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VIBRATION BEHAVIOR OF THE TUBULAR CHASSIS FOR A CAR USED IN FORMULA STUDENT RACE

Calin ITU, Maria Luminita SCUTARU, Sorin VLASE

Abstract: *The chassis represents, along with the engine and transmission, one of the vital components for a car. This is the reason why the subject is intensively studied in specialized literature and numerous solutions are proposed. In this paper, we deal with the particular case of a racing car, which imposes additional requirements regarding the requests that appear in the structure and safety in case of an accident. The method used in the work was the finite element method, which proved to be a useful, stable method of modeling and solving problems, verified by practice. The modeling and discretization was done using the well-known classical procedures The eigenfrequencies and eigenmodes of vibration of chassis used in Formula Student was obtained. The research used the experience of some pilots on such cars, to identify which are the sensitive parts of the assembly. The obtained results were communicated to the design team and thus the solution of a racing car was reached which was successfully used in student car competitions..*

Key words: *racing car; eigenvalues; eigenmodes; Formula Student; chassis; vibration; FEM*

1. INTRODUCTION

The chassis of a vehicle has many functions, it represents, along with the engine and transmission, one of the important parts of a vehicle. The construction of a chassis must ensure the unity of the entire assembly, take over the effect of accelerations (when accelerating and braking), the effect of any unwanted impact and offer advantages related to vehicle stability. As a consequence, the chassis is a part of great interest for the car builder, which is why there are numerous studies regarding the role and problems involved in the design and manufacture of this element. There are more types of chassis used in automotive engineering, for the race car is common the tubular chassis. An advantage of this type of chassis is its three-dimensionality. This constructive solution allows a significant increase in the torsional rigidity of the vehicle. The solution is mainly used in racing cars as it can ensure a high level of safety if an accident occurs. In this case, the chassis supports the body as well as other parts of the car. The construction achieved in this case is much stronger and more stable. This also comes with disadvantages, the requirements imposed on the production process and, implicitly, the costs become significantly higher. This type of chassis will be used in the application studied in our paper.

For the analysis, design and manufacture of vehicle chassis, numerous studies were carried out and useful results for the industry were obtained. In what follows, some of these studies are reviewed.

Optimizing the solution, in order to achieve the lowest possible weight of the chassis, within the imposed resistance constraints, represents an important desire of the designers of such structures. Thus in [1] a new optimization method is described. The constraints imposed concern the condition of simulating various situations such as J-turns, lane changes, roads of different qualities and in different conditions of humidity and temperature. The method is validated by creating a chassis under certain conditions imposed on the suspension of a real car. The dynamic characteristics of the chassis body represent the basic parameters for designers. An experimental modal analysis (EMA) method is presented in [2]. In the work, the objectives are to determine the natural

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frequency, the damping factor and the eigenmodes of vibration. The obtained results allowed useful interpretations and comparisons for the designers. A solution, monitoring the deformations of the chassis during the operation of the vehicle, is presented in [3]. Fiber Bragg Gratings sensors are used for the proposed solution. The problem solved in the study is to be able to transfer the deformation entirely to the optical sensor, without losing the signal. The results confirm the possibility of mass production of detection foils. Different methods of study, design and optimization are presented in [4,5]. The use of virtual models has become the study method in this field as well. In [6] a virtual prototype was made to achieve efficient handling of a high performance vehicle. The chassis characteristics were optimized to achieve the tasks imposed by the design theme. Virtual models allow the elimination of testing processes that were previously done on the vehicle prototype. For the case studied, more than 500,000 USD are saved in the design and testing process. Reducing the weight of a chassis is a major problem in the automotive industry. In this way, the dynamic performances are improved, but at the same time, the fuel consumption decreases under the same operating conditions, and therefore the carbon footprint also decreases. To achieve this, new and composite materials are used. A description of these weight loss methods is presented in [7-9]. In [10] a chassis designed for an electric vehicle is presented.

