Vehicle modelling using an integrated FEM–multibody approach

G. Manzilli (†) – E. Pisino (☆)

Abstract

In these late years automotive industry has continuously increased its efforts in comfort analysis. Using an integrated multibody – FEM approach a new methodology has been developed, allowing the calculation of mechanical vibrations in the complete range of human sensitivity. Simulations involving complete vehicle models taking into account the influence of subsystems dynamic flexibilities have lead to results very close to the experimental tests. The AMFP (ADAMS Modal Flexibility Pre–processor) program, originally designed by MDI to meet FIAT Research Center requests, allows an interactive handling of FEM bodies, guaranteeing a fast generation of ADAMS flexible subsytems. High frequency response of suspension and seat attachment points of a car with flexible chassis (retrieved from MSC/NASTRAN eigen analysis) performing an obstacle passing maneuver is described.

Introduction

Vehicle comfort is defined as the containment of the combined disturbances coming from noise and vibrations. In the automotive industry comfort improvements studies regard the frequency range from 0 to 200 Hz. Obviously is increasingly important to predict comfort levels from the first development stages of a new car.

Different approaches can be chosen to model the dynamic behavior of a vehicle, depending on the frequency range to be analyzed. Multibody models (with rigid car bodies) are normally used to predict vibrations in the range of human sensitivity (0–100 Hz), while FEM (Finite Element Modelling) is adopted for acoustical studies around 20–200 Hz.

The integration of these two approaches allows the calculation of the mechanical vibrations in the complete range of human sensitivity, taking into account the influence of the dynamic flexibilities of vehicle chassis and subframes.

A methodology and a software interface were developed so as to integrate the multibody and FEM capabilities, allowing the study of flexible bodies within a multibody code through the use of modal data.

With this methodology a full vehicle ADAMS model with deformable chassis has been created and analyzed (fig. 1). The deformable body was defined using modal data coming from MSC/NASTRAN, and allowed a representation of the dynamic behavior of the vehicle in the frequency range up to 200 Hz.

(†) *Engineer – Mechanical Dynamics Italy s.r.l.* (☆) *Engineer – FIAT Research Center*

