ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0010.2906

INITIAL NUMERICAL ANALYSIS OF A SMALL ELECTRIC VEHICLE

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Abstract

This article presents a concept of a two-seat urban electric vehicle, whose model was developed in the FEM Nastran-in-Cad software. The performed simulations formed an optimization tool applied for the purpose of a study involving the distribution of the vehicle mass and its impact on the strength parameters of the body. The study focuses on the impact of the vertical road characteristics on the stress transferred through the vehicle's body throughout drive conditions. In addition, a quasi-static analysis was performed with regard to the deformation of the load-bearing elements resulting from external impact forces with various magnitude and contact angle.

In the article, the authors focused on the study of the impact of vertical road characteristics on the stress that is transferred through the vehicle body, as it occurs in driving conditions. The simulations presented in the article focus on the procedures applied during the analytical and numerical analysis with the purpose of developing an environment to test the structural components of the vehicle in terms of its response to vertical road roughness. The analysed system examined the impact of the road surface on the occurrence of stress and displacement in the structure of the body of the designed vehicle.

Keywords: *vibrations, car chassis, finite element method, dynamic modelling, suspension*

1. Introduction

At present, the congestion in urban areas contributes to the increase of the level of environmental pollution. One of the approaches to tackle this problem is based on the application of clean urban transport. For this purpose, the currently applied measures are implemented to ensure that vehicles put into service are more energy-efficient. This approach also involves the application of electric drivetrains and reduction of vehicle size. As a result, the electrical motor starts to replace the classical internal combustion engine as a source of power. One of the basic advantages of the classical powertrains based on combustion engines is associated with the greater vehicle range compared to the electrical drive; however, it directly produces pollution, which is transmitted into the atmosphere. One of the main reasons for the existence of congestion in cities is associated with the fact that the space that is designated for the use of car passengers is not sufficiently filled. This is most often represented by the fact that vehicles, whose role is to carry a number of passengers, are usually occupied by a single person. This causes significant loss of space in the urban transport.

The dimensions of a powertrain based on a combustion engine are considerably bigger than a drive based on an electric motor. In this, the space occupied by the combustion engine is the greatest as it occupies the central space in the engine compartment, and this directly affects the increase of the vehicle dimensions. Knowing this, the initial stages of the design of the car body include dimensions of the engine compartment. However, if we analyse the electric drive, we can note that the substitution of an electric motor in the place of the combustion engine can lead to a smaller space occupied in the engine compartment coupled with a better distribution of the vehicle weight. However, the electric drive demonstrates a considerable drawback, as it comprises energy stores (batteries) with a considerable mass, which affects the increase of the car mass.

Hence, we need to find a location for the battery pack so as to ensure an adequate distribution of the vehicle mass. This is one of the reasons why the application of an electric drive needs to involve the need to develop new solutions with regard to the car design.

The design of an electric car can depart from a classic structure of a combustion engine and apply a completely new approach to the vehicle architecture. An important consideration for the case of an electric vehicle is associated with an adequate planning of the place needed to install the battery pack, and this step involves the need to modify the design of structural elements used in a vehicle. The most feasible solution procedure in this regard comprises finding a new location for the battery pack, i.e. in the central place in the car body. This, in turn, requires that the strength of the vehicle frame in such places have to be modified. Nevertheless, there are areas of the body in which empty zones exist, and they can be filled so as not to waste the available space. These areas can be filled by batteries and other assemblies. At present, the most common method applied with the propose of testing the fundamentals of the vehicle design is associated with the development of a prototype of the body, which can be applied for subsequent tests. However, the development of a prototype is a cost- and time-consuming process. For this purpose, the use of other, less costly methods is recommended, such as digital prototyping. The basic advantage of digital prototyping is associated with the potential easily and quickly modifies the components of the structure of a virtual model, which is often not very feasible with regard to an actual prototype. However, the basic impediment of the digital model is associated with the transfer of the actual drive conditions to the research involving a virtual prototype.

