Copyright © 2001 Society of Automotive Engineers, Inc.

02FAS-1

Floor Drilling Gantry System

Evert P. Adams
Boeing Commercial Airplanes
Equipment Services

James A. DeLand
Boeing Commercial Airplanes
Manufacturing Research and Development

Tony E. Gale
ElectroImpact, Inc.

Mike J. Ryan
ElectroImpact, Inc.

ABSTRACT

A new process for the drilling of floor panel fastener and fitting holes, plus the installation of fittings has been developed. The process integrates a Laser Tracker to check and align a floor grid assembly; a two spindle, CNC controlled, gantry drilling system to drill the floor grid assembly; a manual work area for the installation of the fittings and other manual work tasks; and a material handling system to move the floor grid assembly through the system. This system provides a cost reduction when compared to replacement cost of previously used equipment. It moves the drilling process out of the fuselage structure, reducing flow time and cleanup. This paper discusses the process requirements, design, and production results for this system.

INTRODUCTION

The Floor Drilling Gantry System was originally designed, and built as a system to replace existing Automated Floor Drilling Equipment (AFDE) for the Boeing 747 aircraft. This new system incorporates features of a moving line process flow by combining the floor build verification, alignment, drilling, fitting installation, deburr, and work hardening processes into one line.

This new process:

1. Eliminates the need for five (5) AFDE machines that drill floor grids inside of the fuselage. These machines were due for replacement thus affecting a cost savings as the Floor Drilling Gantry System costs less than the replacement cost of the 5 machines it replaced.
2. Increases machine utilization as 747 floor assemblies are now processed through the floor drilling gantry system, rather than have machines positioned at several dedicated locations dependant on the floor section being drilled.
3. Moves the drilling process out of the fuselage resulting in a flow time reduction as well as eliminating the requirement to clean chips out of the fuselage structure.
4. Eliminates hard tooling used to locate fittings. This results in a cost savings.
5. Eliminates manual labor processes, as all freighter fitting hard point locations in the past had to be located by fixed tooling and drilled by hand. Now these locations are determined by an automated probe routine and drilled by the system.

PROCESS

DESIGN PARAMETERS

The Floor Drilling Gantry System is designed to drill floor panel fastener and fitting holes plus install fittings on wide body aircraft floor panel assemblies, outside of the aircraft body structure. It can accommodate assemblies up to 6.7 m wide by 16.76 m long by 0.37 m thick.

Other design parameters include:

1. Concurrent work processes on a single floor grid assembly i.e. drilling, manual fitting installation, inspection, etc.

2. Multiple floors in the system at the same time (material handling system can handle two floors at the same time).

3. Maximize simultaneous spindle use (use both spindles at the same time).

4. Minimize the hole-to-hole drilling time, by minimizing the time it takes to position the spindles from hole location to hole location.

5. Enhance the safety of the fitting installation process.

6. Increase system reliability by locating service access points in easily accessible locations; extensive use of visual management, simplify mechanical systems; enhanced system status reporting via the CNC.

PROCESS FLOW

The process starts with the attachment of a tooling fixture called a strongback to a floor grid assembly. The strongback is used as a transportation and pallet fixture as the floor grid assembly is moved through the system, from initial assembly to installation in the aircraft. The assembly is transported, by trailer, from the build area to the floor drilling and fitting installation area. There the assembly is loaded via crane onto the floor drilling material handling system, where it is automatically coupled and prepositioned for build verification and alignment.

A laser tracker (Leica LTD500 with DME) is used to check the floor grid assembly for dimensional accuracy, proper mounting on the strongback, and angular alignment to the floor drilling gantry (gantry). A manual (pneumatic powered, man aboard, manual positioned) gantry is used in this area to provide access to the top of the floor grid assembly for the installation/removal of laser tracker targets and other operations. The system is designed to adjust the floor grid assembly on the strongback (for straightness) and then to rotate the strongback in the X – Y plane, parallel to the gantry. On completion of the laser tracker check, the floor grid assembly is ready for advancement into the gantry for drilling. Note: the laser tracker is used to check the volumetric position accuracy of the gantry spindles.

