NUMERICAL SIMULATION OF ULTRASONIC TIME REVERSAL MIRROR IN A PLATE WITH DEFECT

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Abstract

The time reversal mirror (TRM) is a method which can be effective in NDE of defects in materials. In this case an input ultrasonic wave is transmitted into the examined sample, then recorded by receiving transducers, time reversed and sent back by the same transducers. A simple numerical model of a solid plate with a crack was developed. The propagation of ultrasonic waves used in time reversal method is studied. A number of tests with different methodology of the TRM procedure is simulated.

Introduction

TRM is one of NDT methods, which can help to detect hardly detectable defects in materials [1], [2]. It consists of two steps. At first, an input ultrasonic wave is transmitted into the tested sample and recorded by receiving transducers. These signals are time reversed, filtered, sent back into examined sample by the same transducers in the second step of the method and finally recorded. Distortions in the signals obtained in the first step, caused by material's defects, are in the signals obtained in the second step multiplied and easily detectable. In simple cases, the position of defect can be approximately located as well. In more complicated cases, where many defects or many reflectors of ultrasonic waves are present, it's difficult to localize the positions of the defects. Under such conditions it can be useful to simulate the real situations by precise and large numerical models [3]. In this paper, a very simple numerical model is presented and tested. Developed numerical model was intended to be as simple as possible, and easy enough to run fast on a common PC. It was programmed in MATLAB. The model is not intended to simulate real world situation, so the choice of material's constants, duration of the pulse and other characteristics are not described.

Numerical model

A simple numerical 2D model of the plate was developed. The model consists of the grid of (250x80) mass points and the springs between them. The Connections between nearby points are shown in Figure 1. Movement of each mass point is determined by well known equation of motion.

$$m\frac{d^2x}{dt^2}=-Kx-B\frac{dx}{dt}$$

In the numerical model the movement of mass point of the grid with index j is determined by derived equations:

$$\vec{v}_j(t)=\vec{v}_j(t-\delta t)-K\sum_{i\in\mathbb{Z}}[\vec{x}_j(t-\delta t)-\vec{x}_i(t-\delta t)](\delta t)-B\,\vec{v}_j(t-\delta t)(\delta t)$$

$$\vec{x}_j(t)=\vec{x}_j(t-\delta t)+\vec{v}_j(t)\delta t$$

where δt is time step, $\mathbb{Z}$ is set of nearby mass points connected with point j.

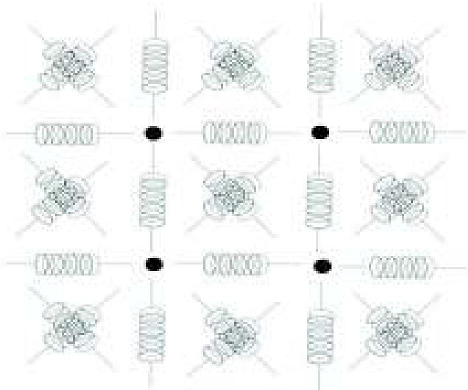

Figure 1: Connections between nearby mass points of the numerical model

In Figure 2 there can be seen schema of the simulated experiment. There are sensors at the left side of frame, which work as transducers as well and the location of crack is marked in the center.

