CFRP Structural Health Monitoring by Ultrasonic Phased Array Technique

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ABSTRACT

The report deals with ultrasonic phased array (PA) application for high-loaded CFRP structural health monitoring in aviation. Principles of phased array technique and most dangerous types of damages are briefly described. High-performance inspection technology suitable for periodic plane structure check is suggested. The results of numerical estimation of detection probability for impact damages and delaminations by PA technique are presented. The experience of PA implementation for designing and efficiency estimation of integrated CFRP structural health monitoring system based on FBGA for impact damage detection is described.

KEYWORDS : *fiber reinforced plastics (FRP), carbon fiber reinforced plastics (CFRP), non-destructive testing, ultrasonic testing, phased array.*

INTRODUCTION

Fiber reinforced plastics (FRP) [1-5] application and adoption of the new production processes [6-8] have become one of the major directions of material authority development. Every year FRPs find still more use in jets, helicopters, space vehicles and many others structures, replacing thus metal analogues. These materials possess specific features. The main of them is high anisotropy of the properties which allows producing structures with optimum characteristics. FRPs are most effectively used for high-loaded jet parts such as caissons of keel fin and wings, and power compartments of fuselage.

Monitoring these parts to detect dangerous defects is necessary in service because of high loads. Defects are developing and growing under loads and impact of climatic factors. It can lead to parts destruction. The most dangerous defects are impact damages. Such defects can be difficult to detect visually. At the same time the impact damages decrease ability of structure to resist compressive loads considerably and can grow in service. Delaminations and cracks (in particular, laminations of stiffening components and panels) are also typical service defects which the leading world aircraft building companies have faced at present.

Nondestructive testing (NDT) methods are applied for FRP defects detection in production and service without destruction. Acoustic, X-ray, thermography and some other methods are used for FRP testing. Acoustic techniques are most widely applied.

NDT became the most progressive developing area of the applied science due to rapid developing physics and technology. Ultrasonic phased array technique has appeared from radiolocation and medicine as a new branch in NDT. Originally this technique was applied for metal parts and structures testing only. However later it began to find wide application for FRP testing. Also rapid developing progressive numerical estimation methods of defects detection probability vs their size for different areas of NDT application must be taken into account.

Ultrasonic phased array technique is the improvement of pulse-echo technique where a multielement probe with the computer controlled excitation (amplitude and delay) of individual elements is used as a transducer. During transmission, the acquisition instrument sends a trigger signal to the phased array instrument. The latter converts the signal into a high-voltage pulse with a preprogrammed width and time delay defined in the focal laws. Each element receives one pulse only. This creates a beam with a specific angle and focused at a specific depth. The beam hits the defect and bounces back. The signals received are time-shifted according to the receiving focal law. Then they are reunited to form a single ultrasonic pulse that is sent to the acquisition instrument. The delay value on each element depends on the aperture of the phased array probe active element, type of wave, refracted angle, and focal depth [9].
The main advantages of NDT by phased array are as follows:

- high productivity in combination with high resolution (in comparison with traditional NDT methods);
- beam focusing in any point of a testing object;
- possibility of testing complex shaped parts and structures;
- testing with different angles of probes by using one multielement probe;
- high reliability of testing results data;
- mobility and relatively low cost efficiency of the equipment (in comparison with automated equipment).

1 FRP SPECIMENS TESTING FOR TYPICAL SERVICE DEFECTS DETECTION

FSUE “VIAM” carries out the researches which deal with NDT of main aviation FRP parts and structures (mainly CFRP) by phased array technique [10-12].
Special CFRP specimens which imitate fragments of high-loaded FRP structures were produced for the researches. One specimen is a CFRP flat panel with the dimensions of 230×460×9.5 mm (Fig.1a), another one is a flat panel with 3 stringers with the dimensions of 480×480×50 mm, and a monolithic panel and a stringer with the thickness of 7 mm (Fig.1b).

a) b)

Figure 1: CFRP specimens for testing

Two of the most dangerous types of service defects namely impact damages and delaminations were generated in both specimens (Fig.2).

