Experimental Characterization of Dynamic Properties of Vehicle Rubber Mounts

ANANT GARG
ID: 2017A4TS0501G

DEPARTMENT OF MECHANICAL ENGINEERING

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A DISSERTATION MID-SEMESTER REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF ENGINEERING IN MECHANICAL ENGINEERING

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1. Introduction

Aim: The project aims to experimentally determine the dynamic properties of vehicle rubber mounts using suitable Dynamic Substructuring methods

Objective: To validate the data obtained from FBS methods with experimental data

Motivation: Dynamic substructuring (DS) is a branch of structural dynamics and is used as a method for breaking down complex dynamic systems into smaller systems, the so-called substructures. Applications range from the automo-tive and aerospace industries to high-tech precision machines and sustainable energy solutions. Component-by-component analysis of a structural system has great advantages over global methods in which the overall system is analyzed.

2. Dynamic Substructuring

Dynamic Substructuring methods consist in dividing a system in subparts that can be analyzed separately then combine them together by an assembly procedure. Such methods were first introduced four decades ago in order to reduce the complexity of dynamical models and to reduce the size of computational models

Although computer power has tremendously improved over the years allowing solving large problems and handling complex models, substructuring techniques are still very popular in engineering since they allow spreading the development work amongst different subgroups. Also, the models become more and more complex (in terms of number of degrees of freedom and in terms of physics modeled) reduction techniques are still necessary for instance when optimizing designs. The concept of substructuring is strongly related to domain decomposition methods which have become the cornerstone of efficient parallel computing.

Different methods of Dynamic Substructuring exist. Two different classes of substructuring methods can be distinguished:

•Time-domain based methods
•Frequency-domain based methods

Experimental substructuring based on Frequency Based Substructuring approaches have become an important research issue in the last years. The advantages of experimental substructuring are numerous:

•It gives the possibility to combine modeled parts from either theoretical or numerical analysis, and measured compo-nents derived from experimental tests. Combining experimental and theoretical models is also referred to as hybrid analysis.

•The effect of changing the properties of a subsystem on the assembled system can be analyzed efficiently. Also by analyzing the subsystems, local dynamic behavior can be recognized more easily than when the entire system is analyzed.

•It allows sharing and combining of substructures from different project groups.

•When a substructure is changed, dynamic substructuring allows rapid evaluation of the dynamics of the complete system. Only the changed subpart needs to be measured and thereby allows efficient local optimization, fast design cycles and subsequently an overall optimization.

•Dynamic Substructuring can be convenient if a measurement cannot be done because the structure is too large or complex to be measured as a whole or if not enough excitation energy can be put in the structure for adequate excitation.

•It allows easier spotting of local problems that might not be visible by testing the entire structure.

Dynamic Substructuring also has some disadvantages. The main disadvantages are:

•Applicability of Dynamic Substructuring is usually limited to linear and stationary systems with constant parameters.

•For experimental substructuring, most measurements are limited to translational degrees of freedom because rotational degrees of freedom are difficult to measure. Assembling rotational dofs is thus a major challenge.

•Dynamic substructuring code can take substantial time to program.

•For experimental substructuring, measurements containing noise are used. The matrix inversion(s) that are needed in the algorithm(s) will propagate measurement noise, resulting in an inaccurate solution for the complete system.

In this work we are mainly concerned with the Frequency-domain based methods

3. About Frequency Based Substructuring (FBS)

Frequency Based Substructuring (FBS) Method is used for the Dynamic Substructuring analysis. In FBS methods, each subsystem is described in terms of Frequency Response Functions (FRF's) of the uncoupled systems.

Modal synthesis methods are easy to implement whenever mass and stiffness matrices of the substructures are known theoretically, e.g. by a finite element model. However they are difficult to apply when dealing with experimental data. If modal synthesis methods are applied on experimental data, an identification technique has to be used in order to be able to determine the mass, damping and stiffness matrices of the subsystems.

The objective of Frequency Based Substructuring (FBS) is to predict the dynamic behavior of a system made of subpart on the basis of free-interface frequency response functions (FRF) of the uncoupled substructures. The FRF are in the assembly procedure represent the structural dynamic stiffness between discrete points of the subsystems in the frequency domain. They can either be determined theoretically or experimentally.

4. About Frequency Response Function (FRF)

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Fundamentally a frequency response function is a mathematical representation of the relationship between the input and the output of a system.

So for example the frequency response function between two points on a structure. It would be possible to attach an accelerometer at a particular point and excite the structure at another point with a force gauge instrumented hammer. Then by measuring the excitation force and the response acceleration the resulting frequency response function would describe as a function of frequency the relationship between those two points on the structure.

