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Experimental Stress Analysis

Using of Digital Image Correlation Method for Experimental Determination of Modal Parameters

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Abstract: High-speed digital image correlation system Q-450 is useful due to its properties also in the area of modal analysis. In the paper are described procedures of experimental determination of eigenshapes and eigenfrequencies of flat steel specimens by method of digital image correlation. In the paper are compared measurements of specimens excited by white noise and by modal hammer. At the end are described advantages and disadvantages of method of digital image correlation used for determination of modal parameters and recommendations that lead to improvement and simplification of measurement procedures.

Keywords: Experimental, Modal, Analysis, Digital, Image, Correlation

1. Introduction

Most of technical equipments are during their operation exposed beside of static also dynamic loading. In order to avoid resonances during transfer of mechanical vibration, it is necessary consider during design of equipment internal dynamic properties of its individual parts. Process of parameter determination is called modal analysis. In experimental modal analysis are the eigenfrequencies and eigenshapes determined from data measured by appropriate experimental method. Theoretical principle is based on relationship between excitation and response of a system in frequency area. For determination of modal parameters is possible to use method of digital image correlation (DIC), which is at present time due to its flexible design of measurement system often used in various areas of practice, development and research [1].

2. Digital image correlation and its using in modal analysis

Method of digital image correlation is a modern optical method designed for precise measurement of 3D displacements and strains by stereoscopic arrangement of cameras. The measurement systems are able to control large amount of surface points with variable contrast on object, which allows visualization of results (fields

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of strains and displacements) in whole searched area [2]. In modal analysis can be used correlation systems that are able to provide high-speed dynamical measurements with sensing frequency 1000 and more Hz.

Program environments of correlation systems do not contain analytical tools for determination of eigenshapes and eigenfrequencies of given object. Determination of modal parameters necessitates additional numerical processing of output data from measurement in different computer environment. Department of Applied Mechanics and Mechatronics TU of Košice has developed a special system in environment Matlab/GUI called Modan v.1.0. for system Q-450 Dantec Dynamics that simplifies postprocessing [3].

The base of experimental determination of eigenshapes and eigenfrequencies relies on appropriate excitation of given object. In order to gain the best possible results it is very important to use appropriate method and intensity of excitation. The most appropriate method by which are excited all eigenfrequencies at once is:

a) acoustic excitation by white noise,
b) mechanical excitation by modal hammer.

In acoustic is used the term white noise for a sound with constant intensity in whole range of frequency. It is stochastic process with infinite scattering so all modes are invoked.

During excitation by modal hammer is in action the impulse of force. The energy from hammer is a function of hammer momentum. Frequency range of excited energy depends mostly on stiffness of contact surfaces that influence shape of force impulse [4].

Fig. 1. Experimental determination of speciman modal parameters by system Q-450.

Intensity of excitation has to be sufficient enough in order to be able to measure all eigenshapes in whole range of measurement. In case of small intensity is increased influence of digital noise that breaks identification of some eigenfrequencies in average frequency spectrum of measured deviations.

Correlation system Q-450 (Fig. 1) records movement of surface of excited object by two cameras [5]. In program Istra4D that ensures all its functions are at process of correlation computed coordinates of surface points and their space deviations in every time step of measurement [6]. The results are stored as files of hdf5 files on hard disc of computer. Number of files of measurement corresponds to number of measurement steps. Files with results represent input data for Modan.

3. Modan v.1.0

Principle of algorithm was described into details in paper [3]. Its substance relies in frequency analysis of time charts of deviations of all points of object's surface. Charts of frequency deviations are determined by Fast Fourier Transformation (FFT). It ensures separation of individual eigenshapes. The first output is then graphical representation of average deviation frequency spectrum on the surface of object. Program identifies local maximums, so-called peaks that in general represents eigenfrequencies of object. As a next step is possible to draw adjacent eigenshape in appropriate scale.

4. Experimental determination of eigenshapes by DIC method

Object of measurement was cantilever flat steel specimen of rectangular shape with dimensions 200 x 250 mm and thickness 0,8 mm (Fig.2). On the surface of specimen was sprayed black and white spotted pattern. During first measurement was object excited acoustically by white noise (Fig.3a) by sound system that consist of generator of acoustic signal, amplifier and loudspeaker. In second case under the same conditions and configuration of measurement system was the object excited by modal hammer Bruel & Kjaer 8206 with PVC spike in the location according to Fig.3b. Frequency of sensing by cameras was in both cases 2000 fps and whole time of acwuisition was 2 seconds. The coordinates of surface points and their space deviations in all time steps were determined by program Istra4D of correlation system. Consequently were the files with results processed by Modan and there were drawn adjacent shapes for chosen frequencies.

