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Identification de singularités structurales distribuées en large bande de fréquence sur plaque renforcée

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This paper aims at designing a damage identification indicator. Location identification of distributed singularities is one of the key aspects of the presented results. It is a pre-requisite to the design of structural damage severity level. Two structural models are hence used to desmonstrate the feasibility of such technique, based on structural waves' measurement and analysis. One is based on a stiffened-panel model where defects are located along two ribs. Depending on the guided-waves' interactions, relevant information is obtained from the k-space. The other one is based on a double-skin plate model made of polypropylene, in order to study the effect on the energy distribution on such a rather well-damped structure. Singularities and their distribution seriously affect the energy transfers and their spatial aspects throughout the plane domain.

1 Introduction

Damage identification of structures attracts always our attention in many engineering fields. According to different levels of damage identification, it is divided into four steps : damage existence, localization, severity/geometry and the prediction of damage evolution. Better we know the damage, easier to offer a safety guarantee of our structures, and to avoid engineering disasters to some extent.

Various techniques for damage identification have been developped in the last few decades[1] among which the structural vibration test is popular due to its easy manipulation and abundant data information. Doebling et al.[2] gave us a thorough review of vibration-based damage identification methods like natural frequency based method, mode shape curvature based method, dynamically measured flexibility based method, matrix update based method, non-linear method, neural network based method, etc. Navabian et al.[3] used mode shape and its derivatives for damage identification in plate-like structures. Zang et al.[4] took reduced FRF response as input data of artificial neural networks for identification of slight damages, etc.

Plate-like structures have a wide application in civil, aeronautic and mechanical engineering. For instance, stiffened panel, double-skin polymer plate, both have a high-strength and relatively low density. This paper aims at find a proper damage assessment indicator for these structure models. The designed indicators are presented in the next section and numerical examples later. Finally a conclusion and discussion for future work is in the last section.

2 Theoretical background

Damage assessment methods for plate-like structures based on different indicators are introduced in this section. In most cases the dynamic response of specific structures could be easily obtained from vibration measurements. For this reason, many damage indicators are designed from these original data.

2.1 Indicator from a propagative point of view

Even though the displacement response under a harmonic excitation is treated for the beginning of the assessment procedure, it could be considered from a wave propagation point of view. The information which contains the wavenumbers and wave modes in k-space are extracted in the same way as does the modal analysis. There are several tools to collect the wave modes information among which we choose the discrete fourier transform (DFT).

For a displacement field of a plate-like structure defined in the plane (x, y) :

$$\omega(x, y, t) = \int_0^{+\infty} \hat{\omega}(x, y) e^{i\omega t} d\omega \tag{1}$$

where the symbol ˆ represents the frequency-dependence of the function, with a discretization both in the (x, y) plane and in the k-space, the information in k-space is shown by Eq. (2) through the DFT :

$$\hat{\hat{\omega}}(k_{xp}, k_{yq}) = \frac{1}{N_1 N_2} \sum_{i=0}^{N_1-1} \sum_{j=0}^{N_2-1} \hat{\omega}(x_i, y_j) e^{-i(k_{xp}x_i + k_{yq}y_j)} \tag{2}$$

By observing the wave mode patterns, highlight part attracts more attention because it brings relatively more energy which gives us a better observation. The guided-waves behaviour between two ribs over the surface of stiffened panel, which corresponds to the vertical lines in k-space, is a good explanation (detail in chapter 3). According to Huang's work[5], this highlight part was filtered manually and an inverse DFT was proceeded after that. The result obtained in the plane (x, y) becomes finally a damage indicator from a propagative point of view.

2.2 Indicator from an energy point of view

From modal analysis to FRF response, the litterature[6, 7] proved that the curvature can be an effective indicator for damage identification in structures, which is calculated by a central finite difference approximation :

$$\phi''_{i,j} = \frac{\phi_{i-1,j} - 2\phi_{i,j} + \phi_{i+1,j}}{h^2} \tag{3}$$

Thus with an external excitation on our plate-like structure, we try to design a damage indicator using some helpful informations in the FRF response. Apart from the curvature which is sensitive to the damaged area, other kinematic variables can be also taken into consideration to form the new indicator from an energy point of view. Because the Lagrangien is the difference between kinetic energy and potential energy, here, we choose the velocity and obtain the final indicator through Eq. (4) by inspiration of the concept of Lagrangien.

$$ind = \frac{1}{2} velocity^2 - \frac{1}{2} curvature_x{}^2 - \frac{1}{2} curvature_y{}^2 \tag{4}$$

3 Numerical examples

3.1 Stiffened panel example

A simulation study on the damage identification in the stiffened panel was carried out in order to verify the feasibility of the first designed indicator. The size of the aluminum panel was $2m \times 2m \times 0.005m$ on which eight steel ribs were equally spaced. The SOLID185 elements in ANSYS were chosen for the modeling of both the panel and the ribs. Along the edges of the stiffened panel, free boundary conditions were used. For the damaged stiffened panel model, two damages whose sizes were $2m \times 0.001m \times 0.015m$, were symmetrically located in the two middle ribs, with a distance of 0.28m to the left edge of the panel (figure 1).

