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A STRUCTURAL INTEGRITY INFORMED APPROACH TO EVALUATING THE PROBABILITY OF DETECTION OBTAINED WITH PERMANENTLY-INSTALLED SENSORS

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ABSTRACT

The move towards using permanently-installed sensors for structural integrity assessment is driven by their ability to detect changes in real-time. Such information can be of great value when evaluating the structural integrity and remnant useful life of the component. However, evaluating the detection capabilities of a permanently-installed sensor is often challenging. The sensitivity of a sensor to an initiating defect is dependent on its relative position to the defect, and there is often an associated uncertainty in where the damage may occur. Naturally, there is a need to optimally compromise between sensitivity and spatial coverage when choosing the appropriate sensor and sensor parameters for each specific application.

In order to evaluate the detection capabilities of a given permanently-installed sensor, its spatial sensitivity would have to be evaluated in conjunction with the spatial uncertainty in damage initiation location. In this research, a finite element approach that incorporates the probabilistic nature of damage initiation is used to map the spatial probability of fatigue damage initiation. A model-assisted probability of detection (PoD) approach is used to map the spatial sensitivity of the sensor. These two maps are then combined to evaluate the overall PoD of the sensor for detecting the initiation of a defect in the monitored component.

To illustrate the approach, the detection capabilities of two permanently-installed sensors are compared in two example situations. The two sensors are a guided ultrasonic wave sensor representing a system with lower sensitivity but higher volume coverage, and a bulk wave ultrasonic sensor representing a system with higher sensitivity but lower volume coverage. The two examples evaluated are based on detecting the initiation of a fatigue crack in a rectangular beam under fatigue bending. In the first example, the beam is under three-point bending, representing a case where the area over which damage may initiate is small, whereas in the second example, the beam is under four-point fatigue bending, representing a case where the area over which damage may initiate is large.

The outcome is a methodology for assessing the PoD of permanently-installed sensors. The methodology may be used for evaluating the efficacy of a monitoring system or be used for optimizing monitoring system design parameters. It will therefore help the adoption of Structural Health Monitoring.

Keywords: Permanently-installed Sensors, Probability of Detection, Structural Integrity Assessment, Fatigue Damage Initiation

METHOD AND RESULTS

A generic example is presented to provide an overview of the proposed methodology for assessing the detection capabilities of a permanently-installed sensor. A rectangular beam is subjected to two different loading conditions as shown in Figure 1 is being monitored by a generic permanently-installed sensor. The loading and support locations adhere to the ASTM C1161 standard. The load applied in the two cases are selected such that the maximum stress experienced by the component is the same. In this analysis, only fatigue damage initiating from surface B as shown in Figure 1 will be considered.

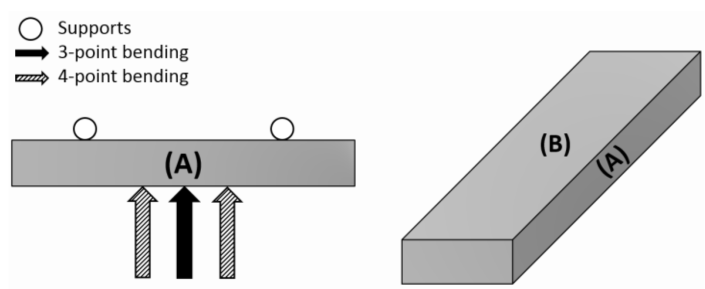

Figure 1: Component and loading conditions for the simulation.

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Using a combination of finite element modeling and probabilistic fatigue data of the material of the component, a spatial map of where defect might initiate, $P_l(x,y)$, can be produced given the number of loading cycles following the Hazard map methodology detailed in [1]. The results for both the three-point bending and four-point bending for one instance (after 10^6 loading cycles) is shown in Figure 2. As anticipated, the likely failure location for three-point bending is concentrated effectively along the central line, whereas in four-point bending, failure may equally occur anywhere in the central portion.

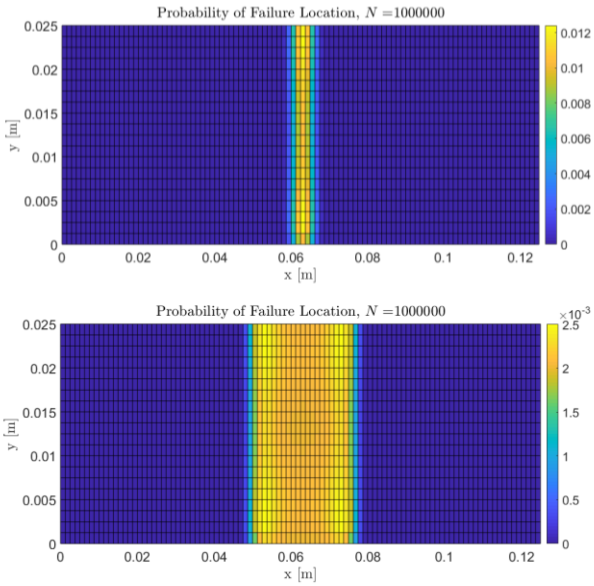

Figure 2: Spatial probability density of fatigue damage initiation of a three-point bending beam (top), and four-point bending (bottom).

On the other hand, a simulated spatial PoD map of the generic permanently-installed sensor, $P_d(x,y)$, is produced and is shown in Figure 3. This can be a spatial PoD map of any permanently-installed sensor obtained through computational modelling or real-life tests.

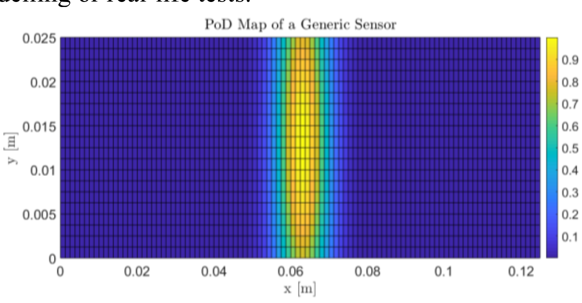

Figure 3: Spatial probability of detection map of a generic permanently-installed sensor.

Using the two maps, the overall spatial detectability map of the monitoring system, $P_D(x,y)$, can then be obtained as follows:

$$P_D(x,y) = P_l(x,y) \times P_d(x,y) \qquad \text{Eq. 1}$$

Thus, the overall expectation that the system will give a positive defect indication given that a defect is present, $E[P_D]$, would be,

$$E[P_D] = \sum [P_D(x,y)] \qquad \text{Eq. 2}$$

In the example presented here, $E[P_D]$ of the generic sensor for a rectangular beam undergoing three- and four-point fatigue bending after 10^6 loading cycles are 84% and 40% respectively. Thus, in this example, if a critical defect is present, it is more than twice as likely to be detected in the three-point bending case than in the four-point configuration. This shows that the value of monitoring is greatly dependent on the confidence in where defect may occur, as well as the spatial sensitivity of the sensor used.

It is therefore important to evaluate a permanently-installed sensor in conjunction with the properties and operating conditions of the monitored component. With the evaluation methodology proposed in this research, quantifiable metrics of the performance of a permanently-installed sensor under specific situations can be obtained. This will be of great value when selecting and optimizing permanently-installed sensors for any given engineering application.

REFERENCES

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