Aspects Concerning Modeling and Simulation of a Car Suspension with Multi-Body Dynamics and Finite Element Analysis Software Packages

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Abstract. In order to overcome the increasing complexity of the new requirements, engineers have developed different problem solving theoretical approaches sustained by the performant computational technology through specialized software. One such example is the Multi Body Systems (MBS) and Finite Element Analysis (FEA) methods which are supported by a multitude of engineering performant software platforms. The current paper focuses on using MBS software to analyze a vehicle suspension and to determine the forces that act on each suspension component. The general approach of this type of simulations requires several steps that ensure a high accuracy of the analysis results. The steps used for the studied subject were: development of a simplified 2 DoF model, development of a full vehicle model, calibration of the vehicle model, suspension simulation and finite elements analysis of the lower control arm. The development of the simplified model was necessary to find the approximate values of several parameters required for the full model. After the simulation performed with the simplified model, the full model was developed and a minimum gap between the simulation and reality was achieved through experimental measurements on a vehicle. The data obtained through data acquisition was used in the calibration of the full vehicle model and the reaction forces determined from the calibrated simulation were used to for a FEA of the lower control arm.

Keywords: car; simulation; multi-body dynamics; MacPherson suspension; multi-link suspension

1 Introduction

The role of the vehicle suspension system is to ensure the road-wheel contact at all time and to set a compromise between the handling and the ride comfort.

Consequently, the vehicle behavior is affected in cornering, crossing obstacle (speed bump, hole, etc.) and accelerating/braking phases by the suspension system settings. This is due to the fact that vehicle behavior depends on how the forces are acting on the wheels or on the ground.

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The suspension system controls the steering system and the ride quality of a vehicle. These functions are the most important regarding the customer satisfaction and vehicle safety. For example, if the vehicle has excessive vertical wheel oscillations, the driver cannot control the steering system on a bumpy road. The bumpy road will transfer the vibrations of the wheels through the suspension system to the passengers.

The suspension system is providing the link between the wheels and the passenger's cabin. One of the important features of the suspension is to position the wheels and tires properly, because the tires should be correctly positioned with respect to the ground to provide a normal life of the tires.

In this paper it is presented a general algorithm to study the car suspension based on performant CAD/CAE packages and compare values with parameters measured on real model.

2 Quarter-Car Model of the Suspension

In order to perform a suspension system analysis, the first step is to create a quarter-car model. This model represents a simplified 2 DoF suspension model that is necessary in the determination of several unknown parameters like the spring and shock absorber parameters. In support of this step, several publications [1–5] are available that present multiple mandatory aspects that have to be taken into consideration when defining the corresponding mathematical model, a transcription in equations of the simplified dynamic model. The mathematical model, developed with the help of the available knowledge present in literature, permits to choose the basic characteristics of the suspension system, like the stiffness and damping coefficient.

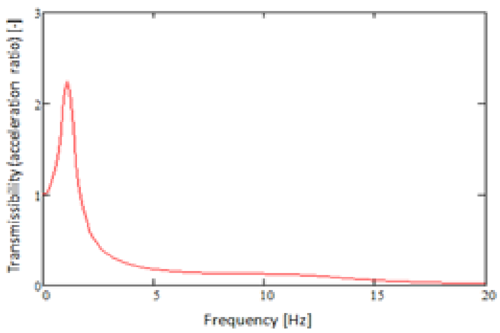

Fig. 1. The acceleration transmissibility function

The input parameters necessary for solving the mathematical model such as the vehicle mass, the natural frequency in absence of damping, the spring deflection and the damping ratio of the shock absorbers were adopted from an existing vehicle and used to solve the model. The output obtained by solving the mathematical model included several parameters and characteristics needed for the full vehicle suspension model, such as spring stiffness, shock absorber damping coefficient and acceleration transmissibility function. The acceleration transmissibility function (Fig. 1) is defined as the ratio of the body response and the excitation generated by the ground irregularities. For normal passenger cars, the peak value is in the range of 1.5…3.

