Localization of Structural Damage Based on First Passage Times for a Pre-stressed Steel Strip

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ABSTRACT
First Passage Time (FPT) maps and histograms of FPT are known to be capable of detecting slight deliberately operated structural changes in a steel strip. In this paper, the question of the localization of the damage is tackled. It is studied by comparing the predictions of a 2-D updated finite element model and the observed experimental results. We numerically simulated various damage scenarios by modifying the damage location until a good match of FPT histograms was found with the experimental investigations of virtually damaged structures. The detection and localization process was proven to be successful and we attribute it to the large sensitivity of the FPT maps and histograms to slight changes in the model.

Keywords: Health monitoring, Detection change, Ageing, Finite Element Updating, Damage Localization

INTRODUCTION

In structural health monitoring, damage can be localized by directly using modal parameters such as eigenfrequencies [1] and mode shapes obtained from experimental data [2] or by comparing those parameters to modal parameters that come from a numerical model [3]. In our case, we used the concept of First Passage Time (FPT) and their histograms in order to detect and to localize damage. The concept of FPT map was firstly introduced in [4, 5] and applied to an experimental model of a tower crane in a wind tunnel in [6]. In this work, the studied structure is a steel strip whose damage has been deliberately materialized by placing a small cubic magnet on the structure. In a previous work of the authors [7], it has been shown that FPT maps and histograms can be used to detect damage. The question tackled here is to localize it. To this aim, a numerical model has been updated and is used to compare numerical and experimental results until a good agreement is observed on FPT maps and histograms.