The development of virtual models designed for application in research is a complex process. This task requires the transfer of physical phenomena onto mathematical and mechanical models as well as collection of sufficient fata from literature or by means of an experiment. Hence, the development of a model of a given environment needs to involve the knowledge of the initial conditions in the given conditions and the values of the actual forces acting on an object. This data can only be derived as a result of a comprehensive analysis of the specific phenomenon and on the basis of sufficient parameters collected and further applied in the calculations. Subsequently, it is necessary to develop a system in which the input signals provided to a given object can give output in the form, whose values and courses are similar to the actual conditions.

The research into structural components of the body involves a number of aspects related to car exploitation during normal drive. In this article, the authors focused on the study of the impact of vertical road characteristics on the stress that is transferred through the vehicle body, as it occurs in driving conditions. This objective was fulfilled by tests performed on a test lane and by numerical studies. After verification of the methodology applied to test the mechanical model of the vibrating mass, it was applied for a test involving a virtual prototype of a small electric vehicle.

The simulations presented in this article focus on the procedures applied during the analytical and numerical analysis with the purpose of developing an environment to test the structural components of the vehicle in terms of its response to vertical road roughness. The analysed system examined the impact of the road surface on the occurrence of stress and displacement in the structure of the body of the designed vehicle. The actual forces represented in the form of vertical displacements were applied by means of a vibrating plate located on a diagnostic line. The data from the tested system (plate-wheel-body) was registered by means of an acceleration sensor. The registered data was subsequently processed to be applied in a virtual model of the tested model of the system on the basis of the finite element method. For this reason, the development of an environment applied to verify the stress of the vehicle structural elements resulting from vertical forces acting on it comprised a number of phases. The first phase involved the acquisition of data derived from the actual environment, i.e. registration of the acceleration of vehicle vibrations. The second phase consisted in the development of a discreet model of the tested vehicle, whose dimensions and mass was derived from an experiment. After completion of the simulations, it was observed that the results are similar to the ones that were gained from tests on a test lane. Subsequently, the model with the prototype of a small electric vehicle was prepared to test it in the subsequent numerical calculations with the purpose of determining the strength of its structural components under the effect of vertical roughness of a road surface during normal exploitation.

2. Test bench applied for measurement of input parameters to model

This phase of the research involved a small vehicle (3-door Fiat Punto). The testing was performed on a test lane. The vibrations were initiated by a vibrating plate, which was in contact with the left front wheel of the vehicle. The measurement of vibrations applied an acceleration sensor. The study focused only on the vertical acceleration of the components of the vibrating system (plate, wheel, body). The data that was collected in this manner was subsequently processed so as to prepare it for further use under the assumption that the parameters of all wheels of the virtual vehicle are the same.

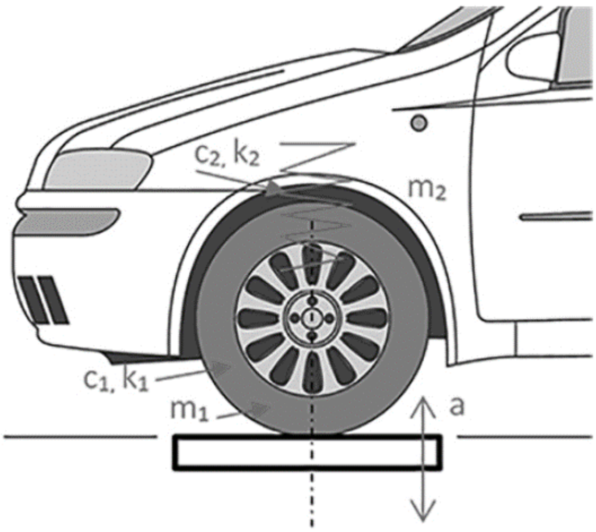

Fig. 1. Diagram of vibrating system

The parameters of the system applied in the study are as follows:

a – vertical acceleration of the plate,
m_1 – wheel mass,
c_1 – damping coefficient of the wheel,
k_1 – stiffness coefficient of the tire,
m_2 – mass of car body,
c_2 –damping coefficient of the damper,
k_2 – stiffness coefficient of the damper.

3. Dynamic model

The work was initiated by the development of a three-dimensional model of the car body. A simplified model of the body was developed in the Autodesk Inventor 2016 program. Once it was developed, the model of the car body was exported to the Nastran-In-Cad 2016 environment.

