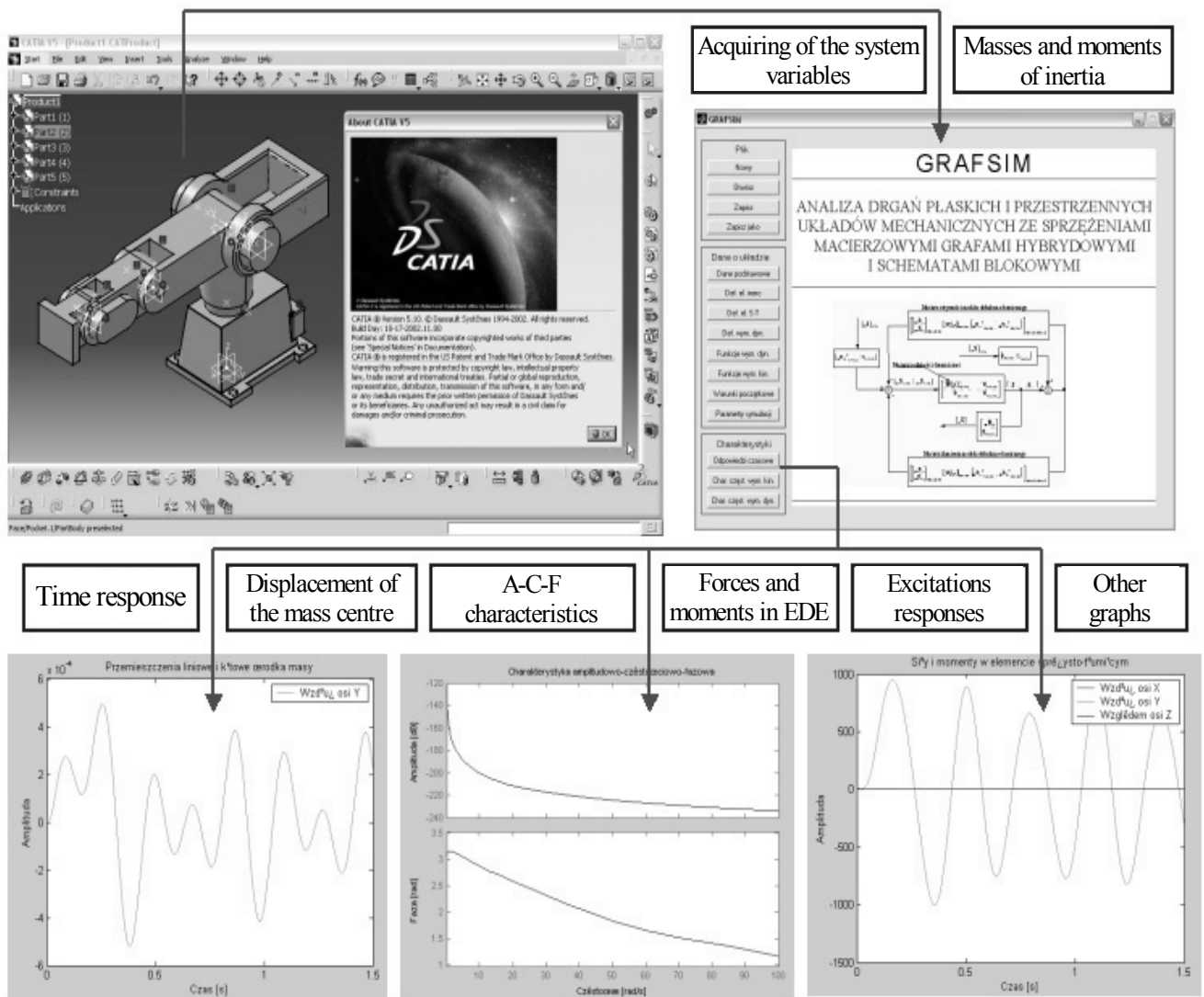

Fig. 1. The model of acquiring physical and geometrical data to the GRAFSIM software

The type of materials of inertial elements were chosen in the way to be very close to the masses of the original objects.

