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Flex Track for use in Production

Paul Thompson and John Hartmann
Electroimpact, Inc.

Ed Feikert
Boeing IDS

Jim Buttrick
Boeing Commercial

ABSTRACT

Lightweight and flexible automated drilling machines are becoming more common in aerospace industry to address the increase in demand for low cost assembly solutions. Successful production implementation of the Flex Track system has been accomplished by matching applications with appropriate design features. Following the concept of small lightweight machines, which rely on local accuracy and sacrifice stiffness and shear mass, the Flex Track tackles problems on a detail level. This paper describes how the evolutionary progress of the Flex Track drilling system has and continues to address the increase in demand for low cost automated drilling systems.

INTRODUCTION

For an increasing number of applications, automation of the drilling process in aircraft assembly has become a necessity to meet higher rates, improved quality, and ease ergonomic issues. At the same time, current initiatives demand significant reductions in conventional capital outlays to meet long-term unit cost targets. Traditional approaches to assembly automation, which employ large machine tool type systems, require significant investments both in the equipment and the infrastructure required to support it. While this approach remains appropriate for many applications, there are typically insurmountable challenges to introduce these large systems into sustaining programs. Often, the existing part fixtures used to index the assemblies prohibit the integration of large automated machinery, due to a lack of adequate foundations or tooling clearances. The Flex Track system provides an alternate low cost and more flexible approach to assembly automation. By adapting to the part, the lightweight Flex Track system provides local accuracy without the structure, mass and foundation requirements of larger machine tools.

As the Flex Track concept transitions from the research lab onto the production floor, the functional design has evolved to address real world applications. The result has been the implementation of a variety of Flex Track configurations to address different production requirements. In addition, a number of subsystem technologies have been developed and integrated into the Flex Track system to optimize the operational efficiency, accuracy and performance. These improvements range from setup aids to spindle enhancements; examples of these technologies are presented below.

2.0 BACKGROUND

The Flex Track concept was conceived specifically to address areas with limited access, which historically have been restricted to manual drilling. These areas include fuselage circumferential joints and wing skin to spar and skin to rib drilling. (1) Flex Track derives its name from its flexible rail system, which conforms to the part surface contour. Once attached to the airframe, the rails provide a solid foundation on which the drilling carriage rides. The steel rails are designed to adhere to radii of approximately 70 inches, both concave and convex. Multiple vacuum cups are used on each rail. Each vacuum cup uses an individual vacuum generator to develop the required vacuum suction to pull the rails into contour. By attaching itself directly to existing aircraft assemblies, the Flex Track brings portable automation to the part.

The Flex Track's ability to conform to the part effectively reduces a 5-axis problem to a 2D flat pattern. NC control of the carriage and spindle motions provides Flex Track with the ability to drill multiple hole patterns through a variety of material stacks without the need for conventional dedicated drill jigs or multiple set-ups. This inherent flexibility allows Flex Track to quickly and cost effectively adapt to multiple applications with only part program changes. Local accuracy is maintained by resynchronization on key part features coupled with the automatic transformation part geometry into the Flex Track axis system. Onboard normality sensors measure surface curvature, which allows Flex Track to verify and correct for small normality discrepancies in areas of high and complex curvature.

The initial Flex Track concept was based on a rail spacing of approximately 8 inches. This provided the head with cross travel between the parallel rails of about 4 inches. Rack teeth cut directly into the rails provide the mechanical drive hardware for the long axis travel. The initial rail sections provided on the order of 72 inches of X-axis travel.

