NEW BEAM DEFLECTION TECHNOLOGIES FOR ULTRA SHORT PULSE LASERS

Paper #

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Abstract

Ultra short pulse lasers pose new challenges on the beam deflection technologies. In this paper we present three recent developments that have an impact on the application of ultra short pulse lasers in industry. The three technologies include:

1. Micro processing with large field of view – combined motion of scanner and stage

This scanning solution extends a laser scan system‘s working field by simultaneously controlling and moving a scan head and an XY-stage, thus delivering clear laser processing advantages, such as high processing throughput with an unprecedented level of accuracy. Process accuracy significantly improves, too, because a scan system‘s positioning error rises linearly with the image field size. The XL SCAN solution‘s combined motions at higher accuracy will use a smaller image field, thereby reducing this error.

2. Micro processing with 5 axis precession drilling and cutting system

This micromachining sub system enables laser micro processing and drilling of flexibly variable geometries as well as laser cutting and structuring. Designed for ultra-short-pulse (USP) lasers, bore holes and cutting edges are exceptionally clean cut and don't require post-processing.

3. 3D micro processing with fully reflective z-Axis scanner

The achieved identical dynamics of all three axes now opens up entirely new processing strategies and opportunities. Furthermore, this new technology uses only reflective optical components. This allows using different wavelengths without dispersion and reduces thermal lens effects at power laser applications.

Introduction XL SCAN

Many applications in the field of micro processing require high accuracy on a relatively large working field. The need for high accuracy leads to short focal distances for the scanner lens and therefore to a small field of view.

In order to extend the field of view we introduce a system that combines the motion of a scanner with the simultaneous motion of a x-y stage and call it XL SCAN. The system is programmed in the extended working field and automatically divides the motion into a path for the scanner as well as a path for the stage.

This decomposition of motion is conducted via a band pass filter that restricts the dynamics of the motion of the stage./1,2/ The residual motion is then passed to the scanner. As a scanner we use the excelli*SCAN* /3/.

Throughput results and drilling of holes

Application	Time tiling motion	Time simultaneous motion	Percentage saved
Circles	5.63 s	3.30 s	41%
Diamond shaped pattern	3.92 s	2.96 s	24%
Hole drilling (jump & shoot)	5.2 s (estimated)	4.42 s for 10,000 holes	15%
Hole drilling (repeated circles / trepanning)	12,2 s (estimated)	11,86 s for 5,000 holes	2 %

Table 1 – Improvement of throughput for different patterns

Table 1 shows the time for tiling vs. simultaneous motion for the different patterns shown above and two different hole drilling experiments. In addition to the patterns of circles and diamonds (already discussed above) two experiments for the drilling of holes have been carried out.

The first test (jump & shoot) shows that it possible to offer simultaneous motion for drilling on a large image plane. Drilling of 10,000 holes (1 mm distance) on an area of 50 x 200 mm was achieved in 4.42 seconds. This would correspond to 2262 holes per second. An estimate on the stitching motion for these 10,000 holes yields 5.2 seconds (3 movements of the table with 263 ms each). This would result in a throughput advantage of 15% for simultaneous movement

In the second test (repeated circles / trepanning) 5,000 holes were distributed over an area of 50 x 100 mm² (distance: 1mm). These holes consist of circles with a diameter of 200 µm that are repeated 3 times (trepanning). An estimate on the duration of a stitching motion yields 12.12 s (one 50 mm table movement with 263 ms + time of the scanner motion). This is a throughput advantage of only 2% of the simultaneous motion. This low value for the improvement is due to the long duration of the marking in the field of view of the scanner, the single tiling motion and the high density of holes.

It is clearly visible that the throughput advantage is higher for those patterns that require more tiling motions. During the hole drilling of the repeated circles only one tiling motion is necessary, and the density of holes is rather high. This results in a throughput advantage of only 2%. On the other hand, for the patterns of circles and diamonds the simultaneous motion results in a substantially higher throughput.

During both hole drilling experiments the density of holes is rather high with the distance of 1 mm between each hole. In a real-life case we expect the density of holes to be much lower resulting in a higher throughput advantage. In general, the increased throughput comes with another advantage – compared to the stitching approach, much smoother motions of the x-y stage can be observed (e.g. 0.25 g vs. 1 g acceleration). This can lead to less structural oscillations and therefore an increased overall accuracy. Furthermore, it can allow using stage axes with reduced dynamics and therefore with smaller motors thus saving cost.

