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STUDY OF THE EXPERIMENTAL MODAL ANALYSIS TECHNIQUES APPLIED TO STRUCTURAL DYNAMICS

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ABSTRACT

The main goal of the present work is to analyze the experimental techniques used in modal analysis, and then apply those techniques to a structural car component in order to evaluate the parameters of the modal test. For this propose the experimental procedure and the equipment are analyzed, specifically the experimental equipment used in the vibration tests, shakers, accelerometers, impact hammers, force transducers, and the support of the structural component. This study will allow a better test performance which will lead to a better interpretation of the analysis results and of the most influent parameters.

The experimental modal analysis resorts to the LMS spectral equipment and SCADA-PC associated software: Test Xpress e Test Lab; in manner to obtain the dynamic response of the structure and identify its dynamic characteristics.

At the same time is determined the dynamic behavior of the structure using the finite element method through the commercial program ANSYS.

The experimental results are extracted by line-fit modal analysis and are used as reference for comparison with the numerical models developed.

Keywords: Structural Dynamics, Experimental Equipment, Modal Analysis

1. INTRODUCTION

A major concern in practical analysis of mechanical structures is to identify their dynamic characteristics, their natural frequencies and mode shapes. These dynamic characteristics are necessary in order to achieve an efficient design and control of the vibrations of structural components. Both finite element analysis and experimental modal testing can be used to obtain the dynamic characteristics required. However, advances in instrumentation and techniques for measuring vibration properties identified from experimental techniques are considered closest to the true

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representation of a structure, while the analytical prediction are considered less accurate because of the many structural uncertainties involved in the calculations. Response data in the frame and performing a subsequent modal analysis of these data, the modal parameters are accurate natural frequencies and mode shapes of the structure can be identified.

Modal testing can be performed using a variety of different experimental techniques. Accelerometer, shakers, impact hammers, and force transducers, measurement systems all have advantages and drawbacks, so each must be implemented where they will be most effectively employed. Accelerometers are by far the most traditional and widely used sensors employed in modal testing. Their ease of use allows for quick, broadband measurements to be made, however the effects of mass-loading (especially at higher frequency ranges or for lightweight structures) can corrupt a measurement.

The objective, in this work, to explore the characteristics of the various components used in experimental modal analysis, then apply the best experimental technique in a real case.

To achieve this goal, we present in this paper a more precise methods of analysis to be associated with the experimental modal analysis and is more concerned with the explanation of the analysis underlying conditions vai experimental modal.

2. DESCRIPTION OF THE EQUIPMENTS AND TECHNIQUES IMPLEMENTED IN MODAL ANALYSIS.

In experimental modal analysis test can be divided into several steps. First is to get an idea of the finite element dynamic characteristics of the structure. With this information, configuration settings may be able to test.

2.1. Fixing structure

The experimental modal analysis should be preceded by some important rules in order to determine more accurately the system response. The first decision to be made, for the testing of experimental modal analysis, will define how the structure will be supported. This definition is important because the experimental results may contain errors and procurement methodology that limit their validity. [1]

There are two ideal conditions of fixing the structure. At first, the structure is in a condition free body. In the second case, the structure is supported by a region of its contour by a totally rigid. Despite this condition, fixing the structure is simple analytic modeling, in practice it is difficult to apply in order to meet the modeling predicts.

In tests free body, the structure is effectively suspended by any means, for example, under conditions mild enough to hang elastic assume that the condition is true.

In the second case, the structure is constrained by a bracket which restricts certain degrees of freedom. This condition appears to be more complex and difficult implementation because, for example, there is always a degree of flexibility whereby the test structure is fixed. One possible way to verify these problems would be measured at the points of fixation the FRF of the base structure, in the frequency range of interest. Then checking whether this response is significantly lower than the response of the test structure. If this condition is satisfied for all coordinates in which it checks the condition of forced bond, can be considered as being rigid base. [1]

Structure completely limited to external loads efforts should be particularly checked to ensure that there is enough energy to excite the structure particularly in vibrational modes that occur at higher energy levels. In figure 1 is shown in the diagram to determine the conditions for the free body.