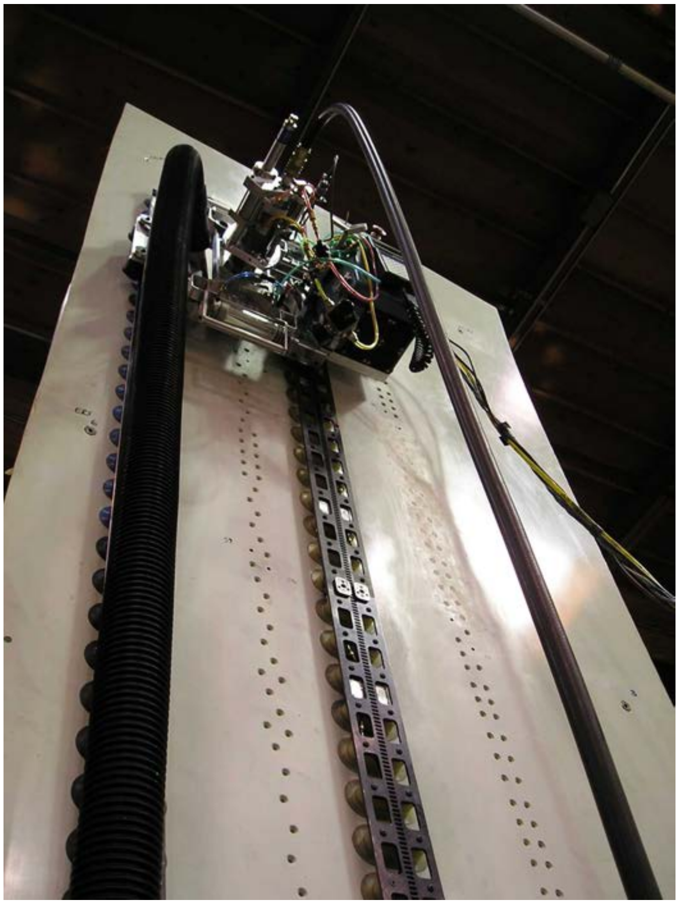

Figure1: Prototype Flex Track

The prototype was successfully demonstrated on a number of trial applications and served as the basis from which the production hardware was developed.

3.0 FLEX TRACK CARRIAGE CONFIGURATIONS

Using the prototype experience, a number of application specific Flex Track configurations have been developed to meet production requirements. Modularity and commonality of components has been a key design driver across all variations. A number of new components have been developed to address both unique and universal challenges encountered when faced with real world applications.

3.1 DOUBLE-ROW CARRIAGE

The Double Row Flex Track (DRFT) system is a productionized version of the baseline prototype Flex Track. The DRFT was developed to drill holes for wing skin to spar and skin to stringer applications. The working envelope for this system is approximately 2 inches between the rails and 72 inches in length. The cross travel provides the ability to drill two parallel rows of holes common to the skin and inner member. Accuracy of these units are +/-0.010 inches in both X and Y over the unit travel. The geometry is well suited to typical wing skin to stringer and spar joints.

The DRFT was designed to drill high tolerance holes up to 5/16" diameter through composite/composite and composite/titanium stacks. The standard Flex Track spindle cartridge is belt driven with an off the shelf Fanuc servomotor. Spindle feed is controlled using a servo driven ball screw. This drive mechanism in conjunction with a fixed relationship between the spindle and the pressure foot insures precision control of countersink depth accuracy. The DFRT spindle speed can be configured with maximum speed between 3000 and 6000 RPM. The spindle accepts HSK 32C tool holders with manual release. Tough titanium holes can be time consuming and previously required multiple setups using manual means or power feed drills. With sufficient power and precision CNC control of feeds and speeds, the Flex Track saves time by finish drilling these holes with the countersink in one shot.

While the Flex Track adapts well to contoured surfaces, the averaging effect caused by the carriage bearing spacing and/or the width between the tracks can affect the ability of the spindle to fully normalize to the complex contour surfaces. For many cases, these effects are small. However, where normality accuracy requirements demand high precision, the DRFT is provided with a rotational correction about the cross axis, or B-axis. Normality sensors are embedded into the pressure foot and are used to sense and verify head to skin normality prior to drilling. Rotational axis corrections up to 5 degrees can be accommodated with the DRFT design.

