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Tip-tilt piezo platform scanner qualifies dynamic beam shaping for high laser power in cutting applications

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Abstract

Dynamic beam shaping raises the cutting speed and increases the cut edge quality. This has been shown several times by the authors in previous publications. This innovative technology offers a large potential in process improvements, especially for laser cutting of thick plates. Commonly used galvanometer driven scanners require large integration space and do have limited lifetime compared to piezo based solutions. Physik Instrumente GmbH & Co. KG and Fraunhofer IWS are developing a piezo based tip-tilt platform scanner, which achieves the necessary dynamic beam shaping functionality, but saves installation space by the factor of eight.
The solution is small enough to substitute conventional deflection mirrors in the optical beam path and is therefore easy to integrate even into existing machines. The present paper introduces the advanced possibilities for the process using this new system technology and demonstrates a possible integration.

Keywords: dynamic beam shaping; oscillation; tip-tilt; piezo; laser cutting; high laser power

1. Introduction

Laser beam cutting is applied for a spectrum of applications with varying demands. Thin sheet cutting is well controlled whereas quality is compromising the productivity in case of thick metal plates (Wandera et al., 2006; Sparkes et al., 2008; Hilton, 2009; Powell and Kaplan, 2012; Hirano and Fabbro, 2012; Goppold et al., 2014; Pocorni et al., 2015; Mullick et al., 2018). The approaches to improve the cutting performance from fiber laser for thick metal plates are manifold, but the idea is always to adjust the spatial intensity

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distribution of the laser spot to the demanded application. The geometrical properties could be influenced as well as the intensity distribution itself (Powell et al., 2000; Olsen, 2011; Wandera and Kujanpää, 2011; Blomqvist et al., 2012; Goppold et al., 2014; Kaakkunen et al., 2014; Stoyanov and Niessen, 2014; Hilton et al., 2016; Laskin et al., 2016; Lin et al., 2016; Kogel-Hollacher et al., 2018; Rodrigues and Duflou, 2018; Sumpf et al., 2005; Fuse, 2015; nLight, 2018). The common procedures belong to the static beam shaping, which means that the beam is modified before the machining process starts. The solution approach of Fraunhofer IWS pursues dynamic beam shaping (DBS) to adapt the laser beam to the demands of thick plate cutting (Goppold et al., 2015; Goppol et al., 2016; Goppold et al., 2017). DBS superimposes an additional beam movement to the feed direction during the process. A main advantage is the maintained intensity distribution of the fiber laser beam because every influence on the process is performed by the spatial and temporal modification of the energy deposition. As a consequence, DBS improves the feed rate and quality for laser fusion cutting of thick metal plates.

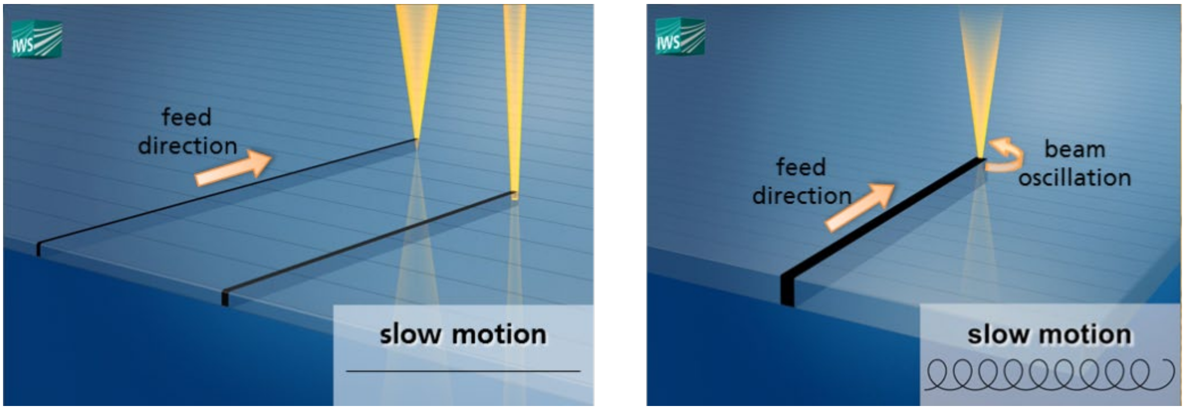

Fig. 1. Static beam shaping with different geometrical properties of the laser beam cutting in one direction (left), whereas dynamic beam shaping superimposes the linear feed direction with an oscillatory motion, e.g. circular (right)

One main constraint for market entry of DBS is the technical implementation into cutting machines. There are only few system technologies that accomplish the claims of laser power, aperture, two-dimensional scanning, scan angle and dynamic, which are necessary for the DBS functionality. In addition, the system technology has also to meet demands of low-effort implementation, e.g. small installation space, easy controllability and high component life time to mention just a few aspects.

