EFIT SIMULATIONS FOR ULTRASONIC NDE

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Abstract

This contribution presents numerical modelling results for typical piezoelectric transducers and non-destructive testing situations. Starting from the transducer modelling of straight-beam and angle-beam probes up to the simulation of the time of flight diffraction (TOFD) technique and the long-long-trans (LLT) technique, results are given as A-scans and time-domain snapshots of the ultrasonic wavefield, which provide an excellent way to interpret the pulse signature shown in the A-scan.

Introduction

Simulation tools in non-destructive testing with ultrasound deserve more and more attention on behalf of their capability to produce real-life synthetic data; these data are of significant help in the interpretation of recorded A- and/or B-scans. EFIT, the Elastodynamic Finite Integration Technique, starts with the elastodynamic governing equations in integral form. This means that EFIT simulates the nature of ultrasonic waves without any approximations. EFIT discretizes the basic field equations uniquely on a staggered grid; a pertinent code has been implemented for widely arbitrary inhomogeneous and/or anisotropic materials. Details are given for instance by R. Marklein (1). In the present contribution EFIT is applied to simulate the radiation field of various piezoelectric transducers: longitudinal vertical, longitudinal 70°, subsurface longitudinal wave and shear 45° probes. This clarifies the physical understanding of the generated wavefield of such transducers. In a second step, these radiation fields are scattered by various canonical defects: idealized planar cracks with different orientation to the incident beam. That way, a test bed for the TOFD and/or the LLT technique is provided. The resulting crack tip signal amplitudes, as they appear in the A-scans, are compared to those of method of moment modelling. Scanning the transducer(s) results in B-scans, and again, EFIT simulations provide an excellent tool for their interpretation.

EFIT simulations for ultrasonic NDE

EFIT is a simulation tool which relies on the direct discretization of the governing equations of elastodynamics; i. e. Newton-Cauchy's equation of motion and the equation of deformation rate (see reference (1)). All field quantities are function of position and time. In the following we present several simulations where we study the ultrasonic wave generation, propagation, and reception in detail. The time-domain snapshots displayed in the figures below can be composed to "wave movies" and played with Windows Media Player or Quick Time Player, which is extremely useful for multimedia presentations. The wave movies visualize the dynamic behavior of the ultrasonic wavefield which is very helpful for the understanding of the ultrasonic wave propagation. Some words to the notation of the different wave types: if we consider plane ultrasonic waves in solids, we find mainly two different wave types which travel with different velocities: the one with the highest velocity arrives first and is therefore called primary (P) wave, the other is then called (S) secondary wave. The polarization acts as a second criterion and this is usually used in NDT, like longitudinal (L) and transversal (T) or short “long” and “trans” or pressure (P) and shear (S). And even further, if we introduce a reference plane, we can differentiate between shear vertical (SV) and shear horizontal (SH) polarization. In this paper we focus on the 2-D P-SV case only. Our standard model pulse is a raised cosine pulse with two cycles (RC2) as shown in figure 1. The carrier frequency f_0 is amplitude modulated with the envelope containing two oscillations. Parameters of the impulse are the frequency f_0, the cycle length T_0 and the total pulse duration T.

Different straight-beam and angle-beam probes

Figure 2 presents the first 2-D EFIT result for an ultrasonic wavefield generated by a long vertical probe with an RC2 pulse as the stimulus. The nearly plane pressure wavefront (P) of the aperture, the concentrically pressure waves (Pl, Pr) and shear waves (Sl, Sr) emitted from the edges of the aperture, Rayleigh surface waves (Rl, Rr) and the lateral head waves (Hl, Hr) are clearly observed. Figure 3 displays time-domain snapshots for different ultrasonic probes in the 2-D pressure-shear vertical (P-SV) case. The main features are clearly observed. For instance, figure 3c shows the wavefield of a longitudinal 70° angle-beam probe, where beside the pressure wavefront (P) the mode-converted shear wavefront (S) is visible.

Scattering by an inclined crack

Figure 4 shows the geometry of an inclined crack which is illuminated by the wavefield of a longitudinal vertical probe. The received A-scan in non-rectified high-frequency (HF) form is given in figure 5a, where the essential crack tip echoes (Pct, Pcb) are identified and indicated in the time-domain snapshots in figure 5b. Due to the stair stepped approximation of the original flat crack in the discrete EFIT grid system several echoes arrive between these signals, which are indicated in the A-scan as noise. In figure 5c a reference solution using the method of moments is presented. The two crack tip echoes are indicated and the amplitude of the echoes coincides with the prediction in figure 5a.

LLT technique

Figure 6 and 7 display 2-D EFIT results for the LLT technique applied to a solid test specimen with a vertical flat crack. The LLT echo as the dominant signal is indicated in the A-scan and time-domain snapshots. Beside this main pulse two smaller echoes are received at the probe. The origins of these echoes are indicated in the snapshots.

