Ad-hoc solutions for ultrasonic inspection of highly complex aircraft composite structures

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Abstract

Nowadays, the ultrasonic inspection (UT) is the most common non destructive technique (NDT) for composite components in the aerospace industry, due to its high accuracy, reliability and the degree of industrialization. Although UT is widely developed, new manufacturing processes and part concepts are continuously pushing the technology for new improvements and applications. This is the case of the geometries resulting from novel out of autoclave composites manufacturing technologies, Liquid Resin Infusion (LRI) or Resin Transfer Moulding (RTM), allow the fabrication of parts in one shoot, with focus in bringing answers to the challenge of manufacturing fully assembled parts and avoiding secondary assembly phases but also limiting the accessibility for NDT inspections.

In this sense, one of the critical issues in the aeronautic sector is the improvement of the inspection of geometries with difficult access and small dimensions. The requirement of the aeronautic industry of guaranteeing the quality of the primary composite structures implies the inspection of the whole component through certified technologies. This constraint, together with the lack of technological solutions for the inspection of regions with limited accessibility is blocking the industrial implementation of optimized manufacturing processes.

The present work describes the design and development of adaptive hardware solutions for the single and phased array UT inspection of internal structures on a highly integrated composite aeronautic component. The final solution has been obtained as result of an iterative design process and manufactured through additive manufacturing technology (Powder Bed Laser Fusion, formerly Selective Laser Sintering) using polyamide. This device was validated in a for inspection of flat surfaces of stiffener internal structure, belonging to the composite flap demonstrators of lengths: 3 meters in a first approach, and 8 m for final validation. This novel inspection solution has been performed in the framework of the FLAP project to develop and innovate the manufacturing process for complex mobile surfaces in a collaboration between Aernnova, through its Composites Division, and CATEC teams.

KEYWORDS: Composites; Non Destructive Technique; ultrasonic inspection.
1. Introduction

Currently, the autoclave process is the most standard technology for composites manufacturing at industrial level and widely used in the aerospace industry. It ensures production quality through thermal and pressure cycles for outgassing volatiles during composites curing process. But autoclaves present also certain constraints. The costs of an autoclave may vary from €200,000 for a small one (order of 1 m), up to several millions for a large autoclave. The operational costs (including maintenance) are significant and may exceed the costs of the autoclave itself during its life cycle [1]. In addition, the processing of composites in autoclave has a limitation determined by the inner useful volume of the equipment that potentially creates bottlenecks in serial manufacturing. This is an inconvenient, considering the current aeronautical industry trend is demanding larger structural components integrated in a single piece avoiding joining assembly processes and flexible production rates.

These constraints have prompted manufacturers to develop out-of-autoclave (OOA) manufacturing technologies, for which resins can be cured in oven, heated tooling or at room temperature.

Open and close moulds infusion processes are the main OOA manufacturing technologies used in aerospace industry. A specific close mould technology is the resin transfer moulding (RTM), in which dry fibers (preforms) are placed in the mould and the resin is injected under controlled pressure and temperatures conditions [2]. Production of preforms and resins used in RTM are generally less expensive than autoclaved prepregs and can be manipulated out of a clean room. RTM process also makes possible to obtain parts with complex shapes, very good superficial quality and dimensional accuracy, eliminating steps of post-processing [3].

The current state of the art for RTM has already reached the aeronautic quality levels of autoclave curing systems, with a level of porosity below 1% and proper dimensional accuracy. However, the high integration and hybridization of structures and materials that RTM allows from a manufacturing perspective, may be in conflict with the quality validation step. Currently, the most common non destructive technique for composites evaluation (inner and outer structures) is ultrasonic (UT). UT requires of a probe for introducing the ultrasonic wave within the material. The probe is usually carried by the inspector’s hand or by industrial robotic arms. This aspect is an inconvenient when considering inaccessible structures. In this way, the object of present work is the design and development of adaptive hardware solutions for the single and phased array UT inspection of internal structures on a highly integrated composite aeronautic component [4-5].

The final solution has been obtained as result of an iterative design process and manufactured through additive manufacturing technology (Powder Bed Laser Fusion, formerly Selective Laser Sintering - SLS) using polyamide. The SLS technique allows fast and flexible manufacturing of varied geometries and minimizing costs and waste compared to conventional manufacturing processes, making it possible to generate different tools ad-hoc for each part to be inspected [6-7].

