Quantitative Thermography for NDE

C. Spiessberger[1], V. Carl[2], A. Dillenz[1]

[1] edevis, Handwerkstr. 55 christian.spiessberger@edevis.de
[2] T-ZfP, Thyssenstr. 183a, 46535 Dinslaken, carl@t-zfp.de

Many applications of optically excited lockin and pulse phase thermography for non-destructive testing purposes are based on analyzing the phase angle difference between intact and defect parts of tested components. A more sophisticated approach is the direct evaluation of the measured phase value. This is often done by calibration tables which link certain phase values to physical parameters like, for instance, thickness. However, the phase value depends not only on thickness but also on thermal properties of the measured interface. Both parameters can be determined with two measurements at different lockin-frequencies without the need of calibration tables. The paper compares the calibration-based evaluation with the new multi-frequency approach.

Introduction

Optically excited thermography is a well-known method to identify and characterize interfaces that are oriented parallel to the surface. The surface of the specimen to be tested is heated by a short flash (pulse thermography) or periodically (lockin thermography) and the generated heat flux is examined. Defects like delaminations in laminates or voids in metals disturb the heat flux. The resulting temperature difference at the surface is detected by an infrared camera. Fourier transforming the acquired temperature sequence can enhance the signal-to-noise-ratio of the resulting phase images significantly.

However, phase values do not represent physical parameters directly. For measurements at two layer systems, e.g. thickness measurements of coatings, calibration measurements can be done at test specimens to link a certain phase value to a certain thickness. However, if the coating or the substrate changes those measurements have to be repeated every time.

The problem can be solved by combining lockin measurements at two (or more) different lockin-frequencies. This method was developed in collaboration of our company with the University of Stuttgart [1].

The paper compares the calibration-based evaluation with this new multi-frequency approach and presents a few applications.

Theory

The calibration technique is quite easy and straightforward. For thickness measurements of coatings, for instance, test specimens with different coating thicknesses are made and measured with pulse phase or lockin thermography. The measured phase angles for particular thicknesses are stored in a look-up-table and can be retrieved to evaluate measurements at real parts.

The multi-frequency approach for lockin measurements is a little bit more complex. The lockin phase value depends on the normalized thickness $d/\alpha^{0.5}$, where d is the thickness and α the thermal diffusivity and the so-called thermal reflection coefficient R. The phase value can be calculated out of following equation [2]:

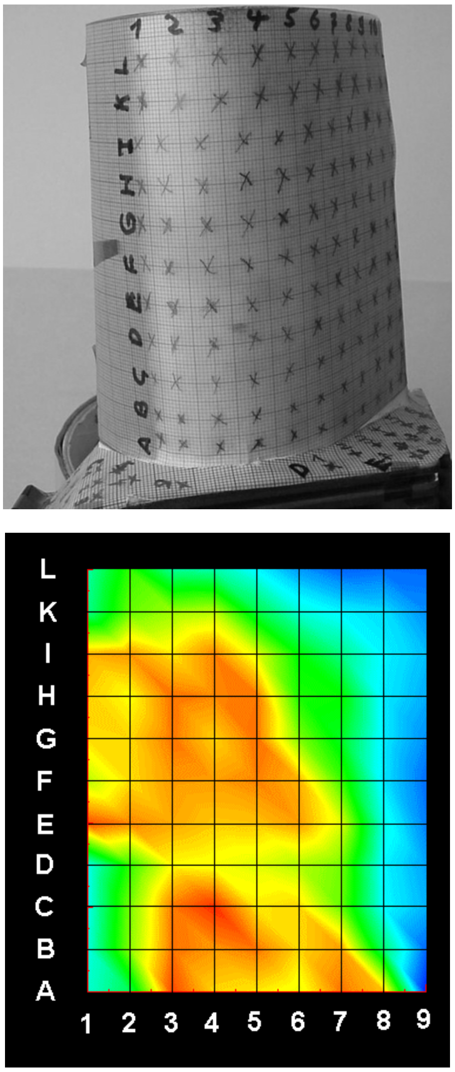

Fig. 1. Turbine blade with thermal barrier coating (top). Calibrated thickness image (bottom). Thick areas are marked red, thin areas blue.

$$\varphi = \arg\left(\frac{1+\mathrm{R}e^{-2d\sigma}}{1-\mathrm{R}e^{-2d\sigma}}\right) \quad . \qquad (1)$$

σ is the thermal wave number including α.

Again, a look-up-table is calculated for all possible values of φ at all required lockin frequencies. *R* and $d/\alpha^{0.5}$ can then be determined out of two phase values at different lockin frequencies. Alternatively, a direct numerical calculation for every pixel is also possible but time-consuming.