In the process of idealization 4 inertial elements were distinguished: body, front and rear axle and the driver's seat. The elements are connected with each other by the elastic-damping elements. There are 11 EDE in the model: two shock absorbers, two springs, two vibration dampers, four tyres and the elastic-dumping element that connecting the car's body with the seat. The directions of appropriate axes of local coordinates systems coupled at the centres of gravity of particular inertial elements and at the elastic-damping elements are parallel, as shown in Fig. 2. The coordinates systems coupled at the centres of gravity of particular inertial elements were also marked on the model, as well as the coordinate systems corresponding to the elastic-damping elements.
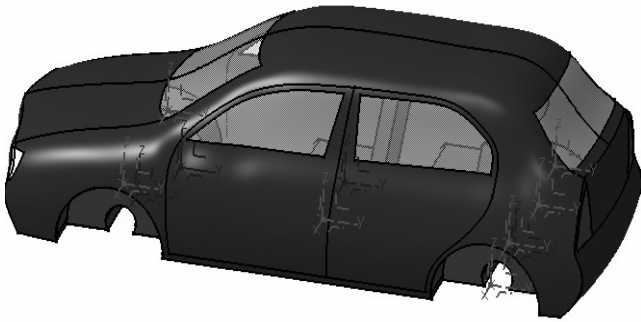
Fig. 2. Passenger car model with local coordinates systems

By utilisation of CATGEN software all necessary system's parameters are acquired from CATIA program. There are masses and centres of gravity of inertial elements, coincidence points of EDE and coincidence points of kinematic and dynamic excitations.

The first inertial element of the passenger car is the body (Fig.3) that was connected with the axles and the driver's seat by the elastic-damping elements.

By means of two elastic-damping elements (shock absorbers) the body is coupled with the front axle. Two additional EDE (springs and vibration dampers) connect the body with the rear axle and one EDE connects the driver's seat to the car body.
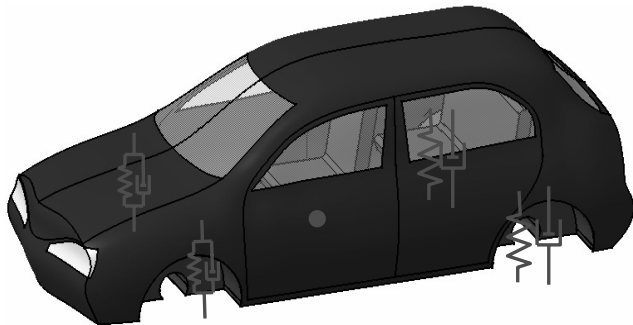
Fig. 3. Car body model (inertial element 1) with coupled elastic-damping elements

Fig. 4 presents the data acquired by the CATGEN program such as masses, coordinates of the centre of gravity and moments of inertia.

Fig. 4. Part of CATGEN window with the description of the car body

Another example of the inertial element of the car model is its rear axle.

The axle has four coincidence points of the elastic-damping elements - two corresponding to the point at which the shock absorber is mounted and two located on the rotation axles designating the point at which the tyres are fixed.

Fig. 5 presents the driver's seat with a coincident point of elastic-dumping element that connects the seat with the body.
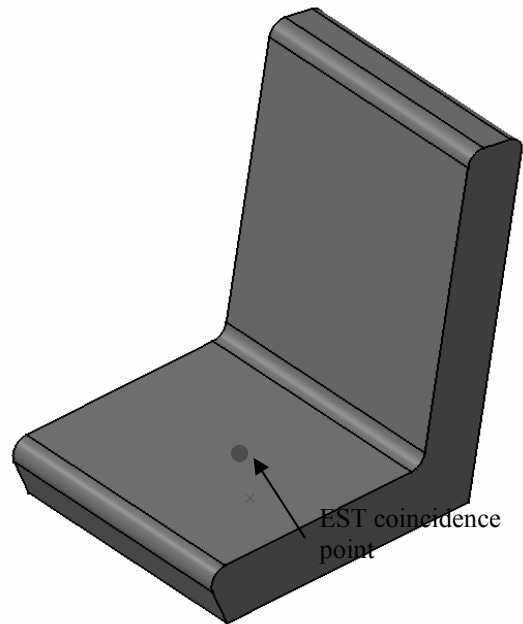
Fig. 5. Model of the driver's seat