With an excitation in the middle of the panel along the

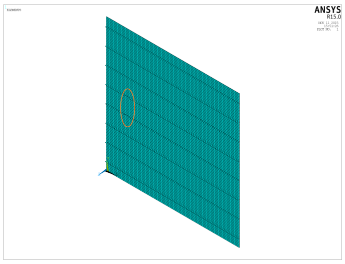
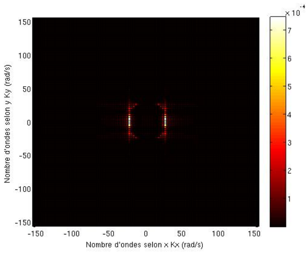
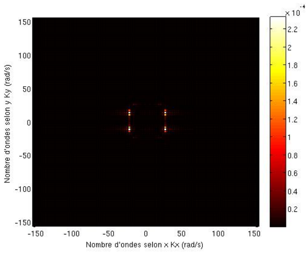


Figure 1: Damaged stiffened panel FE model.

normal direction, the nodal displacement were extracted. Depending on the guided-waves' interactions, results with and without damage in the k-space near 2000Hz by average are shown in figure 2.



(a) Damaged panel



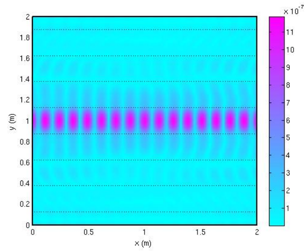
(b) Undamaged panel

Figure 2: Averaged DFT results near 2000Hz of the damaged and undamaged stiffened panel

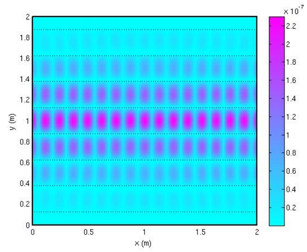
To reach a more clearly guided-waves behavior in the (x, y) plane, a filtering process which was mentioned in precedent chapter was realized and the figure 3 told us the different wave components and their proportions of the guided-waves behavior between the two middle ribs. As a result, the first damage indicator designed for this stiffened panel can distinguish the existence of the damage.

3.2 Double-skin plate example

Another simulation study on the damage identification in the double-skin plate model made of polypropylene



(a) Damaged panel



(b) Undamaged panel

Figure 3: Filtered results near 2000Hz of the damaged and undamaged stiffened panel

was carried out in order to verify the feasibility of the second designed indicator. The size of the plate was $0.6m \times 0.8m \times 0.01m$, whose thickness was composed of a 0.75mm-thick upper layer, a 8.5mm-thick rib and a 0.75mm-thick lower layer. There were 97 ribs whose sizes were $0.6m \times 0.0005m \times 0.0085m$ in total, equally spaced with an interval of 8.3mm. The ribs were numbered sequentially from the bottom to up. A distance of 1.6mm was between the first/last rib and its nearest edge. The SOLID185 elements in ANSYS were chosen for the modeling of both the two layers and the ribs. Along the edges of the double-skin plate, free boundary conditions were used. With an excitation in the middle of the plate along the normal direction, dynamic analysis was performed for the following calculation.

From the point of view of energy distribution, the second damage indicator which was inspired by the notion of Lagrange gave us an assessment for this model. Two types of damages were discussed: the damage in the ribs and the damage on the skin. For the first damage modeling, there were 100mm-long damages respectively in the 32th and 33th ribs with a distance of 100mm to the nearest edge (see figure 4).

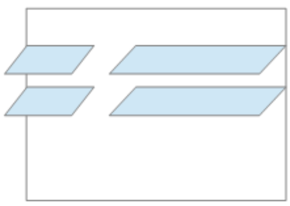
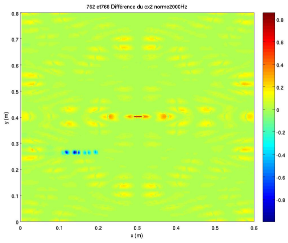


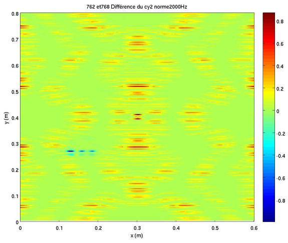
Figure 4: Schematic diagram of damage in the ribs

The results in figure 5 shows the difference between the square of the normalized curvature fields in the two mutually perpendicular directions, horizontally and vertically, with and without damage. From these figures, the possibility of the indicator's localization function appears.