Results

The calibration method can successfully be applied to thickness measurements of coatings. The measured phase values are converted into thicknesses using a look-up-table. Figure 1 presents as an example a pulse thermography

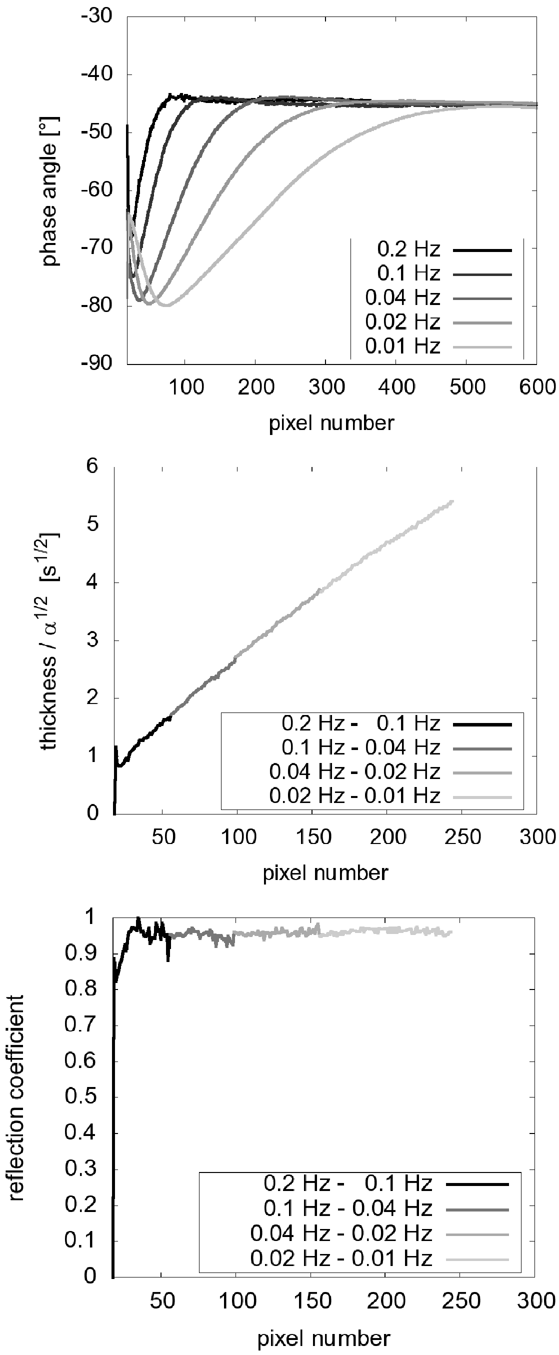

Fig. 2. Phase values along a polymer wedge for five different lockin frequencies (top). Calculated thickness (middle) and reflection coefficient curves (bottom).

measurement at a turbine blade. The photograph at the top shows the turbine blade, the bottom image is the calculated thickness image out of the measured phase image.

Multiple measurements (at least two) at different lockin frequencies are needed to determine $d/\alpha^{0.5}$ and *R*. Figure 2 shows the procedure exemplarily at a polymer wedge. The graph at the top shows the phase values along the wedge. Thicknesses (middle) and reflection coefficients (bottom) are then calculated out of the phase values. The thickness and reflection coefficient diagrams are a combination of all five phase curves.

This technique can be, as a matter of course, also be applied to “real” components, not just wedges. The thickness image of a landing flap (figure 3) was evaluated in the same way.

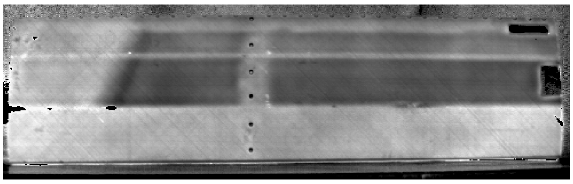

Fig. 3. Thickness image of a landing flap.

Conclusion

Quantitative evaluation of pulse and lockin thermography phase images can be done with calibration tables. This is a very straightforward and easy-to-handle approach. However, many calibration measurements have to be performed at test specimens beforehand which can be expensive and time-consuming.

The presented multi-frequency lockin approach is much more versatile and can be applied to a wide variety of specimens and testing problems.

References

1. C. Spiessberger, A. Gleiter, G. Busse. Merkmalsextraktion und Defektklassifizierung mit Lockin-Thermografie, MP Materials Testing, Vol. 50, pp. 632-637, 2008.
2. C.A. Bennett, R.R. Patty. Thermal wave interferometry: A potential application of the photoacoustic effect. Appl. Opt. Vol.21, pp. 49-54, 1982