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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Introduction

The investigation of complex shaped carbon fiber parts is a common need of the industry. Classical ultrasonic systems are commonly used, wide-spread and very efficient. However, these techniques are often limited to simple shape objects. Major problems arise when the shape of the element to be investigated is complex (peak, valley, small radius of curvature…). To overcome these problems laser ultrasonic systems can be used and the recent developments show promising results.

Laser ultrasonic systems can use different wavelengths for ultrasound generation. Usually CO_2 lasers emitting at 10.6 µm wavelength are used. When a laser ultrasonic system is mounted on a robotic arm, very complex shaped objects can be considered. However, the optical fibers for 10.6 µm wavelength are not capable to cope with laser ultrasonic system requirements. Therefore, infrared systems use jointed articulated beam delivery systems which reduce the flexibility of the robot arm and significantly limit the feasible scan paths.

To circumvent this limitation, an all-fibered laser ultrasonic system can be used. In our case the ultrasound is generated with a pulsed laser operating at 532 nm. This system is placed on a robotic arm. The beam delivery is performed through optical fiber only. Therefore, this system is more adapted for analyzing very complex shaped objects. But visible generation is generally assumed to be less efficient and produces lower quality signals.

In order to balance the advantages and limitations of both of these systems a CFRP plate including artificial defects has been investigated. We compare the performances of visible and infrared generation systems:

- A 10.6-µm laser ultrasonic system, called LUIS, available at Centre Technologique Aérospatial (CTA) at Montreal, Canada (shown at Figure 1).
- And an all-fibered laser ultrasonic system working at 532 nm wavelength operated by Centre Spatial de Liège (CSL) in Belgium (shown at Figure 2).

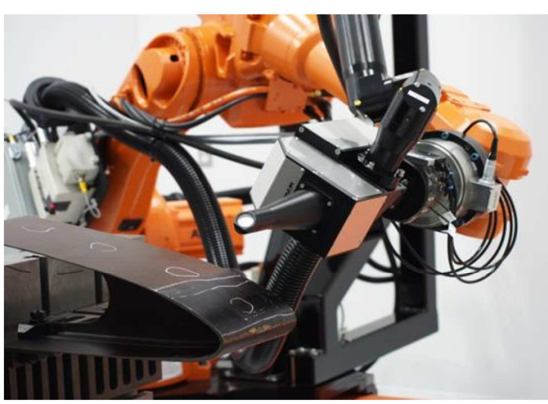


Figure 1. LUIS

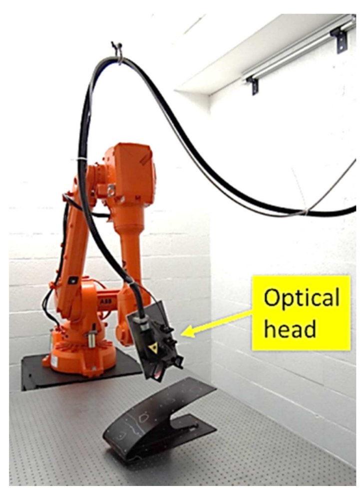


Figure 2. CSL system.

First observations

To perform A-scan acquisition, both systems use a Tecnar pulsed generation laser (PDL) laser coupled with a two-wave mixing (TWM) detection probe. Therefore, only the generation signal differs.

The first differences can already be observed before any measurement. First, the LUIS uses a tube and mirror beam delivery system because of the lack of efficient optical fibers at 10 µm prevents. This induces some constrains on the flexibility of the movement of the robotic arm. For this reason, scanning of complex shaped object is more limited with the LUIS than the CSL all-fibered system.

On the other hand, visible generation is more flexible, but the displacement of the fiber during a scan can have some impact on the measurement. To study the impact of the fiber, we have fixed a plate to the laser ultrasound probe, as shown in Figure 3. The robot arm is then moved while observing the same spot on the plate. (The trajectory of the probe is shown at Figure 4.a, and an example of an A-scan is show at Figure 4.b). All the A-scan recorded during robot displacement are assembled to produce a B-scan of the trajectory (Figure 4.c), where we can observe strong variations, especially on the bang (top of the figure). We can also see in Figure 4.d the variation of the amplitude of the first echo along the trajectory.

Figure 3. Investigation of the impact of the optical fiber on the A-scan generation with a CFRP plate fixed to the robot arm.