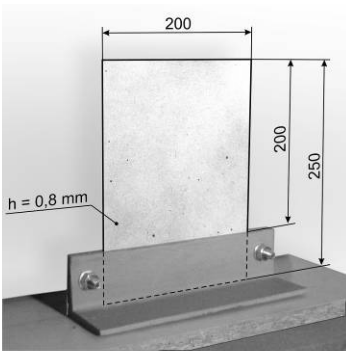


Fig. 2. Positioning of specimen and its dimensions.

In order to verify average deviation frequency spectrum determined by DIC method was the response of specimen in chosen point at the same time measured by sensor of acceleration Bruel & Kjaer 4507B. For the measurement was used system Pulse6. By using numerical integration was gained amplitude spectrum of accelerations transfered to spectrum of deviations. Such frequence charts were compared with charts gained from first measurement.

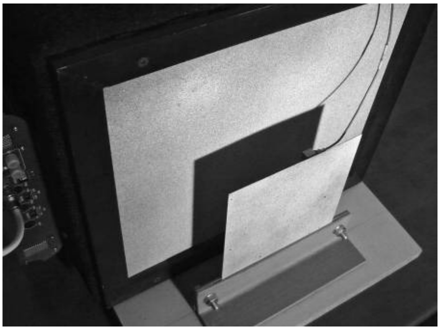


Fig. 3a. Excitation of specimen by acoustically acting white noise.

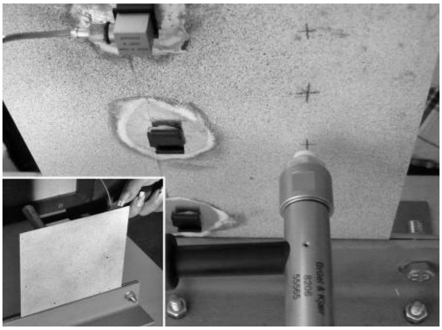


Fig. 3b. Excitation of specimen mechanically – modal hammer.

In Fig. 4 are depicted graphical representations of deviation frequencies during excitation by white noise. Deviation frequency charts from measurement with using modal hammer are given in Fig.5. From comparison of charts results that eigenfrequencies determined by method of digital correlation are in good correspondence with frequencies that were determined by system Pulse6. On the base of comparison of average deviation frequencies from excitation by white noise and excitation by modal hammer can be stated that the excitation by modal hammer gives amplitudes in orders bigger and there were excited also frequencies that were not remarkable for case of excitation by white noise. Shapes that correspond to these frequencies (not frequency 63,125 Hz) were substantially complicated and it was not possible to say if these are eigenshapes of specimen.

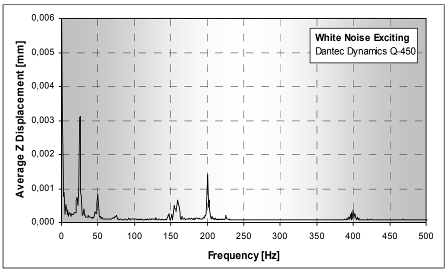


Fig. 4a. Frequence dependency of deviations measured by system Q-450 Dantec Dynamics excited by white noise.

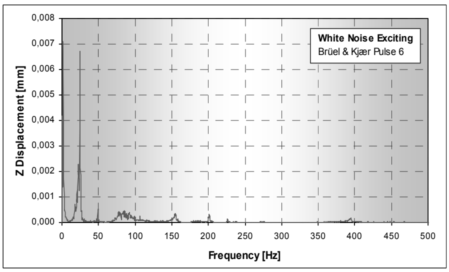


Fig. 4b. Frequence dependency of deviations measured by system Brüel & Kjær Pulse6 excited by white noise.

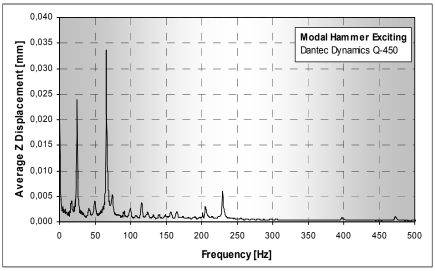


Fig. 5a. Frequence dependency of deviations measured by system Q-450 Dantec Dynamics excited by modal hammer.