The Finite Element Method (FEM) proves, also in this case, to be a powerful method for analyzing the stresses that appear in the body of the chassis and the vibrations that may appear in the service. Thus, the project for a car used in Formula Student was created using this method [11]. The geometric model of the chassis was made based on the previous experience of the design team using Solidwork, after which it was analyzed with the ANSYS software. The loads that the chassis body supports in the following stress situations were studied: bending, vertical and lateral, lateral torsion and horizontal lozenging. The results were used to obtain the optimal version for this racing car. FEM was also used to obtain a lighter version for a racing car [12] since the weight of the vehicle participating in such competitions must be as low as possible. Thus, a lightweight carbon fiber reinforced polymer (CFRP) monocoque chassis structure is proposed. It respects the structural, safety, ergonomic and aesthetic requirements and is at the same time very light. An original methodology for optimizing the structure of racing cars is proposed in [13]. The methodology is applied for the design and fabrication of a tubular chassis. The FEM is applied to obtain the optimal range and the results are then verified experimentally through laboratory tests. In this way, a chassis with increased bending and torsional rigidity was obtained, but with a reduced weight. In the case of the studied application, the stiffness was three times the weight, increasing by only 5%. Similar studies are presented in [14,15] where solutions are offered for the design of a car with reduced weight. The study of vibrations of the frame structures is made in [16].

Racing cars are subjected to high loads, which is why they have been studied in a particular way, as there is a rich literature in the field. For racing cars the main type of chassis used is the space frame chassis. Making such a type of chassis involves many problems. For the driver, the main problem is the frontal and side impact. A CAD model built using SolidWorks 2016 is presented in [17]. The paper formulates recommendations regarding the requirements of the chassis. The objective of the study was to reduce the maximum tension and deformation through a judicious design of the chassis structure. A similar analysis is done in [18] for the numerical analysis on the chassis of the space frame of a Formula Student car. The aim of the study is to stiffen the chassis structure. CATIA and SolidWorks were used for modeling and calculations. To verify the results, frontal impact, torsional and side impact tests were performed. Another application for a Formula Student racing car is presented in [19]. Useful indications and recommendations regarding the design of such chassis are made in [20-22]. O solution for a chassis construction of a flying car is presented in [23]. An interesting method of approaching the problem is realized in [24]. Methods to solve the problems related to design of a cassis are presented in [25-27] and different non-conventional materials that can be used in design are studied in [28-32].

The study and optimization of a structure for the construction of a chassis represents a problem with many objectives to be fulfilled and, as we have seen, many researchers have dealt with this subject. In the present work, we are dealing with the vibration analysis of a chassis for a racing car used in Formula Student. The rigidity of the whole assembly is increased to prevent it from splitting, under the action of the forces that appear during the race of the chassis frame, which leads to an inappropriate behavior of the car.

This behavior was observed by car drivers previously, on a designed and executed version of the chassis.

2. MODELS AND METHODS

The tubular chassis of a racing car for the Formula Student competition is made up of tubular bars that form a structure with multiple missions. Figure 1 shows the studied racing car and highlights the structure of the used chassis [33]. It must allow the placement of the engine and the other components of the car and at the same time it must ensure the necessary resistance during the race and low deformability. There are also requirements related to safety in the event of an accident, but that is not the subject of the work.

The experience gained over the years determined the shape that this structure has, of a tubular chassis. At the moment, the designers intervene only in the topology of the structure and in the materials from which it is made. They have little leeway in changing the established structure. In order to achieve the optimal shape, detailed studies and experimental checks are necessary.

The current version and chassis manufacturing technique are the result of several decades of research and development, obtained after several hundred models of racing cars.

In the present work, the study is oriented towards the vibration behavior of the chassis. The research was determined by the signals of the pilots regarding the presence of some unwanted vibrations, especially when entering curves, which required the stiffening of the chassis.

