U.P.B. Sci. Bull., Series D, Vol. 81, Iss. 4, 2019 ISSN 1454-2358

COMPARATIVE STUDY BETWEEN THREE METHODS OF MEASURING OF NATURAL FREQUENCIES AND MODAL DAMPING

Ramdane YOUNES [1 2]*, Nouredine OUELAA[1], Mohamed Cherif DJAMAA[1]

The determination of the natural frequencies and modal damping is very important for the survival of structures and rotating machinery. The precise knowledge of these frequencies allowed avoiding the appearance of the resonance phenomenon, which represents a real danger for these structures. In practice, the measurement of natural frequencies is influenced by several parameters, such as the mass of the sensor, the type of excitation and the boundary conditions. In this work, we present the results of natural frequencies measurements by three different methods in order to see which of them is closest to that obtained by numerical simulation. The first method consists of exciting the structure by a shock hammer and measuring the vibration signal by an accelerometer glued to the beam. In the second method, a vibration exciter equipped with an impedance head is used, which allowed to directly obtain the Frequency Response Function (FRF). The third method consists of fixing, on the vibration exciter, a force sensor with a metal rod to excite the structure and the vibratory signal is measured by an accelerometer glued to the beam.

The results of the three methods show that the natural frequencies obtained by the impedance head are closer to those of the numerical simulation, which is explained by the absence of the mass added by the accelerometer. For modal damping, the results obtained by shock hammer excitation are better than those of the two other methods. The absence of stress on the free vibrations of the beam due to this type of excitation gives resonance frequencies with a bandwidth at -3 dB wider than in the case of the other two methods where the vibration exciter blocks the free vibrations of the beam.

Keywords: Modal analysis, natural frequencies, modal damping, excitation type, impedance head.

1. Introduction

The vibration characteristics play a fundamental role in the structural analysis and dynamics design of all kinds of engineering systems. The accurate evaluation of the vibration characteristics and dynamic performance is a

[1] Mechanics and Structures Laboratory, Université 8 Mai 1945 Guelma, BP. 401, 24000 Guelma, Algeria.
[2] Mechanical Engineering department, Badji Mokhtar University, P.O. Box 12, Annaba 23000, Algeria.
*Corresponding author: Ramdane YOUNES, Email: ramdane_ys@yahoo.com

prerequisite for dynamics design, parameter identification and fault diagnosis in the design and analysis of these systems.

The identification of dynamic structural features is of great importance in many industrial fields such as automotive, aerospace, rotating machinery, robotics, civil engineering, etc. Several studies have been conducted on numerical and experimental techniques to identify the dynamic behavior of structures.

Modal analysis methods are relatively new investigative methods that have been used to establish and / or improve the understanding of the dynamic model of real structures. Experimental modal analysis allows the identification of dynamic structural parameters or modal parameters of a structure such as resonant frequencies, damping and modal deformations. The dynamic behavior of the structure under particular excitation conditions in the absence of any self-deletion requires only the knowledge of these parameters. This is why experimental modal analysis has become, thanks to advances in computer science and instrumentation, a privileged method of investigation in the field of structural dynamics [1].

The first methods developed in the years 1950-60 were the modal appropriation methods which consisted of applying to the structure a set of harmonic excitation forces suitably distributed in amplitude and in phase, giving a proportional structure response to its own mode of the associated conservative system [2]. The EMA method estimates the modal parameters of the structures as a function of the input force and the recorded output responses. The input force is applied to the structures by shakers or impact hammers, and the output responses are usually measured by accelerometer sensors. Therefore, the experimental instruments and data signal processing methods play a fundamental role in the estimation of the modal parameters [3-7]. In the machinery vibration analysis field, it is important to ensure quality of the machined part and to avoid unexpected downtime before the scheduled maintenance [8].