CATGEN can automatically read out the coupling coordinates of particular elastic-damping elements (Fig.6); whereas it is up to the user to designate the angles between the elastic-damping elements and particular coordinate systems axes of the inertial elements.
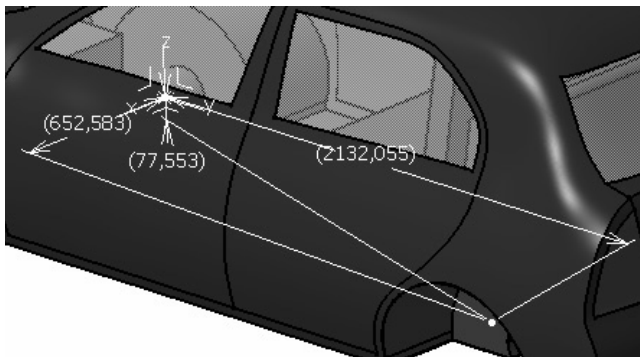
Fig. 6. Inertial element with distinguished coupling coordinate of EST

The application makes it possible to set attachment coordinates of EDE and inertial elements (Fig. 7) and introduce the constraints on the degrees of freedom for the inertial elements. In the case of a 3D system, it is possible to constrain 3 displacements and 3 rotations (Fig.8).
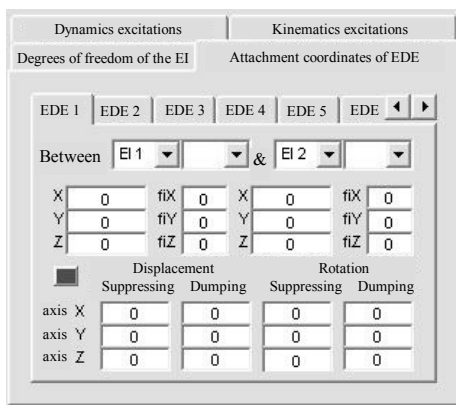

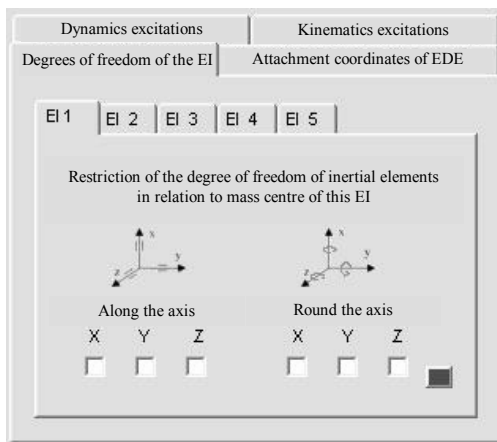Fig. 7. Part of CATGEN's dialogue window with coupled EDE 1 coordinates

Fig. 8. Constraints to the number of the degrees of freedom

By using the windows of the CATGEN application, the engineers can easily distinguish the elements exposed to the dynamic or kinematic excitations. There are a lot of possibilities for the user to chose a proper excitation function. It can be a random, sinusoid, impulse, step, rectangular, angular, cross-cut, trapeze or any excitation function in the form of algebraic formula. The kinematic excitation may be defined as a displacement, velocity or acceleration function, depending on the conditions that prevail in the discussed model of a mechanical system.

By means of a dialogue window (Fig.9) basic parameters of the simulation are determined.
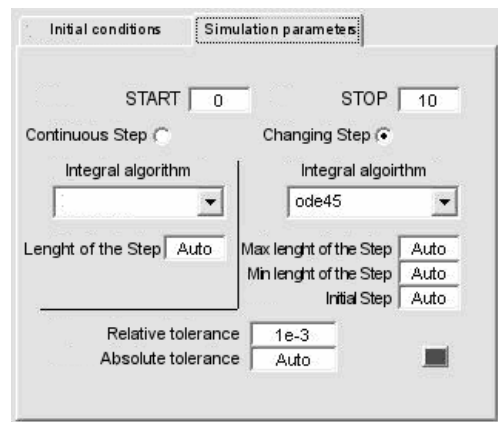