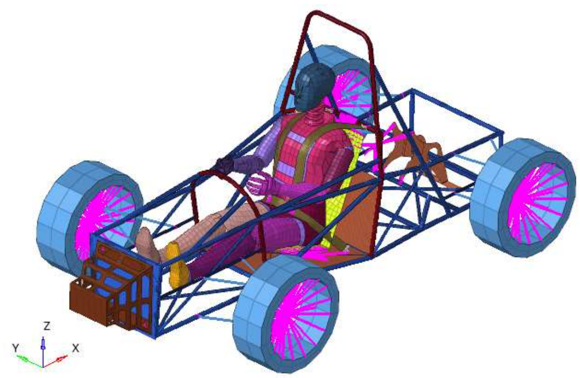

Fig. 1. The race car for Formula Student [33]

The body of the chassis, made up of tubular bars, is shown in Figure 2. The material used to manufacture the bars is steel, the most common material used because it has many advantages. Low cost price is one of them. Then it can be easily processed and welded and the technologies of processing, handling and mounting are extremely well known.

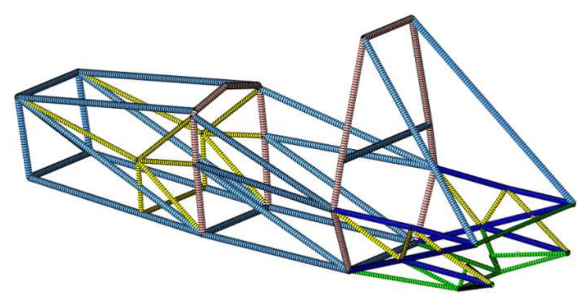

Fig. 2. The tubular chassis

FEM and Altair Hyperworks package are used for modeling and calculations. The calculus is performed for two types of structure, the initial version and the improved version. The constructive modification performed to improve the behavior of the chassis is made to the topology of the rear part of the structure.

The initial version of the structure is detailed in Figure 3. FEM provides a realistic simulation environment. The performances of the proposed structure solution can thus be easily illustrated.

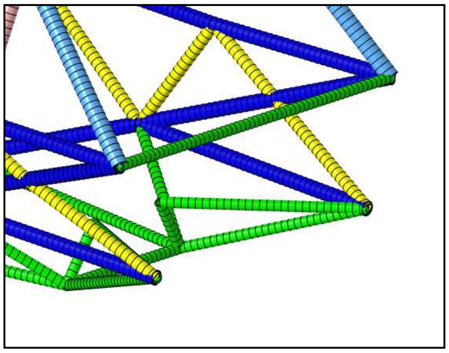

Fig.3. The back side of the structure –detail

To increase the torsional stiffness of the structure, additional bars were added. The proposed solution is presented in the following section.

3.RESULTS

The natural frequencies obtained after the analysis with finite elements are presented in Table 1. The six natural pulsations equal to zero, corresponding to the rigid ody motion, were not presented in the tables.

The structure's eigenmodes of vibration are shown in Figures 4-9.

Table 1.

The eigenfrequency [Hz] - first version

Mode	Frequency [Hz]
1	41.886
2	45.631
3	66.938
4	73.266
5	90.938
6	102.572
7	103.372
8	118.473
9	125.638
10	129.201
11	130.292
12	133.394
13	139.122
14	149.323

