Machining strategies for versatile ultra-short pulse laser applications

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Abstract

The emerging ultrafast laser systems facilitate the processing of a huge material variety. In order to utilize the whole capability of ps- and fs-lasers, three different machining options were established at LLT. Surface structuring or cutting of temperature-sensitive materials with galvo-scanners; trepanning systems for drilling arbitrary holes and cutting with positive conical, perpendicular or negative conical kerfs; fixed optics combined with a x-y-positioning system for cutting metal foils or synthetic materials.

A non-thermal laser cutting process generally causes conical kerfs. This disadvantage can be avoided utilizing a novel piezo-stack-based trepanning system. Additionally, the taper angle of holes and kerfs can be adjusted. Besides drilling circular holes, the system offers the distinctive feature of fabricating high quality elliptical, rectangular or star-shaped structures.

Applications with scan-heads afford a huge process variety with many modifiable parameters. The optimization of those process parameters using the so called full factorial design of experiments (matrix of all process variables) will be illustrated with an example.

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Keywords: Ultrafast lasers; precision processing; surface treatment; trepanning; cutting

1. Introduction

The light material interaction of ultra-short laser pulses is well known for several years, so the shortens of pulses skips the melting phase during ablating materials, furthermore less energy is diffusing into the substrate, Chichkov et al. (1996). Thus material processing with ultra-short pulsed lasers enables burrless and cold machining. But by increasing output power of ultra-short pulse beam sources, heat accumulation becomes an important role, Weber et al. (2012) and Döring et al. (2011).

Solving this challenge, different technologies like beam shaping: with diffractive optics, Račiukatis et al. (2011), or with flexible optics, such as acousto-optic deflector, Bechtold and Schmidt (2014), or Spatial Light Modulator, Knorr et al. (2014), have been developed to split up or to scatter the beam, so beam interaction area can be enlarged and heat accumulation decreased. Using a high relative velocity between beam and surface is another approach to minimize thermal effects: therefore galvanometer scanner, Neuenschwander et al. (2013), or polygon scanning systems have been using, Neuenschwander (2014), besides circulating the beam with help of trepanning systems is an additional option against heat accumulation while drilling holes, Mayer et al. (2013).

At LLT three different ultra-short pulsed laser machining technologies have been established: cutting with fixed cutting head and moving work piece, drilling and cutting with a piezobased trepanning system and surface treatment and cutting with galvanometer scanning heads.

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2. Machine and Components

The experimental setup for cutting with fixed optics; with and without using the trepanning system is presented in Fig. 1. The main parameters of used components are listed in Table 1.

Table 1. Machinery.

<table>
<thead>
<tr>
<th>Component</th>
<th>Type</th>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine</td>
<td>LLT Applikation: Microcut 2000 UKP</td>
<td>Max. velocity</td>
<td>500</td>
<td>mm/s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max. acceleration</td>
<td>20</td>
<td>m/s²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Positioning accuracy</td>
<td>±1</td>
<td>µm</td>
</tr>
<tr>
<td>fs-Laser</td>
<td>Light Conversion: Pharos</td>
<td>Wavelength</td>
<td>1028</td>
<td>nm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pulse duration</td>
<td>290</td>
<td>fs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max. pulse energy</td>
<td>200</td>
<td>µJ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max. average power</td>
<td>10</td>
<td>W</td>
</tr>
<tr>
<td>ps-Laser</td>
<td>Trumpf: TruMicro5050</td>
<td>Wavelength</td>
<td>1030</td>
<td>nm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pulse duration</td>
<td>6</td>
<td>ps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max. pulse energy</td>
<td>62,5</td>
<td>µJ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max. average power</td>
<td>50</td>
<td>W</td>
</tr>
<tr>
<td>Scanhead</td>
<td>Scanlab: HurryScanII 14</td>
<td>Focal distance</td>
<td>100</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max. velocity</td>
<td>4500</td>
<td>mm/s</td>
</tr>
<tr>
<td>Trepanning System</td>
<td>Invented by: Bayerisches Laserzentrum in cooperation with LLT Applikation</td>
<td>Focal distance</td>
<td>50</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max. amplitude beam angle</td>
<td>±5</td>
<td>°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max. amplitude eccentricity</td>
<td>±500</td>
<td>µm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max. frequency (sinus signal; closed loop)</td>
<td>300 / 18000</td>
<td>Hz / rpm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Typ. frequency (arbitrary; closed loop)</td>
<td>50 / 3000</td>
<td>Hz / rpm</td>
</tr>
</tbody>
</table>