3 Full-Vehicle Suspension Model

The generation of the full-vehicle suspension model requires some prerequisite steps such as the selection of a vehicle class and a vehicle type in order to use an adequate set of data as input in the simulation. For this model a medium class hatchback vehicle was considered for the necessary input data.

For the simulation presented in here, a front MacPherson suspension and a rear multilink suspension with 4 arms were considered for the full-vehicle model. This choice was made due to their popularity among the main automotive constructors and due to a good performance and compatibility with the selected vehicle.

A transverse-mounted engine front-wheel drive car was considered. In order to develop a realistic equivalent model, able to be used in a design process, for the main components of the chassis system there were created simplified CAD models, which were then connected using MBS software platforms, Figure 2. The software platforms used to perform the analytical modeling of the vehicle were LMS Virtual Lab [6] and LMS Driving Dynamics [7].

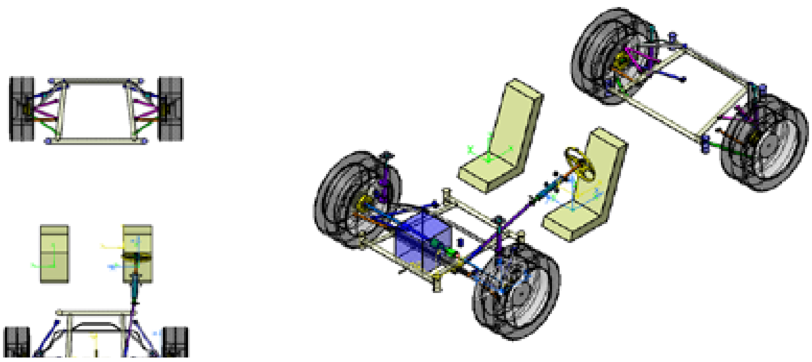

Fig. 2. Complex-model used for the study of car suspension system, designed in LMS Driving Dynamics and LMS Virtual Lab

After the tuning of the vehicle properties on the 2 DoF quarter-car model [8], the main characteristics of the suspension were transferred [9] to the new 3D models of the MacPherson and multilink suspensions adopted for the car's front and rear axles.

Then, several simulations were performed to simulate the suspension system into different situations and to analyze the vehicle behavior. Two scenarios with different test cases were considered for the simulation.

The first case is defined by the scenario in which the vehicle crosses over a speed bump with both wheels while the second scenario considers the vehicle is crossing over the speed bump with only one wheel. A total of six tests were performed, involving different speeds, from which four speed tests were intended for the first scenario and two speed tests for the second scenario.

Any kind of simulation gives as output different parameters that can serve for the results interpretation but only some of them are suitable for such a purpose. For the current case, the acceleration on different components represented the most suitable parameter for engineering evaluation of the suspension behavior. The obtained values of the acceleration were collected from front passenger seats and from the left lower control arm.