TOFD technique

Figure 8, 9, 10 and 11 display 2-D EFIT results for the TOFD technique. Here we study in figure 8 and 9 the vectorial elastic case compared to the scalar acoustic case given in figure 10 and 11. Figure 9a displays the A-scan for the elastic case. The first two echoes (Pr, Pl) are generated by the longitudinal wave from the right and left edge of the emitter. The important echoes (Pct, Pcb) from the top and bottom crack tip are indicated in the A-scan and the snapshots. Figure 11 shows comparable results for the scalar acoustic case, where the echo from the top crack tip is much larger as in the elastic case (see figure 9a).

Conclusion

EFIT has been applied to a wide set of real-life problems. Here we have presented only some selected examples. Further results can be found in the literature, for instance in reference (1) and references therein and our website www.tet.e-technik.uni-kassel.de.

References

(1) R. Marklein, *Numerical Methods for the Modeling of Acoustic, Electromagnetic, Elastic and Piezoelectric Wave Propagation Problems in the Time Domain Based on the Finite Integration Technique*, Shaker Verlag, Aachen, Germany, 1997, (available from http://www.shaker.de), (in German).

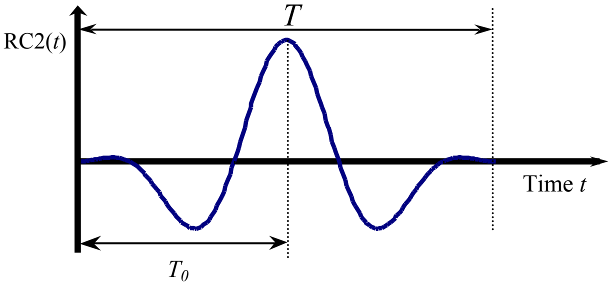


Figure 1. Time history of the raised cosine pulse with two cycles: RC2(*t*). The carrier frequency is $f_0=1/T_0$ and T is the pulse duration. Here $T=2T_0$.

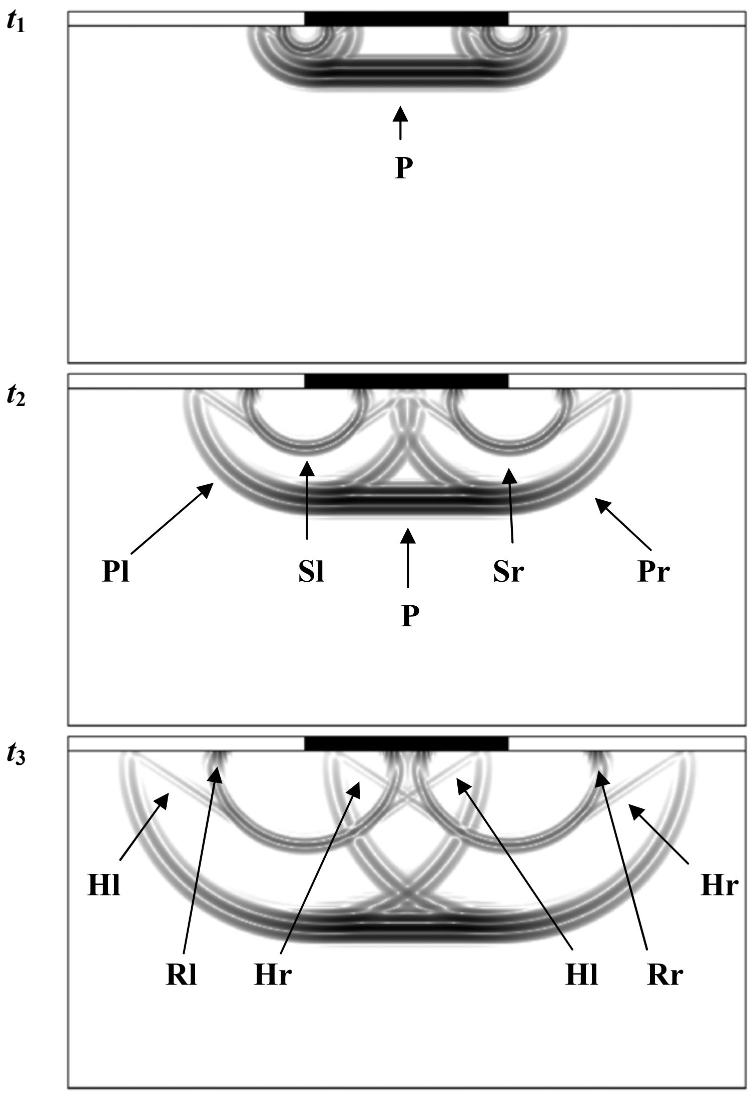


Figure 2. EFIT time-domain snapshots of the ultrasonic wavefield generated by a longitudinal vertical straight-beam probe. The position and size of the probe is indicated by the black bar. Displayed is the magnitude of the particle velocity |v| at three different time points t_1, t_2 and t_3 with $t_1 < t_2 < t_3$.

