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FR9200175

CEA-CONF- -10690

NUMERICAL SHAPING OF THE ULTRASONIC WAVELET

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Communication présentée à : 5. European Conference on Nondestructive Testing
Sarajevo (YU)
22-27 Sep 1991

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September 22-27

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ABSTRACT

Improving the performance and the quality of ultrasonic testing requires the numerical control of the shape of the driving signal applied to the piezoelectric transducer. This allows precise shaping of the ultrasonic field wavelet and corrections for the physical defects of the transducer, which are mainly due to the damper or the lens. It also does away with the need for an accurate electric matching. It then becomes feasible to characterize, a priori, the ultrasonic wavelet by means of temporal and/or spectral specifications and to use, subsequently, an adaptative algorithm to calculate the corresponding driving wavelet. Moreover, the versatility resulting from the numerical control of this wavelet allows it to be changed in real time during a test.

INTRODUCTION

One way to increase the capabilities of ultrasonic testing is to control the temporal and spectral characteristics of the transmitted wavelet. Presently, most of the piezoelectric transducers are impulse driven. Therefore, the properties of the transmitted wavelet, especially its shape and lentgh, are highly dependent on good electrical matching of the piezoelectric transducer to the transmission device, and on the specific physical properties of the transducer. That is, on the resonant frequency of the piezoelectric plate, on the quality of its damping and on its lens.

Controlling the shape of the electrical exciter signal applied to the transducer provides numerous advantages. It allows precise shaping of the ultrasonic field wavelet, suppression of the electrical matching problem and correcting for transducer physical defects, whatever their origins. It is, thus, possible to rectify bad acoustic damping or the presence of additional unwanted transmitted wavelets that, generally, are so close to the main wavelet that there is almost complete mixing of the two. Such parasitic wavelets arise principally from the damper base, the lens mismatch with the coupling liquid, or the diffractive edges of the piezoelectric disk.

NUMERICAL SHAPING OF THE TRANSMITTED WAVELET : PROBLEMS AND SOLUTIONS

The shaping of the ultrasonic transmitted wavelet creates new possibilities for investigations in the NDT field. But its implementation requires the use of numerical signal processing ressources and the solution of some non-obvious electronic problems.

The main difficulties arise from the high values of the transducer capacitance, in other terms, form the high capacitance loading encountered in some nuclear NDT measurements. The equivalent capacity of the transducers involved in these cases can reach values of the order of ten nanofarads. Moreover, the voltage level of the exciter signal applied to this capacity reaches values of the order of a hundred volts. As for the slope of the voltage, dV/dt, it depends on the spectral width characteristic of the transducer, but the study of some typical cases shows that it involves a feed current with a value of the order of ten amperes.

To satisfy all these constraints, the electronic exciter must act as a wide-band powerful current source. But such a source is not commercially available. All the wide band power amplifiers on the market are designed to work in the voltage mode with a 50 ohm load. We selected the most recently available power MOS transistors. Their fast switching of high currents at high voltages, like their low rdson provide a partial answer to the problem. Nevertheless, their grid capacity value may increase to a few nF for the most powerful devices and they have a highly nonlinear transconductance. The low level voltage grid control was achieved by means of commercial intergrated circuits, while the software was used to correct for the transcondutance non-linearity. Put in another way, the loop of the adaptive algorithm which calculates the exciter wavelet includes the correction for non-linearity, which is necessary for its fast convergence. This method makes it possible to have maximum reduction of the electronic analogue section, where the design and development are always more critical than for the numerical part.

With the present techniques, the full integration of the transmitting unit limits the peak voltage applied to the transducer to a low ceiling value, which is about ten volts. To compensate for this low voltage level, about ten times less than what is usual, the voltage gain of the receiving unit must rise to a high value, which may reach, for example, a hundred decibels in visualizing the echo due to crack edge diffraction. In such a situation, the signal to noise ratio becomes so poor that it becomes necessary to use a signal processing method to improve it.

We have chosen a pulse compression method built around pseudo-random codes that are well known under the designation of GOLAY'S complementary series [1], [2]. The association of these codes with a numerical modulation-demodulation method, involving the convolution and correlation operators, provides an exact solution to the problem [3]. Indeed, compared with the other conceivable pulse compression techniques [4], [5], [6], this method produces no hash noise, is compatible with the ultrasonic wavelet pulse shaping method [7] and is completely transparent to the acoustic phenomenon observed. M.J.E. GOLAY discovered and described a number of algorithms [1] for generating families of complementary series which have a length that is a power of two. Thus, with the help of a calculator, we carried out a search for all the optimum complementary pairs [2], based on a criterion which minimizes the hash noise level, each of the two codes being taken separately. With these optimum pairs, we have obtained a significant improvement in signal to noise ratio, which, for example, reaches approximately 37 decibels in the case of 256 elements and an oversampling rate factor equal to ten [3]. Moreover, all of the many experiments that were carried out using code lengths form 8 to 256 show exact agreement between the experimental results and the theoretical predictions. In particular, the improvement of the signal to noise ratio increases by 3 decibels each time the code length doubles.