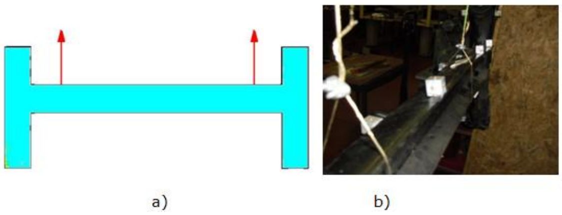

Figure 1 a) Scheme of setting conditions for free body**;** b) Experimental test image

In tests, the structure is suspended on two points with a steel wire of negligible mass in each projection, and conditions that allow binding behavior similar physical conditions free.

2.2. Components of the suspended structure

By applying a force to the structure by means of excitation system, as we single purpose of transmitting axial forces, giving full freedom to the structure in the direction concerned. This requirement applies to the fact that, by applying the force in a direction framework can respond with movement in all directions, if that does not happen we might also inadvertently introduce these directions.[2][3] To ensure an adequate excitation force is necessary to choose properly the Shaker, ensure the correct assembly of the system, and designed to ensure that nothing interfere with measurements.

Using an example, modal analysis free body is to hang an object suspended by strings of length *l* of negligible mass, and then excites through a conductor which is one of the most used methods. As shown in Figure 1.

This effect can be described by the oscillatory motion of motion equal to a simple pendulum, the mass of this body supposedly concentrated with good approach in order to be treated as a point mass. A simple pendulum consists of a particle of mass *m*, suspended by a thread length *l* and negligible mass as shown in Figure 2.

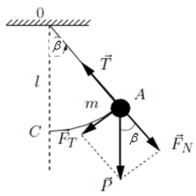

Figure 2 Simple Pendulum

The forces acting on the pendulum are Tension (T) in the wire and weight (P), which is in figure decomposed into its components tangential and normal (radial).

$$F = ma = mg \tag{1}$$

where g is gravity acceleration

$$|F_N| = |T| = ma_n = mg\cos\beta \tag{2}$$

$$|F_T| = ma_t = mg\sin\beta \tag{3}$$

where a_t is tangential acceleration and a_n is the normal acceleration

From figure 2 we have;

$$|F_T| = -ma_t = -mg\sin\beta\,, \leftrightarrow a_t = -g\sin\beta \tag{4}$$

The tangential component of the force $|F_T|$ have maximum value when β is maximum, and zero when $\beta = 0$. The inverse happens with normal component of force $|F_N|$.

Considering only angles where $\sin\beta = 0$ whit β in radians we have;

$$a_t = -g\beta \tag{5}$$

s is represented by arc length AC, as shown in Figure 2,we can write:

$$s = \beta . l, \text{ where } \beta = \frac{s}{l} \text{ and is the trajectory and is trajectory space} \tag{6}$$

Change equation (6) in equation (5) we obtain;

$$a_t = \frac{-g}{ls} \tag{7}$$

Do not forget that the tangential acceleration is the second derivative of the position so;

$a_t = \ddot{s}$

As a conclusion, the acceleration is directly proportional acceleration of gravity will and inversely proportional to the length of the wire.

Knowing further that the angular velocity is given by:

$$\omega = \sqrt{\frac{g}{l}} \tag{8}$$

we can say that the acceleration is directly proportional to the coordinated linear or angular.

Change equation (8) in equation (7) we obtain;

$$a_t = \omega^2 . s \tag{9}$$

Considering the mode of excitation of free body (Figure 1), equal to the motion of a pendulum (Figure 2), we conclude that the experimental modal analysis we make the free body must only take into account the tangential component of the disturbing force. Thus, in general, to select the correct driver can use is equation (1).

2.3. Experimental Instrumentation

2.3.1 Shakers

In experimental modal analysis, it is normal to use electrodynamic shakers. These devices induce an initial displacement followed by a sudden relaxation of the structure to vibrate freely. As the Shaker is attached to the structure to ensure minimum interference response of the structure, and also ensure that is the input signal of the system of mathematical equations. The right choice of excitation signal, is one of the essential steps for a proper analysis. The right choice of the excitation function depends on the signal analysis equipment, the characteristics of the structure, the accuracy of the desired results, and the excitation mechanism chosen.

Typically, the shaker is driven by a signal analyzer wich may have a large number of functions for excitation of the structure, as well as random excitation (random), sinusoidal excitation or transient.

In order to validate this conclusion resorted to the driver V200 Series Vibrators existing in Mechanical Engineering Laboratory (LEM), and analyzed the feasibility of their application in the excitement of the concrete structure.

In Table 1 can observe the reference values of the Shaker, which were used in the study on the parameters of the driver.