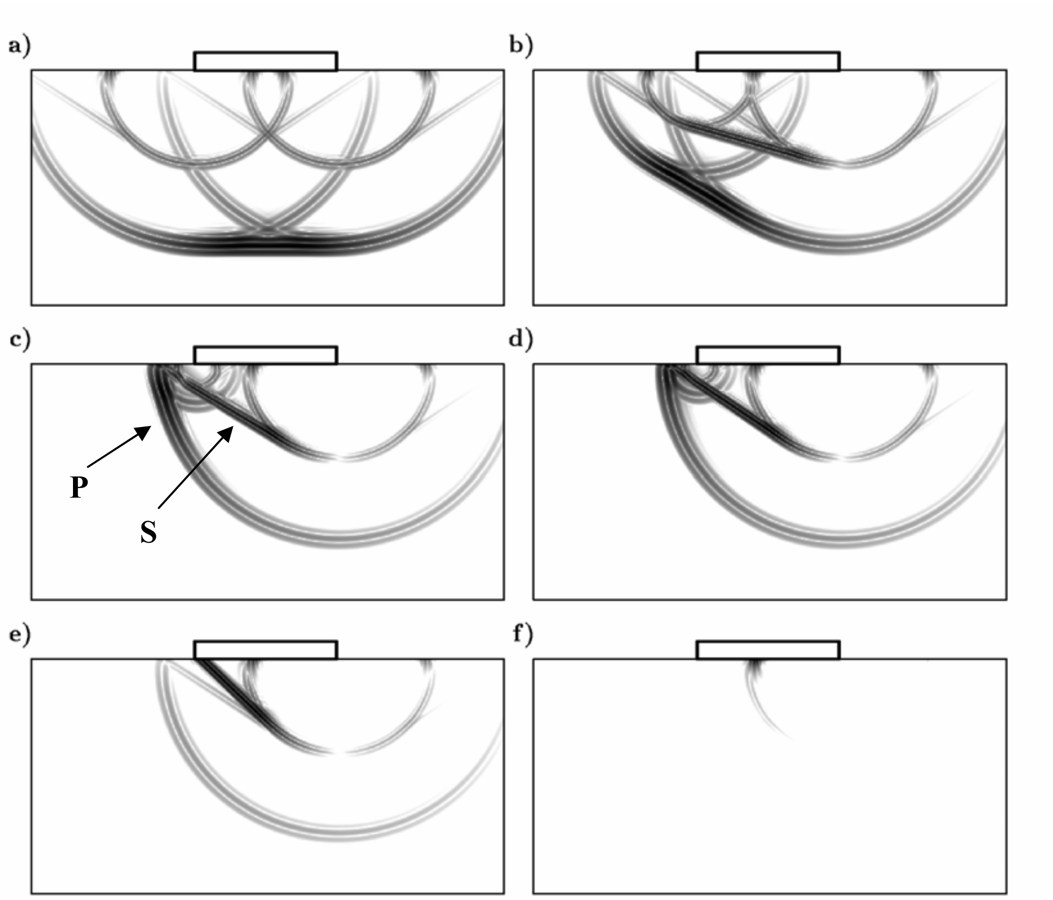


Figure 3. Time-domain EFIT ultrasonic transducer modeling in the 2-D pressure-shear vertical (P-SV) case: a) longitudinal 0° wave transducer; b) longitudinal 30° wave transducer; c) longitudinal 70° wave transducer; d) subsurface longitudinal wave transducer; e) shear 45° wave transducer; f) Rayleigh wave transducer

