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A STUDY ON THE INFLUENCE OF FORCE EXCITATION FREQUENCY ON THE LOAD RECONSTRUCTION METHOD

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Abstract. Knowing the force that is acting on a given system is of great importance in engineering problems, when the system is exposed to unknown loads and if it is not possible to directly measure the force that is acting on the system it is necessary to use an inverse method to determination of these forces. The dynamic load reconstruction method uses a frequency domain analysis and Moore-Penrose pseudo-inverse of the frequency response function (FRF) of the system. The methodology consists in the application of dynamic loads in a finite element model in the time domain and to recover estimates of the loads at points that can not be measured directly and thus to evaluate the influence of the excitation frequency of the force in the method of study.

Keywords: Load reconstruct, Pseudo-inverse, Moore-Penrose.

1. INTRODUCTION

The problems of load reconstruction or identification it has been investigated for some decades and can be embedded within so-called inverse problems, where the outputs of the problems are available and from them are estimated their inputs. These problems can be very difficult to solve when it is not possible complete knowledge of the dynamic responses of the system. When it is not possible to obtain or measure a correct excitation conditions directly, for example, vibratory forces acting at the interface of two bodies, consequently the use of an inverse or indirect method to reconstruct the load history is necessary.

Regarding the direct or indirect determination of loading, a direct problem is understood as the one in which the applied forces are known and if it is desired to estimate the reactions in the supports. The inverse or indirect problem of load determination is when one wants to determine how many forces are applied, their location of application and their magnitudes (Maia, *et al.*, 2011).

One of the first investigations using pseudo-inverse of Moore-Penrose to solve load reconstruction problems was conducted by Barlett and Flannelly in 1979. They proposed a method of determining vibratory loads using only the vibration data of the fuselage of a helicopter and ground test, based on studies from manufacturers to increase their reliability and meet the needs of the US Army. Laboratory tests were carried out to verify the method and determine the vibrational forces of a dynamic helicopter model and in general obtained good results in which the errors of the forces predicted in the model were within the limits of instrumentation precision (Barlett and Flannelly, 1979).

Dobson and Rider presented a review of excitation forces indirect calculation techniques from the structural response data measured. They observed that many of the problems analyzed were due to the procedure of matrix inversion of frequency-dependent terms, because the frequency response function matrix (FRF) has poor conditioning near the resonance and anti-resonance conditions leading to significant errors (Dobson and Rider, 1990).

The work done by Vishwakarma, 2010, one of the recent in this subject, are presented two techniques in frequency domain that use the Moore-Penrose pseudo-inverses method for load reconstruction in order to evaluate the structural integrity of a missile model (Vishwakarma *et al.*, 2010). The methodology used in this work for load reconstruction is based on the first technique presented by him, the direct form of load reconstruction.

The paper presents an ongoing work that uses a technique to reconstruct the dynamic loads history by using a frequency domain analysis and Moore- Penrose pseudo-inverses of the frequency response function (FRF) of the system and from this, is studied the influence of force excitation frequency in this method.

There are four sections in this paper. Section 2 describes the computational procedure and methodology applied in this study. In Section 3 contain the case of study with results obtained. Finally, the concluding remarks are presented in Section 4.

2. COMPUTATIONAL PROCEDURE

A computational procedure was conducted, where initially, a full harmonic analysis was run using the software OptiStruct/HyperWorks (HyperWorks, 2013) in order to obtain the FRF matrix. The procedure consists in applying a unit load at free end of the finite element model and thereafter measuring the acceleration response in points and directions of interest for all frequencies in the range established. The study model as well as the directions and forces tested can be seen in the next section.

A full transient analysis was run, with a load curve is segmented into suitable load steps, in order to obtain the acceleration data. The load step files were composed by using a time step in seconds. Consequently, by solving the load step files, the acceleration in time data can be extracted from the nodes of the finite element model.

