

## White Paper

### An Inline Monitoring Approach to Non-Destructive Weld Inspection – Possibilities and Limitations

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#### Abstract

Welded joints are usually inspected by ultrasonic non-destructive testing (UT) after completion of the weld. However, such a conventional offline NDT approach is inefficient in case of complex welding techniques, large structural components or expensive materials. If structurally relevant defects are found, a repair is no longer possible and the whole component has to be rejected. For a better identification of defects during the welding process, a temperature-resistant inline monitoring approach is necessary. In the present contribution we describe a multi-method approach based on three different techniques: Phased Array Ultrasonic Testing (PAUT), Acoustic Process Monitoring (AE) and Laser Speckle Photometry (LSP). We present results of inline measurements during Laser-Multi-Pass-Narrow-Gap-Welding of Nickel super alloys and compare the results with posterior ultrasonic immersion testing and metallographic micrographs.

#### Keywords

Ultrasonics, Phased Array, Weld Inspection, Inline Measurement, High Temperatures

#### I. Introduction

Welded components assembled from thick metal sheets are usually produced using conventional welding techniques. In recent times, laser multi-pass narrow-gap welding has increasingly been utilized for this purpose. Using this laser technique, metallic components with a large wall thickness of up to 120 mm can be welded efficiently layer by layer. Due to economic reasons, a conventional NDT approach based on ultrasonic testing of fully welded components after the welding process is inefficient. If structurally relevant defects in expensive high-performance materials are found, a repair is no longer possible and the whole component has to be rejected. For a better identification of defects during the welding process, a temperature-resistant inline monitoring approach would be necessary. In a collaboration project with the Fraunhofer Institutes IKTS, IWS and IWM, funded by the Fraunhofer-Gesellschaft within the context of the WISA programme, a multi-method approach based on three complementary testing procedures has been developed and successfully verified.

#### II. Methodology and Results

In the project we investigated three different methods, Phased Array Ultrasonic Testing (PAUT), Acoustic Process Monitoring (AE) and Laser Speckle Photometry (LSP). They are described in the following subsections together with selected results.

##### II.1 Phased Array Ultrasonic Testing (PAUT)

By using phased array transducers consisting of a large number of single elements, a specifically adapted wedge and the PCUS® Pro Array electronics developed at IKTS, it is possible to perform ultrasonic beam steering and focusing. In the project a pulse-echo method was developed that allows automatic scanning of the whole depth of the narrow-gap weld and imaging of relevant defects like inclusions, pores and lack-of-fusion defects. Moreover a high-temperature resistant and inline capable testing concept was developed. It involves high-temperature wedges with integrated couplant and coolant circulation as well as a temperature warning system (Fig. 1, Fig. 2).

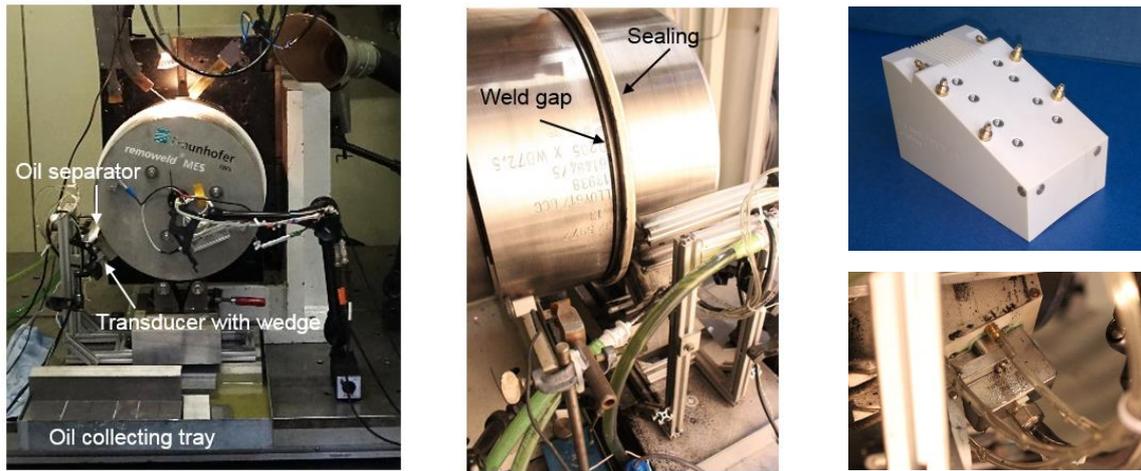


Figure 1: Welding system of Fraunhofer IWS used for laser multi-pass narrow gap welding of thick-walled cylindrical components (left picture). An inline capable phased array set-up with high-temperature wedge with integrated couplant and coolant circuits (top and bottom right) was installed. It is supplemented by a mechanical surface collector for the low-viscous and high temperature resistant couplant. An additional sealing ring close to the weld prevents the welding gap from contamination (picture in the middle).