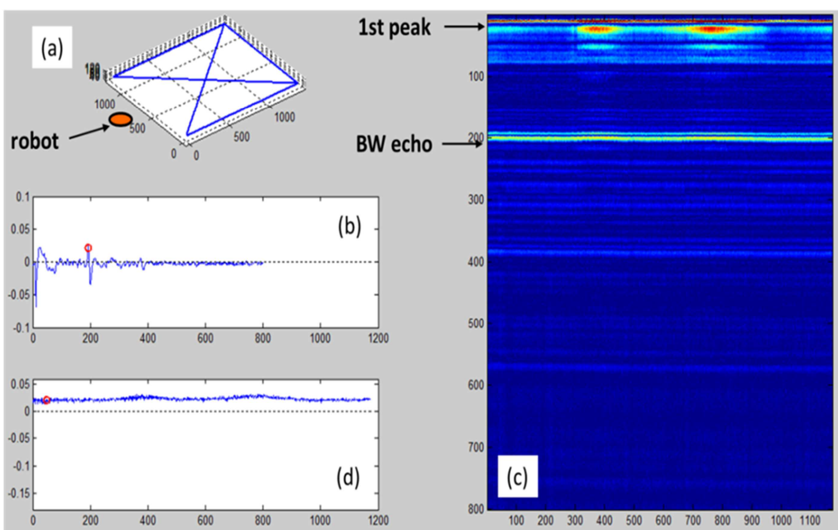
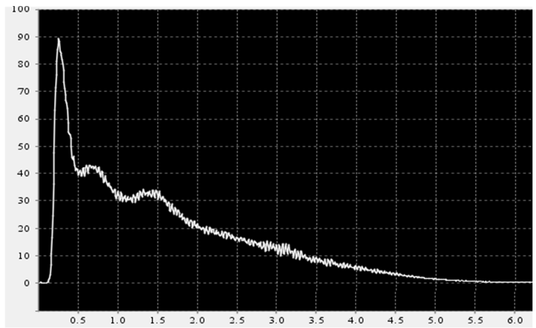
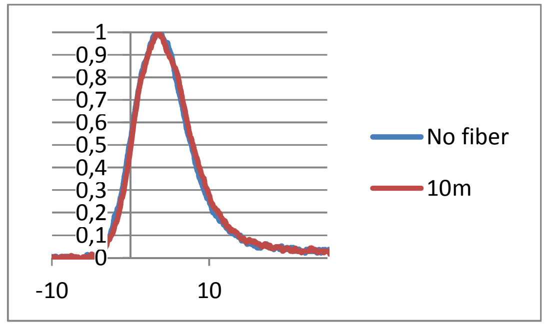


Figure 4. Investigation of the impact of the optical fiber: (a) 3D trajectory of the laser ultrasonic probe, (b) example of an A-scan, (c) B-scan along the robot trajectory, and (d) amplitude of the first echo along the trajectory.

We have also observed the pulses shape and have seen differences. In the visible system, the laser can generate highly repeatable pulse. This way, we obtain homogenous generation signal, whereas the LUIS pulse shape changes from pulse to pulse. More specifically, the intensity ratio between the peak and the tail of the pulse changes from pulse to pulse. Because the ultrasounds are only generated by the peak, the A-scans vary from pulse to pulse with this system.



(a)

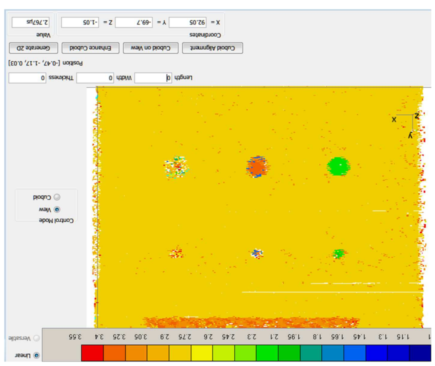


(b)

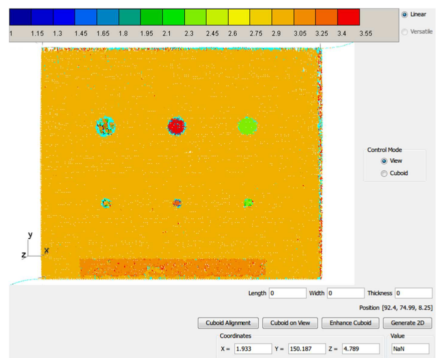
Figure 5. Comparison of the shape of the pulse of (a) the LUIS, and (b) CSL system (arbitrary scale).

Comparison of the scans

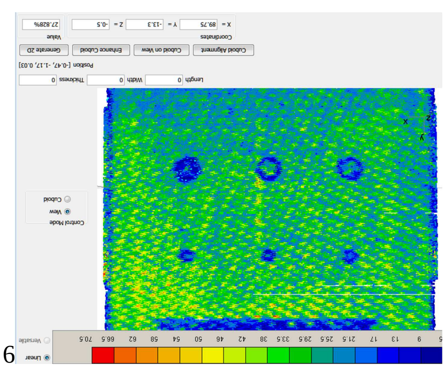
The CFRP plate has been scanned by both systems and the results are shown at Figure 6. We can observe similar C-scan for both time of flight (ToF) and amplitude scans. In these measurements, no filtering or signal correction have been applied.



