5-Axis Flex Track System

2012-01-1859

Published
09/10/2012

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doi:10.4271/2012-01-1859

ABSTRACT

Flex Track Systems are seeing increased usage in aerospace applications for joining large assemblies, such as fuselage sections. Previous systems were limited to work pieces that allowed the tracks to follow a gentle radius of curvature, limiting the locations where the system could be used. This paper describes a new 5-Axis Flex Track System developed to expand the usage of the systems, allowing them to process work pieces containing complex and irregular contours. Processing complex contours is accomplished through the addition of A and B axes providing normalization in multiple directions. These new systems are configured with the latest multi-function process capabilities allowing drilling, hole quality measurement, and temporary or permanent fastener installation.

INTRODUCTION

The Flex Track System, shown in Figure 1, uses a flexible steel rail attached to the work piece through vacuum cups as the base for a numerical controlled drilling system. Having the machine directly attached to the work piece allows the system to process large work pieces, such as aircraft fuselage sections, without requiring large tooling. Because the drill tool is attached directly to the work piece, movement of the part within the tooling has a minimal effect on hole location and quality. In 2009 the Flex Track System was expanded with additional process tools, namely an onboard camera for part location, a hole measurement system, and a fastener installation system.

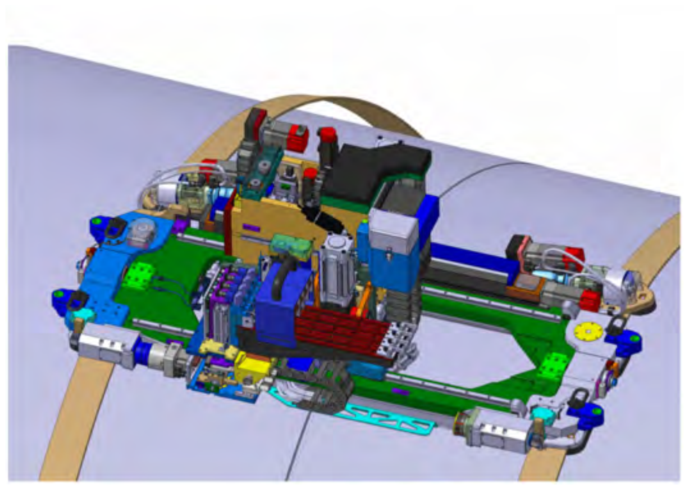

Figure 1. 5-Axis Flex Track System

The basis of the 5-Axis Flex Track System is the Multifunction Flex Track System developed in 2009. This previous system is limited to processing sections that have a gentle radius of curvature, with equal radii at each vacuum track location. Through the development of adjustable vacuum cups and normalization axes, the system was expanded to allow the processing of sections containing complex and irregular contours. The system is capable of moving to a location, normalizing, drilling and countersinking a hole, measuring the hole diameter and countersink depth, and installing either a temporary or final fastener.

TRACK DESIGN

A new design was needed to allow the tracks to follow a complex contour while maintaining the same airframe station orientation. This was accomplished by allowing the vacuum cups to rotate independent of the track rail. Each cup is set relative to the rail based on the angle of the taper where that particular cup contacts the surface, shown in Figure 2. Because this angle may change moving around the circumference of the fuselage the tracks are not interchangeable, each track section is set up for a specific location. Once the cup angle is initially set, loading the track sections onto the fuselage can be accomplished quickly through the use of quick splice fittings.

Figure 2. Vacuum Track

The size of the vacuum cups was also increased from previous designs due to the increased weight of the machine and increased forces seen while drilling larger diameter holes though titanium. Each vacuum cup is fitted with a small Venturi vacuum generator. Individual Venturis allows the system to isolate vacuum leaks to the failed vacuum cup.

Because the two vacuum rails forming the X-axis can follow different radii of curvature, the two drive tractors must travel different distances to maintain the Cartesian relationship between the X- and Y- axes. A non-driven axis, the C-axis, shown in Figure 3, is used to measure the angular difference between the Y-axis and the primary X rail. When the X-axis is in motion, the primary X drive is driven at the feed rate commanded in the NC program, while the secondary X drive feed rate is scaled based on the current angle between the X primary rail and the Y axis. The active C-axis allows the system to process irregular contours while maintaining the correct X and Y axis relationship.

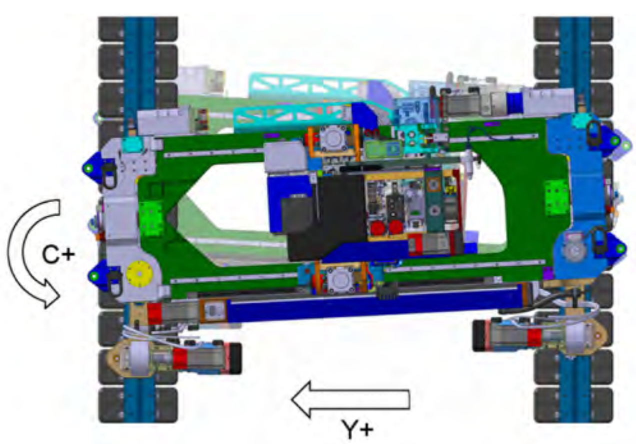

Figure 3. C-Axis Rotation

NORMALIZATION AXES

Once the Flex Track System has positioned the drill head at the location of the hole to be drilled, the pressure foot extends to provide clamp up forces while drilling. The nosepiece at the end of the pressure foot contains normality sensors which are used to measure the angle between the drill spindle axis and the work piece surface. The system is then able to adjust the drill head angle to ensure that the final hole is within normality specifications. Normalization is accomplished through the addition of two axes, A and B, which rotate about the X and Y axes, respectively.