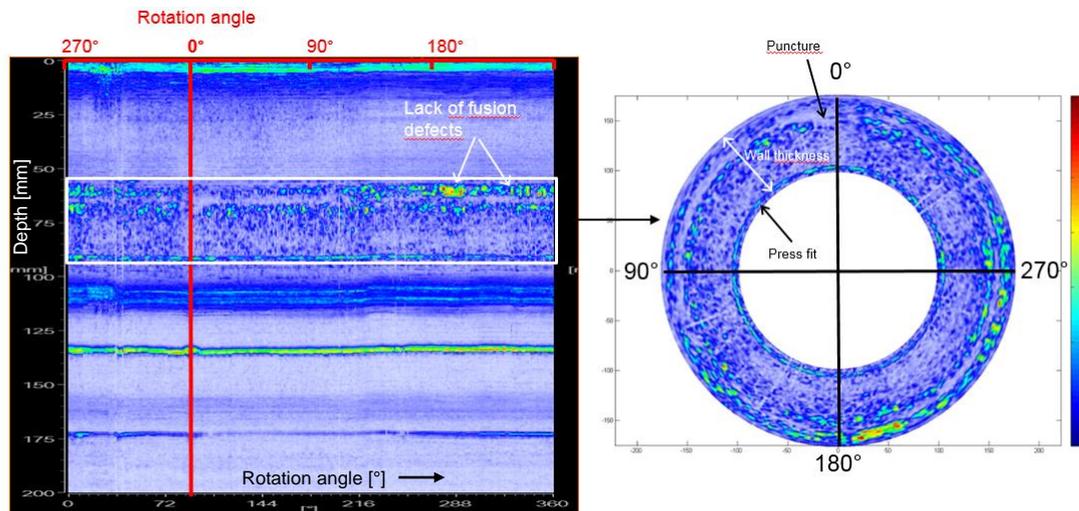


Figure 2: Rotational B-Scan (on the left) and corresponding polar plot (on the right) of a PAUT measurement obtained at a circumferential narrow-gap weld of a Nickel super alloy 617. The results can be displayed inline for each single layer of the weld during the welding process.

## II.2 Acoustic Process Monitoring (AE)

The welding process continuously produces acoustic emissions (AE). These are detected by an appropriate sensor placed directly on the surface of the welded component. Following data reduction, the inline acoustic signatures in the frequency range between 50 and 600 kHz are compared with a database of reference signatures. This comparison allows to evaluate the welding process and to identify defects and other imperfections and irregularities (Fig. 3, Fig. 4). Signal extraction is done via slip-ring collectors.

## II.3 Laser Speckle Photometry (LSP)

Laser Speckle Photometry is a method of evaluating speckle patterns produced by laser illumination of the weld immediately behind the weld beam. A CMOS camera detects and evaluates these patterns and their temperature- and time-dependent behavior by a special software inline (Fig. 5). Correlations were found between speckle signals and surface-related defects on the one hand and changes in process parameters on the other hand.

