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The application of motion magnification method in 3D digital image correlation

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Abstract. The paper deals with an application of phase based motion magnification and its using in high speed digital image correlation. The aim is to use the magnification method to magnify vibration motion of an investigated structure at specific frequency when the excitation level or response level is low. Three measurements were performed. As the first one, experimental modal analysis was performed to find natural frequencies and mode shapes of the investigated object. Subsequently, the measurements of vibration responses of the object were performed by digital correlation system under the low and high-level excitation, when the object was excited by harmonic signal with frequency corresponded to natural frequency of a chosen mode. The video sequences captured under the weak excitation were subsequently magnified and the results were compared with the measurement done under the strong excitation.

Introduction

Optical methods are used more often than before in field of engineering. The optical methods have many advantages. The current trend and highly discussed topic is computer vision in interdisciplinary scientific field. Many scientists deal with this subject. In this paper, the phase-based motion magnification technique is used to magnify mode shape when the excitation is weak. The phase-based motion magnification method was researched to make subtle motion to be visible from video and it is an extension of techniques motion magnification and Eulerian motion magnification [1], [2], [3]. The base of this techniques is an analysis of motion or colour changes in complex-valued image pyramids. Authors present their approach as microscope for changes in videos. The application of phase-based motion magnification method in mechanical engineering can be found in publication [4], where authors determine operational deflection shapes and natural frequency of cantilever beam and pipe. The response is measured by accelerometer, laser vibrometer and displacement is derived from motion caught by high speed camera. The time series from accelerometer and laser vibrometer were integrated to obtain displacement. The all results are compared with each other. They rated the noise floor in the signal, too. A.J. Molina-Viedma et al. [5] determined mode shapes of cantilever beam excited by dynamic shaker by harmonic signal and they measured responses by digital image correlation system. In this work, the application of motion magnification in frequency domain is being studied.

Proposed procedure

As the first, the experimental modal analysis was performed order to find suitable mode for magnification. Then the structure was excited via vibration shaker by harmonic signal with frequency correspond to natural frequency of the chosen mode with two different excitation levels.

The process of measurement with DIC – Q450 Dantec Dynamics

The process of measurement with DIC consists of follow steps. A stochastic pattern has to be applied on the surface of investigated structure to ensure the correlation. It is necessary to set the cameras to the investigated object and to calibrate the device using a calibration target. Istra 4D is control software for the correlation device, where calibration, acquisition and correlation are done. Frames captured by two cameras are stored in cameras' memory and then transferred to the computer via LAN interface. The series of images with specific frame rate is a video. The region of interest is selected. The following image matching process is called correlation. The displacement and deformation fields are the results of the correlation process. In the case of experimental modal analysis, the measurement was started automatically after the hit of impact hammer. Manual acquisition was used for measurements with shaker.

Experimental modal analysis

The object of interest was steel rectangular plate with dimension 250 x 180 mm. The plate was attached to a vertical stand in the center of the plate through a screw connection. The responses were measured by DIC system Q450 Dantec Dynamics with two high speed cameras. Frequency rate of cameras was set up to 3600 Hz. The frequency range of measurement was 0-1800 Hz. A stochastic pattern was sprayed onto the surface of the plate to ensure image correlation process. The excitation was done by the impact hammer Bruel & Kjaer Type 8206 hitting on the rear side of the object. Measurement chain is shown in Fig. 1. The evaluations were performed in DICMAN 3D [6]. The complex mode indicator function (CMIF) plot obtained by experimental modal analysis is shown in Fig. 2. There are lot of peaks that represent the presence of natural modes. The mode with the frequency 880 Hz was chosen for further analyses. Its mode shape is also shown in Fig. 2.