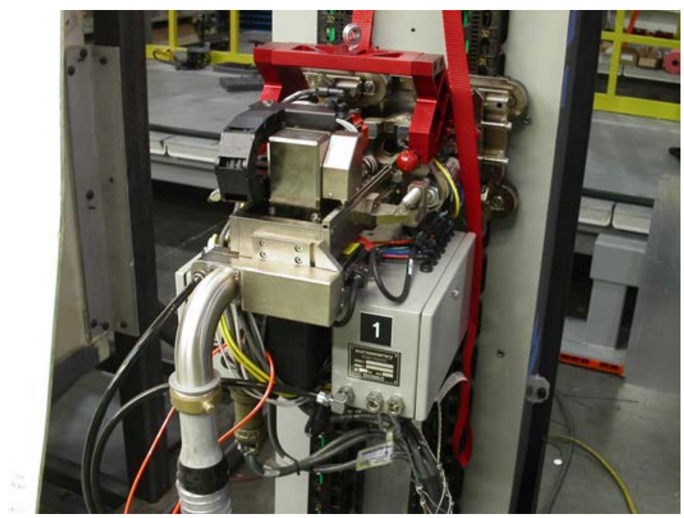

Figure 2: Double Row Flex Track

The DRFT is provided with an enclosed pressure foot, which supports both flood and mist lubrication systems. Flood coolant is guided to the tip of the drill using an air jet delivery system. This unit is equipped with a chip extraction vacuum, which is used to recover all chips and recycle the coolant. Flood coolant recovery typically exceeds 98%, which eliminates the sticky mess typically associated with floor coolant applications.

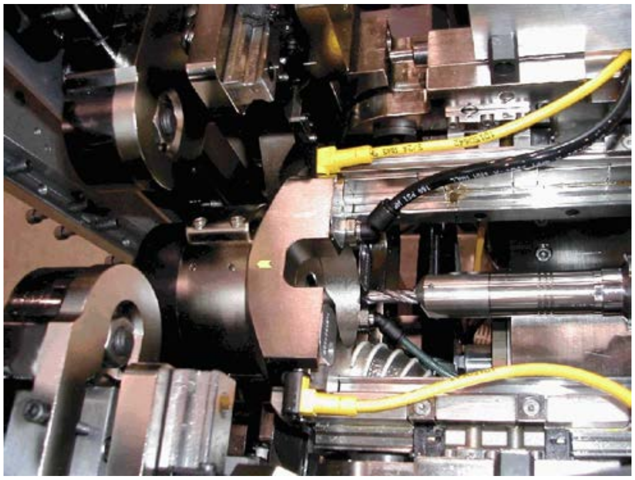

Figure 3: DRFT Pressure Foot

3.2 WIDE CARRIAGE

The Wide Carriage Flex Track (WCFT) design was developed to eliminate the need to perform multiple set-ups. The initial WCFT entered production in April 2005. With up to 20 inches of cross travel between the rails and an extendable 72" of travel along the rails the WCFT is able to cover a large area with only a single setup. Setup times are sometimes the most tedious operator involved operation. The WCFT envelope is particularly well suited to primary splice areas such as fuselage joins, which include multiple fastener rows.

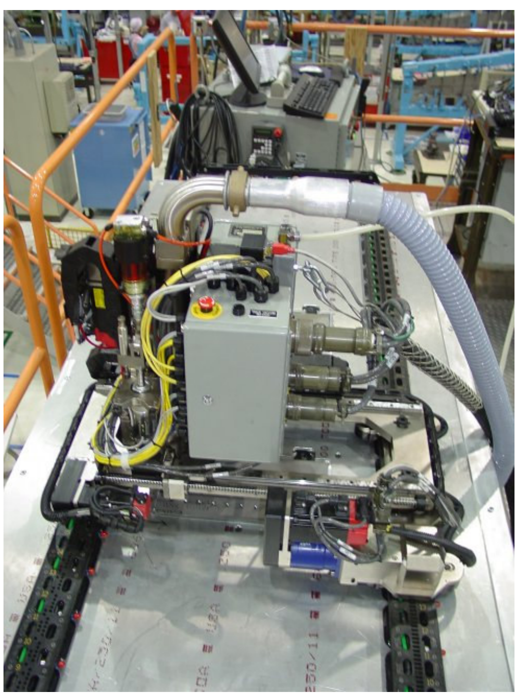

Figure 4: Wide Carriage Flex Track

The Primary components, e.g. spindle, drive components, are common or of similar design with other Flex Track models. Due to the width of the rail spacing, the WCFT is provided with A-axis rotational correction functionality.

