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Simulation of Induction Heating for Infrared Thermography with consideration of spectrum artefacts

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Abstract

Induction thermography is identified as a promising non-destructive testing method for detecting and characterizing surface cracks in metals. The sample to be inspected is heated with a short induced electrical current pulse and the infrared camera records the temperature distribution and transient temporal behavior at the surface during and after the heating pulse. When a surface defect such as a crack or porosity is present, it locally modifies the electrical and thermal conductivity, so that the eddy currents are deflected and thermal gradients appear in the vicinity of the defect, allowing their detection with the help of appropriate signal and/or image processing.

For the study of metals generally inspected in aeronautics (Nickel Base superalloy, Titanium, Aluminium,...), the detection contrast associated with a defect depends on many parameters specific to induction excitation: i) the power density deposited locally and therefore the type of inductors, ii) the electromagnetic skin thickness monitored through the magnetic excitation frequency, iii) the heating time and iv) the waveform of the excitation signal. Therefore, the whole excitation chain, the inductors and inductor/workpiece coupling, the heating head including the power transformer and the oscillating RLC circuit, the power and signal generator, must be optimized in order to maximize the probability of detection of sub-millimetre defects in metallic materials. The work in [1], carried out in lock-in multi-pulse acquisition mode, highlights the importance of generating short heating periods in order to have thermal diffusion lengths less than 1mm and thus short analysis times for the inspection of small defects. In this case, the issue is to ensure a sufficient signal-to-noise ratio (SNR), and therefore to inject sufficient energy into the material by Joule effect. A solution proposed in [1] consists in repeating the induction shots N times, using the lock-in multi-pulse acquisition technique and, so, increases the SNR, in particular on the phase images of the Fourier transform.

In this paper, we propose simulations by solving the finite difference heat equation on a simple case, i.e. a plate containing a notch defect. The time signals at each pixel around the defect are simulated, in order to study the contrast between a sound area and one containing a defect. The analysis of the time derivatives of the signal and a discrete Fourier series decomposition allow to locate on the signal the most favourable portions to maximize the contrast of detection on defect. The results show that due to the low-pass behavior associated with a defect (resistance and thermal capacity), the edges of the excitation step should ideally be very fast to maximize the phase contrast associated with the defect, especially from the first moment of the induction heating. However, in real practice, the speed of these rising and falling edges is limited by artefacts: i) switching losses in the power electronics, ii) Joule and iron losses in the inductor and the heating head, iii) the imperfect impedance matching between the generator and the inductor, iv) the electrical impedance of the whole excitation chain, which introduces a speed limitation on the excitation slew rate. The originality of the proposed work consists in proposing a model able to simulate this slew rate artefact on the excitation step and to account for the thermal consequences on the degradation of the defect detection contrast. A frequency-domain representation is proposed in order to identify on the Bode diagram the thermal transfer function associated with the material response from the a priori knowledge of the emission spectrum of the excitation signal containing the slew rate artefact. This representation, using the thermal impedances, reveals a cut-off frequency associated with the healthy material, different from the cut-off frequency associated with the defect, which depends on the geometrical extent of the defect. The simulation results are compared with the experimental ones and show a good ability of the model to reproduce the artefact of the rise velocity limit of the step. Finally, the simulations allow the design of an optimal excitation chain in order to maximize the defect detection contrast.

REFERENCES

[1] B. Oswald-Tranta, Lock-in inductive thermography for surface crack detection in different metals, Quantitative InfraRed Thermography Journal, Volume 16, 2019-Issue March 2019.