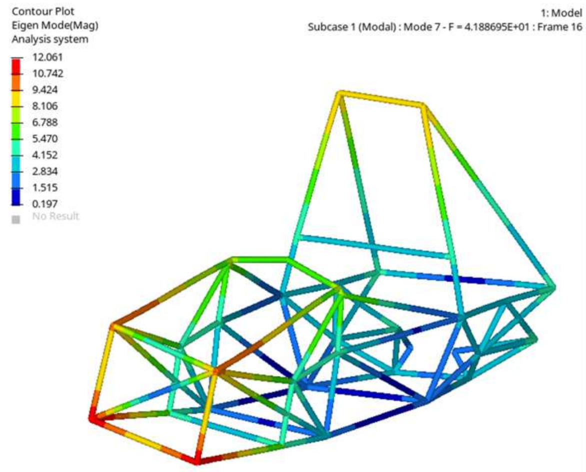

Fig. 4. The 1st mode of vibration

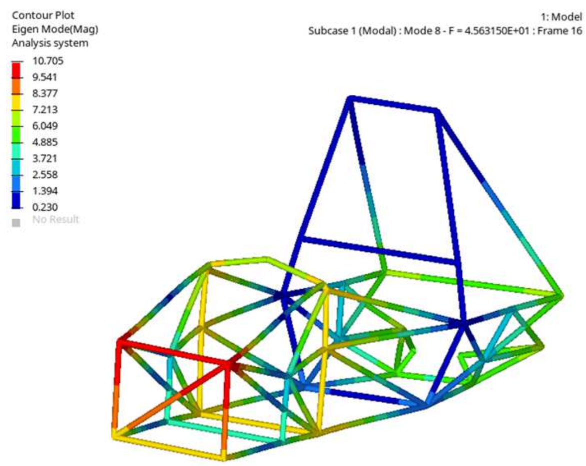

Fig. 5. The 2nd mode of vibration

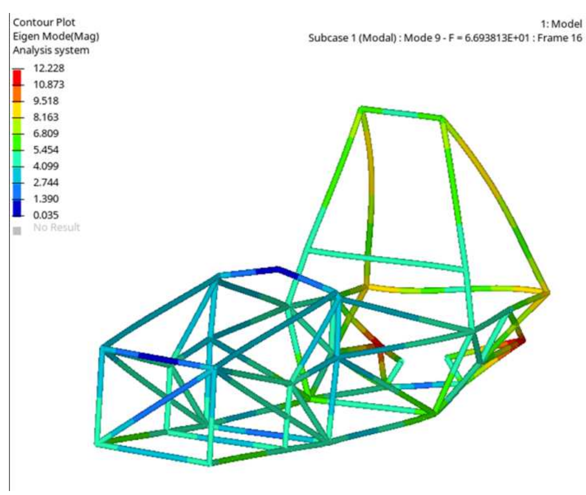

Fig. 6. The 3rd mode of vibration

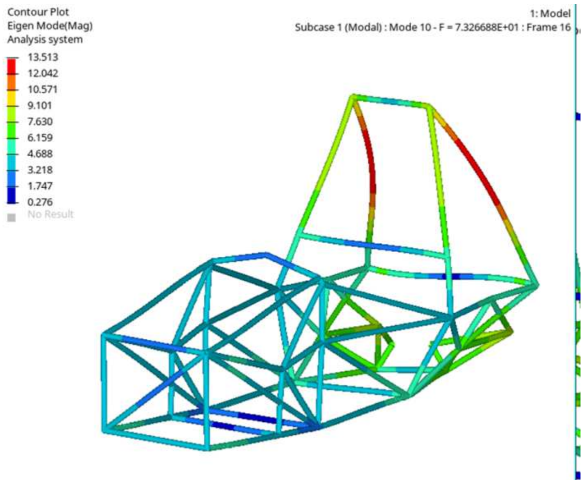

Fig. 7. The 4th mode of vibration

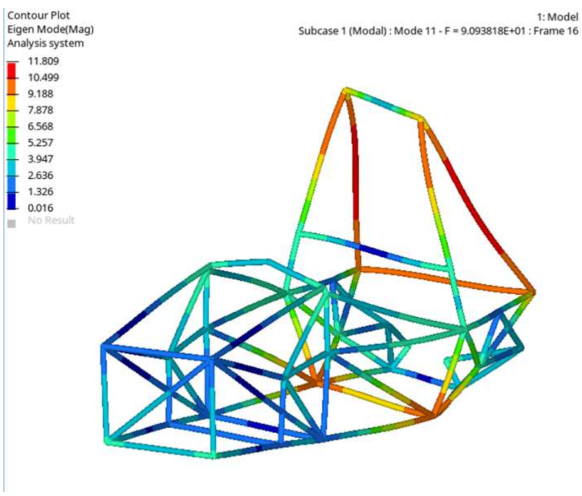

Fig. 8. The 5th mode of vibration

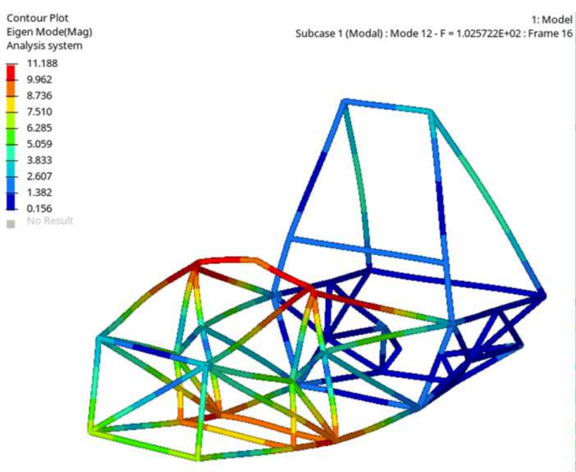

Fig. 9. The 6th mode of vibration

3. IMPROVED STRUCTURE

The observations of the pilots as well as a static calculation of the structure revealed the need to stiffen the chassis. For this purpose, additional bars were added to the back of the chassis (see Figs. 10-11). The topology of the structure was changed, as it is the easiest operation to perform. Changing the dimensions of the bars or the materials would require important design changes, which would require a large consumption of resources.

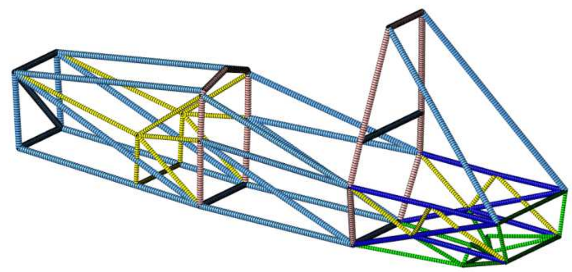

