DATLAS – A NEW APPROACH FOR MONITORING OF THE LASER WELDING PROCESS

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Abstract
Laser welding is nowadays a widely used, established welding technology. Critical components often require highest weld quality without any defects. The reliability can be sensitive to changes of the process conditions, thus costly post inspection is often applied. Automated process monitoring could eliminate post-inspection. However, due to the complexity of the welding process commercial systems neither provide a comprehensive documentation as reference nor a systematic and safe method for determining a monitoring criterion. Therefore new correlation criteria have to be empirically identified for each new application.

The recently launched research project DATLAS (Data Interactive Process Monitoring for Laser Welding) aims at understanding the context between dynamic process changes causing laser welding defects and the dynamic sensor signal obtained for commercial in-process monitoring by photodiodes or cameras. Seven Swedish companies selected different cases, specified by the metal, thickness, joint type, laser and a typical welding defect to be detected and studied. The context between the welding process dynamics and the sensor signal is investigated by high speed filming of motions of the melt pool surface as well as of the plasma plume followed by numerical simulation of their thermal radiation that eventually illuminates the sensor and leads to a signal versus time. The research hypothesis assumes dynamic correlations either by transients of the geometry or the temperature field of the welding process. From the cases a more general theory shall be developed in order to explain the context between process and signal dynamics, thus supporting monitoring systems and their industrial use.

Key words: laser, welding, monitoring, defects

1. Introduction
Modern production strategy involves accomplishing highest product quality by safely mastering the process technology prior to costly post treatment off-line quality control. Mastering a process commonly relies on process monitoring or in some cases on on-line closed loop process control. The monitoring system will create failure messages and/or an

alarm signal if the process in some defined way exceeds the allowed tolerances, while the closed looped control system will continue the process but instantly adjusting the parameters so that defects are avoided.

Laser material welding which is performed by either heat conduction welding or more commonly penetration (key-hole) welding is basically a thermal process taking place in the interaction zone where the laser beam interacts with the material to be welded. The process emits radiant emissions from the interaction zone which are used for the contact-less monitoring of the process. The key-hole welding process is a very complex, dynamic beam-metal vapour/plasma work piece interaction where the key-hole is pressurized by the metal vapour/plasma which prevents it from collapsing. Due to the dynamic fluctuations in the plasma formation the process can be monitored by acoustic emission [1] but for practical industrial process monitoring acoustic emission have the potential to serve as an accompanying method in combination with optical process monitoring techniques [2].

Mainly, process monitoring of the laser welding process is done on-line observing selected emissions from the weld process by using systems based on photodiode [3] sensors or cameras, e.g. CCD-cameras [4]. The observation of emissions cover the range from UV (< 300 nm) to the far infra red (> 10 000 nm), thus covering the plasma and metal vapour created by the weld process, back reflected laser light and temperature radiation from the weld zone.

The laser welding process is highly dynamic and the emissions are strongly fluctuating. It has been shown that useful information can be extracted from these emissions in spite of the strong fluctuations and that these fluctuations contains information about weld quality like partial/full penetration, surface defects and penetration depth [2].

For industrial use, commercial process monitoring systems have been developed and introduced to the market. These systems are normally based on photodiodes, where most of the strategies developed detect the fluctuations of the emissions and compare them with reference emissions from defect free welds. There are also systems based on camera sensors [5]. The photo-diode sensors can be used as a single or multiple sensor system, figure 1, where the weld defect detection ability increases if a multiple sensor system is used. I this case two, three or more signals are simultaneously recorded and analysed. In principal, these multi sensor systems can detect different types of weld defects like porosity (due to keyhole collapse or oil/grease pollution), lack of fusion (due to lack of laser power, focal position-, process gas- or weld speed changed, gap with, misalignment), holes or incomplete (partial) penetration [6].

