APPLICATIONS OF ULTRASONICS IN THE AERONAUTIC INDUSTRY

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Abstract

All vital structures from aeronautic products have to be tested for structural integrity along their whole life. Ultrasonic testing is one of the mostly used methods in production and maintenance; indeed it is widely used on metallic structures and it fits uniquely the needs for the always more numerous composite structures. Although ultrasonic testing has been used for decades in the aeronautic industry, the methods and tools are constantly evolving as they are to be adapted to new materials, processes or part geometry.
Modelling is an important development axis as it shall enable to reduce the time for developing procedures and provide with quantitative information on the effective sensitivity. However, further efforts have to be made in the field of composite material, to take into account anisotropy and heterogeneity. For production or maintenance, methods without contact, or offering higher flexibility or geometry adaptation, are also much needed.

Introduction

Ultrasonic is one of the major testing methods currently applied in the aeronautic industry. Indeed, it is the most adequate method for quality assessment of composite structures and as so is used for all structural parts made of composite. This represents yearly the testing of hundreds of hectares.

Beside are ultrasonics widely used in maintenance testing as well, as they enable the detection and quantification of various defects such as disbond or delamination in composite materials, and crack or corrosion in metallic ones.

Nevertheless new aircraft programmes call for improved structures and require new developments in ultrasonic methods and tools.

Overview of development trends

Developments

Current developments in the aeronautic industry are characterised by the reduction of manufacturing and exploitation costs.

Reduction of manufacturing costs is achieved through the introduction of new assembly processes, such as laser welding for metallic or resin transfer moulding for composite, as well as by reducing the number of components necessary for the realisation of a given structure.

Reduction of exploitation costs calls for lighter structures or increased maintenance intervals.

These two trends lead to a more important use of laminate materials, eventually mixing metallic and composite sheets, to the testing of more complex geometries or to the necessity to implement NDT methods adapted to new processes.

Consequences for NDT

The consequences can be split in:

- necessity to develop methods for new processes, mainly welding, where relatively small defects have to be found
- need to test more complex parts
- adaptation to new laminates, with more contrasted impedances, and materials with higher frequency filtering
- necessity to adapt the methods to an even more complex maintenance environment.

More generally, the number of parts to be tested tends also to increase, which implies less availability of production systems and more time devoted to the analysis.

The answer is prepared through R&D actions, mainly focused on methods, or hardware, and tools, or software and information systems.

Implementation of advanced ultrasonic methods

The main developments and applications currently discussed to tackle with production and maintenance constraints are:

- improvement of scanning speed
- tolerance to geometry
- reduction of coupling constraints
- enhancement of information quality
- embedded NDT systems for maintenance.

Phased array ultrasonics

Phased array ultrasonics, and more generally multi-channel ultrasonics, are one major axis to address some of these items. They are currently being transferred into production, and should be soon used in maintenance two. Electronic scanning and focusing are explored in order to achieve more tolerant systems.

Gains in scanning speed up to a factor of 10 have been demonstrated in simple areas and possibilities are open to test complex slopes and radius. In the carbon/epoxy part presented below, which exhibits most of the constraints, it has been possible, using separate emission and reception laws, to inspect important slopes with only a loss of 2 dB of the signal.

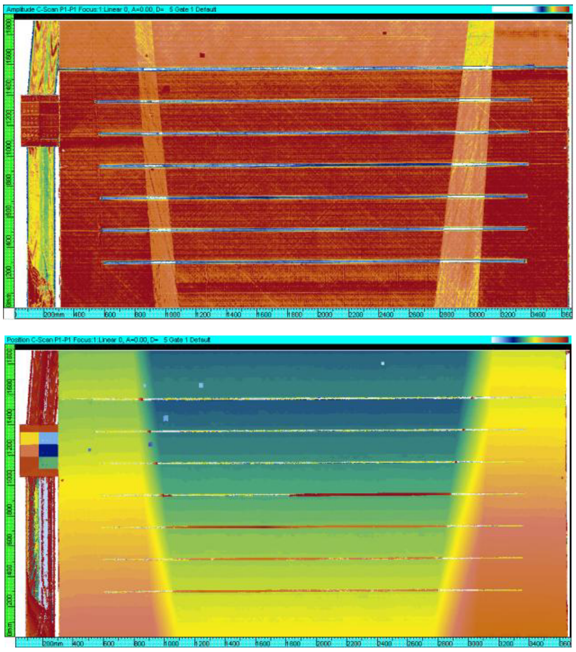

Figure 1: amplitude and time of flight of a composite part with important slopes

In a similar way, solutions are being investigated to test internal and external radius automatically. Such a regular profile is a case where a very high benefit can be derived from applying phased array technology. The use of mechanical or electronical focusing is evaluated. Preliminary results are presented below; they prove the possibility to inspect an angle of 90°. However, the tolerance to radius geometry has still to be improved.

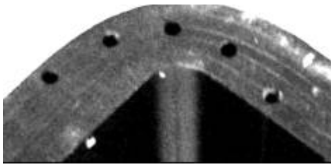

Figure 2: through holes in a radius to be tested externally

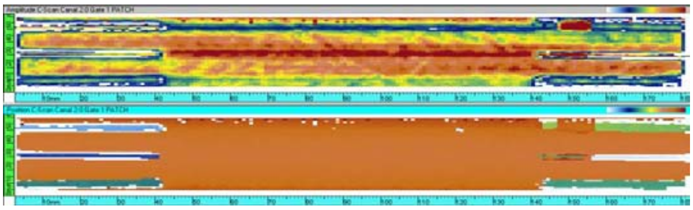

Figure 3: time of flight and amplitude of the radius

Another interesting feature of phased array is the possibility to apply them in production or maintenance with a very simple scanning system, one axis being sufficient, and to record a very rich information, enabling the same reliability in the diagnosis as a complete 2D scanning.