Then, the acceleration data are converted into the frequency domain through the FFT procedure applied to the data. From this we can calculate the forces in the frequency domain and then transform the data into the time domain applying the IFFT in them. Fig. 1 illustrates a flow diagram with the load reconstruction technique used in this study, where H is the FRF matrix, H^+ is the pseudo-inverse matrix of H, Y is the response matrix and F is the vector of reconstructed load.
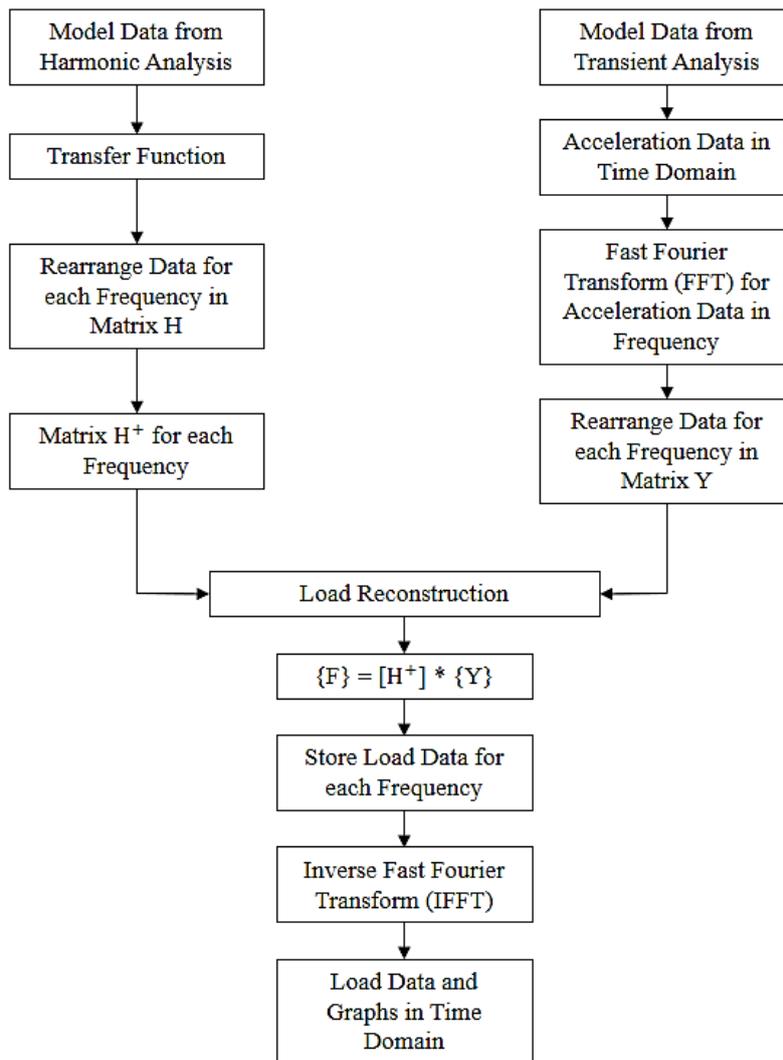

Figure 1. Load Reconstruction Process (Santos e Marczak, 2016).

3. CASE OF STUDY AND RESULTS

The case of study for load reconstruction is composed of one force applied to the cantilever beam model and sixteen measurement points as shown in Fig. 2. The measurement points chosen to obtain the answers are equidistant from each other, this distance is equivalent to L/17 of the total length (L) of the beam. The harmonic analysis for the FRF matrix assembly is performed for the 0-1024 Hz frequency range. The time interval used in the transient analysis was 0.00098 seconds. The force is applied in the y-direction and the results are extracted from the sixteen different points of the force application site. For the cantilever beam was considered a uniform square section, the properties of the material and geometric are described in table 1.

Table 1. Properties of the study model.

