



3D digital image correlation methods for full-field vibration measurement

Mark N. Helfrick^a, Christopher Niezrecki^{a,*}, Peter Avitabile^a, Timothy Schmidt^b

^a Department of Mechanical Engineering, University of Massachusetts Lowell, One University Ave, Lowell, MA 01854, USA

^b Trilion Quality Systems, 200 Barr Harbor Dr., Suite 400, West Conshohocken, PA 19428, USA

ARTICLE INFO

Article history:

Received 31 January 2008

Received in revised form

9 August 2010

Accepted 27 August 2010

Available online 24 September 2010

Keywords:

Digital image correlation

Full-field measurement

Vibration measurement

Mode shape correlation

Modal testing

ABSTRACT

In the area of modal test/analysis/correlation, significant effort has been expended over the past twenty years in order to make reduced models and to expand test data for correlation and eventual updating of the finite element models. This has been restricted by vibration measurements which are traditionally limited to the location of relatively few applied sensors. Advances in computers and digital imaging technology have allowed 3D digital image correlation (DIC) methods to measure the shape and deformation of a vibrating structure. This technique allows for full-field measurement of structural response, thus providing a wealth of simultaneous test data. This paper presents some preliminary results for the test/analysis/correlation of data measured using the DIC approach along with traditional accelerometers and a scanning laser vibrometer for comparison to a finite element model. The results indicate that all three approaches correlated well with the finite element model and provide validation for the DIC approach for full-field vibration measurement. Some of the advantages and limitations of the technique are presented and discussed.

Published by Elsevier Ltd.

1. Introduction and motivation

There has been a significant amount of effort expended in the development of test and analysis tools for the correlation and updating of analytical models used for structural dynamic predictions over the past twenty years. In that time, many model reduction methods [1–5] have been developed for correlation to determine the adequacy/accuracy of the models developed. In addition, there have been many approaches developed to provide expansion of measured mode shapes [1–5] necessary for the updating methodologies employed to refine models. Model reduction and expansion has been the “Achilles Heel” in the overall process. The severe mismatch between the relatively few measured degrees of freedom (DOF) for the test data when compared to the finite element model has been a roadblock to the efficient and effective correlation and updating of these analytical models.

Over the past two decades, there has been a tremendous growth in the models developed, whereas the corresponding test data has not grown at such a fast pace. In the 1980s, the number of measurements made might be as high as 100 triaxial measurement points, while the model may have been as large as 200,000 DOF. At that time, this mismatch was a significant hurdle that needed to be addressed. Many reduction/expansion algorithms were developed to provide the best possible matching between these data sets. Today, the number of measurement points may have only grown to as high as 450 triaxial measurement points, whereas the finite element model has grown to well over a million DOF in many

* Corresponding author.

E-mail address: Christopher_Niezrecki@uml.edu (C. Niezrecki).

applications. Suffice it to say that the model size has grown much faster than the corresponding test model size, further complicating the mismatch in model size for test/analysis/correlation.

Many full-field vibration measurement techniques do exist and are used today. Common ways to obtain vibration measurements include using a wide array of accelerometers and the properties of a monochromatic light source such as a laser. The latter method includes numerous techniques including a scanning laser vibrometer, digital speckle shearography, (DSI), electronic speckle pattern interferometry (ESPI), and holographic interferometry [6–9]. Full-field measurement of vibrating structures is typically conducted by either attaching an array of numerous sensors to the structure or by performing roving accelerometer (or modal hammer) measurements. Unfortunately, the use of accelerometers will mass load the structure and can only provide the same number of measurements as the number of accelerometers available. If a roving measurement is made, a significant amount of measurement time is required and the force excitation provided to the structure may not change during the test.

