SHORTENING AND STANDARDIZING THE PULSE SHAPE OF PIEZOELECTRIC
TRANSUDERS IN THE MEGAHertz REGION

Ch. Hüllin, H. Rieder, and H.-J. Welsch
Fraunhofer-Institut für zerstörungsfreie Prüfverfahren, D-6600 Saarbrücken, FRG

The optimization of ultrasonic pulse shape by digitally generated excitation functions is demonstrated. Experiments show correspondence of objective function and measured pulse shape. Shortening of pulses down to 1/5 of "natural" -20 dB width was achieved. The enhanced axial resolution can be useful in non-destructive testing and medical diagnosis with ultrasonics.

INTRODUCTION

The use of ultrasonics in nondestructive inspection or in medical diagnosis is to a large amount based on piezoelectric electro-acoustic transducers. When pulse-echo methods are applied, the transducer is generally excited by a delta-like electrical pulse or by a burst signal with a given centre frequency. When excited by a delta-pulse, a decaying oscillation is generated in the transmitting transducer. The frequency of the oscillation and the damping constant are influenced by the mechanical and piezoelectric properties of the transducer material, by the backing and by electrical or electronical elements (e.g. resonant tuning circuits). The tolerances of these transducer elements on the one side, imperfections during the fabrication process on the other side (e.g. bad bonding of backing and protection layers) are the reasons for non-identical ultrasonic pulses of "identical" probes. Exciting the transducer by a burst signal with a smooth envelope reduces the variability at the cost of a rather extended ultrasonic signal with poor axial resolution. Though well-known for many years, this problem gained more and more attention in recent time when increasing safety requirements in technical areas (e.g. nuclear power plants, pipelines, offshore devices) forced the development of extremely sensitive and reproducible ultrasonic inspection techniques. Special automatic multi-probe systems cannot be tuned to the physical limits because of the mentioned tolerances in the ultrasonic pulse shape.

The reduction of pulse-shape tolerances together with increased resolution in the time domain is easily done in a computer by the well-known deconvolution process [1] (sometimes called "inverse filtering"). On-line deconvolution (e.g. by SAW-devices) is rather expensive, because a special filter design is needed for every individual probe.

Some years ago WINTER et al. [2] demonstrated the analogic process on the transmitter side. He applied an optimized electrical pulse to an electro-acoustic system in the kHz region, the response of which was significantly shorter than the natural length of the delta-response. The extension of this "inverse excitation" technique is now possible into the MHz frequency range, which is of interest for most NDI/NDT applications as well as for medical diagnosis. The "inverse excitation" has been studied in the Fraunhofer-Institut für zerstörungsfreie Prüfverfahren (IZFP) [3].
PRINCIPLE OF "INVERSE EXCITATION"

The optimized excitation of transducers can be realized by the set-up shown in Fig. 1. In the first step a delta-pulse is used as excitation function in the ultrasonic system, which is given by a power amplifier, the transmitting transducer T, the propagation medium, the reflector, the receiving transducer R, and again an amplifier. At the output of the system now the impulse response function I(t) is converted into discrete values I_p(t_n) by the analogue-to-digital converter ADC and transformed into the frequency domain by Fast Fourier Transform FFT. In a parallel path the desired pulse shape given by the discrete-valued objective function O_p(t_n) is transformed into the frequency domain. When using inverse filtering, the filter transfer function is calculated by the point by point division of objective spectrum by the actual spectrum. Here this transfer function is interpreted as the spectral representation E_p(ω_n) of the excitation pulse to be generated. This spectrum is retransformed into the time domain. Now the excitation function E_p(t_n) is gained. It is stored in a cyclic memory CM. The one-step optimization is completed.

Usual operation starts by reading and converting the excitation pulse into an electrical signal by a digital-to-analogue converter DAC, amplifying it, etc. As a result, the response of the ultrasonic system is given by O(t), the objective function.

Some remarks concerning the practical application should be made:
- The usable spectral range is limited in general at least by noise and quantization errors. When the objective function is chosen, this must be considered.
- Obviously, other than delta-excitation functions can be used for the calibration loop, when their spectral composition is compensated.
- The usable spectral interval can be extended, when the calibration loop is used iteratively.

