ULTRASOUND BURST PHASE THERMOGRAPHY (UBP) FOR APPLICATIONS IN THE AUTOMOTIVE INDUSTRY

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ABSTRACT. The use of elastic waves in combination with thermal waves allows to separate structural information about investigated components from defect specific thermal signatures. Ultrasound Burst Phase thermography (UBP) is an defect-selective and fast imaging tool for damage detection. This contribution presents results obtained on various kinds of problems related to modern automobile production (crack detection in grey cast iron and aluminum, characterization of adhesive-bonded joints etc.). Advances resulting from frequency modulated ultrasound excitation will be presented.

INTRODUCTION

In the automotive industry there is an ever increasing demand of reliable non-destructive testing methods. Mass production requires short cycle times and automated processes. Defect selective NDT-techniques are appreciated for such applications. The main advantage is the high probability of defect detection of such “dark field” methods: they show only the defects themselves while all other features are suppressed. Ultrasound Burst Phase thermography (UBP) is one example of an established defect selective testing method.

Ultrasound Burst Phase Thermography is a rapid and reliable non-destructive technique derived from Ultrasound Lockin Thermography (ULT) which was developed a few years ago [1]. Both ULT and UBP provide defect selective imaging using thermal waves generated by elastic waves. The mechanism involved is local friction or hysteresis which turns a variably loaded defect into a heat source which is identified by thermography even in the presence of complicated intact features [2, 3]. In comparison to the sinusoidal excitation of the ULT method, UBP uses only short ultrasound bursts to derive phase angle images [4]. Therefore UBP combines the advantages of both lockin and pulse thermography. It allows for faster measurements with a better reproducibility while the advantages of phase images are the same: depth resolved recognition of defects, suppression of inhomogeneous emissivity and temperature gradients. We present the application of UBP detecting typical defects of automotive materials and components.

Principle of UBP

UBP uses short burst signals for sample excitation. The heating up followed by a cooling down period is recorded by an infrared camera. The local spectral components of that signal provide information about defects in almost the same way as the Lockin technique but with an improved robustness against coupling problems and a reduced measuring duration. As the characteristic defect signal is contained in a limited spectral range while the noise typically is distributed over the whole spectrum, one can reduce noise as well. That kind of evaluation technique using Fourier [5, 6] or Wavelet transformations [7] is also applicable to flash-light excited thermography. The signal to noise ratio of ULT and UBP images (and hence defect detectability) is significantly better than just one temperature snapshot image in a sequence.

Experimental Setup of UBP

FIGURE 1 shows the setup with a locally fixed ultrasound converter and the IR-camera monitoring the temperature distribution on the component surface after the short ultrasonic burst. It is based on the set-up for ultrasound Lockin thermography described previously [8] and used later on for acoustic pulse excitation [9, 10], but extended with a sequence recorder and a software evaluation module for the Fourier transformation and subsequent evaluation. An ultrasonic transducer is attached to the sample and acts as a heat generator (by converting elastic energy to thermal energy due to local hysteresis-effects). The infrared camera monitors the resulting thermal signal on the sample surface. A control unit synchronizes the infrared camera with a modified ultrasound amplifier operating at resonance frequencies from 15 to 25 kHz. The burst duration typically ranges from 50 ms up to a second. The whole measurement is performed within less than 1.5 seconds.

Though the elastic wave source is rated up to 2.2 kW, there are losses due to the coupling between converter and component thus leading to a typical acoustic power between 10 W and 200 W injected into the inspected sample.