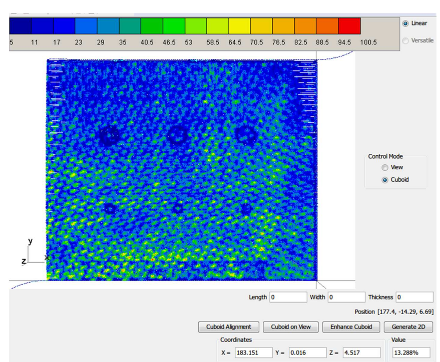
(a) ToF CSL system



(b) ToF LUIS



(c) Amplitude CSL system

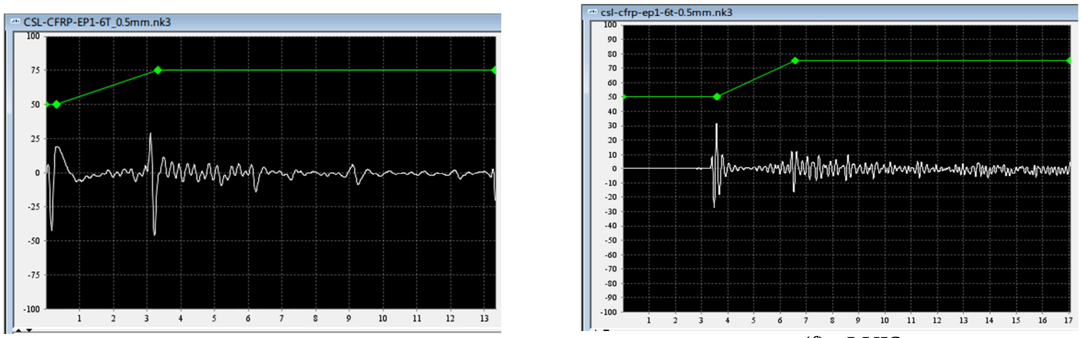


(d) Amplitude LUIS

Figure 6. Comparison of the C-scans obtained by both systems.
(CSL system scans have been rotated for easing the comparisons.)

Both ToF C-scan show similar results (Figure 6.a and Figure 6.b), it is not clear that any system better than the other. However, some differences can be observed in amplitude C-scans (Figure 6.c and Figure 6.d). The overall amplitude seems higher in the CSL system. But it is difficult to make meaningful conclusion at the C-scan level.

We need to go at the A-scan level for a more in-depth comparison. A-scans representative of the surface of the plate with both systems are shown at Figure 7.



(e) CSL system (f) LUIS

Figure 7. Comparison of the A-scan obtained by both systems. (The green line is the time gain compensation).

We can observe that the CSL system has a better signal to noise ratio, and that a higher number of echoes can be observed. One could conclude form this observation that visible generation provides better A-scans. However, in our set-up, the color of CFRP plate has changed during the measurement. It is not currently clear if this is due to chemical properties variations, or permanent damaging of the surface, but the latter is suspected. Indeed, microscope investigation of decolorized area of the plate shows that the resin at the surface of the sample has disappeared in some region (see Figure 8). Also, we have observed that multiple scans of the same surface increases the number of region where the resin is removed.

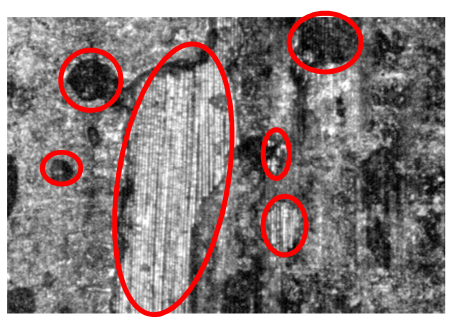


Figure 8. Microscope image of the surface of a decolorized CFRP sample plate.

No such phenomenon has not been observed with the LUIS. We think that LUIS generation beam power could therefore probably be increased without any problem whereas visible laser power should be reduced to avoid damaging. By decreasing visible generation, and increasing infrared generation, the A-scans could potentially improve for LUIS compared to the CSL system. For this reason, we cannot conclude and further investigations will be performed in the future on this topic.

Conclusion

In this article, we have compared two laser ultrasound system, one with infrared generation, and the second with visible generation. We have been able to show that the visible system is much better on the point of view of flexibility. Repeatability is also better for the visible system, even though some variation have been observed for large displacement of the robot, due to fiber movements. We have performed laser ultrasounds on the same CFRP sample plate, and we have shown the main differences on the C-scans and A-scans generated by each system. From these scans, we have seen that visible generation seems better at first sight. However, more in-depth investigations show that the generation beam intensity has not been compared in similar conditions. Even through visible generation of the CSL system shows better amplitude and better signal to noise ratio of the A-scan than the LUIS, the surface of the sample has been damaged. To avoid damaging, generation laser beam intensity need to be reduced. Therefore, no conclusion can be made currently. Further investigations need to be carried on, and we are not currently able to conclude on the performance of both techniques.