The material handling system maintains the floor grid assembly alignment to the gantry as the floor is advanced through the system.

Prior to bringing the assembly into the drilling zone, the gantry spindles are checked against two, pneumatically powered, pop-up monuments (Gantry Reference System) for positional accuracy. The spindles are compared against each other for each monument. Renishaw probes are used in each spindle, with system control via a CNC probing routine. Note: The probing data is saved and compared against prior runs to check for any positioning anomalies.

On completion of the Gantry Reference System probe routine, the floor grid assembly is advanced via the material handling system, as controlled by the CNC, into the drilling zone. A known reference point on the floor grid assembly is probed to determine X-Y-Z translational position coordinates. The system operator uses the gantry video system to verify and adjust probe position to find the reference point. With the reference point located, an automated probe routine is run, determining part location and the part coordinate system. With the assembly coordinates determined, a tool change operation is initiated via the part program starting the marking and drilling sequence. Note: the Gantry system is designed to mark, with ink, potential hole locations, and drill holes at programmed positions. The marking / drilling zone is 6.7m in the horizontal direction by 4.3m in the longitudinal direction.

When drilling is completed in the first zone, the floor grid assembly is advanced to the next zone. While the second zone is being drilled, quality assurance inspection and manual fitting installation are performed on the first zone. This process is repeated until the last zone is drilled and the fittings have been installed.

To eliminate the need of drilling the floor grid assembly in two passes: fitting installation holes on the first pass and floor panel fastener holes on the second pass, the floor panel fastener holes in the fittings are predrilled on another machine. The fittings are kitted prior to drilling the floor panel fastener holes. After predrilling, they are re-kitted for installation.

A second manual work area is located at the output of the fitting installation area. This is also the system unload area. A manual (pneumatic powered) gantry is provided in this area for access to the top of the floor grid assembly. Additional processes, such as hole work hardening and other fittings installation, are completed in this area.

The floor grid assembly and strongback are unloaded from the floor drilling system and transferred to the roll over stanchions. After the assembly is inverted (required for installation into the aircraft body structure), it is loaded onto a transportation trailer and sent to the installation area.

Machine

The Floor Drilling Gantry System consists of a rigid gantry that spans across a 6.7m wide by 4.3m long drilling area, which rides on a parallel set of precision beds. This system is CNC controlled by a GE Fanuc

150i control system. Multiple axes are required to drive two independent drill heads across the face of the gantry while additional axes provide part transportation into the drilling area.

Longitudinal Axes

High precision and stiffness are required along the X/U-axes for fast, stable and accurate positioning. Driving the gantry are four GE Fanuc AC servomotors (two on each side) through preloaded double pinion gear trains and racks. These axes are set up in a combination configuration (split / tandem combination). Encoders included in the motors ensure speed detection. Four adjustable preloaded gearboxes, two on each base of the gantry

Figure 1: Gantry Drill Machine (Floor covers not installed)

ensure proper alignment. Heidenhein glass scales provide position feedback. Pitch error compensation on the X/U-axes ensures accurate positioning.

The longitudinal axis is capable of up to 0.635 m/sec velocity (rapid transient setting).

Linear Motor

Linear motors provide fast, compact, and accurate translation of the spindle assemblies on the horizontal axis. The use of magnetics rather than mechanical devices for translation enables full usable travel of the gantry for both heads. One head can be parked on one end and the other head can be used to complete drilling of the entire part.

By eliminating the mechanical devices, such as ballscrews and gearboxes, system reliability and maintainability is enhanced. Velocity and acceleration are also increased. The component limiting velocity for this application is the Heidenhein linear scale. The horizontal axes are capable of: up to 9.8 m/sec^2 acceleration and 1.99 m/sec velocity.

The two spindle assemblies share the same linear motor permanent magnets, linear rails, and Heidenhein linear scale. The scale is capable of supporting two read heads: one for each spindle.

Vertical Axes

Each spindle is positioned on its own vertical axis. The vertical axes are positioned by servo powered ballscrews with pneumatic counterbalance assist. Heidenhein linear scales are used for position feedback. The servo encoders provide velocity feedback.

