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New Aspects of Monitoring with a CMOS camera for Laser Materials Processing

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1. Abstract

A new system for process monitoring of laser beam welding based on a CMOS-camera was presented in former presentations [1,2]. The system observes the welding process online and coaxial to the laser beam. Until now we have got various experiences with this system in industrial applications and experimental trials.

For example the system yields interesting results for cutting processes with regard to incomplete cut and development of dross.

Another application will show the availability of the system for welding in the automotive industry. One of the most interesting processes in this industry is the welding of zinc coated steel sheet in an overlapped joint configuration. Due to the low evaporation temperature of zinc, it is necessary to weld this material with a defined gap between the two plates. Recorded films are analyzed and some effects as a consequence of different gap widths are presented in the films. The films and the resulting curves show the possibility to monitor certain weld failures, caused by different gaps in between the joint.

2. Introduction

The answer of the workpiece interacting with a high power laser is a strong emission of secondary radiation. This radiation carries information about the dynamics of the laser process and the quality of the resulting weld seam or cutting kerf [3].

The secondary radiation is used by a lot of optical sensor devices to monitor the working process.

The most frequently used system in research and commercially available process diagnostic systems [3] is a photo diode with optical filters delimiting the detected radiation to a certain spectral range. The advantages of such detectors are high temporal resolution of the recorded signals and a low price compared to other devices like spectrographs or cameras. A disadvantage of the photo detector is its one-dimensional view (i.e. spatially integrating the signal) of the process which limits the signal evaluation to an amplitude and frequency analysis of the recorded data.

A solution is the use of a camera positioned coaxially to the laser beam [1,2,4,5,6]. The setup for a system using a Nd-YAG laser is presented in figure 1. This is an exceptional position for the camera because it is possible to obtain information from the inner parts of the keyhole. The software of the camera evaluates different failures and process parameters online with the help of characteristic regions within the image of the camera. Today this system is used in industrial applications to monitor welding processes.

However it is possible to use the recorded films to analyze the process and to improve process parameters. These possibilities are described in the following chapters using an example for the welding of zinc coated steel.

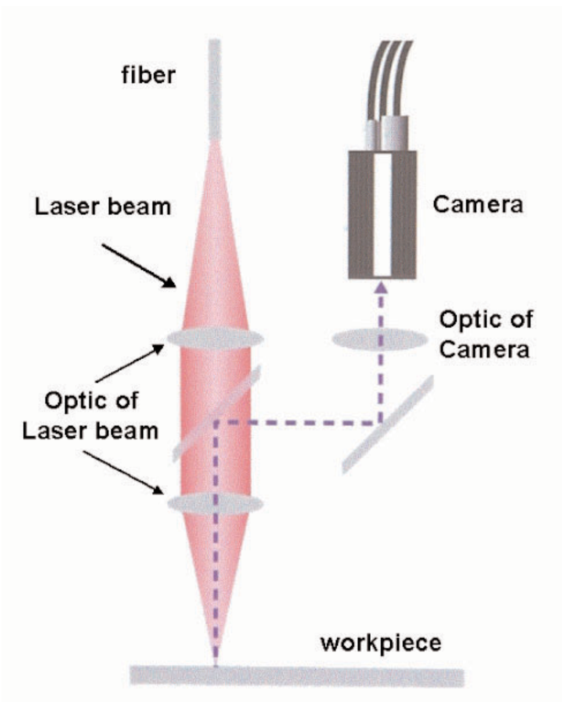


Figure 1: Monitoring setup for a Nd-YAG Laser

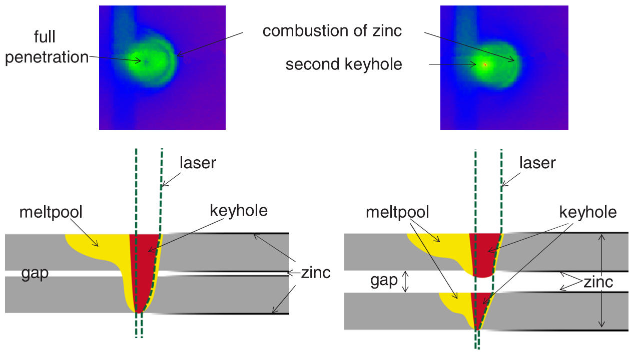
This system is applicable for welding as well as cutting processes. A second example shows some results to detect dross under the cutting kerf.