To visualize the efficiency of the pulse shaping process, some experimental signal graphs taken form references [3] and [7] are shown below. These signals were acquired using a bare piezoelectric plate, i.e., without any damper or lens and which had a center frequency of 1Mhz. Figure 2 shows the surface echo obtained with a thick steel plate while the piezoelectric plate was excited by the signal plotted in figure 1. Figure 3 shows, for the same exciting conditions, the mixing of the surface echo and the adjacent flutter echo which appears when the thick plate is replaced by a thin one. Few differences can be seen between this signal and the previous one, except for the signal train which, in the second case, refuses to vanish. (Fig. 1, 2, 3)

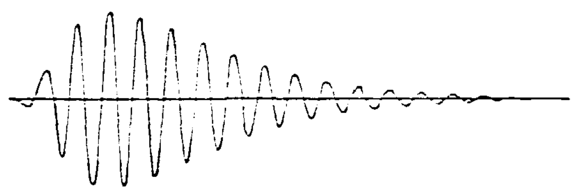

Figure 2

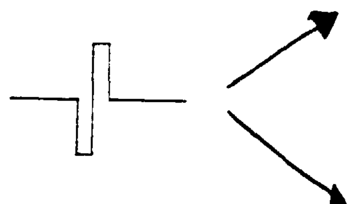

Figure 1

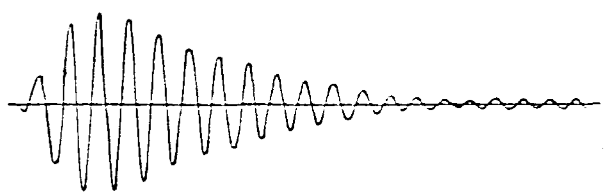

Figure 3

Subsequently, the same experiment was carried out using numerical shaping of the transmitted signal. Figures 4 and 5 give, respectively, the aspects of the exciting wavelet and of the surface echo reflected on the thick plate surface. It can be seen in figure 6 that the shortness of the surface echo is now sufficient to reveal the existence of the adjacent successive echos that are clearly separated from each other when the thin plate is used a reflector. Figure 7 shows the echo obtained under the same conditions, except for the reference wavelet which is replaced by its Hilbert transform. The association of this echo with the previous on makes it possible to directly reconstruct the analytic echo which has a modulus represented by the dotted line . (Fig. 4, 5, 6, 7)

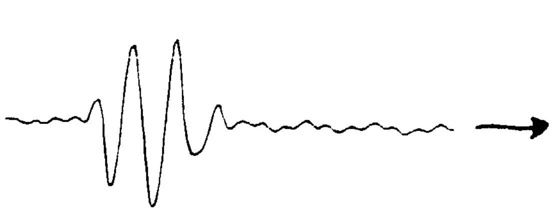

Figure 4

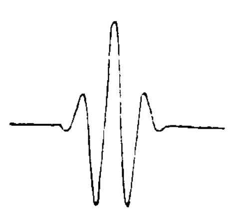

Figure 5

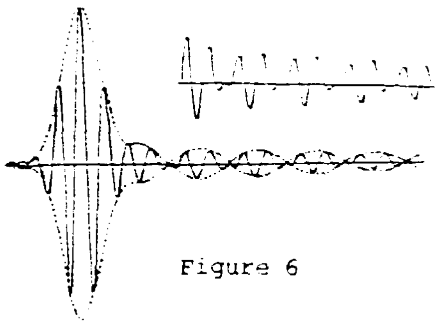

Figure 6

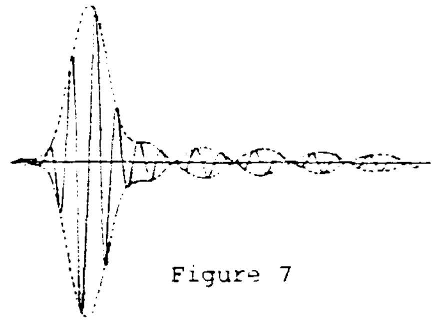

Figure 7

Finally, figure 8 shows the aspect of one of the two pseudo-random noisy echos obtained from the use of an optimum complementary pair with a length of 128 and figure 9 shows the final result after processing both echos. (fig. 8, 9)

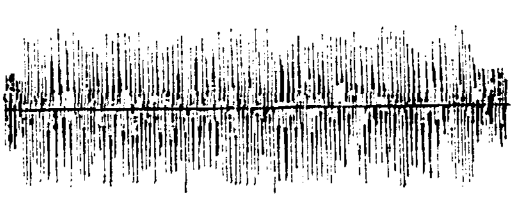

Figure 8

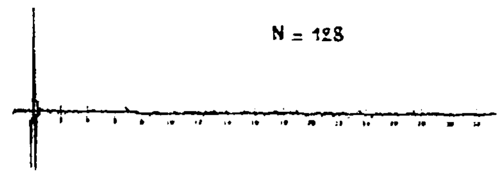

Figure 9

CONCLUSION

The numerical control of the shape of the transmitted ultrasonic wavelet increases the possibilities for NDT investigations.

The experiments confirm that it is now conceivable for a given testing situation to specify, a priori, the temporal and/or the spectral characteristics of the suitable ultrasonic wavelet. Nevertheless, there is still a final restriction which must be noted ; the spectral width of the selected wavelet must stay within the limits of the spectral width of the transducer.

With this conditions satisfied it is possible, using a wide band transducer, to sound the materiel to be tested, with several wavelets with bands that are shortened and shifted. Then, subsequently, all of the echos obtained can be processed with, for example, a polarity-threshold algorithm. The aim of such processing is to reduce the scattering noise reflected from the granular structure usually encountered in stainless or composite materials.

Another interesting application is the generating of exactly the same transmitted wavelet with all of the transducers from the same production run, despite the inevitable diverse defects that result from the manufacturing process. This standard wavelet, which must have good temporal and spectral localization, may be used as a reference for the test, along with a standard reflector. The standard couple, wavelet-reflector, then defines test specifications that are completely independent of the transducer's characteristics, thus ensuring the reproducibility and quality of the NDT measurement.

Finally, the numerical control of the ultrasonic wavelet provides a versatility that makes possible the real-time switching of the wavelet transmitted by the same transducer during the same test. Thus, the wavelet is selected to fit the type of materiel being tested or to fit the specific type of defect that is being scanned, with the aim of improving both detectability and characterization.

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