»ULTRASURFACE«
ULTRA DYNAMIC OPTICAL SYSTEMS
FOR HIGH THROUGHPUT LASER SURFACE PROCESSING
AGENDA

1. Motivation & goal of the ultraSURFACE project
2. Project relevant technologies
3. Concept & approach
4. First results
5. General information about the beneficiary & role in the project
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Motivation

- Surface processing techniques are widely used in industry
- Laser based processes…
  - … offer high flexibility, precision and quality
  - … offer new possibilities for creating complex surfaces
- The throughput of these processes is often not sufficient for an economic, industrial application
- In the same time:
  Laser sources getting more and more affordable
Goal

Overall goal:
Increase the throughput of laser based surface treatment processes by a factor of 10

Project title:
»Ultra Dynamic Optical Systems for High Throughput Laser Surface Processing«
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Laser processes
Laser structuring (LS)

- Achieve small structures in micrometre scale
- With each pulse a tiny amount of material is removed by ablation
- Processing of 3D parts is achieved by sequential processing of tiles
- The low throughput is still limiting this technique to the processing of moulds rather than the processing of the work piece itself / individual parts
Laser processes
Laser polishing (LP)

- Based on remelting a thin surface layer and smoothing the surface due to the surface tension
- Initial roughness of Ra = 1 – 10 µm can be reduced down to Ra = 0.05 – 0.5 µm
- Process has been adapted to 3D parts for a circular shaped beam profile
- In-house developed 3D CAM-NC process chain allows the processing of complex 3D parts using simultaneous processing
- First industrial applications already showed the potential of this new technology while the throughput is still one of the main limitations
Laser processes
Laser thin-film processing (LT)

- Tool for improving the performance of technical components e.g. wear, corrosion protection or electrical conductivity
- Often a 2-step process involving the deposition of the film followed by a heat treatment
- Lasers represent a versatile alternative to conventional heat treatment: processing of thermally sensitive substrates, defined local treatment of a component
- In many fields of application requires long processing times and not adapted for complex 3D components yet
Laser processes
All processes

- A laser scanner is used for a fast \((v>10\, \text{m/s})\) beam deflection in 2D/3D

![Laser scanner and focusing lens](image)

- For almost every application a circular shaped beam profile is used

![Gaussian and Top-Hat profiles](image)
Optical elements
Piezoelectric deformable mirrors (PDM)

- The shape of continuous faceplate is deformed by piezoceramic (PZT) actuators working on transverse piezoeffect
Optical elements
Piezoelectric deformable mirrors (PDM)

- Low cost actuators
- Free edge
- Can be coated with all available coatings (up to 1 kW load)
- Response: 1.5 kHz
- Correction range (8 um per actuator)
- 19 to 109 actuators
- 30 and 50 mm apertures
Optical elements
Diffractive optical element (DOE)

1. Using diffraction and interference phenomena, Holoor designs a special pattern for a desired result.

2. The special pattern is applied over a substrate to create the DOE using a lithography process(es).

3. The DOE is implemented into a system to achieve desired or improved output.
Optical elements
Diffractive optical element (DOE)

- Beam splitting
- Beam shaping
- Beam focal shaping
- Others: sampling, phase corrections
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Concept & approach
Increasing throughput

Throughput:

\[ TP = \left( t_{npt} + \frac{A}{v \cdot dy \cdot n_{Laser}} \right)^{-1} \]

\( t_{npt} \quad \) non-prod. Time \( \downarrow \)
\( A \quad \) Area \( \uparrow \)
\( v \quad \) Velocity \( \uparrow \)
\( dy \quad \) Track offset \( \uparrow \)
\( n_{Laser} \quad \) # Laser \( \uparrow \)

State of the art
Circular or square intensity distributions

Meandering tool path
Concept & approach
Multi-beam, beam-shaping

State of the art
Circular or square intensity distributions
Meandering tool path

Laser structuring
-> Multiple beams for parallel processing
-> Increase \( n_{\text{Laser}} \)

Laser polishing
Compensating heat losses at the edge
Melting
Heat treatment
Drying
Sintering

Laser thin-film proc.

Low intensity
High intensity

-> Process adapted intensity distributions
-> Increase \( v \) and \( dy \)
Concept & approach
Adaptive beam-shaping for 2D/3D processing

State of the art
Perpendicular angle of incidence

NON-perpendicular angle of incidence

Processing conditions change with angle of incidence

Adaption of intensity distribution within 1 ms
Adaptive distortion of intensity distribution by dynamic optics -> f(β)

Constant processing conditions
Concept & approach
Adaptive multi-beam positioning for 2D/3D processing

2D scan field
- Different scan positions
- 4x4 spot array, distortion-free (small scan angle)
- Distorted spot array (large scan angle)

3D surface processing
- Individual spot position control
- Focused laser beams
- 3D work piece
Concept & approach
S.M.A.R.T. objectives

»Ultra Dynamic Optical Systems for High Throughput Laser Surface Processing«

SO1 - Dynamic and flexible beam-shaping optics for laser surface processing
SO2 - Multi-beam optics for parallel laser surface processing
SO3 - Ultrafast synchronisation of optics and machine for 3D processing
SO4 - Validation in industrial scenarios
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Beam-Shaping Optics (SO1) - Concept

- **Analytical model for deformable mirror (PDM) shape**
  - PDM surface shape is calculated based on actuator voltages and integrated into optical design software
  - evaluation of beam-shaping capabilities of state-of-the-art PDMs
  - results for 79 channel piezo-electric DM (⌀ 50 mm):

  - additional (static) beam-shaping element required
Beam-Shaping Optics (SO1) - Concept

- **Adapted concept:**
  - beam is pre-shaped with a rotatable diffractive optical element (DOE)
  - PDM compensates for scanner and 3D-surface related distortions
Beam-Shaping Optics (SO1) - Realization

Software Process control
CAM Data Management

Controller
Galvanometer
Focus shifter
Deformable Mirror
Hollow Shaft Motor

Laser Source
DOE

Laser Source
Fraunhofer ILT

Controller
Galvanometer
Focus shifter
Deformable Mirror
Hollow Shaft Motor

Laser Source
DOE

Fraunhofer ILT
Beam-Shaping Optics (SO1) - Realization

PDM

DOE
Multi-Beam Optics (SO2) - Concept

- DOE (diffractive optical element) splits initial beam into separate beams
- 1st relay lens focuses light into intermediate focus
- 2nd relay lens images DOE into scanner
- Spot position control unit for individual beam positioning
Multi-Beam Optics (SO2) - Spot Position Control Unit

- Independent $x$, $y$, and $z$-positioning of each beam
  - $z$: miniaturized focus shifter for each beam (+/- 3.5 mm)
  - $x + y$: 2 rotatable plane-parallel glass plates per beam (+/- 400 µm)
- Compensation of:
  - Local surface tilt (>10°)
  - Distortion of spot array for large scan angles
Multi-Beam Optics (SO2) - Spot Position Control Unit

- Focus shifters
- Miniaturized servomotor
- Fused silica plates
- Scanner motor

100 mm scale
Multi-Beam Optics (SO2) - Realization

Software Process control
CAM Data Management

Spot control unit

Controller

Laser Source

DOE

ultra SURFACE
Machine Tool (SO3) - Concept

- Mechanical engineering
  - 5 numerical axis
  - granite base
  - measurement probe integrated
- Utilities (electrical, pneumatics, safety, ..)
  - protective atmosphere
  - suitable laser safety housing
Machine Tool (SO3) - Realization
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Contacts & role in the project

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