3. Observation of zinc coated steel sheets

The welding of zinc coated steel in an overlapped joint is difficult. Due to the lower boiling point of zinc (~900 °C) in comparison to the melting point of steel (~1530 °C) the heating of the workpiece induces blowholes in the weld, if no gap is present between the two sheets. The gap enables the evaporated zinc to exhaust from the interaction zone.

On the other hand if the gap becomes too wide the connection between the two plates will be lost. However, to make sure that the gap has the specified value, it is necessary to monitor the process with respect to the gap width.

This article will discuss one effect, which could be dangerous for the weld quality of such lap joints. Under normal conditions a small gap is useful for the process as described before and only one keyhole and meltpool is formed in the interaction zone. This situation is sketched on the left side of figure 2. Additionally a typical picture from the coaxial adopted camera (figure 1) is presented in figure 2. A green circle in front of the keyhole can be recognized in the picture. It shows the combustion front of the zinc on the upper surface of the plate. The green region behind this circle depicts for the whole keyhole. In the center of the keyhole region an intensity minimum is visible. This minimum stands for full penetration. This effect is well documented in former papers [1,5].



Parameter: Nd-YAG-Laser; P_L: 4 kW; f: 200 mm; v_s: 3m/min; r_F: 0,6 mm; overlapped joint

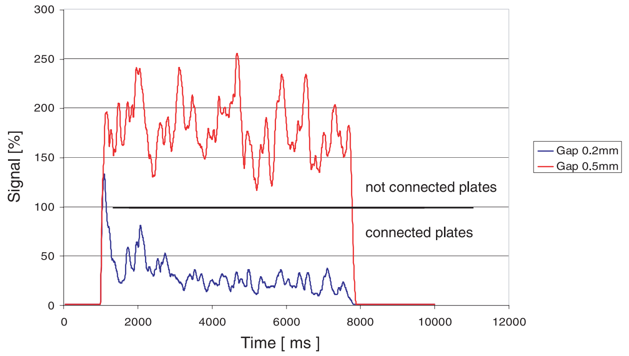
Figure 2: welding of zinc coated steel with different gaps

The connection of the two plates fails, when the gap width increases to a point when there is not enough melt to bridge the gap. In most cases the upper meltpool collapses under these conditions. The resulting weld seam is disturbed and after welding a strong deterioration of weld quality is obvious.

Sometimes the welding conditions are similar to the situation described on the right side of figure 2. The gap is just wide enough to loose contact between the 2 meltpools of the two plates and the laser beam is strong enough to produce two different welding processes on both plates without of any connection. This is a very difficult situation for the user because the quality of the weld is without visible failures when viewed from above and below.

In figure 2 the image on the right side presents a typical picture from the coaxial camera system for this situation. Instead of the intensity minimum in the center of the keyhole a small intensity peak is observed and correlates with this situation. The interpretation of this result is that the camera looks through the keyhole in the upper plate of the workpiece and observes the second keyhole in the plate below. We use this effect to monitor the process with our system.

An algorithm was applied, which is able to find this peak in the image of the keyhole. The time resolved curve is presented in figure 3. Excluding the start situation the algorithm shows a strong correlation with the effect of not connected plates.



Parameter: Nd-YAG-Laser; P_L: 4 kW; f: 200 mm; v_s: 3m/min; r_F: 0,6 mm; overlapped joint

Figure 3: time resolved search for the peak in the center of the keyhole

4. Monitoring of dross during a cutting process

Another possible application for a coaxial monitoring system is the cutting process. An example is presented in this paper, which shows the influence of dross under the cutting kerf on the images observed with our camera.

The application uses a CO_2-Laser with a ZnSe-lens as the optic for the laser beam (figure 4). Hence, the camera looks through a plate, which is transparent for light with a wavelength higher than 550 nm and reflects light of the CO_2- Laser beam. Under these conditions the optic of the camera is a combination of the ZnSe-lens and the lens of the camera.

