Laser Cutting Head for High-Brightness Lasers

A cutting-edge solution for 1 µm metal cutting

Detlev Wolff and Jean-Baptiste Karam

The present market of metal laser cutting machines is mainly dominated by laser sources that emit radiation in the wavelength range around one micron. The majority of these lasers generate radiation through pumping of ytterbium doped fiber or ytterbium doped disks, or directly from gallium arsenide (GaAs) semiconductor diodes. The latter direct diode approach has been increasing its market share due to a significant increase of beam quality. A few years ago, high-power direct diode lasers were used for applications where low brightness (BPP between 20 – 30 mm mrad @ 4 kW) was sufficient, such as laser brazing and hardening. With the latest improvements in beam quality, reaching 4 mm mrad and below, direct diode lasers are now suitable for laser cutting applications, which are dominated currently by other laser types. This article investigates cutting quality and speed using the II-VI Highyag laser cutting head BIMO-FSC in combination with a direct diode laser. In addition, the machine controlled and independent adjustment of focus position and diameter of the BIMO-FSC have been analyzed in regards to optimization of the piercing process.

Typically, laser processing head manufacturers design optical layouts for a rather small wavelength bandwidth in order to avoid the need for broadband coatings that are typically more expensive and thicker. Increasing thickness of coatings will result in a higher absorption and hence higher tendency of focus shift. This is one of the reasons why II-VI Highyag tailored its laser cutting head BIMO-FSC to be used with high-brightness diode lasers. The one used for the investigation is equipped

Fig. 1 II-VI Highyag laser cutting head BIMO-FSC

with a 150 mm focal length focusing lens. The combination with a 100 µm fiber cable core diameter offers continuous adjustment of spot size ranging from 120 to 320 µm. Furthermore, the wide adjustment range of the focus position and focus diameter offered by the BIMO-FSC allows for cutting a broad variety of materials with thicknesses up to 25 mm.

The investigated cutting tests have been conducted with Teradiode's 4 kW direct diode laser named Terablade. Its wavelength is designed at 970 nm which is shorter than the typical wavelengths of disk lasers (1030 nm) and fiber lasers (1070 nm).

Besides different wavelengths, the fiber lasers and diode lasers can differ in beam profile. Fig. 2 shows that both beams have only slight differences at the focus position. Propagating into the near field area, a vast difference in beam profile becomes obvious. While the beam of the fiber laser propagates in a Gaussian like manner, the beam of the diode laser starts to form a TEM_{01} mode at two Rayleigh lengths (z_R = 5.5 mm for magnification of M = 1.5) away from the focus position.

One of the application benchmarks of high-brilliance lasers is their performance in cutting ferrous and nonferrous metals. For this reason, stainless steel (1.4301) and mild steel (S235) have been selected for the cutting tests. The stainless steel cuts were processed with nitrogen for the fusion cutting process, and the mild steel cuts were processed with oxygen for performing flame cutting. The spot size was kept constant at 150 µm for comparability reasons.

Fig. 3a and 3b illustrate the excellent cut quality achieved with the diode laser. The remarkable cutting performance regarding surface roughness can be explained by the optical design of the BIMO-FSC and the higher absorption rate of the metals at shorter wavelengths. The quality of the cutting samples stands out with only shallow striations above the very smooth middle and bottom of the workpiece edge.

Advantages of machine controlled focus adjustment

The BIMO-FSC allows for cutting of various sheet thicknesses and materials

Company

II-VI HIGHYAG
Kleinmachnow, Germany

II-VI HIGHYAG, a subsidiary of II-VI Inc., is one of the world's leading suppliers in the laser material processing industry. Its innovative laser processing heads and beam delivery systems enable the efficient use of the laser beam for the most demanding advanced manufacturing applications such as laser cutting, laser welding and laser brazing.