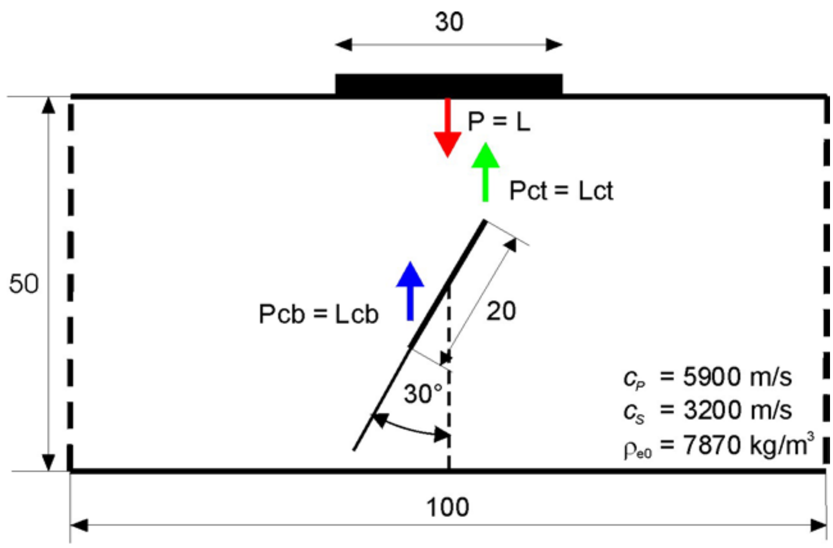
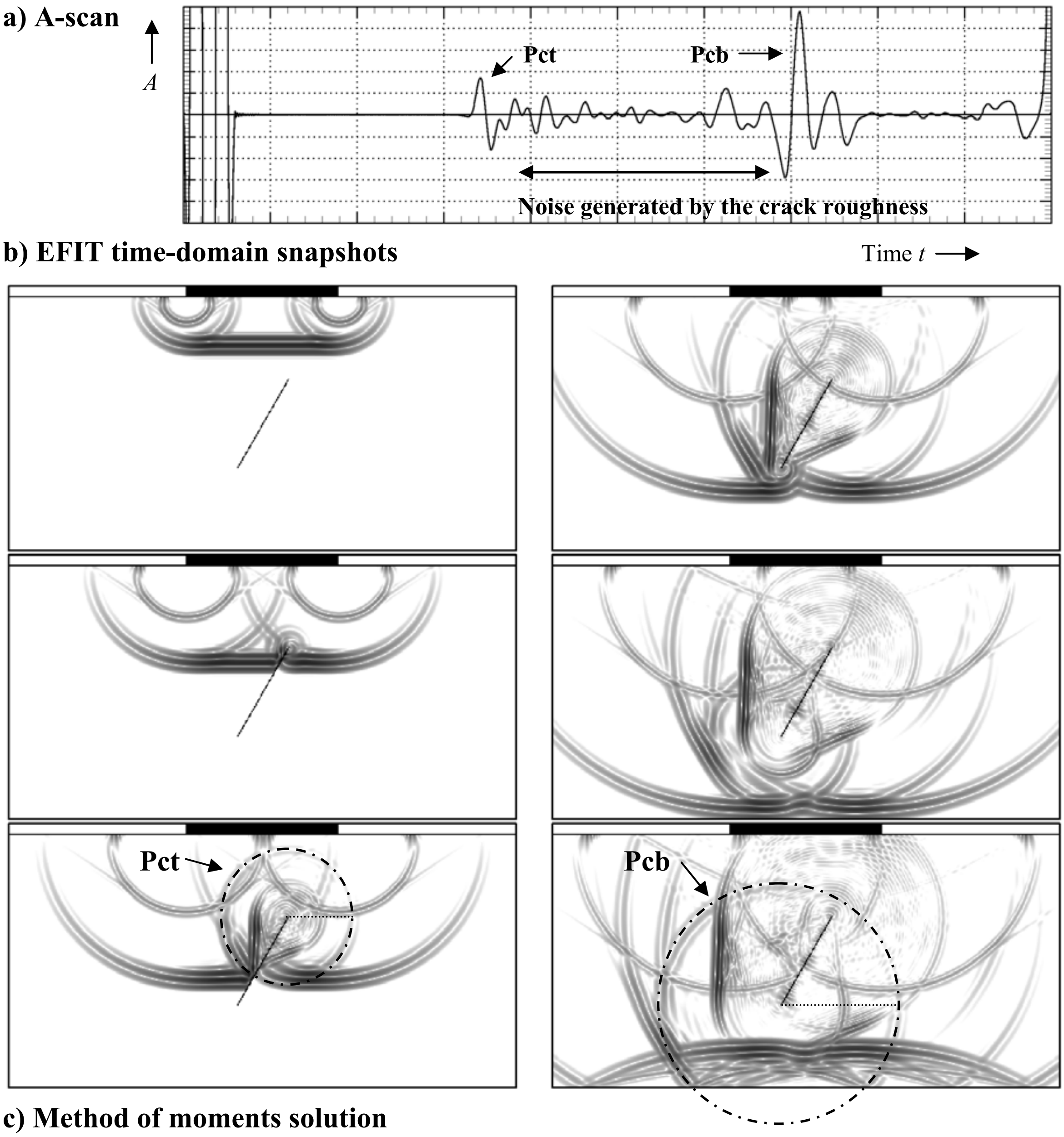


Figure 4. LLT geometry for the 2-D EFIT simulation. The black bar indicates the position of the 2 MHz long straight-beam probe. P=L is the incident longitudinal wave; Pct=Lct is the diffracted echo from the top tip and Pcb=Lcb is the diffracted echo from the bottom tip of the inclined crack.