Holographic interferometry is a well established optically based measurement technique that allows scattered light from a structure to be recorded and superimposed with light from that same structure measured at another instance in time. If the structure experiences a deformation, the relative phases of the recorded images will cause observable interference patterns throughout the field of view. As a structure vibrates, holographic interferometry is able to map the one dimensional contours (fringes) of the vibration pattern from which mode shapes can be inferred. Bands of points which have common light intensities represent displacement isolines. The technique is well suited for high frequency measurement (> 20 kHz) where traditional accelerometers are not as effective. Although, it is possible to extract quantitative measurements, obtaining absolute displacements for a structure is somewhat cumbersome and not widely performed in the vibration community. The technique is however well suited to providing a qualitative representation of the vibration patterns of a structure at prescribed operating frequencies. Numerous examples of holographic interferometry measurements on vibrating structures and further discussion of holographic interferometry can be found in the following references [8–14]. DSI and ESPI are similar to holographic interferometry and can provide full-field measurement to visualize static and dynamic displacements of structures with optically rough surfaces. ESPI has been shown to provide well-correlated mode shapes and could be used as an alternative to laser Doppler vibrometry when high spatial resolution is desired [15]. In addition to stationary testing, ESPI using a pulsed-laser source can measure in-plane heat- and centrifugally-induced displacements of components rotating with tangential velocities up to 300 ms^{-1} [16]. For rotating structures, shearography has been shown to be more resilient to rigid body motion than ESPI or holographic interferometry and may be better suited for industrial applications [17,18]. A drawback for the optical techniques mentioned is that they only directly provide relative displacements and are limited to measurement along a single axis. For example, the authors have previously worked with laser holographic data on turbine blades that are used to compare/correlate to finite element models and for statistical evaluation of replacement blades. The lack of 3D data is one of the critical stumbling points when evaluating this type of data. Many times it is difficult to distinguish different modes when only the one-dimensional data are available.

Scanning laser Doppler vibrometers (LDVs) are commonly used in the vibration community to measure the velocity of a surface over a broad area of interest. The laser light reflected back to the sensor from the structure is compared to a reference beam and a relative shift in frequency between the beams will correlate to the surface velocity at the beams location. As opposed to the other optical techniques, a measurement at only one point on the structure's surface is made at a time, leading to long duration measurements. Likewise, the vibration levels during the entire scan needs to be consistent. To address the lengthy acquisition time, Continuously Scanning Laser Doppler Vibrometers (CSLDV) and Fast Scan SLDV (FS-SLDV) were developed and have been shown to provide accurate measurements using a variety of excitation types. Rather than pausing at each discrete measurement point, a CSLDV sweeps the measuring beam over the area of interest while simultaneously making a measurement. Alternatively, the FS-SLDV method is a direct extension of the conventional SLDV that makes measurements at discrete points. The differentiating feature is that the dwell time at each point is optimized depending on the number of response cycles needed to obtain a good measurement [19]. These two techniques have been extended to modal analyses using impact and pseudo-random excitations [20]. CSLDV can also be used to measure the vibration response of rotating structures [21]. To date, CSLDVs are primarily used for research and have not been made commercially available. Although three dimensional scanning laser vibrometer can provide 3D data at a wealth of points, the equipment is very expensive and can only make measurements in an asynchronous manner. Additionally, all measurement methods employing one or more lasers are especially vulnerable to small shifts in experimental setup during measurement and performance suffers when large rigid body motion in the structure is present. A measurement method that can provide a three dimensional quantitative measure of a vibrating surface over a large area in a simultaneous manner, without being sensitive to rigid body motion would be very beneficial.

Today, three-dimensional digital image correlation (DIC) techniques have come a long way from their conception in the 1980s. Images taken from a stereo pair of charge coupled device (CCD) cameras can be used to determine surface geometry and displacement in three dimensions of any object whose surface has had a contrasting speckle pattern applied to it. This non-contact full-field technique can take measurements at thousands of points on the surface of an object in a single snapshot.

With this abundant wealth of information now available from test, the ability to perform meaningful correlation with large scale finite element models is greatly improved. This paper presents traditional data that was obtained from a previously tested dryer-cabinet panel and compares it to newly acquired data using the DIC approach as well as data

Download English Version:

<https://daneshyari.com/en/article/559735>

Download Persian Version:

<https://daneshyari.com/article/559735>

[Daneshyari.com](https://daneshyari.com)