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A CMOS camera as a tool for process analysis not only for laser beam welding

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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 [1,2,3]. The system observes the welding process online and coaxial to the laser beam. Until now we got some new experiences with this system in industrial applications.

On the basis of these experiences we found, that this system can be a useful tool for the inspection of the interaction zone during materials processing using a laser beam. The recorded films can be analyzed by the software of our system. The resulting curves are presented directly during the process. The data streams can be stored as an ASCII file and read in by another software.

The possibilities of our methods are illustrated by one example for a welding process with a ND-YAG laser beam.

The resulting images are interpreted as the absorption front. From the recorded images it is possible to conclude on the gradient of the front.

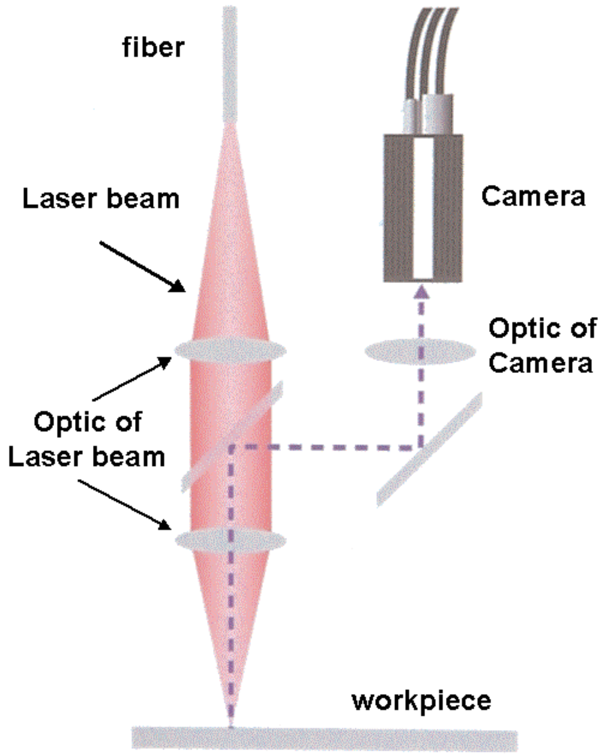


figure 1:
Monitoring setup for a Nd-YAG Laser

2. Introduction

Laser welding of metals is accompanied by the emission of radiation from the laser induced plasma and the melt pool. The radiation contains much information describing the interaction zone between laser beam and workpiece. This radiation can be used to monitor the welding process [1].

Using an arrangement coaxial to the laser beam (Figure 1) it is possible to get informations from the vapour (plasma) and the melt pool within the capillary [2,3].

This kind of measurement is described in several presentations during the last two years. For the monitoring task a CMOS camera is used. A CMOS camera has two advantages observing welding processes [1].

Firstly it is possible to use defined regions of interest on the chip. This is a great advantage for a monitoring system because, in most cases, only a small part of the image field of the camera is really necessary and the frame rate of the camera depends on the quantity of pixels within the small region of interest.

Secondly the conversion of light intensity to voltage is not linear but logarithmic. The result is a very high dynamic range of the CMOS sensor over 120 dB light intensity (typical CCD-camera ≈ 60 dB). In principle this makes it possible to observe the keyhole region and the melt pool at the same time.

The system is used for welding applications with ND-YAG and CO2- ND-YAG laser beams. A typical setup for a ND-YAG laser beam is presented in figure 1. In any case the camera observes

the process in a coaxial and centered position to the laser beam. 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 online different failures and process parameters with the help of characteristic regions within the image of the camera. Today this system is used in industrial applications to monitor the welding process.

But it is also possible to use the recorded films to analyze the process and to improve process parameters. By the hand of an example for full and partial penetration these possibilities are described in the following chapters.

