Northrop Automatic Stringer Driller

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Automatic Stringer Drilling System

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ABSTRACT

Northrop Corporation manufactures body panels for the Boeing 747 aircraft. There are 1259 different stringer configurations used on the three 747 models with an average of 839 stringers per ship set. Until recently, all drain holes and skin coordination pilot holes were drilled manually using plastic application template tools (PATTS). Inventory costs were high and manual drilling errors led to excessive scrap and rework rates. Northrop engineers recognized that automating the stringer drilling process would produce higher quality parts at a lower cost.

Northrop worked with Electroimpact, Inc. to develop the Automatic Stringer Drilling System (ASDS). The ASDS automatically clamps and drills all straight and contoured stringers used on the 747. Stringers are mounted on a rotating platform that provides +/- 90° of motion. Two servo-servo drills are mounted on a cantilevered arm with 25 feet of X-axis travel. An infrared linear encoder maintains the X-axis accuracy within +/-0.002" over the 25 foot work zone. A statistical process control (SPC) system monitors the time, date, axis position, spindle rpm, peak spindle current, feed rate, and peak feed current for each hole drilled. Initial studies show cycle times are reduced by 80% with a dramatic drop in scrap and rework rates.

INTRODUCTION

Northrop Corporation has produced fuselage panels for the Boeing 747 aircraft for several years. There are 1259 stringers used for these panels; an average of 839 stringers per ship set for each of the three versions of the 747. Until recently, skin coordinating pilot holes and drain holes were drilled in the stringers using hand drills and fiberglass templates known as PATTS (plastic application template tools). This manual drilling process was slow, inflexible, and a costly source of scrap.

The manual system using PATT's to drill stringers has a number of significant disadvantages. It takes an average of 27 minutes to drill a stringer using a PATT. The manufacturer must maintain an inventory of 1259 PATT's which is expensive. To minimize the time wasted finding and changing PATT's several identical stringers are drilled at one time, which leads to large stringer inventories and more expense. PATT's are prone to mechanical failures such as loose drill bushings which cause elongated or misplaced holes. In addition, tracking engineering changes and revisions is extremely difficult since PATT's are not very flexible. Even a slight design change might require that several PATT's be physically modified. Overall, PATT's and manual stringer drilling is slow, tedious, and expensive.

The 747 stringer drilling process was an excellent candidate for automation. Several automatic drilling machines were available on the market, but the cost and complexity were enormous for a machine with a sufficient work envelope. A simple machine was proposed - a dedicated system designed for drilling long, thin parts. Called the Automatic Stringer Drilling System, this machine rotates the stringer to provide drilling access to three sides of the part rather than taking the conventional approach of rotating the drilling heads. The result is a compact, cost-effective solution to a complex problem.

Task Specification

Stringers found on the 747 are roughly 3 inches wide, 1-1/2 inches tall and range from 1-1/2 to 24 feet long.

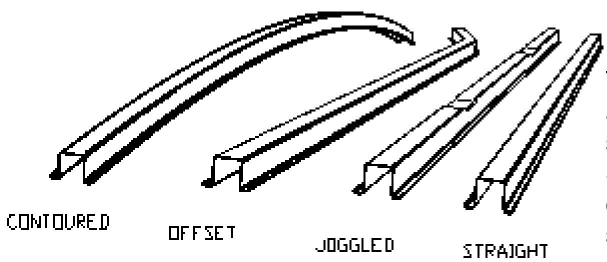


Figure 1. - Four Types of Stringers

They are made of 7075 aluminum alloy anywhere from 0.050" to 0.125" thick. Most stringers are roll-formed. A few are machined. Stringers are straight, contoured, joggled, or offset. Figure 1. above shows the four types of stringers.

Joggled and offset stringers generally require extensive tooling to accommodate their irregular geometries. However, the majority (approximately 75 - 80%) of the stringers to be drilled for the 747 fuselage are straight or contoured. Therefore, simple, easy-to-use tooling effective for straight and contoured stringers was preferred to a complex system compromised for holding irregular stringers.