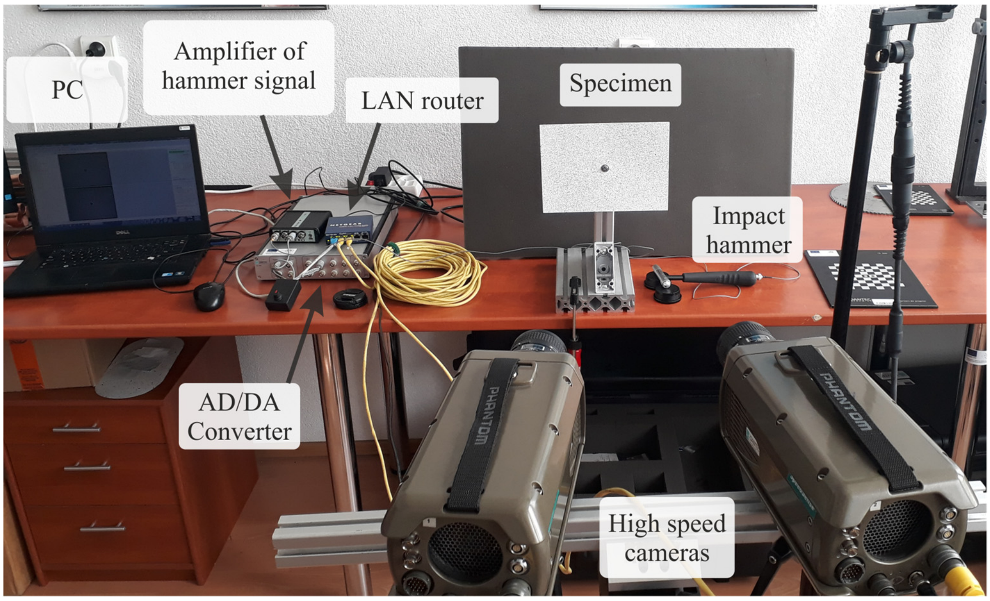

Fig. 1: Measurement chain

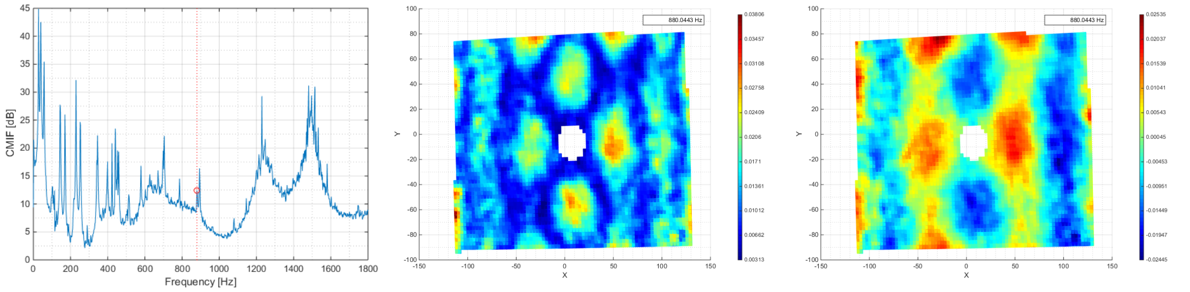

Fig. 2: Modal analysis results: CMIF function (left), absolute shape of the chosen mode (middle), real shape of the chosen mode (right)

Harmonic excitation of the object

The specimen was attached to dynamic shaker Veb Robotron type 11076 and excited by harmonic signal with the frequency 880 Hz. Two measurements were performed, when the structure was excited with high-level and low-level of excitation, separately. Both measurements were performed under the same conditions, only the amplitude of excitation was changed. The evaluation process was done in DICMAN 3D. The CMIF function from high-level excitation measurement is in Fig. 3. There is a significant peak on the frequency corresponding to the excitation frequency. Corresponding mode shape is shown in Fig. 3. This mode is excited very well, which is also evident from the clearly recognizable shape of vibration.

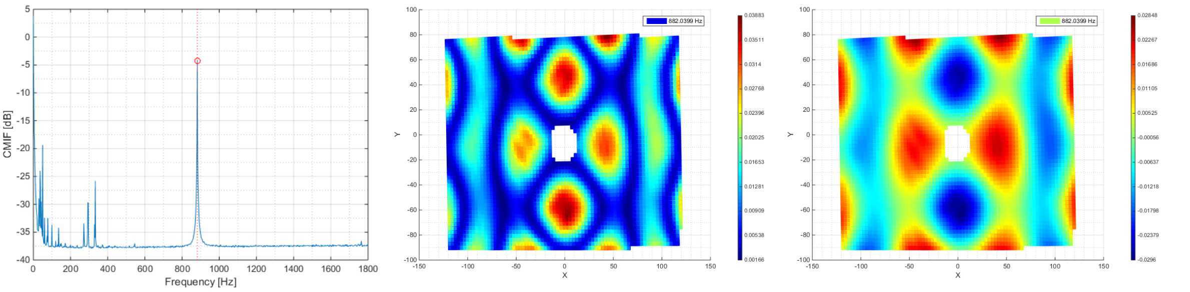

Fig. 3: The results for high-level excitation: CMIF (left), absolute mode shape (middle), real mode shape (right)

In Fig. 4, the results of the measurement under low-level of excitation are shown. As can be seen in CMIF plot, the magnitude of the peak at excitation frequency is much smaller than in the previous measurement. It is due to smaller level of the excitation. Since the mode is not sufficiently excited, its shape is noisier. Video sequence from this measurement was subjected to phase-based motion magnification.