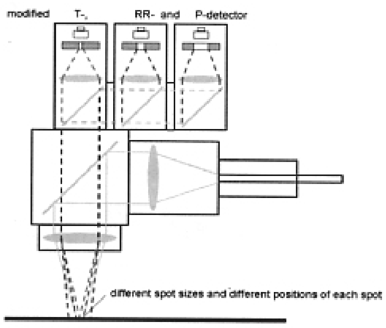

Fig. 1. *Principle for photo-diode multi-sensor arrangement [6]*

Although there has been extensive research in this area there exist no commonly known or shared knowledge of the context and correlation between the recorded signals from the weld emissions and weld defects. Instead, for each application there has to be time consuming analyses and comparison of reference signals from defect free welds and signals from the actual welds, figure 2. Deviations larger than user set limits for each signal creates alarms but still the reason for the deviations must be analysed, often by destructive testing methods.

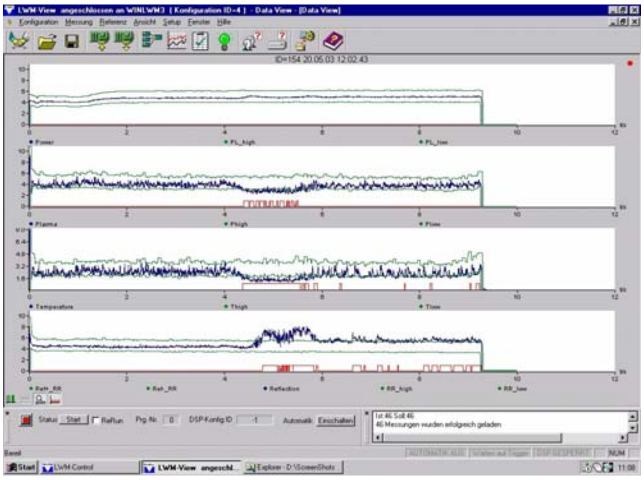

Fig. 2. *Sensor signals form a multi-sensor process monitoring system indicating weld defects, due to a large gap in a lap welding application, as the actual signal is outside the reference signal levels*

2. The DATLAS project

The industry has a strong need for a systematic method which safely and quickly leads to signal-defect correlations, and also for higher reliability of the correlations. Often failures are not detected or in contrast, the production is interrupted due to false alert signals. Eventually, the dream scenario is 100% reliable detection of any failure, which permits to eliminate expensive post-inspection. Purely empirical treatment is unsatisfactory. Instead, an in depth understanding of the physical context between the welding process and the signal is desired - for confidence and control.

In order to develop the context and correlation between the recorded signals from the weld emissions and weld defect, a new project, DATLAS (Data Interactive Process Monitoring for Laser Welding) has been started in Sweden. In contrast to the experiment-based, empiric state-of-the-art of process monitoring, DATLAS aims at theory-supported and systematically generic research. Instead of developing one more case study, knowledge shall clearly converge to fundamental, generally applicable understanding of the context between signal and defect. In case of success, the findings of the project will not only be highly valuable for improved, controlled application of process monitoring in industry. Also from a scientific point of view, this will also lead to strongly improved process knowledge, particularly the physical mechanisms causing defects, which is still very unsatisfactory today. Also an improved basic understanding will improve industrial applications. The understanding of discrepancies between defects and the sensor signal can also lead to advanced sensor development matched to the process in a better way, e.g. arrangement and type.

2.1 Methods and research strategy

Figure 3 illustrates the cooperation of different methods to be applied as a highly innovative but challenging approach to understand the context between the defect mechanisms and signals. When a transient mechanism (e.g. keyhole collapse, Fig. 3(a)-(d)) causes a defect (e.g. pore), the monitoring system records a signal, Fig. 3(b), through thermal surface emissions. The surface will be qualitatively observed through high speed imaging, Fig. 3(c) and quantitatively by a series of triangulation sensors, Fig. 3(d). From the measured dynamic relief simulation (ray tracing) of the emissions, Fig. 3(b), shall predict the photodiode signal, to explain the context.