Fig. 9. Simulation parameters

Fig.10 presents a dialog window of the CATGEN software were initial conditions in a form of linear displacements and velocities as well as angular displacements and velocities can be determined.
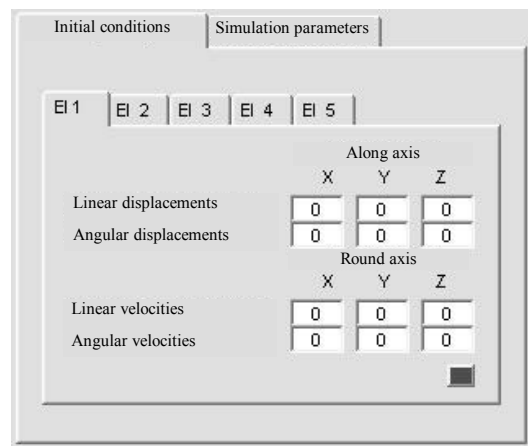

Fig. 10. "Initial conditions" window

There are many other important windows of CATGEN software that were widely discussed and presented in works [2,11]. When all the data is put into the CATGEN interface a proper input file is generated and sent to the GRAFSIM program.

3. Numerical analysis of a passenger car model as an example of the GRAFSIM software utilisation

GRAFSIM software [Fig. 11] has been used to generate exemplary time responses and amplitude-frequency-phase graphs of the a car model system that was loaded by kinematic excitations, simulating uneven road along which the vehicle is moving. The program uses a transformation algorithm of a model structure into a matrix hybrid graph (mhg) structure [1] and after that mhg is transformed into the matrix block diagram that is presented on fig 12. This diagram is used in the Simulink environment to generate all of the possible types of graphs and its structure is fully compatible with the structure of the considered mechanical system.

Figs 13-16 present windows of the GRAFSIM program that allow the user to generate time responses of inertial elements and elastic-dumping elements on set kinematic and dynamic excitations.
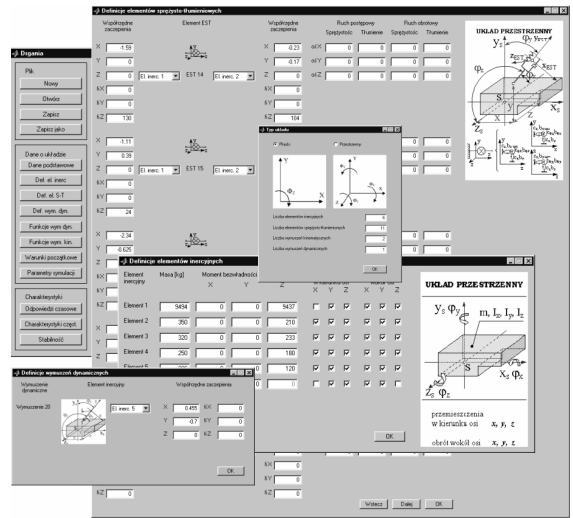