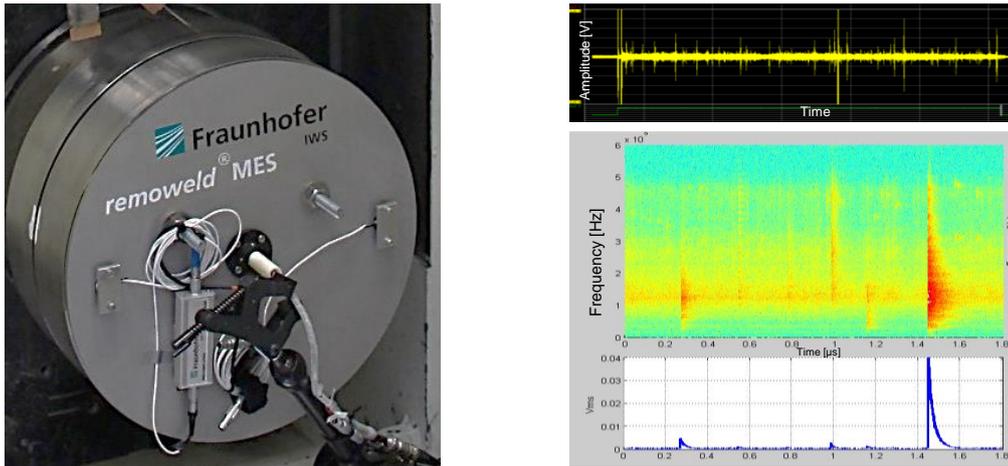


Figure 3: Installation of AE sensors on the front surface of the welded component (picture on the left). A placement on the shell surface is also possible. The pictures on the right show a typical AE signal with discontinuities caused by defects and welding irregularities as well as the corresponding spectrogram representing an acoustic fingerprint of the welding process and its outcome.

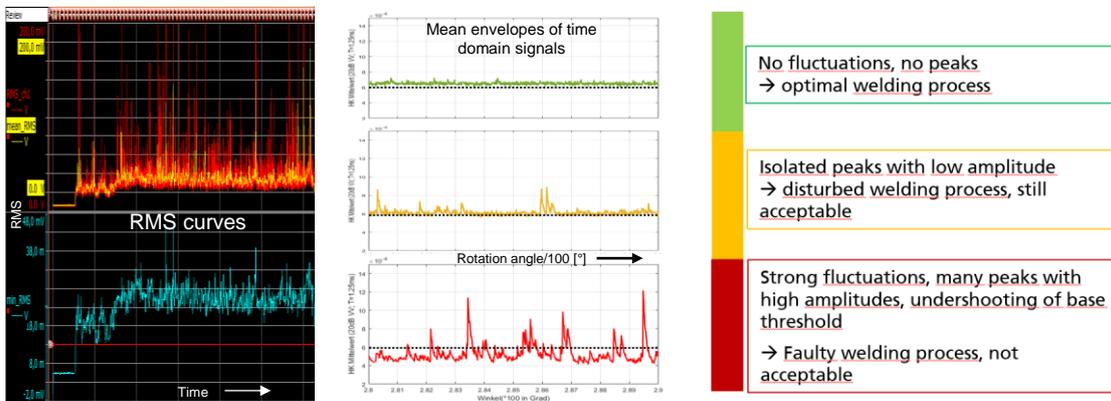


Figure 4: Typical course of RMS signals (left picture) and mean signal envelopes (middle) during welding. From the different curves a traffic light control based on acceptable green and yellow process windows and non-acceptable faulty welding conditions marked in red can be derived and used for inline monitoring (on the right).