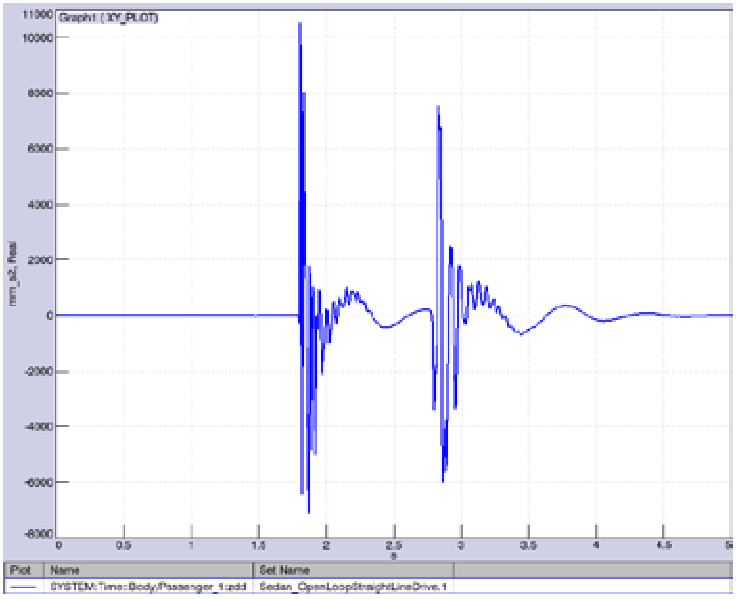

Fig. 3. Computed vertical acceleration at the driver seat when the car is crossing with 20 km/h over a 50 mm height speed-bump

Table 1. Maximum acceleration recorded in the simulation model

Maximum acceleration recorded in the simulation	10 km/h	20 km/h	30 km/h	40 km/h	20 km/h L	20 km/h R
Lower control arm [m/s^2]	20	28	62	130	30	11
Left seat [m/s^2]	5.8	11.9	14	24	12	8
Right seat [m/s^2]	8.3	12.8	26	38	7	10

In the Figure 3 it is represented the time evolution of the driver-seat acceleration obtained from the simulation in the case in which the vehicle crosses the 50 mm bump-stop with a speed of 20 km/h. The acceleration plot reveals two spikes: the first spike corresponds to the acceleration recorded at the driver seat when the front wheels cross over the speed bump, while the second spike corresponds to the moment in which the rear wheel crosses over the speed bump. The acceleration recorded when the front wheels go over the obstacle is higher due to the fact that the place of observation is close to the place of impact. The results from all the simulations are synthetized in the Table 1 and Figure 4.

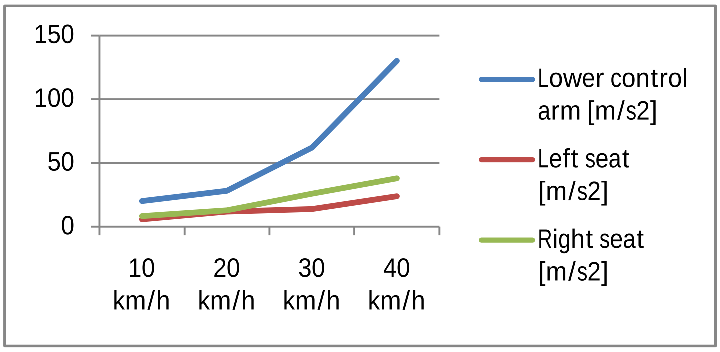

Fig. 4. Maximal accelerations computed at different driving speeds

4 Measurements on the Vehicle

In order to check the simulation model with real values of parameters, some measurements were made on a car crossing over a speed bump in the same condition. For the measurements, an LMS SCADAS data acquisition system was used with PCB PIEZOTRONICS sensors. The sensor locations are presented in Figure 5.

Fig. 5. Sensors location as following: lower control arm, left-seat and right-seat sliding rails

Table 2. Maximal accelerations recorded by measurements on the car

Maximum acceleration recorded in the measurement procedure	10 km/h	20 km/h	30 km/h	40 km/h	20 km/h L	20 km/h R
Lower control arm [m/s^2]	15	26	51	110	35	7.6
Left seat [m/s^2]	4.8	11	13	21	12	5
Right seat [m/s^2]	7.2	12	23	33	6.1	9.2

