

Automation of Pulsed Thermography using Computer Numerical Controlled Manipulator for CFRP Honeycomb Structures

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Abstract

Pulsed Thermography (PT) is a non-contact nondestructive testing (NDT) technique which is suitable for testing of Carbon Fiber Reinforced Plastic (CFRP) honeycomb sandwich structures. Commercially available PT systems have smaller coverage area in a single exposure which is mainly constrained by the number of heating elements required for providing near uniform surface heating. Automation facilitates easier repeatability and precise location of defects especially for testing of large structures. Compared to other C-scan systems automation of PT system is easier as it is an area interrogation method and does not need precise alignment of the imaging hood (enclosure with heating system and infrared camera). In this paper, attempts made in programming the path of the PT imaging hood for covering the surface of large flat and cylindrical segment structures are given. The thermographic images are interpreted at various scan paths as grid corresponding to the field of view of camera. Scan path generation covers the entire test component and ensures the full coverage of the component which will increase the probability of detection (POD). Compared to manual scanning, advantages are reduction of evaluation time, automatic recording of thermographic images of large data, uniform heating at the curved regions by maintaining camera hood normal to surface of test component, minimizing human errors, reducing the number of testing persons and safety of the infrared (IR) thermography camera and operators.

Key words: Pulsed thermography, Nondestructive testing, Carbon fiber reinforced plastic, Honeycomb sandwich, Probability of detection

1. Introduction

High specific stiffness, specific strength and tailorability of composite materials make designers prefer them for weight critical applications. Sandwich construction of these materials provides improved stiffness and it is preferred structural configurations for many applications. Nondestructive testing (NDT) plays a major role for assessing the quality of these products especially for aerospace applications.

Automated water coupled C-scan ultrasonic testing (UT) is a well proven test method for doing NDT of large composite honeycomb structures. If the coupling medium adversely affects the properties of the composite products during service, water coupling cannot be applied for testing of these

structures. Air coupled ultrasonic testing[1],laser ultrasonics[2],laser sherography[3],pulsed thermography [4], lock in thermography [5]are non-contact test methods.Air coupled ultrasonic testing can avoid coupling medium, however, proper assessment at edges and cut out locations is difficult because the bending of ultrasonic waves at these locations.Laser ultrasonic system has got the advantages of testing the products from larger distances compared to the other ultrasonic methods,but, it is very costly. Laser sherography directly measures the surface strain anomalies in the component, howeverdiscrimination between debond and delamination is difficult. Pulsed thermography (PT) like laser sheorgraphy system is area interrogation methodwhich can differentiate debond and delamination based on the characteristics of cooling curves.

Manual scanning using PT system is tedious and time consuming process. Automation of PT system using Computer Numerical Control (CNC) manipulatoris reduced the testing time and avoids the manual handling of IR camera.CNC program [6] is requiredbased on the geometry of the component corresponding to different scan path of camera for flat and cylinder segments for automatic testing. Similar flat and cylinder segments can use the same CNC programfor testing respectively but it differs for various sizes. Manual writing the CNC program for different size components are time consuming and it is avoided by automatic generation using Matlab [7] codes. Variable inputs have been given for generating CNC program based on the geometryof the component. Another advantage is that Matlab codes can be edited or modified based on our requirement.

2. Experimental sections

2.1. System configuration

The schematic of PT facility is shown in Fig.1.In current study, the PT system (EchoTherm)(Fig.2) is supplied by Thermal Wave Imagingwith IR camera from M/s.FLIR. This is integrated with an indigenously developed 5 axes (3 linear axes : X, Y, Z and 2 rotary axes :1and 2)CNC manipulatoras shown in Fig.3. The imaging hood (Fig.4)is mounted on the end effector location (second rotary axis) with an offset of 330 mm from the z-axis.