The simulations of the physical phenomena in the numerical studies applied a three-dimensional model of the vehicle, which was able to respond to the input signal with the force corresponding to the actual road characteristics. However, the model excluded the effect of other external forces acting on the vehicle, such as vibrations of the engine parts. The study also adopted an assumption that that car body is represented by a stiff and uniform shape. The model applied in the simulations included seven degrees of freedom. The structure subjected to the tests was based on the components representing the suspension as a vibrating model with two degrees of freedom and a single kinematic force acting on it, i.e. acceleration given by the vertical vibrations of the plate. In summary, the collected data included the profile of the vertical road roughness characteristic, which was converted into a series of forces acting on the car at four contact points between the wheels and the road surface. Each of the four DSS models applied a different value of the force, which represents the road roughness along which the vehicle rolls.

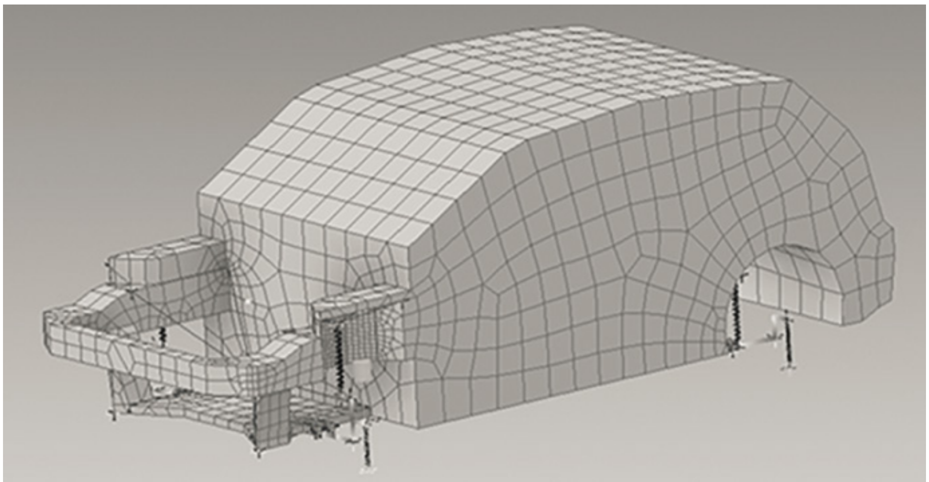

Fig. 2. Discreet model of the car body

The modelling of the front suspension was performed by adoption of several simplifying assumptions involving the elimination of elastic rubber components such as sleeves, bushes and washers from further considerations. The arm was substituted by the element comprising a beam whose kinematics maintained the characteristics of the original. The vehicle's wheel was represented by means of a point mass, which interacts with the vibrating plate through an elastic-damping component. The physical parameter of the tire, i.e. damping (c_1) and stiffness coefficient (k_1) were derived from the literature. The damper and spring were substituted by an elastic element, and adequate values of damping (c_2) and stiffness coefficients (k_2) were taken from the literature.