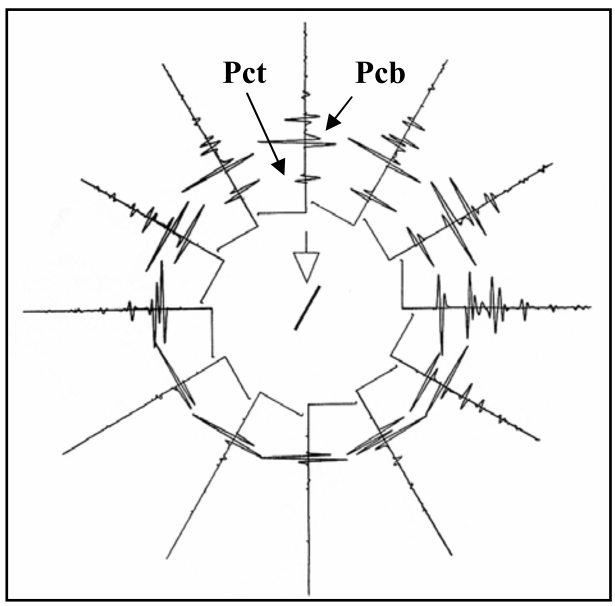


Figure 5. 2-D EFIT simulation of the LLT technique: a) A-scan in high-frequency form; b) EFIT time-domain snapshots of the magnitude of the particle velocity vector, the dash-dotted circles indicate characteristic of the cylindrical pressure wavefront from the top and bottom crack tip (Pct and Pcb); c) reference solution using methods of moments (MoM) for the free-space case and plane pressure illumination

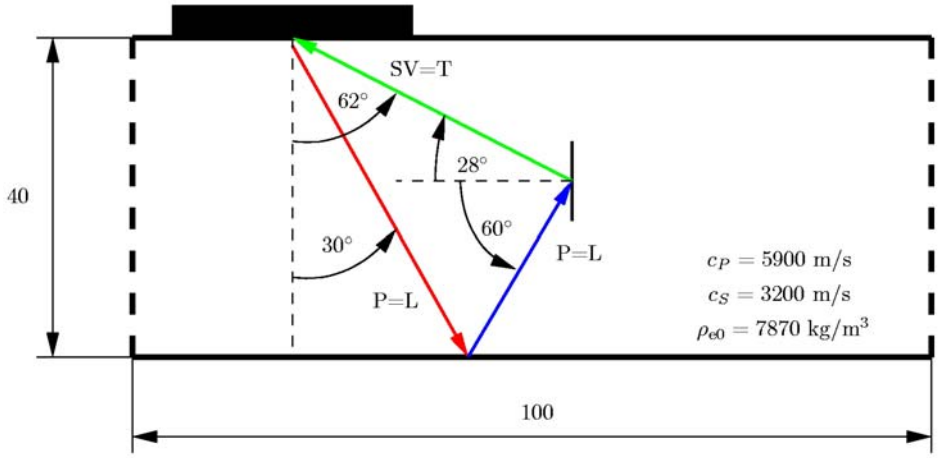


Figure 6. LLT geometry for the 2-D EFIT simulation. The black bar indicates the position of two angle-beam probes, a 2 MHz 30° longitudinal angle-beam probe and a 2 MHz 62° transversal angle-beam probe.

