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5-axis scanner for precession drilling

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Abstract

A novel precession drilling system with a flexible 5-axis scanner allows hole drilling with high aspect ratios and straight walls. In precession drilling, the angle of incidence can be adjusted relative to the laser beam path to create shape geometries not possible with conventional laser drilling methods. The angle of incidence is adjustable in a ±7.5 deg range and the beam path permits operation in a 2.5-mm diameter field with rotational frequencies up to 500 Hz. A 200-µm deep hole with a diameter of 100 µm and straight walls can be drilled in under 1 sec. Results of the drilling process are presented.

Keywords: Drilling; precession; scanner; five-axis micro-machining; angle of incidence

1. Market need

Multiple markets require industrial processing of parts at the micrometer level: Applications range from fuel injector holes for gas and diesel engines to micro-structuring in the watchmaking industry and spinnerets for the textile industry. Ultra Short Pulse (USP) lasers facilitate processing of diverse materials such as 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 positively or negatively tapered walls in round, elliptical or more complexly formed bore holes [Foehl (2011), Lehner et al. (2003), Michalowski (2014), Walther et al. (2008), Weber (2015)].

2. Five-axis laser processing

The past few years are marked by upheaval, as laser processing (with its countless advantages) increasingly displaces EDM manufacturing [Foehl (2011), Raydiance (2004-2012)]. 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.

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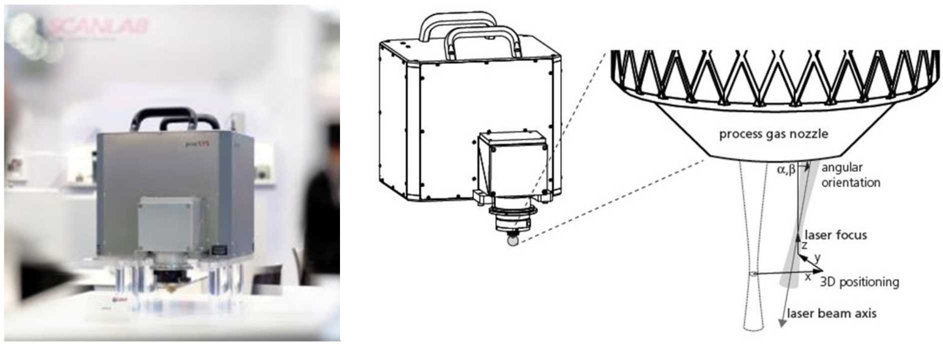

Fig. 1. SCANLAB’s "precSYS" five-axis micro-machining and precession drilling subsystem.

SCANLAB has introduced an innovative precession subsystem to the market that uses 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 (Fig. 2).

3. Realization: Designed for automated series manufacturing

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).

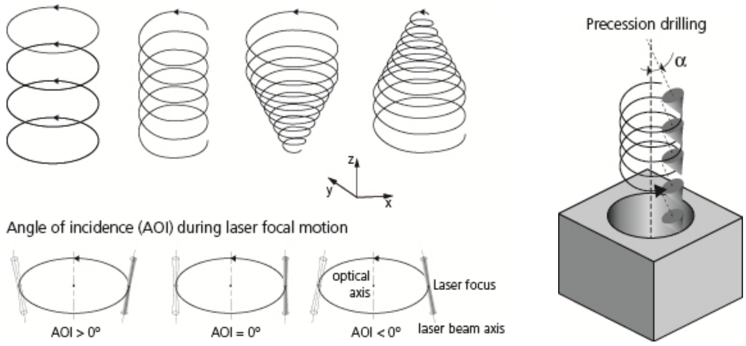

Fig. 2. System design for flexible laser processing in the µm range.

Based on galvanometer technology, the system works without rotary optics, thereby drastically increasing reliability and contour fidelity. 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 system allows highly dynamic and contour-true processing with maximum accuracy. It is constructed to be robust and thermally stable. Moreover it is servo-regulated for stable positioning at maximum precession frequencies and permits definition and execution of trajectories with 0.1 µm step increments.

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

The simplified principle of operation is achieved via five galvanometer axes as follows. 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. The superimposed movements are calibrated at SCANLAB and can be easily programmed in the precSYS’s own DrillControl software.