Modulus of elasticity - E	210GPa
Poisson's ratio - v	0.3
Density - ρ	7850kg/m^3
Length - L	1 m
Thickness - e	10 x 10^{-3} m
Width - b	10 x 10^{-3} m

In order to evaluate the influence of excitation frequency on the method of load reconstruction, two types of loads were applied to the study model. The applied and the reconstructed loads can be visualized in the subsections 3.1 to 3.2.
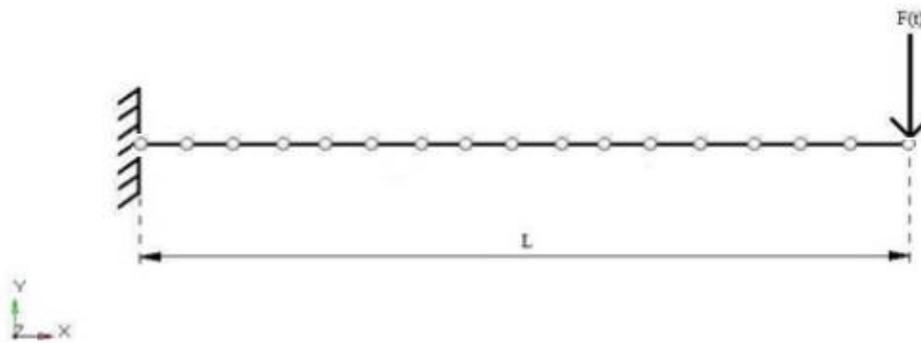

Figure 2. Representation of the model: a cantilever beam.

3.1 Force 1

Figures 3 and 4 illustrate the results obtained in the frequency and time domain, respectively, from the study method for a sinusoidal periodic load.

It can be noticed from the results that the applied method for resolution of the problem was able to reconstruct the load initially applied.
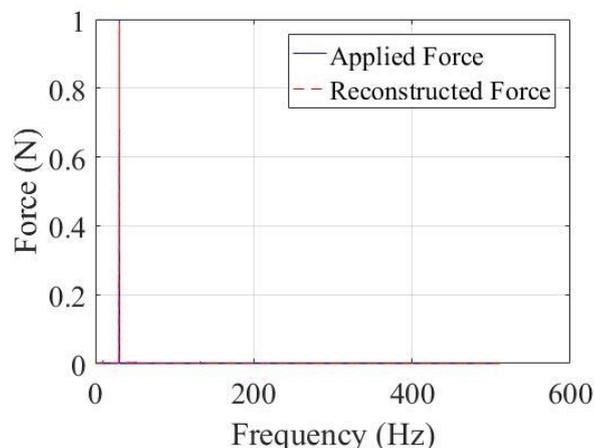

Figure 3. Comparison between the applied and reconstructed force in the frequency domain.
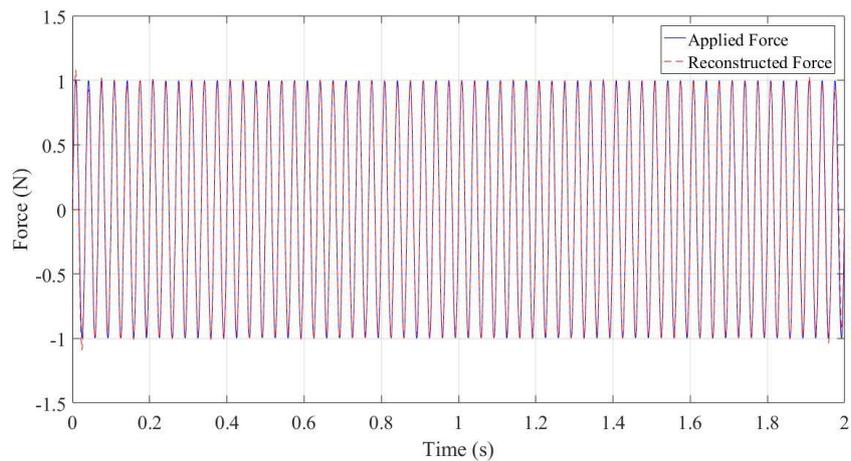
Figure 4. Comparison between the applied and reconstructed force in the time domain.