The basic formula for a frequency response function is:

$H(f) = Y(f)/X(f)$

Where $H(f)$ is the frequency response function,

$X(f)$ is the input to the system in the frequency domain and

$Y(f)$ is the output of the system in the frequency domain.

5. Structures

In this work, mainly the following four structures and their combinations have been studied.

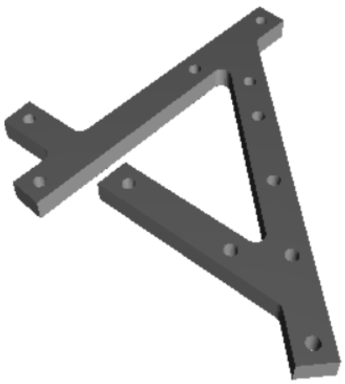


Fig 1. Structure A

fig 2. Structure ACase1

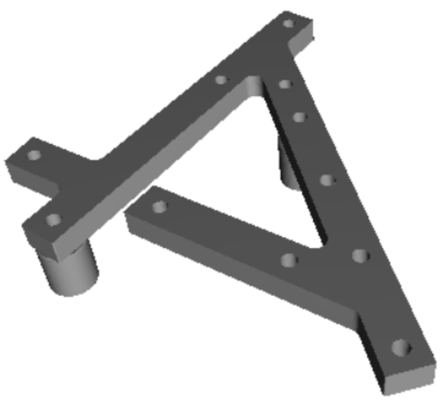


Fig 3. Structure ACase2

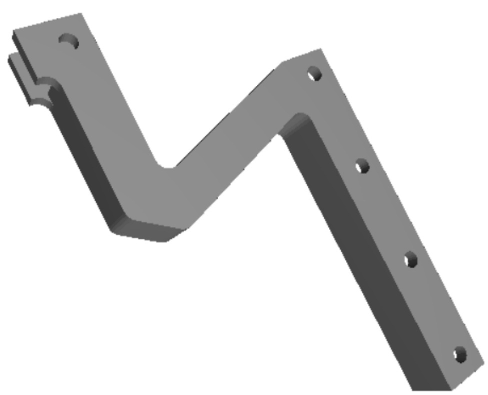


fig 4. Structure B

6. FRF Synthesization

The mass and stiffness matrices contain the information about the mass and stiffness distribution of the dynamic system. By solving the eigenvalue problem, the eigenfrequencies and eigenvectors of the system are determined. Calculated eigenvectors can be animated with ease. For the FRF synthesization mode superposition method is used.

FRFs can currently only be synthetized at the nodes from the numerical model. Therefore, it is necessary to find the nodes closest to the desired locations in the numerical model and update them. The orientation of the generated FRFs is independent of the direction in the numerical model and will not change with the updated location.

FRFs have been synthesized for the following three cases:

To place the sensors, impacts and virtual points, an interactive display from pyFBS module was used.