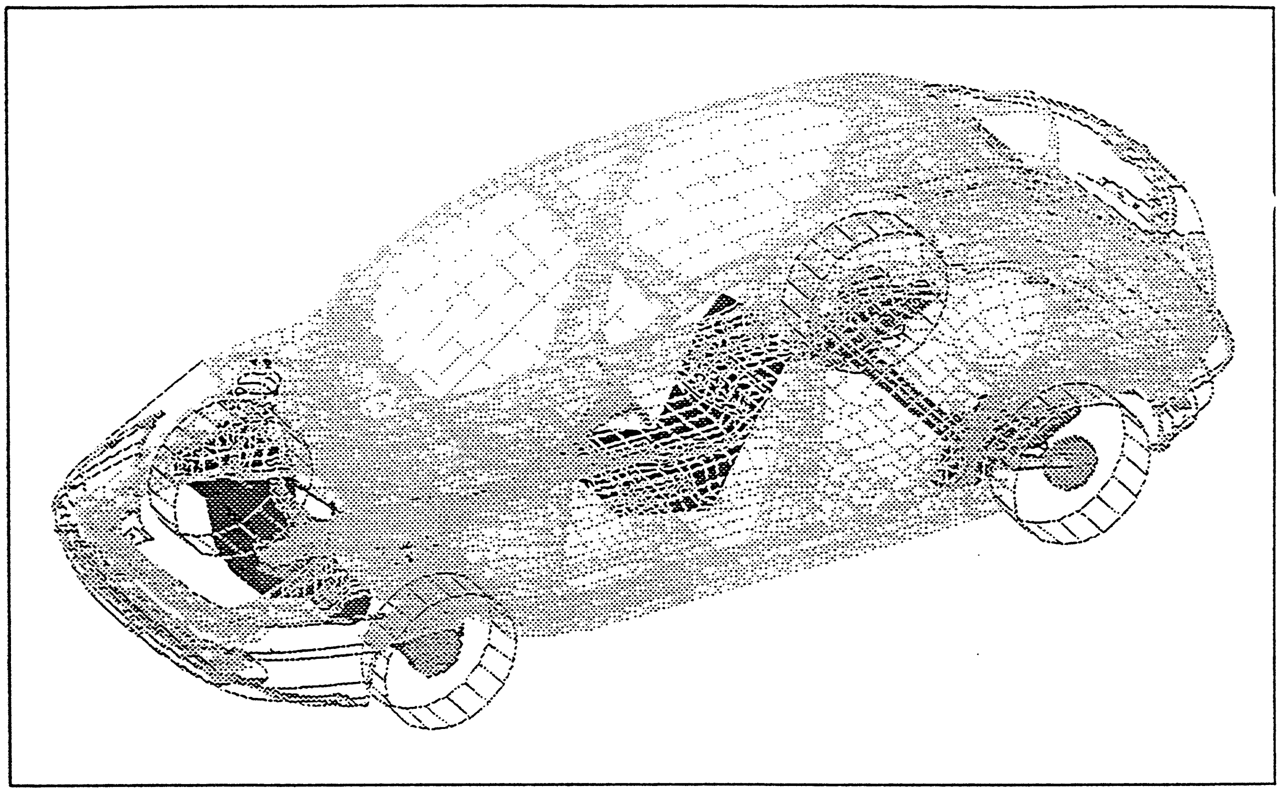

Figure 1 : flexible chassis car model

Multibody/FEM integration

Traditional multibody models have been used for many years to study the vibrational properties in automotive environment. These models are composed of rigid bodies connected by ideal links and coupled by force elements. They accurately represent the system dynamics for frequency up to about 30 Hz. The necessity of obtaining vibrational results up to (at least) 100 Hz requires the introduction of flexible car bodies instead of the rigid ones.

Experimental data demonstrate the presence of natural frequencies determined by the car chassis and sub–systems at frequencies up to 200 Hz. Modelling of this behavior is a difficult problem since it involves both small structural deflections (normally studied with FEA codes) and large rotations (normally studied with multibody codes). The answer to this problem is the insertion of flexible body models in multibody vehicle simulations.

Various approaches have been proposed to include flexible bodies within full non–linear multibody models [1] [2]. Some use modal analysis techniques, but employ constraint modes or are limited to the linear approximation, while others are based on discrete flexibility.