Each spindle housing is made from aluminum. Aluminum is used to reduce assembly weight, resulting in a reduction in momentum produced by the velocity of the horizontal axes.

Each vertical axis is capable of up to 0.254 m/sec velocity.

GMN High Frequency Spindle

The spindles are 170mm flange cartridge style milling spindles with HSK63a hydraulic powered drawbars, 8kw power output constant from 3000 to 12000 RPM at 100% duty cycle, with constant torque from 0-3000 RPM and additional features.

Each spindle can pick up tools from it's own tool changer located at the end of travel at each end of the gantry.

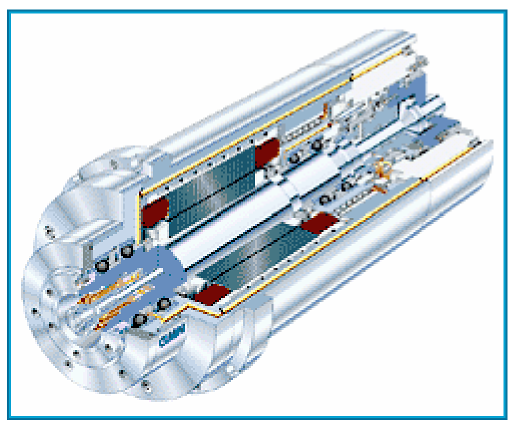

Figure 2: GMN High Frequency Spindle Graphic Courtesy of GMN USA

I-J axes

Minor axes parallel to the major X/U-axes provide +/- 25 mm of travel. The extra travel enables a spindle assembly to position independent of the second spindle head and the gantry. This feature provides for X/U compensation in Y/V for each spindle. Less X/U-axes moves produce faster hole-to-hole drilling times. It enables both heads to drill simultaneously even though the holes are not always in the same X/U position, but can be staggered in X/U up to 40+mm. Both spindles drill together in excess of 90% of the time because of this design.

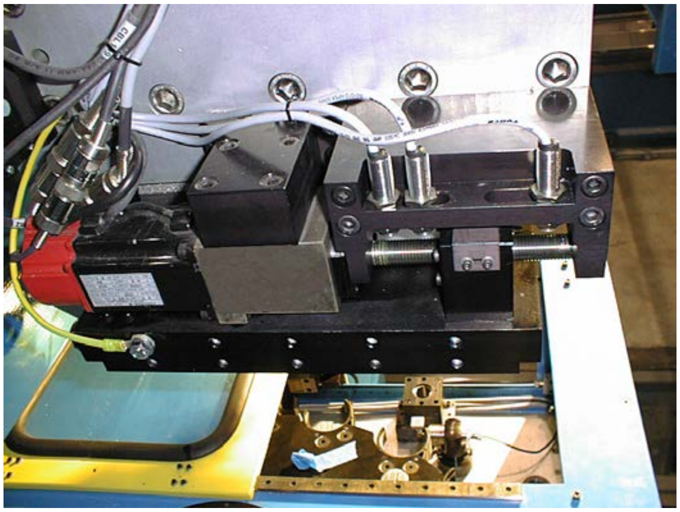

Figure 3: J-Axis

Material Handling

The Material Handling System provides part transportation. This system consists of two parallel outer rails that provide precise rolling surfaces to maintain a fixed assembly height. The center rail, where the drive carriages are mounted, maintains assembly straightness through the system. The guide carriages transport floor grid assemblies through the Floor Drilling Gantry System via GE Fanuc Alpha 6 motors with 8mm gear rack and pinion. Carriage braking, for part stability while drilling, is accomplished by activating an air brake near the linear bearing cars of the carriage assembly. Auto loading of the floor grid assembly provides faster load times and more accurate part positioning. Absolute servo encoders provide system position and velocity feedback.