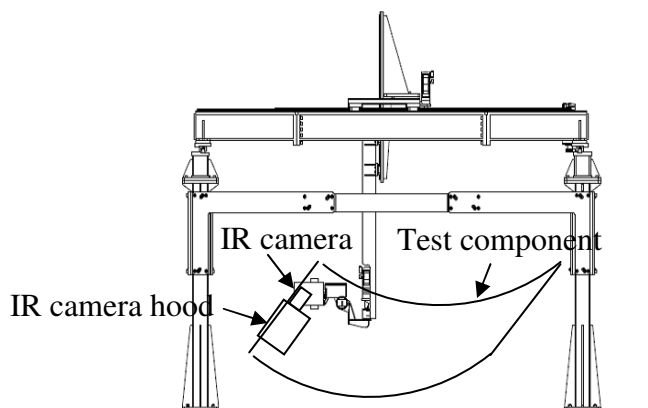


Fig.1.Schematic of PT facility



Fig.2. Photograph of pulsed thermography system

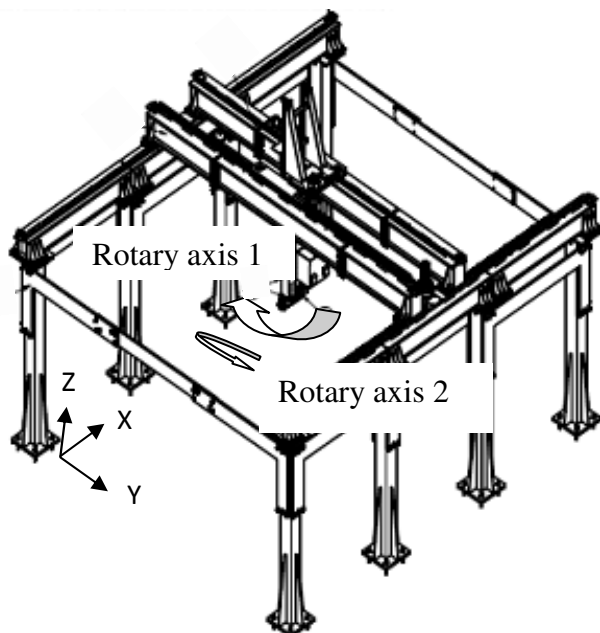


Fig.3.Schematic of CNC manipulator

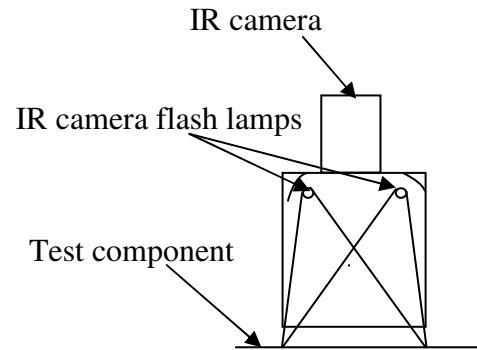


Fig.4.Schematic of PT imaging hood

The opening of imaging hood is 270 mm x 370 mm which limits the area that can be covered at an instance. Large parts are to be divided into smaller sections corresponding to the image hood opening. EchoTherm system has software called MOSAIC which can stitch the images for viewing the entire component in a single screen. It has got a feature to preselect the scan path (the path that imaging head has to move to cover the entire component surface). According to the scan path the movement of the imaging head was done using CNC program which incorporated dwell time (the time required for capturing PT image sequence) and external trigger command for PT system. For different shapes and sizes of the products, independent CNC program incorporating the above features need to be written considering the standoff distance (distance from component to imaging hood).

Programming has been done using Matlab to create the CNC code required for testing flat and cylindrical segments and results are presented in the next section.

2.2. Flat components

Length and width of component are fed as input to the Matlab program. The output of Matlab program is the CNC program with all the necessary coordinates and commands for manipulator movement and IR camera triggering. The overlap between two adjacent scans is taken care by the coding. This ensures the complete scanning of components. Same CNC program can be utilized for testing of both sides of flat components. Based on the trails carried out on specimen corresponding to the test component, acquisition time [8] was estimated and considered while coding. Scanning profile for a typical flat component is shown in Fig.5.

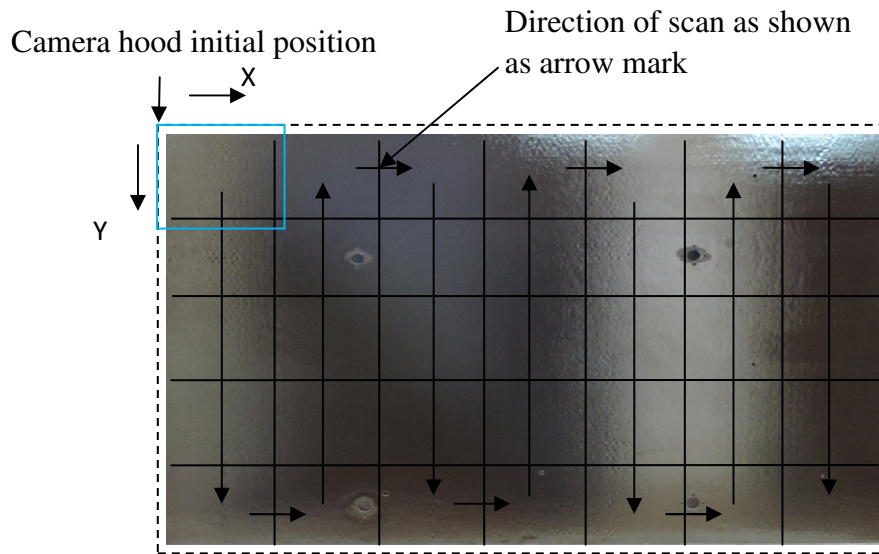


Fig.5.Scanning profile for a typical flat component

2.3. Cylinder segments

CNC program for cylinder segments(Fig.6) need to account for curvature of the components. The coordinate movements with respect to z-axis and second rotary axis are accounted while programming.