The primary requirements for the automatic stringer drilling system were simplicity, high speed, and expandability. Since the ASDS would be replacing a manual process plagued by high inventory and maintenance costs, there was a strong emphasis on simplicity.

In order to do the job of several workers using PATTS, the ASDS would have to be much faster than the manual drilling process. In order to meet production rates, hole-to-hole cycle time must be no more than 4 seconds. A stringer with 75 holes would then take 5 minutes to drill. Drilling the same stringer with a PATT requires roughly 27 minutes.

While dedicated machines are often the most effective solution for a given task, Northrop recognized that the ASDS was likely to out-live the process for which it was designed. With that thought in mind, Northrop emphasized the need for expandability. The ASDS should be designed so as to be useful for Northrop's next commercial aircraft program.

DESIGN METHODOLOGY

The ASDS is a dedicated machine tool designed for drilling long, thin parts. The machine consists of a welded steel base, an L-shaped arm, a shuttle table with two drilling heads, and a long rotating part bed on which a stringer is clamped. Figure 1.1 (facing page) shows the overall layout of the ASDS.

The machine base is a self-supporting steel weldment. The top plate is milled to provide a flat surface on which to mount the X-axis bearing rails and the part bed stanchions. Two I-beams provide bending stiffness. Shear plates and end caps insure torsional rigidity.

The machine arm is an L-shaped aluminum weldment which rides on the X-axis bearings. The X-axis is a rack and pinion gear drive equipped with a preloaded split pinion anti-backlash mechanism. Mounted on the back of the machine arm is an electrical junction box. Power and signal cables run from the control cabinets to this junction box through a large cable track. The Arm Control Panel is mounted to the front of the machine arm.

The shuttle table is on the right-hand side of the machine arm. The shuttle table holds two Model 04 servo-servo drill spindles. Drill #1 uses a #30 wire size bit to drill coordinating pilot holes. Drill #2 uses a specially ground 5/16" bit to drill drain holes. When the #1 drill's bit is removed, a Renishaw MP-11 part probe can be mounted in order to digitize parts. The shuttle table is the Y-axis of the machine. Drills #1 and #2 are axes Z1 and Z2 respectively.

The rotating part bed is the fifth axis of the ASDS. Called the A-axis, the part bed is driven from both ends using the split-axis capability of the Allen-Bradley 9/260 CNC control. The part bed has 64 pneumatic clamps that hold the stringer in place while it is being drilled. All 64 pneumatic clamps are controlled as a whole by the CNC. Alternately, sets of four clamps can be manually controlled by the sixteen override valves provided.

FIXTURING - After careful research, it was found that the inner dimension of the stringer "hat" was 0.975" for all rolled stringers and 1.000" for machined stringers. ASDS uses this inner surface to locate stringers in its flexible fixture. Stringers are centered in the 'Y' direction by precision ground steel bars that are bolted to the part bed. These steel parts are 1/2" wide and roughly 1/4" high. Plastic bars cover the steel stock to prevent marring and to provide a snug fit with the inside surface of the stringer. The plastic bars are attached using thumbscrews to allow easy changing for different stringers. Only two sizes are necessary: 0.975" for rolled stringers and 1.000" for machined stringers. All surfaces of the machine that contact the part are covered with non-marring plastic

A stop is mounted on the end of the part bed to locate the stringer in 'X'. With the stringers positively located in 'Y' and 'X', it is not necessary to probe each part before drilling. This greatly increases the cycle rate of the machine.

A stringer is fixed to the part bed by 64 pneumatic clamps. The clamps arms have plastic pads that press against the reverse flange of the stringer. When deactivated, the clamp arms lift and rotate 90 degrees, providing clearance for part removal or installation. All 64 clamps may be activated at once by the CNC, or clamps may be toggled in groups of four using the 16 manual override valves mounted beneath the part bed. Flow restrictors are installed on each clamp to control the rate at which the clamps close. A check valve in the pneumatic system insures fail-safe operation of the clamps. If shop air pressure suddenly drops, clamp force is maintained for a minimum of four hours.