Against this background the present paper introduces tip-tilt piezo scanners as advanced system technology for the demands of high power laser material processing. At the beginning (section 2), the design and functional principle of a tip-tilt piezo scanner is explained. Section 3 investigates the optical properties, whereas section 4 examines the integrability. Eventually, the tip-tilt piezo scanners proof their suitability realizing DBS to improve the cutting process.

2. Tip-tilt piezo platform scanner for macro laser material processing

Tip-tilt piezo scanners from Physik Instrumente GmbH & Co. KG are versatile positioning systems. They are commonly used for high-dynamic operation in scanning and tracking applications among others. These applications usually operate with low laser powers in milliwatt range. The scanner has a modular setup, whereby various designs and footprints and thus diverse performance levels can be realized. The tip-tilt piezo drive comprises a movable platform on which any optical element can be mounted. In consequence, just the specifications of the optical element are crucial for multi-kilowatt laser power applications.

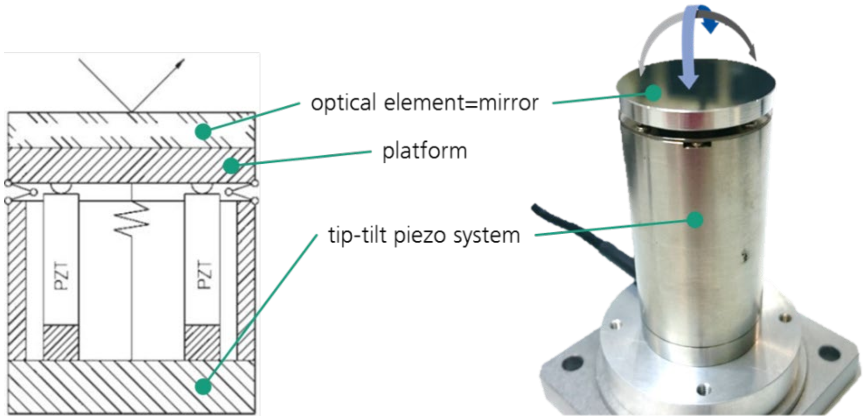

Fig. 2. Schematic diagram (left; Karle, 2018) and picture (right) of a tip-tilt piezo platform scanner with differential drive

A differential multi-axis tip-tilt piezo platform scanner was utilized for laser cutting trials. A mirror was mounted on the platform, which is tilted in two axes by four piezo drives. Hence, it is a one-mirror-solution. The piezo actuators are arranged in pairs around 90° and both of them move the same platform in push/pull mode at the same time. The motion platform is displaced around a fixed center of rotation. More detailed information about tip-tilt piezo scanners can be checked in Karle, 2018.

3. Optical characterization of tip-tilt piezo platform scanner

In the following section, a tip-tilt piezo scanner was analyzed concerning laser power capability and optical imaging. The first characteristic depends on the selected mirror. The mounted mirror is a standard component of fused silica with 25 mm aperture and a reflective coating for 1030-1090 nm wavelength at 45° angle of incidence. As depicted in figure 3 left, the mirror passes 4 kW multimode fiber laser power without any damage. The power loss could be reduced through particularly adapted mirror specifications.

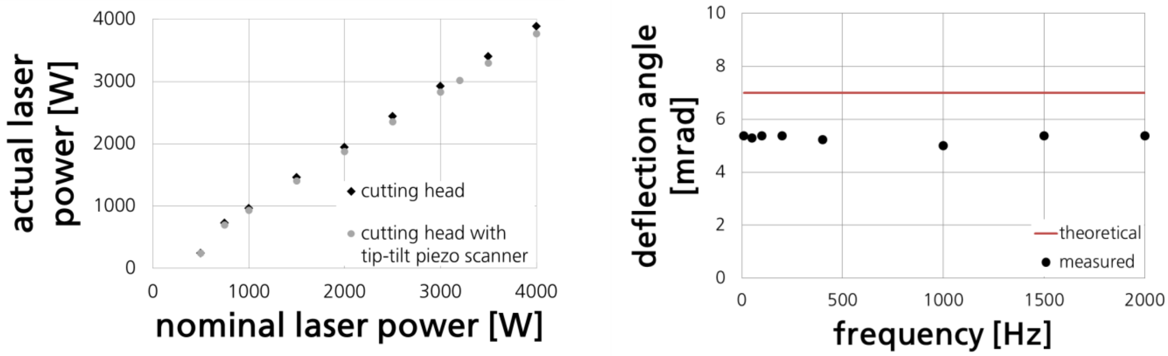

Fig. 3. Laser power capability (left) and deflection angle depending on the oscillation frequency (right) of the utilized tip-tilt piezo platform scanner

The analysis of the optical imaging takes place in two steps. The first one is to check if the optical imaging is still free of aberrations after integrating the tip-tilt piezo scanner into a standard laser cutting head. Therefore, the scanner is stationary positioned as simple mirror without any movement. Figure 4 on the left exhibit an accurate beam profile.