6.1 Structure AB

Structure AB (A+B): Structure AB is the combination of structure A and B

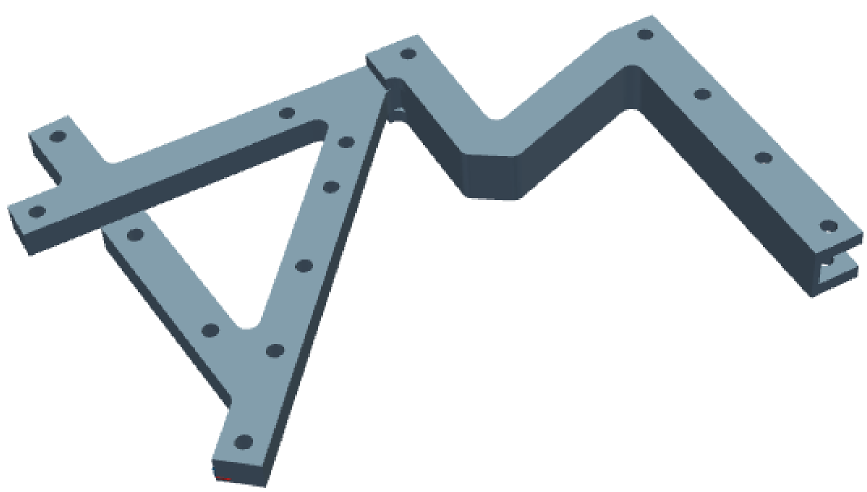


Fig 5. Structure AB

6.1.1 AB with Channels and Impacts

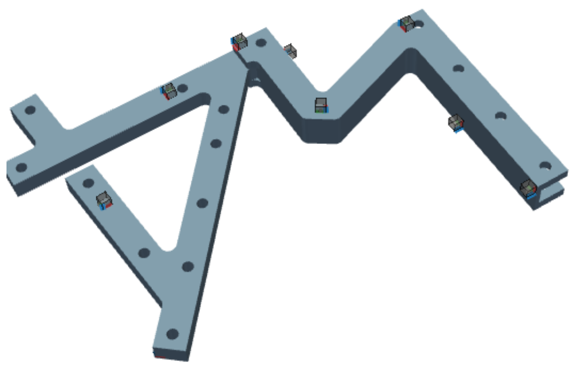


Fig 6. AB with sensors

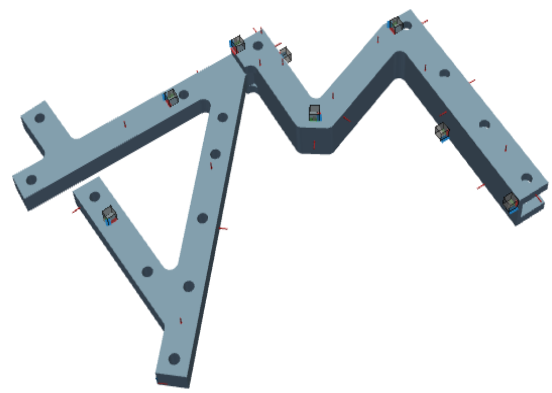


fig 7. AB with sensors and impacts

6.1.2 Modal Analysis of AB

Modal analysis of structure AB was performed in ANSYS Workbench with 28,000 nodes. Below is the FEM analysis of AB at mode 6

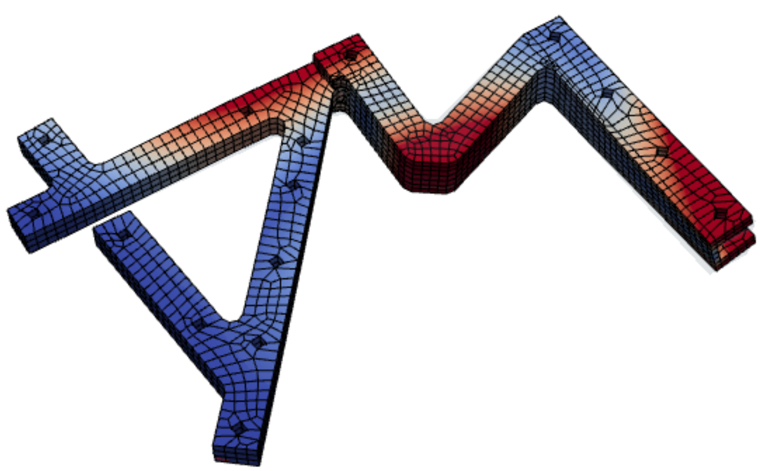


Fig 8. Mode shape of AB at mode 6

First 10 Modal Frequencies: [36.27 48.33 79.16 172.87
192.29 238.41 305.05 409.89 566.47 710.73]

6.1.3 FRF Synthesis of AB

FRF Synthesis of structure AB

	Name	Quantity	Position_1	Position_2	Position_3	Direction_1	Direction_2	Direction_3
3	S2 X	Acceleration	-41.679129	278.837681	22.100001	0.639191	-0.769048	0.0
0	I1	Force	14.310876	207.958594	17.000001	0.000000	0.000000	-1.0