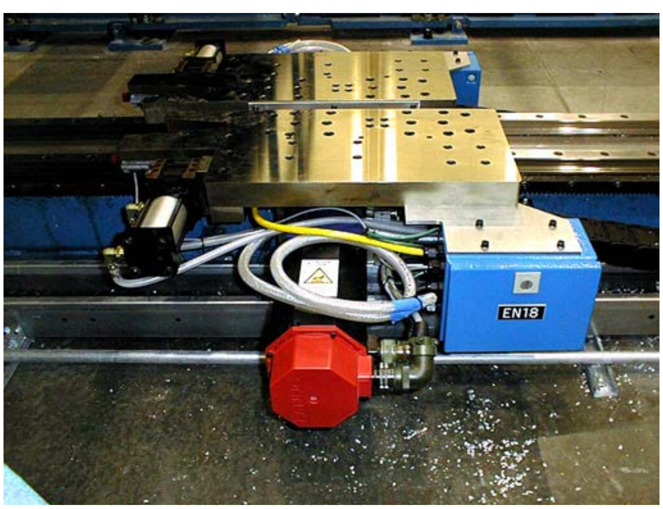

Figure 4: Material Handling Carriages

Laser System

Each spindle assembly has two 1 milli-watt line lasers for creating a visual crosshair at the drill point. The lasers are turned on automatically during probing, drilling or marking process.

There are two functional CCTV cameras. Each spindle houses an overview camera. There are two flat panel monitors located on the operator's platform. Each camera view comes from the backside of the spindle, which provides clear images for positioning and monitoring machine processes.

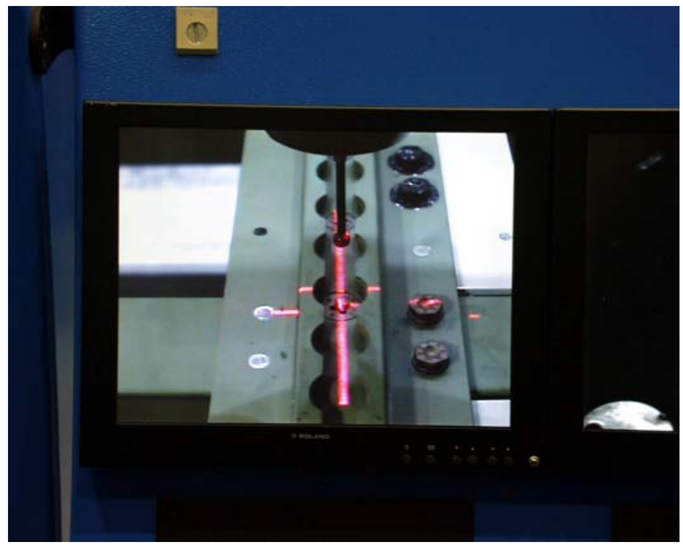

Figure 5: Laser Cross Hair and CCTV

Reference system

A foundation reference system is incorporated into the floor of the material handling system, which extends into the drilling area. Two pop-up posts with precisely located bushings are used to check for inconsistencies of the machine. Each spindle assembly uses Renishaw touch probes (two probes per spindle) to compare hole locations. Note: the probe tips are of a different size. The size of feature being probed is used to determine which probe will be used.

Figure 6: Gantry Reference System

The Renishaw Touch Probe (MP3) is a special tool that is used to measure feature locations and dimensions on the floor grid. It has an IMM/IMP inductive transmission data connection at the spindle, which is used to tell the CNC when the probe has touched a feature. An audible beeper is mounted on the operator console for operator assistance.

The MP3 probe has a wear resistant industrial ruby tip, which is mounted to the end of a ceramic cylinder. This cylinder activates very small switches in three axes. This type of probe works well in determining position of various features of a part. The touch probe is shown in Figure 5.

Automatic Greasing

An air-operated Lincoln grease pump, injectors, and other various supporting equipment supply automatic greasing. The system automatically supplies a specific amount of grease to bearing cars on the machine that are difficult or impossible to grease manually. Manual greasing ports are supplied for alternate maintenance.

Drill Lube System

The Accu-Lube system dispenses a user-adjustable mixture of air and cutting fluid to the drill while undergoing a drilling process. The cutting fluid is injected into an air blast for a short duration during the drilling cycle. The air blast is on continuously. A manually operated, auxiliary air blast nozzle is mounted adjacent to the Accu-Lube nozzle to provide extra air to clear the drill of nested chips.