The new method developed in CRF (FIAT Research Center) include deformable structures within a multibody code by using modal data generated by FEA analysis and a mixed "rigid + modal" approach [3]. The flexible body is defined as an assembly of a rigid part (the body reference), a set of equations describing the structural dynamics using the modal approach, and the matrices transforming back and forth the forces and the displacements between the spatial and modal domains (fig. 2).

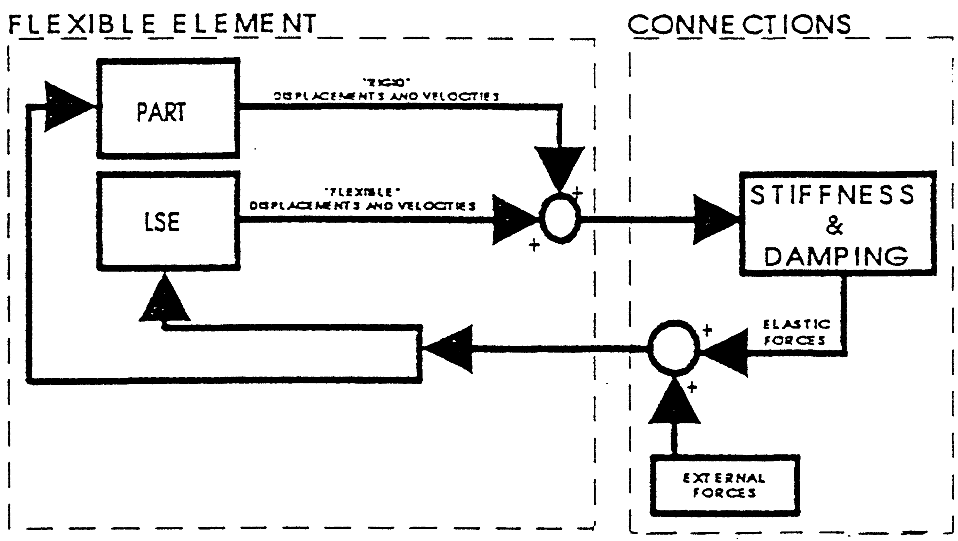

Figure 2 : ADAMS model of a flexible structure

This approach has been implemented with ADAMS using modal data generated by MSC/NASTRAN [4]. A special interface, AMFP (ADAMS Modal Flexibility Pre–processor) was developed at FIAT Research Center together with MDI (Mechanical Dynamics Inc.) to translate the eigendata calculated by MSC/NASTRAN directly into the ADAMS matrices. AMFP permits the user to interactively select or modify the characteristics of the model by manipulating a graphical representation of the flexible body.

