Parameter Sensitivity in Experimental Wave Propagation Studies with Beam like Structures: Shadow of Chaotic Scattering in Continuum Structural Dynamics?

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Summary. Chaotic scattering is one of the most underlining nonlinear dynamics phenomena in quantum mechanics. Traditionally it is studied either from a classical particle dynamics standpoint or/and from a wave functions one via Schrödinger's linear wave equation. Chaotic scattering of waves, referred to as wave chaos, is thus possible in linear elastic media with local anomalies since the latter support wave propagation. In continuum linear mechanics chaoticity-ergodicity stems from ray splitting dynamics on the scatterer, either in the form of material or geometry anomaly. In our experiments-targeted for damage diagnostics-with flexible beam structures, we have found cases of irregular sensitivity of Collocated Acceleration Signals (CAS) on the parameters of sequentially distributed excitation pulses (modal hammer-induced) and cases with no sensitivity at all. We claim that the detected irregular sensitivity of CAS databases is the shadow of chaotic scattering of propagating elastic waves from local damaged areas.

Introduction

In structural engineering applications we come across structures of a dominant dimension which in turn is spanned by a varying cross-section, for example a blade or wing. These important structures can develop during service fatigue damage under stress rising local areas in addition to impact-induced fracture damage. In theoretical investigations and in practice, wave propagation is used as a means to detect damage. Extreme sensitivity to the parameters of the excitation source would not be desired in a damage detection scheme. *However, the phenomenon of chaotic scattering could lurk and render the dynamics sensitive, and thus difficult to interpret wave measurements in complex structures*. The dynamics phenomenon of chaotic scattering of waves is the most basic underlining dynamics phenomenon encountered in quantum mechanics [1,2]. The governing equation is Schrodinger's equation, which is a linear wave equation. Thus chaotic scattering is possible in linear elastic media. Here chaos is due to the splitting of rays interacting with the boundaries [2,3,5]. These studies deal with wave chaos in small scale elastic media [2,3]. In this work, we deal with experimental wave propagation in beam like structures. Our protocol of pulse interrogation, leading to the collection of collocated acceleration signals (CAS), leads us to the detection of extreme excitation parameter sensitivity of the POD modes of CAS databases. The sequential pulse interrogation method parallels the classical scattering analysis one [1].

The Experimental Collocated Accelerations Signals Approach

Figure 1 is a photographic view of beam like structures we use in our experimental studies. We collect information on free dynamics by the following method: We apply sequentially-with sufficient rest time between pulses-pulses by a modal hammer over a set of points marked on a properly selected material curve on the beam surface. The sequential pulse induced responses of the structure are sampled simultaneously at three locations by state of-the-art accelerometers. This kind of transient dynamics response is referred to as collocated acceleration signals (CAS). Being raw information since related to a point, it is processed with proper orthogonal decomposition (POD) tools to mine useful-and-physics carrying critical information [6]. In the present study, a remarkable result is the sensitivity of CAS databases. Figures 2-3 present POD-analysed CAS databases for beam structures depicted in Fig. 1.

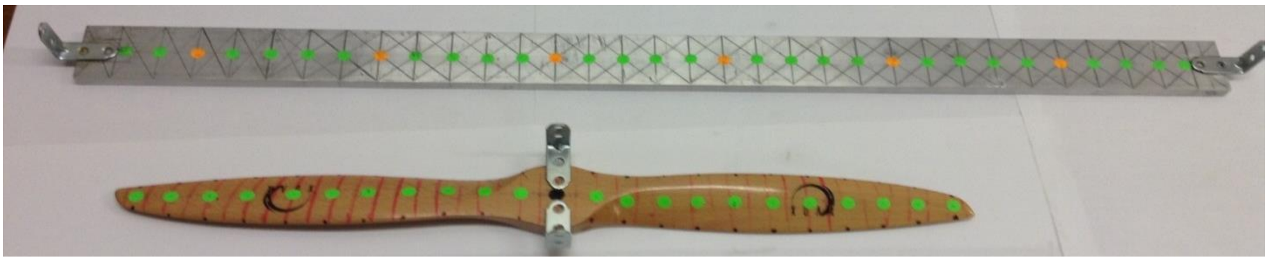

Figure 1 Samples of one-dimensional elastic structures used to collect wave propagation dynamics information in the form of collocated acceleration signals [6]. The surfaces of the wooden propeller are machined smoothened, whereas the surfaces and edges of the aluminum alloy beam are not. The structure is excited in floating configuration (free boundary conditions) with a modal hammer.

Conclusions

Numerous physical experiments with beam like structures result in the following finding: For the wooden propeller structure, the typical CAS database *is not sensitive* to the parameters of the interrogating impact pulses. This beam like structure had *its edges and surfaces machine-smoothened*, thus minimizing wave scattering. On the contrary, for the uniform alumunum alloy beam, the typical CAS database exhibits *irregular sensitivity* on the parameters of interrogation impact pulses. The aluminum alloy beam *has sharp edges and not polished surfaces*, thus enhancing wave scattering. *We claim that the detected irregular parameter sensitivity of CAS is evidence of irregular (chaotic) scattering.* Waves in elastic media admit chaotic scattering from nonlinearities at the boundaries [5]. Wave chaos phenomena at the continuum level in linear elastic media is a fact: It is due to the geometric nonlinearity stemming from wave mode conversion, referred to as ray splitting dynamics, at the boundary [2,3]. Our future work focuses on advancing the CAS concept as a model-free data processing framework to detect and exploit chaotic scattering for advanced diagnostics in structural systems.

