Drive & Control **profile**

Higher Levels of Automation Lift Productivity for Airbus A380 Wing Assembly Process

The Airbus A380—the world's largest commercial aircraft.

Overview:
Electroimpact of Mukilteo, WA, is the prime contractor for supplying automation tools to the Airbus plant in Broughton, UK, which assembles the wings of the Airbus A380, the world's largest aircraft. The assembly process occurs in several phases: 1) wing-panel assembly (Stage 00), which employs four 165-meter-long automated wing-skin production lines using Electroimpact's E4380 riveting-bolting machines; 2) wing-panel manipulators, which use servo hydraulic arms to position the panels for the next stage; 3) wing-assembly production (Stage 01), which uses a massive four-story-high jig that incorporates Electroimpact's HAWDE (Horizontal Automated Wing Drilling Equipment), a portable CNC drilling machine

Challenge

Meet demanding technology specifications for wing assembly of world's largest passenger aircraft.

Bosch Rexroth Solution

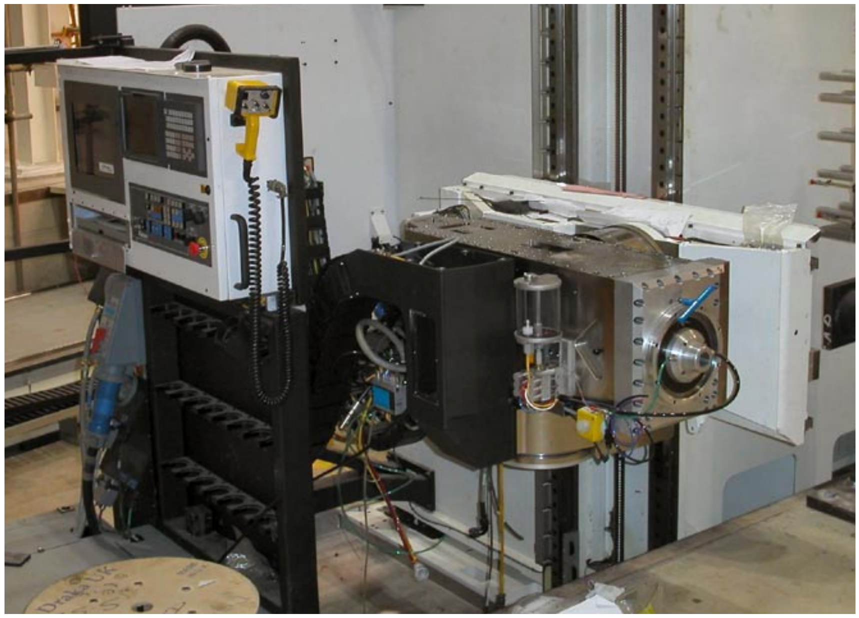
- Rexroth linear guides, ball screws, runner blocks and guideways
- Servo hydraulic arms to transfer wing panels to wing-structure jigs
- Rexroth HNC 100 servo hydraulic controller and servo solenoid valve

Benefits

- High accuracy on machine lines
- Rexroth HNC provides position control with seamless transition between position and force control
- Precise, smooth travel from Rexroth roller rail in GRAWDE machine for drilling Airbus undercarriage area
- High performance technology and support, reduced process time

and hydraulically operated remote-tool/worker-access platforms. This equipment works in conjunction with the GRAWDE (Gear Rib Automated Wing Drilling Equipment) mobile system used for attaching the undercarriage to the lower wing.

Electroimpact collaborated with Rexroth to provide hydraulic and linear-motion solutions to meet demanding technology specifications and tight schedule requirements. Electroimpact needed to phase in delivery of machinery as the facility ramped up operations to position, drill, rivet, and bolt the approximately 180,000 holes needed to produce a single Airbus 380 wing box. Thanks to a higher level of automation, the Broughton plant can employ a process flow model to produce four pairs of wings a month — the largest and most productive wing-assembly plant in the aviation industry.



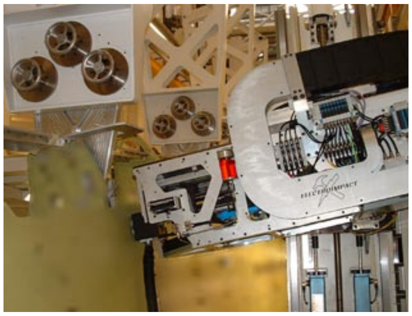
Custom-built Electroimpact HAWDE machine speeds wing-panel production.