Table 1 Values of shaker

Parameters	Values
Force	17.8N
Frequency	5-1300Hz
Acceleration	890m/s^2
Displacement Peak to Peak	5mm
Amplitude	2.5mm

2.3.2 Impact Hammer

Another excitation equipment is the impact hammer, which produces a kind of transient excitation, and usually applied manually. The use of the impact hammer has many advantages, its use and transportation are convenient and cost is low. It is a convenient way to excite structures not too long, which can transmit the excitement as much as possible throughout the structure. Its poor implementation can be affected by noise or other side effects that seriously affect the quality of results. Another problem with the impact of existing tests is the possibility of multiple impacts registry analyzer. Various impacts may occur, for example, when the structure is lightly damped test therefore the structure can react against the hammer before it leaves the structure after the initial impact. [4]

Setting up a test using an experimental modal impact hammer is described in Figure 4.

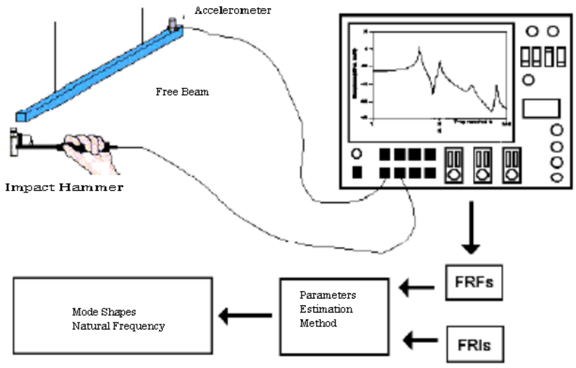

Figure 4 Scheme test using impact hammer**.(**Ricardo Sutério, 2010)

The range of frequencies for modal analysis is a function of the hardness of the contact surfaces and the ends of the hammer. In Table 2 can observe the reference values of the impact hammer, which were used in the experimental test.

Tabela 2 Values of impack hammer

Parameters	Values
Sensibility	11,2mV/N
Frequency Range(-10dB)	0-600Hz
Measurement Range	440NpK

Uses an edge soft to low frequencies and a harder for high frequencies.

2.3.4 Accelerometers

The mechanical response of a structure can be defined in terms of speed or acceleration. The acceleration has a more sensitive response that the velocity and displacement. For this reason, experimental modal analysis is preferable to use accelerometers to measure the response of a structure. Thus, in all cases, the accelerometer structure connection test should always be as rigid as possible. Given these considerations, as well as other requirements is important to select the accelerometers in each case. In Table 3 we see the reference values of the accelerometers were used in these experimental studies.

Tabela 3-Refernce values for accelerometers

Parameters	Values
Sensibility	10.2 mV/m/s^2
Frequency Range(15%)	0.5-3000Hz
Broad Band Resolution	0.0015m/s^2 rms

By the equation (10) we can know the minimum value for the acceleration possible to get good results.

, where A is the amplitude (10)

Relating the value obtained by equation (10) and the reference values of Shaker using equation (1), we find that he has the ability to excite structures with a mass up to 7Kg, with a frequency of 5Hz, considering the use of accelerometers with the resolution of 0.0015m/s2 rms. From this analysis we can conclude that the mass to excite should be up to 2.5 times the Shaker Force. Therefore, it was not possible to use this Shaker for the realization of the experimental modal analysis, because the model in study have 25 Kg.

3. EXPERIMENTAL PROCEDURES

3.1. Introduction

In real cases, the analytical solutions available are difficult to apply the same approximate solutions modeled using finite elements. In such cases, it becomes necessary to use experimental modal analysis. On the other hand, experimental analysis is essential to validate results and give credibility to the theoretical solutions developed.

The experimental procedures have been developed and improved to model a physical system, when subjected to dynamic type applications. However, these techniques are limited to technique and experience of the operators. For the system model under study by means of an experimental modal analysis (EMA), it is necessary to have a set of their response functions Frequency (FRFs). Experimental modal analysis is used to measure the dynamic behavior of the structure and to obtain the system frequency response functions (FRFs).

In this work case, it was decided to use a hammer to impact with fixed response, which leads to obtaining a clear line matrix FRF, which leads to obtaining francs column the matrix FRF.

3.2. Experimental test of an Industrial Application

In tests, the structure was suspended on condition free body. The assembly allows 6 rigid modes shapes, 3 translations and 3 rotations. We opted for this type of fastening part because, in addition to being easier to put into practice ensures that the system studied is not influenced by external factors. To perform the experimental modal analysis was used the following equipment:

Spectrum analyzer SCADAS III, impact hammer, three accelerometers with different sensitivities and the Software MODAL IMPACT LMS for modal identification.