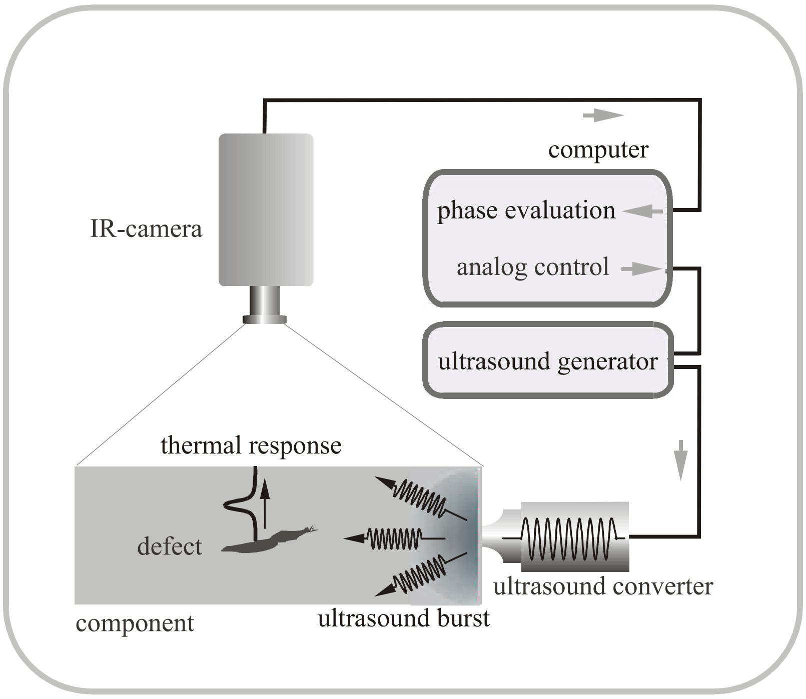

FIGURE 1. Principle of ultrasound excited thermography

APPLICATIONS OF UBP IN THE AUTOMOTIVE INDUSTRY

The weight of modern cars suffers from new built-in devices and requested enhanced crash safety. In order to keep fuel consumption low and to maintain the quality of driving dynamics, the structural weight needs to be reduced. An ever increasing number of lightweight components and materials in automotive applications results in a need of enhanced quality inspection (both in production and service) on materials that differ significantly from classical automobiles.

Crack Detection in Automotive Components

FIGURE 2 shows a part of a car body (aliminum pressure casting). A fine crack had been found in the curvature of a fin. For examination with elastic wave thermography, ultrasound power of 2.2 kW was applied for 200 ms. The subsequent cooling down was recorded for less than 2 seconds with a camera frame rate of 110 Hz. A Fourier transformation at a frequency of 0.75 Hz provides the defect-selective phase signature. For a better localization of the detected crack both the thermal image before the burst and the phase image were superposed (FIGURE 2, right). FIGURE 3 shows the crack detection in an engine block of a motor-cycle.

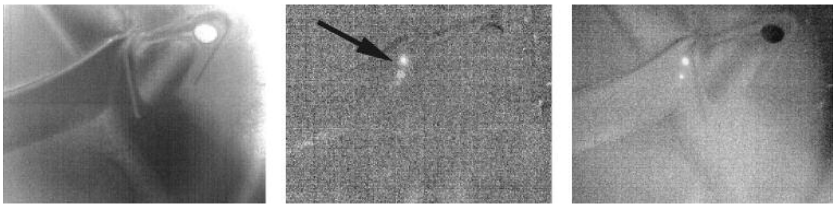

FIGURE 2. Part of a car body. Left: thermal image in the range of 3 to 5 µm before ultrasound burst excitation, middle: defect-selective burst phase evaluation at 0.75 Hz, right: superposed image.

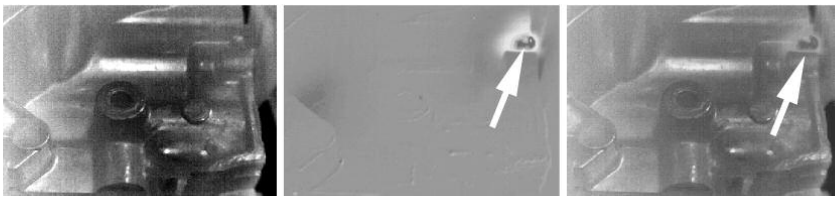

FIGURE 3. Crack in an engine block of a motor-cycle. Left: thermal image in the range of 3 to 5 µm before ultrasound burst excitation, middle: defect-selective burst phase evaluation at 1.00 Hz, right: superposed image.

These examples demonstrate the potentials and advantages of ultrasound burst phase evaluation unambiguously:

- UBP is a dark field method with a high probability of defect detection
- the phase signatures are independent from temperature gradients and variable emission coefficients
- detection of cracks underneath the surface is possible (advantage over the established color penetration test)
- automation is possible
- cycle times below one second per inspection are practicable

Characterization of Shrink Fits /Press Fits

Another application is the characterization of shrink fits. The burst phase evaluation in Figure 4 shows a bushing pressed in an automobile engine block. Contrary to the locally enhanced losses and consequently selective heating of the deficient shrink fit the intact one (bottom) remains inconspicuous.