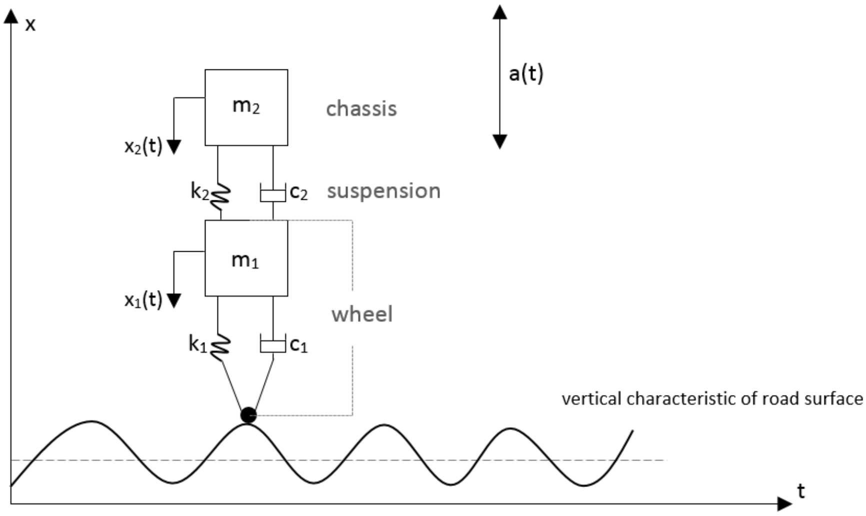

Fig. 3. Vibrating model with two masses accompanying acting kinematic forces

The vibrating plate in contact with the vehicle tire was developed in the form of a point mass (m_3). The vertical force applied by the plate was modelled as the function of acceleration in time. The vehicle body was made from panel elements.

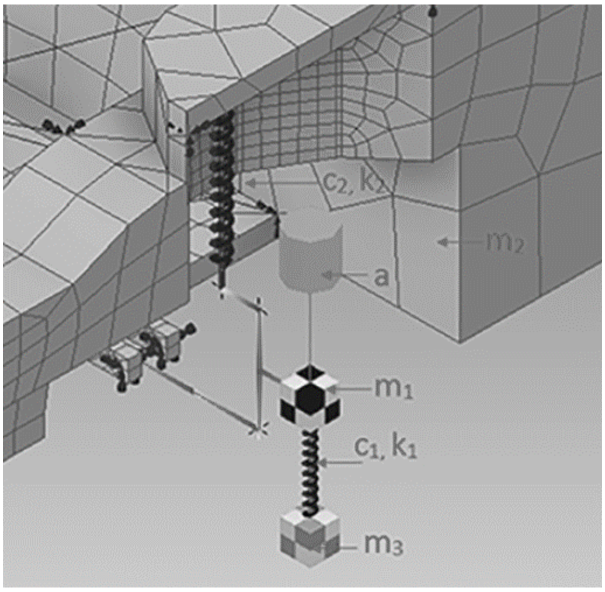

Fig. 4. Diagram of the model of front suspension

Figure 5 contains the curve representing acceleration of the plate. The vibrating plate is capable of representing the characteristics of road roughness, which occur during the vehicle drive. The course of the acceleration of the vibrating mass was selected by the manufacturer of the equipment in such a way that the phenomena occurring in the suspension during the test are similar to the ones that are encountered on a normal road. The software applied in the simulations converts acceleration into the vertical displacement in time.

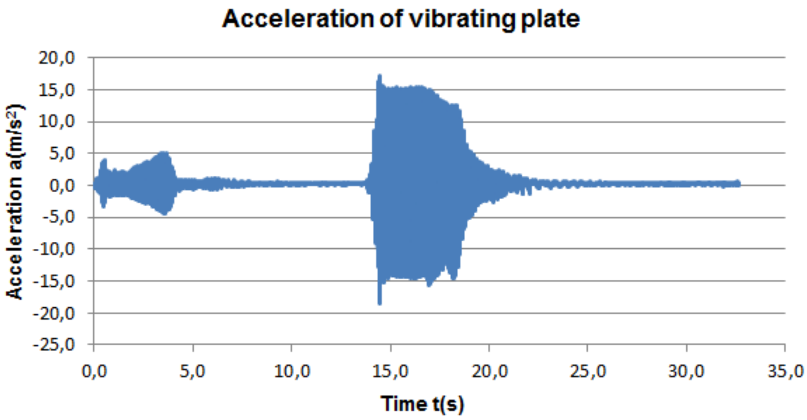

Fig. 5. Vertical plate acceleration

4. Numerical studies

The testing was performed by application of a simulation called Direct Transient Response Analysis. The duration of the simulation was taken to be equal to 25 s. The charts illustrating the course of the vertical acceleration of the modelled components of the suspension were developed on the basis of a test probe, which was applied for the collection of acceleration data in a selected section of the model. In the considered case, the probe was used in similar places to the ones where the acceleration sensor was installed during the tests performed on the test lane.

By comparing the two courses in Fig. 6, we can see that they assume similar values of the maximum amplitude; however, they differ in terms of the course of the function. The time steps applied in the registration of the vertical acceleration are considerably distinct from the steps in the simulation due to the various progress of the simulation in time.