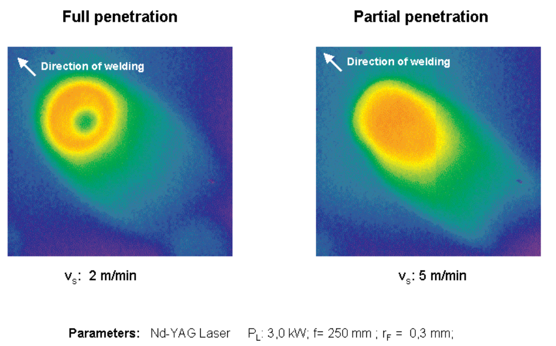


figure 2: Full and partial penetration during laser beam welding with ND-YAG lasers

3. Monitoring of full Penetration

The observation of full and partial penetration with the help of a camera which is positioned coaxial and centered to the process s well known and described for example in [4].

Two typical images for full and partial penetration are presented in figure 2. The measured intensity distribution shows the keyhole and the melt pool of the weld.

In the case of full penetration the geometrical form of the keyhole region is like a circle with an intensity minimum at the back side of the keyhole.

In the case of partial penetration the intensity distribution is more elliptical and the intensity minimum is lost. It is possible to interpret these images in the case of ND-YAG laser beam welding in that way, that the observed intensity distribution is ruled by the radiation of the surface of the melt and not by the radiation of the laser induced plasma. This assumption is supported by the interaction between the radiation of the laser beam with the metallic vapour within the keyhole caused by the mechanism of the inverse Bremsstrahlung[5]. Due to the smaller wavelength of the ND-YAG laser in comparison to the CO2- laser the interaction between the radiation of the beam and the vapour is negligible. Therefore the temperature of the vapour is deep in comparison to the temperature of a plasma, which is generated by a CO2- laser beam.

From this point of view the intensity distribution shows the isotherms of the melt pool in the keyhole region. The minimum of the intensity distribution shows the hole through the workpiece.

Therefore the hole is a sufficient indicator for full penetration.

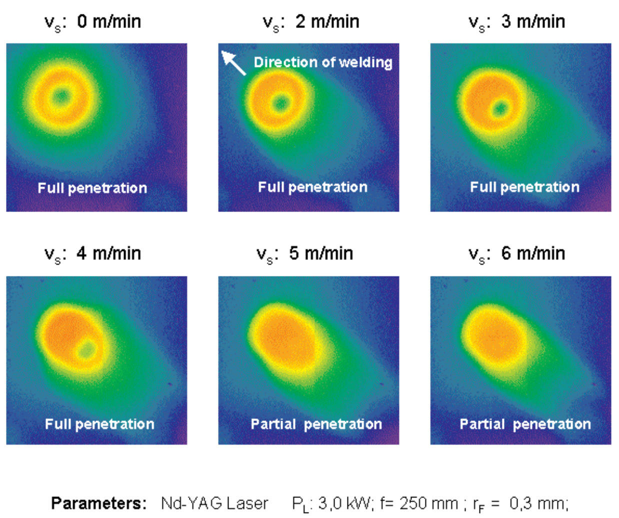


figure 3: Averaged images of the keyhole with different welding speed

In figure 3 some averaged images of welding with different welding speeds are presented. The first image shows a process with no speed. Interesting is the position of the hole in the center of the intensity distribution. The hole is not shifted to the back-side of the keyhole. If the welding speed will be increased, the shift of the hole can be observed. In the next chapters the geometrical structure of the keyhole will be analyzed. 4.

4. Spatial Analysis

The first diagram is the cross-section through the images in the direction of the welding speed. In figure 4 the cross-sections of the 4 weldings with full penetration are compared.

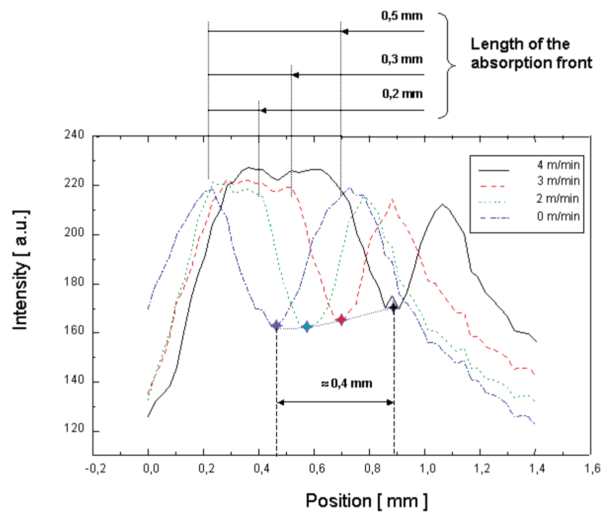


figure 4: Comparison of cross-sections through the intensity distribution in the direction of welding speed