www.highyag.com

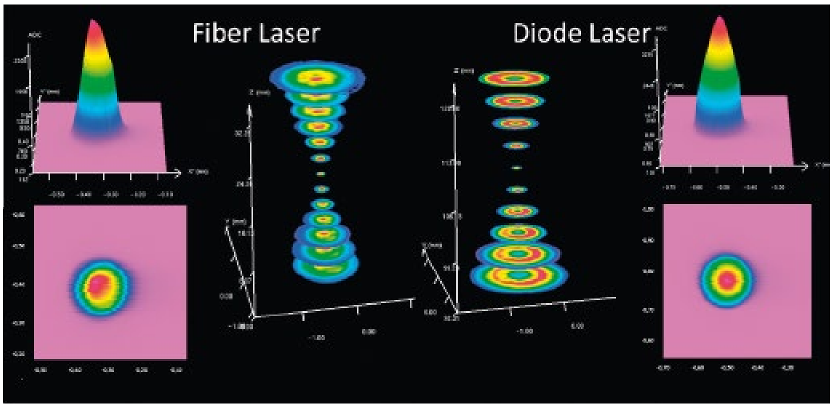


Fig. 2 Beam profile comparison including intensity profiles in focus position: fiber laser left, diode laser right

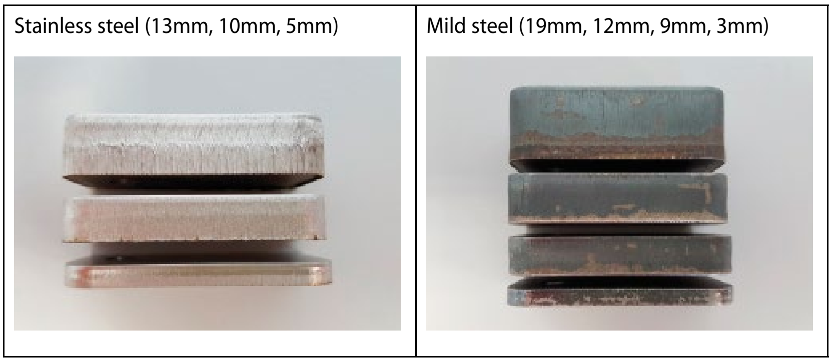


Fig. 3a Photos of the cutting samples

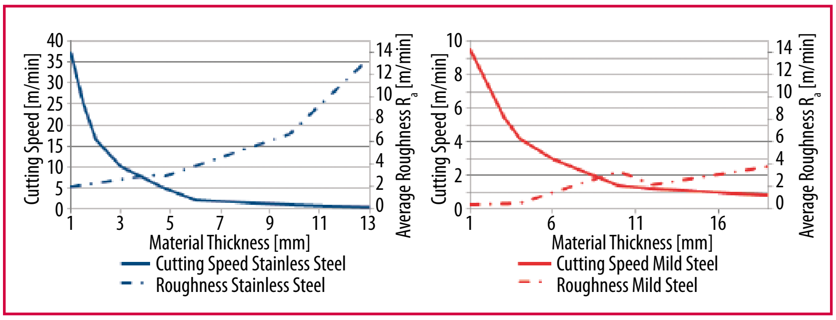


Fig. 3b Cutting speed and roughness

by machine controlled and independent adjustment of both focus position and focus diameter. The investigation hereafter illustrates the advantage of this capability during the piercing process.

One of the major challenges for cutting thick mild steel is to create a fast and stable piercing process. In general, the laser is directed to the material surface and melts and evaporates the metal until a hole is created. For this process, there are at least three values that can be optimized:

- hole diameter
- piercing time
- amount of spatter

A small hole diameter is the first precondition to cut filigree contours even at thick workpieces. Unnecessary long piercing times should be avoided to minimize the processing time. The amount of spatter can directly affect the cutting process stability. For instance, spatter may contaminate the optical elements and influence the capacitive height sensing which is fundamental to monitor the height of the cutting head. Therefore, a minimized amount of spatter corresponds directly to higher machine uptimes. In summary, an ideal process is supposed to pierce a small hole in a fast manner without blowing up too much material.