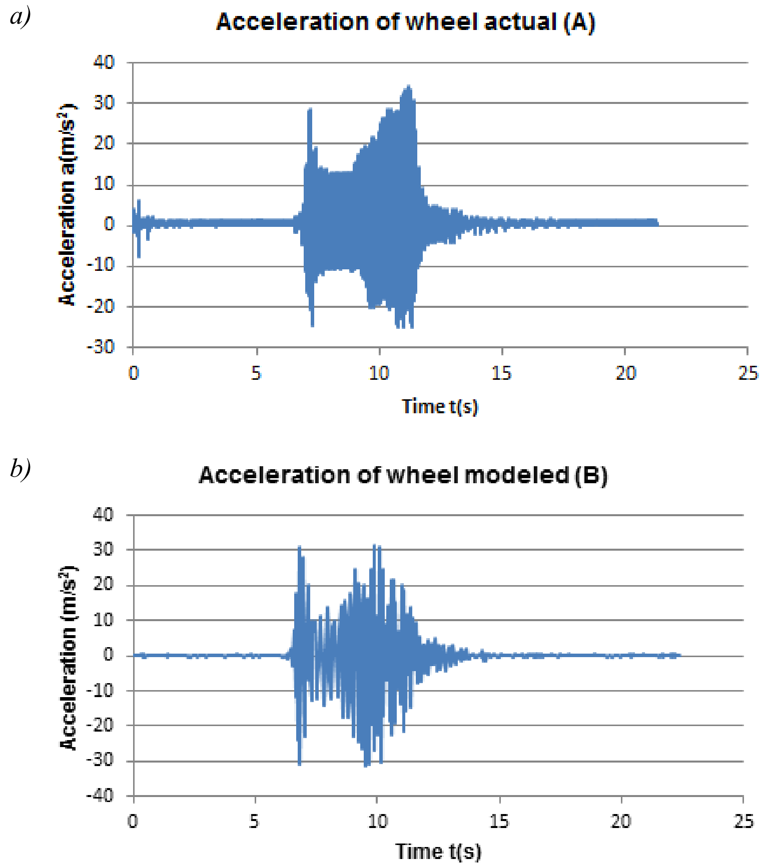

Fig. 6. Comparison of vertical wheel acceleration: a) actual, b) modelled

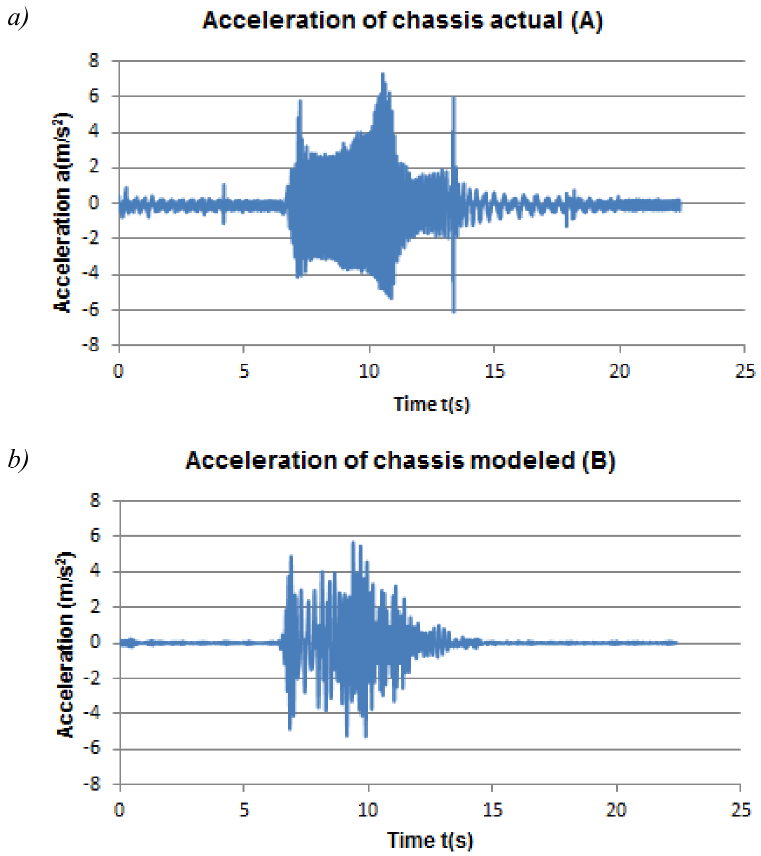

Fig. 7. Comparison of the values of vertical body acceleration: a) actual results, b) modelled results