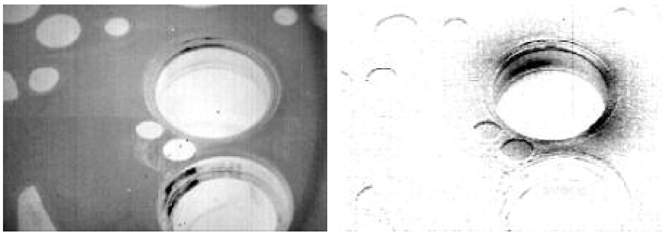

Figure 4. Detection of a defective shrink fit of a bush in an automobile engine block (burst phase evaluation , duration 200 ms, 2.0 kW at 0.5 Hz).

Characterization of adhesive-bonded joints

Besides the detection of cracks in classical metallic structures such as aluminum and grey cast iron, new applications for the UBP method are adhesive joints. In modern automobiles more and more crash optimized bonds are applied. These safety relevant adhesive-bonded joints – over 100 m per automobile – have to be inspected during production process. Defects to be detected are entrapped air, poor adhesion, kissing bonds, and non cured or missing adhesive. The following examples in FIGURE 5, FIGURE 6, and FIGURE 7 show the potentials of UBP.

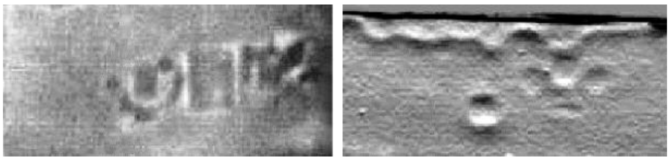

FIGURE 5. Characterization of adhesive-bonded joints. Phase signatures of two aluminum lap bonds (epoxy resin). Left: artifical defects, right: entrapped air (Sobel filtered).

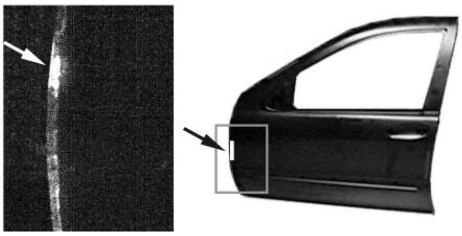

FIGURE 6. Artificial defect (missing adhesion) in a test door. The door was examined with an ultrasonic burst (300 ms, 2.2 kW). In phase evaluation at 1.0 Hz (left) the missing adhesion appears as a white area (see marker).

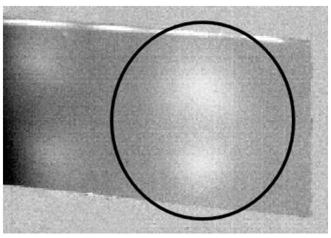

FIGURE 7. Detection of a non-cured adhesion in a steel lap bonding (epoxy resin) using ultrasonic excitation (burst duration 200 ms, 2.0 kW, phase evaluation at 0.31 Hz).

ADVANCES BY ULTRASOUND FREQUENCY MODULATION

By applying a monofrequent excitation to a sample it is not unlikely that this frequency matches to a resonance of the vibrating system. The result is a standing wave pattern. Due to hysteretic losses in the elongation maximum, these standing elastic waves can appear as temperature patterns causing misinterpretations: In the worst case the defect could be hidden in a node (“blind spot”) while the standing wave maximum might appear as a defect. This can be avoided by using two or more ultrasound converters with several frequencies simultaneously or, even better, by frequency modulation of a sinusoidal signal. In these cases the standing wave pattern is superimposed by a field of propagating waves giving sensitivity also where only nodes existed before.

Monofrequent ultrasound excitation in comparison to frequency modulation method including the corresponding spectra of the excitation signal is shown in FIGURE 8 schematically.