THE ROTATING A-AXIS - A key feature to the design of the automatic stringer drilling system is the rotating A-axis. By providing access to three sides of a clamped stringer, the A-axis eliminates the need for a gantry-type robot with a wrist. These robots are large, expensive, and notoriously inaccurate.

The A-axis consists of a hollow steel tube, called the part bed, which is supported by 17 stanchions along its length. Each stanchion contains a set of precision needle roller bearings. Collectively, the stanchions form a long hinge, allowing the part bed to rotate +/- 90°. The part bed is statically balanced to minimize the torque required to drive it and to minimize twist due to torsional loading.

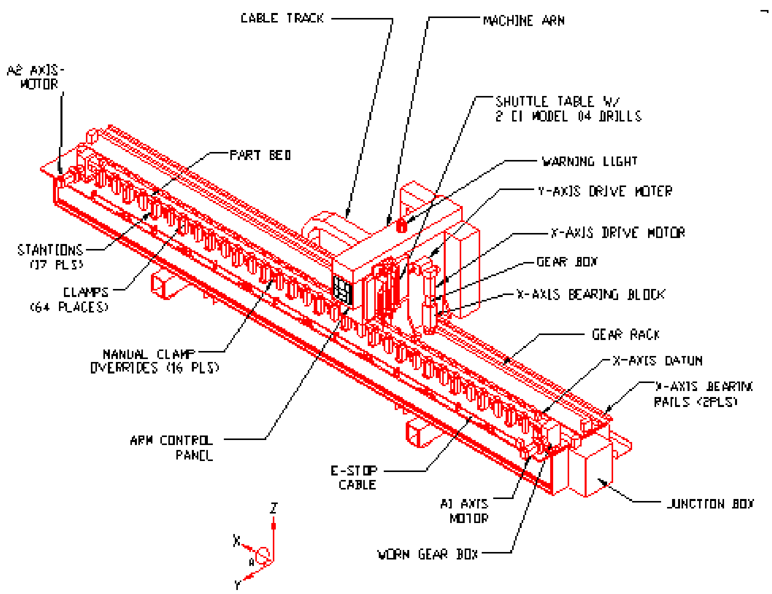


Figure 2. - The Automatic Stringer Drilling System

The A-axis is driven from both ends by servo motors attached to 60:1 reduction gearboxes. This arrangement is necessary to insure the torsional stiffness and accurate positioning of the part bed. The two servomotors are controlled by the CNC as a split axis. In split axis control, feedback from one servo motor resolver defines the axis position. The difference in position between the first motor and the second is called following error. The second motor of a split axis drive is controlled by a simple feedback loop designed to always minimize following error.

The A-axis may be positioned to any angle between -90° and +90°, not just the five positions currently used (-90°, -45°, 0°, +45°, +90°). Maximum controlled feed of the A-axis is 90° / second.
THE X-AXIS DRIVE SYSTEM - The X-axis drive system is a rack and pinion type. It is powered by a DC servomotor through a high-precision planetary gearbox. A split-pinion anti-backlash device was implemented to minimize backlash in the power train. The device has a large drive gear fixed to the pinion shaft and a small anti-backlash gear preloaded by belleville washers. Preload is maintained under all normal accelerations and decelerations.

A Renishaw RG2 Linear Encoder System measures position along the 25 foot X-axis. The RGHD-2 digital read head delivers 5-micrometer (0.00018") resolution. Since the Renishaw encoder was used as a secondary feedback device, positioning errors due to inaccuracies in the rack and pinion drive system were minimized. The X-axis positioning system was tested with a laser interferometer and found to be accurate within +/- 0.002". No axis compensation was used in the CNC control.

THE SERVO-SERVO DRILL UNITS - A prominent manufacturer of DC servomotors was consulted during the design of the Model 04 Servo-Servo Drill for this project. The phrase "servo-servo" refers to the drills servo motorized spindle and servo motor driven feed system. The Model 04 combines an 18 hp, 12,000-rpm DC servomotor with a high precision drilling spindle. The motorized spindle uses neodymium-iron-boron rare earth magnets to achieve the highest possible power to weight ratio.