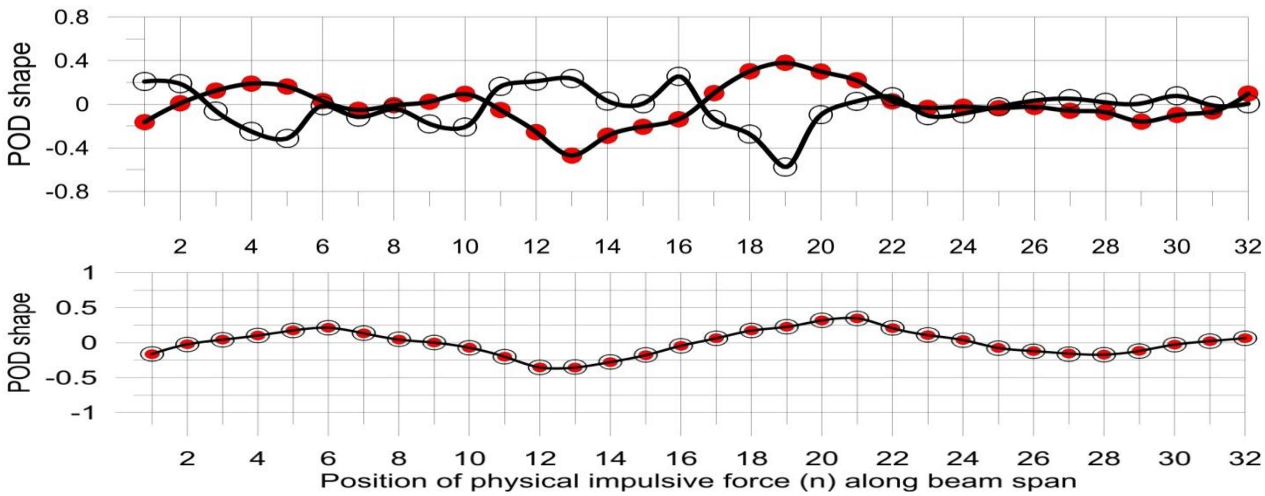

Figure 2 Unit shape of the 1st POD mode of CAS databases-two samples (filled, open circles) of pulse interrogation sequence applied by modal hammer on the aluminum alloy beam in Fig. 1. Top: irregular sensitivity of shape to impulse parameters (location, intensity). Bottom: the almost identical 1st POD unit shapes of two CAS databases (filled, open circle) collected at different locations and when the initial portion containing the irregularly scattered waves has been dissipated and we are left with the steady state free vibrations. Thus the possible chaotic dynamics indicated by the detected sensitivity are transient and have to do with the scattering of the wave with homogeneities. The aluminum alloy beam does not have its edges smoothened like the wooden propeller.

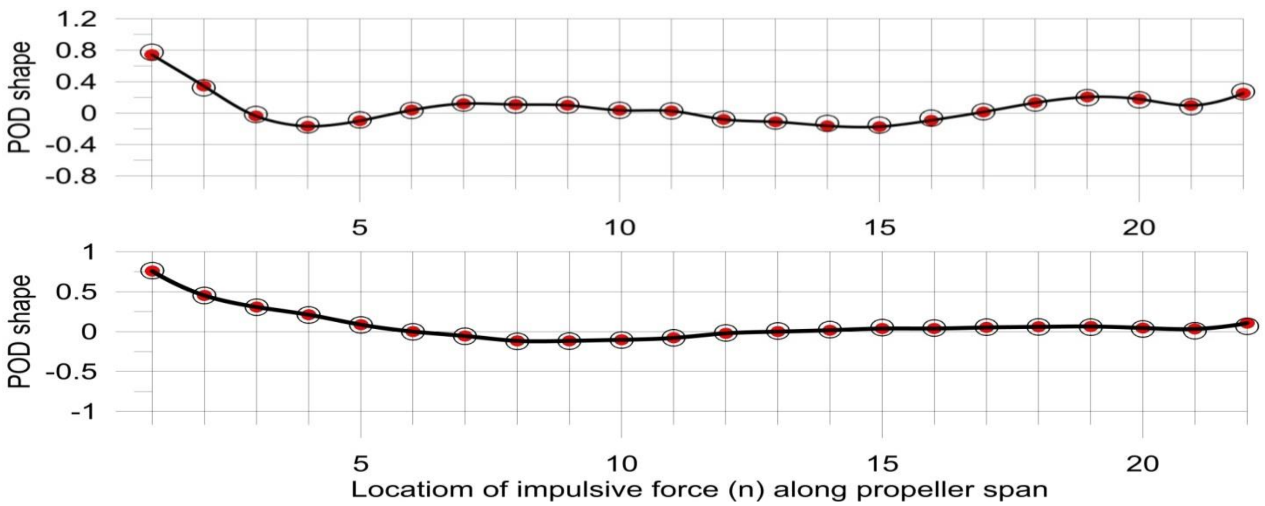

Figure 3 Top: Unit shape of the 1st POD mode of CAS databases- two samples (filled, open circles) of pulse interrogation sequence applied by modal hammer on wooden propeller beam in Fig. 1. The sensitivity seen in Fig. 3 (top) is absent. Bottom: the almost identical 1st POD unit shapes of two CAS databases (filled, open circle) collected at different locations. The absence of irregular sensitivity and the spatial invariant of the POD shape are due to the absence of irregular scattering and the fact that the dynamics are in the weakly nonlinear regime.

References

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