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Industrial Paper

Welding with ultra-high-power cw lasers

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Abstract

New ultra-high power laser sources with high brilliance and BrightLine Weld beam shaping functionality allow an excellent weld seam quality, a large welding depth, a high welding speed and a large working distance. Challenges to be addressed in this context involve the thermal management of the optical arrangement to facilitate stable focal parameters and thus stable processes.

New optics, both fixed and scanner optics, are developed to cope with the new laser sources. We show the stability of the focal position and the beam parameters over time and laser power with the results of beam parameter measurements for various optics using a new 24 kW cw laser at BPP 4 mm·mrad. The beam intensity distributions at different z-positions and BrighLine Weld configurations show the wide range of beam shapes possible with one optical setup.

The advantages of this versatile tool are demonstrated with application results of deep penetration welding.

Keywords: Bright Line Weld;high brilliance laser; beam shaping; laser scanning systems

1. Introduction

As new laser sources with higher beam quality and high laser powers become available, also the tools to focus the laser beam onto the workpiece need to be adjusted to the new situation. Design measures need to be taken in the optics to retain stable and reliable welding processes. Challenges to be mastered include managing thermal lensing as well as protection against back reflection, resulting for example from processing of high-reflective materials. In the field of deep penetration welding, fixed optics are the standard tool to perform deep weld seams with low feed rates. On the other hand the use of laser scanners enables laser remote welding with high productivity and high flexibility. Thus both type of optics are used in the application fields of high brilliance lasers.

2. Experimental Setup

2.1. Laser source:24 kW TruDisk

Advances in thin-disc laser technology have enabled the scaling of laser power and beam quality of the current TruDisk resonator to the level of 12 kW per disk with a beam parameter product of BPP 4 mm·mrad at 1030 nm

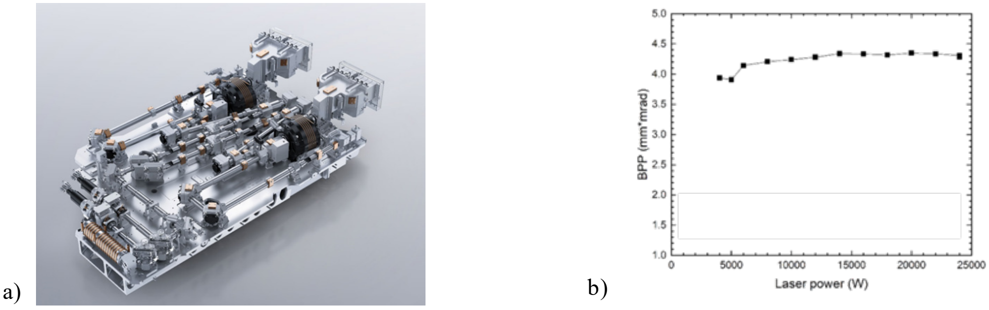

Figure 1. a) Graphical illustration of TruDisk with 24 kW output power and BPP 4 mm·mrad, b) Measured beam parameter product (BPP) behind a 20 m long fiber as a function of the laser output power.

wavelength. A total laser power of 24 kW is achieved by polarization combining of two resonators (see Fig. 1). The beam parameter product of BPP 4 mm·mrad is retained after a 20 m long fiber.

Furthermore, the laser device is equipped with BrightLine Weld technology. By that, each port can be individually configured in such a way that the laser power can be coupled into a dual-core fiber and flexibly be distributed between the fiber core and the fiber ring. This results in an adjustment of the power distribution on the workpiece which allows a massive leverage of the process quality.

The laser source is connected to the processing optics by means of a dual-core laser light cable (LLK), having a 100 µm core and 400 µm ring diameter.

2.2. New generation of programmable focusing optics (PFO33)

The PFO33 optics contains a 2D-scanner using to the pre-objective-scanning principle. Lightweight scan-mirrors are moved by drive units with digital encoders. This principle enables to reach all points in the processing range of the scanner with high dynamics and constant beam quality with nearly constant working distance. For the experimental investigations presented here, a collimator of focal length 140 mm and an objective of focal length 450 mm was employed.

2.3. New generation of fixed optics (BEO D70)

The second type of optics implemented in the experimental setup is a fixed optics equipped with protective glass, smoke bell, crossjet and metal vapour suppression unit. Gas and water flows are monitored as well as the protective glass. The optics can be configured both in 90° and in 0° angle, with or without an observation of visual light to monitor the working piece. All combinations were measured, but for the experimental investigations presented here the 0° version with a collimator of focal length 200 mm and an objective of focal length 300 mm was employed.

Both optics are designed to operate at power levels up to 24 kW. For this, the water cooling channels are guided through the metal mounts of the essential components such as the collimation, the deflection unit and the objective, making the heat transport much more effective.

Both types of optics are robust against back reflections due to high-quality reflective material. An integrated scattered light sensor will prevent damage by switching off the laser in case of unexpectedly high levels of back reflections.

