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Stabilization of a laser welding process against focal shift effects using beam manipulation

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Abstract

Two measures to enhance welding process stability with respect to a varying focal position are presented and discussed with regards to possible effects of laser power efficiency increase.

Spatial beam movement was caused by a deflecting mirror and proved to create a welding process with a higher constancy in welding depth when changing focal position. A larger cross sectional area of the weld seam was measured showing increased laser absorption when compared to a static beam.

Sinusoidal laser power modulation was tested for varying focus positions and proves to induce a deeper weld seam at moderately increased cross sectional areas. The power modulated welding process is dominated by the influence of melt dynamics which can be guided by choosing suitable modulation parameters.

Both systems can be used to stabilize the welding process against loss of joint area or loss of connection which may occur due to focal shift in high brightness laser beam optics.

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1. Motivation

Various investigations were made in the past to describe the effect of spatial and temporal laser beam modulation on the laser welding process. Less process defects like pores and spatters could be achieved by using power modulation [1][2][3], and new challenges in materials joining, like copper-aluminum joints, were

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investigated [4]. But also for a standard aluminum welding process an increase in process efficiency was measured [5].

With the development of high-brightness laser sources it becomes more difficult to find a stable focal position of the laser beam waist because of the time dependent response to thermal load and optical distortions in the transmitting optics inside the laser processing head [6][7]. Measuring and correcting the focal position is one measure to react. Another approach is to increase the robustness of the welding process itself against thermal shift of the focus position. The presented investigations were made to further look into the potential of beam modulation especially with the aim to reach a more robust process with respect to a focus shift. A general theory on the potential to increase process efficiency is presented.

2. Theory

When a shift in focal position occurs, induced by misalignment or by beam distortion caused by laser power absorption in the optics, the beam radius ω_z on the workpiece surface is enlarged according to

$$\omega_z = \omega_0 \cdot \sqrt{1 + \frac{z^2}{z_R^2}} \quad (1)$$

where ω_z denotes the beam radius in the beam waist, z the distance from the beam waist in propagation direction and z_R the Rayleigh length of the beam configuration. This leads to a change in the maximum intensity of a laser beam on the surface I_z , depending on the laser power P provided.

$$I_z = \frac{P}{\pi \cdot \omega_z^2} \quad (2)$$

A drop in intensity leads to a lower penetration depth and often to a decrease in the cross sectional area of the weld seam. According to [8] the absorption in the keyhole is depending on the diameter at the opening and the depth. Therefore depending on the resulting decrease in aspect ratio less energy is absorbed and used to melt material to create a maximum joining area. In the extreme case a changeover from deep penetration to heat conduction welding takes place [9] and may cause a missing joint.

3. Experimental Setup and Results

Two methods were investigated to enhance the stability against focal shift effects and efficiency of laser welding of aluminum with a TruDisk 5001 laser.

3.1. Spatial Beam Oscillation

In the first method the laser beam was deflected with a fast scanner to superimpose a circular movement of the focal spot on the work piece to the constant feed speed of 5 m/min of the work piece itself.

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