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Crack Detection and Identification Using Vibration Signals and Fuzzy Clustering

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Abstract

Cracks in machine and structural components are among the most critical faults that require immediate attention by operations and maintenance personnel. In many cases it is difficult to directly and accurately identify the fault type and its extent under varying operating conditions. Therefore the ability to monitor and diagnose machine and structures health at early stages of fault initiation is one of the fundamental requirements of the development of online machine monitoring systems. This work demonstrates a novel procedure for crack detection and identification in an experimental set-up. Cracks of different lengths are introduced at three different locations along a cantilevered steel beam. The beam is exposed to several forms of excitation at different levels of amplitude and frequency. The excitation is introduced to the beam next to its fixed end using an electromagnetic shaker controlled by an arbitrary function generator. The vibration signals are analyzed for the beam dynamic signatures in the form of statistical moments, frequency spectra and wavelet coefficients. These are then used as features to create a data-partition using fuzzy relational clustering. The objective is to correlate crack length and crack propagation to the statistical moments, frequency spectra and wavelet coefficient data. The work will be later extended to supervise learning by training a classifier in a two-class problem to identify signal features that correlate to critical faults

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Keywords: crack detection; nondestructive testing; machine learning; fuzzy relational clustering; vibration; feature selection; pattern recognition

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1. Introduction

Cracks in machine component and structures are among the most encountered fault types. It is difficult to identify these types of faults especially during their initiation stage using direct inspection procedures. The ability to monitor and diagnose health of machines and structures at early stages of fault initiation is one of the fundamental requirements of the development of monitoring systems. The machine or structural monitoring systems should be able to accurately identify the fault type under varying operating or loading conditions.

The existence of a crack reduces the stiffness of the structure [1, 2] and therefore changes its natural frequencies. This makes it possible to investigate the changes in the frequency spectrum features of the structural vibration response in order to predict the location of crack damage. Many researchers have utilized vibration behavior of structures to develop intelligent crack detection methods. A kurtosis-based prediction scheme for crack location and size detection in Plexiglas cantilever beam based on the fundamental vibration mode has been proposed in Ref [3]. A hybrid neuro-genetic algorithm was proposed by Sahoo and Maity to detect damage in a cantilever beam [4]. A method based on genetic algorithm (GA) was also used to monitor changes in the natural frequencies of a structure in Ref [5]. A modified principle component analysis (PCA) method has been applied to selected frequency bands of the frequency response function (FRF) in order to generate damage features for pattern recognition [6]. The location and depth of the crack in a cantilever beam were determined using a particle swarm optimization (PSO) algorithm in Ref [7]. A fuzzy adaptive PSO (APSO) for predicting both the size and location of the crack on a beam using numerical and experimental studies was proposed in Ref [8]. Frequencies measured using single-input multi-output (SIMO) based experimental modal analysis (EMA) of the clamped-clamped beam with crack were utilized to identify crack location and its severity by the frequency-based approach as well as using a GA [9].

The objective of the present paper is to investigate the application of the fuzzy clustering method using experimentally obtained vibration response data to predict the location of cracks in a cantilever beam. Signal processing techniques such as Fast Hartley Transform (FHT) and Fast Fourier Transform (FFT) have been used as features to for edge-detection using clustering with applications in infrastructure monitoring are presented in Ref [10]. A principal component based unsupervised clustering algorithm for bridge crack detection is described in Ref [11]. We extend the unsupervised clustering methodology to use features from signal processing of vibration signals to identify whether a beam has a crack and if so discriminate between patterns based on distance of the crack from the fixed end of the beam. In this paper, the fuzzy relative clustering (FRC) in the relational feature space is used.

2. Experimental Setup

Steel beams measuring 0.0625 in x 1 in x 16 in are used for this work. A TMS model 2007E electrodynamic shaker is used to excite the beams at 3 inches away from the fixed end. Figure 1 shows a schematic of the experimental setup. Seven excitation frequencies are chosen at 20Hz, 40Hz, 60Hz, 68Hz, 70Hz, 80 Hz, and 100Hz. Beams with three different crack locations {5 in. (inner), 8 in. (central) and 11 in. (outer)} measured from the fixed end are prepared. Each beam has only a single crack. This resulted in 28 different combinations of the data sets including the beam with no crack. Vibration signals are collected using a Kistler accelerometer (model 8622, with sensitivity of 9.34 mV/g and 500 g measuring range) mounted on the beam near its fixed end. All data are recorded via a National Instruments USB-6211 data acquisition device at a sampling rate of 1000s/s.

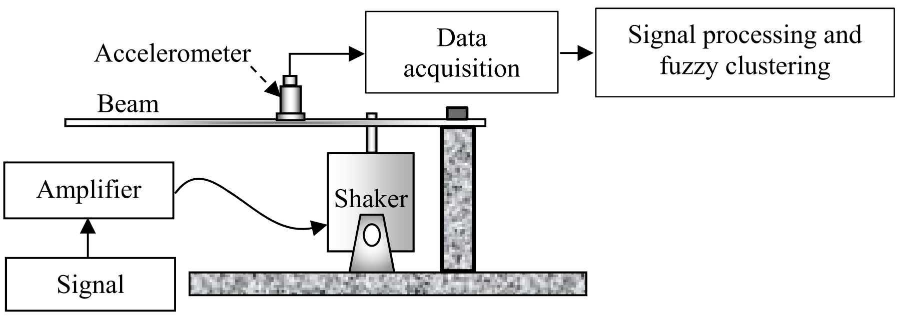

Figure 1. Experimental set-up