Finally, the indicator fields with and without damage



(a) Direction of the ribs

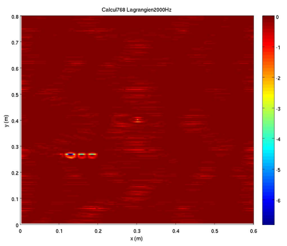


(b) Perpendicular direction of the ribs

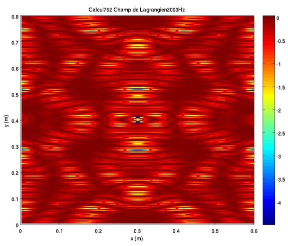
Figure 5: Difference of the normalized curvature fields between the plates with and without damage in two mutually perpendicular directions at 2000Hz

are shown in figure 6, from which both the existence and the localization of damage identification are realized. Furthermore, it is not necessary to have the undamaged plate model, in other words, the baseline model.

However, when the second type of damage was



(a) Damage in the ribs



(b) No damage

Figure 6: Indicator fields of the double-skin plates with and without damage at 2000Hz

manipulated by the same method, the results (figure 8) are not obvious enough. For the damage on the skin, we chose the same location as that of the first type, which was between the 32th and the 33th ribs, 6mm-wide and 100mm-long, with a distance of 100mm to the nearest edge (figure 7). Thus this second indicator is sensitive to the damage in the ribs.

Now the further discuss is concentrated on the damage in the ribs. The length of damage was shortened. The figure 9 shows the indicator field with 4mm-long damages in the 32th and 33th ribs. We notice that the zone with a

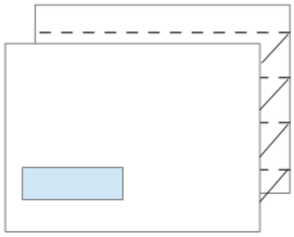


Figure 7: Schematic diagram of damage on the skin

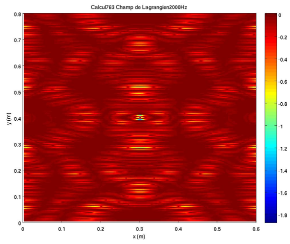


Figure 8: Indicator field of the double-skin plate with damage on the skin

relatively small amplitude is shortened respectively. Thus this indicator also tells us the length of damage, in other words, the gravity level of damage.

Another 10mm-long damage was created in the 23th and

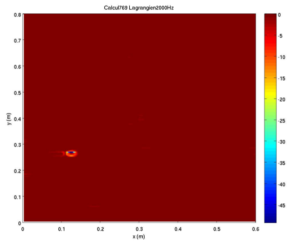


Figure 9: Indicator field of the double-skin plate with 4mm-long damages in the ribs

24th ribs. The indicator field in the figure 10 shows exactly the location and the length of damages. Furthermore, the double-skin plate with three damages, which were composed of the two damages we had discussed above and a 4mm-long damage in the 61th and 62th ribs, was studied. From the figure 11 we can see that the indicator works well when there are several damages.

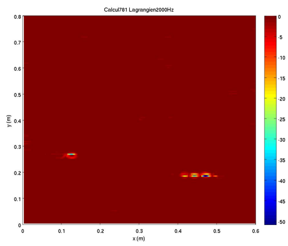


Figure 10: Indicator field of the double-skin plate with two damages in the ribs

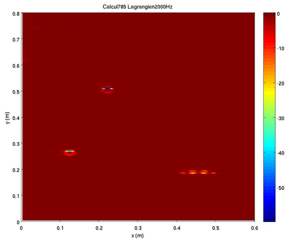


Figure 11: Indicator field of the double-skin plate with three damages in the ribs

4 Conclusion

In this paper, two vibration-based damage indicators for plate-like structures are presented. The first indicator which involves the information in k-space can detect the existence of damage in the stiffened plate. The second indicator, seems more effective, can tell us not only the damage existence, but damage localization and severity as well in the double-skin plate and it works for both single and multiple damages.

For the future work, the experiments will be carried out on the double-skin plate to prove the effectiveness of the second indicator. In this case, questions like density of sensors, environmental noise should be taken into consideration.

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