Using AMFP

AMFP (ADAMS Modal Flexibility Pre–processor) is an auxiliary package specially designed to meet modal flexibility approach in ADAMS. It mainly consists of a graphical interface allowing the user to interactively manipulate a FEA structures, adding connections, forces and output requests on it (fig. 3). The final output of the program are an ADAMS dataset fragment and a matrix file, enabling a modal description of the body using LSE (Linear State Equation). AMFP interface is easy and immediate to use. Structures can be dynamically rotated, translated and zoomed using only the mouse. Mode shapes animation and other graphical utilities help in better understanding the FEA models before merging them in a multibody environment. Special "pop–up" panels for the body input/output description are provided, allowing rigid–flexible elements interfacing. Due to the complexity of the approach such kind of user–friendly interface is absolutely necessary. Doing the work by hand would be extremely tedious and error prone.

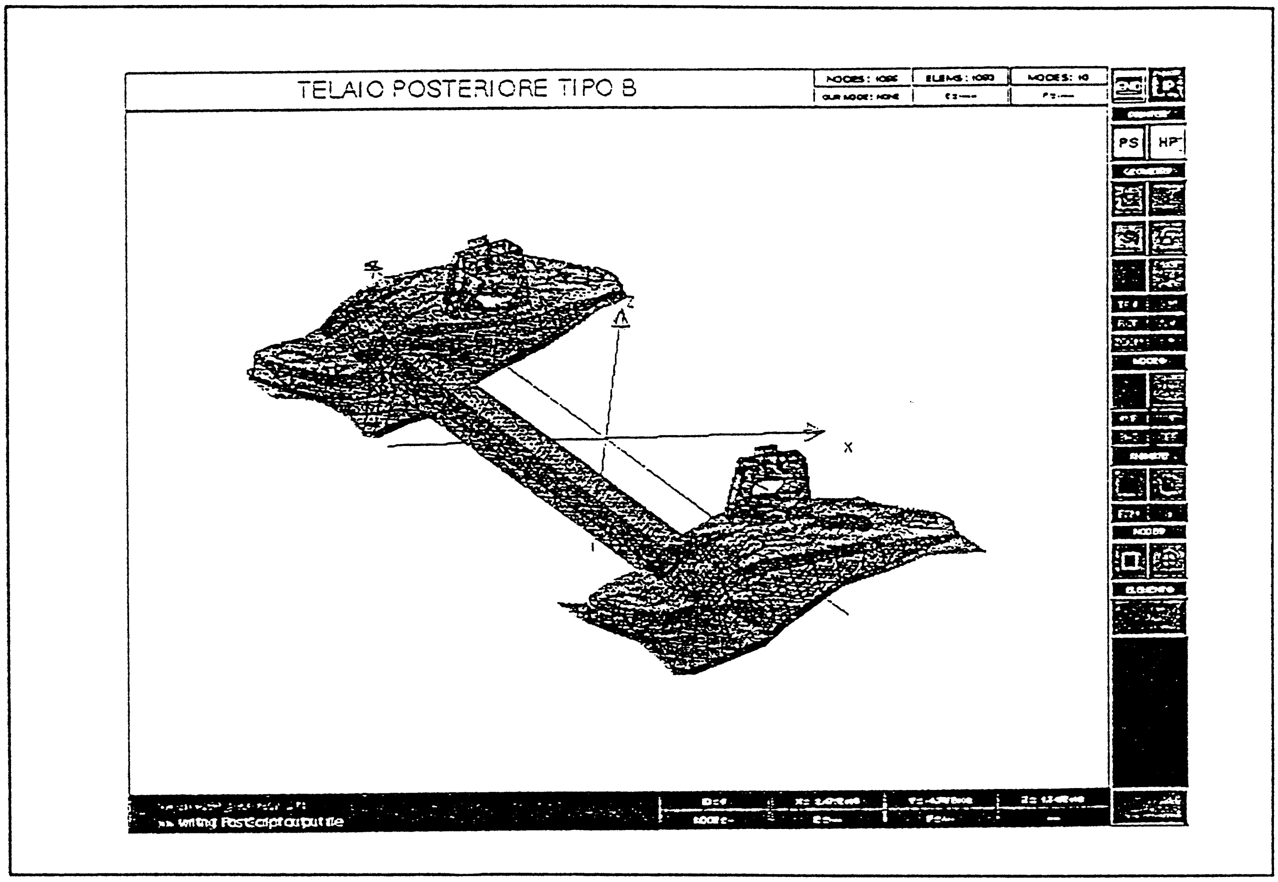

Figure 3 : AMFP program interface

Vehicle modelling

The analyzed vehicle is a medium car with front McPherson suspensions and a subframe holding all rear suspension components. The front suspension presents three connection points with the chassis, two for the leg and one at the dome. Rear subframe is connected in four points, while engine is held by three mounts. All the attachments are flexible and highly non–linear. The tested maneuver is 100x25 rectangular obstacle passing at the speed of 50 km/h.

A software interface (I.RI.S. – Integrated RIde Simulator) has ben developed by CRF in order to automatically and safely create ADAMS multibody vehicle models, including subsystems such as wheel and engine suspensions, power train, steering system, tires, seats and so on. These models contain several types of non linearities that heavily affect the vehicle response. Examples include the non linear kinematics of wheel suspensions and non linear component models such as those used to represent the shock absorbers, power steering, tires, bushings and bumpers. The various non–linear elements of the vehicle model are necessary to obtain simulation results well correlate, in the frequency range from 0 to 30 Hz, with experimental tests over rough roads (fig. 4).