Scope of the challenge:
The Airbus A380 is the largest commercial aircraft in the world, and the only twin-deck, four-aisle jet in the air. The base passenger design seats 555 in three classes. The triple-decker freighter design hauls up to 150 tons. By comparison, the U.S. military's tank-transporting C-5 Galaxy can carry only a 135-ton payload.

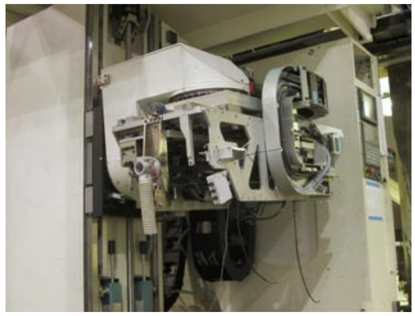
The scale of the A380 is huge: The wingspan is nearly as long as a football field — 261 feet, versus the C-5's 223 feet. Each wing stretches 119 feet from wing tip to fuselage; together, they hold 41,000 gallons of fuel, plus the landing gear. The large wing surface area — 9,100 square feet — improves takeoff and landing performance.

The wing manufacturing process for the A380 consists of creating a framework from spars and ribs — the wing structure — which is eventually covered with a skin of metal panels. Spars run the length of the wing. In addition to front and rear spars, an immense 21-ft.-long x 6-ft.-wide spar runs down the center. Ribs cross the spars, extending from the leading to the trailing edges of the wing.

The E4380 wing panel machine attaches stringers to the skin in the Stage 00 cell.



HAWDE unit automatically drills holes during the Stage 01 wing process without the quality and speed compromises of manual operations.



Close-up of the rotated head of the HAWDE CNC drilling machine used in Stage 01.

Panels, which consist of an aluminum alloy skin reinforced by stringers, are then attached to this framework.

The panels are produced concurrently in a separate operation. First, skins are formed to the proper curvature. Stringers are made to fit that contour, then are attached to the skin to ensure proper shape and strength by the E4380 machines in the Stage 00 cell. The A380's upper wing uses the largest single skin, which is 111 feet long.

The completed panels are then moved to the structure for assembly. After being loaded into a jig, the panels are positioned, drilled, countersunk, riveted or bolted with titanium lockbolts onto the pre-drilled framework.

The entire process is both labor and automation intensive, especially at this scale—a complete "wing box" takes weeks to produce, which, even so, is very fast by industry standards.

Construction of the A380's wings presented several large challenges for Airbus's manufacturing team in Broughton, U.K., and for its prime contractor for wing-assembly automation tools, Electroimpact, Inc.

Focusing on the design and manufacturing of quality aircraft assembly tooling, Electroimpact is known for its engineering culture—nearly 70% of its 250 employees have an engineering degree. Engineers in charge of a program are empowered to take total responsibility, including vendor selection. For the Airbus programs, Electroimpact choose to work with Bosch Rexroth for its best-in-class hydraulic and linear-motion solutions and applications expertise, as well as Bosch Rexroth's distributor, Pacific Power Tech, based in Seattle.

Stages of wing construction

"The assembly process is done in two stages," explains Electroimpact's Ben Hempstead. "For the initial stage, which Airbus calls Stage 00, Electroimpact provided four lines of fixtures for building up the upper and lower wing panels. This is a highly automated process in which riveting-bolting machines traverse the panels attaching stringers to the skin. Virtually no manual labor is required in this cell.

Next, the panels are moved to the structural wing-assembly process. The huge size of a completed panel—up to 111 feet long and weighing 8,818 pounds—poses a big problem. "Using cranes doesn't work," says Electroimpact's Ted Karagias. "The wing panels are distorted when suspended from the cranes."

Stage 00 E4380 machine positioned over panel fixture.

Instead, Electroimpact devised a multi-arm manipulator to maintain the panel's proper form and provide precise positional control while presenting the panel to the wing structure for fastening.

The Stage 01 structural-wing-assembly process is more labor intensive than the Stage 00 operation. The assembled skin panels are positioned by the manipulator into four-story high jigs, which contain other wing parts — ribs, spars, leading and trailing edges. For the upper wing, a combination of mobile drilling machinery (HAWDE) and manpower accessibility is required over the large surface area of the upper wing panels. For the lower wing, holes as large as 1.25 inches in diameter are drilled for bolting the lower wingskins to undercarriage reinforcements.