Once the normality error has been established, the A- and B-axes are used to adjust the drill head orientation relative to the work piece. The axis of rotation for both the A and B axes intersects the spindle centerline, minimizing the effect of rotation on tool point position. Using position feedback from the clamp axis, the X and Y position changes for A and B rotation can be calculated and compensated for to maintain tool point position

A-Axis

The A-axis provides rotation about the X axis, shown in Figure 4. A servomotor and ballscrew-driven actuator, offset from the pivot location, are used to control motion while an absolute encoder mounted on the pivot shaft provides position feedback. Additionally, the A-axis assembly is preloaded by a pair of high-force gas springs to minimize the effects of backlash in the actuator assembly. The A-axis rotation allows the system to process sections where the work piece is not parallel to the machine base plate, such as locally flat fuselage sections. The current A-axis is configured to allow for +1/−5 degrees of travel.

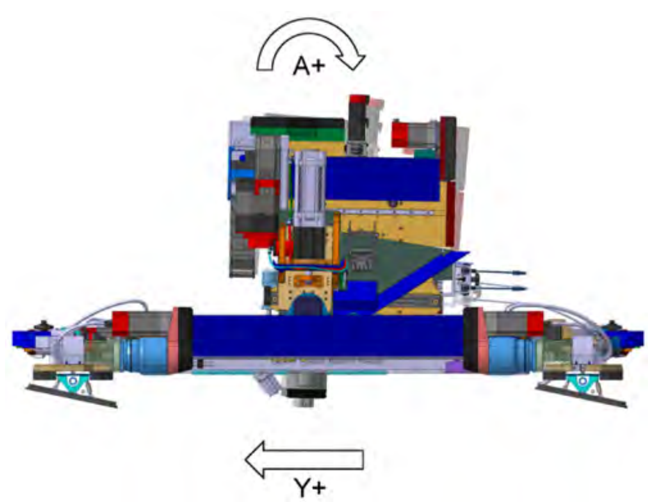

Figure 4. A-Axis Rotation

B-Axis

The B-axis provides rotation about the Y axis, shown in Figure 5. A servomotor driven curved rack and pinion is used to control motion, while an absolute encoder mounted on the pivot shaft provides position feedback. The curved rack is located such that the center of the curvature is coincident the B-axis pivot location. To allow the two vacuum rails to follow different contours, the B-axis is only driven from the primary rail side. The secondary rail side is non-driven and allowed to rotate as needed during machine positioning. It is equipped with a brake which locks after normalization to provide stability while drilling. The B-axis rotation allows the system to process sections where the radius of curvature of the vacuum tracks experiences step changes, such as across a lap joint or locally flat sections on a fuselage. The current B-axis is configured to allow for ± 5 degrees of travel.

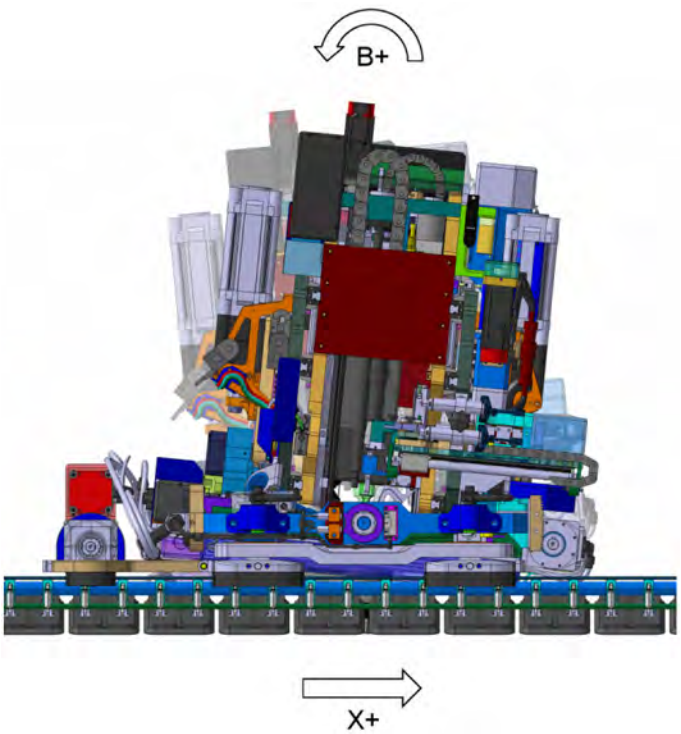

Figure 5. B-Axis Rotation

PROCESS TOOLS

The process tools on the 5 Axis Flex Track System are based on the tools found on the Multifunction Flex Track. They consist of a drill spindle, resync camera, hole inspection system, and fastener insertion system, shown in Figure 6. The fastener insertion system has been expanded to allow the installation of either temporary single-sided fasteners or final fasteners.

