Laser Assisted Dry Ice Blasting
A Hybrid Machine Tool Concept for Cleaning and Recycling

Effizient und schonend reinigen
Innovative Verfahren zur Reinigung, Entschichtung und Vorbehandlung von Oberflächen

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Institute for Machine Tools and Factory Management
Technical University Berlin

Fraunhofer Institute for Production Systems and
Design Technology

- 1986 IWF and IPK moved into PTZ
- 450 employees (scientists, service and students)
- More than 70 test areas and 7 special laboratories on approx. 7 100 m²
- Budget of 24 Mio. Euro
- Spin-offs and start-ups by 12 % of former staff members

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Berlin
Overview Structure of Presentation

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Introduction

Collaborative research center SFB 281 “Disassembly Factories” for the development of recycling technologies funded by the German Research Foundation DFG

TFB: Components, systems, methods and information technology tools for practical product and material cycles

Development of the hybrid cleaning technology with dry ice blasting and laser (E7)

Motivation:

- Recycling requires a de-coating and a cleaning process as well as a pre-treatment.
- Environmental friendly technologies dry ice blasting and laser
- Removal of highly adhering or hard contaminants, protective or functional coatings
Stand-alone-Technologies

Dry Ice Blasting I

One-way blasting medium: Solid carbon dioxide pellets

\[ T_p = -78.3^\circ C \]
\[ \rho_p = 1100 \text{ kg/m}^3 \]
\[ l_p = 5 - 15 \text{ mm} \]
\[ d_p = 3.0 \text{ mm} \]
Stand-alone-Technologies

Dry Ice Blasting II

Removal Mechanisms:

- Impact
- Thermal Effect
- Sublimation
Stand-alone-Technologies

Dry Ice Blasting III

Dry ice blasting equipment:
Artimpex device “Cryonomic Cab52”, based on the injection principle, blasting nozzle “G 5000” (venturi injector)

- **Blasting pressure:**
  Up to 16 bar
- **Principle:**
  Because of independent adjustable blasting pressure (2) and transport pressure (3) capable of injection principle as well as compressed air blasting
- **Dry ice mass flow:**
  Up to 20 - 105 kg/h
Stand-alone-Technologies

Dry Ice Blasting III

Dry ice blasting equipment:
ICETECH device “ICEBLAST KG 30”, based on the compressed air blasting principle

- Blasting pressure: Up to 16 bar
- Principle: Compressed air blasting
- Dry ice mass flow: Up to 30 - 100 kg/h
- Blasting nozzles: asdf
Stand-alone-Technologies

Dry Ice Blasting IV

Dry ice blasting equipment:
KIPP device for carbon dioxide snow blasting

- Blasting pressure: From 4.5 to 16 bar of compressed air
- Liquid carbon dioxide pressure: High pressure liquid carbon dioxide bottle, 57 bar
- Liquid carbon dioxide mass flow: From 20 up to 45 kg/h
Stand-alone-Technologies

Laser Processing I

**Interaction Laser-Material:**
- Reflection
- Transmission
- Absorption

**Material removal process:**
- Absorption
- Sublimation, ionisation
- Melting
- Isothermal plasma
- Adiabatic expansion

![Graph showing laser wavelengths and materials absorption]

<table>
<thead>
<tr>
<th>Laser Type</th>
<th>Wavelength (µm)</th>
<th>Absorptance A [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excimer Laser</td>
<td>193, 308</td>
<td>248</td>
</tr>
<tr>
<td>Nd : YAG Laser</td>
<td>1.06</td>
<td>16</td>
</tr>
<tr>
<td>CO Laser</td>
<td>~ 5.4</td>
<td>5</td>
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<tr>
<td>CO₂ Laser</td>
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</tbody>
</table>

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Stand-alone-Technologies

Laser Processing II

**Equipment for Laser processing:**
Dilas Diodenlaser device “Dilas Diodenlaser 1500 W”

- Wavelength: 940 nm ± 5 nm
- Laser power: Up to 1500 W
- Laser frequency: In cw-modus* applied
- Pulse duration: In cw-modus* applied
- Diameter of focus: 3,8 mm x 8 mm

*cw-modus: continuous-wave modus
Stand-alone-Technologies

Laser Processing III

Equipment for Laser processing:
Bauer+Mück Nd:YAG solid state laser device “SV10”

- **Wavelength:**
  1064 nm

- **cw-laser power:**
  18 W (TEM-mode), 100 W (multi mode)

- **Laser frequency:**
  0 kHz up to 10 (250) kHz

- **Scanner frequency:**
  0 Hz up to 300 Hz

- **Pulse duration:**
  90 ns

- **Diameter of focus:**
  20 µm (direct), 200 µm (fibre)
Metrology

Standard of comparison and measurement device I

Material removal rate:
• Defined standard of PUR-2 component varnish
• Detection of surface profile transversal to the robot’s movement
• Software based calculation of cross sectional area (CSA)
• Information of material removal transversal to robot’s movement (estimation of necessary overlapping)