Fig. 10. The improved version of the tubular chassis

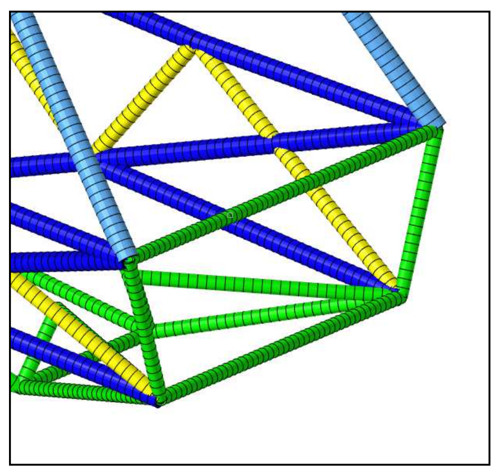

Fig.11. The improved back side of the structure

Eigenfrequencies were determined for the structure strengthened in this way. The results are presented in Table 2. In general, an increase in eigenfrequencies is observed, which is due to the stiffening of the structure. The tubular chassis proved to be the most frequently used in Formula Student. This is due to its simplicity and the ease of making changes to the structure, something also found in the current study. A disadvantage would be the greater weight, being made up of steel elements welded together. Fig.12 shows a comparison between the eigenfrequencies in the two cases.

Table 2.
The eigenfrequency [Hz] - second version

Mode	Frequency [Hz]
1	41.829
2	46.580
3	67.989
4	75.294
5	94.087
6	104.684
7	106.309
8	129.166
9	133.895
10	136.226
11	137.284
12	148.899
13	152.741
14	159.932