3.3 OFFSET CARRIAGE

The Offset Flex Track (OFT) was developed primarily to drill hole patterns along the edges of parts, where the tracks cannot straddle the work area. These applications include the leading edges of wings, ribs, fuselage frames and door surrounds. The OFT provides the capability for drilling both between the rails and outside the rails. The current OFT configuration provides 4 inches of travel within the rails and 4 inches of travel outside the rails. Feedback from normality sensors, common to all Flex Track configurations, insures the system drills normal to the part surface. To overcome normality errors introduced with the non-symmetric loading due to the cantilevered configuration, the OFT is provided with a +/- 5 degrees of A-axis rotational correction similar to the WCFT. The increase work area covers of the OFT has the added benefit of reduction of the number of different setups.

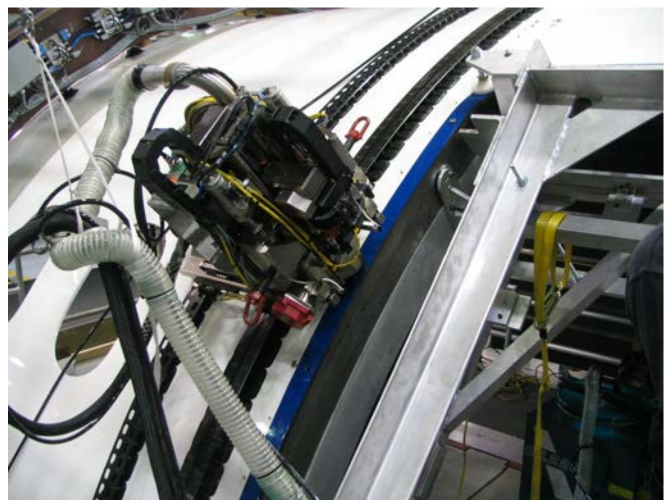

Figure 5: Offset Flex Track

3.4 HIGH TORQUE CARRIAGE

The success of the initial production Flex Track units drove the development of a system with increased drilling capacity. The baseline Flex Track system are capable of drilling up to 5/16 inches diameter holes in titanium and up to 7/16 inches diameter holes composite or aluminum. To increase the drilling capacity, the High Torque Flex Track (HTFT) spindle was upsized to accept a HSK 40C tool holder. The spindle motor frame size was increased to 90 mm, which more than doubled the available drilling torque. The HTFT was developed to address the large hole drilling requirements on the new Boeing 787 aircraft. This system is designed to drill holes up to 5/8 inches through composite materials.

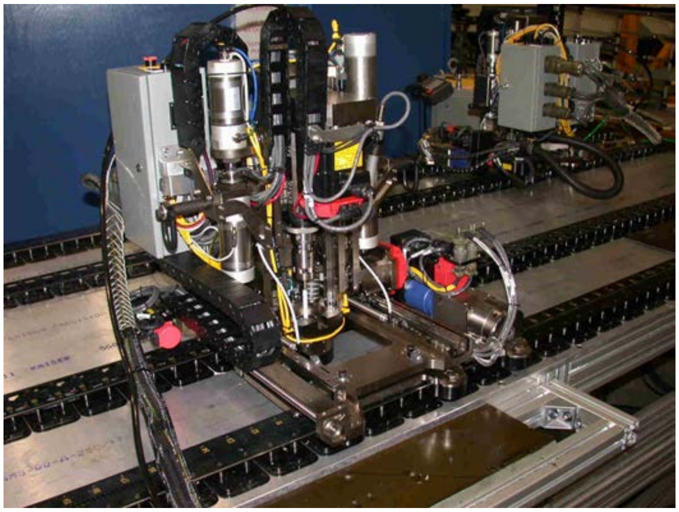

Figure 6: High Torque Flex Track

4.0 FLEX TRACK CONTROLS

The Flex Track system is controlled by a standard Fanuc Powermate control. The control system hardware is contained within a portable cabinet, which can be easily rolled around the factory to meet the changing needs and applications. All control cabling is provided with quick disconnects to enhance portability.

