Performances comparison of a laser ultrasonic system using 10.6 µm infrared or 532 nm visible generation beam for the investigation of CFRP

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Context and introduction

• **Composite samples**
  – From aerospace industries
  – Fully made of CFRP
  – Generally ~ 1 m² size
  – Complex shapes

• **Develop a medium cost industrial LU system**
  – Flexible lightweight optical head
  – Based on two-wave mixing
  – Compact optical head
  – Interfaced to a 6-axis robot for scanning

• **Analysis of two system with the same detection system**
  – Influence of the generation system
  – Impact on the usability of the whole LU-system
Comparison of two LU systems

• **Detection**
  – PDL laser Tecnar with TWM detection probe
  – flexibility → 10 meter robust flexible conduit
  – Working @ 1.06 µm
  – Interfaced to a 6-axis robot for scanning

• **Generation**
  – CO₂ lasers (10.6 µm)
    • LUIS system @ CTA (Montréal, Canada)
    • More generally used
    • No optical fiber → less flexible (mirror reflection system)

  – Best wavelengths: 3.3 and 4 µm
    • No commercial and cost-effective solution currently available

  – YAG Q-switched lasers (532 nm)
    • CSL system (Liège, Belgium)
    • Ultra 50 from Quantel @ 532 nm
    • 30 Hz repetition
    • 30 mJ at the output power
Two tools compared

- **CSL system**
  - Visible generation: 532 nm
  - All-fibered system

- **LUIS**
  - Infrared generation: 10µm
  - Periscope system
TECNAR probe

Object

Detection Probe

Flexible Conduit

DLF: Detection Laser Fiber
SBF: Signal Beam Fiber
SB: Signal Beam
DBS: Dichroic Beamsplitter
GLF: Generation Laser Fiber
GLB: Generation Laser Beam
M: Mirror
FL: Frontal Lens
• Fully fiber-coupled system
  – Detection by Two-Wave Mixing
    • fiber-coupled system by Tecnar
  – Generation by YAG laser (green)
    • fiber-coupling by CSL
  – Lightweight optical head on robot-arm
CSL system: Complex-shape object

(a) C-Scan Amplitude

Defects seen at different angles

C-Scan Time of Flight

LU2016, Linz (Austria)
• **Same detection system**
  - PDL and TWM by Tecnar

• **Generation by CO$_2$ laser (10 µm)**
  - Laser illumination brought by a complex articulated arm with mirror and protection tube
C-scan: Amplitude

CSL system (532 nm)

LUIS (10 µm)
C-scan: Time of Flight

CSL system (532 nm)

LUIS (10 μm)
Comparison of two LU systems

• **Generation signal**
  – Shape and duration of the pulse
  – How to bring laser pulse to the sample

• **Absorption physic difference**
  – How does it affects the A-scan produced
  – Surface damaging
CO₂ pulse energy ratio between peak and trail is not constant between each pulses

High repeatability of the 532 nm laser pulse

Shape of the pulses are different

Normalized pulse shape (10 µm)  Normalized pulse shape (532 nm)

Time (µs)  Time (ns)

No fiber  10m
Bring laser pulse to the sample

- **10 μm: periscopic system**
  - Less flexible
  - More restriction on the movement of the robot arm
  - Safety restriction due to high power invisible light

- **532 nm: optical fiber**
  - Highly flexible
  - Few restriction on the movement of the robot arm
  - Effect of the fiber on the generation pulse
Effect of the optical fiber

- **CFRP coupon**
  - Attached on the optical head
  - Position of best detection
  - Move the optical head all along the workbench (1.8 x 1.2 m²)
Effect of generation fiber curvature
A-scan comparison

- Flat CFRP plate

CSL system (532 nm, 30 mJ)  LUIS (10 µm)
A-scan comparison

- Flat CFRP plate

CSL system (532 nm, 30 mJ)  LUIS (10 µm)
Visible generation: surface damaging
Visible generation: surface damaging

Sane surface  Decolorized surface  Heavily decolorized surface
Visible generation: surface damaging

Sane surface
Decolorized surface
Heavily decolorized surface
Visible generation: surface damaging

- **Observations**
  - Impact seems to remove resin first
  - Damage fibers afterward
  - Multiple scan of the same surface increases the damage observed

- **Vary from samples to samples**
  - All CFRPs are not equals
    - Some sample present no damaging and not decolorization at all
    - Others present decolorization at very low pulse energy
  - Resin recipes are not provided (!)

- **Not the visible laser only**
  - 1064 nm probe can also damage surfaces
Conclusion

• Preliminary study
  – No clear conclusions can be made yet

• Noticeable differences
  – Pulse shape and duration
  – Fiber effect on the visible generation
  – Echoes visibility in the A-scans

• First observation
  – Visible generation is competitive with CO$_2$ generation
  – Decolorization of the sample is the main drawback