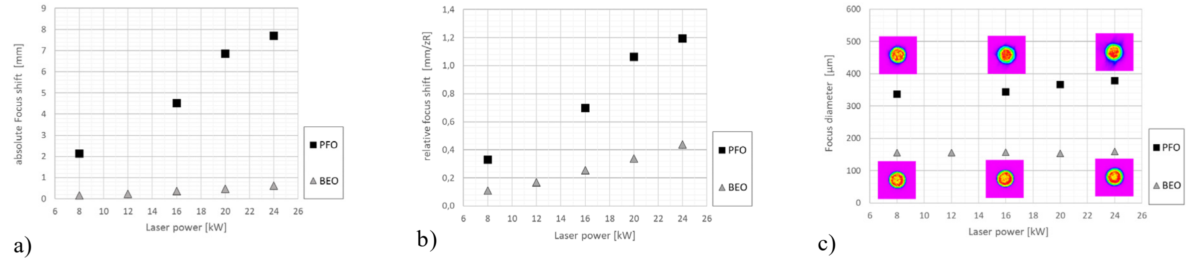

Figure 2. Measurement of the focus shift in mm a) and scaled to the Rayleigh length zR b) and measurement of the waist diameter of the new BEO D70 (triangles) and the new PFO 33 (rectangles) c). The insets show beam profiles at the waist location measured at power levels 8 kW, 16 kW and 24 kW accordingly.

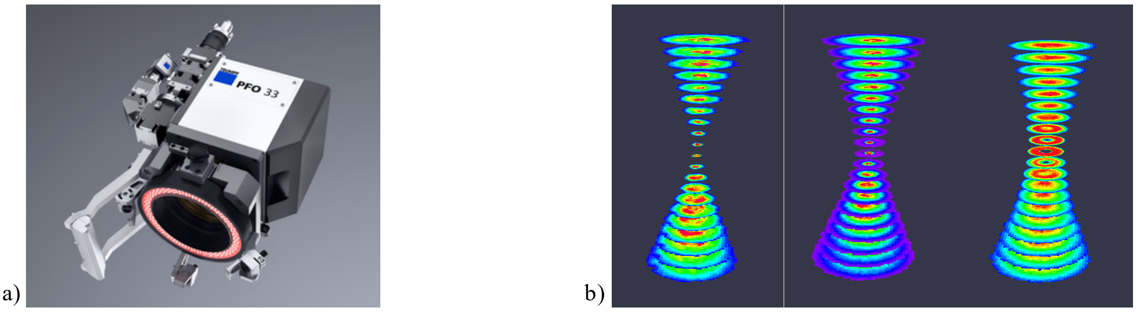

Figure 3.a) Graphical illustration of the new generation programmable focusing optics (PFO 33) b) Beam shaping with BrightLine Weld technology with a 100/400 µm dual core LLK at 24 kW laser power. Measured beam profiles with 100% laser power in the core (left), with 50% laser power in the core and 50% in the ring (middle), with 100% laser power in the ring (right).

3. Experimental Results

3.1. Optical characterizations

The beam parameter product of the 24 kW laser was measured behind a dual-core LLK with 100 µm core and 400 µm ring diameter according to ISO 11146 using a commercially available beam profiler (Metrolux LPM200). As shown in Fig.1b), a practically constant beam quality of ~4 mm·mrad was measured over the entire performance range of the laser.

Furthermore, the stability of the focal position was investigated as a function of the laser power transmitted through the optics. For this reason, the axial position of the beam focus was measured by means of a non-contact beam profiler (Ophir BeamWatch) at several power levels over intervals of 10 min time duration each. Additionally beam profile measurements at the working field of the optics were carried out with a beam profiler (Primes HP-MSM).

The results of these measurements are summarized in Fig. 2. As seen in Fig. 2a) and b), the maximum focus shift at 24 kW amounts to 8 mm in case of the scanner optics (rectangles), and ~0,6 mm in case of the fixed optics (triangles). Scaled to the Rayleigh length (zR) of the focused beam this corresponds to 1,2·zR for the scanner optics (zR = 6,5 mm) and 0,4·zR for the fixed optis (zR = 1,4 mm). The latter includes much less optical components, therefore such a low focus shift at 24 kW laser power is feasible.

The measured spot diameter, shown in Fig. 2c), amounts to ~400 µm for the scanner optics and ~150 µm for the fixed optics respectively. Note the different magnifications of 450:140 in case of the scanner optics and 300:200 in case of the fixed optics. The insets of Fig. 2 display the stability of the beam profile at different power levels. Over the entire power range of the laser, the changes in the beam profiles are small, especially for the fixed optics nearly no difference is detectable.

These low values assure that the combination of the 24 kW laser with both optics can be employed for stable and reproducible laser welding results.

To demonstrate the beam shaping functionality of the setup the beam profile was measured at different power distribution settings. As shown in Fig. 3b), by means of BrightLine Weld technology the full 24 kW laser power can be switched between the core (left) and the ring (right) or be flexibly split in a programmable manner between the core and the ring of the LLK.