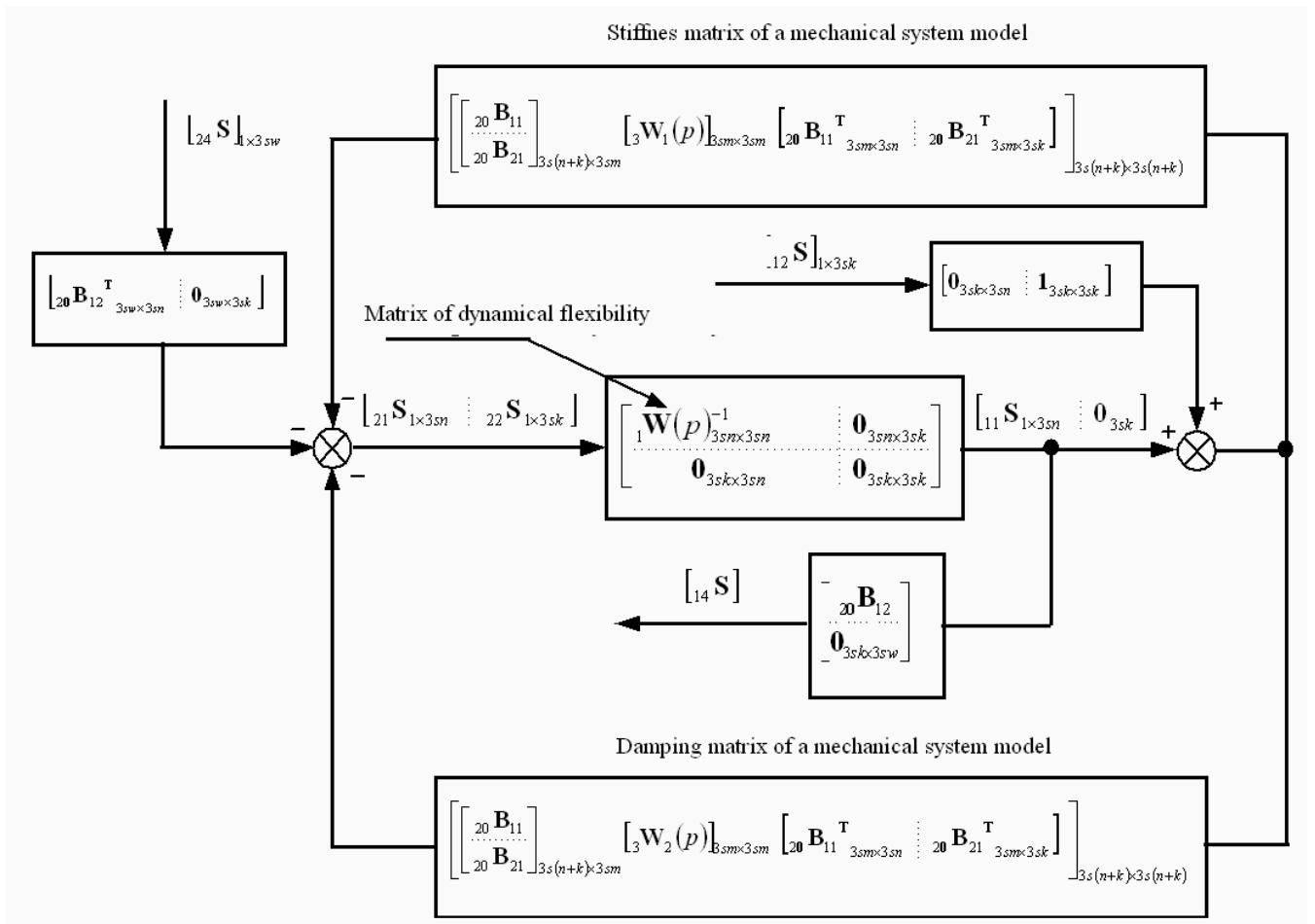Fig. 11. Some of the example windows of the GRAFSIM software

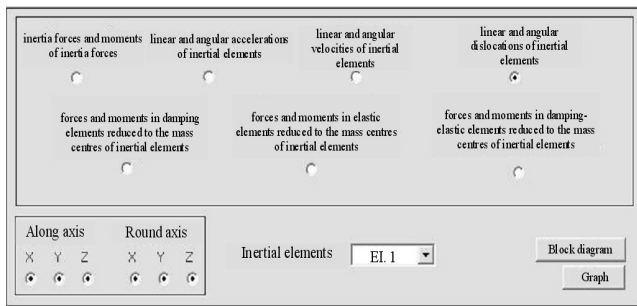Fig. 12. The matrix block diagram of a mechanical system

Fig. 13. GRAFSIM'S program time responses window of inertial elements on set excitations
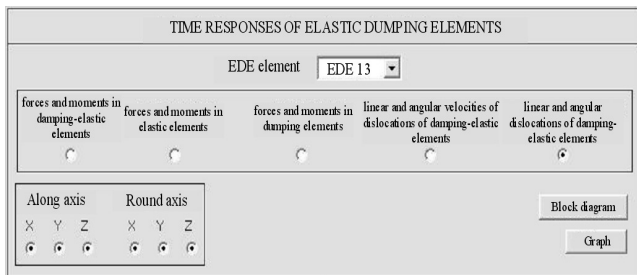

Fig. 14. GRAFSIM'S program time responses window of elastic dumping elements on set excitations
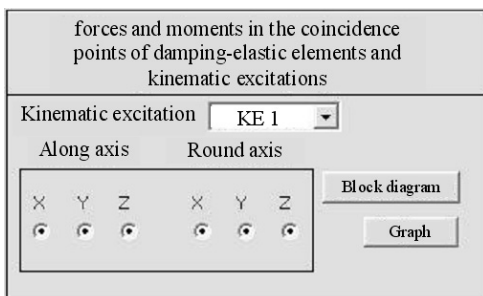