The most peculiar effect in the diagram is the movement of the hole in the intensity distribution over 0.4 mm. This corresponds with the radius of the laser beam. The second effect is the change of the face of the curves itself. In the case of no welding speed a symmetric form of the intensity distribution is observed. With increasing welding speed the shape of the intensity distribution becomes more and more asymmetric. Interesting is, that the shape of the backside of the keyhole keeps its shape. The asymmetry is caused by a flat region of high intensity in the curves. This region is absend in the case of no welding speed. This region is interpreted as the absorption front. The high values of the measured intensity are an indicator for high temperatures as the result of the interaction of the surface of the melt pool with the laser beam.

In figure 5 the weldings with partial penetration are compared

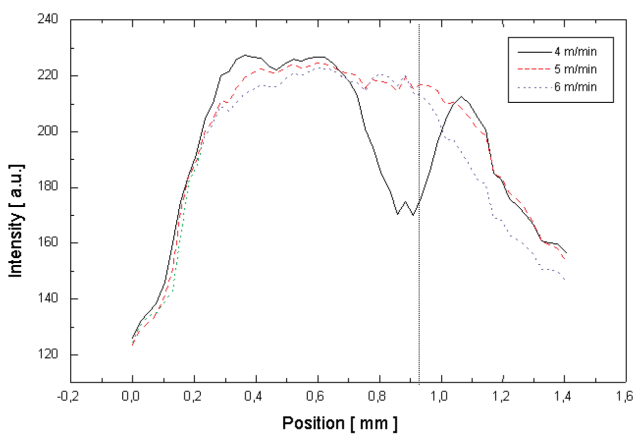
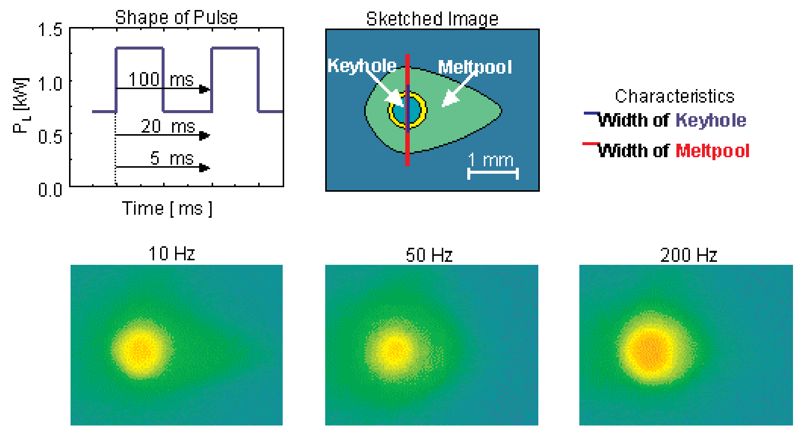


figure 5: Cross-sections through the intensity distribution in the direction of welding speed for full and partial penetration

with the welding of 4 m/min, which is at the edge between full and partial penetration. At the position from 0 to 0,2 mm all curves are very similar. Due to the higher speeds the laser beam has to heat more material and the result in the curve is a smaller value of the intensity in the beginning of the absorption front. At a position of 0,6 mm the intensity value of all curves becomes similar again.

After that point the hole in the intensity distribution of the weld with a welding speed of 4m/min is found. The end of the hole at a Position of 0,9 mm corresponds to a reduction of the intensity values in the welds with higher speed. From the position of 1,1 mm the intensity of the 4m/min welding reaches the values of the 5 m/min welding. From that point both curves are very similar again.