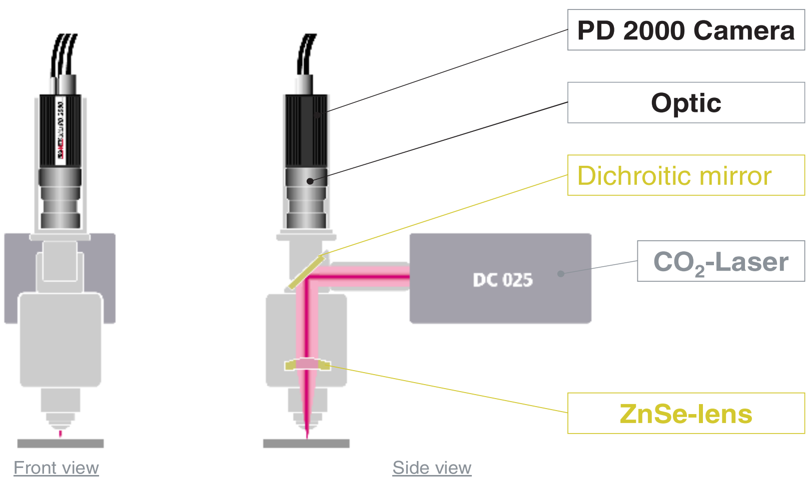
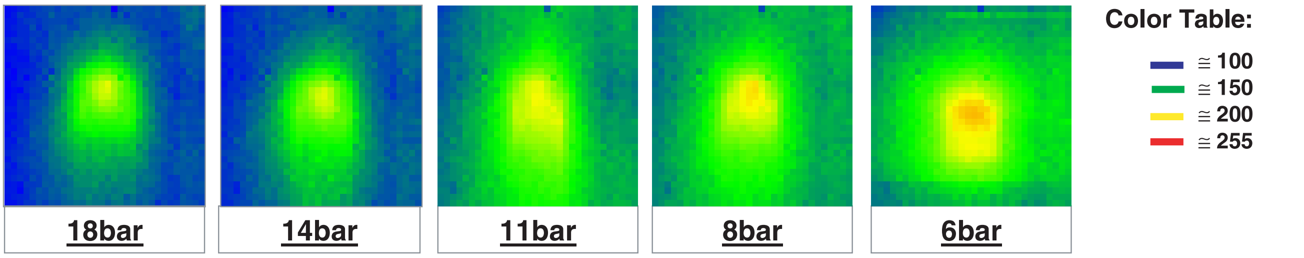


Figure 4: Monitoring setup for cutting with a CO_2-laser beam and a ZnSe-optic

The application is the automatic production of models for a specified subject like car bodies. The model will be formed by plates lying on top of each other. Under these circumstances dross will disturb the form of the stacked plates and inevitably the model itself. This guideline makes a monitoring system necessary to ensure a process without of dross.

Our procedure to find a possibility to monitor a new process (like cutting) is, to analyze films, which correlate with the specified process attribute. The first step is to record



Parameters:
Laser power (cw) : 1000W Cutting speed: 5m/min Focal position: -0,7mm Gas: Nitrogen

Figure 5: Images with changing gas pressure

a film while cutting with process parameters producing dross and compare the images with images from a cutting process without dross.

The most significant process parameter to produce dross is the pressure of the cutting gas. Some typical images are presented in figure 5 under different pressure conditions. Other process parameters are kept constant. It is obvious that the intensity in the center of the image increases with decreasing pressure of the cutting gas. This effect correlates with the probability to produce dross. The breakpoint is close to 8 bar. A cut with 6 bar gas pressure produces dross everywhere.

The interpretation of these images is that with decreasing gas pressure the thickness of the melt at the cutting front increases. With this the source of the radiation increases and more molten material is present to produce dross.

The images show the possibility to detect dross formation by the intensity of the center of the cutting process. Based on these results an algorithm which uses a histogram of the pictures in the region of the cutting front was selected to analyze the process.