Accuracy for the simultaneous motion

To measure simultaneous accuracy, a grid of 13x13 points over a range of ±144 mm in both directions (distance 24 mm) was marked using simultaneous motion. The stage moves in a meander shape through the points while the scanner is marking crosses in a zig-zag-shape at about plus and minus 75 % the scanner field of view. Via this approach a demanding example (stage dynamics and used field of view) which allows evaluation of the accuracy of the simultaneous motion is generated.

Table 2-4 and Fig. 3 shows the accuracy achieved using simultaneous motion. The stage motion is a meander shaped motion shown as a green line in lower left corner of the figure. The Scanner motion consists of point to point jumps in a zig-zag pattern resulting in the pattern shown. The accuracy achieved with simultaneous motion is 11µm max deviation.

The simultaneous accuracy consists of many contributing errors, e.g. static errors, following errors, structural resonances, etc. Here the accuracy seems to be mainly influenced by the static scan system and stage accuracies.

	x-axis	y-axis	radial
Min.	-2.0 µm	-5.0 µm	0.0 µm
Max.	5.0 µm	1.0 µm	5.4 µm
Standard deviation	1.3 µm	1.1 µm	1.4 µm
Mean	0.9 µm	-0.7 µm	1.6 µm

Table 2 – Static error of the scan system

	x-axis	y-axis	radial
Min.	-4.2 µm	-5.1 µm	0.0 µm
Max.	6.1 µm	4.7 µm	6.6 µm
Standard deviation	1.6 µm	1.8 µm	1.2 µm
Mean	0.1 µm	0.8 µm	2.2 µm

Table 3 – Static error of xy stage

	x-axis	y-axis	radial
Min.	-7.8 µm	-9.7 µm	0.0 µm
Max.	8.9 µm	4.1 µm	11.0 µm
Standard deviation	2.9 µm	3.1 µm	2.6 µm
Mean	-0.8 µm	-3.5 µm	4.9 µm

Table 4 - Accuracy achieved in simultaneous motion

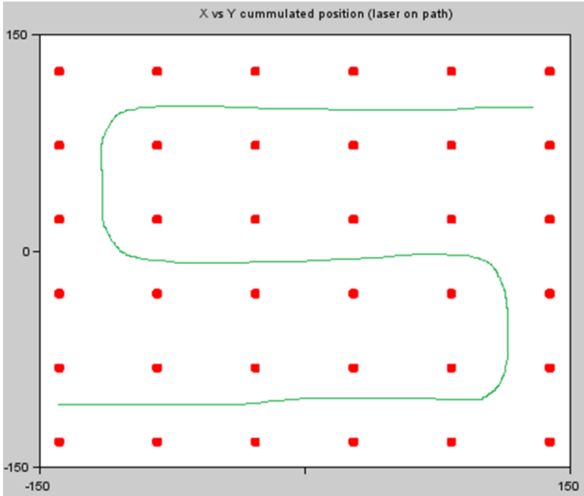

Fig 1 – Schematic representation of the stage path (green) and the simultaneous motion path (red) not true to dimensions and details

Conclusion XL SCAN

The simultaneous motion control of a laser scanner and an x-y stage allows for a throughput increase of up to 41% depending on the pattern. Stitching errors can be avoided by simultaneous motion and the accuracy of the marking is generally improved through the reduced field of view that the scanner must address. We present results of the simultaneous motion which show maximum deviations from the target position of +/-11 µm for a focal length of 100 mm. In general, the simultaneous motion shows improvements over the tiling motion that makes it a promising technology.

Introduction precSYS

In multiple markets there is a need for industrial processing of parts on the micrometer level: The applications cover fuel injector holes for gasoline and diesel engines as well as micro structuring in the watch making industry and manufacturing of spinnerets in the textile industry. Using Ultra Short Pulse (USP) lasers a variety of materials can be processed, like glass, hardened metals, ceramics and plastics. All industries are on the lookout for efficient, precise and flexible micro-machining technologies to fulfil the new requirements. Drilling holes with high aspect ratios has become a particularly important application. Today's laser machining challenge is how to fabricate holes with high aspect ratios, high precision and perpendicular wall angles, i.e. drilling of cylindrical or even negatively tapered walls.