Surface quality:
• Measurement of the surface roughness according to DIN EN ISO 4287

Taylor Hobson contact instrument for measurement of surface finish, form and contour “Talysurf-120L”:
• Diameter of the contact device: 2 µm
• Angle of the contact device: 60°
• Error of measurement: < 0,15 µm
• Measuring range: 2 mm
• Measurement length: orthogonal 20 mm, collinear 5 mm
Effizient und schonend reinigen

Laser Assisted Dry Ice Blasting

Metrology

Standard of comparison and measurement device II

Material volume removal rate or cross sectional area (CSA):

- Surface profile transversal to the robot’s movement
- Software based calculation (Talymap Univ.) of cross sectional area (CSA) of removed material
- Calculation of volume removal rate in case of different feed speeds
- Gravimetric analysis in case of too rough surface for calculation of CSA
- Tests with Rusted specimen and thermal sprayed coatings

Maximum depth: 163 µm
CSA: 1,21 mm²
Optimization of Stand-alone-Technologies

Dry Ice Blasting I

Optimization of dry ice blasting pressure and blasting angle
Optimization of Stand-alone-Technologies

Dry Ice Blasting II

Optimization of dry ice mass flow and blasting distance

![Graphs showing optimization of dry ice mass flow and blasting distance.](image)
Optimization of Stand-alone-Technologies

Laser Processing I

Optimization of laser focus and distance of laser pulses on the workpeace
Optimization of Stand-alone-Technologies

Laser Processing II

Optimization of laser frequency and holding time between laser pulses
Hybrid Cleaning Strategy

Increased thermal effect of dry ice blasting, final laser cleaning

- Laser-heating to increase the thermal effect of dry ice blasting:
  - Energy addition by controlled power output of the laser
  - Thermal camera to observe surface temperature, to control increased thermal effect and to avoid thermal stress
  - Possibility of reduced mechanical effect due to increased thermal effect of dry ice blasting

- Final laser cleaning after preliminary purification by dry ice blasting:
  - Preliminary cleaning by dry ice blasting removes most of contaminant or coating
  - Final camera assisted laser cleaning process removes residues of contaminant or coating
  - Possibility of a pre-treatment by laser processing (e.g. roughening of the surface)

- Combination of both strategies:
  - Preliminary cleaning by laser assisted dry ice blasting removes most of contaminant or coating
  - Final laser cleaning process removes residues of contaminant or coating
Hybrid Machine Tool Concept

Laser assisted dry ice blasting, combination of laser assisted dry ice blasting and final laser cleaning process
Results of Hybrid Tests I

Laser assisted Dry Ice Blasting

Improvement of the material removal rate of up to 500% compared with dry ice blasting.
Results of Further Investigations

- Mechanical Effect:
  - -78.5°C: 100%
  - 20°C: 85%
  - 200°C: 66%
  - 500°C: 49%

- Thermal Effect:
  - -78.5°C: 15%
  - 20°C: 34%
  - 200°C: 51%
  - 500°C: 51%

Starting Temperature of Gas Turbine Parts [°C]
Results of Hybrid Tests II

Final Laser Cleaning

Improvement of the cross sectional area (material removal rate) between 28 % and 49 % compared with dry ice blasting.

Problem of comparing the improvements of final laser cleaning and laser assisted dry ice blasting:

- Disadvantage of CSA/mass based comparison:
  Any removed material is weighted equal
- Removing the highly adhering residues of preliminary cleaning by dry ice blasting can’t be compared with the first percentage that can easily be removed
- Due to inhomogeneity highly adhering residues of contaminants or coatings remain only partial, have to be removed selective.

Comparison of DIB vs. hybrid

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Surface Quality

Measurement of the surface roughness according to DIN EN ISO 4287

- Average roughness $R_a$
- Mean total roughness $R_{tm}$ *
- Total roughness $R_t$

* $R_c$ according to DIN EN ISO 4287
Summary

- **Stand-alone technologies**: Dry ice blasting and laser processing are ecological alternatives of conventional cleaning and de-coating methods. Both technologies are not suitable to remove highly adhering, hard or thick contaminants / coatings.

- **Laser assisted dry ice blasting**: Improvement of the removal rate of up to 500% compared with dry ice blasting.

- **Final laser cleaning after preliminary dry ice blasting**: Improvement of the removal rate between 28% and 49% compared with dry ice blasting.

Outlook

- Combination of preliminary laser assisted dry ice blasting and final laser cleaning and optimization of parameters

- Automation: Thermal camera to control the laser power according to the surface temperature and image recognition to identify residues for a selective final laser cleaning process

- Economical evaluation tool to determine the break-even point for specific cleaning / de-coating tasks