The constant quest for quality improvement in all areas of mechanical engineering has led designers to use experimental modal analysis as a preferred tool for getting a better understanding of the dynamic behavior of structures. This is why these techniques have gone far beyond aeronautics to focus on structures in the field of transport (vehicles, railways, boats ...) [9-12], civil engineering structures (bridges, cooling towers, group beds ...) [13-15] and more generally to all materials likely to be subjected to a severe vibratory environment. A whole methodology has been thus developed downstream from the modal analysis concerning, for example, dynamic sub-structuring or the readjustment of finite element models with respect to the actual structure.

Performing a modal analysis test generally requires the measurement of the vibratory response of the structure as well as the excitation force at different points thus allowing the calculation of the Frequency Response Function (FRF).

Conventional methods of excitation are usually the electrodynamics exciter and the impact hammer.

In this work, we carried out a comparative study based on the modal analysis of frequencies and modal damping, of a free cantilever beam, between the results obtained by numerical simulation and those obtained by three experimental methods of these modal parameters.

The numerical simulation results are obtained by finite element method using Solidworks software.

2. Procedures for natural frequencies measurement

For the experimental validation, three experimental setups are used (Figs.1.a and b) defining three methods of frequency spectra measurement and FRFs.

The characteristics of the tested beam are:

A cantilever steel beam of length l = 0.5m, width b = 0.03m, thickness h = 0.005m, density = 7850 Kg/m^3, Young's modulus E = $200*10^9$ N/m^2, inertia moment I = $bh^3 / 12 = 0.3125*10^{-9}$ m^4 and section S = 0.00015 m^2.

First method (electrodynamics exciter)

In the first method, the beam has been excited with a white noise, generated by the Pulse B&K 16.1 vibration analyzer, which is amplified by an amplifier. The excitation is transmitted to the structure with a metal rod attached to a force sensor type B&K 8230 connected to the end of the electrodynamics exciter. The measurement of the vibration response is performed by an accelerometer glued near the beam free end to avoid the vibration nodes and to ensure the appearance of all vibration modes from a single measurement. (The experimental setup is the same of figure 1.b without using the impedance head)

Second method (hammer exciter)

In the second method, the conventional natural frequency measurement method has been used, which consists of exciting the structure with a hammer and measuring the vibratory response by an accelerometer glued near the beam free end.

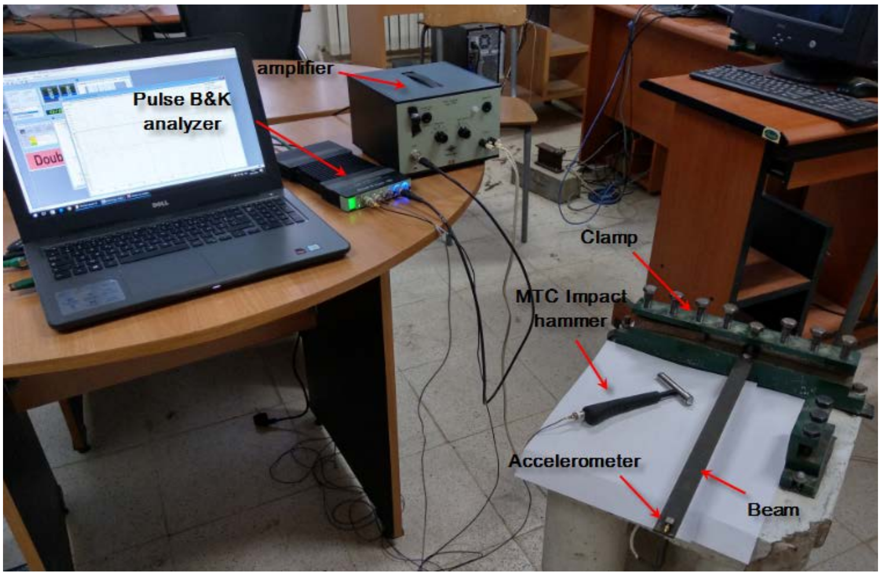

Fig. 1.a. Experimental setup for the second experiment

Third method (impedance head)

In the third method, both excitation and vibratory response measurement are performed by an impedance head type B&K 8001 (force sensor plus accelerometer), fixed directly on the electrodynamics exciter. The advantage of this method is the absence of added mass to the structure (no sensor is glued to the beam). The sensor mass have a great influence on the natural frequencies in the case of thin structures.