3. Application

3.1. Cutting ps-/fs-Lasers and fixed optics

In Fig. 2 (a) and (b) bronze was cut with ps-laser and fixed optic, the cutting speed was set at 20 mm/min, otherwise it would not be possible to get this 25µm small solid joint. Using a fs-laser enables much higher cutting speed with less thermal effects, Ancona (2009). Therefore a stent structure of 150 µm thickness was cut with a maximum speed of 600 mm/min, see Fig. 2 (c) and (d).
3.2. Cutting and drilling with ps-Laser and trepanning system

Cutting with fixed optics and ultra-short pulse lasers has the disadvantage of conical kerfs. In Fig. 2 kerfs at beam exit side are 6 respectively 10 µm smaller as at beam entrance side. This drawback can be eliminated by cutting with a rotating tilted beam by using a trepanning system. The result of a trepanning-cutting application is illustrated in Fig. 3. A wire of 45 µm width and 30 mm length was cut in 100µm stainless steel with a ps-laser. The conical kerfs were compensated by trepanning with an angle of three degree, so that beam entrance and exit side have less than one micron difference in width.

But the main advantage of a piezo-stack-based trepanning system is the variety of shapes, which are possible to drill by tilting two mirrors in the system. So the system is not limited on circular shapes even squares, rectangles and arbitrary structures are possible. In Fig. 4 versatile shapes are demonstrated: Fig. 4 (a) and (b) shows a filter structure with circular holes of 200 µm diameter and a pitch of 25 µm in hexagonal alignment with low surface roughness. Different possible shapes were illustrated in Fig. 4 (c). Additional, all trepanning parameters can be changed while drilling. Therefore, a structuring or drilling process is realizable in several steps in order to enhance the surface quality.

3.3. Micromachining with ps-laser and galvanometer scanning system

By structuring with galvanometer scanning systems heat accumulation plays an important role. In Weber (2012), Döring (2011) and Ancona (2009) pulse to pulse heat accumulation in drilling processes have been explicated. The following examples should show that, two more types of heat accumulation can be characterized.
Fig. 5. ps-laser and galvanometer scanning application on 130 µm kapton-foil; (a) Application matrix: varying velocity (left slow, right fast), pulse energy (1. to 10. line) and number of scans (1. matrix 1x, 2. matrix 6x, 3. matrix 11x); (b) varying number of parallel lines; (c) Result of cutting application.

In Fig. 5 (a) full factorial experiments with parameter: pulse energy, velocity and number of scans are demonstrated. The first part of the matrix displays the pulse-to-pulse-heat-accumulation: pulse repetition rate was constant, velocity increased from left to right (pulse overlap decreased from left to right) and pulse energy was enlarged from first to tenth line. Thus, at an energy input per unit length of 0.04 mJ/mm edges are getting damaged. While repeating the matrix five times the damage threshold was reached at 0.03 mJ/mm and by repeating ten times the damage starts at 0.02 mJ/mm.

If structuring geometries have a high density, the energy cannot flow into substrate. Thus, small areas heat up and degrade, see Fig. 5 (b). The material around high packed structures can absorb more energy, therefore the substrate degrades only at the inner side, see Fig. 5 (c).

4. Conclusion

The machining technologies and strategies are important for material treatment with ultra-short pulsed lasers; otherwise pulse-to-pulse-, rerun- and geometry-density-heat-accumulation are responsible for the thermal damaged results.

References