Phase Angle Thermography for depth resolved defect characterization

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Abstract

Optically excited Lockin-Thermography is a non-contact NDE-method which found its place in a broad field of applications. However, the depth information about thermal boundaries (i.e. defects) which is included in the resulting phase angle images has not been extracted rigorously till now. A simple approach is presented in this paper.

1. Lockin-Thermography

Due to periodic surface heating a thermal wave is injected into the specimen. At subsurface-defects (i.e. cracks, delaminations) the thermal wave is reflected and finally superposed with the incident wave at the surface. With an infrared camera, several excitation periods are recorded. The Fourier transform (performed at the modulation frequency) results for each pixel in a phase and a magnitude value.
The depth range of this method depends on the thermal diffusion length

$$\mu = \sqrt{\frac{\alpha}{\pi f}}$$

with modulation frequency f and thermal diffusivity α. Therefore, lower frequencies allow deep-lying defects to be discovered. Figure 1 shows how the phase values at three wall thicknesses depend on modulation frequency. This behaviour of thermal wave superposition allows a 3d reconstruction of subsurface boundaries.

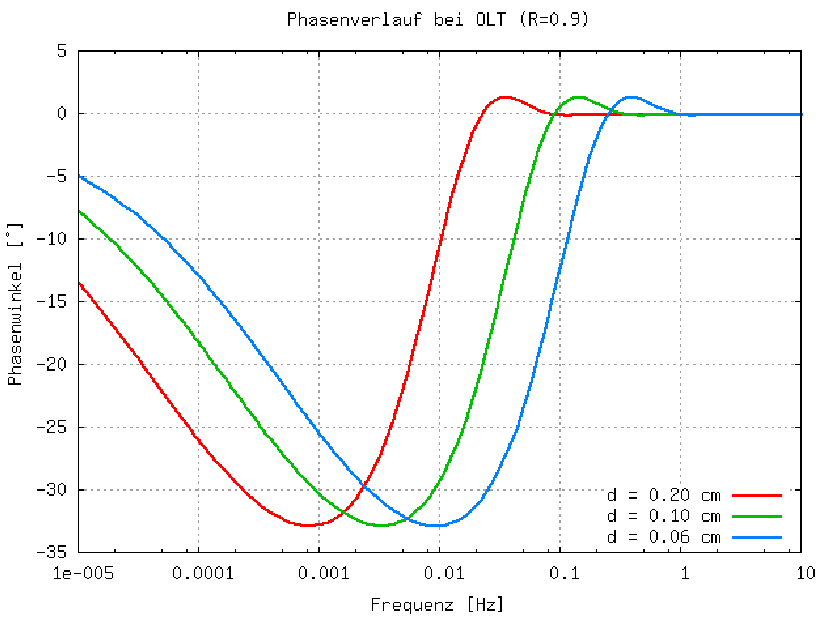
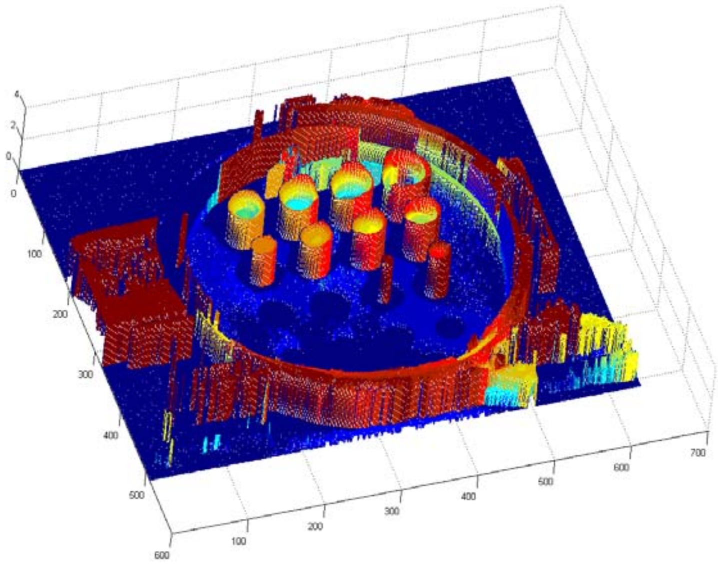


Figure 1: *Phase angle value depending on the lockin-frequency.*

2. Depth profiling and visualisation

On the base of phase angle values obtained at several excitation frequencies, thermal boundaries can be displayed in a 3d plot, similar to tomograms: As the frequencies where the minima of the curves occur (Fig.1) are correlated with local depth (in a homogenous material with constant thermal diffusivity), an image of such frequencies displays directly local depth. This is true at least in a 1d approximation where lateral heat flow is ignored. The following example shows such a frequency image obtained on a model specimen consisting of PMMA (polymethylmethacrylate) with flat bottom holes drilled from the rear side.



For applications it should be kept in mind that the location of the minima in Fig 1 depends on depth normalised to diffusion length. Hence, to obtain reliable local thickness data, either thermal diffusivity needs to be known or a calibration is required that is based on two known thicknesses.

Keywords: Thermography, 3d-visualisation, depth profiling, phase evaluation.