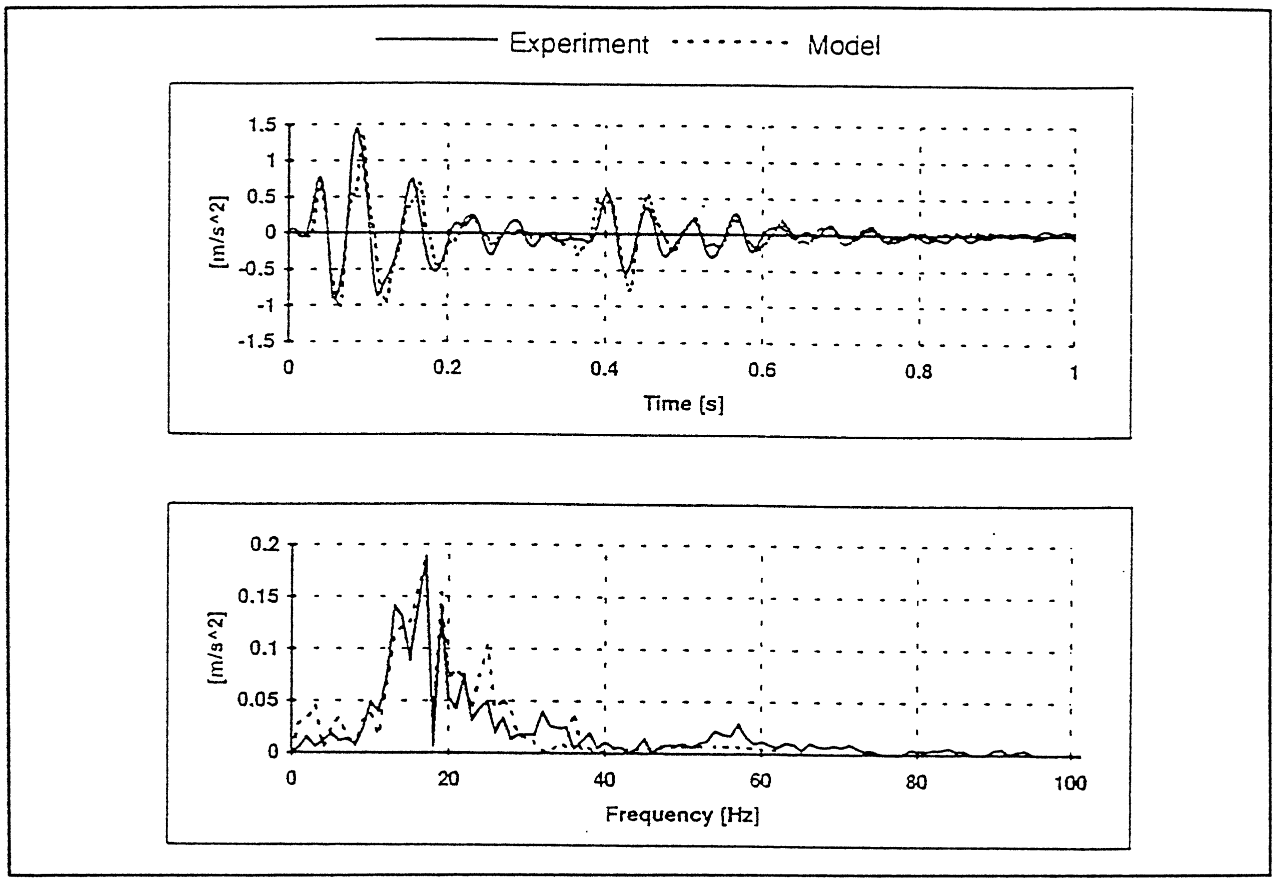

Figure 4 : experimental vs multibody model comparisons (steering wheel acceleration)

The flexible model has been derived from a previous "full rigid" version of the same, created by I.RI.S. The suspensions and engine connections with the chassis were simulated through non–linear bushings based on force–displacements splines (along X–Y–Z). The simple (rigid) part simulating the chassis has been substituted with a dataset fragment containing all the data needed for a modal representation of the structure. The chassis itself was built using AMFP (ADAMS Modal Flexibility Pre–processor), trying to make as few changes as possible to the base dataset. This can be done simply using in AMFP the same ADAMS identifier (parts, markers, spline ...) already adopted in the rigid model. A wise definition of flexible structure interface with the system embedding it can reduce dramatically the debugging and "tuning" efforts. After merging the flexible body statements with the rigid system some simulations have been carried out to verify the behaviors of the flexible model compared to the rigid one. Only after a positive response from these tests and measured data comparison the model has been considered affordable and its results analyzed.

The combination of rigid and flexible elements provides a model which accurately represents the dynamic response of the vehicle up to 200 Hz.

Simulation results

As previously described the vehicle rigid model gives good results up to 30 Hz, but fails completely in matching structural properties at higher frequencies (fig. 5). Between 50 and 120 Hz two main sub–system resonances can be detected with experimental analysis, the first (20–100 Hz) due to the chassis, and the second regarding the rear subframe.

The proposed goals for the "ADAMS flexible" project were to obtain a correct full spectrum from simulation results, and this would have involved a model with rear subframe and chassis as flexible elements.To avoid problems caused by the complexity of the flexible structures to include within the rigid systems two models have been created, one embedding only the deformable subframe, and another containing only the flexible chassis. A complete model composed of both flexible structurtes is currently under testing.

The results obtained from the first model can be seen in figure 6, where frequency response from the simulation covers experimental data, demonstrating how the LSE modeling of the subframe has effectively improved ADAMS model.

As plotted in figure 7 also the results from the flexible chassis model fit into the experimental data, allowing a complete covering of the interesting frequency range.

Errors in amplitude can be explained considering the approximation introduced by the constant modal damping used in matrices translation. Difficulties in obtaining a correct modal damping through FEA analysis lead to the development of methodologies allowing the import of experimenal (i.e. measured) modal data.