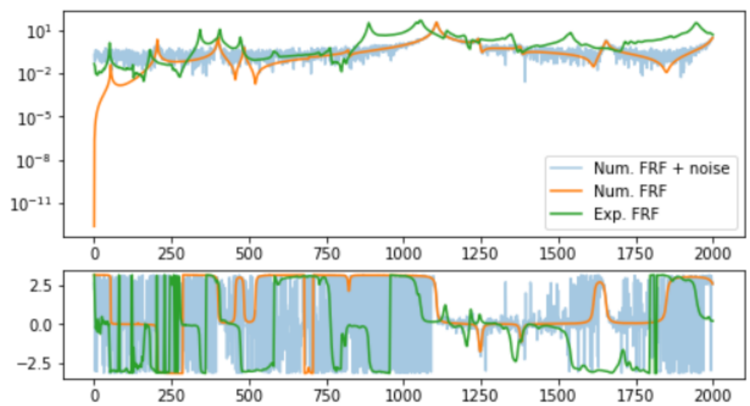


Fig 9. FRF of structure AB

6.2 Structure Case1 (Acase1 + B): Structure Case1 is the combination of structure Acase1 and B.

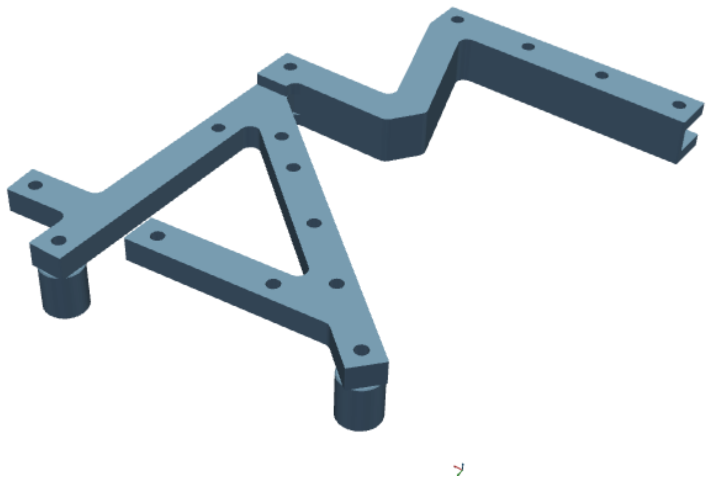


Fig 10. structure Case1

6.2.1 Case1 with sensors and impacts

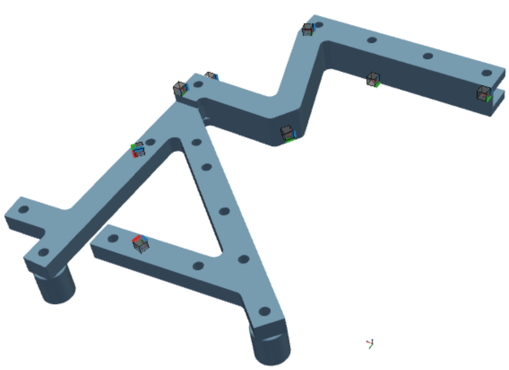


Fig 11. Case1 with sensors

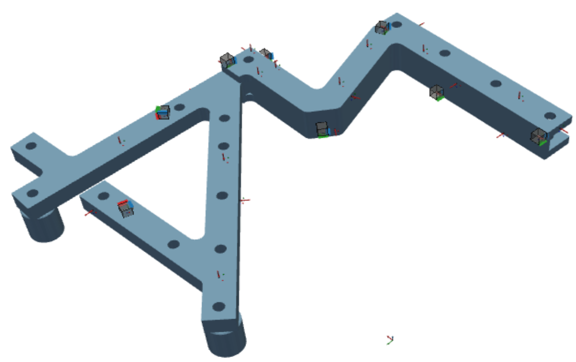


fig 12. Case1 with sensors and impacts

6.2.2 Modal analysis of Case1

Similar to structure AB, modal analysis was performed for Case1

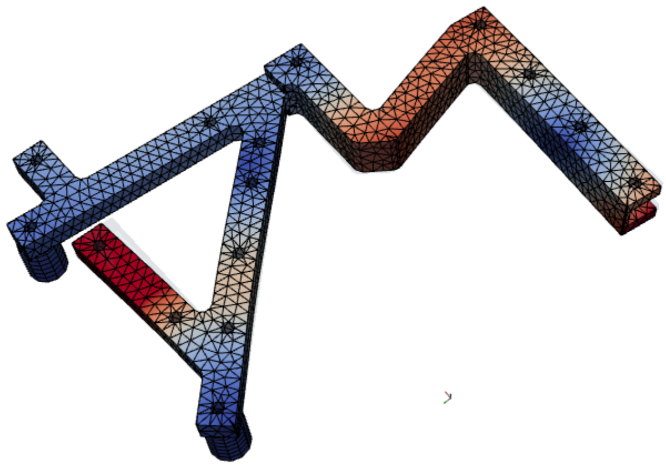


Fig 13. Mode shape of Case1 at mode 6

First 10 modal frequencies: [52.14 137.53 198.96 381.28 468.65 505.45 610.02 760.45 828.50 1024.96]