Sector radius (R), sector angle(θ) and segment length (L) are inputs to the Matlab program. Scanning profile for a typical cylinder segment is shown in Fig.7. Separate codes are written for scanning both sides of the cylindrical segments by accounting the standoff distance.



Fig.6.Cylinder segment

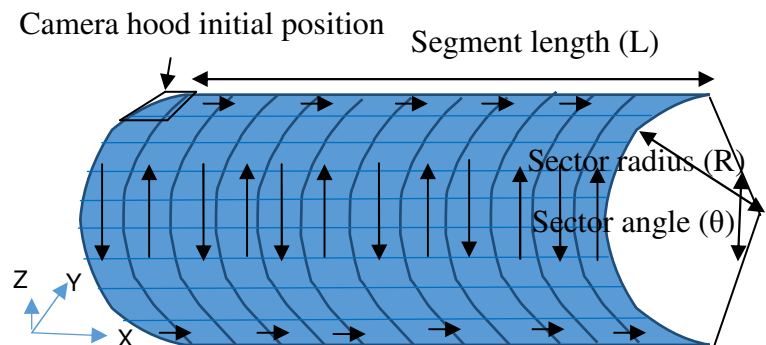


Fig.7.Scanning profile for a typical cylinder segment

3. Results and discussion

Based on the maximum thickness of the skin, the acquisition time is verified for deeper defect detection and it is incorporated in the Matlab program for generation of CNC program corresponding to the component tested. The thermographic images corresponding to each frame has been interpreted separately for finding the presence of defects. Plotting the log time temperature curves on each image is used for identification of defects at various locations. Defect has been detected by the variation in the slope of the log time temperature curves (cooling curves) between the defect and good region. Variation in the temperature profile of image is visualized by various color palettes for better appearance of the defect. The size and location of defects are validated using the inbuilt scale which is calibrated by known distance in the image. The thickness variation and staggering details of the layup of skin are incorporated to achieve the proper judgment of results. Image processing software has been used for enhancing the image quality for better interpretation of results. Each thermographic images are stitched together to form the entire projected component surface. Stitched images of flat component and cylinder segments are shown in Fig.8 and Fig.9 respectively. The location of defects was traced from the reference position.

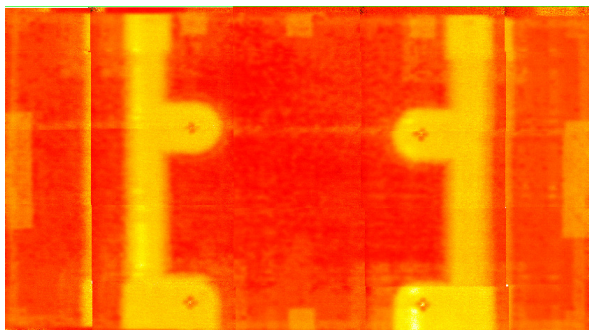


Fig.8. Stitched images of flat component

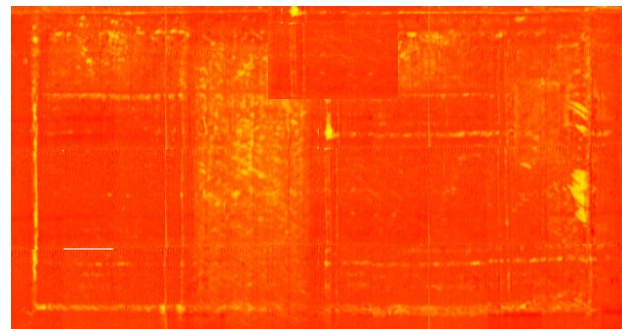


Fig.-9. Stitched images of cylinder segment

4. Conclusion

As part of scan path generation for different product configuration using CNC 5 axis machine, a Matlab code has been used for generating CNC code required for flat and cylindrical components. The code is being extended for the generation of CNC programs for conical and other generic shapes.

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