Starting at stage 00: wing-panel assembly

To manufacture skin panels, Airbus U.K. and Electroimpact teamed up to create a highly automated facility.

According to Hempstead, "We faced several challenges in this program, namely how to bring a fixture of stringers and machined skin panels together in a precise build configuration, while an automated machine tool fastens the components into a skin panel assembly. At this stage, speed, accuracy, and operator safety are critical to this success."

Each wing surface is comprised of five panel assemblies, 20 panels total. The Airbus Stage 00 facility produces 16 of these panels.

Massive, multi-arm manipulator maintains proper wing-panel shape during transfer to the Stage 01 jig.

Traditionally, these panel assemblies were built on manual jigs, requiring many skilled workers to locate and drill holes, pull components apart for deburring and cleaning, apply sealant, and insert two-piece lockbolt fasteners. Panel assemblies were then transported to a riveting machine for final rivet installation. Production rates were limited by the number of jigs in production, worker access and speed, and hole quality and rework requirements. Finished panel quality was also limited by how well the fixture held the components in proper contour.

But Electroimpact believed there was a better way. "Building on our previous work for the Broughton facility, we ended up expanding the system's performance envelope and accuracy of earlier panel production machinery," says Hempstead. "The result is a new generation of wing panel machines. Our design goal was to enable one operator to set up, load NC tapes, verify accuracy, and configure the fixtures."

For the Airbus A380 panel-production facility, Electroimpact built four machine lines, each with two machines for upper and lower surface panels. Each line includes three fixtures, where four panels are loaded. The jigs hold the components in accurate form and location while the automated machines drill, rivet, and bolt the components together. Sealant is applied to the components during the jig load. No temporary fasteners are used.

Thus after fastening, the wing panel assemblies are complete. No interim operations are needed to clean and deburr. The one-up assembly process reduces handling damage and positioning inaccuracies (datum errors). The machines can install rivets and bolts in diameters of 1⁄4 to 1⁄2 inch, with a stack range up to 2.5 inches. Automated cold working, hole probing, countersink sealing, and collar installation are all included.

Achieving high-accuracy goals was possible, because the machines and fixtures used many highly accurate linear axes employing Rexroth linear guides and ball screws. Machine accuracy is a function of deflections of welded and machined components. Typically, deflection and running accuracy of linear guides and ball screws add errors. To minimize deviations, several sizes and styles of Rexroth runner blocks and guideways were specified, because they provide excellent performance on several axes.

Highly pre-loaded roller runner blocks, pre-loaded ground ball screws, and caged-ball runner blocks were employed, because pre-loading ensures rigidity of the system and thereby maximizes accuracy.

"We're designing the machines and fixtures concurrently with the wing design," says Hempstead. "Consequently, some aspects of the design cannot be completed until late in the program. That means schedules and lead times are tight. Fortunately, we've been supported every step of the way by Rexroth.

"Accurate estimation of vendor-supplied product lead-time is critical in keeping assembly on schedule. I'm happy to say that since operation began in March 2003, the Stage 00 facility has been producing assemblies on time and with far better speed, quality and accuracy compared to manual and earlier automated systems."

Interim stage: install panels to wing substructure with manipulators

After the wing panels are produced, they must be moved to the wing-structure jigs. Because the largest panel is up to 111 feet long, the huge scale creates a big material handling problem.

To meet this challenge, an Airbus team of Alan Ferguson, Allan Ellson, and Jim Rowe of Airbus called upon Theodore Karagias of Electroimpact. Karagias headed an Electroimpact team — comprised of Charles Hopper, Remco Spiker, Laurence Durack and Matt Kerschbaum — to devise a solution. Instead of cranes, Electroimpact created an array of six coordinated servo hydraulic arms that engages the panel along its entire length.

According to Karagias handling a wing panel with multiple support points is very difficult. "Basically you have a statically indeterminate system. The panels will twist, bend, and kick as they react to the forces introduced by lifting equipment."

"To overcome this problem, two of the six arms control the vertical position of the panel," says Karagias. "The other four arms act as slaves imparting a constant programmed force upon the wing panel. That way, when the positioning arms are commanded to move either up or down, the load-seeking arms follow along to maintain the panel's form."

Len Hathaway of Pacific Power Tech, Seattle, WA, was instrumental in assisting the Electroimpact team to specify the Rexroth hydraulic components for the project. The primary axis of movement is maintained in closed-loop servo control by a Rexroth HNC 100 servo hydraulic controller. The HNC integrates an SSI linear scale, load cell, and a Rexroth servo solenoid valve. This configuration provides fine position control with seamless transition between position and force control.