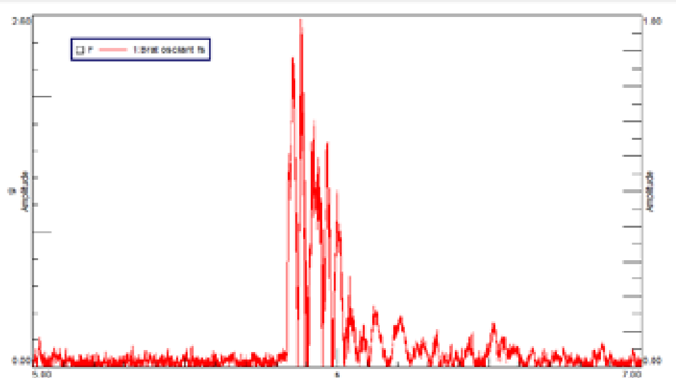

Fig. 6. Acceleration measured on the lower control arm

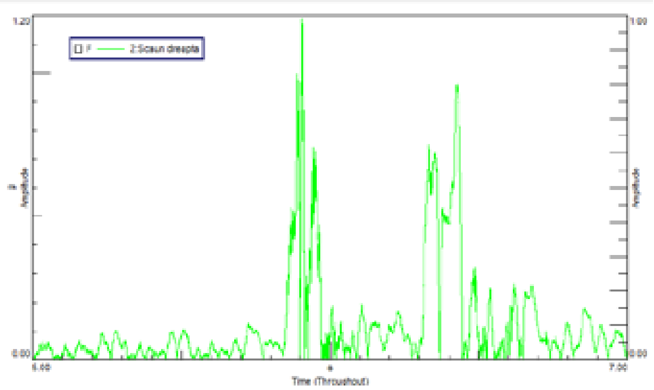

Fig. 7. Acceleration measured on right-seat sliding-rail

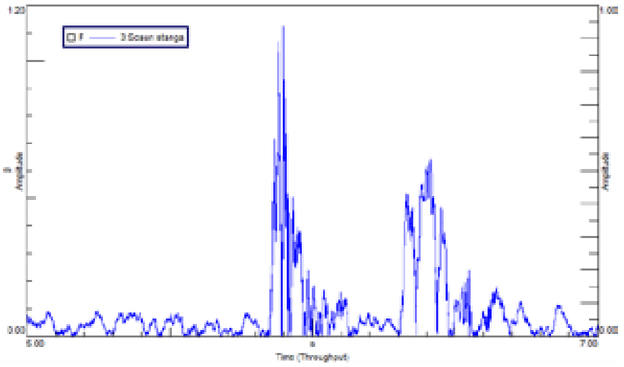

Fig. 8. Acceleration measured on left-seat sliding-rail

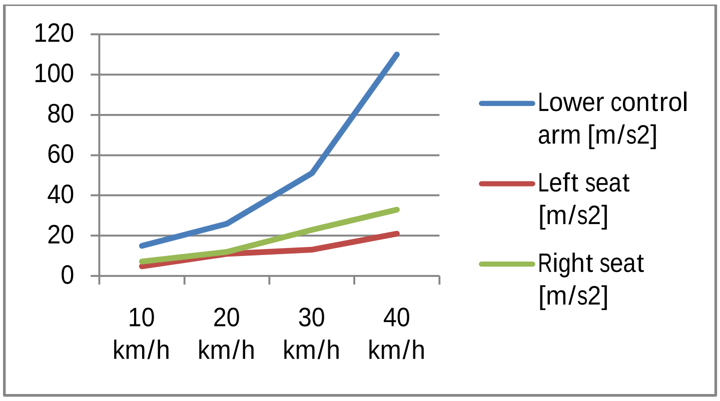

Fig. 9. Maximal accelerations measured at different driving speeds

The results obtained by the measurements made on the car crossing with 20 km/h over a 50 mm speed-bump are presented in Figures 6, 7 and 8 are synthesized in the Table 2 and Figure 9.

5 Comparison of the Measurements Parameters with the Simulation Results

The comparison of the above results, obtained both by simulation and measurement, it may be observed that the results are almost similar, which make the authors confident that the model is well tuned and may be used in other study cases.

Once created the equivalent model of the series vehicle, new testing events could be imagined and studied in order to optimize the vehicle behavior by changing different input parameters to show their influence on output parameters.

These correlations show once again that the simulation based on MBS software is a modern approach the engineers can use to “learn” the suspension modeling and to improve vehicle dynamic behavior.