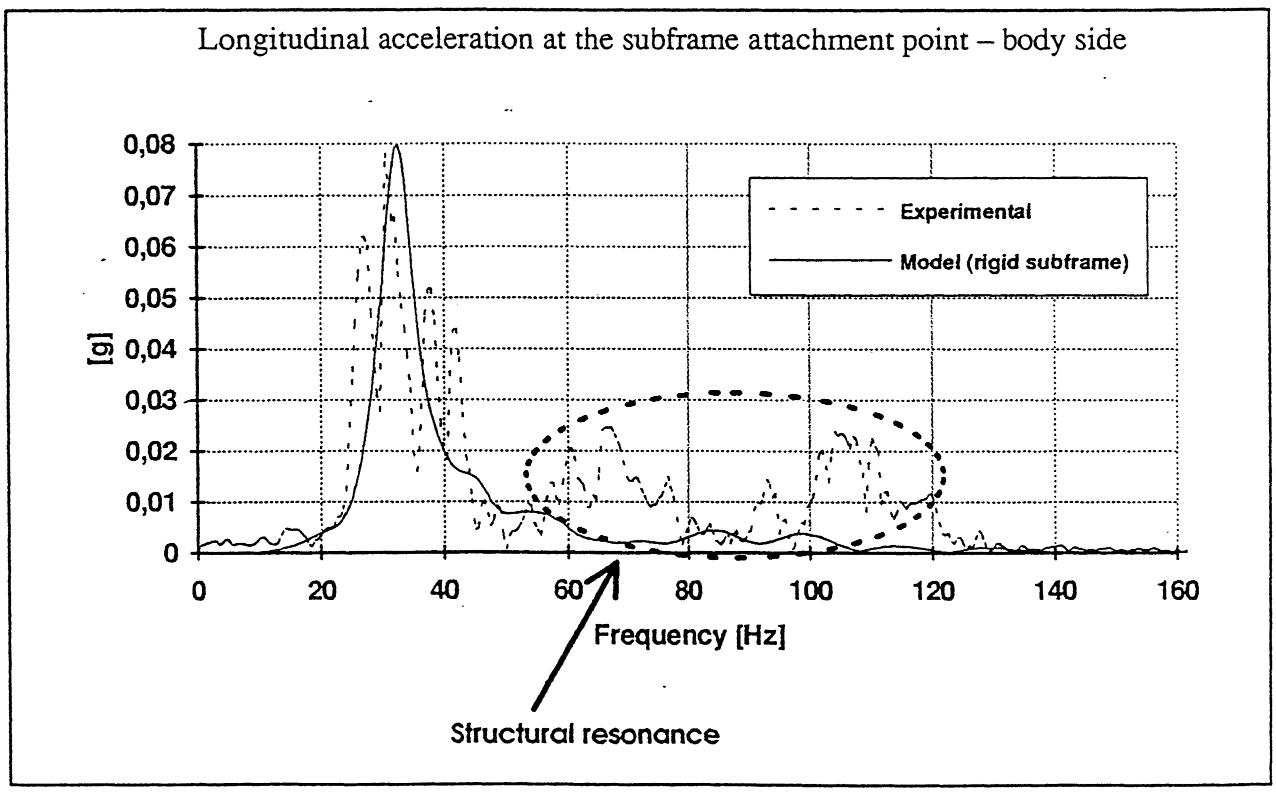

Figure 5 : rigid model analysis results

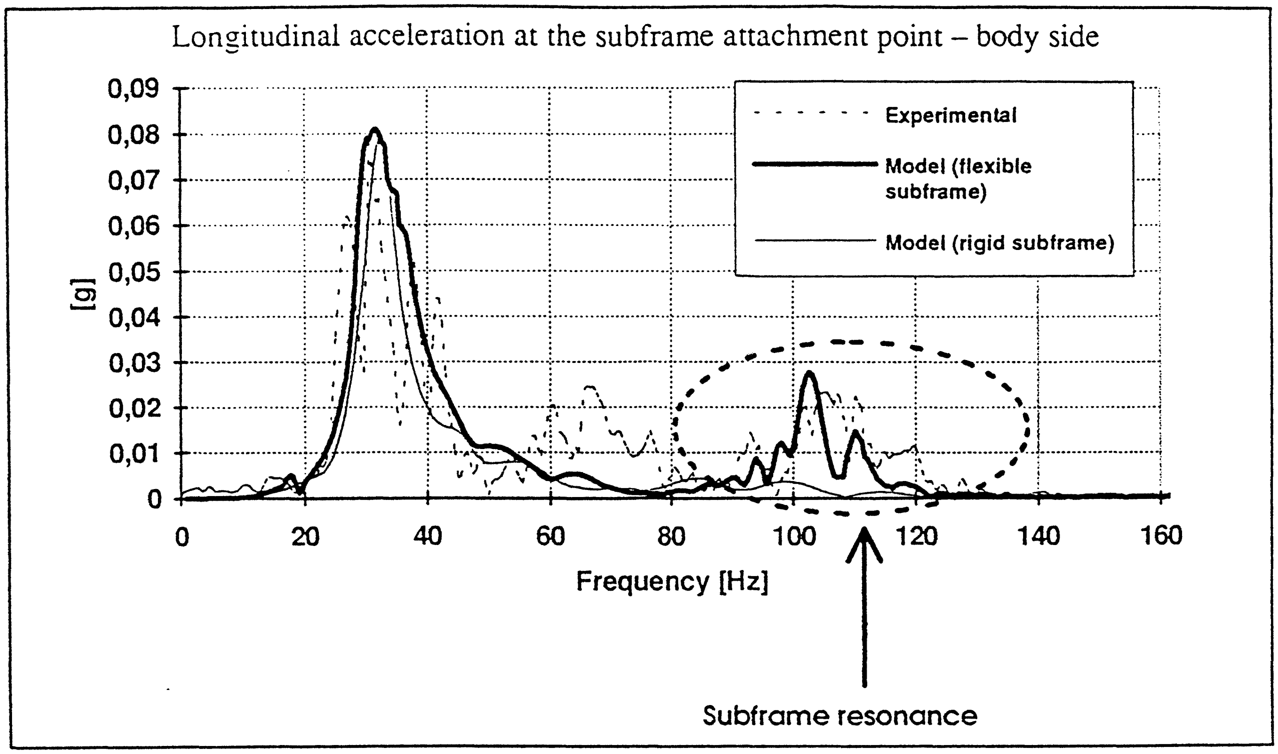

Figure 6 : flexible subframe model analysis results

