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Production Implementation of a Multi Spindle Flexible Drilling System for Circumferential Splice Drilling Applications on the 777 Airplane

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ABSTRACT

With the recent development of a multi spindle flex track drilling systems for aerospace applications, the challenges of testing and implementation on existing airplane programmes require unique technical methodologies and solutions. This paper discusses the technical approach, problems encountered and methodologies/solutions used to successfully implement a multi spindle flex track drilling system for circumferential splice drilling on the 777 airplane. The multi spindle system uses varieties of flex track carriages attached to flexible vacuum tracks for wide inside drilling. The hardware and software challenges encountered during the interfacing of the multi spindles are discussed as well as the complex problem of indexing and locating all detailed components of the splice accurately and with high repeatability. Design changes completed to make the equipment production ready along with the key hole feature probing hardware (Renishaw, Laser & Vision) and techniques are also presented in this paper. The usage of carbide drills with unique carbide material specification and drill geometry design is presented as part of the tool life optimization process. NC programming techniques and algorithms used to compensate for contour variability on circumferential splices are also discussed. Material handling equipment design and implementation process for this multi spindle flex track drilling cell is provided. The detailed test plan along with the incremental implementation methodology used to establish first a stable, then a robust and ultimately a completely optimized process with all technical variables accounted for is presented through the body of this paper.

INTRODUCTION

The first set of (3) Flex Track drilling machines were delivered to the 777 Fuselage Manufacturing area in December 2008. A test and implementation programme was initiated to develop the automated drilling processes for the circumferential splice drilling which would culminate in the qualification of both equipment and processes. The challenges faced during the process development from the hardware, software and part indexing are presented in the following sections. NC programming procedures as well as the development of a combined carbide drill & countersink for this process are also discussed. The test programme is now nearing completion and a robust automated drilling & countersinking process has been established with the focus now shifting towards the process optimization portion of the programme to help realize the maximum productivity gains associated with the introduction of automation. Figure 1 shows the 3 machines on the 777 fuselage, pen marking on a mylar sheet as part of the NC programming verification process.

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Figure 1. Flex Track Drilling Machines on 777 Fuselage

PROCESS DEVELOPMENT

After careful planning and development of a detail schedule the first Multiple Spindle Flexible Drilling System was released and authorized to be deployed onto a 777 aft fuselage circumferential splice joins and start conducting a series of machine and process validation testing. Testing and implementation on production 777 aft fuselages sections revealed several manufacturing challenges as testing and fuselage assembly production work was often times happening simultaneous. These challenges would need to be addressed to adhere to the already aggressive production schedules while completing the necessary testing. Production management quantified these challenges and categorized these tests as follows. Testing that produced no production value such as machine and hardware fit-up. Testing that validated while performing limited production work tasks such as locating of part, undersize drilling, full-size drilling with limited countersinking. The final category of testing produced complete drilling and countersinking tasks that met engineering and drawing requirements.

It was quickly realized that scheduling of work would have to be sometimes flexible if testing milestones were to be met. Minor changes to build sequence had to be made to support the new automated drilling process. Completion of frame splices and floor beam to frame installations were required in order to stabilize the structure enough for the deployment of Multiple Spindle Flexible Drilling System. This work was done concurrently when drilling with manual processes. Because of the extremely wide drilling envelope several panel handling fittings used to manipulate panels in the Floor Mounted Assembly Jigs (FAJ) interfered with the Automated Drilling System and Gantry Handling System. The removal of some of these fitting also required the above mentioned work to be completed prior to removal. Only minor modifications to work deck flip doors were required to accommodate machine passage to other work decks levels. Facilities changes included 480v service installed to power the Drilling System and Gantry Handling System.

PART INDEXING - Initial part indexing plan required the addition of Determinant Assembly (DA) holes added to the fuselage panels that would match up with DA holes in to splice plates. Shear ties and stringer splice would then be located to the plate using existing tool locating methods. It was found through data collection that tolerance build up across the circumferential join areas forward and aft produced too much variability to use DA philosophy when locating plates to the fuselage panels. It was also noted that this locating process would also require more K hole locations because of inconsistent detail part locations. A new indexing process was needed and sub assembly of details was the solution. The detail parts consisted of splice plates, shear ties and stringer splices. These were then assembled into splice plate assemblies in a feeder line operation (Figure 2). These splice plate assemblies were then located to center of the forward and aft fuselage panel gap. Clocking index of splice plate assemblies was achieved by clamping stringer splices located on the splice plate assembles to the stringer ends that are permanently attached to forward and aft panel assemblies. This indexing philosophy not only produced a repeatable process of indexing the detail parts to the plate and fuselage panels it also reduced the amount of time it took to locate the parts to the fuselage panels in preparation for drilling.

