Mechanical Systems and Signal Processing 98 (2018) 968–999

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Broad frequency band full field measurements for advanced applications: Point-wise comparisons between optical technologies

Alessandro Zanarini

University of Bologna, School of Architecture and Engineering, DIN - Industrial Engineering Dept., Mechanics of Machines, Viale del Risorgimento 2, I-40136 Bologna, Italy

A R T I C L E I N F O

Article history:
Received 13 August 2016
Received in revised form 9 April 2017
Accepted 24 May 2017
Available online 8 June 2017

Keywords:
Full field vibration measurements
Full field FRFs
Full field ODSs
Rotational dofs
Experimental dynamic strain & stress maps
Spectral methods in fatigue life assessment
Model updating
Full field EMA
Optical metrology
SLDV
Hi-Speed DIC
Dynamic ESPI

A B S T R A C T

The progress of optical systems gives nowadays at disposal on lightweight structures complex dynamic measurements and modal tests, each with its own advantages, drawbacks and preferred usage domains. It is thus more easy than before to obtain highly spatially defined vibration patterns for many applications in vibration engineering, testing and general product development. The potential of three completely different technologies is here benchmarked on a common test rig and advanced applications. SLDV, dynamic ESPI and hi-speed DIC are here first deployed in a complex and unique test on the estimation of FRFs with high spatial accuracy from a thin vibrating plate. The latter exhibits a broad band dynamics and high modal density in the common frequency domain where the techniques can find an operative intersection.

A peculiar point-wise comparison is here addressed by means of discrete geometry transforms to put all the three technologies on trial at each physical point of the surface.

Full field measurement technologies cannot estimate only displacement fields on a refined grid, but can exploit the spatial consistency of the results through neighbouring locations by means of numerical differentiation operators in the spatial domain to obtain rotational degrees of freedom and superficial dynamic strain distributions, with enhanced quality, compared to other technologies in literature. Approaching the task with the aid of superior quality *receptance* maps from the three different full field gears, this work calculates and compares rotational and dynamic strain FRFs. Dynamic stress FRFs can be modelled directly from the latter, by means of a constitutive model, avoiding the costly and time-consuming steps of building and tuning a numerical dynamic model of a flexible component or a structure in real life conditions. Once dynamic stress FRFs are obtained, spectral fatigue approaches can try to predict the life of a component in many excitation conditions. Different spectral shaping of the excitation can easily be used to enhance the comparison in the framework of any of the spectral approaches for fatigue life calculations, highlighting benefits and drawbacks of a direct experimental approach to failure and risk assessment in structural dynamics when dealing with complex patterns in real-life testing.

Are optical measurements and spatially dense datasets really effective in advanced model updating of lightweight structures with complex structural dynamics? The noise shown in the raw signal of some experiments may pose issues in proficiently exploiting

---

E-mail address: a.zanarini@unibo.it
URL: http://www.diem1.ing.unibo.it/personale/zanarini.

http://dx.doi.org/10.1016/j.ymssp.2017.05.035

the added data in a fruitful model updating procedure. Model updating results are here compared between scanning and native full field technologies, with comments and details on the test rig, on the advantages and drawbacks of the approaches. The identification of EMA models highlights the increasing quality of shapes that can be obtained from native full field high resolution gears, against that (some time unexpectedly poor) of SLDV tested.

1. Introduction

From their beginning [1] full field measurements were showing the other side of the structural dynamics: a highly detailed spatial domain against the lumped sensor placement, with surface operative deflection shapes rapidly changing from frequency to frequency, functions of the complex superposition of the eigensolutions in non-conventional patterns, giving relevant information on where to better locate the lumped vibration sensors or strain-gauges. With the recent development of the digital processing of optical measurement results it appears possible to have access to reliable full field quantitative data [2].

A non-native full field instrumentation like the Scanning Laser Doppler Vibrometer (SLDV) has expanded the technique of contact-less point measurement in time/frequency domains to a fine grid of locations, thus extending the concept of the velocity sensors to a detailed acquisition, also adding no mass to the specimen. Thus SLDV is nowadays the reference when the need of spatially detailed FRF measurements for NVH tools is demanded, because SLDV has kept the same peculiarities of previous technologies and proven procedures. Native full field technologies, those based on an imaging sensor that acquires information synchronously at every point, approach the measurement from the point of the acknowledged quality obtainable in the spatial domain, especially in terms of consistency of the deflection field in the neighbouring points, as investigated by the author in the recent past [3,4]. Electronic Speckle Pattern Interferometry (ESPI) gives nowadays [4–6] an extremely accurate displacement field at the single frequency of interest; but having populated data in a broad frequency band can be prohibitive, due to time-consuming stepped sine excitation/acquisition. Digital Image Correlation (DIC), with high-speed cameras, has good detail in the time resolved displacement maps, but can be more limited in the frequency domain, due to the specifications of the cameras, which, though, are seeing rapid electronics improvements; the extraction of the correlated fields is still very time demanding. Whether ESPI or DIC is used, broad frequency band *receptance* FRFs can be successfully extracted also from native full field technologies [6,7]. Native Full Field FRFs can be the strong link between advanced experimental analysis and numerical modelling, adding highly consistent and detailed fields to proven NVH approaches and fatigue life, reliability or integrity predictions, giving an alternative to the SLDV technology, with successful applications [8–15].

Extensive and comparative research work has been carried out by the author at Vienna University of Technology, Austria, with the project TEFFMA[1] to assess advantages and drawbacks of today full field measurement techniques (SLDV, DIC, ESPI) on a common experimental set-up, where Full Field FRFs have to be extracted in a broad frequency range, as briefly described in Paragraph 3, whereas also recent works [16,17] are limited to DIC and LDV only.

The first contribution of this paper is the extensive overview of accurate and high resolution impedance model for *receptance* FRFs, described and discussed in detail in Paragraph 4, with emphasis on the accurate point-wise comparison on SLDV, Hi-Speed DIC and dynamic ESPI, which makes it possible to precisely match the results of different gears on the same set-up and same physical location. It gives thus the opportunity to underline the high quality, benefits and drawbacks of experimental models nowadays obtainable from optical techniques in vibration engineering, starting from the selection of proper test references.

Many times the rotational degrees of freedom (dofs) are disregarded for complexity or burden of their measurement, while are recognized as relevant [18,19] for the successful build of a reliable dynamic model for complex structures. Also, it is common practice, when dealing with structural dynamics in fatigue predictions, to assess dynamic strains by means of lumped strain measurements and finite element models: few strain gauges are placed on the structure and the numerical model is paired with the measurements to simulate the distribution of strains, eventually of stresses with constitutive parameters of the material. But more than a question may arise: where should we locate the gauges? Are we doing a complete tuning of the numerical model, or just a qualitative pairing with the tests? Can we do better to enhance the estimation of the whole dynamic behaviour [3,4,6,20], and finally of the structural reliability prediction [7–10,21,22] of the components?

One possible path in advancing failure analysis is to raise the quality of the numerical models by means of better assumptions in the formulation of the elements and a closer geometrical relationship with the actual component (as really manufactured, not only on drawings), by means of extensive material tests and overall model updating, to tune the numerical model on the structural dynamics responses, such as displacement, velocity or acceleration measurements in many points

---

[1] A. Zanarini, Experienced researcher at Vienna University of Technology, Institute of Mechanics & Mechatronics, Austria, for the project TEFFMA - Towards Experimental Full Field Modal Analysis, financed by the Marie Curie FP7-PEOPLE-IEF-2011 PIEF-GA-2011-298543 grant from 1/2/2013 to 31/7/2015.