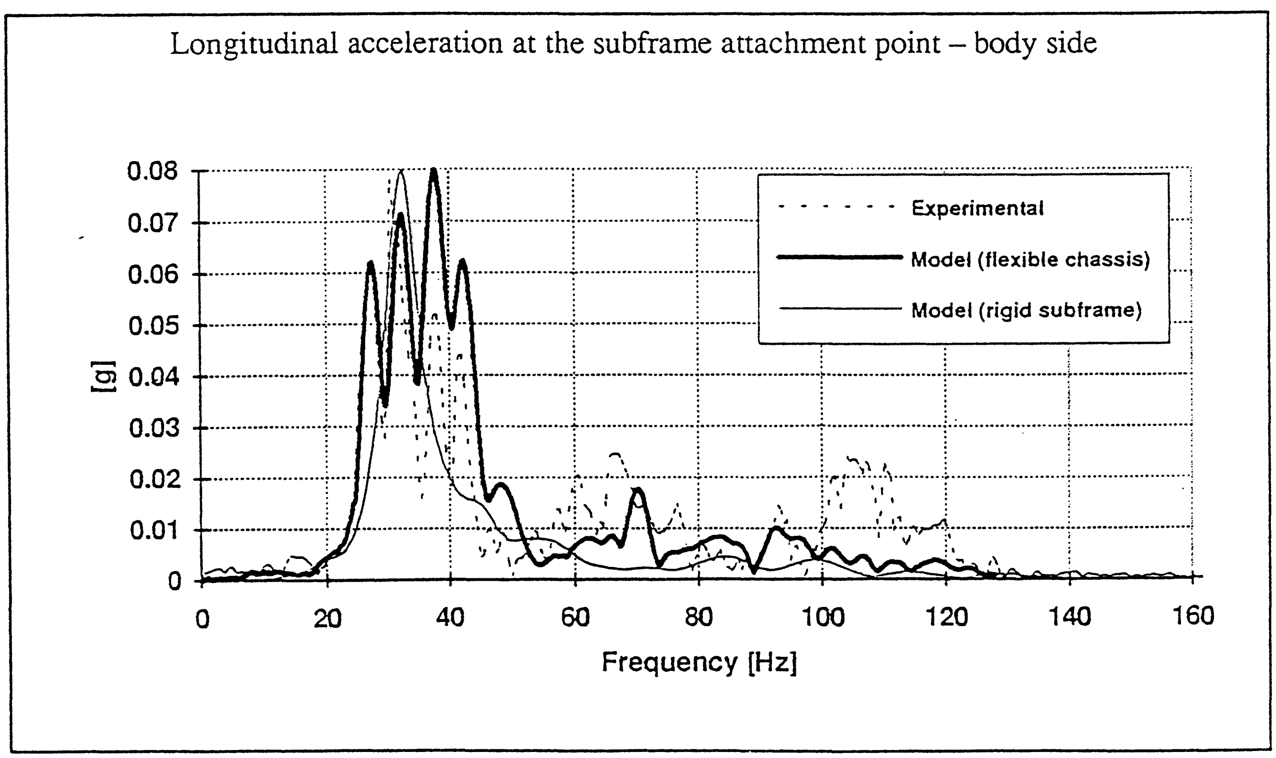

Figure 7 : flexible chassis model analysis results

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