The second step is to visualize the dynamic beam shaping. Hence, the tip-tilt piezo scanner was two-dimensionally oscillated. This is illustrated in figure 4 on the right. The oscillatory motion of the laser beam is inconspicuous. One of the most important characteristics of high dynamic applications, as DBS, is the stiffness of the mechanical tip-tilt piezo system. The resonant frequency is derived as a function of the stiffness and serves to qualify the system. The general rule of thumb is: The higher the resonant frequency, the higher the maximum operating frequency. The resonant frequency accounts up to multi-kHz and is directly dependent on the weights that are mounted on the platform. The optical deflection angle of the utilized tip-tilt piezo system is up to 7 mrad in an unloaded application without optical element. The effective deflection angle is dependent on the weight of the optical element and on the oscillation frequency. In figure 3 on the right is shown, that the utilized tip-tilt piezo scanner achieves on the average 5.3 mrad up to 2 kHz frequency. Consequently, the dynamic behavior of the scanner (frequency and deflection angle) has still potential for further improvement.

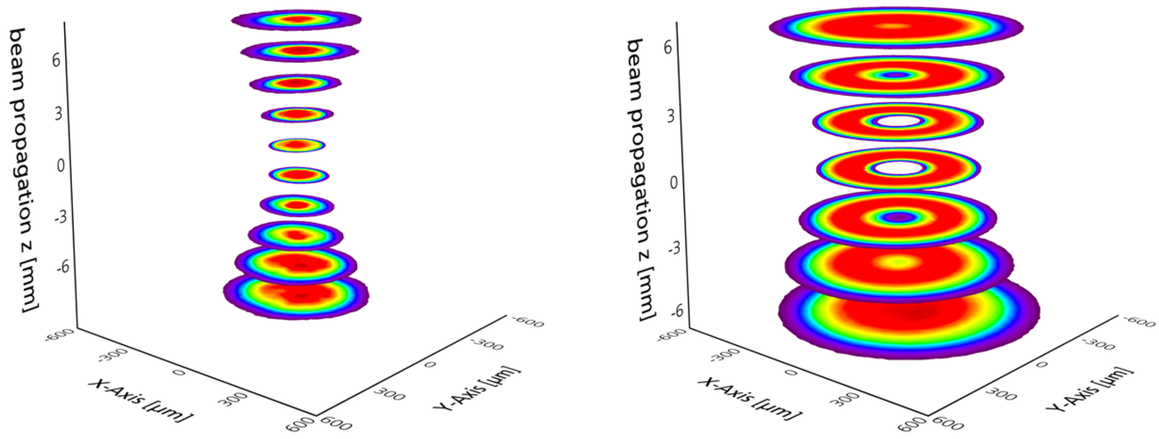

Fig. 4. Diagnostic of the static (left) and two-dimensionally, circularly oscillated (right) laser beam with tip-tilt piezo platform scanner

At the beginning different demands were mentioned such as laser power, two-dimensional scanning, etc., which are necessary for a system technology that accomplishes DBS. These optical functionalities were successfully validated for the tip-tilt piezo scanner. The following section deals with mechanical implementation, which is one main challenge for DBS to enter the laser material processing market.

4. Mechanical implementation of tip-tilt piezo platform scanners into cutting machines

The tip-tilt piezo scanner is a one-mirror solution that achieves two-dimensional oscillation with just one optical element. This is the main advantage compared to other scanners that need one optical element for each movable axis. As a result, installation space of a tip-tilt piezo scanner is reduced by a factor of eight compared to commonly used galvanometer driven scanners with the same functionalities. This small size enables an easy implementation of the DBS device into cutting machines for the first time. Many cutting machines hold deflection mirrors in the optical beam path. The idea is to substitute one deflection mirror with a tip-tilt piezo scanner. That requires almost no supplementary installation space, but provides additional functionality to improve the cutting process significantly. In the particular case shown in figure 5, the collimation unit is mounted orthogonal to the cutting head integrating the tip-tilt piezo scanner. But, it is also possible to design a straight setup.