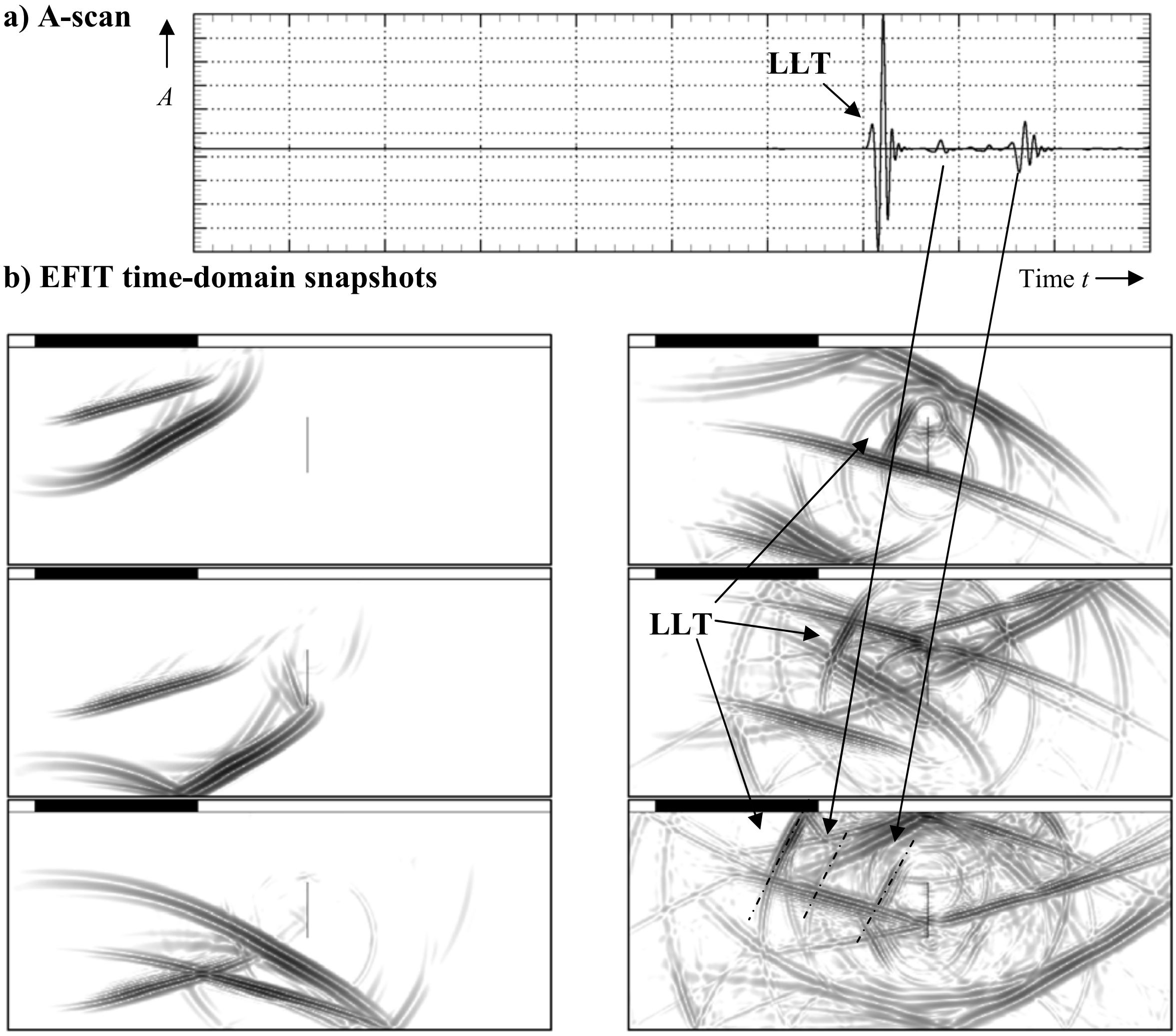


Figure 7. 2-D EFIT simulation of the LLT technique: a) A-scan in high-frequency form and b) EFIT time-domain snapshots of the magnitude of the particle velocity vector. The dash-dotted lines indicate the characteristic of the received echoes.

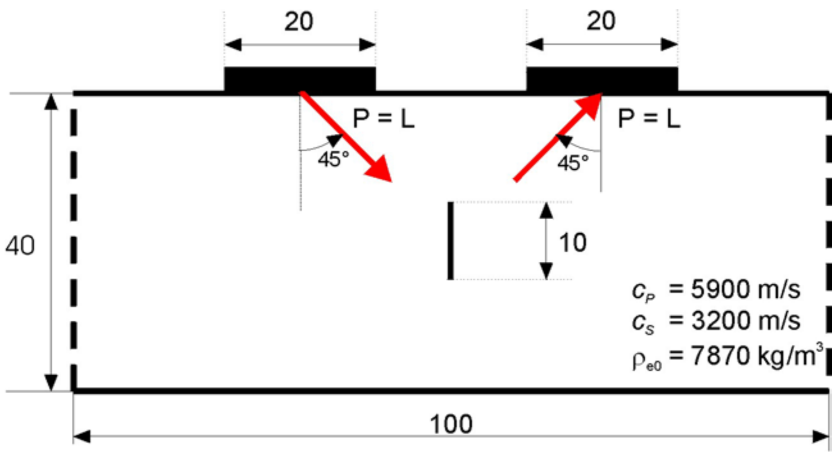
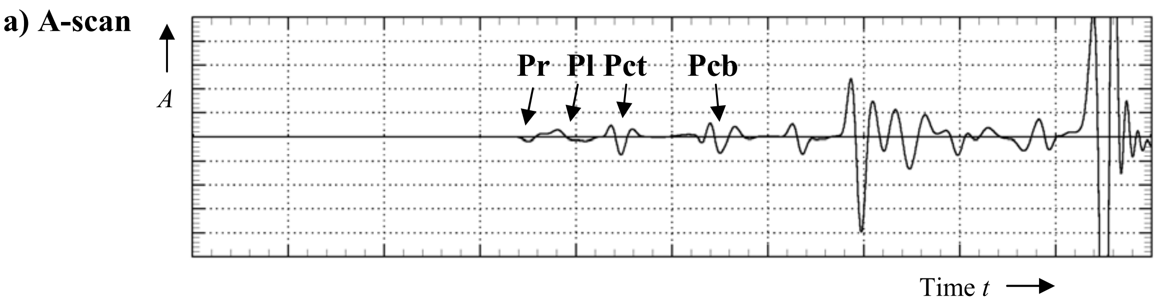


Figure 8. TOFD geometry for the 2-D EFIT simulation. The black bars indicate the position of two angle-beam 45° long 2 MHz probes.