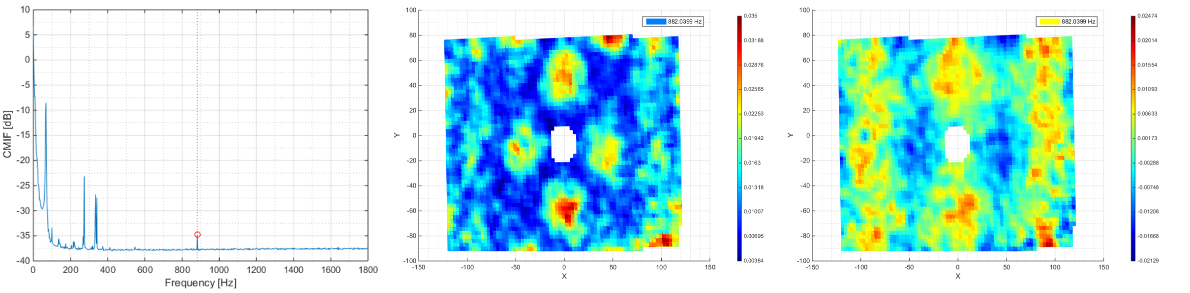

Fig. 4: The results for low-level excitation: CMIF (left), absolute mode shape (middle), real mode shape (right)

Motion magnification was applied on videos recorder by both cameras. After applying magnification, the videos have been subjected to correlation process in ISTRA 4D and fields of displacements were subsequently process by DICMAN 3D. CMIF function, absolute and real shape of vibration after the magnification are shown in Fig. 5.

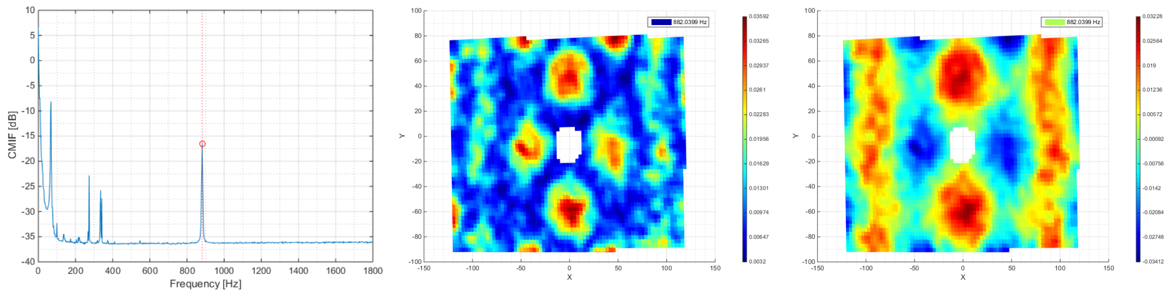

Fig. 5: The results for low-level excitation after the magnification: CMIF (left), CMIF (left), absolute mode shape (middle), real mode shape (right)

Modal phase collinearity (MPC) describes the spatial consistency of the identified mode shapes and it is an indicator which quantifies the collinearity of the phase angle in the identified mode shapes and determines their accuracy. The MPC values are ranged from 0 to 1, where 0 indicates a complex mode, and 1 represents a perfect in-phase (normal) mode. The MPC factors of the analysed mode for all three measurements are listed in Table 1.

Table 1: Comparison of MPC factors of the analysed mode from all measurements.

Mode: 880 Hz	Modal analysis	High-level excitation	Low-level excitation	After the magnification
MPC	0.53474	0.9818	0.6485	0.74445

Discussion and conclusions

The application of motion magnification in digital image correlation seems to be very effective technique that allows to improve the responses of the structure. It can be used in the cases, when the excitation is nonsufficient, or response is too weak or loaded with higher noise. In the paper, the phase-based magnification method was used to magnify the chosen mode of the analysed structure that was excited by low-level harmonic signal with the frequency of the mode. The magnified video sequences were imported back to correlation software and subsequently used to calculate the 3D displacement fields of the magnified vibration response. After the magnification, the shape and MPC factor of the given mode were improved. The resultant quality depends on the settings of parameters such as frequency width, gain, filter type, bandwidth, etc., by which the magnification is controlled. Their influence will be detaily investigated in the further work.

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