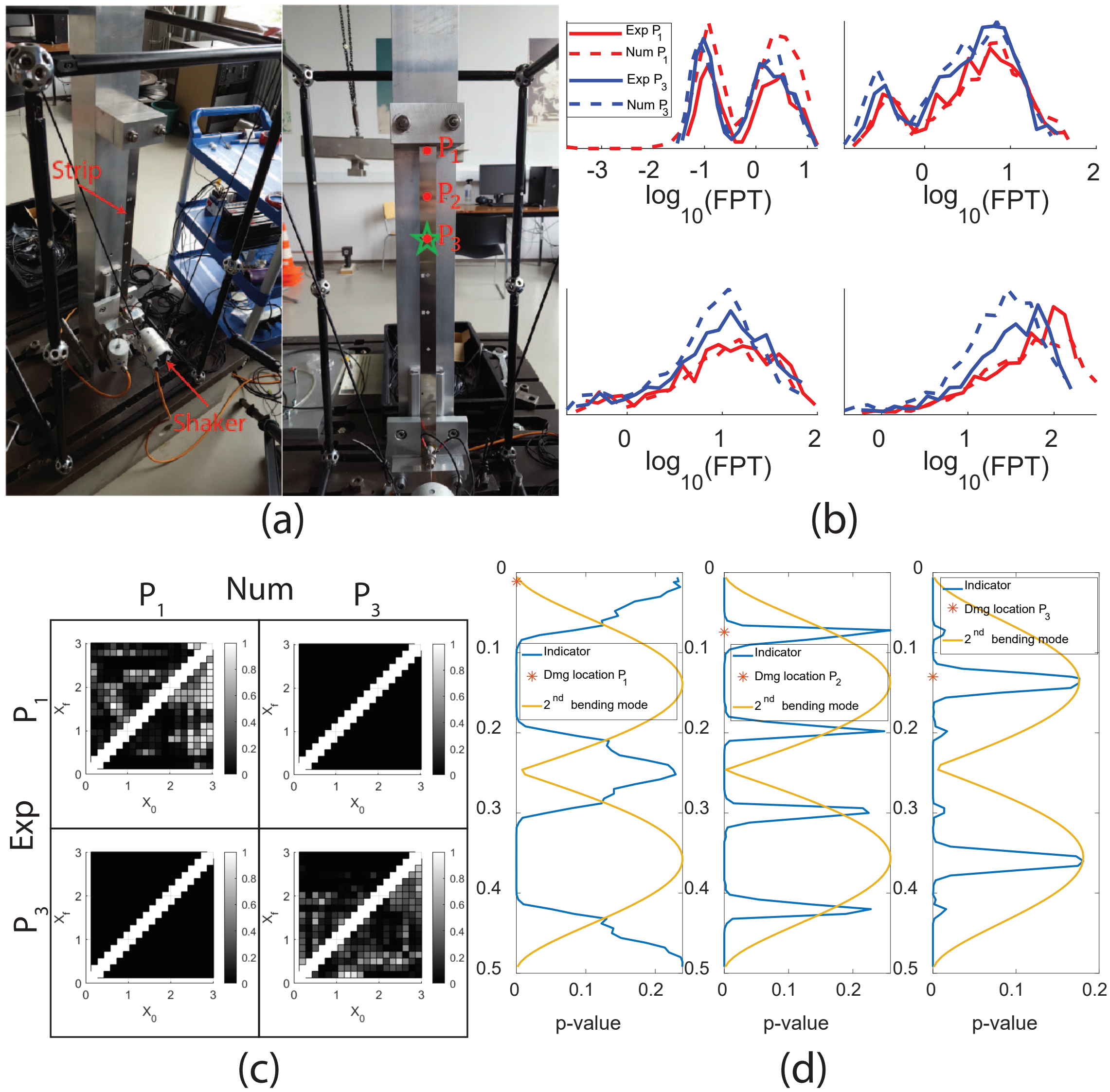

Figure 1: (a) experimental setup, (b) histograms of FPT at four different locations on the FPT map, (c) p-values from Kolmogorov-Smirnov test when the magnet is at P_1 and P_3 and (d) localization of the damage based on the average of p-values as an indicator for each magnet location

MODAL IDENTIFICATION AND NUMERICAL MODEL

The experimental setup is made of a steel strip, a horizontal shaker (TV 50009) and a polytech laser transducer as shown in Figure 1(a) and is the same as in [8]. The modal identification has been achieved by using a white band-limited noise in the range [3; 200] Hz. The first six bending modes have been identified as in [8]. Then, the numerical model has been updated until a good match was observed for the eigenfrequencies and the mode shapes. The updated parameters of the model include the rotational constraints at supports, Young's modulus and geometrical and mechanical modeling of the shaker and impedance head. The Bayesian model updating was performed with the Metropolis-Hastings algorithm which returns credible intervals for the model parameters.

DAMAGE LOCALIZATION

In order to simulate damage on the steel strip, a small cubic magnet has been placed at three different locations called P_1, P_2 and P_3 as shown in Figure 1(a). The structure has been excited by a white band-limited noise whose frequency content is in the range of the second bending mode. The structure velocity has been measured by a laser at location P_3 represented as the green star in Figure 1(a). Then, the response of the numerical model has been computed by placing the magnet at each of the 85 nodes of the FE model. FPT histograms are derived from the experimental and numerical data. In Figure 1(b), four histograms of the FPT at four different locations on the FPT map are represented; each of them is given in the configuration where the magnet is at location P_1 or P_3. Good agreement can be observed for the same magnet location. In order to compare those histograms, the Kolmogorov-Smirnov test has been used and for each combination of histograms a p-value can be obtained. In Figure 1(c), four p-values maps are therefore shown, combining two numerical histograms and two experimental ones. It can be observed that greater p-values are located inside the map when the magnet is at the same location while p-values are closer to zero when this is not the case. This gives us great confidence in using p-values as an indicator for damage location. With this in mind, we used the average p-value of the whole maps as an indicator of the likeliness of similarity in damage scenarios between the actual experimentally observed damage and the numerically simulated ones. In Figure 1(d), this similarity indicator is represented for three different experimental tests where the damage was localized at points P_1, P_2 and P_3 respectively. The use of the average p-value on the maps provides very satisfactory results. Indeed, when the magnet is close to the support (damage is difficult to detect), the proposed method concludes that the most probable positions of the damage are close to the supports or to the mid-span. In other words, by placing the magnet close to the supports or in the middle of the beam, the average p-value is very similar since the histograms of FPTs on the maps are very similar. When the magnet is at locations P_2 and P_3, the idea is more or less the same. For P_2, four different locations are identified which results from the symmetry of the second bending mode. For P_3, the magnet is located on the maximum value of the second bending mode and therefore two locations are identified.

CONCLUSION

P-values from FPT histograms show good results for damage localization. In order to improve the results, two different bending modes could be used to reduce the number of identified regions as potential damage location such as the second and third bending modes.

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