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EXPECTED AMPLITUDES OF ULTRASONIC ELASTIC WAVES SCATTERED FROM ROUGH DEFECTS

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ABSTRACT

Ultrasonic NDE techniques, such as time-of-flight diffraction [1] (TOFD), have been developed using modelling and experiments, and are well understood when cracks are smooth and straight. However, in environments where there are extreme changes in temperature and pressure, as with nuclear power station components, the damage that occurs is often not uniform. Rough cracks are formed and these are much more challenging to characterise.

The qualification of ultrasound inspections of defects that are expected to be rough (typically thermal fatigue or stress corrosion cracking) is presently very conservative, owing to the uncertainty of the amplitudes of rough surface reflections. Any individual rough surface is unique and so scattering signatures differ from one surface to the next. The pragmatic solution is to apply a large safety threshold on the expected reflection amplitude, but this can lead to unnecessary shut-downs and early retirement of components.

An alternative approach has been developed by the authors, whereby the expected reflection from a rough defect can be predicted using a statistical model [2]. Although every rough defect is randomly determined, it is possible to anticipate statistical metrics of a rough surface using extensive industrial databases of characterised in-service defects. Given only the angle of incidence and two statistical parameters, the expected reflection amplitude is obtained instantaneously for any scattering angle and length of defect. The method has been investigated for the scattering of both incident longitudinal and incident shear waves, and includes the subsequent mode-conversion.

The stochastic model uses a stationary phase adjustment of the Kirchhoff approximation (KA) method [3]. For the range of validity of KA (established in [4,5]), the method has been found to be very accurate upon validation against Monte Carlo simulations of large numbers of different surface profiles, which share the same statistical parameter values. The simulations have been performed for both KA and with high-fidelity finite element (FE) methods incorporating the GPU software package Pogo [6].

An example is illustrated for shear-wave normal incidence in Figure 1. The roughness is characterised in terms of the deviation of height (σ) from a smooth reference surface and the spread of these heights (λ_0) [3]. Both parameters are expressed as multiples of the incident wavelength. The expected specular reflection intensity (in dB) of the shear-shear mode is plotted versus the RMS height σ for a fixed correlation length λ_0. The agreement between the stationary phase method (solid red) and KA method (dashed black) is excellent. A 95.4% confidence interval (two standard deviations) is also shown for the KA method (dashed blue).

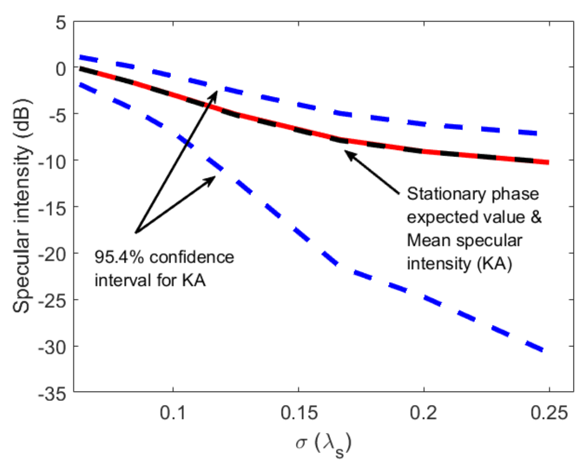

FIGURE 1: Expected specular reflection intensity of the shear-shear mode for $\lambda_0 = \lambda_s$. Stationary phase prediction (solid) and KA (dashed) for 4000 surfaces.

A better understanding of rough crack scattering will ultimately enable the current industrial thresholds to be safely eroded and

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will lead to a reduction in down-time and an improved confidence in the safe operation of nuclear power plants.

Keywords: Randomly rough surface, elastic wave scattering, Kirchhoff approximation

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