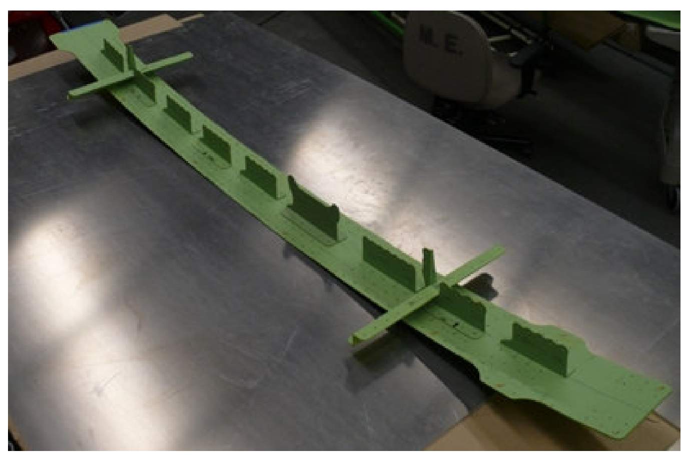

Figure 2. Subassembly of splice plate, shear ties & stringer splices

CARBIDE DRILL/COUNTERSINK DEVELOPMENT – Based on an experiences with an existing drill point geometry being used in other drilling processes on the 777 airplane, a 135 degree, 4 facet split point was chosen as the optimum drill point geometry for the automated programme drills (Figure 3). All shanks were standardized to a 10 mm diameter to be used with a tool holder based on the Schunk Tribos Tool holding system [1]. Multiple carbide grades were explored for this programme and eventually 2 were selected for the test and implementation programme. Grade 1 selected is a 10% cobalt content tungsten carbide grade with a hardness of HRA 91.9, Transverse Rupture Strength > 3600 N/mm^2 and a grain size < 0.6 µm. Grade 2 selected is a 9% cobalt content tungsten carbide grade with a hardness of HRA 94.4, Transverse Rupture Strength > 3900 N/mm^2 and a grain size < 0.2 µm. Both carbide grades were tested using the same drill point geometry. The drills were tested using no surface coating on the drills as a baseline and then tested with a Chemical Vapour Deposition (CVD) coating of Titanium Diboride on the surface for improved wear resistance. Drill sizes varied from 0.1875 inches to 0.371 inches based on fastener sizes and the countersink profile varied based on the types of fasteners used on the circumferential splices. Hole quality (size, surface finish etc) were monitored along with wear on the drill during the drill life testing for performance. As part of the testing spindle speeds and federates were varied and monitored to establish the optimum drilling parameters for the various drill sized used. A baseline requirement was set for minimum acceptable drill life. Both carbide grades performed well and met the performance criteria. All drill development was done in collaboration with Apache Aerospace Inc. [2].

Figure 3. Carbide Drill & Countersink

All the drills were set into the toolholders and measured for lengths using the Schunk TRISet Presetting system [1] as shown in Figure 4. The accurate length offsets provided by this system contribute greatly to holding the countersink depths within a ± 0.001 inch tolerance band. Additional benefits of this presetting system include wear monitoring of the drill point using a photo microscope which is an integral part of this system. Technical data showing the variability of the hole quality with the magnitude of the wear on the cutting edges was generated and plotted to show the trends and relationship between hole quality and cutting tool wear. Tool life and hole quality data was then used to select the final drill type and the carbide material for production use.

Figure 4. Tool Presetter

HARDWARE & SOFTWARE DEVELOPMENT

The multi spindle system is deployed onto the panel circumferential splice area of a 777 fuselage section using a motorized Gantry Handling System [3]. The GHS can handle up to three Flex Tracks on a 24 foot assembly of flexible vacuum track (Figure 5). Sections of additional track are quickly added to each end of the loaded assembly. The Flex Track drilling head spans 2 of the fuselage frame bays and is designed to be removable from the track itself is for maintenance. Each Flex Track head weighs 220lbs. Each section of track weighs 13lb. The entire assembly of 16 track sections and 3 Flex Tracks weighs in below 900lbs, and traverses a distance of 50 feet covering a possible drill envelope of 140 sq ft.

Figure 5. Gantry Handling System

The Flex Track vacuum track design is fundamentally important, as it is the base structure adhering to the structure of the airplane. For the circumferential fuselage splice the track was increased in height from a

1 inch offset to 2 inches, the cups were designed with no metal contact points to protect the clad surface, and the airline was increased to handle large airflow. This change allowed for the Flex Track to travel over fittings and temporary fasteners, not mark the surface, and create over 50 tons of suction. The nine track sections were originally designed in specific sections; 5 of which would be permanently spliced and loaded with the Gantry Handling System, 4 more would be spliced on [3]. However the 9th track section quickly abandoned as existing tooling was not allowing for the use of the Flex Track at the extreme ends of travel. The permanent splices were reduced to 4 tracks; this helped also by keeping the loaded rails above the upper deck of the scaffolding at all time. It was soon realized that unique track sections would not be a robust system, daily the tracks needed to be removed from the airplane, the permanent splices were disassembled 4 times a week to move jigs, and the tracks were always changing configuration. Sometimes only 2 Flex Tracks were running on the fuselage sometimes all three. The methodology required to keep the track sections in the right order was difficult to manage. The solution was to make identical track sections and allow for quick change splicing (Figure 6.).