Fig. 15. GRAFSIM'S program time responses window of forces and moments in the coincidence points of elastic-dumping elements and kinematic excitations
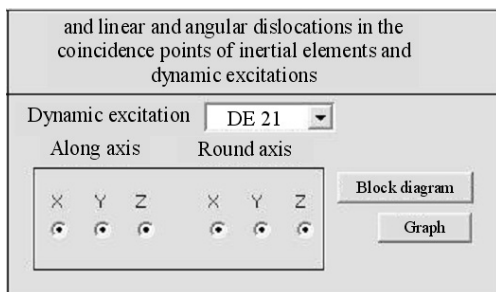

Fig. 16. GRAFSIM'S program time responses window of linear and angular dislocations in the coincidence points of inertial elements and dynamic excitations

The amplitude of kinematic excitation acting on the front left wheel of the car in the form of displacement impulse function is 0,08[m] and its duration equals 1[s]. The vehicle can only move in a vertical direction because of the set constraints. Figs 17 - 19 present exemplary output functions that were achieved during the analysis process.
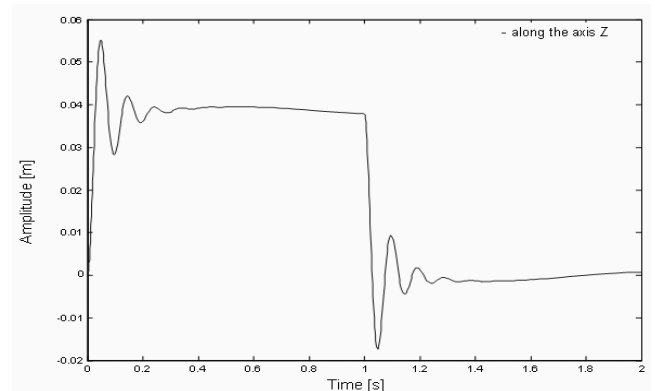

Fig.17. Graph of displacement changes as a response of the vehicle front axle to given kinematical excitation
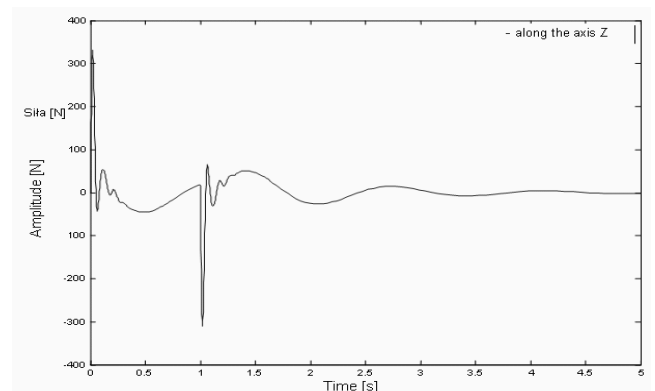

Fig.18. Graph of the force of inertia changes as a response of the vehicle driver's seat with the driver axle to given kinematical excitation
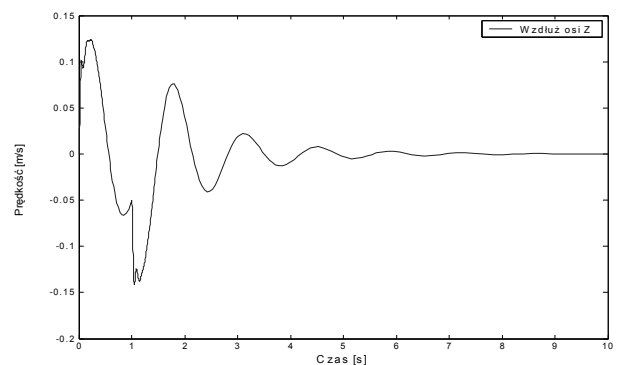

Fig.19. Graph of velocity changes as a response of the vehicle driver's seat with the driver axle to given kinematical excitation