On the basis of the analysis of these charts, we noted that just as for the case of the vertical acceleration of the wheel, the values for the actual object as well as for the model are similar in terms of the amplitude; yet, their courses are different. This is probably due to the factors resulting from various distribution of the mass between the model and the actual frame of the vehicle. In addition, the modelling excluded the impact of the vibrations damping of the vehicle components. In summary, the results of the numerical simulations are not in complete conformity with the results gained from analytical study. The reason for this is associated with the simplified structure of the analysed phenomenon.

After a comparison of the results gained from the analytical study with the results gained from simulations, we concluded that they could be applied for the initial verification of the designed vehicle body despite the fact that it does not completely represent the actual phenomena in the vehicle. This decision is principally justified by the existence of similar results of the reaction between the components of the body.

5. Determination of the strength of a small electric vehicle

New designs of small electric vehicles continuously appear in the automotive industry nowadays, as they provide sustainable urban transport. The drivetrain architecture of such vehicles differs considerably from the classic combustion engine. This is due to the use of a different source of energy to drive the vehicle. For the case of electric vehicles, the energy used for driving is stored in batteries, which mass is high due to reasons related to the current technology. Hence, during the process of the development of vehicle components, it is crucial to identify an adequate location for installing the battery pack so as not to affect a loss of the projected traction driving characteristics.

For these reasons, the authors have developed a vehicle, which can be adapted to use an electric drive. On this basis, a shape of the body was designed with considerably reduced dimensions mainly as a result of the reduction of the length of the front part of the vehicle where a combustion engine is located in the traditional design. It was assumed that the vehicle should be listed as a class B1 vehicle. The drivetrain is based on electrical motors located in the rear vehicle axle. The structure is based on a design comprising a frame.

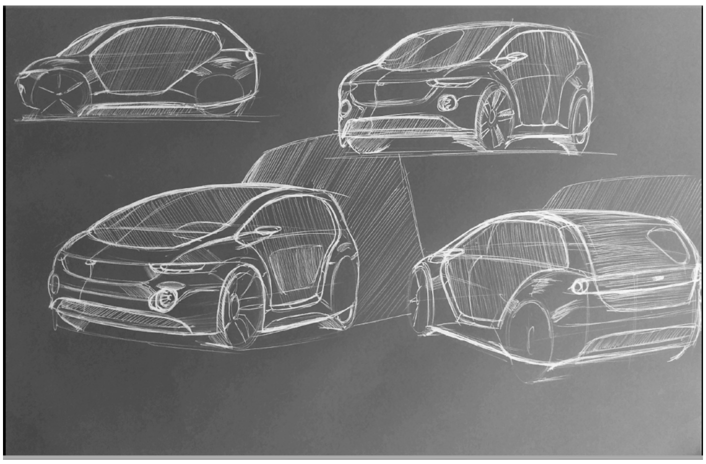

Fig. 8. Prototype of the design of a new electric vehicle

The dynamic simulations applied an original three-dimensional model of the vehicle developed by the authors. This vehicle was made from scratch by application of a new shape of the body and the assemblies. The support structure is based on a frame, onto which the components of the vehicle are installed. The verification of the selection of the profiles was based on the application of quasi-static simulations performed in the MES environment.