6.2.3 FRF synthesis of Case1

FRF Synthesis of Structure Case1

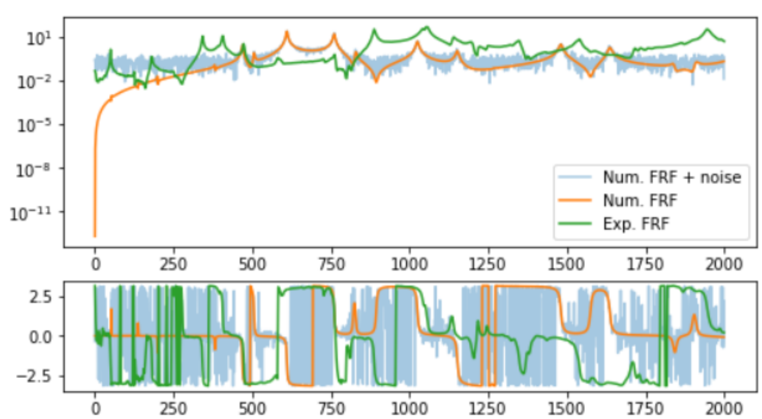


Fig 14. FRF of structure Case1

6.3. Structure Case2 (Acase2 + B): Structure Case2 is the combination of structure Acase2 and B.

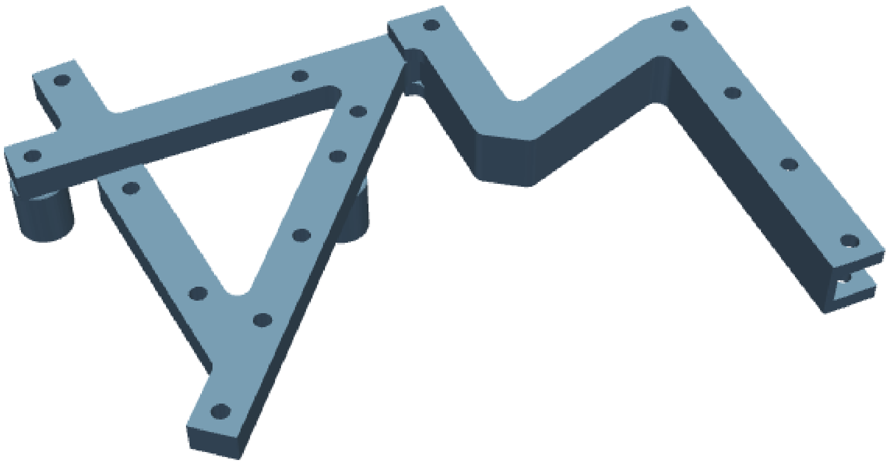
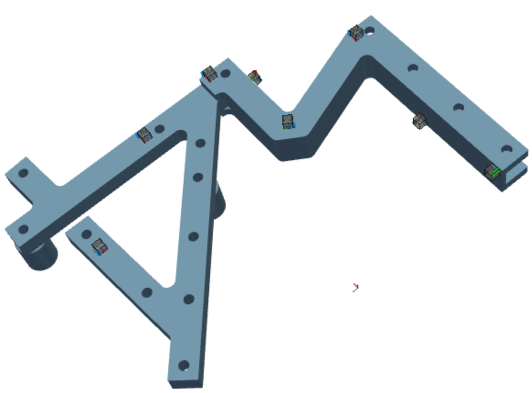


Fig 15. Structure Case2

6.3.1 Case2 with sensors and impacts



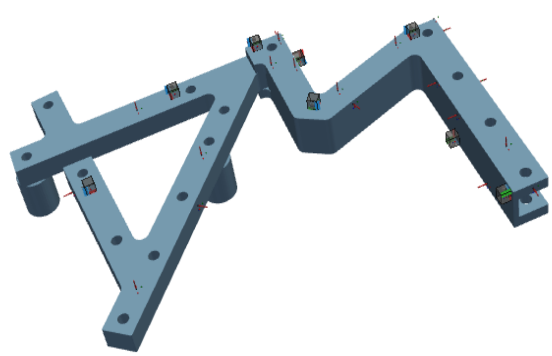


Fig 16. Case2 with sensors

fig 17. Case2 with sensors and impacts

6.3.2 Modal analysis of Case2

Similar to AB and Case1, modal analysis of Case2 was performed for Case2

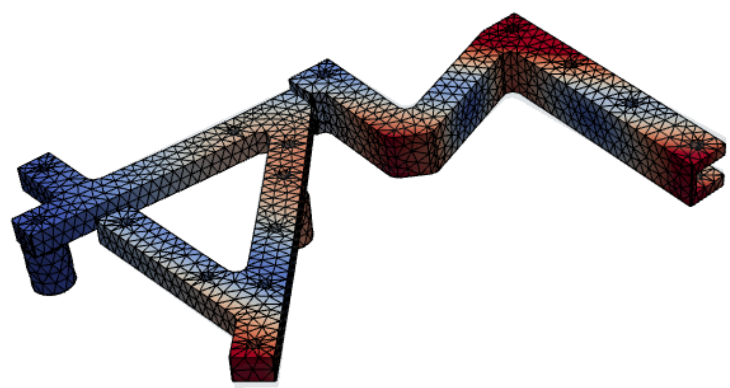


Fig 18. Mode shape of Case2 at mode 6

First 10 modal frequencies: [36.32 48.33 79.16 172.87 192.30 238.41 305.05 409.90 566.47 710.73]

