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

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ABSTRACT

Flex Track Drilling systems are being used increasingly in aerospace applications providing low cost, highly efficient automated drilling systems. Certain applications like circumferential splice drilling on large size airplane fuselages require multi spindle flex track systems working in tandem to meet production efficiency requirements. This paper discusses the development of a multi spindle flex track drilling system for a circumferential splice drilling on the 777 airplane.

The multi spindle system developed uses a variety of flex track carriages attached to the flexible vacuum tracks to allow for offset or wide inside drilling. Segmented machine programmes allow these multiple machines to be deployed on the same circumferential splice on the airplane providing the multi spindle system. Interfacing of the multiple spindles is achieved by a custom OEM interface using a single screen thereby ensuring simplicity of operation. A central database location ensures that all programmes are current and maintains operational status of all holes being drilled. Tool life monitoring is also provided to ensure consistent tool changeovers for maintaining hole quality and process capability. Flexible track lengths can be spliced together for long lengths and shortened for clearance or areas using smaller programmes. This paper also discusses the development of the carriage hardware specific to the 777 airplane requirements using the methodology of adapting existing flex track system designs as well as point design specific to the 777 Fuselage Circumferential Splice Drilling Application.

INTRODUCTION

In the fall of 2007, a Boeing internal cross-functional team was chartered to investigate implementation of automation technologies to mitigate the challenges that have increased with higher production rates in 777 fuselage assembly. A technical report published by this team proposed the application of selective automation to the 777 Fuselage Integration processes. By implementing selective automation the benefits of reduced repetitive injuries, reduction of skin quality defects and lower cycle time in some of the fuselage integration processes would be realized. An additional benefit would also be the resultant consistent/repeatable and reliable process. These improvements would drive a better work environment, which would reflect on better attendance, less attrition and a higher employee morale. This Technology implementation would result in an improved product to the customer.

After a detailed investigation of current build processes of longitudinal and circumferential splices it was determined that the focus should be on automation of the drilling of the circumferential splice on the 777-300 airplane, Aft fuselage section. To reduce developmental cost it was determined to use as much as possible off-the-shelf technologies with minimal developments needed to adapt to the 777 airplane requirements. Also taken into consideration was that the equipment chosen would need to be adaptable with few or no changes to current Floor Assembly Jig (FAJ) or floor mounted equipment (FME).

SELECTIVE AUTOMATION PROPOSAL

A technical evaluation of the longitudinal and circumferential splice drilling and fastening processes revealed that application of automation to selected portions of these processes would provide the greatest benefit for the investment incurred. On circumferential splice drilling and fastening processes it was discovered that the drilling processes constituted almost 70% of the total process time. These drilling processes included pilot drilling of holes, full size drilling of holes as well as countersinking processes. Any implementation of automation on these drilling processes would yield major gains in productivity including additional benefits of improved ergonomics, improved skin quality and overall an improvement of the production process and overall product quality.

The study of the automation of the fastening processes for the circumferential splices yielded that gains realized by automation would not result in great improvements in productivity for these processes. Some of the gains would be offset by the additional process monitoring time as required by engineering specifications for the automated fastening processes. By focusing on the drilling processes only of the circumferential splices, the automation equipment requirements were also greatly simplified due to the omission of additional fastener insertion end effectors, clamp up equipment etc. This allowed the team to evaluate more options for the automated drilling equipment as many suppliers met the specifications for the drilling equipment but not for the drilling/fastening equipment, making it easier to obtain off the shelf automated drilling equipment. A time study along with an ergonomic study, combined with production process data including quality charts was compiled to help arrive at a decision for development and implementation of selective automation in 777 Fuselage Integration.

CURRENT PROCESS

The current baseline process for drilling and fastening of the circumferential splices is a complete manual process. This process starts with location of the splice plates, shear ties and at the end stringer splices as shown in Figure 1 and Figure 2. Circumferential splice plates are currently located for station and buttock line by hand, using drawing references. Then shear ties and stringer splices are then located with multiple locating jigs (LJ's). All parts are secured with undersize temporary fasteners. At this point in the process all holes are drilled undersized from existing pilot in parts through skin. Depending on size and parts stack-up holes are drilled in step-up process to final size by hand or power feed equipment.