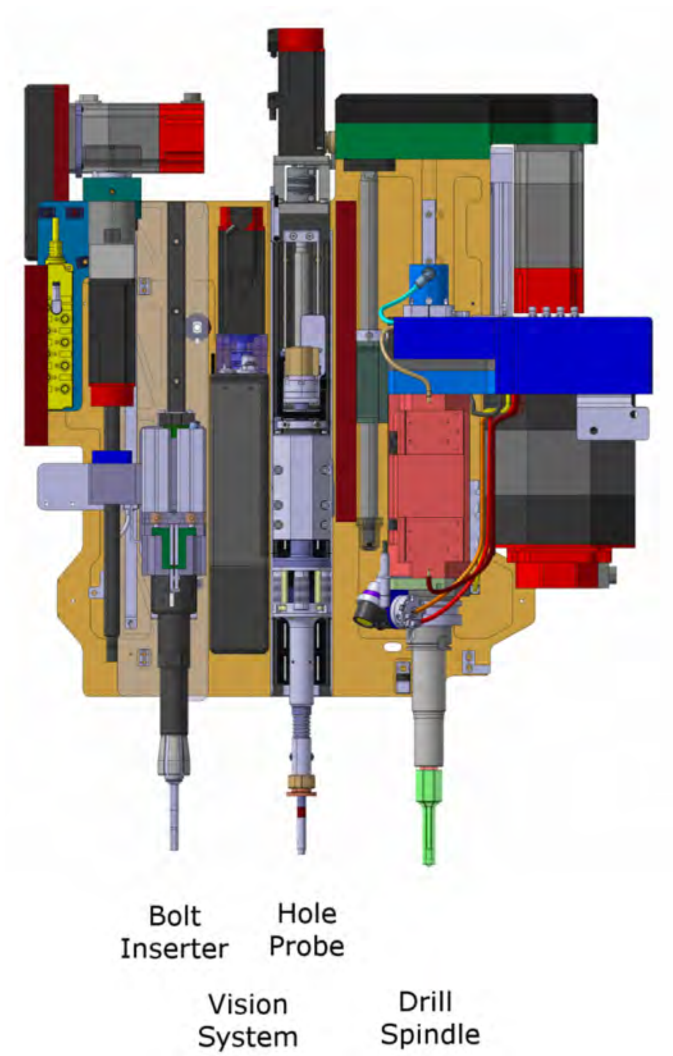

Figure 6. Process Tools

The drill spindle is driven by an 8 Newton-meter continuous rated motor and is capable of drilling holes up to 7/16 inches in diameter through carbon fiber and titanium stacks up to 1.9 inches thick. Drill feed is controlled through a servomotor and ballscrew using an absolute linear scale for secondary position feedback. Secondary feedback enables the system to have a drill and countersink feed accuracy of ± 0.0005 inches.

The onboard hole inspection system is capable of measuring the hole diameter profile in multiple orientations, as well as countersink depth, and overall stack thickness. An onboard proving ring is used to calibrate the system before each measurement cycle. Hole diameter is measured to ± 0.0002 inches and countersink depth to ± 0.001 inches.

A vision system is integrated into the Flex Track system allowing for the location of existing features in the work piece. These located features are used for aligning the machine coordinate system onto the workpiece. The vision system is capable of locating a feature and aligning the spindle axis concentric with the feature to ± 0.005 inches.

A variety of fastener installation systems have been integrated into the Flex Track System. The original fastening system used on the Multifunction Flex Track System carried single sided temporary fasteners in a cartridge onboard the system and installed them using a CNC controlled electric torque wrench. The fastener installation system has been expanded on the 5 Axis Flex Track System, adding the functionality to install final fasteners. Two final fastening systems have been developed depending on application. In each of these systems the fasteners are stored in an offline hopper system and transferred to the Flex Track through feed tubes. Sealant is applied to the countersink face and the bolt is installed in the work piece, using either a puller on the back side of the part or using a pneumatic rivet gun mounted on the Flex Track. After the fastener is installed, the head flushness relative to the work piece is measured.

SUMMARY

The latest development to Flex Track technology is the 5 Axis Flex Track System. The system was expanded through the addition of two normality axes and improved vacuum tracks which allow the system to process work pieces containing complex and irregular contours. The fastener insertion system has also been modified to allow the installation of final fasteners. Two variations of the 5-Axis Flex Track System are planned to enter production in 2013; one will process the section 47 - 48 circumferential join on the Boeing 787 and the other will process final fuselage assembly on the Boeing 777.

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The Engineering Meetings Board has approved this paper for publication. It has successfully completed SAE's peer review process under the supervision of the session organizer. This process requires a minimum of three (3) reviews by industry experts.

ISSN 0148-7191

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