6.3.3 FRF synthesis of Case2

FRF Synthesis of Case2

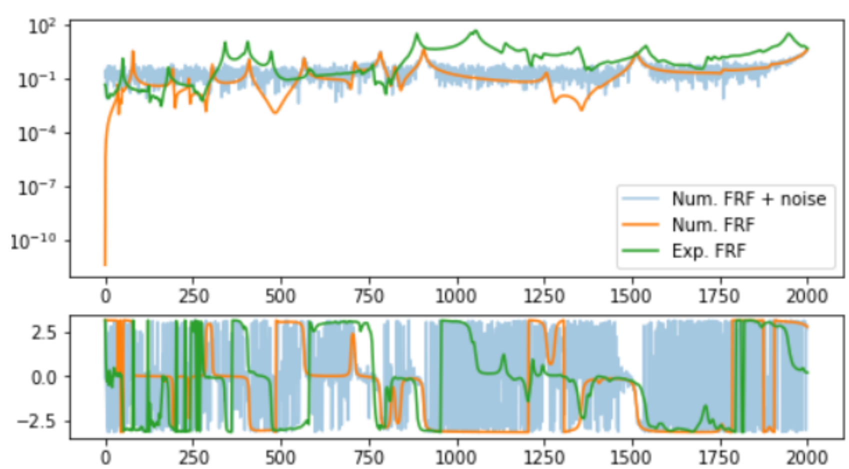


Fig 19. FRF of Case2

7. System Equivalent Model Mixing (SEMM)

System equivalent model mixing (SEMM) is a method based on Frequency Based Substructuring (FBS) and enables the construction of hybrid dynamic models by combining numerical and experimental models.

With System Equivalent Model Mixing (SEMM) frequency based models, either of numerical or experimental nature, can be mixed to form a hybrid model. This model follows the dynamic behaviour of a predefined weighted *master* model. A large variety of applications can be thought of, such as the DoF-space expansion of relatively small experimental models using numerical models, or the blending of different models in the frequency spectrum.

SEMM was performed for the following three cases:

7.1 Structure AB (A+B): Structure AB is the combination of structure A and B

	Name	Quantity	Position_1	Position_2	Position_3	Direction_1	Direction_2	Direction_3
24	S9 X	Acceleration	315.196534	207.024374	20.318070	0.0	0.0	1.0
24	I25	Force	306.717813	255.034685	27.000001	0.0	0.0	-1.0

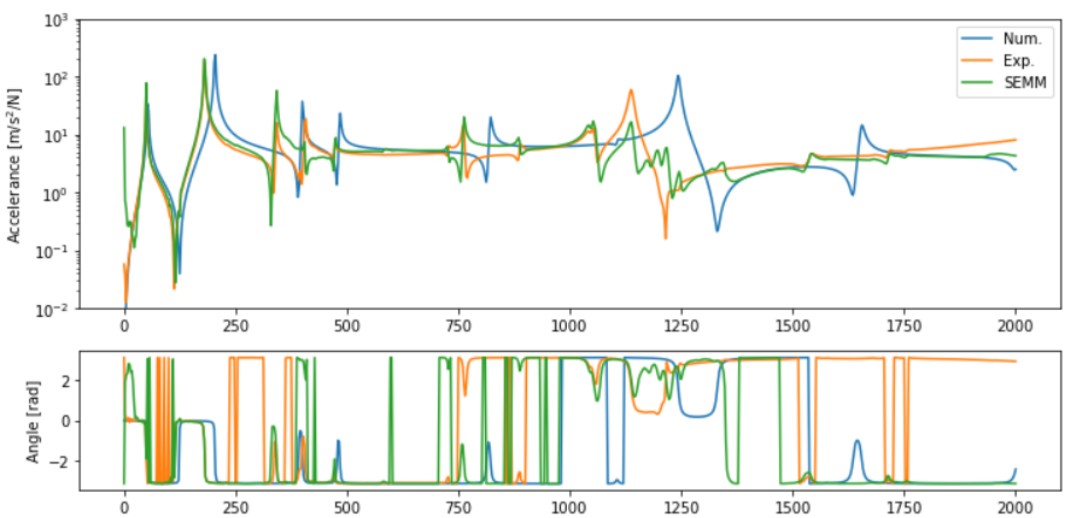


Fig 20. SEMM for Structure AB

7.2 Structure Case1 (Acase1 + B): Structure Case1 is the combination of structure Acase1 and B.

	Name	Quantity	Position_1	Position_2	Position_3	Direction_1	Direction_2	Direction_3
24	Sensor 9x	NaN	34.329754	-104.797234	338.710052	0.999848	-0.017452	0.000000e+00
24	Impact 25	NaN	202.233261	34.870251	333.724182	-0.999848	0.017452	5.924889e-08

