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Identification of damage in plates using full-field measurement with a continuously scanning laser Doppler vibrometer system

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ABSTRACT

An effective and reliable damage identification method for plates with a continuously scanning laser Doppler vibrometer (CSLDV) system is proposed. A new constant-speed scan algorithm is proposed to create a two-dimensional (2D) scan trajectory and automatically scan a whole plate surface. Full-field measurement of the plate can be achieved by applying the algorithm to the CSLDV system. Based on the new scan algorithm, the demodulation method is extended from one dimension for beams to two dimensions for plates to obtain a full-field operating deflection shape (ODS) of the plate from velocity response measured by the CSLDV system. The full-field ODS of an associated undamaged plate is obtained by using polynomials with proper orders to fit the corresponding full-field ODS from the demodulation method. A curvature damage index (CDI) using differences between curvatures of ODSs (CODSs) associated with ODSs that are obtained by the demodulation method and the polynomial fit is proposed to identify damage. An auxiliary CDI obtained by averaging CDIs at different excitation frequencies is defined to further assist damage identification. An experiment of an aluminum plate with damage in the form of 10.5% thickness reduction in a damage area of 0.86% of the whole scan area is conducted to investigate the proposed method. Six frequencies close to natural frequencies of the plate and one randomly selected frequency are used as sinusoidal excitation frequencies. Two 2D scan trajectories, i.e., a horizontally moving 2D scan trajectory and a vertically moving 2D scan trajectory, are used to obtain ODSs, CODSs, and CDIs of the plate. The damage is successfully identified near areas with consistently high values of CDIs at different excitation frequencies along the two 2D scan trajectories; the damage area is also identified by auxiliary CDIs.

1. Introduction

Development of structural damage identification techniques fast grows since unpredicted structural failure may cause catastrophic, economic, and human life losses. A reliable and effective nondestructive damage identification method is important to maintain safety and integrity of a structure [1]. Since damage-induced changes in physical properties of a structure, such as mass, stiffness, and damping, can cause detectable changes in modal characteristics of the structure, i.e., natural frequencies, mode shapes, and modal damping ratios, vibration-based damage identification methods have attracted much attention and become a major research topic of structural dynamics [2]. Different vibration-based methods have been investigated by many researchers. Basically, these methods can be classified into four categories [1], including natural-frequency-based meth-

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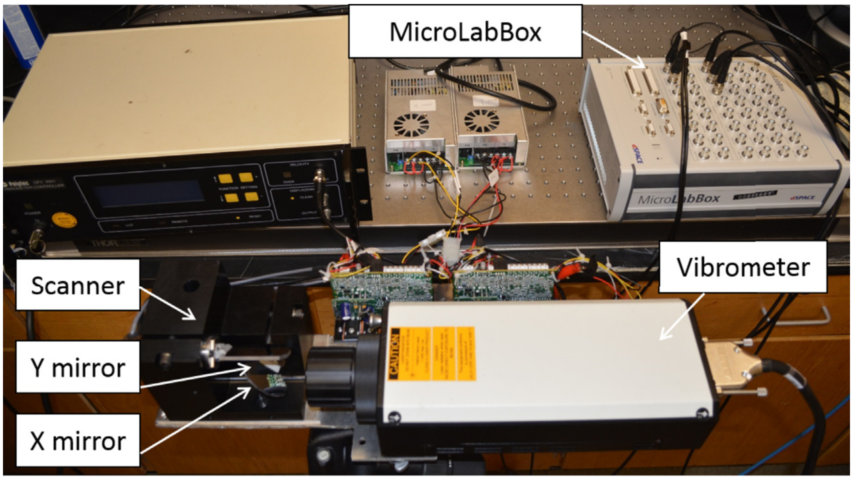

Fig. 1. Components of a CSLDV system.

ods [3–5], mode-shape-based methods [6], curvature-mode-shape-based methods [7–9], and other methods based on modal parameters [10]. Compared with natural-frequency-based methods, mode-shape-based methods and curvature-mode-shape-based methods are more sensitive to local damage and can be used for damage identification. Cornwell et al. [11] generalized a strain energy method from one dimension (1D) for beams to two dimensions (2D) for plates, which only needs mode shapes of plates before and after damage. Wu and Law [12] used changes in a uniform load surface (ULS) curvature to identify damage in plates and they found that the ULS curvature is sensitive to local damage under noisy measurement. Yoon et al. [13] extended a gapped smooth method [14] from 1D to 2D and studied composite plates to evaluate performance of the method. Qiao et al. [15] presented numerical and experimental studies of composite plates using curvature-mode-shape-based methods and compared three different damage identification algorithms. Zhang et al. [16] proposed a damage identification method for plates using the curvature of a frequency shift surface, which can be more accurate than mode shapes in practice. Surace et al. [17] presented a numerical method based on a polynomial annihilation technique to detect discontinuities in piecewise smooth functions and their derivatives, and applied it to identify damage in plates. Rucevskis et al. [18] proposed a curvature-mode-shape-based method for identification of damage in plates. They used a finite element model to study different levels of damage severity, measurement noise, and sensor sparsity, and evaluated robustness of the method. Xu and Zhu [19] used weighted mode shape differences between a damaged plate and an associated undamaged plate. The real undamaged plate is not needed and a mode shape of it can be obtained by using a polynomial to fit the mode shape of the damaged plate. Xu et al. [20] proposed a multi-

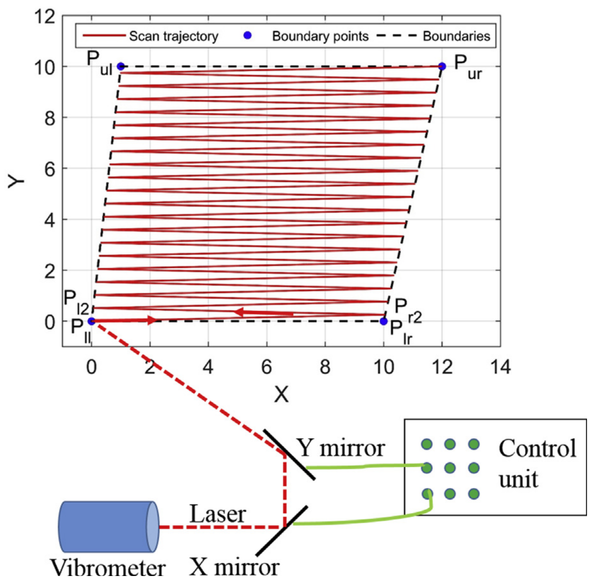

Fig. 2. Horizontally moving 2D scan trajectory for a plate.