The Model 04 is a "smart" drill. Drill cycle parameters are fully programmable and closed-loop feedback is available for quality assurance and other purposes. The drill may be configured to use its own "canned" cycles in which parameters are entered directly into the drill controller using an IBM PC, a dumb terminal, or a custom operator interface. Drill cycle parameters include spindle speed, feed rate, rapid advance rate, retract position, end-of-rapid-advance position and full-forward position. Customized cycles such as pecking cycles, multi-material stack up cycles, and countersink cycles are easily programmed. A special "touch-off" cycle, included with the standard control, is used to digitize drill bit length. The drill controller is also capable of monitoring spindle and feed current as measures of drilling torque and thrust. If one prefers not to use the Model 04's internal systems, the drill may be controlled directly by a CNC mill controller. The drill is programmed in the CNC as a spindle axis and a linear feed axis.

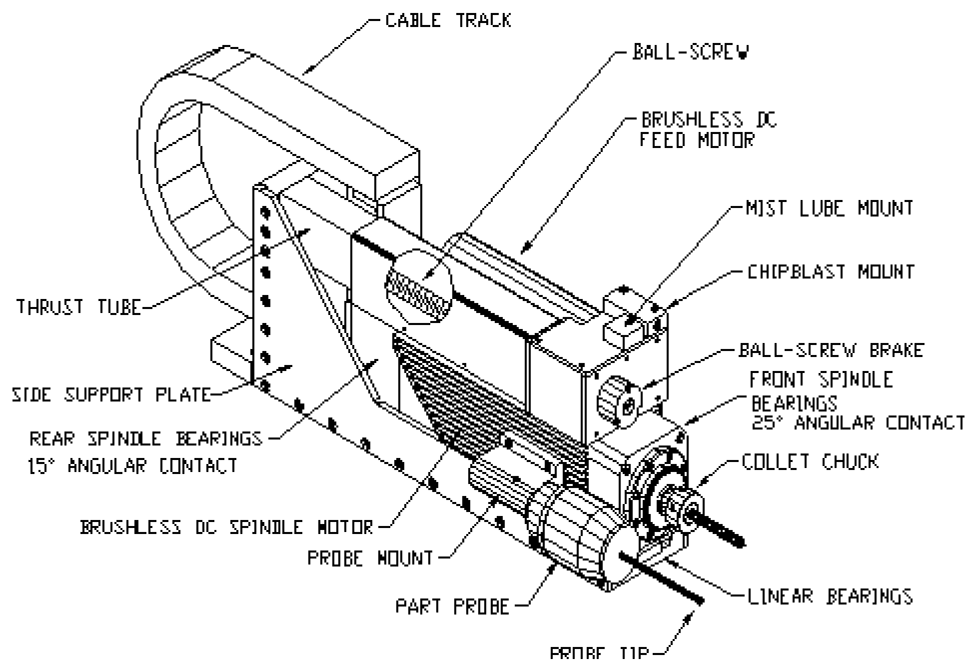


Figure 3. - Model 04 Servo-Servo Drill

The Model 04 is compact (<4.1" wide) and light weight (<50 lb). It may be mounted from the bottom or the rear for shuttle table or wrist-type machines. The Model 04 uses a single-angle 1/2" Erickson collet. The spindle runout is less than 0.0003" at 1" from the collet. Each drill is equipped with coolant mist, and chip blast nozzles. Figure 3 above shows the physical layout of the drill. For drilling 747 stringers, the ASDS only needs to drill two different hole diameters, 0.129" for coordinating pilot holes and 0.313" for drain holes. Specially ground, "piloted" bits were designed for drilling the drain holes. These bits minimize drill walk on the curved surface of the stringer. Since the machine has two drilling heads, tool changes are only necessary to replaced dull drill bits.