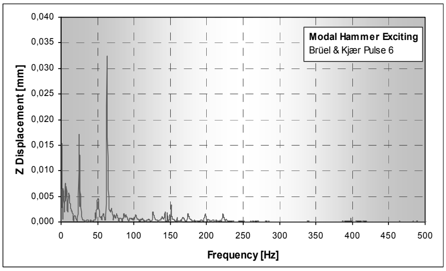


Fig. 5b. Frequence dependency of deviations measured by system Brüel & Kjær Pulse6 excited by modal hammer.

Chosen eigenfrequencies of specimen determined from average frequency spectrum of deviations of surface points are together with adjacent eigenshapes for both cases of excitation given in Table 1. For visualiyation was used 3 times smoothing of surface and in case of excitation by white noise was magnification scale 20000. Colour map of surface represents magnitudes of absolute deviations into direction of excitation i.e. direction of axis Z.

Table 1. Chosen eigenshapes of specimen (part 1)

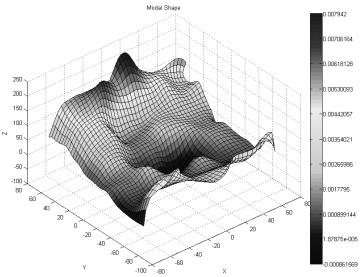
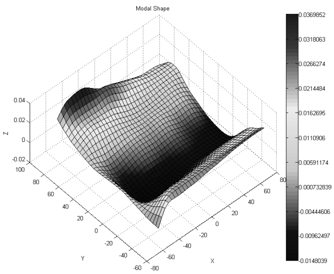
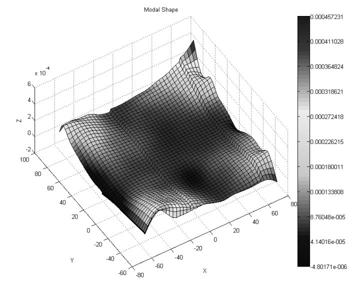
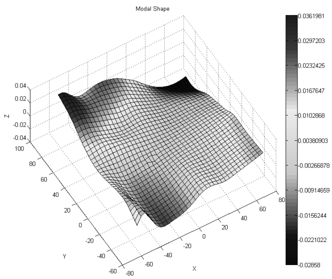
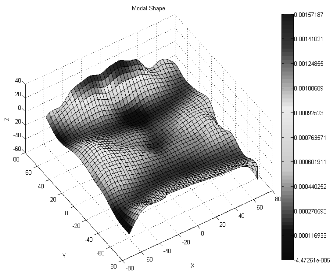
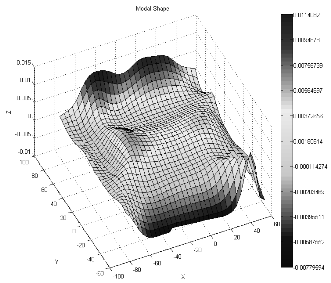
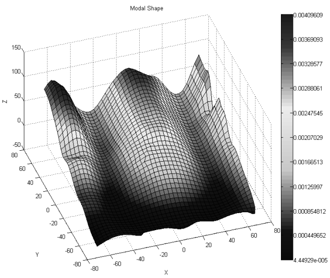
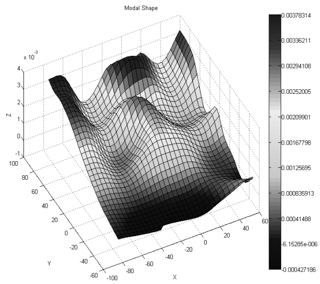
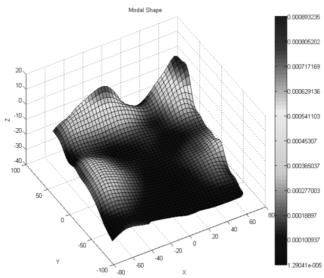
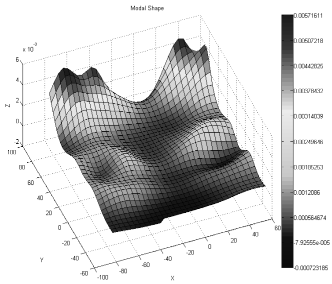
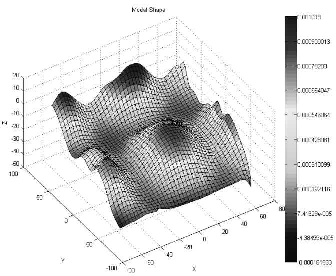
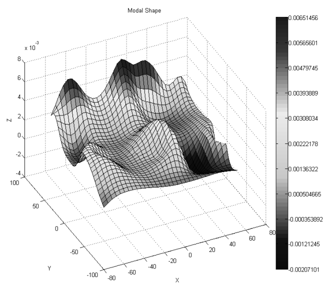
Frequency	Excitation by white noise	Excitation by modal hammer
25,4 Hz		
63,1 Hz		