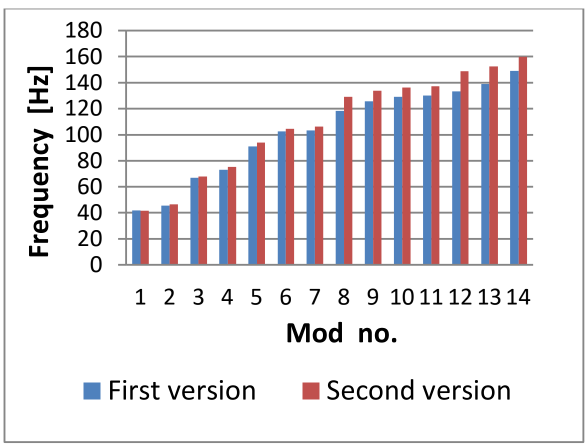

Fig.12. The comparison between the two version studied

Today, in the racing car industry, the main attention is paid to the design stage, in which, respecting the existing norms and regulations, we seek to obtain a structure that ensures optimal performance. The chassis is the central element of the vehicle, similar to the skeleton of animals. As a result, determining the stiffness and vibration behavior of the tubular chassis is a very important element in the design.

4.CONCLUSIONS

The objective of the work was to determine the eigenfrequencies and eigenmodes of a tubular structure that meets the minimum conditions imposed in the Formula Student competition. Such a structure must have a low weight and a high torsional rigidity. Other constructive limitations imposed by the location of the engine and other equipment on the chassis lead to a chassis shape that must be analyzed carefully. The drivers claim inappropriate behavior in curves and unwanted vibrations related to the opening (deformation) of the chassis. For this purpose, within the work, the problem of the structure's own vibrations was studied and a stiffening of the structure was proposed by adding additional bars. It was found that this constructive modification led to the stiffening of the entire chassis and the increase of the values of its eigenfrequencies. The drivers also reported that the opening of the chassis and the occurrence of unwanted vibrations were reduced, making driving the vehicle easier. FEM was used for the modeling and analysis of the structure. In the design stage of a Formula Student chassis, the ergonomics and safety of the driver, the constraints imposed by the positioning of the engine, the attachment of the suspension and other mechanical components are the factors that determine the constructive form and the dimensioning of the structure. The mesh with beam-type elements used in the finite element analysis represents the most convenient study solution due to its simplicity and the results that can be obtained very easily.

Obviously, the study can be further developed, looking for other stiffening options or using different materials. At the current stage, the variant with tubular bars is the simplest and easiest to apply, which is why the study focused on this type of structure.

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Comportarea la vibratii a sasiului tubular pentru un automobile utilizat in competitiile Formula Student

Rezumat. *Șasiul reprezintă, alături de motor și transmisie, una dintre componentele vitale pentru o mașină. Acesta este motivul pentru care subiectul este studiat intens în literatura de specialitate și sunt propuse numeroase soluții. În această lucrare ne ocupăm de cazul particular al unei mașini de curse, care impune cerințe suplimentare cu privire la solicitările care apar în structură și siguranța în caz de accident.Metoda folosită în lucrare a fost metoda elementelor finite, care s-a dovedit a fi o metodă utilă, stabilă de modelare și rezolvare a problemelor, verificată in practică. Modelarea si discretizarea s-au realizat folosind procedeele clasice binecunoscute. S-a obținut frecventele propri simodurile propri de miscre ale structurii sasiului utilizat în Formula Student. S-a propus o solutie impla de rigidizare a structurii. Cercetarea a folosit experiența unor piloți pe astfel de mașini, pentru a identifica care sunt părțile sensibile ale ansamblului. Rezultatele obținute au fost comunicate echipei de proiectare și astfel s-a ajuns la soluția unei mașini de curse care a fost folosită cu succes în competițiile auto studențești.*

Calin ITU, Prof.dr.hab.ing., TRANSILVANIA University of Brasov, Department of Mechanical Engineering, calinitu@unitbv.ro

Maria Luminita SCUTARU, Prof.dr.hab.ing., TRANSILVANIA University of Brasov, Department of Mechanical Engineering, lscutaru@unitbv.ro

Sorin VLASE, Prof.dr.hab.ing.math., TRANSILVANIA University of Brasov, Department of Mechanical Engineering, and Romanian Academy, Institute of Solid Mechanics, C. Mille 15, Bucharest, svlase@unibv.ro