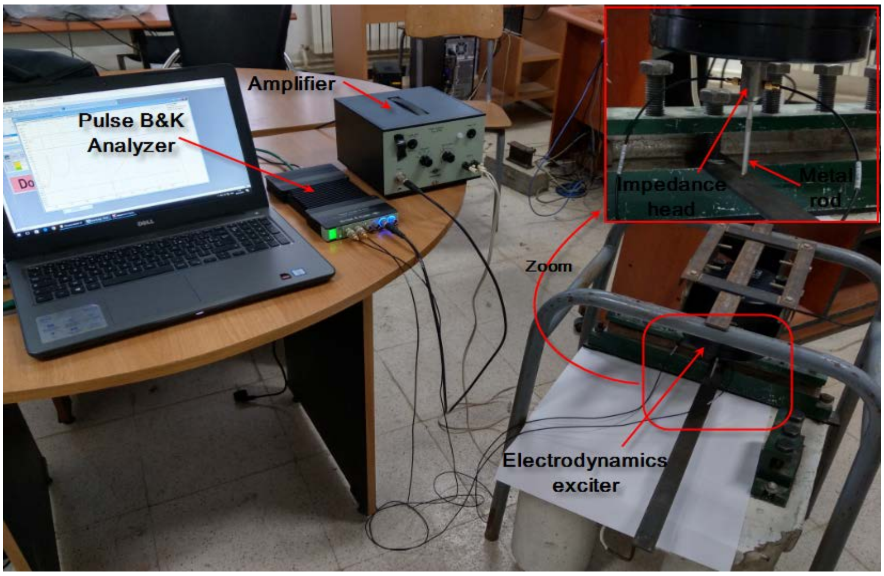

Fig. 1.b. Experimental setup for the third experiment

3. Treatment of results and discussions

In this section, we present the results of frequencies and modal damping of a cantilever steel beam, obtained by three measurement methods as described above. For the damping case, a rubber material is glued along the beam.

Results of the first method

Fig. 2 and Fig. 3 show the frequency spectra obtained after smoothing the spectra obtained directly from the measurement and which has many fluctuations. These spectra give the natural frequencies of the beam with accuracy but do not allow the extraction of the modal damping by the software ME'Scope VES'4, which uses the -3dB bandwidth method. The fluctuations that appear on the measured spectra prevent the calculation of the modal damping. For this reason, we have smoothed these spectra before extracting the modal damping.

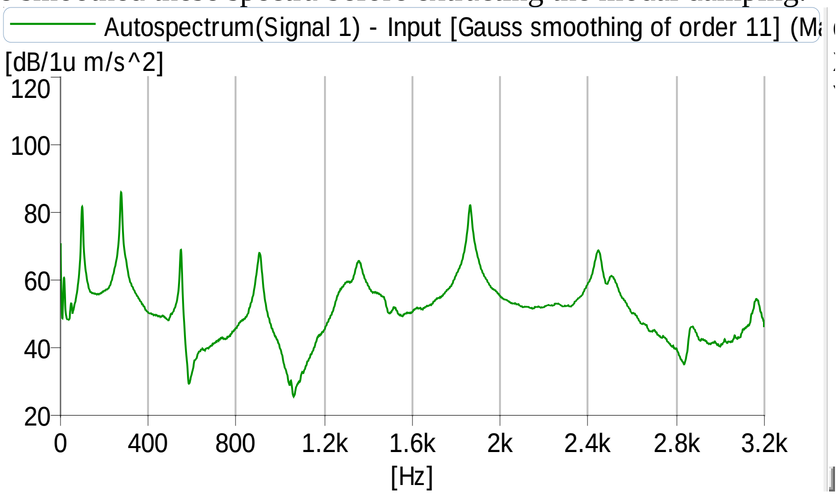

Fig. 2. Frequency spectrum obtained after smoothing. Case without damping.