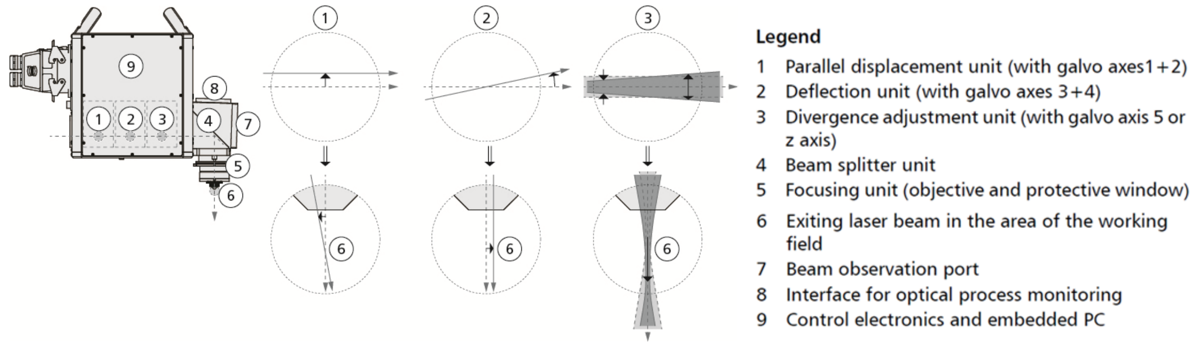

Fig. 3. Subunits of the precSYS scan unit and principle of operation.

The graphical user interface (GUI) facilitates straightforward creation and testing of micro-machining jobs. The intuitive software interface with 3D job visualization helps to generate, select and simulate processing jobs. The job designer additionally allows varying the diverse process parameters and compensating workpiece tolerances. Drill sequences can be easily defined. Factory calibration enables description of laser motion directly in metric units within precSYS's cartesian image field coordinate system. Control and remote communication are possible via Ethernet.

The system is fully suitable for industrial use. It features modular construction, water cooling and a sealed, gas-purged beam path. This contributes to the high precision results of USP-laser processing and ensures a long life for the optical components. It makes precSYS a low-maintenance product with resilience against fluctuating temperatures, ablation particles, dust, etc. Furthermore, the system offers two observation ports for process-monitoring add-ons.

It is precisely factory-pre-calibrated and can be equipped with an optional automatic fine–adjustment package. This package contains an integrated sensor and a controller that runs on the embedded PC. With this feature, the location and angle of the incoming beam is measured close to the working area. An additional maintenance program compensates variation in the location and/or inclination of the incoming beam by fine-adjusting the galvanometer zero position. This alignment feature ensures repeatable process results even under changing operating conditions.

The software facilitates management of one or several systems for serial production. The standardized interface for XML data exchange allows straightforward remote connectivity to PLCs, and thus integration into modern automated manufacturing environments. Hence, it is fully open to all requirements of factory automation and modern IOT architectures (internet of things).

4. Drilling Results

The 5-axis scan system achieves impressive 3D processing results, with sharp, burr-free and molten-free bore hole entrances and exits, as well as smooth bore hole interior topographies.

Fig. 4 shows an array of holes in steel and a close up of a single hole of this array. Particularly impressive is the burr-free and molten-free bore hole entry. A 200-µm deep cylindrical (0° taper) hole, with a diameter of 100 µm and straight walls, can be drilled in under 1 sec (Fig. 4d). It's possible to manufacture an array of bore holes in the 2.5-mm diameter image field without an extra x-y translation stage.

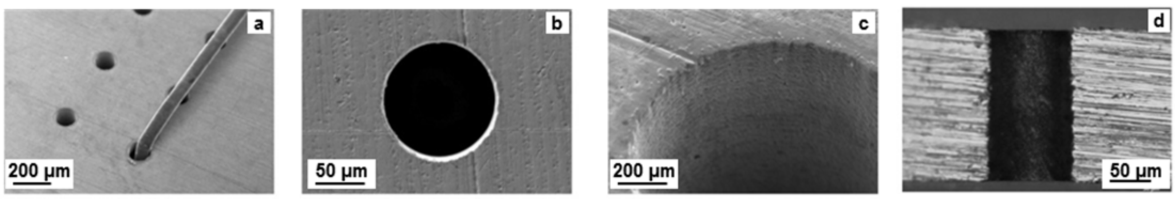

Fig. 4. (a) 100-µm bore hole array in steel (entrance side) compared to a human hair; (b), (c) single bore hole from (a) magnified; (d) cross section of a 0° taper 100-µm-bore hole in 200-µm-thick steel (process time ~1s).

A bore hole with a diameter of 100 µm was processed in 500 µm thick ceramic. The boundary condition is a straightness tolerance of max. ±2 µm. The chosen process strategy consisted of 2 steps with superimposed z-axis movement and an inclined beam. The first step – roughening – consists of several spiraling jobs shaping the hole. The second step – finishing – consists of several round-trips with helical jobs. The measuring report for the resulting wall angle shows remarkable straightness of ±0.7 µm for the 1:5 aspect ratio (Fig. 5).