Figs. 20-22 depict the decibel amplitude-frequency-phase characteristics expressing relative changes in selected system parameters as a dynamical excitation function for a system with and without damping.
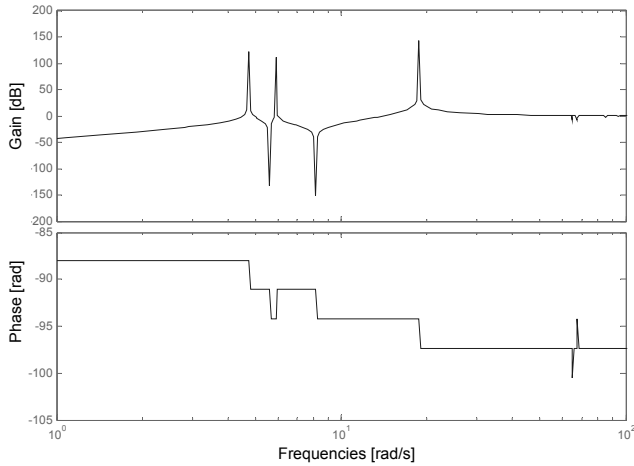

Fig. 21. Decibel amplitude-frequency-phase characteristics of the vehicle model expressing relative inertial force of the driver's seat with the driver as a dynamical excitation function acting upon the driver's seat in the direction of axle for free vibrations

The analysis of the derived graphs indicates that the maximal vibrations amplitude in the form of the inertial force of the driver's seat with the driver vibrations reaches the value of 320 [N].

The maximal vibrations amplitude in the form of linear acceleration reaches the value of $3.4 \left[\frac{m}{s^2} \right]$.

The maximal vibrations amplitude in the form of velocity of the centre of the driver's seat with the driver mass for linear velocity is $0.012 \left[\frac{m}{s} \right]$.
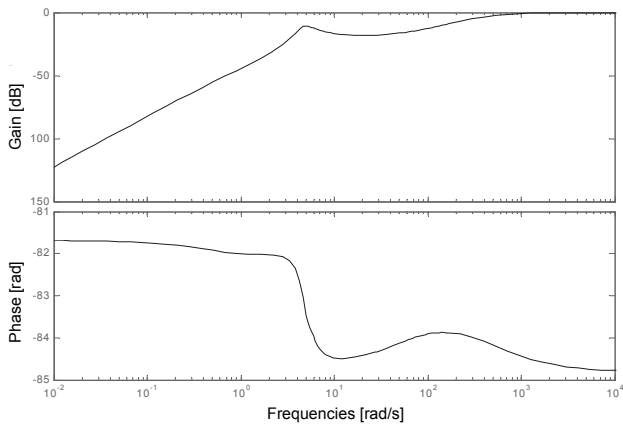

Fig. 22. Decibel amplitude-frequency-phase characteristics of the vehicle model expressing relative inertial force of the driver's seat with the driver as a dynamical excitation function acting upon the driver's seat in the direction of axle for dumped vibrations

The maximal vibrations amplitude in the form of inertia centre displacement of the driver's seat is 0.055 [m].

Table 1 presents the resonance frequencies of the free vibrations of the vehicle model calculated in GRAFSIM software.

Table 1

	$\left[\frac{rad}{s} \right]$	[Hz]
1	3.41	0,54
2	5.87	0,94
3	6.84	1,09
4	21.03	3,35
5	65.05	10,40
6	67.36	10,70
7	85.08	13,50
8	94.25	15,00

4. Conclusions

The control functions can be easily formulated in many various ways, leading to the input function that can be treated as a disturbance or as a control signal. It is also possible to generate the equations of state in relation to the defined inputs and outputs of the system.

During the analysis process, by using all acquired data, GRAFSIM software generates operating dynamical characteristics (transmittance), and matrices of the state that describe the model of a mechanical system. The GRAFSIM software in the automated way designates equivalent transmittance of the analysed system on the grounds of the block diagram's set inputs and outputs, and determines the matrices of the state.

The method of determining operating dynamical characteristics in GRAFSIM is directly based on designating equivalent transmittance of the system in view of its defined input and output (simplification of the block diagram).

The software that was shown and discussed in the article constitutes a cheap and user-friendly tool for the engineers making analysis of the vibrations of complex 2D and 3D mechanical systems.

Acknowledgements

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