6 Design Components Based on Finite Element Analysis

Furthermore, the control arm of the MacPherson front suspension was selected as a part of design process example. This component was selected because it is a main part that connect element between the wheel and the car body and it is subjected to extreme stress. The lower control arm design could be improved in order to be more resistant and lighter. Also, its design can be made in order to use with specific bushing connection.

The complex simulation model permitted to calculate the forces that act on the parts and, taking them as input data for the numerical simulation, the control arm was analyzed with the FEA.

The preprocessing of the input data started from geometric modeling of an existent-car's control arm and then modeling the constraints and loading taking in account parameters of bushing connection [10]. The constraints were created to reflect the simulation model previously generated. Also, the forces were extracted from the simulation model, by creating some extreme simulations to calculate the higher forces which are acting on the lower control arm.

After the generation of the FEA model of the part in LMS Virtual Lab, a finite element analysis was made using NX Nastran solver. The post-processed FEA results allow to designer to show the maxim values of displacements and stresses. In Figure 10 it is presented the field of Von Mises stress with maxim value in an area with small radius.

In case of inadequate values of output parameters it is possible to modify some input parameter and, solving the model, to optimize the structure. On the other hand, taking into account the obtained displacements and input forces, it can be found the value of stiffness of the control arm to be used in complex MBS simulation model to increase the accuracy of results.

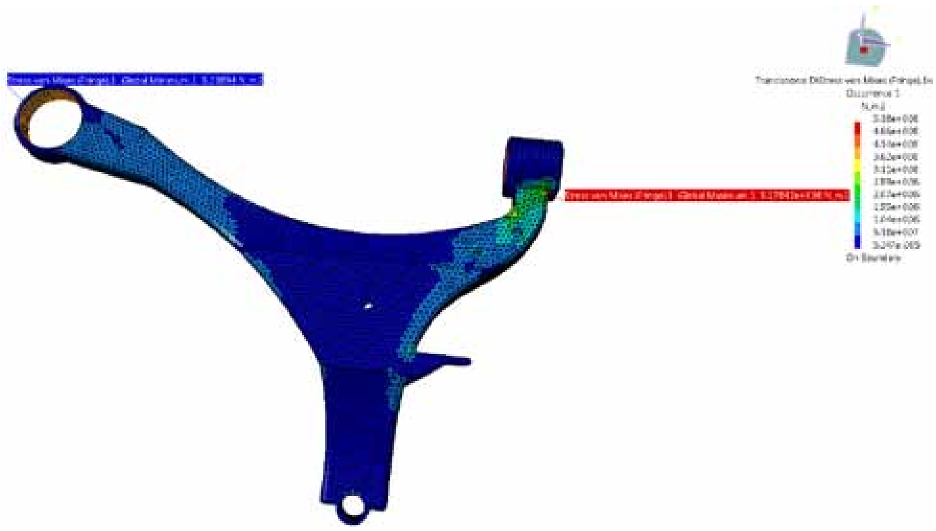

Fig. 10. Results of finite element analysis created on a new design of the control arm

7 Conclusions

As the automotive industry is moving forward very fast, the engineers needs to evaluate various solutions that helps them to analyze the vehicle behavior. One of the most important approaches is to create accurate virtual models with which the engineers could study the vehicle subsystems dynamics and choose the best solutions based on theoretical and testing data.

At this moment there are many performant software packages on the market, that allow simulating full vehicle models. In order to develop design processes, engineers need to create their own solution.

This paper presents a starting point on how a simulation model should be created using CAD/CAE and experimental testing to achieve adequate dependencies between design parameters by comparing the measured parameters on real vehicle with complex simulation model results. The complex simulation MBS model was developed based on preliminary simplified model, which allowed obtaining more accurate values of design parameters.

In order to design the structure of various parts, in the paper is presented as example, FEA modeling and post processing data for a lower arm. Thus, it is possible to optimize the structure of element and to find more accurate values of stiffness to be taken in account MBS models.

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