Non contact ultrasonics

Laser ultrasonics and air coupled ultrasonics are two methods being investigated for new programmes. Both of them present the advantage to suppress coupling constraints. Air coupled ultrasonics are envisaged as an alternative to current water jet installations on sandwich structures. Implementation in production has already been realised on parts which wouldn't withstand water.

In addition to these features, laser ultrasonics present a quasi complete tolerance to geometry and their use in production could greatly simplify the robotic part of testing systems.

Embedded NDT systems for maintenance

In order to reduce maintenance costs, new approaches are envisaged as an alternative to conventional NDT approach in complex situations, such as complex access or a need for longer maintenance intervals. A dedicated system could be embedded in the structure at the production stage and could inform later on of the arrival of a defect, or even give information to enable the sizing of the defect. This approach is generally referred to as structural health monitoring. Current investigations are focused on the development of sensors and the evaluation of their suitability. As the systems are intended to be embedded in the structure, more complex aspects will have to be considered: integration, general behaviour in aircraft environment, certification aspects, etc.

Implementation of advanced tools

Physical implementation of the testing is not the only difficulty met today. One major point, not mentioned yet, is linked to the development phase of a new product. It is very hard to participate actively to early development with design or stress offices as almost no tools are available to evaluate the testing of a new part at an early design stage, let us say CAD definition.

A second major axis of improvement concern all diagnosis aspects, as the time dedicated to diagnosis and its complexity are still increasing.

Modelling tools

The development of a new aircraft tends to be shorter. Available NDT tools are mostly based on experimentation and possible problems are highlighted by the end of the development, long after the design and stress parameters (defect size) have been defined., resulting often in complex inspection procedures.

The availability of modelling tools, enabling to calculate the ultrasonic response from a part, taking into account material and geometry aspects, shall bring NDT people more reactivity in the discussion of new structures. It shall in the following phase reduce drastically the time necessary to develop and validate new procedures. It can bring in the last phase inputs to refine a complex diagnosis.

Analytic modelling tools enable to deal with most of the configurations met on metallic structures. Yet they are not applied to the processing of representative composite structures. Indeed, anisotropy, heterogeneity and geometry are three parameters adding to the difficulty of the modelling.

Preliminary investigations were made on the slope case mentioned earlier. The material has been homogenised and the anisotropy was taken into account. It showed that the part anisotropy tends to bend the ultrasonic field in a favourable way, which would explain the small amplitude loss observed in the area. However, more investigations are required before validating the behaviour.

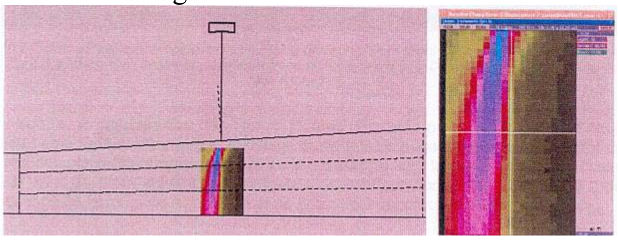

Figure 4: ultrasonic field bended by the material anisotropy

Some very specific evaluations could however be conducted on composite materials. In the last years, the thickness of composite structures has been increased by a factor 2 to 4, and the thickness of individual plies went up from 125 µm up to 250 µm and even 300 µm. This led to combined phenomena which changed widely the ultrasonic signal. The possibility to use modelling enabled to deal with the parameters separately and thus to improve the understanding. Investigations are running to understand in a similar way the influence of porosity.

In aeronautic, it is also necessary to quantify the size of the defects that can be detected with confidence which results in the so-called Probability of Detection. The experimental approach is tedious and costly. A combined approach based on modelling and experimental data could be envisaged. Developments are beginning on this axis.

Diagnosis aspects

Developments concern two main aspects in diagnosis. First of all, complex situations appear where classical amplitude and time of flight analysis don't provide with a adequate information on part quality. Typical information expected from NDT would be in such a case the welding of thermoplastic structures or the through-depth repartition of pores in a composite material. In order to perform such an analysis, it is necessary to look for more information in the A-scan signal. Modelling is again a tool in this phase in order to uncouple the various phenomena that may be present.

Another important point concern the diagnosis phase, in production and maintenance operations. As already mentioned, the surface of parts that are being tested and thus analysed is tremendous. It is necessary to develop tools in order to facilitate the diagnosis to the operator. Such tools typically combine new presentations of the available information (B-scan in some cases or representation of fused data) with expert rules used to pre-process the ultrasonic signal. These tools play an important role as they enable the operator to concentrate on possible defects.

Conclusion

Ultrasonic inspection is a major testing technique in the aeronautic industry. Its use tends to increase as most of the new assembly processes require quality assessment based on NDT methods, where ultrasonic often offers good performances.

Most of the new structures and assembly processes require adaptation of the methods and development of refined diagnosis. Beside the implementation of powerful methods such as phased array, it is necessary today to progress in the field of modelling. Indeed, modelling tools offer a way to understand ultrasonic propagation in complex material and geometries. It appears primordial to tackle with advanced tools for the modelling of ultrasonic interaction in composite materials.