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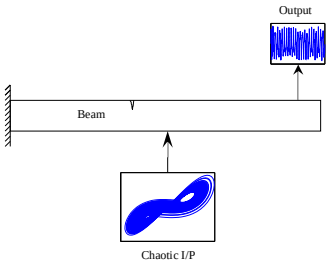
Department of Mechanical and Aerospace Engineering

Detection of Damage in Beam Structures via Chaotic Excitation

Abstract

This research is focused on detecting cracks in beam type structures. A chaotic signal is used to excite the structure and statistical & chaotic properties of the resulting time series are analyzed to detect the presence of crack. A SDOF approximation of a beam with opening and closing crack is analyzed to establish that salient statistical and chaotic parameters, namely, standard deviation, skewness, and wave fractal dimension are strongly influenced by crack properties. Next, an experimental setup is built to validate the simulation response. The time-series data obtained from experiment are subjected to same analysis which reveal that standard deviation, skewness, and wave fractal dimension can yield information about the severity of crack in beams.

Problem Definition



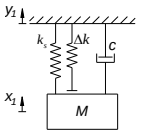
- Apply excitation at base
- Record o/p response
- Analyze o/p response

SDOF Approximation

Equation of motion

$M\ddot{x}_1 + c\dot{x}_1 + kx_1 = c\dot{y}_1 + ky_1 \quad \text{for } x_1 \geq 0$

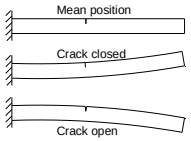
$M\ddot{x}_1 + c\dot{x}_1 + k_s x_1 = c\dot{y}_1 + k_s y_1 \quad \text{for } x_1 \leq 0$



where

$k = k_s + \Delta k$

$\frac{\Delta k}{k} = \frac{a}{h}$ for small crack sizes[1]



k: stiffness of homogeneous material

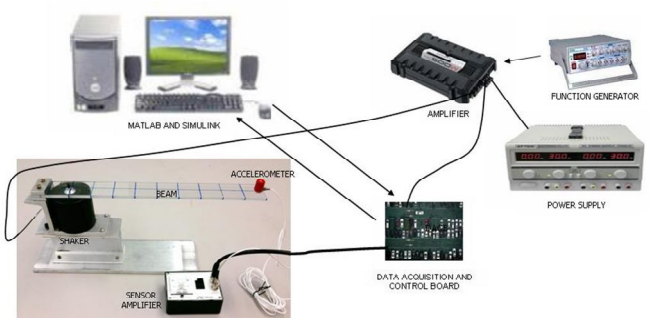
k_s: stiffness of material during stretching

a: crack depth

h: beam thickness

[1] J Ryue and P R White, 2007

Experimental Setup



Chaotic signal is generated in MATLAB and is supplied to shaker via DAC board and amplifier. Accelerometer measures the time-series data which is recorded in MATLAB for further analysis.

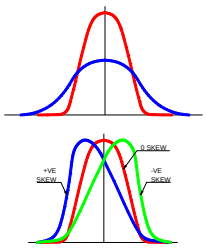
Analysis Parameters

(i) Standard Deviation

$$\sigma = \left(\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2 \right)^{\frac{1}{2}}$$

(ii) Skewness

$$\text{skewness} = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^3}{(n-1)\sigma^3}$$



(iii) Wave Fractal Dimension (WFD)

Fractal dimension applicable for waveforms. Measures waveform comlexity. Always lies between 1 and 2 and calculated as,

$$WFD = \frac{\log(n)}{\log(n) + \log(\frac{d}{L})}$$

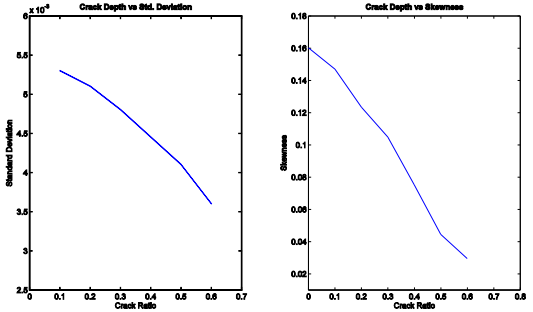
d = diameter estimate = max dist(1,i)

L = total length of curve

n = number of steps in curve, $L / \bar{\alpha}$

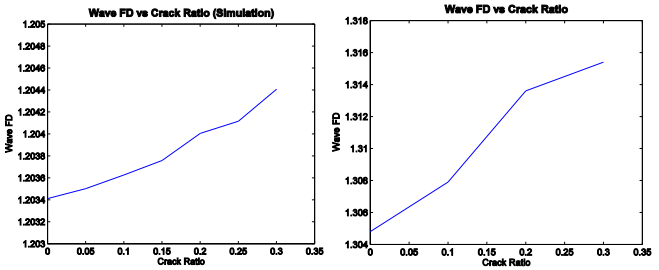
$\bar{\alpha}$ = average step

Standard Deviation and Skewness



- Standard deviation and skewness of recorded time-series decreases with increasing crack size
- The unidirectional change makes these parameters suitable for use in detection of crack

Wave Fractal Dimension



- Wave fractal dimension was calculated by simulation and from recorded time-series data from experiment
- Results show proportionate increase of WFD with increasing crack size

Acknowledgement

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