EXPERIMENTAL RESULTS

The principle of "inverse excitation" was realized in an experimental laboratory set-up. The main components are Biomation 8100 transient recorder, POP MINC 11 computer, and INTERFACE Mod. RS 660 word generator. The DAC and the pulse-mode power amplifier were developed and built in IzfP. As reflector in the calibration loop generally a flat extended surface (e.g. the backwall of a metallic specimen) was used, because it does not alter the spectral content of ultrasonic pulses.

The time and frequency domain representations of a backwall echo are shown in Fig. 2 a and b, respectively. This echo was recorded applying delta-excitation to the probe RTD SET 1, which is a 1 MHz, 45° transverse wave type with separate transmitting and receiving transducers. The latter property is important, because the optimized excitation function is rather extended and so a large "dead zone" appears when single-transducer probes are used.

Shortening the pulse means increase the effective frequency bandwidth. In this case the used range was limited to the interval 0.6 to 1.6 MHz. To compensate the slope of the spectrum of the echo, it is necessary to put more energy into the frequency components near the edges of the used interval. The calculated "inverse excitation function" (Fig. 3a) therefore mainly contains two components, the centre frequencies of which are about the factor 2 apart.

The corresponding backwall echo is shown in the lower part of the figure. Compared to the echo in Fig. 1 a the shortening to less than the half of the -6 dB pulse length is obvious. Further the ultrasonic pulse is symmetric within the limits given by digitalization errors. If the pulse-length is measured using the envelope of the complex signal amplitude, the -6 dB and -20 dB width can be reliably deter-
mined. In the mentioned study [3] pulse shortening to 1/3 of the -6 dB width and to 1/5 of the -20 dB width, together with good agreement of objective pulse and measured pulse, could be attained.

The increased axial resolution is demonstrated in Fig. 4, where the superimposed echoes of the backwall of a steel plate and of a flat-bottom hole (diameter: 5 mm, depth: 1.5 mm) are shown. For the upper record (4a) delta-excitation of the 3 MHz normal-incidence transducer was applied. The echoes are not separated. The lower A-scan was produced with inverse excitation. Reflector echo RE and backwall echo BE are clearly separated. The distance of the peaks of the complex amplitude's envelope can be evaluated and corresponds to the expected value of 0.5 μs.

CONCLUSIONS

Optimized, digitally generated electrical excitation of ultrasonic transducers has been demonstrated. This technique is able to generate ultrasonic signals shorter than the "natural pulse length" and standardized pulses with significantly reduced influence of individual transducer's characteristics. Further applications are compensation of dispersive propagation (e.g. in layered media) and on-line correlation for pattern recognition purposes (namely when the excitation is optimized with respect to the expected reflectors).

As an example of application in nondestructive testing, a block diagram of a device for weld inspection is shown in Fig. 5. Because multiple probes and probe combinations are used, every cycle needs its own optimized excitation pulse. These pulses - computed after the analysis of the respective delta-response functions - are stored in a segmented memory and read out consecutively. Apart from the transducer electronics no modifications of ultrasonic systems are necessary.

REFERENCES


2 Winter, T.G., Pereira, J., and Bee Bednar, J., "On driving a transducer to produce pulses shorter than the natural period of the transducer." Ultrasonics, May 1975, pp. 110-112.

Fig. 1 Optimized excitation of ultrasonic transducers by digitally generated electric signals.

Fig. 2 Time (a) and frequency (b) domain representation of a backwall echo.

Fig. 3 Inverse excitation function (a) and corresponding echo (b).

Fig. 4 Axial resolution

Fig. 5 Application of inverse destructive inspection
Fig. 4 Axial resolution with delta-excitation (a) and inverse excitation (b).

APPLICATION IN MULTIPLE PROBE SYSTEMS

US-NDT OF
PRESSURIZED VESSELS
PIPELINE WELDS
THICK COMPONENTS
HEAVY PLATES

Fig. 5 Application of inverse excitation in a multiple probe system for non-destructive inspection of welds.