Figure 1. 777 – Buttsplice Components (splice plates, shear ties, stringer splices)

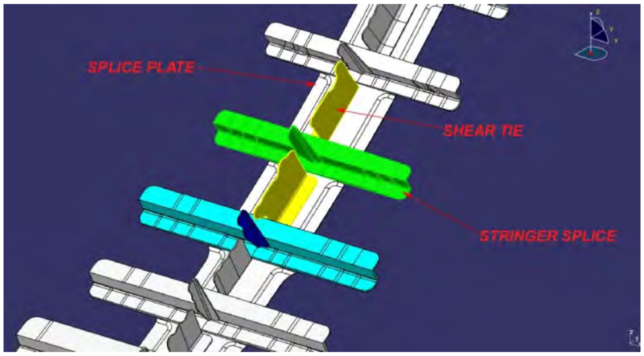


Figure 2. 777 – Buttsplice Components (Detail)

Currently the set-up, part locating, drilling and countersinking process of aft fuselage circumferential join takes roughly 100 man hours. Hand drilling and countersinking of more than 3,000 holes poses several challenges including, fastener locations and types must be identified prior to drilling to mitigate drilling/countersinking of incorrect fastener hole sizes and countersinking types. Simultaneous operations are hindered by FME equipment (flip doors scaffolding and ladders) requiring multiple shift operations. Hole and countersink sizes and stack-ups require multiple cutter changes. In some areas large stack ups of more .750 inches requires power feed drilling operations which also requires mounting of drill jigs (DJ's). Chip recovery during drilling/countersinking operations is also an issue with the current process.

PROPOSED PROCESS

EQUIPMENT SELECTION

Various off the shelf technologies were evaluated by the cross-functional team for the automation of the circumferential splice drilling processes. These included robotic drilling, overhead gantry (5 axis) drilling, track based portable drilling systems such as Mini-Flex Track and finally track based machine drilling systems such as Flex Track Drilling Equipment. All technologies were evaluated for technical feasibility of use for the circumferential splice drilling processes. The Flex Track Machine based system provided the most feasible solution for an off the shelf based machine as it required the least amount of modifications to meet the 777 Fuselage integration requirements. Other advantages offered were ability to cover drilling of holes on wider footprint adjacent to the circumferential splice. This offered the ability to drill more holes using the automation equipment than originally envisioned. Another benefit was that Flex Track Technology originally developed by Boeing offered a familiarity advantage over other technologies giving it a higher probability of success during implementation. At the end the Flex Track Machine offered the best right size, most efficient & simple and the least modified off the shelf solution for the selective automation programme.

TECHNICAL DEVELOPMENT

Drilling circumferential splices and frames is difficult to automate due to the inherently large machine needed to traverse the great expanse of the fuselage accurately. Existing airplane fuselage assembly jigs were not designed to accept large pieces of automation for drilling these splices. However the Flex Track attaches directly to the fuselage and uses the massive parts it's drilling as the primary machine base. Although initially designed for fuselage drilling the standard Flex Track was too short and narrow to be well suited for the splice drilling, and individually too slow.

Flex Track technology is well suited for fuselage drilling as lightweight flexible tracks splice together indefinitely and small local transformations eliminate the need for 'global' accuracy [1]. Track designs use compressed air and hundreds of venturi pumps to generate vacuum. The single set-up needed for 777 is long at over 50 feet, generating more than 35 tons of suction from almost 500 vacuum cups. One problem was how to supply air to the starving venturi's, another was that such a long assembly of track acts like a wet noodle, and where is it stored? Finished hole patterns over a meter in width forced an entirely new Flex Track design, an Extremely Wide Flex Track or EFT.

By using the Fanuc PowerMate CNC the Flex Track control easily handles the synchronous drives and the total of seven axis needed for an EFT. Previous Flex Track Designs have five servo axis', X,Y,Z, servo spindle, a extra rotation axis A [2], the EFT needs another two. First an EFT needs another X-axis, let's call X', to accurately position the Flex Track. Without X' even the lightweight head becomes a problem as it travels far away from a single drive axis vacuum rail causing large moments on the single drive rail resulting in a twist and walking of the rail.