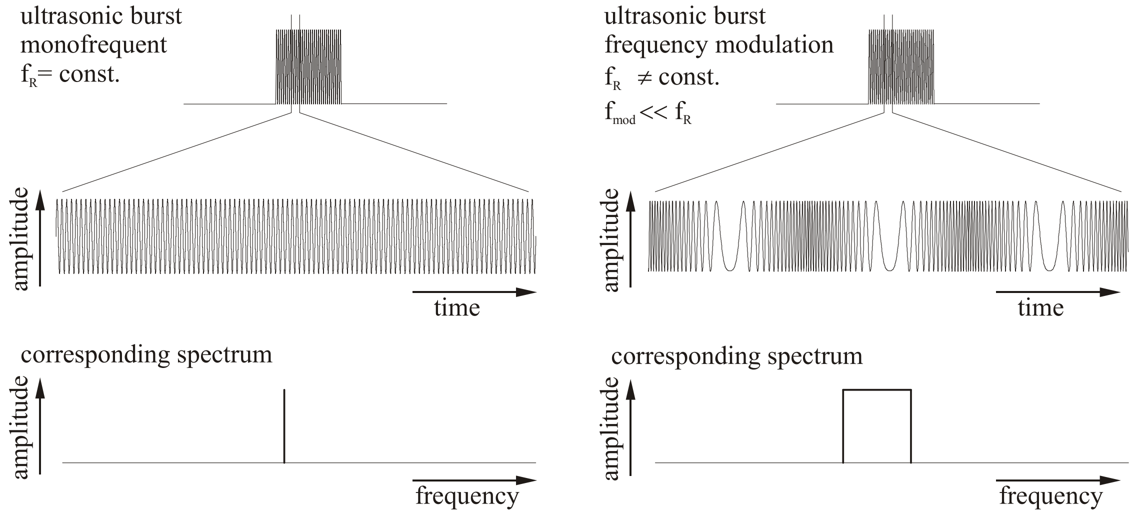

FIGURE 8. Schemata of monofrequent ultrasonic burst (left) in comparison to a frequency modulated excitation (right) and the corresponding spectra.

Fiber composites such as carbon fibre reinforced plastic (CFRP) are increasingly being used for automotive lightweight constructions. The overheating of such components can cause serious problems. The measurements presented in FIGURE 9 are examples for thermal damage detection in a 3 mm CFRP plate using ultrasound activated thermography. In comparison to one single temperature image taken from the recorded sequence 0.52 s after the ultrasound burst (maximum thermal contrast) the advantages of the phase evaluation are quite obvious. But the monofrequent excitation (f_R = 20 kHz) leads to a temperature pattern caused by standing elastic waves with all the drawbacks mentioned before. A significant enhancement was achieved by wobbling the excitation frequency from 17 to 23 kHz with a modulation frequency of 25 Hz. The pattern disappears completely, just the thermal damage occurs.

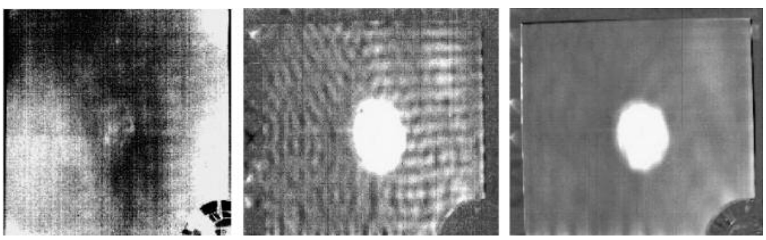

FIGURE 9. Three kinds of ultrasound thermography performed on the same local thermal damage in a CFRP-plate. Left: one image taken from the recorded temperature sequence 0.52 s after ultrasound burst (maximum thermal contrast), middle: monofrequent excitation f_R=20 kHz, phase evaluation at 0.06 Hz, right: frequency modulated excitation (f_R=17…23 kHz, f_{mod}=25 Hz), phase evaluation at 0.06 Hz.

CONCLUSION

Ultrasound Burst Phase Thermography (UBP) has clear advantages as compared to conventional pulse thermography: Sensitivity variations within the detector array as well as optical sample characteristics such as inhomogeneous temperature distribution and varying emis sion coefficients on the sample surface are suppressed. Furthermore the signal to noise ratio is improved significantly. The probability of defect identification is thus improved at a reduced measuring time. Automation is possible, a cycle time less than one second per measurement is achieved. The performed measurements show the broad spectrum of applications in the automotive industry.

By applying a frequency modulated ultrasound burst the disturbing temperature patterns caused by standing elastic waves were eliminated.

However, the high excitation power contained in short pulses or bursts could damage the inspected structure. The simultaneous use of several ultrasound converters provides a homogenous low power density in the material to be inspected. This results in an efficient and non-destructive excitation so that even larger components can be examined with this technique.

ACKNOWLEDGEMENTS

The authors are grateful to the Lehr- und Forschungsgebiet Klebtechnik (RWTH Aachen, Germany) and to Airbus Deutschland GmbH (Bremen, Germany) for cooperation and providing samples.

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