3.2. Deep penetration laser welding

The high laser power makes this laser particularly suitable for deep penetration welding. In the experimental trials presented here, we employed both a high-alloy steel plate (1.4301) with a thickness of 40 mm and a Cu (Cu-ETP) plate with a thickness of 20 mm. A fixed optics with a focus diameter of 150 µm, as presented above, was used, with Argon as shielding gas, to create linear bead-on weld seams. Using the BrightLine Weld beam shaping functionality the laser power was split 75% into the 100 µm core and 25% in the 400 µm ring of the dual-core LLK.

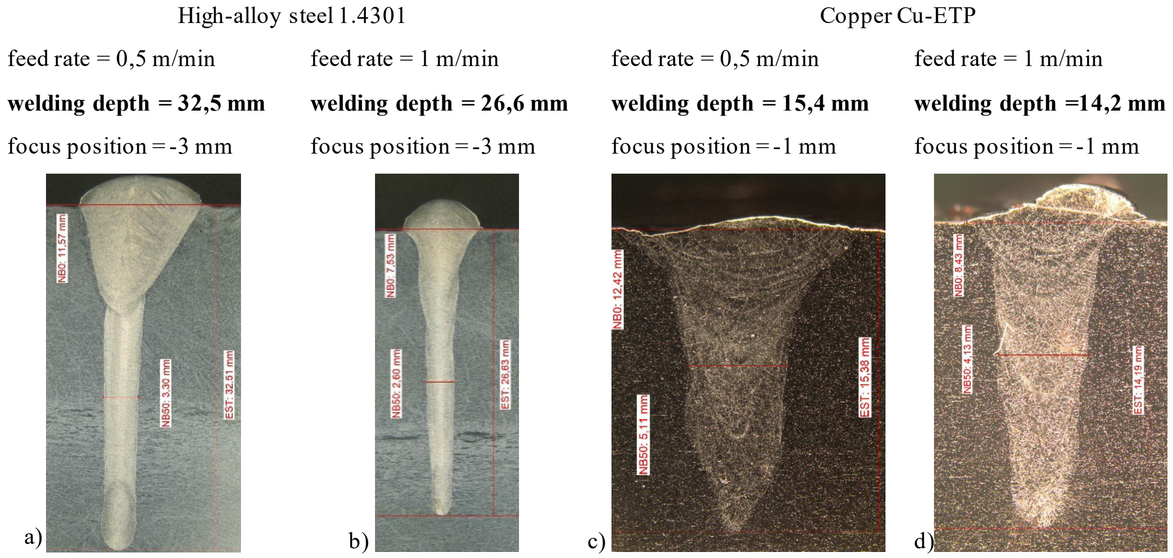

Figure 4. Bead-on-plate welding results using a high-alloy steel plate (1.4301) of 40 mm thickness (a and b) and a copper (Cu-ETP) plate of 20 mm thickness (c and d), 24 kW laser power and BrightLine Weld laser power ratio 75% core – 25% ring.

At 0,2 m/min welding speed with the focus positioned 5 mm below the surface, the 40 mm steel plate is completely penetrated. At such low speeds the top part of the weld seam becomes very wide. A further increase of the keyhole depth is hindered, related to the recoil pressure in the keyhole, forcing the heat to expand to the sides. Welding under vacuum conditions would change the cross section and increase the penetration depth.

Due to lower density of the solidified melting pool and tensions in the material a volume surplus is created without any additional material. At a welding speed around 1 m/min the width of the seam surface is significantly reduced, and a larger part of the laser power is used to increase the depth. Welding depths around 30 mm were achieved in this regime.

Due to its high reflectivity at the wavelength range around 1000 nm, and due to its high thermal conductivity, copper constitutes one of the most challenging materials in the application field of laser welding with infrared light. Typically, in deep penetration welding in copper with a top hat distribution, boiling occurs at the bottom of the keyhole, resulting in unstable welding depth and spatter formation. The smooth transition of the beam profile in the outer part of the spot using to the BrightLine Weld beam shaping, induces a ring of melt around the top part of the keyhole that reduces the spatter formation and increases the stability of the melting bath.

At low welding speeds the process is less effective, a bigger part of the heat is transported in the material, increasing rather the width than the depth. This is seen in figure 4 c) and d): the penetration depths at 1 m/min and 0,5 m/min are very similar, but the seam is much wider with the lower speed.

Welding depths of more than 15 mm were achieved in a copper plate of 20 mm thickness with very few spatters and a good seam quality.

4. Summary

Based on the novel design of the new generation of PFO 33 and BEO D70, highly stable and reliable welding has become possible at a power level of 24 kW. We demonstrated the stability of these optics in combination with the new TruDisk 24001, incorporating BrightLine Weld beam shaping functionality, and have shown results of deep penetration welding, achieving welding depths of 40 mm in high-alloy steel and 15 mm in copper.

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