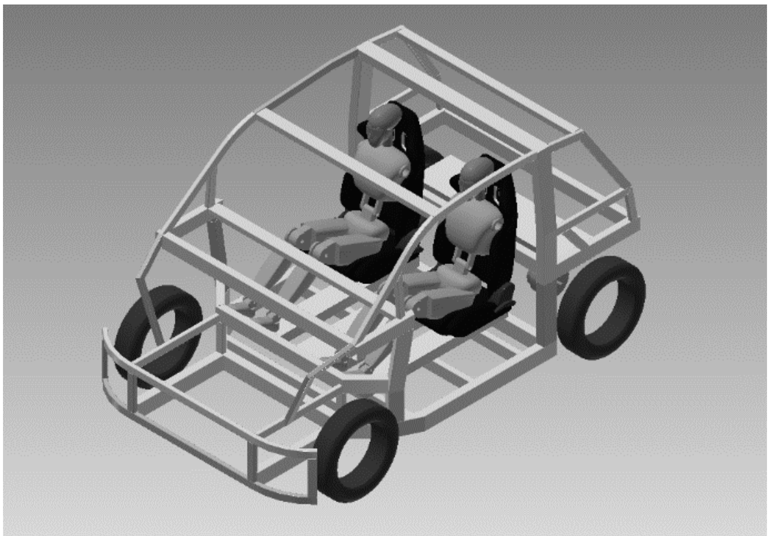

Fig. 9. Prototype of the structural elements of the electric vehicle

The model of the prototype was transferred into the Nastran-In-Cad environment on the basis of the same procedure as the one applied with regard to the model. As a consequence of the application of an adequate design method using frame generator, the model could be successfully converted into a design made of beam elements. The passengers are presented in the form of a point masses secured to the vehicle structure by parts represented by rigid bodies. The suspension was implemented by application of a model used for its verification. The batteries are presented as point masses fixed to the framework by application of ideally stiff elements.

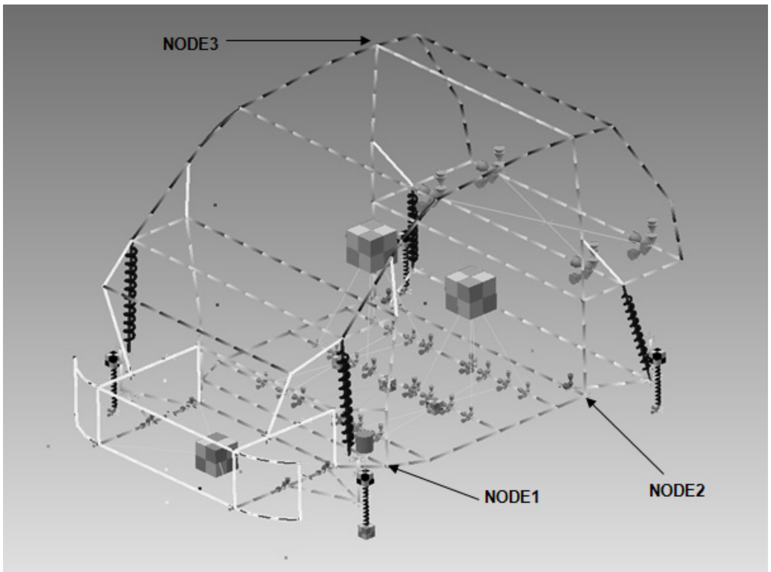

Fig. 10. Vehicle framework presented as a numerical model

The parameters used in the system:

– tire damping c_1 = 150 Ns/m,
– tire stiffness k_1 = 75000 N/m,
– damping coefficient of damper c_2 = 1800 Ns/m,
– stiffness coefficient of damper k_2 = 29000 N/m,
– prototype mass = 681 kg,
– wheel mass = 18 kg,
– vibrating plate mass = 15 kg.

Similar as for the case of the reference model, this simulation involved the force applied to the vibrating plate in contact with the front right wheel of the vehicle. This test provided output data such as: stress, displacement, and deformation. This data could be transferred to any place in the vehicle frame. The results were presented as time curves. The model provided information regarding the response of the frame to the vertical displacement resulting from the application of forces induced by the simulated road characteristics. As a result of such operations, it was possible to derive and correct the details of the structural elements of the frame, in which the admissible stress was exceeded. This simulation served as an optimization tool in the study involving mass distribution and its impact on the strength parameters of the vehicle body.

Figure 11-12 shows response beams of loads by vertical characteristic of road surface. Time courses representing displacements and stresses in selected control nodes in the chassis.