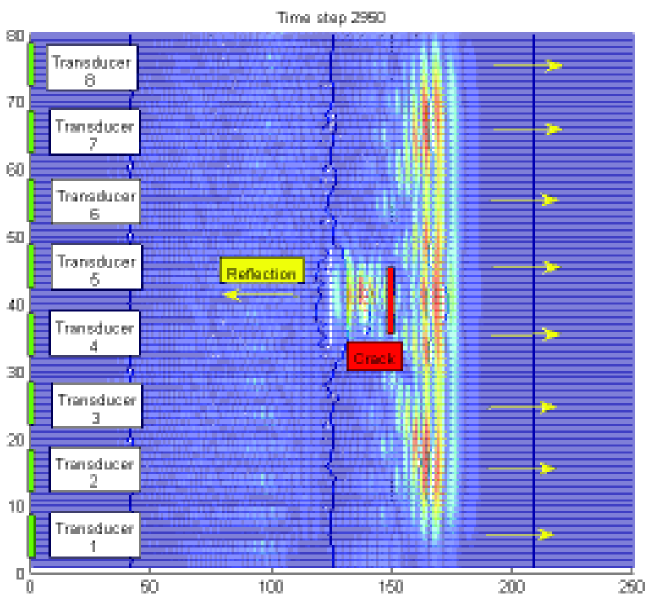

Figure 2: Simulation 1, time step 2950

Simulation 1

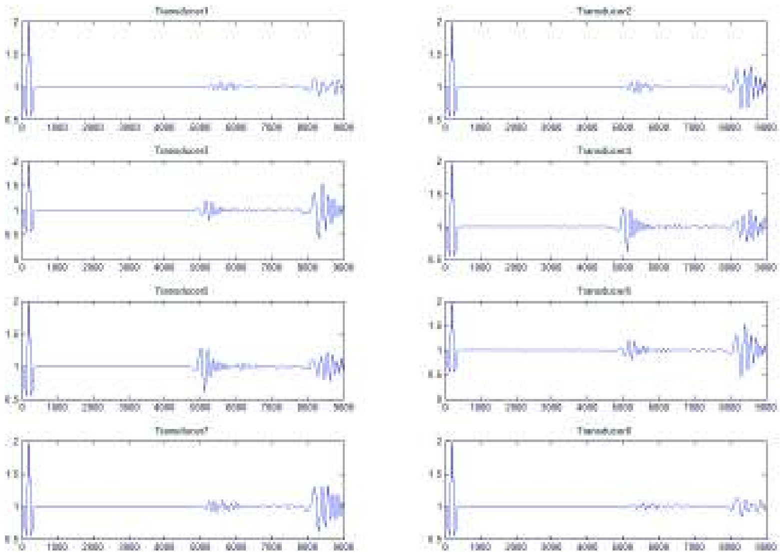

Figure 3: Simulation 1, recorded signals

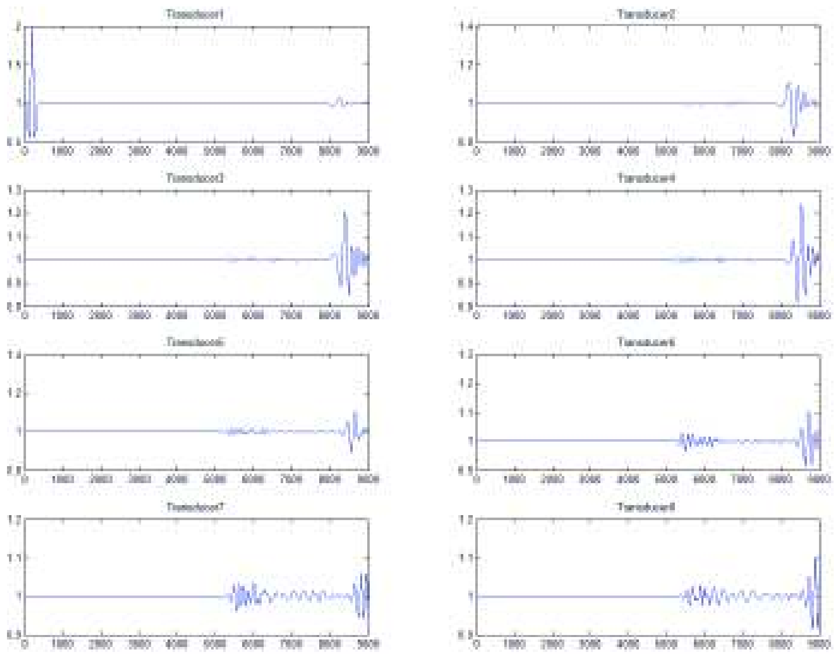

Figure 4: Simulation 2, test 1 (sending is transducer 1), recorded signals

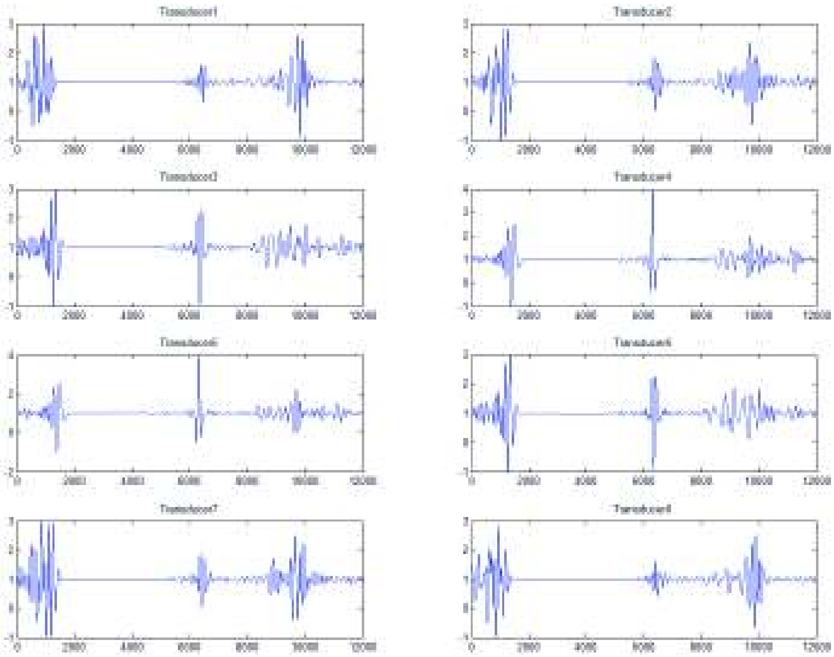

Figure 5: Simulation 3, recorded signals

Simulation 1 represents first step of TRM method. All transducers sent the Ricker's pulse through the grid of interconnected mass points. In Figure 2 is visualized situation in the time step 2950. There are marked positions of sensors and the crack. Propagating initial pulse and reflected waves are visible as well. “Colors” corresponds the velocity of mass point. In Figure 3 are shown signals recorded in this simulation by “sensors”. We can seen the initial Ricker's pulse, the echo of the crack, and the back-wall echo as well.

Simulation 2

In real world situations is often difficult to send signals from all transducers at the same moment. Usually we are limited by number of arbitrary waveform generators, and only one transducer transmits signal in one experiment. Simulation 2 reflected this situation. Eight tests were performed successively. In one test, only one transducer is sending the initial pulse and all other transducers are recording signals. Then, signals received by one sensor in all tests are summed and compared with results obtained in Simulation 1. Only negligible differences between both simulations were detected. The highest and the average deviations were 1,15% and 0,06%, respectively. In Figure 4 are shown signals recorded in test no.1, when transducer no.1 was transmitting. It can be seen that waves reflected on the crack propagated mainly to sensors 7 and 8, as expected.