Parameters: Nd-YAG Laser P_L: 1,0 ± 0,3 kW; v_s: 3,5 m/min; f= 200 mm ; r_F = 0,3 mm;

figure 6: Shape of pulse and the shape melt pool

5. Control of the penetration depth by geometrical parameters of the keyhole

Due to the results and the analysis of the images before, it is possible to get geometrical parameters of the keyhole using a coaxial process monitoring system. A problem is the measurement of the penetration depth, because there is no possibility to get an information of the depth from the measured intensity. Under this conditions it is not possible to find a linear dependency of the penetration depth on the intensity of the laser induced plasma, which is used to monitor the penetration depth in the case of CO2- laser beam welding . It seams to be necessary to measure the penetration depth by geometrical values of the keyhole or the melt pool. The aim of the following measurements is to find the best parameters for controlling the penetration depth.

In figure 6 an experimental setup is presented, which is used to compare two characteristic parameters. These can be observed in the image of the monitoring system, the width of the keyhole and the width of the melt pool at the position of the keyhole. The arrangement of the two characteristics is described in the sketched image of figure 6. The idea is to excite the melt pool and the keyhole by pulsing the laser power. The shape of the pulse is described in figure 6. Under the sketched setup typical images are presented for different pulse frequencies. The most significant reaction of the changed frequency is the shape of the melt pool, which is more circular in the case of higher frequencies. The typical form of the melt pool as it is known from continuous laser beam processes, can be observed for the pulse frequency of 10 Hz.

But how do these shapes correspond to the obtained penetration depth. Therefore a longitudinal cross-section through the weld seam of the corresponding welds are presented in figure 7. A reaction on the pulse of the laser power can be observed in the cross-section.

In the case of 10 Hz the penetration depth reaches an equilibrium and a static depth is obtained. A comparison with the corresponding signals from the width of melt pool and the width of the keyhole shows, that the width of the keyhole follows the pulse of the laser power instantaneously. The width of the melt pool is damped by the characteristic frequency of heat conduction.

In the case of 50 Hz it is possible to see the change in the laser power also in the resulting penetration depth. The signal of the width of the melt pool is strongly damped. The width of the keyhole#follows the pulse shape.

In the case of 200 Hz the penetration depth is no longer influenced by the shape of the pulse. An averaged depth is achieved. The two signals reacts in the same way.

These curves shows, that the best correlation between the obtained penetration depth and the observable geometrical parameters of the welding process can be achieved, if parameters from the keyhole are used. Signals from the melt pool are damped by the heat conduction.

6. Conclusions

The achieved images from a coaxial process monitoring system using a CMOS camera can be interpreted as geometrical parameters of the keyhole like the absorption front. With this interpretation it is possible to explain the intensity minimum in the case of full penetration as a hole through the workpiece. Based on this interpretation a correlation between observable geometrical parameters and the penetration depth was investigated. Due to the heat conduction follows the width of the keyhole the penetration depth better than the width of the melt pool.

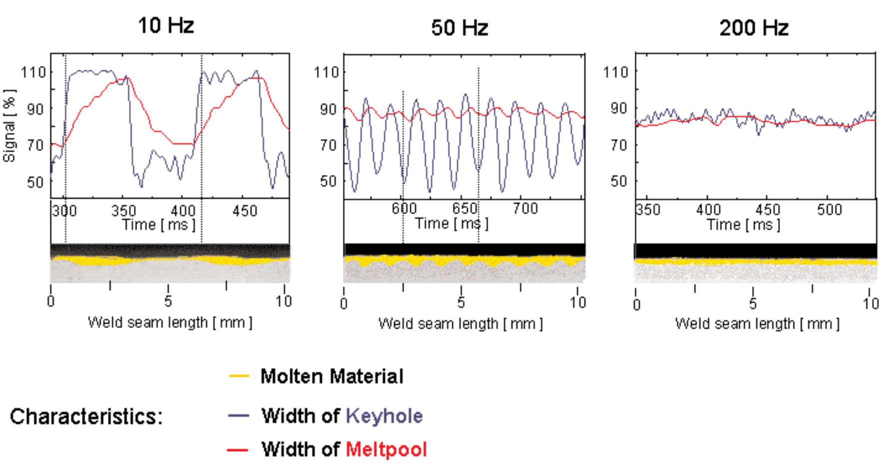


figure 7: Penetration depth and melt pool excitation

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