According to Karagias, the servo axis provides exceptional control over panel position, and the Rexroth HNC controller imparts several important system benefits, namely:

- Reducing the statically indeterminate problem to a determinate one, allowing flexible wing panels to move as if they are a rigid part.
- Controlling distribution of force imparted upon the wing

A close up view of E4380 machine and Stage 00 jigs.

panel to control the panel's shape and how it is presented to the wing structure.
- Simplifying system level PLC logic and position control instructions.
- Allowing direct access to all critical system components and providing servo control via the SSI port using analog and digital I/O, ProfiBus, and CANbus fieldbuses, regardless of PLC scan rates or network speeds.

When put to the test, the wing-panel manipulator successfully loaded its first A380 wing panel. "It took a lot of teamwork to create this system," notes Karagias. "And thanks to great collaboration, the pieces just fit together beautifully."

Stage 01: wing-structure assembly

After the wing panels are loaded in the Stage 01 jig, two operations are performed: 1) fastening the wing panels to the rib-and-spar structure, which requires automated drilling, bolting, and positioning employing Electroimpact's HAWDE machine; and 2) attaching the undercarriage reinforcement through the lower wing skin, which uses Electroimpact's GRAWDE system.

HAWDE

Based on previous successes, Airbus approached Electroimpact to automate wing-panel fastening to the wing structure. Traditionally, this task is done by drilling, bolting and positioning the panels manually. Automating the process meant overcoming several challenges with unique solutions.

Airbus A380 wing after removal from main assembly jigs.

"The basic challenge was how to transport equipment from jig to jig between port and starboard wings, while accommodating necessary manual work on all vertical levels," says Ryan Haldimann of Electroimpact's HAWDE team. "In effect, the machine tool needed to be transported along Y (vertical) and X (horizontal) directions of travel, similar to a tool head in a gigantic CNC machine."

As a solution, the Electroimpact team of six headed by Rick Calawa created the HAWDE machine — a portable unit that can travel around a panel section by using elements integrated into each jig. To give workers access all around the wing structure, the jig incorporates "flip" flooring. Each flip floor consists of a small platform for worker access, which is pivoted up when the completed wing is removed. A single jig uses 150 flip floors, each employing a Rexroth hydraulic cylinder for smooth, reliable actuation.

Ultimately, four jigs will be in use, requiring 600 Rexroth cylinders.

Because Electroimpact is responsible for both the jig and the HAWDE unit, an unprecedented level of integration was achieved. Right from the initial concepts, all mobile elements of the machine were integrated into the jig. To move the 7000-lb machine from jig to jig, a transporter crane is used. Level-to-level movement employs an elevator that is capable of aligning the machine beds to within .005 inch.

In addition to facilitating worker access, the HAWDE unit must drill holes in the wing where the flip floors are located. To reach areas of the wing where flooring is normally located, the machine performs a "Y-Shift," where the Y-column of the machine extends above its normal position by about one meter. This is accomplished using a Rexroth size 45 roller rail system for guiding, and a hydraulic cylinder for lifting the floor. Thanks to the precision of Rexroth hydraulics, the machine can perform shift maneuvers while maintaining its overall volumetric drilling accuracy.

Movement along the X axis uses a square rail guide way and a gear rack. All other axes use traditional linear and rotational bearings. The machine incorporates a number of tools: a drill spindle capable of up to 7000 rpm in 1⁄4 to 5/8-inch diameters, a bolt inserter for inserting slave fasteners, a hole probe for measuring hole diameters and a camera for synchronizing the machine to positioning (datum) holes in the wing.

In November 2003, the HAWDE machine was put into production. 10,000 holes later, Airbus Team Leaders note: "Manual drilling has always involved some quality or speed concessions. But as far as we're concerned, the HAWDE is operating without such limitations."

According to Haldimann, "Success like this takes teamwork. We've been able to design a machine with a high level of integration into the jig, which makes the HAWDE very easy to use and able to meet all expected criteria."

GRAWDE

Concurrent with wing-panel attachment, Stage 01 production also involves attaching the undercarriage reinforcing and wing skins to the landing gear structure. Titanium flathead bolts up to 1.25-inch in diameter are inserted through a stack of materials up to four inches thick.