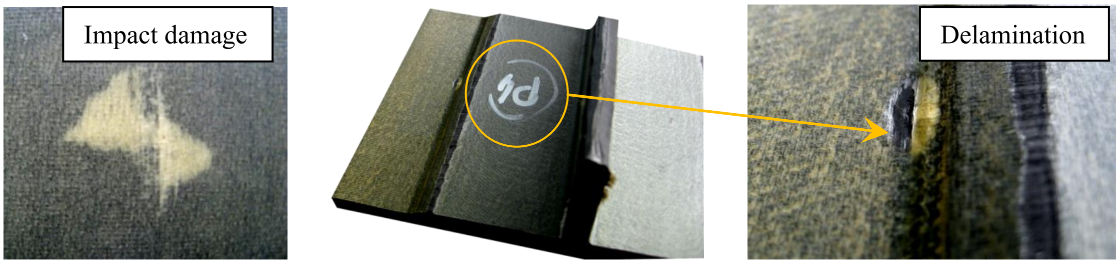

Figure 2: Imitation of FRP defects in service

The ultrasonic flow detector of Omniscan MX (Olympus NDT), the linear phased array of Olympus NDT 5L-64-NW1 with 5 MHz operation frequency, the encoder and 2D Glider were used in the research.
Ultrasonic flow detector setting was made with sensitivity equivalent to ensure the detection of a 5 mm diameter flat bottom hole, and by using time corrected gain. Electronic scanning was made by the group of 8 active elements of linear phased array with 64 elements. Test results are illustrated in Fig.3.