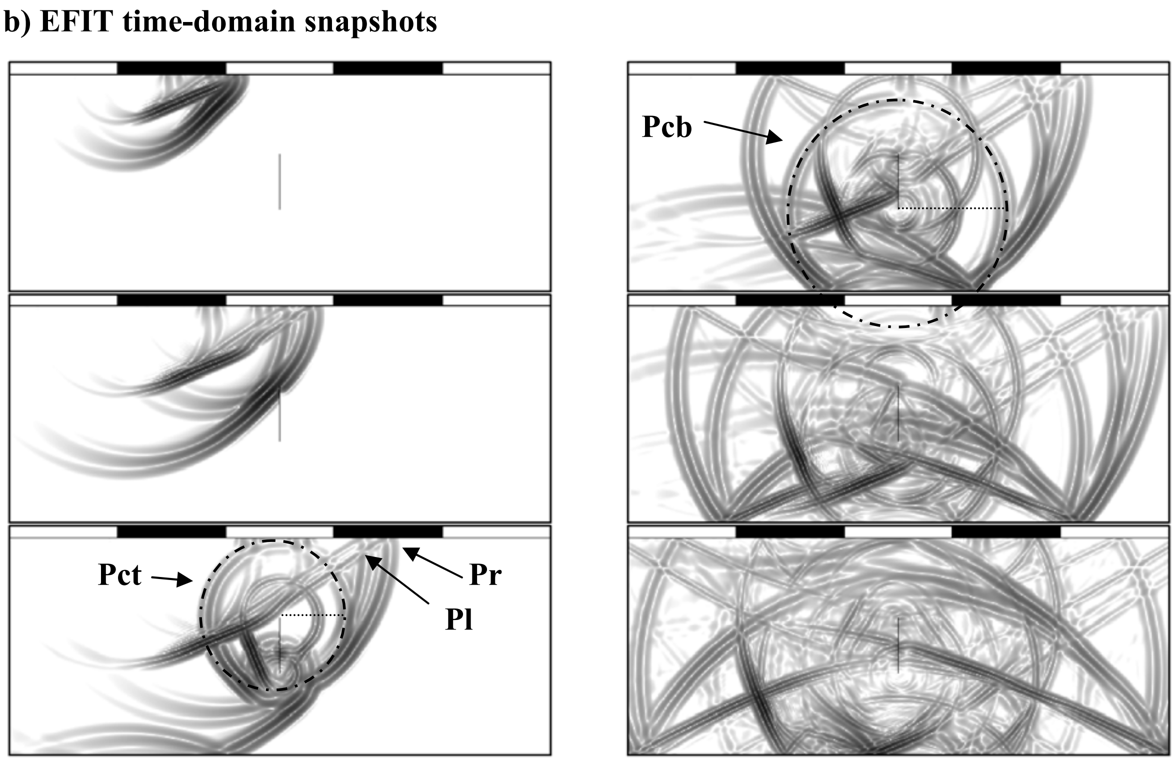


Figure 9. 2-D EFIT simulation of the TOFD technique: a) A-scan in high-frequency form and b) time-domain snapshots of the magnitude of the particle velocity vector. The dash-dotted circles indicate the characteristic of the crack tip echoes.

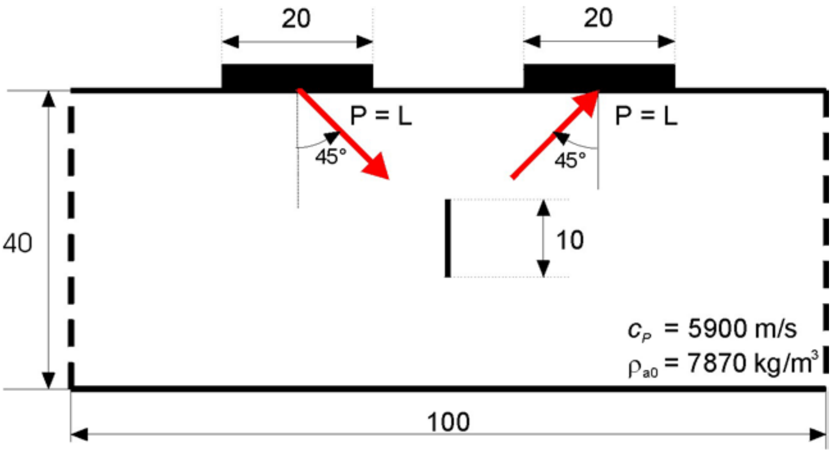


Figure 10. TOFD geometry for the 2-D EFIT simulation. The solid material is treated as a scalar acoustic medium with the parameters indicated in the figure. The black bars indicate the position of two angle-beam 45° long 2 MHz probes.