3.2 Force 2

A multi-sine signal was also tested, as can be seen in Fig. 5 and 6 the results obtained in the frequency and time domain respectively.
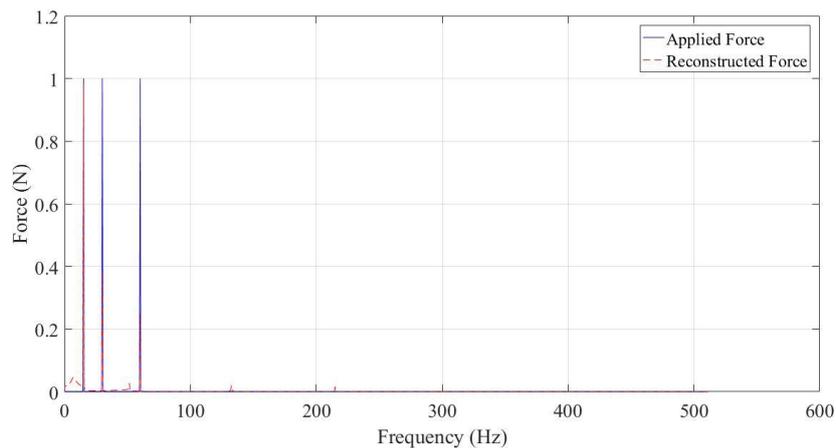

Figure 5. Comparison between the applied and reconstructed force in the frequency domain.

Evaluating Fig. 5, with the reconstructed signal in the frequency domain, it is possible to note that the frequencies were reconstructed, but the amplitude was only maintained at the lowest frequency present in the multi-sine signal.
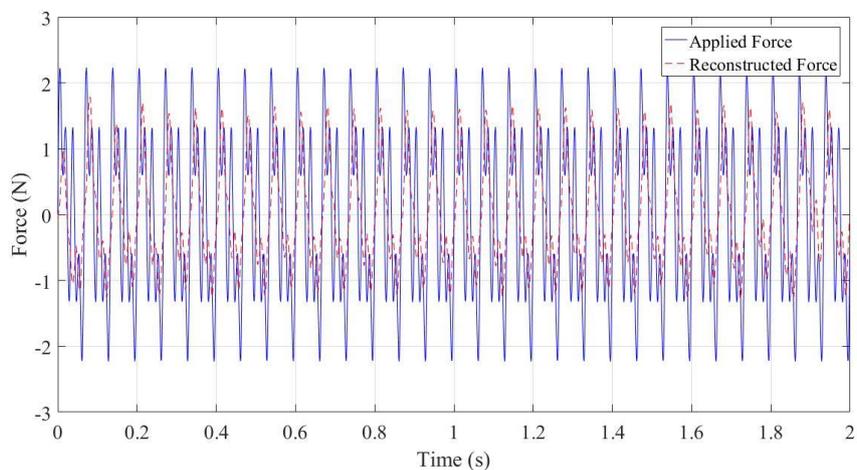

Figure 6. Comparison between the applied and reconstructed force in the time domain.

4. CONCLUSIONS

In this study, the influence of force excitation frequency on the load reconstruction method has been examined in two cases of load. In the first case the method was able to completely reconstruct the applied load, but in the second case the method was not able to reconstruct the magnitude of all the frequencies present in the load.

The loss of magnitude that occurred in the second case may be related to the frequency of the excitation force used to be within a bad conditioning range of the FRF matrix. According to Uslu, et. al., 2007, a high condition number at certain frequencies tend to make the results of the load reconstruction process unreliable.

Finally, it is still intended to evaluate the methodology for other types of load and the influence of the number of measurement points of the responses, considering the condition number of the FRF matrix.

5. ACKNOWLEDGEMENTS

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