"Traditionally, this operation is done manually in wing box assembly jigs," says Brent Thayer, the Electroimpact engineer in charge of automating this process. "But manual hole drilling requires massive drill templates and large positive feed drill motors. The work is physically demanding. In spite of these large tools, the holes must be drilled in multiple steps to reduce the thrust loads, a process which adds process time. Plus, new templates are required for most wing design changes. In view of all the variables, achieving the required hole quality using a manual process is very difficult."

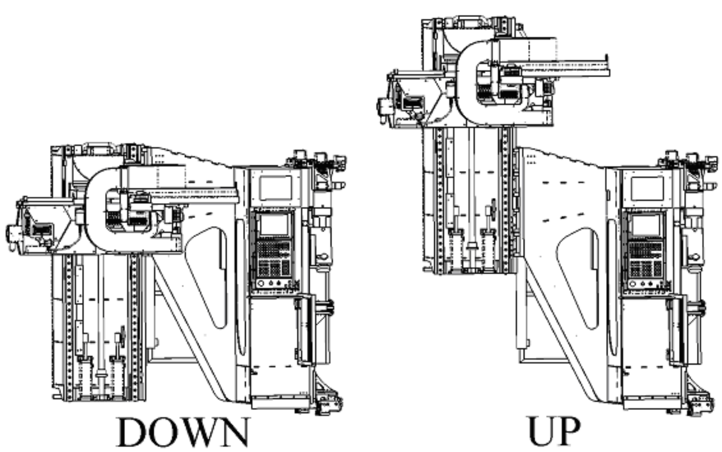
Airbus U.K. asked Electroimpact to explore a more efficient, automated drilling method. But designing automated drilling equipment capable of drilling these holes, yet permitting manual access within the wing box assembly jig, was a significant challenge.

"The time spent drilling in this area of the wing is less than 10% of total wing box build time," he says. "To remain cost effective, the drilling equipment must be flexible and mobile for use on multiple surfaces and assemblies. They use it, then move it."

In conjunction with the Airbus U.K. team, Electroimpact developed a mobile automated drilling system for the A380 undercarriage area — the GRAWDE. The program involved an extensive cutter development effort. The machine can drill up to 1.25-inch-diameter holes with countersink in a single operation and 12 different wing surfaces in total.

Similar in design to a five-axis post mill, the GRAWDE uses a Rexroth roller rail for the X, Y, and Z axes. The Y and Z axes use Rexroth ball screws. These linear-motion components ensure precise, smooth travel to meet tight tolerances.

The GRAWDE machine pushes on the parts being drilled



A drawing showing the variable height of the HAWDE machine for jig clearance.

with a specialized pressure foot to stabilize the wing skin while drilling. Sensors or pre-programmed angles ensure the holes are drilled normal to the curved aerodynamic surface.

As with HAWDE, it was important to integrate the machine with the wing jig. “Over 90% of the wing box build is manual,” Thayer emphasizes. “So an ergonomic design that facilitates manual work access is a must.

“Because the machine needs to drill holes near the factory floor level, the top of the machine beds are located below grade. Bi-fold decking at the factory floor level covers the machine beds and provides proper ergonomic work zones for manual operations. Again, high-performance Rexroth hydraulics are used to move the floors up to provide machine access.

“Like the other programs, the GRAWDE has been a huge success,” says Thayer. “It consistently produces higher quality holes than the manual process, so the hard manual work has been eliminated. Plus, it’s easier to incorporate last-minute design changes, because we can avoid expediting expensive, long-lead-time drill templates.”

Conclusion:

The truly large scale, multi-stage wing-assembly operation for the Airbus A380 involves four programs — panel fabrication, wing-panel manipulation, wing-panel assembly (HAWDE), and undercarriage reinforcement (GRAWDE) — all requiring extensive collaboration between Airbus, Electroimpact, Rexroth, and other vendors.

“The goal was not just to design machinery that automates manual tasks,” says Ben Hempstead, “but also to improve quality and reduce process time. This requires a lot of collaboration with our vendors. In Rexroth’s case, we get high-performance technology, but also high-performance support to meet short lead times and tight schedules. That level of collaboration gives us the boost we need to perform at the levels required for the Airbus A380 wing-assembly facility.”

Rexroth
Bosch Group

FORM Airbus (0207)

Bosch Rexroth Corporation
5150 Prairie Stone Parkway,
Hoffman Estates, IL USA 60192-3707
Telephone (847) 645-3600
www.boschrexroth-us.com