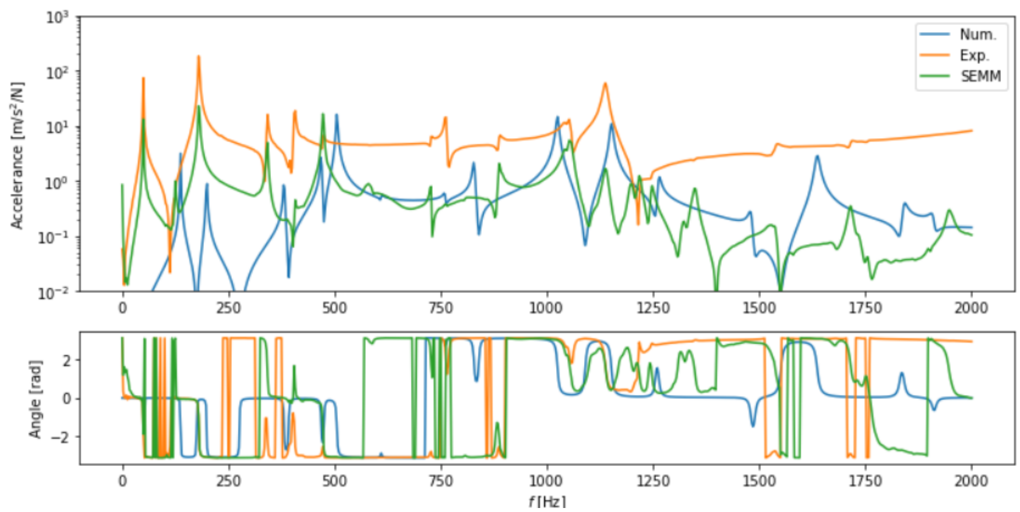


Fig 21. SEMM for Case1

7.3 Structure Case2 (Acase2 + B): Structure Case2 is the combination of structure Acase2 and B.

	Name	Quantity	Position_1	Position_2	Position_3	Direction_1	Direction_2	Direction_3
24	Sensor 9x	NaN	-72.936829	-74.009697	388.590149	0.004884	-0.000085	0.999988
24	Impact 25	NaN	-11.859510	2.374748	417.927338	0.945519	0.325568	0.000000

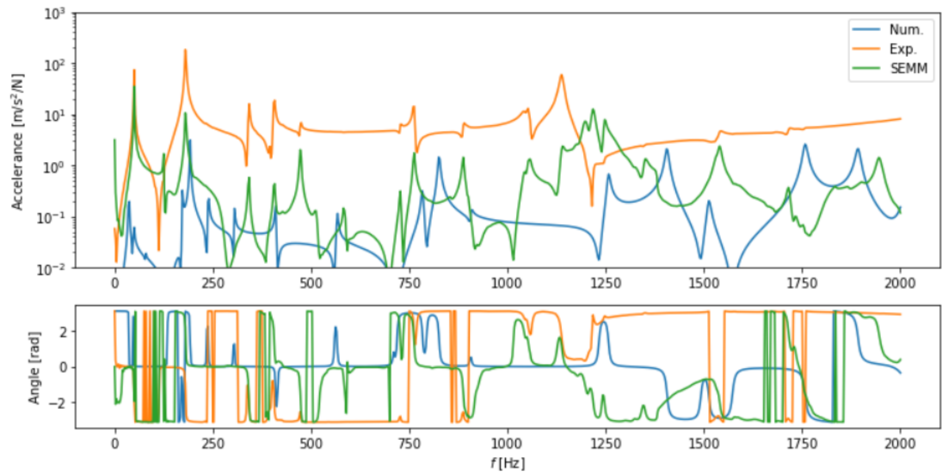


Fig 22. SEMM for Case2

8. Virtual Point Transformation (VPT)

A virtual point (VP) is an interface used to connect components which allows the engineer to build up, for example, a full vehicle model. The point is “virtual” because typically it cannot be measured directly. By placing sensors around the VP and by assuming the local region behaves rigidly.

The Virtual Point includes both translational and rotational degrees of freedom, data which traditionally is impossible to obtain. The transformation also gives valuable insights about the quality of the measured data and the resulting FRF model. Force impacts are transformed in a similar fashion.