In figure 6 three typical histograms from the pictures with changing gas pressure are presented. The most obvious change in the histograms is the shift of the maximum to higher values if gas pressure decreases. Therefore an algorithm was developed, which looks for the maximum within the histogram. This algorithm was used to make a time resolved analysis of the working process. In figure 7 a typical result for the time resolved analysis is presented. An octagon was cut and from one side the kerf with the resulting analysis of the recorded film is presented. The correlation of the signal with the kerf is obvious and a future monitoring system can use this result with a limit to detect dross or no dross.

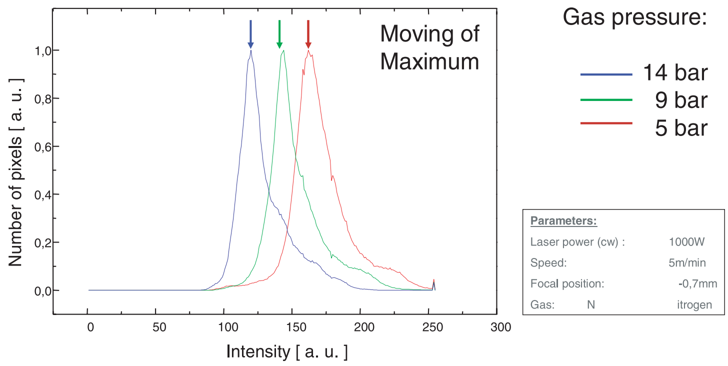


Figure 6: Histogram Analysis

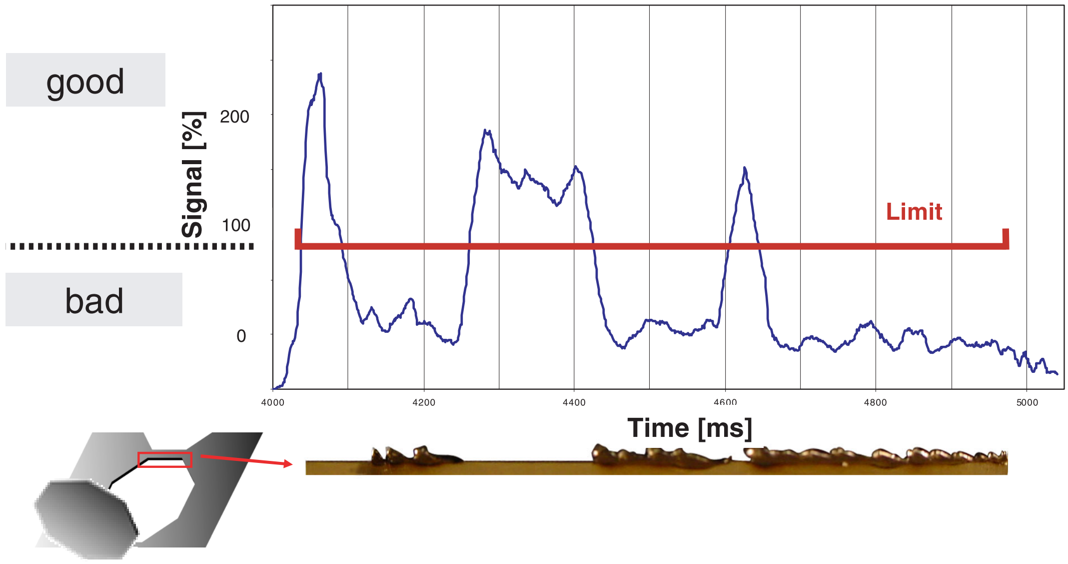


Figure 7: Time resolved Analysis

5. Conclusion

Two new aspects of monitoring material processing with a camera positioned coaxial to the laserbeam are presented in this article.

In the first part results of welding zinc coated steel are presented. Due to the evaporation temperature of zinc, zinc coated steel in an overlapped joint will be welded normally with gap between the two plates.

If the gap width becomes to wide the connection of the two plates is lost and two separate seams are formed in the upper and in the lower plate, which appear visually to be good. This phenomena could be detected using the camera based system.

The second part shows a cutting application. The task is the observation of dross. Dross formation can be intensified if the pressure of the cutting gas decreases. This results in a higher intensity directly at the cutting front, which can be used to monitor the cutting process for dross formation.

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