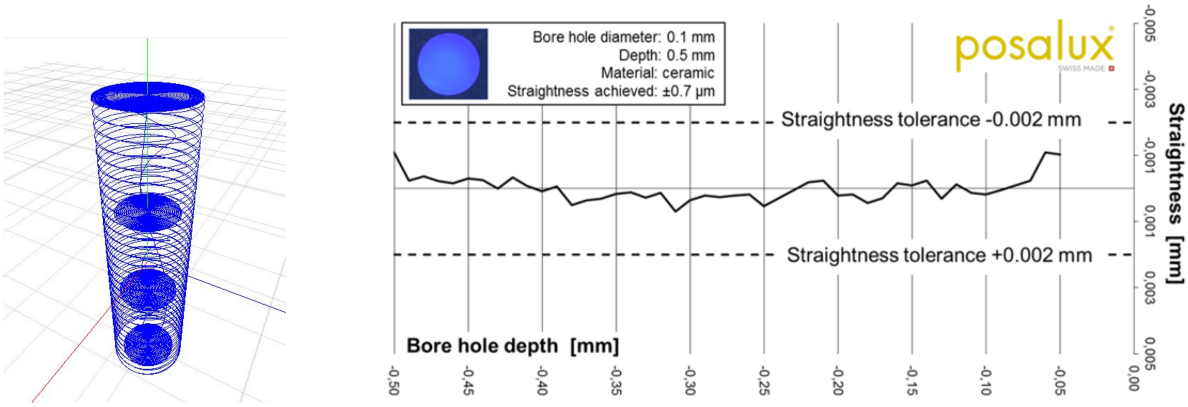

Fig. 5. Visualization of the 3D laser focal motion path in precSYS's software DrillControl (left), Measuring report for a 100-µm-bore hole generated with a precSYS in 500 µm thick ceramic (right) - provided by Posalux SA.

Fig. 6 shows ideally-formed round, elliptical and flexible geometries. The flexible geometry in Fig. 6c was created by overlapping two ellipses (190 µm long, 110 µm wide, 300 µm deep). In addition, the angle of incidence can be set for machining in precession mode (the beam performs a precession movement about the axis of symmetry) or in fixed mode (the beam inclination remains fixed with respect to the optical axis). Based on galvo technology, it's also possible to create lines with varying angles of incidence. In addition to circular, elliptical or line structures in a 2.5-mm diameter image field, text with various fonts and font sizes can be marked in an image field up to 5 mm in diameter (Fig. 6d).

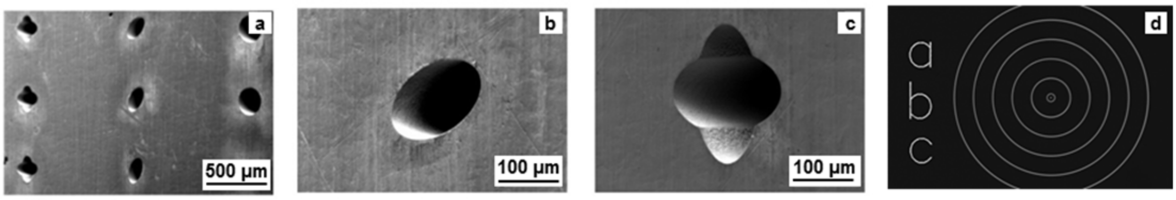

Fig. 6. (a) Flexible geometries in 300-µm-thick steel; Details of figure (a): (b) Elliptical bore hole (190 µm long, 110 µm wide); (c) Geometric flexibility achieved by two overlapping ellipses; (d) Marking pattern for labeling – 0.5 mm font size, font type SimpleStraight3.

Conclusion

We describe a galvanometer-based five-axis precession drill head and present results achieved with this scan head. The system is particularly well suited for USP micro-machining applications thanks to:

- Robust, industry proven water-cooled and gas-purged design
- High dynamic performance by way of small galvanometer movements which reduce processing time
- Flexible geometries: Circle, ellipse, line, superposition of all elements, array of elements in the field of view
- High power and high energy capability
- Novel software DrillControl for user-friendly creation of micro-processing operations with 3D visualization

The system offers an optional alignment feature to ensure repeatable process results even under changing operating conditions.

Unlike classical EDM processes, the laser process is independent of the processed material and the finishing operation is achieved with the same laser tool. It's possible to combine drilling with cutting, marking and micro-structuring of parts using just one machine.

We show results of the drilling process with straightness of ±0.7 µm at a 1:5 aspect ratio. A 200-µm deep hole with a diameter of 100 µm and straight walls can be drilled in under 1 sec. We show implementation of flexible geometries and combining drilling with marking.

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