In this study, the developed system was validated for inspection of flat surfaces of stiffeners internal structure, belonging to the composite full scale flap demonstrator. The current certification process requires the inspection of inner parts to validate the full structure.
2. Materials, equipment and methods

An ultrasonic system (Olympus OMNISCAN MX) has been used for the non-destructive inspection in the internal stiffeners of the component. The selected ultrasonic probes were: (i) a single element (V201-RM; 5 MHz) and (ii) a phased array probe (5L64-NWI1 / SNW1-0L-IHC-C) [8], joint to the mini-wheel linear encoder and a 15-meter-long cable BNC microdot. The inspection was carried out in water immersion (water column of 2 mm), with a main gain of 3.00 dB and a wedged delay of 10.37 µs.

Standard CFRP specimens as well as SLS polyamide partial demonstrator sections were both used for the verification tests. The defined patterns included known defects: flat-bottomed holes of different size (Ø12 and 6 mm) and position/depth in thickness (0.4 mm from outer/inner surface and half thickness), as indicated Figure 1a. This approach allowed verifying the correct functioning of the inspection system configuration. Additionally, a CFRP full scale flap was manufactured through one-shot RTM process. The 3 meters long demonstrator structure (corresponding to the 8 meters long flap tip end) was used for validation tests (Figure 1b).

The positioning prototype system was manufactured by SLS (3D Systems HiQ Sinterestation - Polyamide powder DuraForm® PA). Due to the complex geometry of the targeted part, the length and the difficult access of the stiffeners surface, it was necessary to customize the tooling with an iterative process, which ensured the correct position of ultrasonic probe and its displacement along the inside of the structure. The positioning tooling is based on the use of a system of magnets that allow its adjustment and fixation to the surfaces to be inspected, as well as its movement along the length of the component following the inspection line defined in each case (Figure 2).
To accomplish with the certification process, a series of lines with an overlap of 3 mm have been defined for the inspection of each one of the stiffeners. These lines adapt according to geometric variations along the length of the flap and each ending at a different length (Figure 3).

Firstly, functionality tests were carried out on partial sections and standard specimens, and later in the partial demonstrator component (3m length). With that iterative approach, the design was corrected and fine-tuned to carry the UT probe along the 8 meter-length final demonstrator flap without relevant inconvenience.

3. Results and discussions

3.1 Functionality tests on partial sections
Verification tests on CFRP standard samples were performed. The set of flat bottom drills on these partial sections of flap were all identified during the ultrasonic inspection by using the probe positioning system (Figure 4). The inspection lines of the complete set of positioning systems developed were verified to allow the complete inspection of the internal surface stiffeners.

3.2 Validation tests on 3m length demonstrator flap.
Inspections of the 3 m length flap demonstrator was performed in order to validate the developed positioning system. Figure 5a shows an example of the most relevant results obtained during these inspections of one of the internal stiffeners. No relevant indications were identified. However, it can be appreciated the presence of intermediate echoes in
one of the stiffeners due to wrinkles produced during the flap manufacturing by RTM which are visible on the open lateral section (Figure 5b).

Figure 5. Results from UT inspection: (a) C-scan (Gate B) and detailed A-scan at start/end of inspected line; (b) A-scan indications corresponding to manufacturing wrinkles and detail of section stiffener.

In addition, respect to the positioning tool function, a separation effect between the probe and the inspected surface was observed in the C-Scan in certain sections, especially at the end of each of inspection lines, corresponding to an attenuation and finally loss of ultrasonic signal (Figure 5a), but also during the movement of the system along the length of the flap (Figure 6).

Figure 6. C-scan (Gate A) indications corresponding to the displacement of the ultrasonic signal.

During the functional test, several improvements were identified that can be summarized as follow (including the correction action):
- Lose of proper positioning during the displacement of the tooling along the inspection line. This was solved by placing stronger magnets, for which it was needed the redesign of the magnets cavities. In addition, redesign of the tooling parts was carried out in order to correct dimensional deviations.
- Lack of adaptation of the tooling respect to the angle variation of the stiffeners from root to tip (∼1-3°). This issue was solved by providing the tooling a degree of flexibility to adapt the position to this variation (Figure 7a and b).
- Large inspection times when wider stiffeners webs need to be inspected. The implemented solution was including a positioning system for the use of the Phased Array (PA) probe (Figure 7c).
4. Conclusions

A complete solution for inspection of inaccessible areas in composite parts by means of ultrasonic testing has been designed and developed. The system was first validated through tests on partial sections and reference samples with known defects. Then, functional validation tests were performed in a 3-meters-length section of the targeted flap component, in relevant operational environment. The developed inspection system is therefore adaptable to complex and large geometries. Finally, and after a redesign phase, the complete set of elements of the positioning system was successfully implemented for the inspection of a real flap structure with 8 meters in length and under serial production quality standards. The time required for the complete inspection of the internal stiffeners of the 3-meter demonstrator was approximately 2 hours. This highlights the improvement that a future automation of the developed system would entail, reducing time and costs of the inspection process of this type of structures.

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