Piercing of mild steel > 15 mm

A common magnification of a cutting head is around $M = 1.5$, which results in a 150 µm spot size at the focus position using 100 µm fiber core diameter. Due to the small Rayleigh length, the beam diverges with a half angle of 53 mrad from the focal plane where the beam reaches the highest intensity. Adjusting the magnification with the BIMO-FSC motorized collimation to a spot size of 320 µm, the half angle divergence decreases to 23 mrad. Assuming that the minimum amount of material which needs to be molten and evaporated is equal to the volume of the beam, Fig. 4 indicates that a larger spot goes hand in hand with a reduced amount of molten material and hence result in faster processing. Obviously, this is valid for thick workpieces only. Investigations were performed at the II-VI Highyag application laboratory with 20 mm mild steel to achieve a fast and stable piercing process with low material blow up and small diameter holes.

To meet this target, pulsed spiral drilling was performed where power, duty cycle, frequency, nozzle distance and gas pressure were adjustable parameters. Highly stable processes were performed with the helical drilling method, where the cutting head is moving towards the workpiece during the process while rotating around its z-axis in adjustable radii.

Fig. 5 shows an optimized pierced hole by adjusting the parameters mentioned above, next to a partially optimized pierced hole. The optimized hole shows reduced diameters on the top side of the sheet. Parameters were set to:

- 3 bar oxygen pressure
- double nozzle with an outer diameter of 2 mm

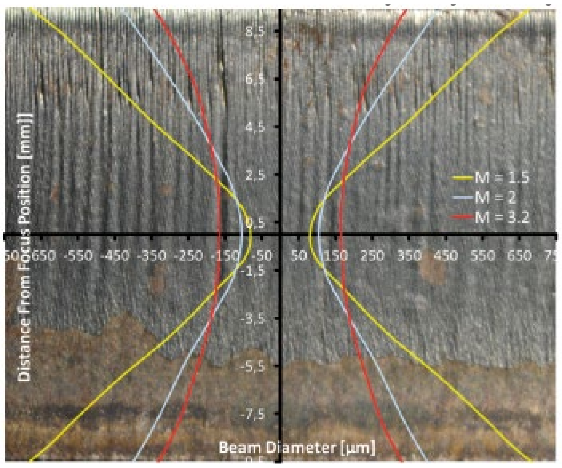


Fig. 4 Adjustment of magnification on a 20 mm mild steel sample

- focus position close to the middle of the workpiece
- 320 µm focus diameter

The piercing was performed in less than eight seconds with a hole diameter of less than 1 mm through the complete cross section. The hole is displayed on the left side of Fig. 5. On the right side, a piercing hole, where the piercing time was reduced about 30 %, is shown. A high power shot of roughly 0.1 – 0.15 s at the beginning leads to larger diameters at the top. The diameter is increased from 809 to 4775 µm while the channel and the exit hole diameter stay about the same. The usually undesired larger top-diameter improves the melt ejection, as the material is blown out concentrically away from the nozzle, e.g. to the sides of the nozzle rather than through the narrow piercing channel. Using this controlled blast at the beginning of the process should always be compensated with a larger nozzle standoff to avoid molten material contaminating the nozzle and the cutting head. While higher pressures shorten the process time, there is a great risk of larger blowouts, which result in hole diameters of more than double the size shown. Without the displayed quality demands, piercing times can be lowered to approximately one second.

It was identified that a decent piercing process should generate holes that are smaller than the following cutting kerf width [1]. This approach supersedes the currently used process of having the piercing hole outside the cutting path. The so called "lead in" is necessary to avoid an area within the workpiece that has an oversized hole width, which would deform the parts contour. With 0.8 mm, the piercing holes diameter remains within the actual kerf width when cutting 20 mm mild steel, which is about 0.8 – 1 mm as measured in previous tests at the II-VI Highyag application laboratory. The magnification adjustment functionality prevents material waste by avoiding piercing outside of the necessary cutting contour. Still, the flame cutting process needs a short time to stabilize and the machine's axis to accelerate. It is evident that some adjustment efforts have to be placed by ramping laser power and speed to achieve a perfect transition between piercing and cutting process. The heat-affected zone (HAZ) of the piercing area which is visible as a discolored area around the channel is rather small and does not reach values above 400 µm. This darker stripe shows where explosions and phase transformations took place. It is shown that nitrogen as an assist gas might lead to smaller HAZs, since it does not heat up the material as much as oxygen does [1].