Figure 7: Flex Track Control Box

The Flex Track systems can be run using a conventional CNC style operator interface or through an enhanced PC based front end. Boeing Advanced Manufacturing Research & Development (AMR&D), who led the implementation efforts for the WCFT, elected to develop an in house interface, which could better be integrated with a previously developed vision scanning system. The software control system or Robotic Assembly Cell Control (RACC) used with the WCFT has been integrated with four other systems throughout Boeing and provided a wide range of capabilities without extensive additional software development. The Graphical user interface (GUI) works hand-in-hand with the GE FANUC's pendant. The pendant provides basic machine jogging and machine to PC communication switches. The GUI provides customized operator functions and system tracking capability.

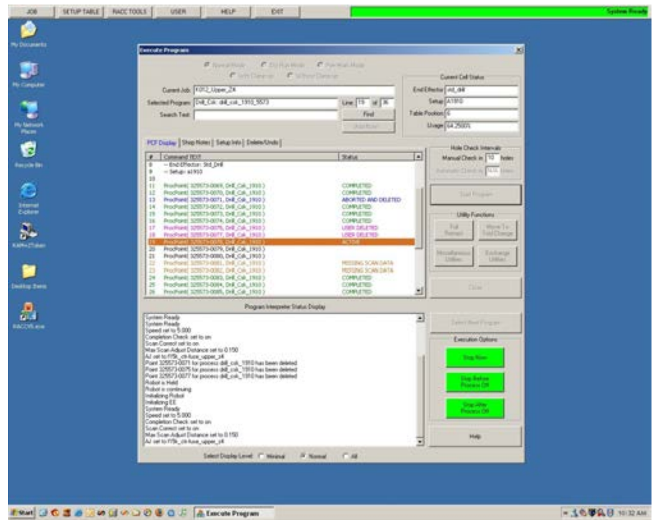

Figure 8: PC Based RACC Provides Common GUI.

4.1 PROGRAMMING

The Flex Track system is a portable NC style drilling system, which adapts to the part and provides local hole positioning accuracy. Since the track conforms to the part, part geometry must be transformed from five dimensional part space to a flat pattern required to suit the Flex Track control. Boeing has developed a CATIA v5 application to automatically generate part programs for the Flex Track drill based off geodesic curves. From the geodesic curves, arc lengths are calculated, which define hole spacing and curved panels. When the machine is placed on a part, it probes reference holes, which are used to transform the dataset into machine coordinates.

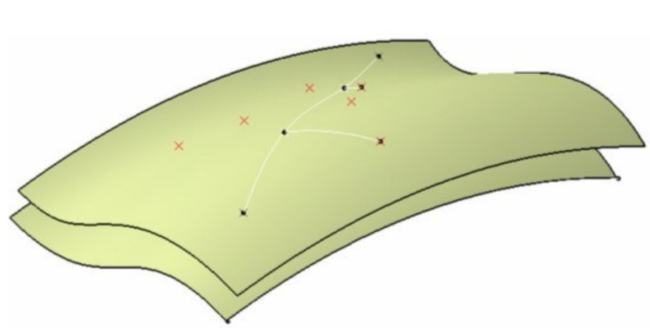

Figure 9: Flat Pattern Generation

The output from CATIA v5 is a *.csv file which contains 2D hole coordinates and hole attributes. This file is then processed by NC Programming where process specific attributes are attached to the *.csv file. The actual machine code is automatically generated by the machine's operator interface.

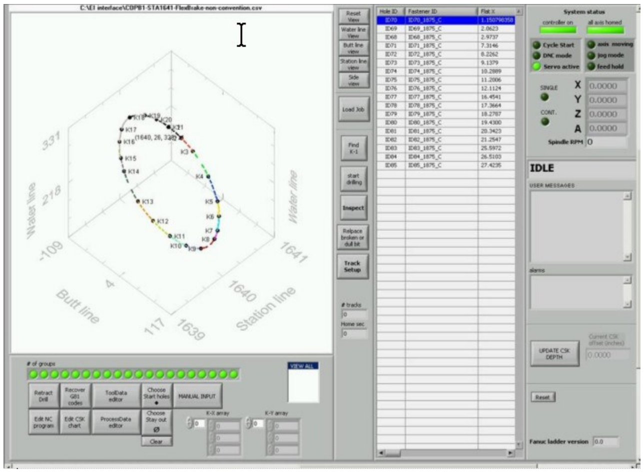

Figure 10: Part Programming Interface

5.0 FLEX TRACK SUPPORT EQUIPMENT

The integration of the Flex Track systems into production has resulted in the parallel development of a variety of support equipment used to optimize Flex Track utilization.