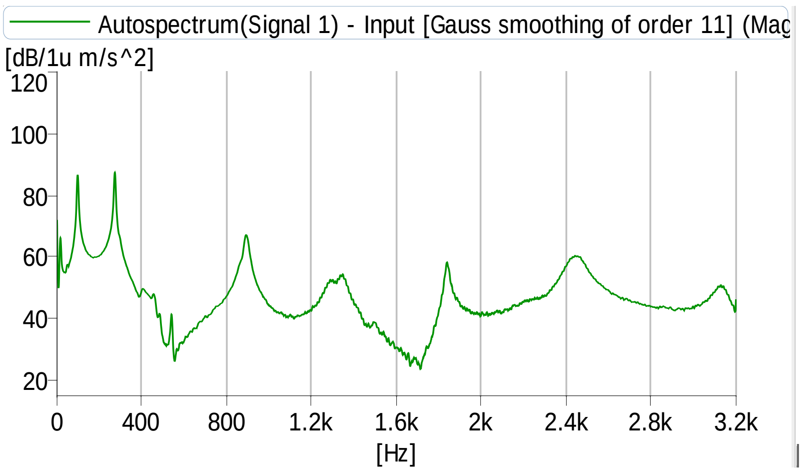

Fig. 3. Frequency spectrum obtained after smoothing. Case with damping.

Results of the second method

The most widely method used for the measurement of natural frequencies and modal damping is based on the excitation of the structure with a hammer and the measurement of the response with an accelerometer. In this method, the FRFs obtained are smoothed on the resonances to determine the frequencies and the modal damping with accuracy. However, we find that antiresonances do not appear on the FRFs (Fig. 4, Fig. 5).

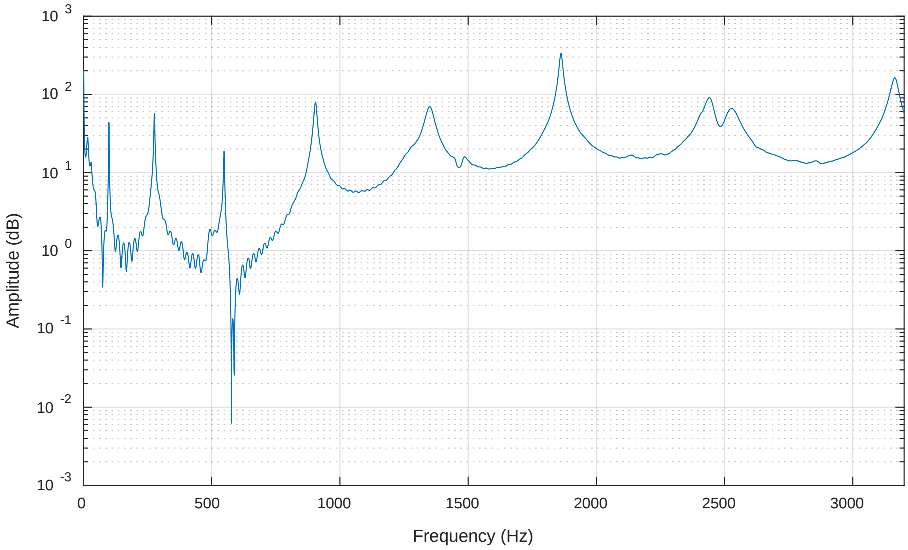

Fig. 4. Frequency spectrum in the case without damping.