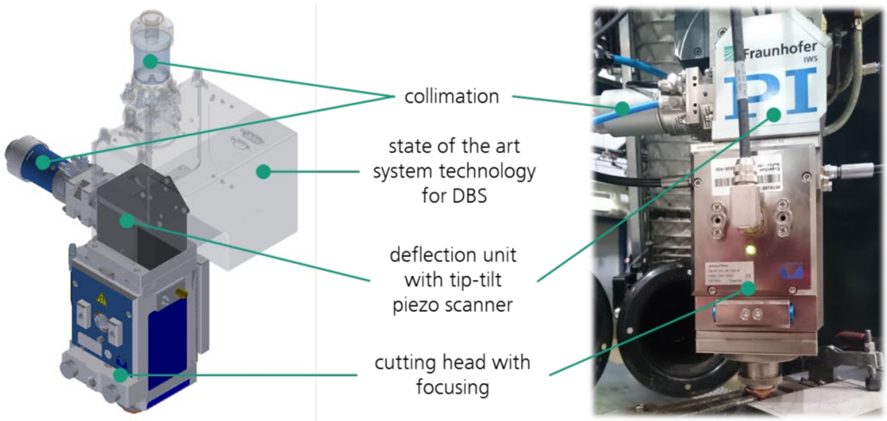

Fig. 5. Setup of dynamic beam shaping in a laser cutting head using a tip-tilt piezo platform scanner; left: schematic illustration demonstrates the reduced installation space compared to state of the art system technologies; right: experimental setup

The tip-tilt piezo systems are equipped with flexure bearings for friction-free motion and therefore provide excellent guiding accuracy as well as a long life time. Tests show that the piezo actuators, that have undergone at least 100 billion cycles, do not exhibit any measureable wear under appropriate ambient conditions (0°C to 50°C) and continue to operate according to specifications. The piezo actuator is very reliable even under extreme ambient conditions (-20°C to 80°C) and this extends the lifetime considerably.

5. Application: laser beam cutting with dynamic beam shaping

Dynamic beam shaping raises the cutting speed and increases the cut edge quality. This has been shown several times by the authors in previous publications (Goppold et al., 2015; Goppold et al., 2016; Goppold et al., 2017). This section demonstrates the transferability of the existing process knowhow to tip-tilt piezo scanners. Therefore, 12 mm stainless steel was cut with 3 kW multimode fiber laser power. The laser fiber diameter accounts 100 µm and is imaged with twofold optical magnification. A sample cut with a standard laser process is depicted in figure 6 on the left. Here a feed rate of 0.6 m/min was achieved and the cut edge shows burr.

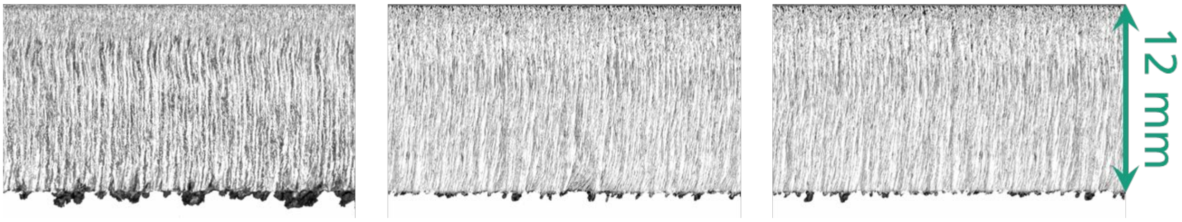

Fig. 6. Cut edges of static beam shaping (left), dynamic beam shaping with state of the art system technology (middle), and similar dynamic beam shaping parameters with tip-tilt piezo platform scanner at 3 kW laser power

The other two cut edges in figure 6 originate from identical DBS parameters and look quite similar. The sample in the middle was cut applying a galvanometer driven scanner and for the right sample a tip-tilt piezo scanner was used. For both cuts a feed rate of 1 m/min was reached. That corresponds with 67 % increase of the cutting speed. On top, DBS reduces the burr significantly.

6. Outlook

Recent and former investigations at Fraunhofer IWS regarding laser fusion cutting of thick metal plates showed that through dynamic beam shaping (DBS) or spatial and temporal modification of the laser beam's energy deposition, respectively, both feed rate and cutting edge quality are improved distinctly. In this context tip-tilt piezo platform scanners were proven to meet all necessary demands to accomplish DBS as alternative drive to conventional galvanometer driven scanners. Moreover, the tip-tilt piezo platform scanners excel through a remarkably reduced installation space.

In order to push the process boundaries even further Fraunhofer IWS and Physik Instrumente GmbH & Co KG are currently working on a next-level tip-tilt solution with advanced temperature management and electronic control. This development aims for applications with similar deflection angles at operating frequencies of up to 4 kHz or even beyond as well as for a laser power of up to 10 kW. This upgrade will surely allow a further significant increase of productivity and quality of thick plate cutting processes.

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