NON-DESTROYING EVALUATION OF ENGINEERING CERAMICS BY HIGH-FREQUENCY ACoustic TECHNIQUES

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INTRODUCTION

In order to detect defects by ultrasound efficiently, it is necessary to make the wavelength comparable to the defect size. Due to fracture mechanics considerations, it is necessary to detect defects smaller than 100 µm in engineering ceramics by NDT-techniques [1]. This requires high-frequency ultrasonics (UT) due to the large sound velocity in ceramics and, in order to obtain sufficient spatial resolution, pulses shorter than 100 ns are needed. A large bandwidth for both the electronics and the transducer are then necessary. The transducer employed may be excited by either an exponentially decaying step-pulse (broadband excitation) or by a rf-carrier pulse.

PHYSICAL BACKGROUND

Depending on the ratio of the defect size a to the employed ultrasonic wavelength λ, one can distinguish three regimes [2]: Rayleigh scattering (a/λ « 1), resonance scattering (a/λ - 1) and geometric scattering (a/λ » 1). If we employ 50 MHz ultrasonic waves in ceramics, we are in the Rayleigh-regime for the order of defect size mentioned above. Neglecting diffraction, the intensity I sc backscattered from a given spherical defect can be estimated to be:

\[ I_{sc} = I_o (f(\pi))^2 \pi a^2 \exp(-\alpha r) \, d\Omega \]  

where \( d\Omega = \Delta F/4\pi r^2 \). Here, \( I_o \) is the ultrasonic intensity irradiated on the defect, \( f(\pi) \) is the backscattered amplitude [3], \( \alpha \) is the attenuation coefficient in the material, \( \Delta F \) is the area of the transducer, \( r \) is the depth of the defect, and \( d\Omega \) is the solid angle subtended by the probe as seen from the defect. Because \( f(\pi) \propto a^2 \), \( I_{sc}/I_o \propto a^6 \). This means that very efficient transducers have to be used in order to get a high signal/noise ratio (SNR) for a given excitation voltage of the transducer. In the case of other defect shapes also expressions similar to Eq. (1) hold good [2].

TRANSDUCERS

We have examined various ultrasonic transducers and found that transducers made out of Polyvinylidene fluoride (PVDF) and the copolymer Polyvinylidene fluoride Trifluoreethylene (P(VDF-TrFE)) are well suited...
for C-scan imaging [4]. They have sufficiently large bandwidth, and by carefully matching the transducers electrically, one can obtain insertion losses as small as 11 dB in immersion techniques. Additionally, they can be manufactured as focusing probes with well matched acoustic impedance to water [5].

**ELECTRONIC EQUIPMENT**

Besides using broadband excitation of the transducer by a step-like pulse with a decay-time of approx. 10 ns (USH 100 made by Krautkrämer-Branson Köln-Hürth, FRG) we also employ sine-burst excitation of the transducer (Fig 1). From various laboratory experiments a prototype was designed with the following characteristics: A continuous wave-signal is generated by voltage-controlled oscillators (VCO) and is then amplitude modulated at low power levels. This allows one to keep the leakage power at minimum by using two Pin-diode switches in series for modulating. After this, the pulses are amplified to approximately 20 W peak power. The system built by us has an on/off ratio of at least 90 dB in the frequency range from 10-200 MHz. The minimum pulse-width contains one rf-cycle and the pulses are switched at their zero crossings. The maximum number of cycles is 256. Particular emphasis is given to obtaining maximum signal to noise ratio (SNR) of both emitting and receiving parts of the electronics allowing maximum sensitivity for defect detection. All parameters of the system can be controlled by a microcomputer or PC [6].

**EXPERIMENTAL RESULTS**

**A-Scans**

In order to test the performance of our system, A-scans were obtained from defects with well-defined size in densely sintered and small grained SiC and Si₃N₄ ceramics. Table I shows our results on the measured SNR. In this case we employed a focusing transducer with a focal length Z = 25 mm. The diameter Dₜ of the piezoelectric element was 3 mm. The influence of the attenuation in the water path and in the ceramic was of minor importance on the measured SNR.

It is striking to note that the difference in SNR as measured for various defects of same size is very small, even though the differences in acoustic impedance of the defects to the host material are quite large. This reflects to the fact that in the Rayleigh regime, the amplitude of the backscattered signal depends, in a rather complicated way, on the elastic parameters of the host material and the defect [3]. Due to

![Figure 1. Block diagram of the system used for high-frequency ultrasonic C-scan imaging. The immersion technique is used for coupling.](image-url)