The Model 04 drill was designed with a mount for a Renishaw MP-11 probe. With the drill bit removed, spindle #1 may be switched to "probe mode". In probe mode, the feed for drill #1 becomes a CNC axis (the Z1 axis). The CNC controller has a "Z Depth" probe cycle to measure relative distances in the Z direction.

PART PROGRAM MANAGEMENT - Because of the large number of different stringers drilled by the ASDS, a part program management system was developed. New part orders are all tracked by computer. Each stringer to be drilled has a "job sheet" associated with it. A bar code on the job sheet is scanned by the computer in the control cabinet of the ASDS. The appropriate part program is copied from the hard drive of the ASDS computer to the CNC controller. If another part program of the same name resides in the memory of the CNC, it is over-written with the new program. Once a part program is downloaded, the part number for the stringer to be drilled is displayed in a comment field on the CNC screen. The operator simply activates the part program and starts the automatic cycle.

STATISTICAL PROCESS CONTROL - The ASDS includes a statistical process control (SPC) data collection system. The data collection program runs under DOS on a 386 PC. It receives the part program block number and current axis position from the Allen-Bradley 9/260 CNC. From the active smart drill, the SPC system receives spindle rpm, spindle peak current, feed rate, and feed peak current. The time and date are logged each time the SPC system is activated or de-activated and each time a hole is drilled. The data are appended to a file on the hard drive of the PC.

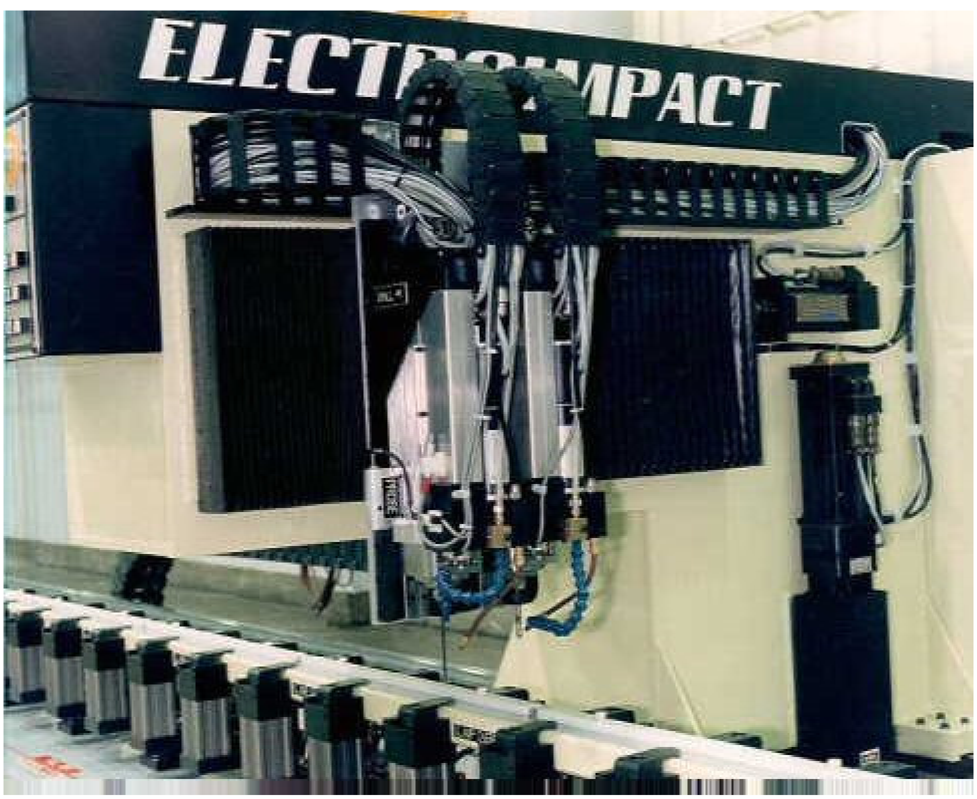
CONCLUSION

Northrop worked with Electroimpact, Inc. to develop an innovative machine tool, the Automatic Stringer Drilling System. The ASDS is replacing hand drilling of straight and contoured stringers on the Northrop 747 production line.