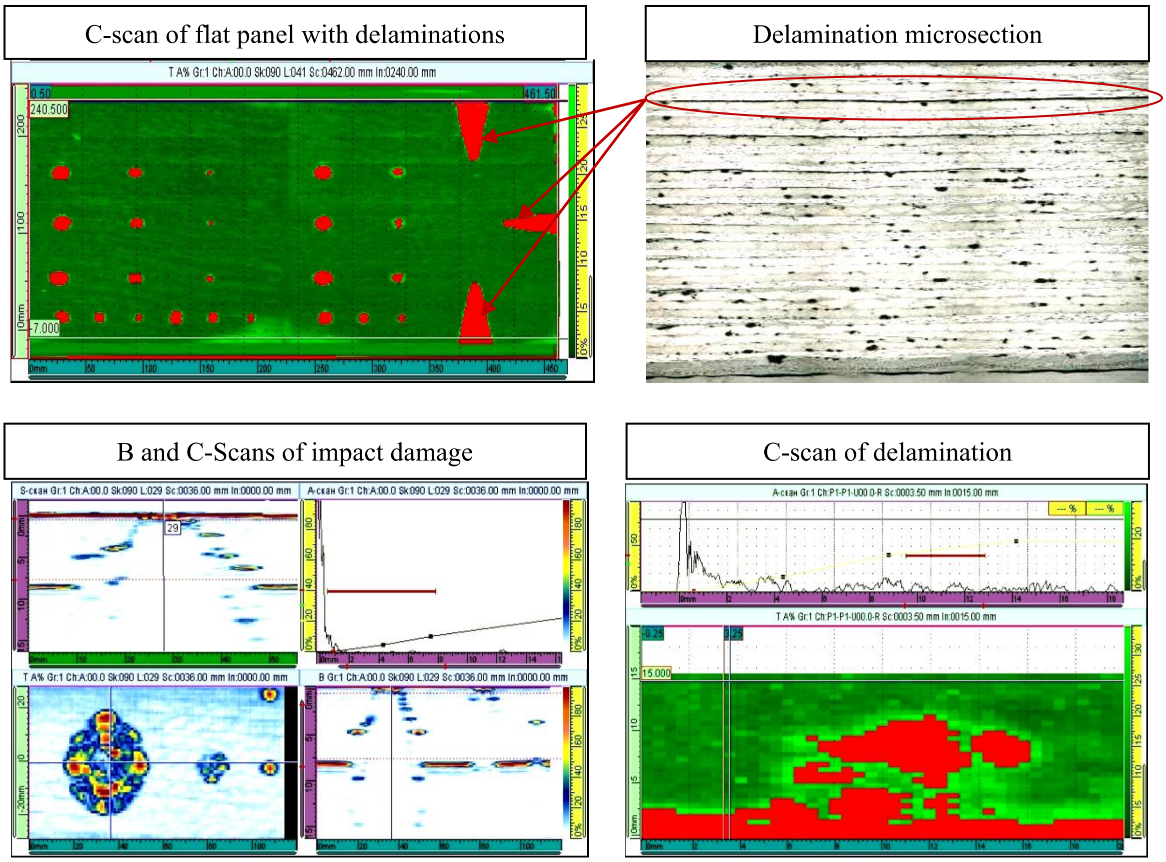

Figure 3: The results of testing delaminations, impact damages and laminations of stiffening components and panel

2 POD ESTIMATION

Estimation of probability of defects detection (POD) vs their size researching was carried out with the aim of reliability service defects detection estimation by using phased array technique for aviation high-loaded structures health monitoring. The set of CFRP specimens with artificial defects which simulated service defects (such as impact damages and delaminations) with the sizes from 3 mm^2 to 1000 mm^2, was produced for the researches. Ultrasonic testing by phased array technique was carried out. The estimation of the real sizes of the artificial defects was made. Statistical data on echo signals maximum amplitudes from defects as well as the values of these defects areas were collected. Mathematical algorithm was developed for processing the collected statistical data and POD curves [13]. Methodological recommendations based on this mathematical algorithm were issued afterwards. The statistical data were processed mathematically and the POD curves for CFRP dangerous service defects vs their size and 95% confidence boundaries were plotted (Fig.4).

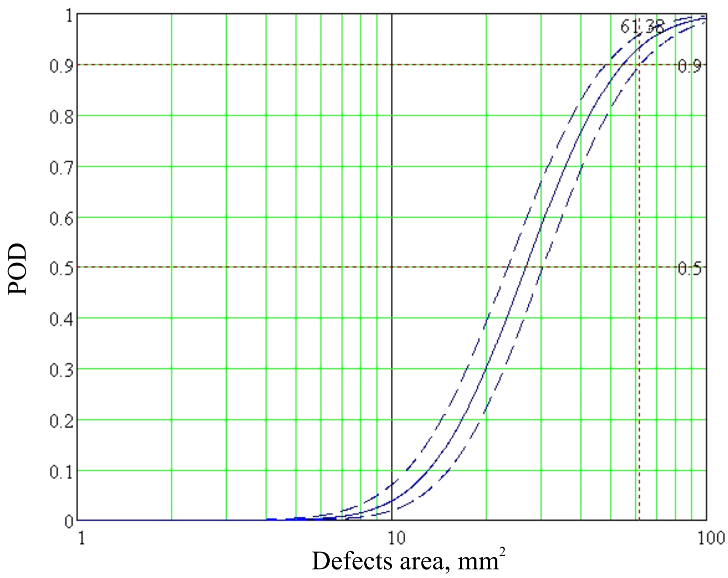

Figure 4: POD curve for CFRP service defects

In practice the specialists pay special attention to $a_{90/95}$ value [14]. This value characterizes the defect size which can be detected in 90% cases with 95% confidence probability (Fig.4). $a_{90/95}$ value was calculated in the process of POD estimation. This value is 61.38 mm^2. It is equivalent to the area of a flat bottom hole with the diameter of 8.84 mm.