Simulation 3

Third simulation represents second step of the TRM method. Signals recorded in Simulation 1 were trimmed so that only echo of the crack remained and were time reversed. Then they were send by all transducers at the same time. In Figure 5 are presented signals recorded by sensors in this simulation. There we can see the original time reversed signals, echoes from the crack, and back-wall echoes. Reflections from the crack are much higher than in Simulation 1, and have the shape of the initial Ricker's pulse in Simulation 1. TRM method is working in this way. The highest reflections of the crack were detected by sensors 4 and 5, as we expected, because they are closest to the crack and opposite to that as well.

Conclusion

A simple numerical model for simulation of TRM method was developed. The numerical model was intended to be simple and easy enough to quickly run on a common PC. It was not intended to simulate some concrete sample of material with known characteristics. The intention was to attempt to develop a simple method for simulation of the ultrasonic waves propagation in solid plate and simulation of TRM.

Simulation 1 and Simulation 3 were two steps of the TRM testing method. Results obtained by these simulations are consistent with expectations and demonstrates that simulation of TRM method was successful. Simulation 2 showed that there were no big differences between the excitation sensor by sensor and the excitation all sensors at once.

References

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Acknowledgments:
This work was supported by the Grant Agency of the Czech Republic under grants No. GACR 103/06/1711 and GACR 106/07/1393.