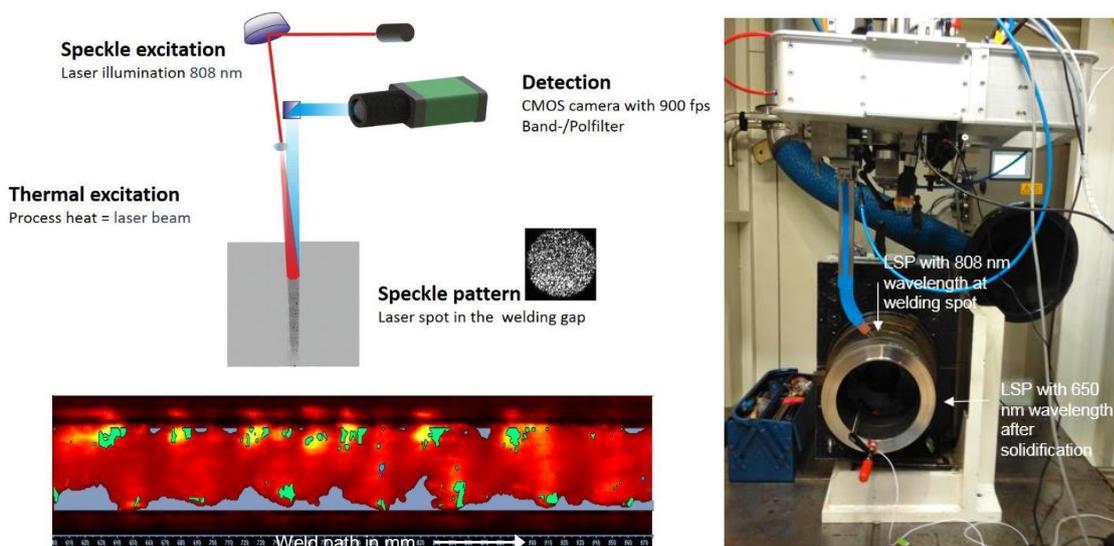


Figure 5: Main principle of Laser Speckle Photometry (top left) and typical measurement pattern indicating speckle fluctuations during welding (bottom left). The picture on the right shows the practical implementation of the LSP system at two different measurement positions (at 12 and 9 o'clock).

### III. Results and discussion

Various defects like lack-of-fusion defects and pores were successfully detected by all three methods and later verified by metallographic images and UT immersion testing (Fig. 6). Current challenges to overcome are the necessary threshold definitions and the minimization of false positive alarms, especially for AE and LSP.

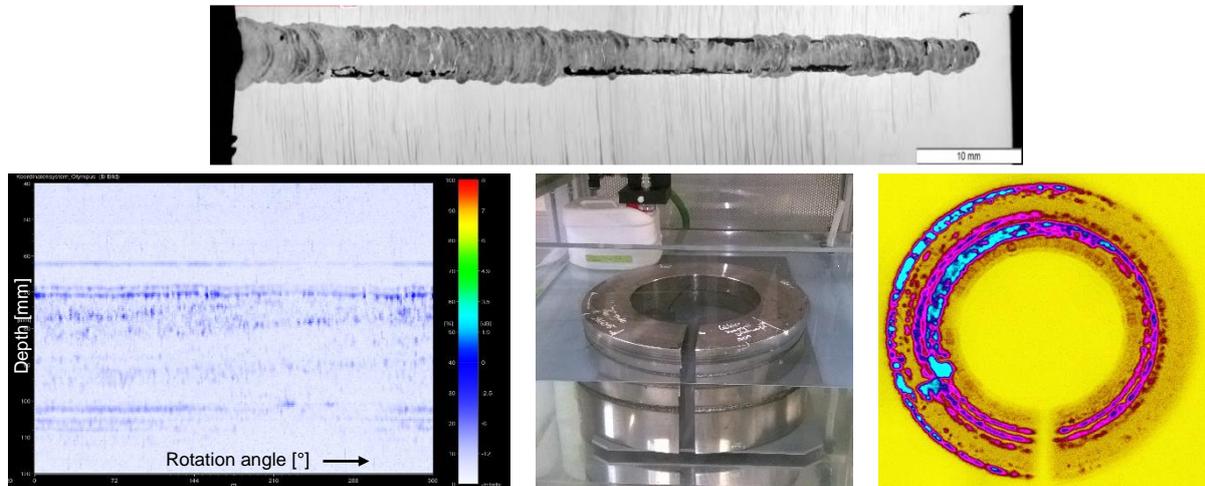


Figure 6: Top: Metallographic micrograph of a narrow-gap weld with lack-of-side-fusions (LOSF); bottom left: Inline PAUT from the shell surface showing strong indications from the upper layer and from bulk defects; bottom center: Posterior immersion testing of the welded component from the plane front face; bottom right: C-Scan result of UT immersion testing showing LOSF indications and grain scattering.

### IV. Conclusion

We described a multi-method approach to temperature-resistant inline monitoring of laser multi-pass narrow gap weldings based on three different techniques, Phased Array Ultrasonic Testing, Acoustic Emission Testing and Laser Speckle Photometry. All three methods have proven their ability to detect fluctuations and irregularities in the welding process itself (LSP and AE) as well as structure-relevant defects like pores and lack-of-fusion defects (PAUT and LSP). In a future scenario one of these methods or a combination of them could be used for inline monitoring of the complete welding process, raising alarms if critical defects or process fluctuations occur. In this case the welding process can be stopped and a potential mechanical repair of weld imperfections in the last welding pass can be initiated. Such a monitoring approach is of high technical and economic interest especially for very thick and large components made of expensive high-performance materials as used in power plants but also for offshore components and additively manufactured products.

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