Table 1. Chosen eigenshapes of specimen (part 2)

Frequency	Excitation by white noise	Excitation by modal hammer
158,8 Hz		
198,9 Hz		
224,8 Hz		
397,8 Hz		

From comparison of modal shapes that were determined by different methods are obvious certain differences. Despite of this fact are adjacent eigenshapes similar. Results of experiments show that the eigenshapes excited by modal hammer are in bottom part of frequency spectrum better then those excited acoustically. Contrary can be stated for high frequencies where are the amplitudes of average deviations remarkable smaller for excitation by modal hammer.

5. Conclusions

In the paper is described procedure of using digital image correlation method in experimental modal analysis. With the help of tool Modan designed for evaluation of measurement is possible to restrain process of experimental determination of eigenshapes and eigenfrequencies to one measurement due to effective excitation of all modes at once. Averaging frequency spectrum of deviations and quality of eigenshapes separated by spectral analysis of time series of all points depends on parameters of excitations.

In case of acoustic excitation depend the results of analysis on frequency range of excitation sound system, its power, dynamical sensitivity of loudspeaker as well as inertiality of its membrane that influence quality of sound signal reproduction. From the measurements results that in bottom boundary of frequence range where the level of acoustic power decreases are excited eigenshapes (despite of their simplicity in idealized case) more complicated and it is effortful to identify them unambiguously. It was demonstrated that the shapes excited in band of higher frequencies with sufficiently high acoustic pressure are unambiguous. Advantage of acoustic excitation bz white noise relies on permanent continual excitation of object during whole time of acquisition. On the other end, by excitation with modal hammer are gained amplitudes of deviations of surface points after impact smaller and smaller due to internal damping of object that influences resulting averaging deviation frequency spectrum.

Because the width of excitation spectrum depends on contact surface stiffness and intensity of excitation on mass and velocity of hammer, it is recommended to check time and frequency dependence of impact force by measurement.

Main advantage of digital image correlation in modal analysis lies in space visualization of eigenshapes of object determined by one measurement and at the same time it is possible to represent beside of resulting space shape of object also its components in directions X, Y and Z. Disadvantage are more rigorous demands for excitation. Restraints of modal analysis depend on technical parameters of correlation system used. Its image point density, sensitivity, frequency of sensing and hardware configuration influence precision of results and range of measurement.

In order to gain the best possible results is suitable to provide repeating measurements under constant conditions of experiment and results of all measurements process analytically together with coherence of time and frequency series of measured deviation amplitudes. Consequently it is necessary to improve properties and possibilities of program system Modan.

Acknowledgement

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References

[1] DANTEC DYNAMICS GmbH, "High Speed 3D Digital Image Correlation System," Publication No.: PI-Q-450_09_01.
[2] Becker T., Splitthof K., Siebert T. and Kletting P., "Error Estimations of 3D Digital Image Correlation Measurements," Dantec Dynamics/Technical Note (2008).
[3] Huňady R., "Návrh algoritmu pre spracovanie a vizualizáciu výsledkov modálnej analýzy," in *Novus scientia 2009*, Košice, November 2009 (SjF TU Košice, Košice, 2009), pp. 394-399. ISBN 978-80-553-0305-5.
[4] Inman D.J., *Vibration with Control* (Virginia Tech, John Wiley & Sons Ltd, Chichester, 2006). ISBN 978-0-470-01051-8.
[5] Trebuňa F. and Šimčák F., *Príručka experimentálnej mechaniky* (TypoPress, Košice, 2007), 1526 s. ISBN 970-80-8073-816-7.
[6] DANTEC DYNAMICS GmbH, "Istra4D / Software Manual Q-450 System" (2008).