There were three independent experimental tests with three different excitation points. The response of the structure was measured by the accelerometers in 25 points. The excitation points, Item 4, Item 6 and Item 8 were selected so as to permit excite all modes present in the structure under study (Figure5).

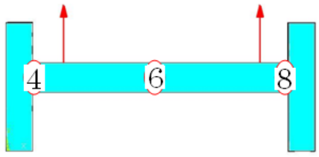

Figure 5 The excitation points

In experimental testing were performed 375 impacts to 3 different points of excitation in the three Cartesian directions global X, Y, Z. Figure 6 and Figure 8 presents the FRF diagrams of results obtained after the excitation at point 4 and 8 respectively, and we can see the natural frequency are similar. Figure 7 shows the values obtained for excitation at point 6, the central bar of the model.

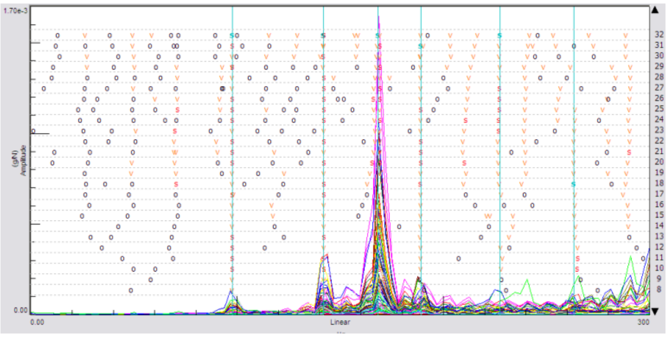

Figure 6 FRFs, excitation at point 4

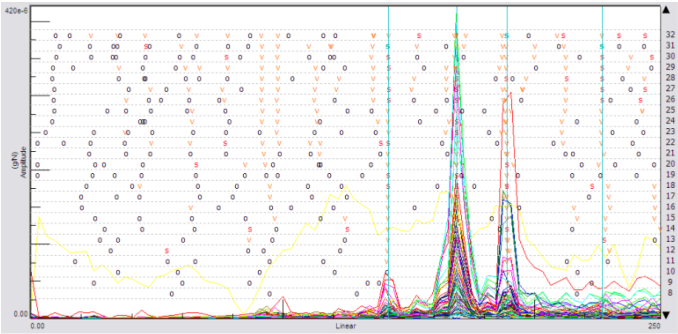

Figure 7 FRFs, excitation at point 6

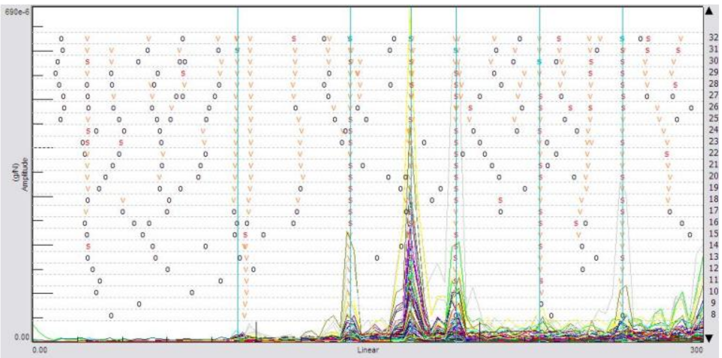

Figure 8 FRFs, excitation at point 8

It is possible to observe that the excite the model in point 6 we could not get the first frequency of vibration, because this corresponds to the torsion mode shape and the excitation point 6 does not allow cause torsion in the model. The second and the third ones are flexion modes and it is possible to get them in all diagrams.

4. CONCLUSIONS

A modal analysis aims at evaluating the dynamic characteristics of structural systems, based on analysis of their response, and measured experimentally, actions that typically they are subject. But the mass to excit should be up to 2.5 times the shaker force.

The mode shapes are closely related to the mode of parts and assembly or whatever their complexity. The proof is in the analysis in the central bar structure study showed that dynamic characteristics similar assembled and disassembled.

Once presented and understood the particularities of the various experimental modal identification techniques can be considered as advantageous to use more than one method to analyze the same information, for comparing the results with each other, is a good way validation of the conclusions of this analysis.

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