There is an Accu-Lube unit enclosed on the side of each spindle assembly. On top of the unit is a small reservoir of cutting fluid for immediate use. This reservoir is designed to withstand the spindle acceleration with minimal sloshing.

A large reservoir of cutting fluid is located at one end of the gantry. Two pumps (one for each spindle) mounted near the large reservoir distribute cutting fluid to the small reservoirs. Level sensors (high and low) mounted in the small reservoirs control the pumps. The small reservoirs may also be filled by operator action from the System control panel, with automatic shutoff by the high level sensors.

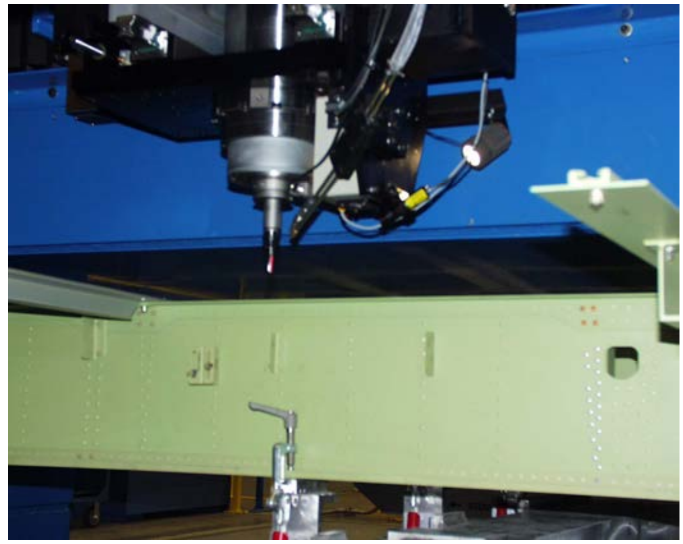

Figure 7: Coolant Application on Tool

Tool changing

The operator may make a manual tool change at the spindle. Each spindle is equipped with a control enclosure that includes: 1) System E-STOP pushbutton; 2) Spindle RUN light; and a manual Tool Change pushbutton. With the spindle stopped, pushing and holding the Tool Change pushbutton activates the spindle drawbar to the tool release/load position.

Automatic Tool changing is accomplished by two horizontal carousel-type toolchangers capable of holding up to 18 tools each. They reside at each end of the gantry. Each toolchanger harbors various tools including drills, probes, and CADO markers. They are housed in a steel cabinet with manual and automatic doors. The manual doors face outboard of the gantry, and are used by the operator to install and removed tools from the carousel. The automatic doors face inboard of the gantry, toward the spindle. They open to allow the spindle to access the carousel horizontally, and close after the tool is changed to protect the tool changer during machine operation.

An operator panel is mounted adjacent to the manual door on each tool changer. This enables the operator to rotate the tool changer to the desired unload/load position and to zero out the tool use cycle counted whenever a new tool is installed.

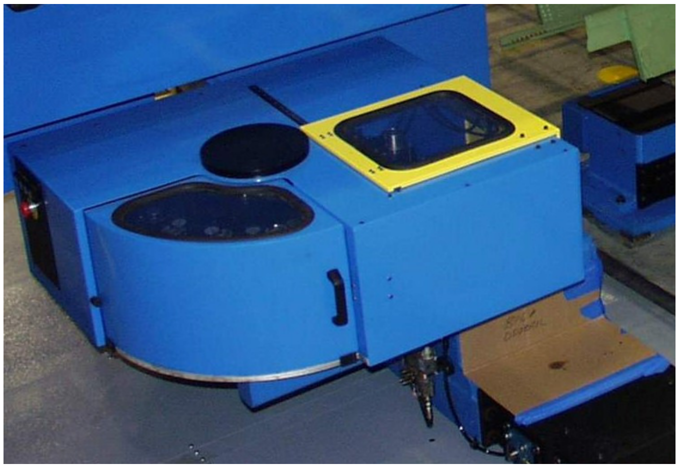

Figure 8: Toolchanger

A tool length probe and a probe ring are mounted in each tool changer. Each tool is checked for length as a part of the tool change sequence. This check sets the system coordinates at the tip of the tool and compares the tool length to the original installation length to check for wear or breakage. The probe ring is used to calibrate the probe system prior to its use.