Figure 6. Quick Change Track Splice

The addition of external air connections helped reduce the time and complexity of splicing tracks together as well as taking them apart and allowed for the plumbing of air at any splice. Some colour coding (Figure 7)was added to eliminate the master tracks from being attached to slave tracks and vice versa. Individual track shut off switches were added so individual tracks could be moved and located easily.

The original thought of loading the track and letting the Flex Track calculate the error in the loading was not going to work as the long track coupled with the large y-travel could allow for some large deviations in hole locations of +/- 0.060". A reference line was drawn from the splice center to track edge to aid in the locating of the track during deployment thus eliminating the errors while loading.

Figure 7. Colour Coded Tracks

With the addition of the C-Axis the Flex Track has the ability to drill complex contour sections on the Fuselage. By keeping the master track on the single contour section the secondary track follows along on the compound contour section.

MACHINE REFERENCING - The lap designed structure of the airplane posed some issues using the offset laser for probing. The laser was offset in the x-direction of the machine, circumferentially around the fuselage. This offset of the laser produces around a -0.050” error when locating the hole center in the machine x-direction on the fuselage versus a flat surface. A theoretical permanent offset value couldn't be accurately applied as a lap join creates a small yet varying radius contributing to a locating error of +/-.010". The Flex Track also has a HSK mounted Renishaw [4] touch probe that can be loaded into the spindle; this is on the drill centerline and was used in validation of the error. Due the error of the location of the laser a solution to offset the laser in the y-direction of the machine was purposed. This offset location of the laser eliminates the error from the laser return on the fuselage. To keep up with the implementation plan the laser was abandoned and the Renishaw was used exclusively until the new laser mounting location was completed. The new laser location worked well but has the problem of not being able to see all the holes that are drilled and visualizing datum holes that are beyond the reach of the machines y-axis travel.

The addition of the camera was deemed necessary as the number of datum holes had increased and the time to find and validate them with the touch probe or laser was too great. Previous versions of Cameras have been removable on spindle center or mounted permanently offset. The offset camera was not considered as the problem with the sine error due to lap joins. The process time for a hole probed with the Renishaw is 90 seconds, the Keyence laser can probe the same hole within 45 seconds, and the OEM camera is able to image the hole and calculate it's position within 10 seconds.

Some software challenges were encountered during the implementation of such a wide Flex Track. Previous Flex Tracks up to 18" wide had been deployed on structures, however original math for translation and rotation had been abandoned due to lack of y-axis travel needed. The EFT sometimes uses datum holes offset in machine y-axis and sometimes offset in the x-axis, the reintroduction of more advanced math algorithms to determine the proper rotation and translation of updated machine coordinates were reintroduced to the flex track.

NC PROGRAMMING – An offline programming system (OLP) is used in conjunction with Catia V5 [5] generate NC part programmes. The Flex Track system uses flat pattern programmes which are developed using the OLP. The OLP (Figure 8) provides versatility in the selection of fastener points, sequence of drill operations, primary and secondary index points, offset surfaces, process parameters etc.

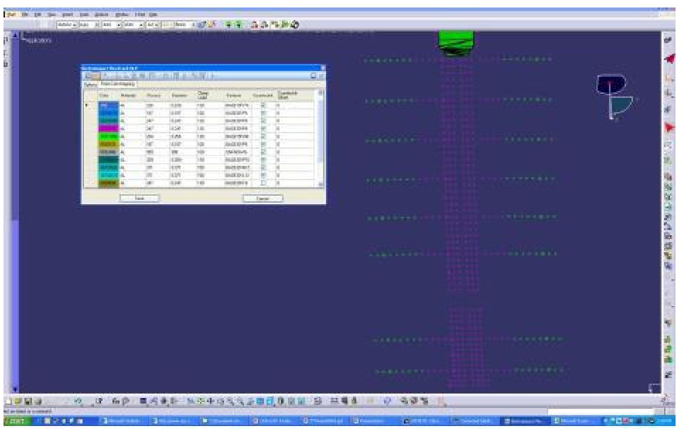

Figure 8. OLP NC Programming System

CONCLUSION

The testing and implementation of the multiple spindle flexible drilling system for circumferential splice drilling on the 777 airplane has produced a robust automated process. Production trials proved that the use of automation in these processes greatly improves the quality of the product by removing the variability associated with any manual process. Process capability indices improved substantially while also providing the benefits of greatly reducing the ergonomic challenges faced in manual processes. The efficiencies gained during the testing and implementation of this programme are leading the way for future automation programmes in the fuselage manufacturing processes.

ACRONYMS

FAJ – Floor Assembly Jig

DA – Determinant Assembly

FME – Floor Mounted Equipment

EFT – Extremely Wide Flex Track

GHS – Gantry Handling System

CNC – Computer Numerical Control

NC – Numerical Control

GUI – Graphical User Interface

X, Y, Z, A, C – Axis Names

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