8.1 Virtual Point Transformation (VPT) at B

8.1.1 VPT at B Structure

VPT was performed at structure B (virtual point can be seen at extreme right of structure B)

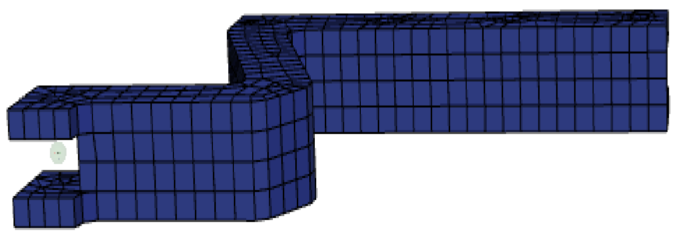


Fig 23. Virtual point in structure B

8.1.2 FRF of B with VPT

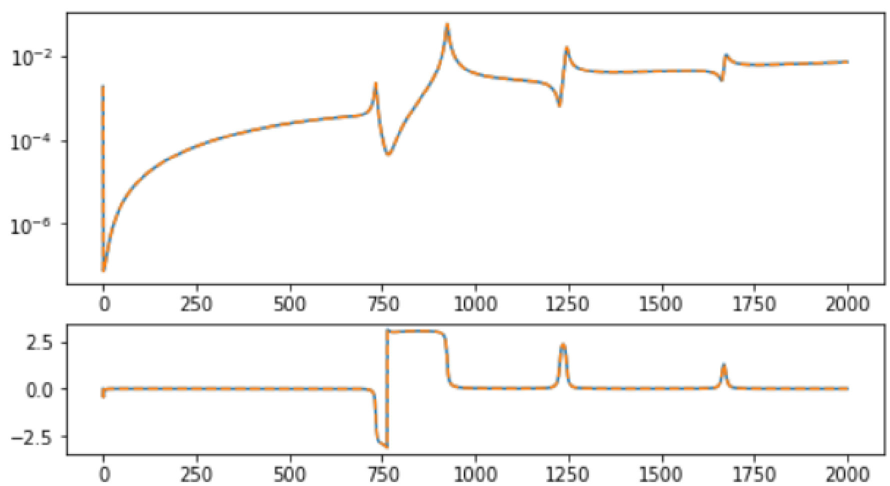


Fig 24. FRF of B using VPT

9. Frequency Based Coupling Method

In order to couple two substructures in the frequency domain, use is made of the admittance and impedance matrices of both substructures. Any two substructures are coupled at a virtual point at a virtual interface. In this study, for coupling LM-FBS coupling methods have been used. For the case of Structure AB, structure A and structure B are coupled at the virtual point shown in the figure x.

LM-FBS coupling methods were used to find the FRF of structure AB by coupling structure A and structure B

9.1 FRF of structure AB using LM-FBS method

	Name	Description	Quantity	Grouping	Position_1	Position_2	Position_3	Direction_1	Direction_2	Direction_3
0	S1 X	AM_AB_final	Acceleration	100	-75.540099	141.570046	17.000001	0.705057	0.70915	0

	Name	Description	Grouping	Quantity	Position_1	Position_2	Position_3	Direction_1	Direction_2	Direction_3
6	H28	AM_AB_final	10	Force	112.653141	258.983585	-10.500007	-0.087156	0.996195	0.0

```
(0.0, 2000.0)
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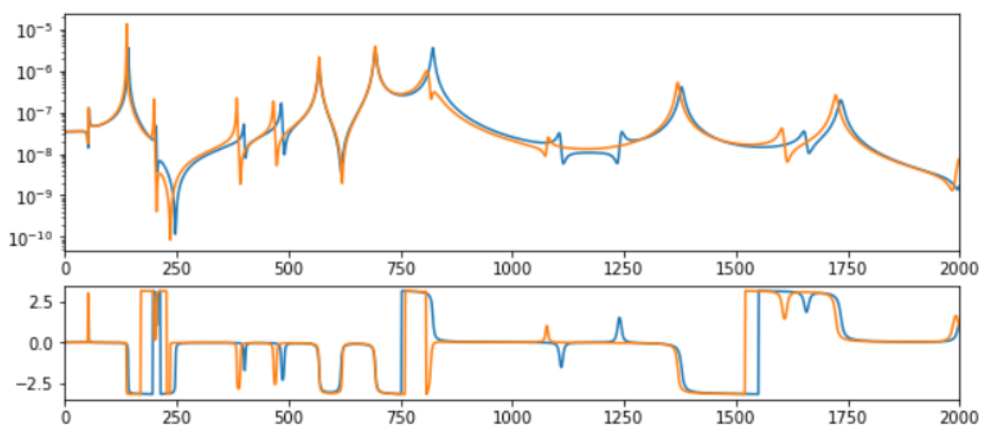

Fig 25. FRF of AB using LM-FBS coupling