<u>Control System</u>

A GE Fanuc 150i, A series, CNC is used to control the Gantry system. It includes the standard GE Fanuc display and operator's panels. The system controls 12 servo axes and the two spindles. The CNC control and panels (display and operator) are mounted in the operator's console. The GE Fanuc Drives and discrete I/O are located in the electrical enclosure.

The control system is tied into the Boeing Local Area Network via a Dell Computer with a Microsoft Windows 2000 operating system. The CNC and PC communicate using the GE Fanuc High Speed Serial Bus. This computing architecture allows persons to log onto the system using their standard Boeing network logon, by taking advantage of the network Active Directory (a feature of the Windows 2000 operating system). Persons authorized to logon to the system are only granted user rights that they have been assigned for this system. This architecture provides a conduit for downloading part programs to the CNC from the Boeing part program repository. It also allows for the capture of relevant data used for Statistical Process Control (SPC) as well as Operational Equipment Effectiveness (OEE).

<u>Profibus I/O System</u>

A Profibus I/O system is used to control the Gantry pneumatic system. This system is incorporated into the GE Fanuc 150i CNC as part of its I/O system. The advantage to the profibus system is in its serial communication standard. This allows the use of a wide choice of products from different manufacturers rather than being limited by a single company's proprietary standard. A single profibus I/O system can have devices from several manufacturers, which allows a designer to fine tune the system according to specific application requirements. Another advantage of using the profibus system is that the components are generally smaller and more compact than traditional rack-and-module proprietary systems.

The profibus system is especially useful in simplifying pneumatic valve systems. The only electrical connections to the valve manifold are the communication cable from the node and a power cable. Previous systems required an electrical connection for each individual valve resulting in a large number of cables and many more inputs to which these were wired.

Production Results

1) Fast hole-to-hole times
   a. 1.9 sec with 25mm span through 13mm aluminum
   b. 2.4 sec with 686mm span through 13mm aluminum

2) Machine proving using CADO marker process
   a. Opened up possible drilling areas. CADO marks verified that areas could be drilled.
   b. Verified initial process using a production floor assembly.

3) Machine is holding tolerance of 0.1mm x 305mm x 305mm pattern
4) The machine can drill diameters of 1mm-10mm through aluminum and 1mm-10mm through 690 MPa steel with no problems. Drilling tests conducted with ER-16 tool holders.
5) Able to run 4 floor sections per week with one machine instead of the previous 4 sections with 5 machines.
6) Reduced number of spindles from 20 to 2.
7) The combination of the use of a laser tracker and high machine accuracy highlights inaccuracies in other stages of production.

CONCLUSION

The Gantry System has proven itself in production. The speed and part quality of the process meets all system expectations. The system has been well received by the machine operators and all manufacturing personnel that are associated with it.

The Gantry System has improved the overall efficiency and quality of the floor drilling process.

ACKNOWLEDGMENTS

We the authors would like to acknowledge the contributions and effort of:

1) The Boeing Floor Drilling Gantry Team: who developed the system requirements,

developed and implemented the floor drilling process and managed the system to its completion.

2) The ElectroImpact Design Team: who designed, built, installed and started up the system.

CONTACTS

Evert P. Adams, PE (Electrical)
Equipment Project Engineer
BSME, MSME - Arizona State Univ.
The Boeing Company
Equipment Services & Tooling
evert.p.adams@boeing.com
(425) 717-4158

Tony E. Gale
Project Manager
BSME - Univ. North Dakota
ElectroImpact, Inc.
tonyg@electroimpact.com
(425) 348-8090

DEFINITIONS, ACRONYMS, ABBREVIATIONS

Laser Tracker – A very accurate 3 dimensional laser inferometer.
AFDE – Automated Floor Drilling Equipment
CADO – Spring loaded ink-marking device that fits in a tool holder. Used to mark hole positions, under CNC part program control, on the structure to be drilled.
CCTV – Closed Circuit Television