5 axis laser processing

The past few years are marked by upheaval, as laser processing (with its countless advantages) increasingly displaces EDM manufacturing. Laser ablation and cutting processes are fast, contactless and force-free. They work on all workpiece materials, exhibit low wear, and don't require additional fluids. Plus, the laser motion paths offer unrestricted flexibility.

Fig 3 – SCANLAB's five-axis micro-machining and precession drilling subsystem

SCANLAB has introduced an innovative precession subsystem to the market that uses a novel 5-axis technology to incline the beam. These five axes (x,y,z,α, β) maximize flexibility for process development beyond typical percussion drilling: e.g. spiral drilling, trepanning and precession drilling, which means the laser is tilted and moved helically.

Realization

The five galvanometer axes allow flexible positioning possibilities, such as 3D-positioning of the focal spot onto workpieces with precise tracking of angles of incidence (AOI). For easy processing, factory calibration allows description of laser motion directly in metric units within precSYS's Cartesian image field coordinate system, which enhances ease of use and repeatability.

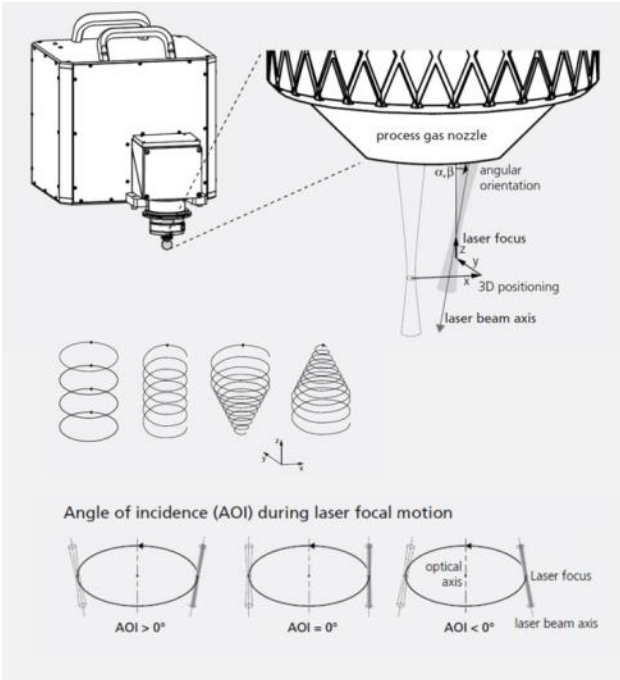

Fig 4 – System design for flexible laser processing in the µm range

Based on galvanometer technology, the system works without rotary optics, thereby drastically increasing reliability. High-end scan technology with small mirror deviations and low moving masses ensures highly dynamic processing, with trepanning or precession frequencies up to 500 Hz (30,000 rpm). precSYS is specifically conceived for USP laser precision processing (typically 300 fs – 10 ps). The optical path is polarization-maintaining and accommodates pulse energies up to 250 µJ.

The angle of incidence (maximum AOI ±7.5°) can be adjusted within the image field. And the lateral position can be varied within a working field diameter of 5 mm for marking jobs, or of 2.5 mm for precession processing. Finally, the focus position's vertical location (z axis) can be adjusted within a range of ±1.0 mm.

The system allows highly dynamic and contour-true processing with highest accuracy: it is servo-regulated for stable positioning at precession frequencies up to 500 Hz and permits definition and execution of trajectories with 0.1 µm step increments.

The principle of operation is achieved via five galvanometer axes. The first two axes are arranged such that an incoming beam can be shifted laterally. This lateral shift results in a beam inclination after the focal lens. The second pair of axes is arranged such that the incoming beam is inclined in two possible directions. This beam inclination results in a lateral shift of the beam after the focal lens. The last galvanometer axis is used to shift the focus position in the z-direction.

Results

The 5 axis scanner system achieves impressive 3D processing results, with sharp, burr-free and molten-free bore hole entrances and exits.

Inserts 1-3 of figure 5 show an array of holes in steel and the close up of a single hole of this array. Particularly impressive is the burr-free, molten-free bore hole entry. Inserts 4 and 5 show another set of holes generated in honor of SCANLAB's 25th birthday. The holes were fabricated via workpiece positioning with an XY translation stage. Drilling of a 200µm deep hole with a diameter of 100 µm with straight walls can be performed in under 1 sec.