5.1 INTERLOCKABLE RAIL SECTIONS

The standard Flex Track system uses a X-axis rail section, which provides 72 inches of travel. For long runs such as a wing skin to spar joint or a circumferential fuselage splice, additional rail travel is required for optimize utilization. Full-length tracks allow the complete application to be accomplished in a single set up. To address this requirement, interlocking rails sections were developed, which can extend the travel of the Flex Track, in theory, indefinitely. Alternatively, the rails can leapfrog each other, such that the machine can continue to run, while tracks are removed and replaced in front of the machine travel.

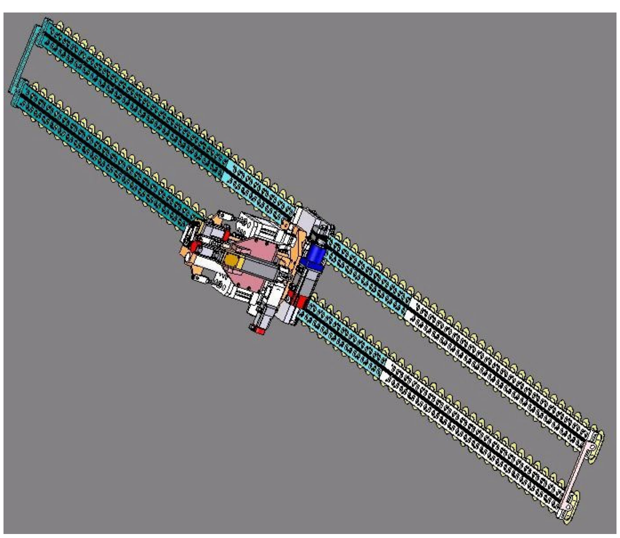

Figure 11: Interlocking Rail Sections

5.2 DATUMING

The Flex Track system provides local positioning accuracy by datuming on known features and transforming its geometry. Various technologies are used to perform this datuming feature.

5.2.1 TOUCH PROBE

One method the Flex Track uses to locate datum holes and features is with a spindle mounted touch probe. A Renishaw OMP40 wireless hole probe mounted to an HSK 32C adapter performs this function. The close proximity to the spindle mounted infrared receiver insures accurate communication during the probe cycle. The wireless feature eliminates nuisance wires. Holes and buttons of any size may be probed to obtain CNC transform coordinates.

Figure 12: Touch Probe

5.2.2 VISION SYSTEM

The Flex-Track optional vision system is used to locate temporary fasteners, holes, and edges on the aircraft. A custom camera mounts on spindle feed axis rails and takes images through the nosepiece when clamped up. These visualized features align the drill patterns to the aircraft to maintain edge margin and pattern location.

Figure 13: Vision System Camera

The system is built around the 640x480 Flea from Point Grey Research. This camera is a compact digital output camera (IEEE-1394) with progressive scan and global shutter. Since the signal carrying cable from the camera will be in close proximity to servomotors, a digital output camera provides better noise tolerance over an analog signal camera. The lens used is a fixed focus, fixed aperture lens sized to provide a vertical field of view approximately equal to the inside diameter of the nosepiece.

Imaging a glass target of known dimension provides camera calibration. This establishes a camera coordinate system, which maps pixel values to engineering units. The camera is then removed, and the Flex-Track drills a hole in a coupon. The camera is then replaced, and the location of the hole determines the offset from the camera coordinate system to the drill centerline.

Lighting is on-axis illumination designed around a Luxeon V from Lumileds. The Luxeon V is a 5W LED that produces 120 lumens of light (700mA continuous operation). The light passes through a cube beam splitter that passes both the image and the light.