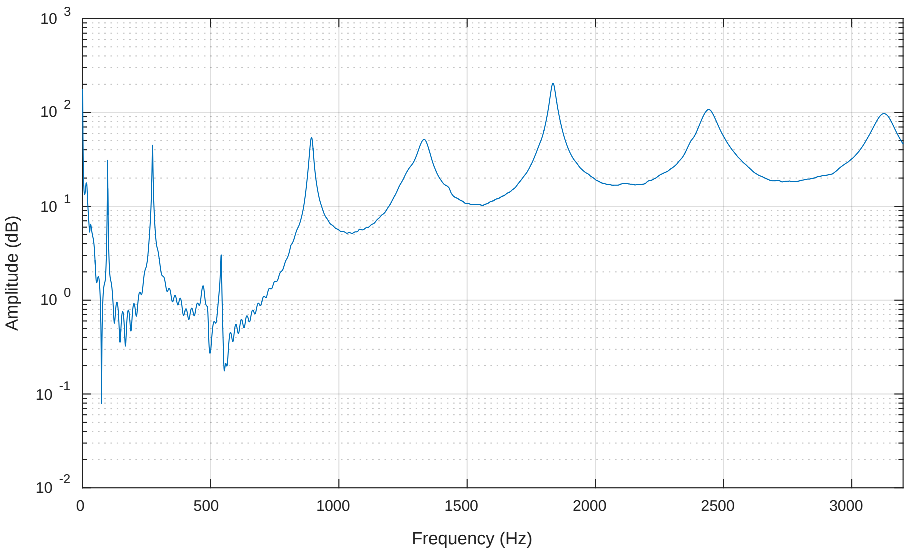

Fig. 5. Frequency spectrum in the case with damping.

Results of the third method

In the third method, an impedance head was used for FRF measurement. The good synchronization between the force sensor and the accelerometer makes it possible to obtain frequency spectra, clearly showing all the resonances and the antiresonances (Fig. 6, Fig. 7).

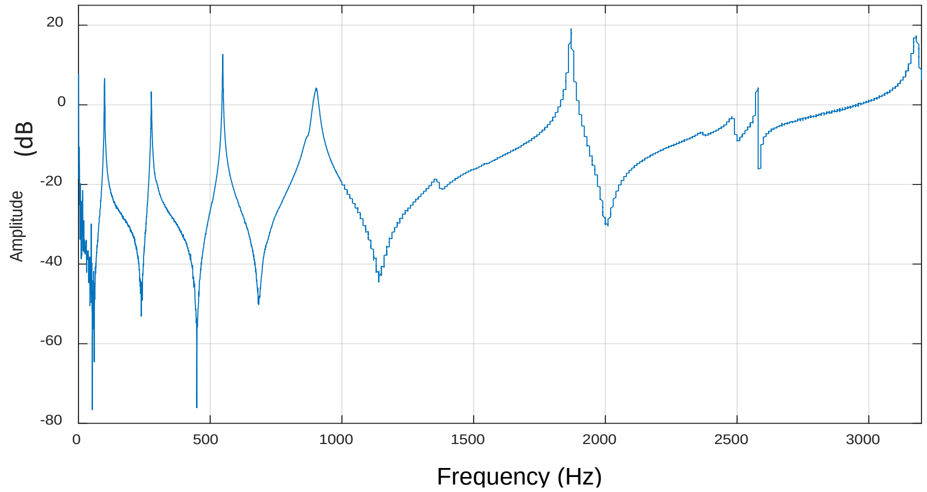

Fig. 6. Frequency spectrum in the case without damping.

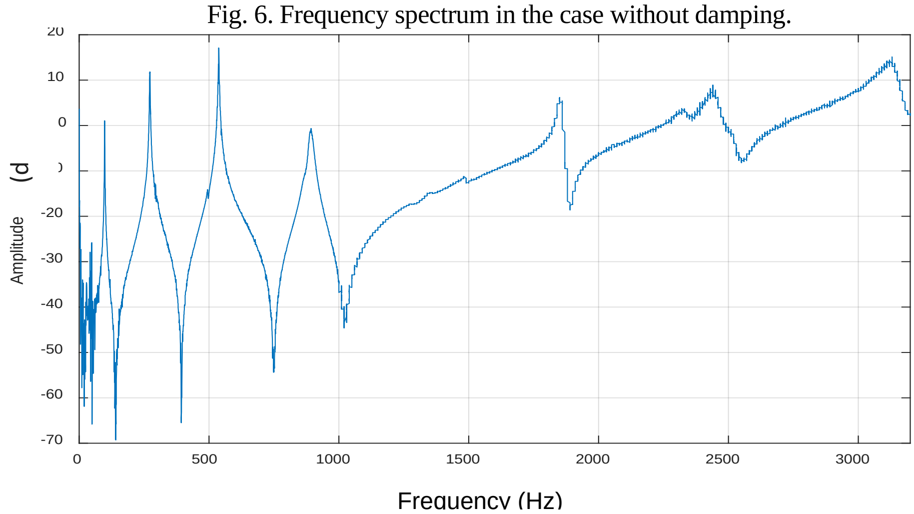

Fig. 7. Frequency spectrum in the case with damping.

