

Application of the Thermal Pulse Method for Nondestructive Evaluation of Embedded Piezoelectric Transducers

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Structural components with embedded piezoelectric sensors and actuators find application in structural vibration suppression and noise reduction, energy harvesting, structural health monitoring, precision positioning, etc.. During fabrication, piezoelectric transducers are supposed to mechanical and thermal depolarization, microcrack formation, etc. Therefore, non-destructive evaluation of the polarization state is required for quality inspection.

A periodic thermal excitation of the piezoelectric material gives rise to a pyroelectric current which carries information on the polarization profile. In frequency domain, the Laser Intensity Modulation Method (LIMM) is well-established [1]. Thereby, thermal oscillations are generated by a periodically modulated laser beam. When thermal pulses are applied with a pulsed laser, the signal is recorded in time domain, but it can be Fourier-transformed and analyzed in the frequency domain similar to LIMM [2].

Recently, we have demonstrated that thermal methods are promising for the non-destructive evaluation of the polarization state and thermal interfaces of piezoelectrics embedded into low temperature co-fired ceramics (LTCC), epoxy resin and polyimide, polyamide 6 as well as high-pressure die-casted Al [3, 4]. At low modulation frequencies, the pyroelectric response of PZT is governed by thermal losses to the embedding layers. In this case, the sample behaviour can be described by a harmonically heated piezoelectric plate exhibiting heat losses to the environment characterized by discrete relaxation times or by their continuous distribution. Thermal relaxation characterizes the thermal contact and, thus, enables locating lamination failures. For Al die-casted piezoceramic modules, the pyroelectric current spectrum allows to distinguish centre-positioned from an off-centre positioned transducers [4].

In this work, we present analytical and FEM (finite element method) models to describe the time dependence of the pyroelectric current of embedded piezoelectrics generated by a laser pulse. Analytical solutions of the one-dimensional heat transfer equation consider a two-layer model, account for the experimentally derived heat pulse shape and the heat loss to the environment. They serve as a proof of the more complex FEM models which allow the consideration of three-layer models. The FEM model provides an understanding of the heat transfer in structurally complex devices excited by laser pulses. However, it underestimates the heat extraction process at the bottom transducer interface. Problems with accuracy of FEM are well known to occur near interfaces exhibiting steeply changing properties. Nevertheless, they are usually ignored in textbooks and manuals. When proved by simplified analytical solutions, FEM modelling provides a useful tool for the understanding of heat transfer processes in such complex devices as embedded piezoelectric transducers.

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