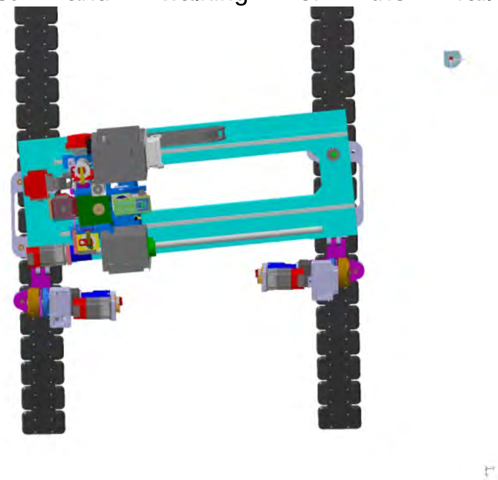


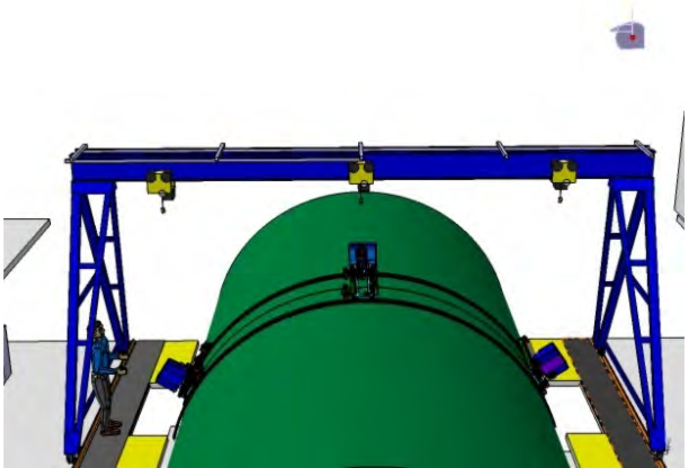
Figure 2, New C-Axis Capability 1

The track design has always been to float one side [2]. The CNC will now tie them together with a new axis of rotation, the C-axis. Closed loop feedback and elimination of track side loads allows EFT to travel accurately along the long tracks. The C-axis is measured using a 1 million count rotary encoder to keep the Cartesian relationship with the primary drive track by driving X'.

Production schedules inherently demand certain tasks take set amount of time. All located now the details have hundreds of backed drilled holes for the automation to find. Automation can reduce time with faster drills and faster drives, but nothing moves faster than adding another machine or two operating on the same machine bed running the same program. Multiple EFT's are still small enough they aren't much of a technical development as an obvious advantage. For this application three EFT's will be used, allowing three automated spindles to be used simultaneously.

777 ADAPTATIONS

In the production environment a Gantry Handling System or GHS, is used to quickly retrieve, store, and deploy multiple EFT's. The GHS solves the flexible rail problem too, by accurately holding the 10 sections of pre-spliced rails. Now the vast majority of the handling is merely lifted or lowered with a touch of a button and rolled away. A custom control was integrated into the GHS and three synchronous lifts are used to lift the EFT's from the fuselage without damaging the rails. A single maintenance mode allows for a retrieval of any EFT from anywhere on the fuselage.



Once the EFT's are deployed the GHS is rolled away and stored. Lastly, four more sections of rail are spliced at each end of the 10 track sections loaded from the GHS.

The new track design needed to incorporate the dual drive, allowing for the new C-axis, allow for more air flow to the venturi's, and also be easy to splice. Also the current cup design needed to change to accommodate the airplane's clad surface. Some of these design requirements are solved with a taller cup design. The taller cups allow more room for air lines, splice plates, and help avoid brackets and back drilled details on the fuselage skin. This is very helpful on such a long track, as an easy splice makes adding and removing track quick. The dual track set-up is over 50 inches wide and clears every obstruction around the splice keeping the EFT out of the way of other work in the cell.

Previous track designs were developed close to the airplane, but increasing the track height off the skin will simplify most of the design problems. The other obvious impact of the increased height is the need to flatten part data to the new track offset. Using a custom pre-processor, the EFT can get flattened machine pattern data developed inside Catia [1],[2], developed at any reasonable distance off the surface being drilled. The flattened machine pattern data programs are developed with relationships based on any two features.

Separating part programs allow for multiple spindles operating on the same track to be working on small discreet programs. Many details are located and fastened in the fuselage join. Some details are loosely located with respect to each other in specific non critical directions while primarily being accurately located in other directions. An EFT needs to reference off features to be able to put an accurate pattern of holes relative to the back drilled holes. A custom GUI shows the part program in relation to the EFT. This same interface ties in with a database for tool and process data, and saves individual progress for each job as completed. A standard feature on the EFT is the laser edge finder using simple macros find holes and verify part to track orientation. Relationships between all the located holes are available to be easily re-acquired by locating a primary and secondary hole. After being drilled a holes status is updated and drill tool life is incremented for fast recovery into a program status. If an EFT is not available to finish the program it started, another EFT can acquire the program and finish.

PROPOSED IMPLEMENTATION PLAN

The implementation plan for the multi-spindle flex track drilling system on the 777 circumferential splice drilling process involves a 2 phase approach comprising of testing (laboratory & factory) and a phased in implementation schedule. The various stages of the plan include:

1) Testing at Electroimpact with drilling coupons.
2) Testing at Boeing laboratories with drilling coupons.
3) Equipment qualification testing for Design & Quality engineering requirements
4) Development of the process monitoring programme
5) Testing of proposed process for parts indexing with ink marking (no drilling) in the factory
6) Testing of proposed process in the factory with parts indexing with drilling of holes
7) Full scale implementation in drilling process in the factory

7.0 Acronyms
EFT: Extremely Wide Flex Track
GHS: Gantry Handling System
CNC: Computer Numeric Control
GUI: Graphical User Interface
X,Y,Z,A,X',C Axis Names

8.0 References

[1] Flex Track Drill, Buttrick, SAE 2003-01-2995, 2003
[2] Flex Track for use in Production, Thompson, Hartmann, Buttrick, Feikert. SAE 2005-01-3318, 2005

CONCLUSION

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ACKNOWLEDGMENTS

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REFERENCES

1. Inclusion of this section is mandatory.
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CONTACT

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ADDITIONAL SOURCES

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

Here is the Definitions section. This is an optional section.

Term: Definition for the term

APPENDIX

HELPFUL HINTS:

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