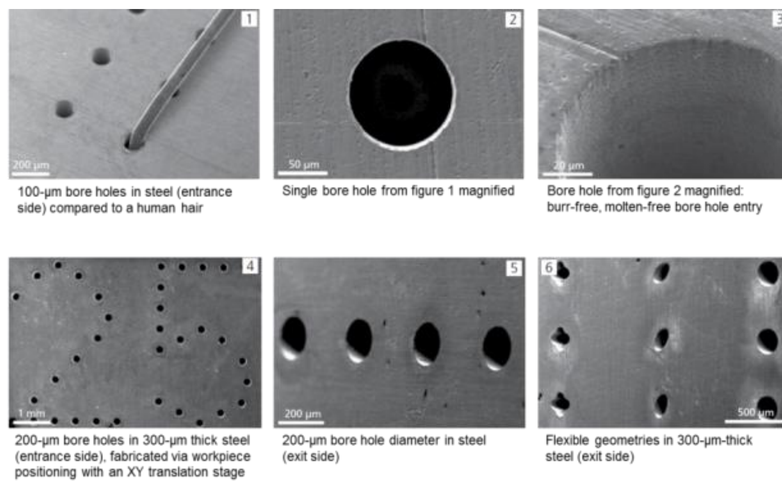

Fig 5 – Selection of processing results

Introduction excelli***SHIFT***

Galvanometer (galvo) scan systems turn a USP laser beam into a very precise and productive tool for micromachining. The laser beam is deflected by two rotatable mirrors driven by high-precision motors with closed-loop position control. The low inertia of the mirrors allows for a much more dynamic positioning of the focus as compared to machine concepts with moving laser head or moving workpiece. Galvo technology has been refined in the last decades and has reached a very high level of performance and industrial reliability.

Realization

In 3D applications typically a lens setup with at least one motorized lens is used to vary the effective focal length of the optical system and to move the focus in the z-direction (perpendicular to the xy-plane). Inherently this type of focus shifter is much less dynamic as compared to the galvos for xy-positioning. Thus the dynamic of a 3D scan system is typically a factor of 3-4 lower as compared to an equivalent 2D scan system.

SCANLAB has developed a new approach for focus shifters based on galvanometer technology, named excelli*SHIFT*. The basic principle of operation relies on an optical system that converts a deflection angle of the laser beam into a variance of beam divergence.

Functional principle of the dynamic focusing unit

Fig 7 depicts the beam path through the double- folded optical setup. The entrance beam is deflected by the mirror of a galvo scanner arranged at the focal point of an aspheric mirror. The aspheric mirror is hit at an off-axis position and images the beam to an intermediate focus. Then the beam is guided to the off-axis point on the aspherical surface symmetrical with respect to the plane perpendicular to the of the aspherical mirror's optical axis by two folding mirrors. Because of the symmetry of this setup the beam is then deflected by the aspherical mirror back to the galvo scanner and the variation of the scan angle of the galvo scanner is canceled out. As the angle of the galvo mirror is varied, the optical path through the setup is changed while the position and direction of the exit beam remains constant. The only remaining effect is a strong spherical aberration of the beam that can be tuned by the angle of the galvo mirror and is utilized to manipulate the divergence of the beam in a controlled way.

This way a rotatable galvo mirror can be employed to shift the focus. The advantages of this approach are that the robust galvo technology can be employed for all three axes of the 3D scan system and the dynamics of the three axes is inherently matched. This promises a very robust and reliable solution for highly productive 3D micro-machining.

Fig 6 – excelliSHIFT

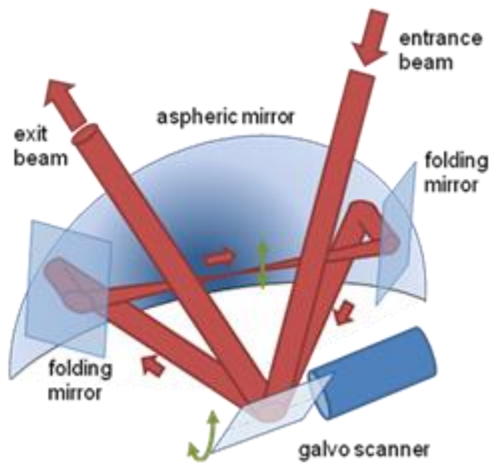

Fig 7 – principle of operation

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