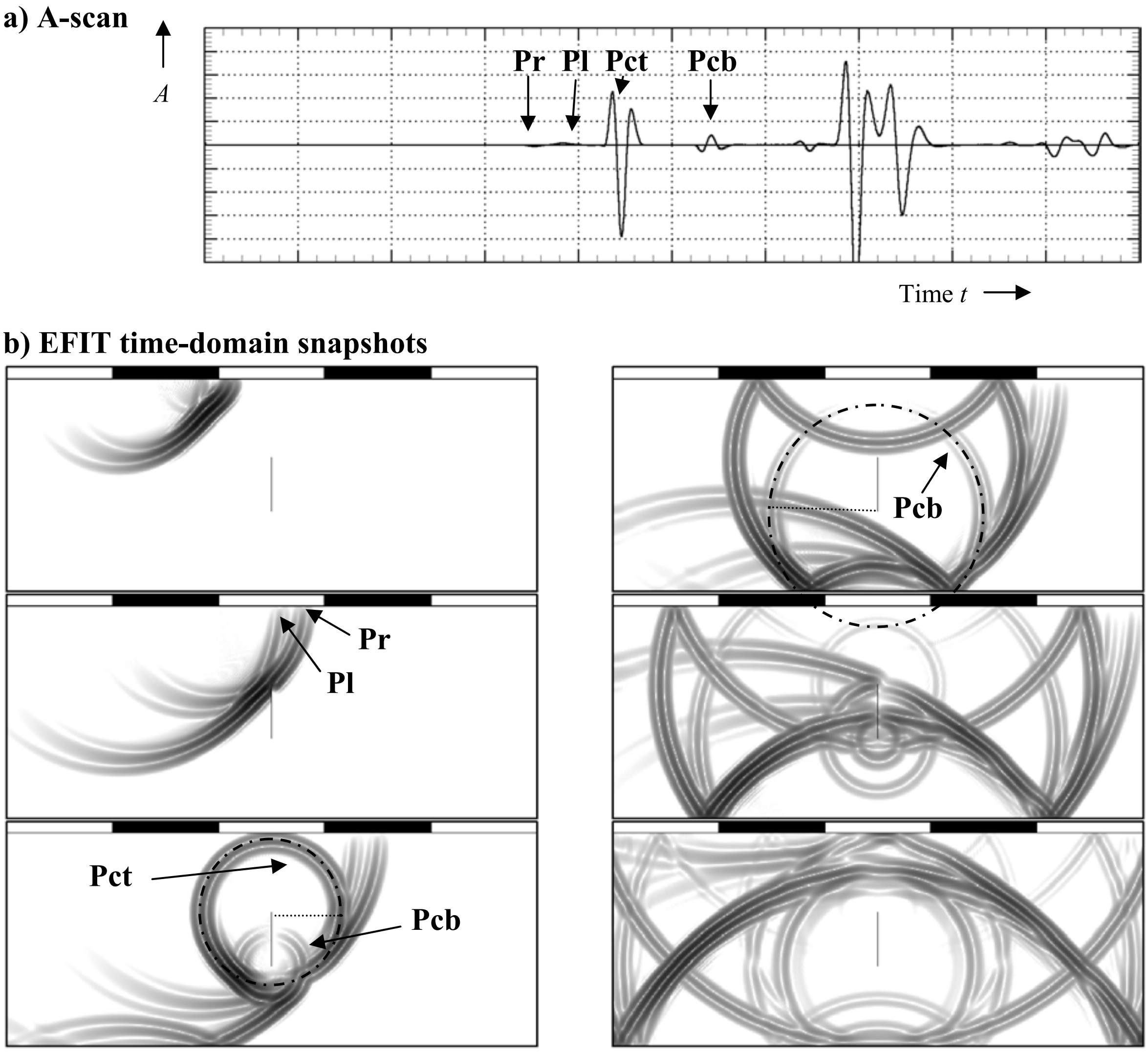


Figure 11. 2-D EFIT simulation of the TOFD technique for the scalar acoustic case: a) A-scan in high-frequency form and b) time-domain snapshots of the magnitude of the particle velocity vector. The dash-dotted circles indicate the characteristics of the crack tip echoes.