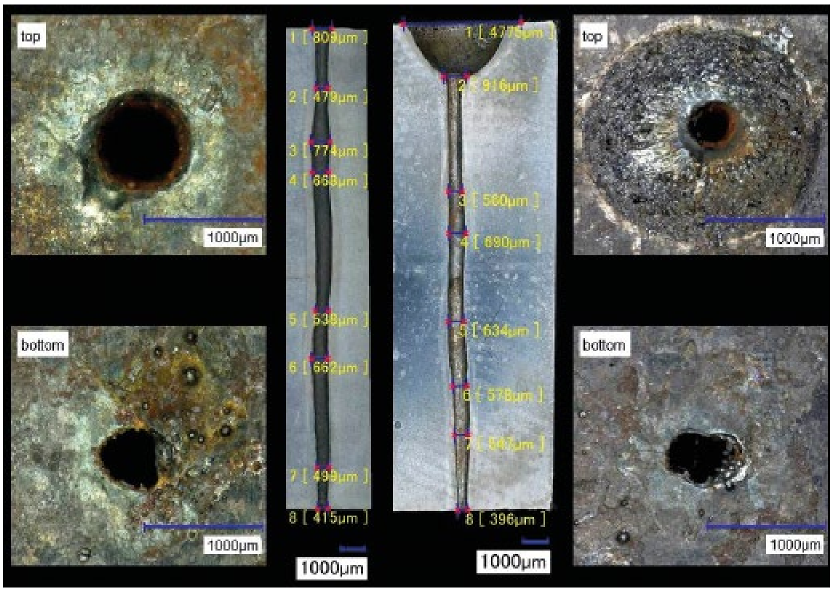


Fig. 5 Mild steel: optimized piercing process with entrance and exit hole on the left side and time optimized process on the right side. Cross-sections of two holes with different pulses at the beginning but identical parameters in the middle

Conclusion

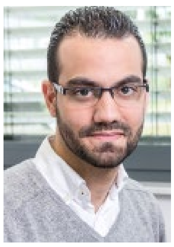
It was shown that the BIMO-FSC laser cutting head was successfully tested and qualified with a direct diode laser source. In addition, the repeatedly conducted caustics measurements have shown that no focus shift issues evolved. The overall positive investigation results lead to the conclusion that the combination of the BIMO-FSC and a direct diode laser source interact in an excellent manner. The investigation has also proven that the machine controlled focus adjustment capabilities of the BIMO-FSC optimize the piercing process by enhanced piercing stability and quality. Based on this, it can be concluded that the BIMO-FSC with its outstanding features enables maximum productivity for laser metal cutting.

DOI:10.1002/latj.201600034

[1] *M. Hashemzadeh:* Fibre laser piercing of mild steel: effects of power intensity, gas type and pressure, *Optics and Lasers in Engineering*, pp. 143-149, April 2014.

Authors

Detlev Wolff studied physics and received his PhD in the field of laser material processing at the Friedrich Schiller University in Jena. He worked in the fields of laser measurement technologies, laser beam sources, and laser material processing. Since 2012 he is Head of Sales at II-VI Highyag Lasertechnologie GmbH.



Jean-Baptiste Karam is a Product Manager for laser cutting at II-VI Highyag Lasertechnologie GmbH. He joined the company in 2013 and is in charge of the product strategy and the life-cycle management of the laser cutting heads. He holds a master degree in physics from the University of Bordeaux, France.

Christine Groß, Marketing Communications, Christine.Gross@II-VI.com, Tel.: +49 33203 8830, II-VI HIGHYAG Lasertechnologie GmbH, Hermann-von-Helmholtz-Str. 2, D-14532 Kleinmachnow, Germany, www.highyag.de