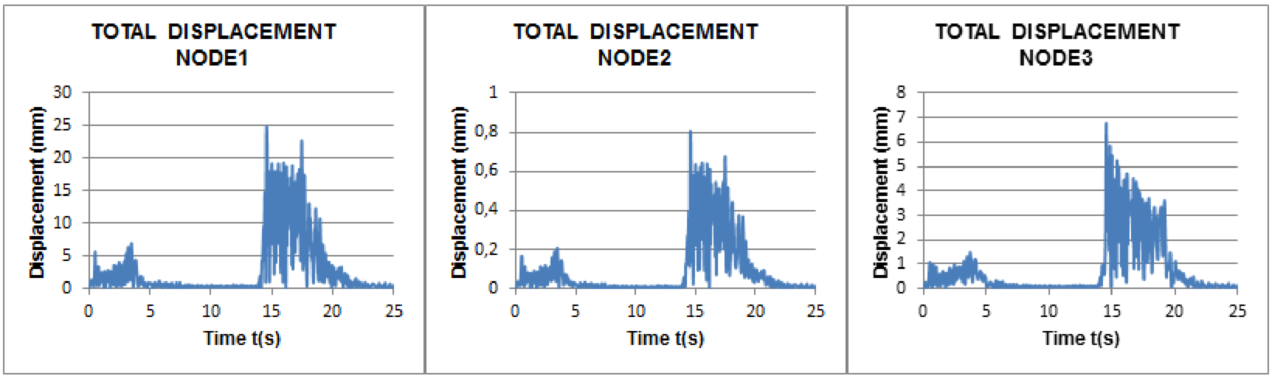

Fig. 11 Time courses representing total displacement in a selected control spot in the body

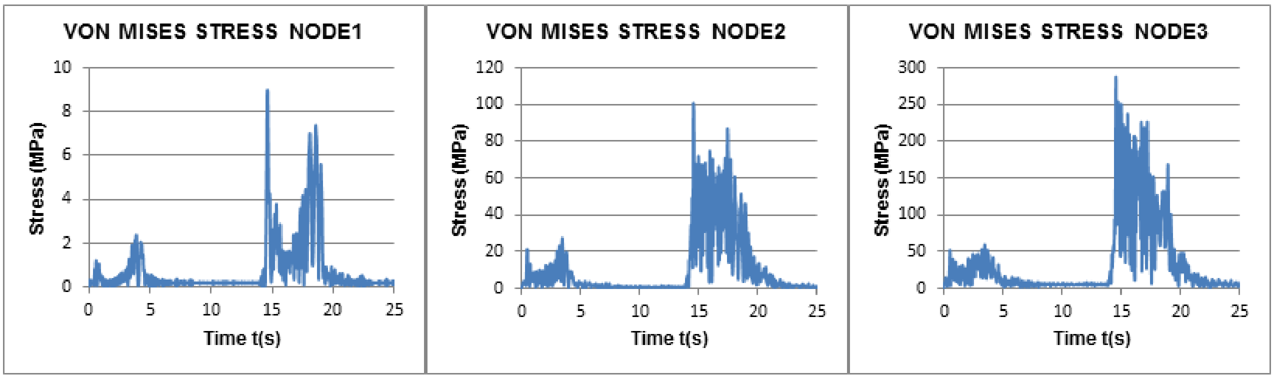

Fig. 12. Time courses representing von Mises stress in a selected control spot in the body

6. Conclusions

The application of analytical method coupled with numerical one offers an effective approach applicable for verification of prototype models. However, we need to bear in mind that the results do not reflect the actual impact of the surrounding environment, as it is relative to a greater number of factors in the given conditions. Nevertheless, virtual prototyping is still a much more effective method of verifying design assumptions than the development of actual models. By application of this method, it is possible quickly to modify the elements of a structure, which is virtually cost-free, which is not possible during the development of real prototypes. These authors intend to extend the existing virtual test bench so as to be able to verify the prototype models by accounting for other variables occurring in an actual vehicle. The environment applied in such verifications will be able to offer a comprehensive simulation of the physical phenomena resulting from the impact of the environment so as to model a wide range of characteristics on a variety of roads.

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