3 PHASED ARRAY TECHNIQUE APPLICATION FOR THE INTELLECTUAL FRP DESIGNING

FSUE “VIAM” is one of the leading Russian companies in the development of the intellectual FRP structures. Within the framework of the development of intellectual CFRPs with integrated optic fiber systems and FBGA sensors, testing CFRP specimens containing optic fiber between layers was carried out to register FBGA sensors reactions on impact damages. Fiber location in the specimens was defined by phased array technique before damaging with the aim to damage specimen in the aria of interest. Moreover it was necessary to define impact damages sizes and the effect of these damages on the fiber location in the specimen. These goals were successfully reached due to phased array technique application.

The ultrasonic flow detector of Omniscan MX (Olympus NDT) and the linear phased array of Olympus NDT 5L-64-NW1 with 5 MHz operation frequency were used for the research mentioned above. Ultrasonic flow detector setting was made with the sensitivity equivalent to assured the detection of 5 mm diameter flat bottom hole. Electronic scanning was made by 16 elements. A-, B- and C-scans testing results were used for optical fiber location definition before and after impact damaging, and also for locating impact damages in the specimens and its sizes estimation. 200 µm size fibers and impact damages location were visually defined in the specimens in the analysis and testing data processing (Fig.5).

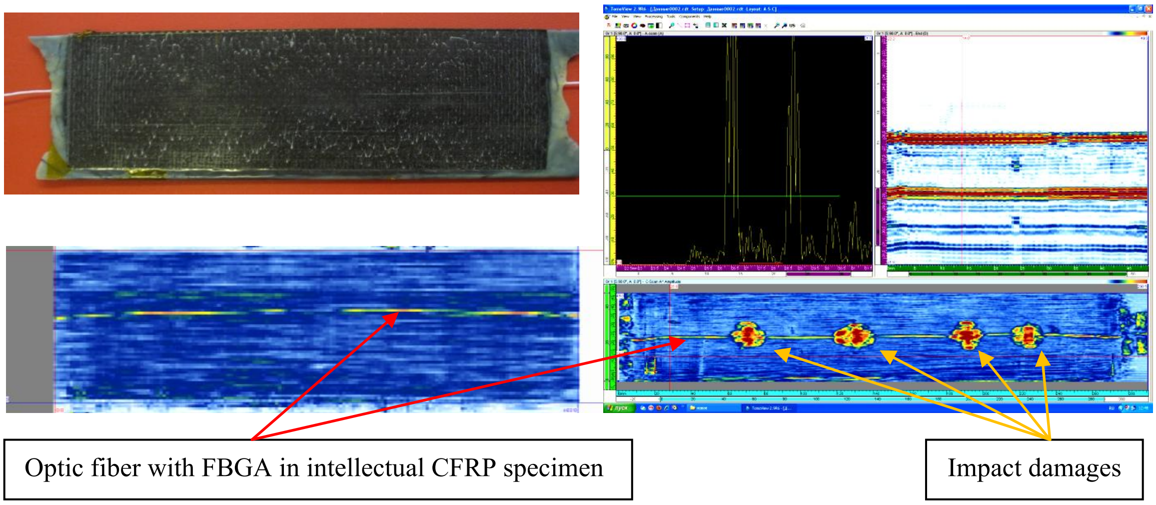

Figure 5: A-, B- and C-scans of intellectual CFRP specimen based on FBGA before and after impact damaging

CONCLUSION

- phased array technique application for high-loaded FRP structures health monitoring in service allows the detection of the most dangerous macro defects such as impact damages and delaminations;
- the value that characterizes the defect size which can be detected in 90% cases with 95% confidence probability $a_{90/95}$ is 61.38 mm^2 (it is equivalent to the area of a flat bottom hole with the diameter of 8.84 mm) for the phased array equipment setting with the sensitivity equivalent to the assured detection of 5 mm diameter flat bottom;
- phased array equipment can be successfully applied for the fiber locating in the intellectual CFRP structures based on FBGAs before and after impact damaging.

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