The LED, beam splitter, camera, and lens are housed in a single enclosure sealed from the environment on the image side by a clear sapphire filter. This protects the optics and electronics inside from dust, scratches, and mechanical impact. The assembly attaches to the Flex-Track by clamping onto the feed-axis rails.

5.3 SET UP AIDS

A principal feature of the Flex Track concept is that local accuracy is maintained by indexing to preexisting datum holes or features. The tracks therefore do not need to be set onto the parts with high precision. This helps to minimize the set up time. The Flex Track rail vacuum locators provide a further enhancement for both handling and location. The vacuum locators clamp to the tracks. An indexing pin attached to the locator provides rough positioning of the tracks relative to the datum holes. This device locates the tracks sufficiently that the datum holes can then be found using an automated routine.

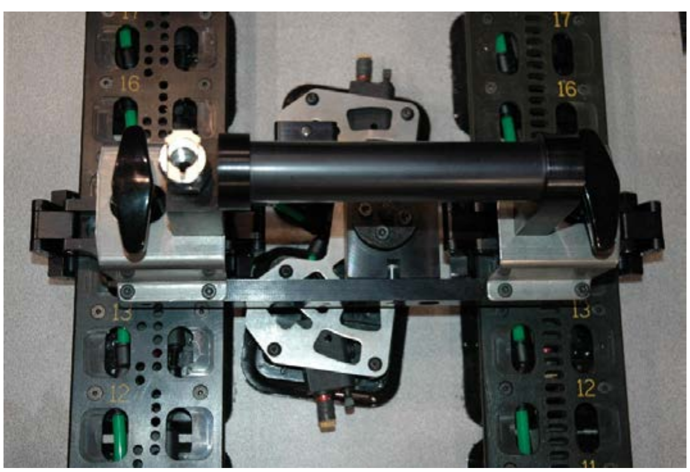

Figure 14: Vacuum Rail Locator

5.4 MACHINE HANDLING EQUIPMENT

Portable machine safety is a big concern; especially when using a piece of equipment, which relies on vacuum generated forces to couple to the work piece. Secondary holding devices need to be attached to the Flex Track to allow the safe and reliable operation without interferences.

Figure 15: Horizontal Flex Track Deployment

While the Flex Track is relatively lightweight, handling equipment is an integral part of the Flex Track design. Challenges include utilizing deployment of the Flex Track into multiple orientations, which include vertical, horizontal, and upside down drilling. Special handling features are integrated into the Flex Track to accommodate the various production applications. The include telescoping counterbalances allow the Flex Track to balance the Flex Track carriage weight and allow the system to fit integrate with a very deep inset on existing tooling.

Figure 16: Vertical Handling with Adjustable Counterbalance

6.0 CONCLUSION & FUTURE WORK

Portable automation puts powerful tools into the hands of operators and provides them with an ergonomic and effective means to accomplish many drilling tasks. Successful production implementation of the Flex Track has been accomplished by matching applications with appropriate design features. Common features provide a baseline automated drilling platform, which is modular enough to tackle tough drilling jobs on numerous applications. The flexible nature of these systems eliminates the need for inflexible dedicated drill jigs.

Using the successful production experience of one-sided Flex Track drilling as a baseline, the next step in the Flex Track development is the addition of fastener insertion. This is currently in work. The ultimate goal is to combine this system with an inner unit to react the clamp up load and allow full one up assembly.

REFERENCES

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CONTACT

Paul Thompson
Electroimpact Inc.
Email: pault@electroimpact.com

John Hartmann
Electroimpact, Inc. .
Email: johnh@electroimpact.com

Jim Buttrick
Boeing Commercial

Ed Feikert
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DEFINITIONS, ACRONYMS, ABBREVIATIONS

Abbreviations & Definitions

CNC: Computer Numeric Controls
FTS: Flex Track System
DRFT: Double Row Flex Track
WCFT: Wide Carriage Flex Track
OFT: Offset Flex Track
HTFT: High Torque Flex Track
GUI: Graphical User Interface
HSK: Industry Standard Tool Holder
LED: Light Emitting Diode
NC: Numerical Control
RACC: Control system provides an integrated control of tool setup and tool life data, NC program execution, scanning data and program location transformation.