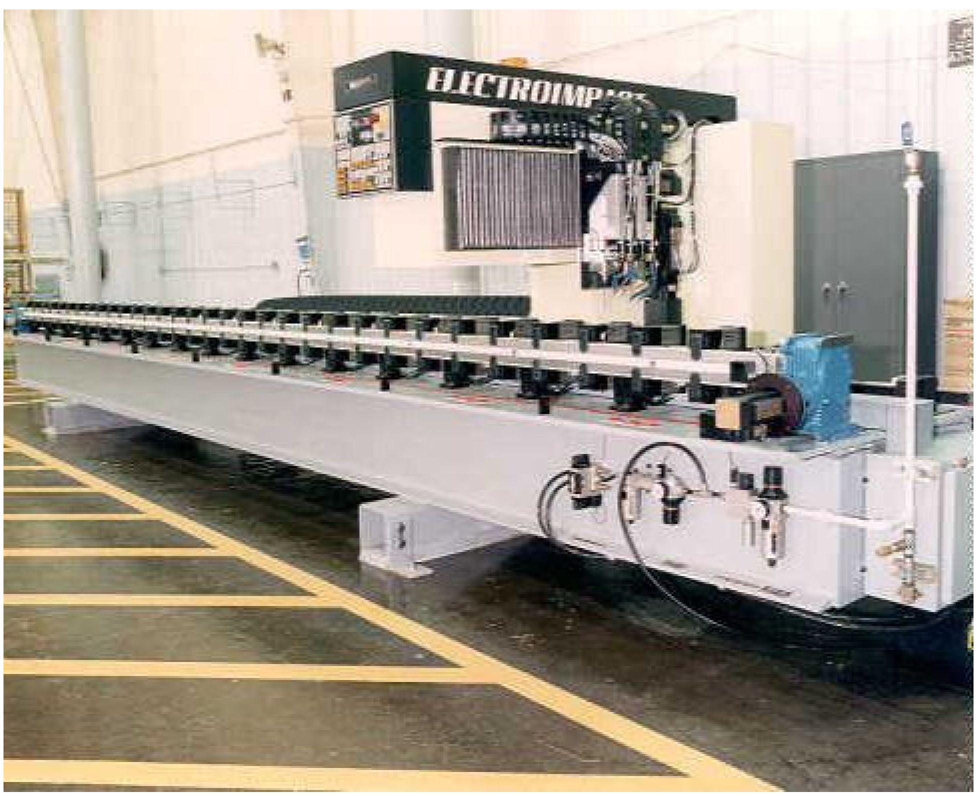
Flexible fixturing allows an operator to simply lay a straight or contoured stringer onto the part bed. No shims or adjustments are necessary. The push of a button causes the 64 pneumatic clamps to engage, firmly holding the stringer in place. The correct part program is automatically downloaded to the CNC when the operator sweeps the barcode wand across his job sheet. The part bed rotates +/-90°, providing access to three side of the stringer. Four minutes later, the two Model 04 servo-servo drills have drilled approximately 75 drain and coordinating pilot holes.
By automating its stringer drilling process, Northrop has improved quality and flexibility while reducing cost. The positioning accuracy of the ASDS is +/-0.002" in the X-axis and roughly +/-0.010" in absolute position. Manual drilling yielded +/- 0.030" positioning at best. Hole quality is vastly improved over the manual process. ASDS-drilled holes are rounder, have smaller burrs, and have no "false starts" as manually drilled holes do. Engineering changes are implemented in software, rather than by physically modifying PATTS. There is no longer a need to maintain a large inventory of fixed tooling (PATTS). Scrap rates are down and are expected to continue to fall as ASDS becomes fully production qualified.

APPENDIX

Picture 1. Arm Control Panel


Picture 2. Machine Arm

Picture 3. Machine and Control Cabinet



Picture 4. Machine with "A" axis rotated 90 degrees