Results of the numerical simulation

The Solidworks simulation software was used to simulate a beam whose characteristics are the same as our beam.

The results of the natural frequencies are presented in figure 8 and Table 1 and it is found that the obtained values are very close to those obtained experimentally with the three methods.

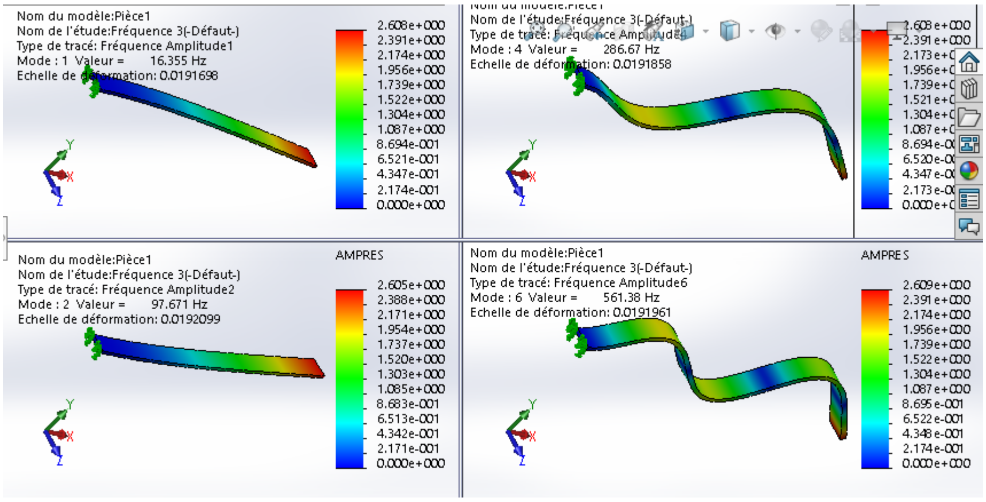

Fig. 8. Solidworks view of modal Analysis of cantilever beam

ME'Scope VES'4 software was used for the treatment of results in order to determine the modal damping in the three cases. Figure 9 shows experimental results of natural frequencies and modal damping for the studied beam obtained by ME'Scope [16].

