Fault diagnosis of a beam by time reversal method: numerical approach

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1 Introduction

Structural health monitoring (SHM) is an important approach in order to evaluate the health state and so the safety and security of structures such as bridges. It also helps to maintain and to extend their servicibilities, to detect and predict their failures. This approach regroups several techniques such as vibration based inspections, acoustic, ultrasonic or magnetic field and radiographic methods. They are based on analyzing variations of some system's characteristics and mapping them to the state of the systems and materials. For instance, in vibration based SHM, the variations of system characteristics in linear and nonlinear dynamics, e.g., frequency and damping shifts, changes of mode shapes and backbone curves, are directly related to the current state of the system.

2 Damage detection with time reversal method

2.1 The time reversal method

In this study, we use an ultrasonic technique for SHM, known as the Time Reversal (TR) method. This technique is based on the time reversibility of the solutions of wave equation in a lossless medium. Effectively, we can observe in equation (1) that there is only even order derivative. So if $p(\overrightarrow{r},t)$ is a solution of the problem, then $p(\overrightarrow{r},-t)$ is a solution too [1].

$$div(\frac{1}{\rho(\overrightarrow{r})}\overrightarrow{grad}(p(\overrightarrow{r},t))) - \frac{1}{\rho(\overrightarrow{r})c(\overrightarrow{r})^2}\frac{\partial^2 p(\overrightarrow{r},t)}{\partial t^2} = 0 \tag{1}$$

The TR is applied in three global steps:
i) an excitation wave is applied via one set of array of transducers at a point A;
ii) then, signal are recorded by other set of array of transducers at a point B;
iii) they are time reversed and are reinjected to the medium at point B and recorded again at point A.
If the wave emitted in step (i) is reflected by a damage, then the re-emitted wave in step (iii) converges towards the reflecting damage. The signal recorded at step (iii) is called ”reconstructed signal”. Then by comparing the input wave (emitted in step (i)) and the reconstructed wave we can detect the presence of a damage [2, 3].

2.2 Principle of experiment

We apply this method on two beams of dimensions $700 \times 50 \times 5mm$. The beams are in aluminium and one of them has a rib of depth $2mm$. The transducers are piezoelectric patches (PZT) placed on both sides of the damage.The geometry of the damaged beam can be seen in Figure 1. The input wave is a Ricker wavelet defined at a center frequency f_c and following the equation (2) :

$$f(t) = \Big(1 - 2\Big(\pi f_c(t - \frac{1.25}{f_c})\Big)^2\Big)\exp\Big(-\Big(\pi f_c(t - \frac{1.25}{f_c})\Big)^2\Big) \tag{2}$$

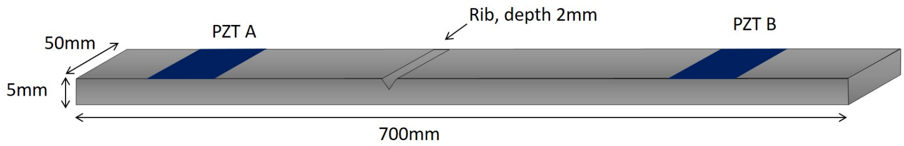

Figure 1: Geometry of the damaged beam

After recording the reconstructed wave we compare it with the input wave. From the healthy beam we can observe that the reconstructed wave is a scaled version of the input wave. If damage exists, the reconstructed signal contains a scaled version of the input wave and time shifted components due to the damage. A scheme of the reconstructed signal is presented in Figure 2 where the time shifted component can be observed.

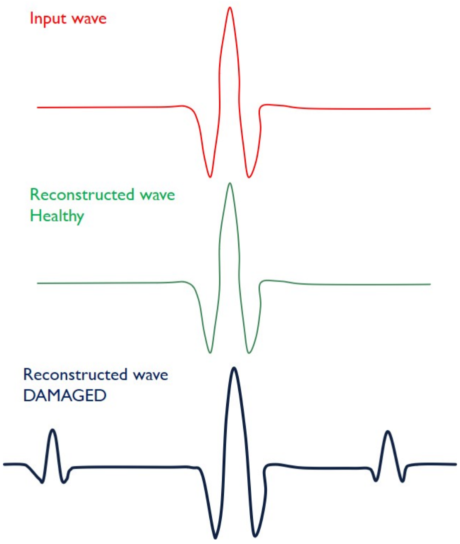

Figure 2: Comparision of input wave and reconstructed signal in case of healthy and damaged structure

3 Discussion and conclusion

The experiment showed that we are able to reconstruct the shape of the signal. However, during applying TR method, following items should be taken into account:

i- controlling the input wave in order to limit the superposition of emitted and reflected wave

ii- recording the signal during an adapted time in order to catch the damaged component

iii- differentiate the signal due to damage and those due to boundaries.

For the first point (i), the idea is to choose a wavelet which is locally conecentrated such as Ricker wavelet for example. But also to choose an adapted wavelength. For the second point (ii), several mesures have to be done in order to choose the best recording and re-emitting window. Finally for the last point (iii), knowing the geometry of the structre we can identify component due to boundaries. Moreove several experiment can also be done with different position of transducers in order to obtain a better view of the structures. These experiment can help in the localisation of the damaged too by measuring the delay of the time shifted component in the reconstructed signal.

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