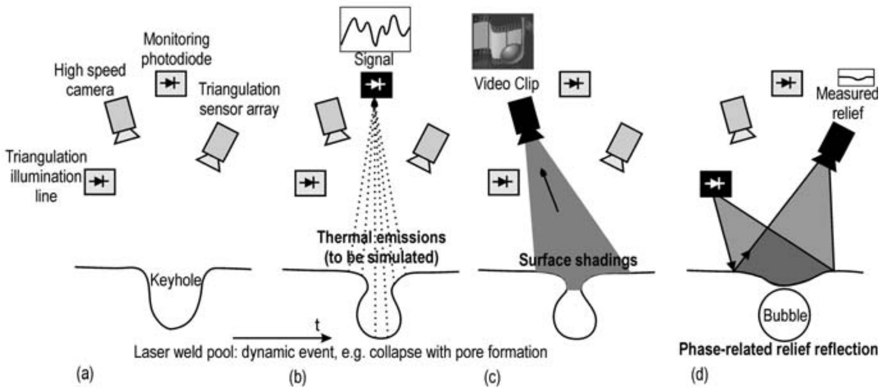

***Fig. 3**. Proposed method for identifying the surface geometry and motion (defect cause) as origin of resulting irradiation signal changes and in turn derivation of a theoretical context: (a) 3 observation instruments, (b) monitoring photodiode (emissions to be simulated by ray tracing), (c) high speed imaging (qualitative), (d) triangulation profile (quantitative)*

The overall strategy for DATLAS is as follows:

- Provocation of typical welding defects for a number of selected demonstrator cases
- High level observation, Fig, 3(c), and measurement, Fig. 3(d), of the transient surface motion (elevation) of the weld pool (defect event), accompanied by monitoring, Fig. 3(b)
- Catalogue collecting of a series of pairs of defect photos and signal change images
- Numerical simulation (spectral ray tracing), Fig. 3(b), of the radiation from the measured surface motions, Fig. 3(d), weighted by emissive and temperature dependence) to calculate the radiation impact (spectral weighted integration of incident rays) on a photodiode sensor
- Comparison between detected and calculated signal along with improvement iterations
- Derivation of an illustrative theory explaining the origin of different welding defects and the context between the signal and the physical defect mechanism
- Modelling of additional correlation to seam tracking and camera post-inspection data

- Developing a generic model that gradually learns (context rules) from data-recording
- Developing a professional user interface and software, resulting in a support tool
- Improvement of the partners' monitoring applications due to better understanding

The key task of the project is sufficiently good measurements in terms of spatial and temporal resolution, suppressing plasma radiation disturbances of the melt surface motion when defects occur, along with accurate computation of the surface radiation including characteristics, emissivity and disturbances towards the sensor. In case of success this powerful combination will tell the whole story of the defects, i.e. their origins and the capability of on-line monitoring.

2.2 Demonstrator cases

In DATLAS, seven Swedish companies are participating by providing the project with industrial demonstrator weld cases, where process monitoring already is used or cases where it significantly would reduce the time spent with expensive post process quality control. The demonstrator cases will be the base for the experimental and theoretical work in the project. Each case will give a specific combination of the weld process, (e.g. keyhole welding, conduction welding, laser hybrid welding) joint type, material composition and thickness, weld parameters, processing conditions causing defects and different types of weld defects. The cases chosen for the first series of experiments are summarized in table 1.

2.3 Expected deliverables

The expected deliverable of DATLAS will be a virtual support tool for monitoring of laser welding that will:

(i) contain a comprehensive, systematic catalogue of defect-signal correlation cases,

(ii) provide high level explanations on the context between the process and the signal,

(iii) enable improvement of commercial process monitoring systems individually for each customer in a generic manner,

(iv) store and analyse monitoring data to trace process fading and product failures.

Table 1. *Summary of demonstrator cases for the DATLAS project to be welded by Nd:YAG or CO_2-laser.*

Materials	Thickness [mm]	Joint types	Weld defects	Other criteria
Mild steel Stainless steel Titanium Zirconium alloy Zn coated steel	0,1 - 12	Butt weld Lap weld Edge weld Flange weld	Geometrical Pores Blow outs Lack of fusion Partial penetration Cracks Craters	Cw welding Pulsed welding Hybrid welding

Although generally applicable, the DATLAS-tool will be matched to the participating end-users and to the system suppliers. The experimental case analysis method will be generally applicable.

DATLAS is a three year project which will end in 2009.

3. Acknowledgements

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