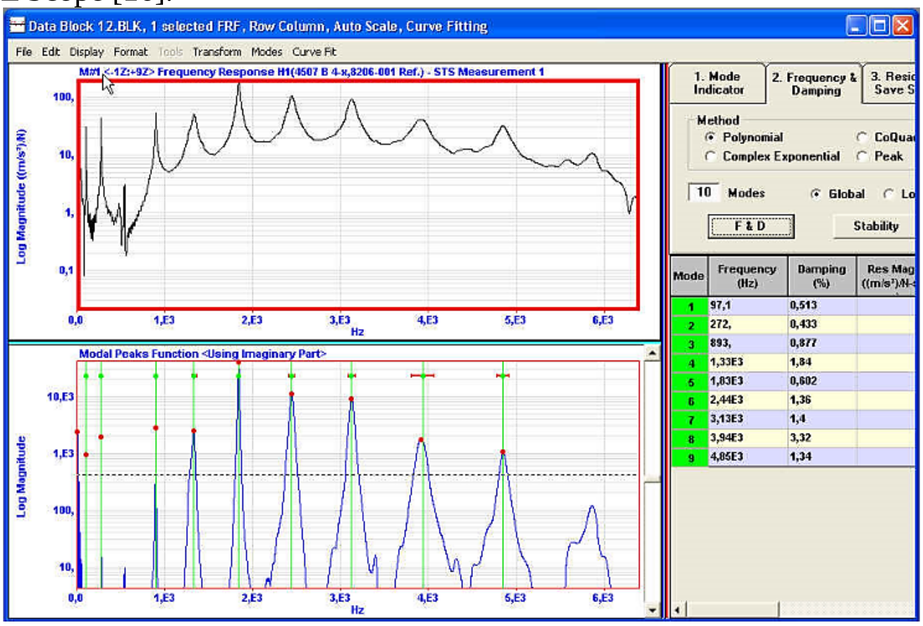

Fig. 9. ME'Scope VES'4 view.

4. Extraction of frequencies and modal damping

In table 1 and in addition to the results of the numerical simulation, all the natural frequencies and modal damping obtained by the three methods presented above are presented using ME'Scope VES'4 software.

Table 1

Frequency and modal damping

mode	Numerical simulation (Hz)	First method				Second method				Third method			
		with damp (Hz)	ζ %	without damp (Hz)	ζ %	with damp (Hz)	ζ %	without damp (Hz)	ζ %	with damp (Hz)	ζ %	without damp (Hz)	ζ %
1	16.35	15	2.57	16	1.65	15	/	15.2	1.58	15	/	15.2	1.68
2	97.67	97.5	0.4	98.5	0.1	97	0.513	98	0.48	98	0.8	99	0.36
3	286.67	272.5	0.42	275	0.34	272	0.444	275	0.45	272	0.33	276	0.12
4	561.38	540	1.14	548	0.89	540	0.299	547	0.25	537	0.17	547	0.119
5	927.67	893	1.21	905	0.21	892	0.84	904	0.61	892	0.98	902	1.05
6	1384.8	1345	2	1356	1.14	1330	1.84	1349	1.28	1341	1.49	1356	1.02
7	1932.4	1839	0.68	1862	0.42	1835	0.602	1861	0.34	1851	0.46	1869	0.2
8	2523.3	2450	0.23	2446	0.35	2440	1.36	2450	0.76	2438	1.6	2481	0.32
9	3296.7	3136	0.35	3168	0.15	3127	1.4	3163	0.46	3124	0.99	3176	0.28

5. Analysis and interpretation of results

For the three methods used to measure the natural frequencies, it is found that the viscoelastic material glued to the steel beam allowed to shift the natural frequencies towards the low frequencies, which is more accentuated for the high rank modes.

The results of the three methods are comparable with those of the numerical simulation. For higher rank modes, the natural frequencies are slightly higher than those obtained experimentally. This is explained by the fact that mathematical models do not take into account the effect of certain parameters such as shear and rotational inertia, which have a significant effect on high frequency.

According to this study, the best method of measuring the natural frequencies which allows the determination of modal damping is the one when the beam is excited by a hammer. The measurement of the beam free vibrations without any external constraint of the exciter as in the case of the two other methods allowed to obtain spectra where FRFs with -3 dB bandwidth resonances much wider, which allows to calculate the modal damping with a better precision.

The measurement of natural frequencies by the impedance head is much easier and more accurate than the other two methods, because there is no mass added by the accelerometer to the structure and there is a good synchronization between the accelerometer and the force sensor incorporated together. The measured transfer function clearly shows the peaks of the resonances and the anti-resonances. The results of the natural frequencies obtained by this method are the closest to the numerical simulation.

6. Conclusions

This study illustrated the complete approach of measuring the frequencies and modal damping of a structure by three different methods. The results obtained experimentally are compared with each other and with the results obtained by a numerical simulation. The comparative study between the three methods shows that the best method of measuring the natural frequencies allowing the calculation of the modal damping is the excitation of the beam by a hammer. The method which makes it possible to obtain the natural frequencies without difficulty and which makes appear on the frequency response all resonances and antiresonances of the beam is the method using an impedance head for the excitation and the measurement of the vibratory response. The bonding of a rubber material along the beam makes it possible to increase the modal damping by shifting the natural frequencies towards the low frequencies, which is more accentuated for the high rank modes.

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