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Automated Riveting Cell for A320 Wing Panels with Improved Throughput and Reliability (SA2)

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ABSTRACT

A new Low-Voltage Electromagnetic Riveting (LVER) machine has entered service at the Airbus UK wing factory in Broughton, Wales, in an assembly workcell for A320 family wing panels. The machine is based on existing Electroimpact technology but incorporates numerous design modifications to process tools, fastener feed hardware, machine structure and the control system. In the first months of production these modifications have demonstrated clear improvements in fastener installation cycle times and machine reliability.

INTRODUCTION

Electroimpact's latest LVER machine entered production at the Airbus facility in Broughton, Wales in November 2006 (Fig. 1). It installs slug rivets, stump-type lockbolts, LGP collars, and flush-head temporary bolts in top surface wing panels in the A320 product family. It is the second machine on the A320 production line, hence the designation "Single-Aisle #2" or "SA2." The first A320 LVER has been producing top surface wing panels for ten years.

The SA2 workcell consists of one machine and two wing panel fixtures. Early in the project we determined that this stand-alone machine would be a development platform for design improvements to reduce fastening cycle time and improve reliability. We sought to combine:

- Technologies transferred from non-LVER Electroimpact machines, such as cartridge spindles and the latest CNC systems;
- Enhancements to the two-tower machine configuration, including more rigid bearing and yoke structures; and
- New concepts in process tool design including the riveting guns, bolt inserter, sealant dispensing, and fastener feed systems.

Figure 1. SA2 wing panel fastening machine.

LVER MACHINE OPERATION

Electroimpact's LVER is a CNC machine tool consisting of two fastening heads operating on the skin and stringer sides of a vertically oriented wing panel assembly (Figs. 1 & 2). The fastening heads are mounted on the legs of an inverted U-shaped structure or yoke. A traveling two-tower gantry supports the yoke via a series of pivoting structures. Servo-controlled axes drive the yoke legs in parallel or differentially to position the fastening heads in five axes (X, Y, Z, A, B).

The fastening heads clamp the panel assembly with loads up to 2000 lb to prevent component separation and interface burrs as fastening operations are performed. A transfer mechanism or "shuttle table" on the larger, skin side head carries a set of process tools which include an electromagnetic riveter (EMR), two spindles, a bolt inserter, a sealant inserter, and a probe for hole diameter measurement. Machines operating on lower wing panel assemblies are also equipped with automated cold work tools. The stringer side head includes an EMR, rotary axis, interchangeable clamp tooling, and interchangeable fastening hardware to form slug rivet tails and swage lockbolt collars.

Various diameters and grip lengths of slug rivets, lockbolts, and temporary fasteners are stored in an on-board feed system utilizing coiled tube cassettes. Fasteners are released from the cassettes and fed through tubing to EMR or bolt insertion tool on the fastening head.

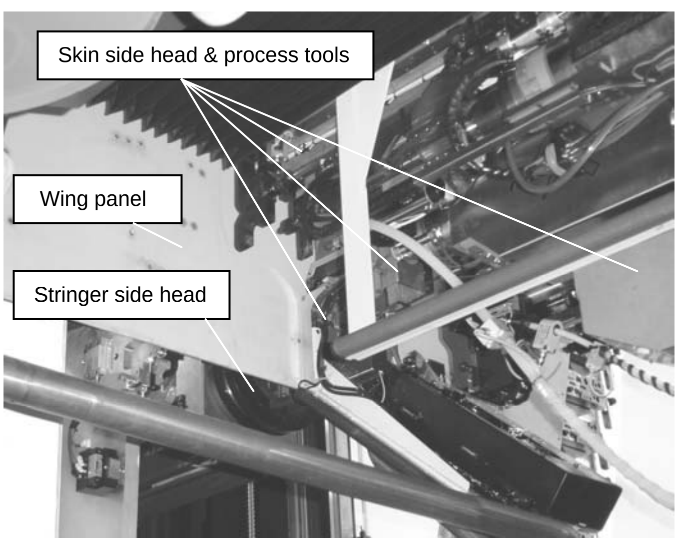

Figure 2. LVER machine fastening heads.

A typical slug rivet installation cycle consists of the following steps:

- Fastening heads clamp on panel and measure material thickness.
- Shuttle table moves to drill position. Spindle drills the rivet hole. Simultaneously, a rivet is fed to the EMR.
- Shuttle table moves to EMR position. Rivet is inserted in hole and measured. If length and protrusion are correct, EMRs fire to form the rivet.
- Shuttle table moves to shave spindle position. Shaver mills rivet head to net height (flush to +.002")
- Fastening heads unclamp. Machine moves to the next fastener location.

A typical lockbolt installation cycle (without cold working) consists of the following steps:

- Fastening heads clamp on panel and measure material thickness.
- Shuttle table moves to drill position. Spindle drills and countersinks the bolt hole. Simultaneously, a bolt is fed to the insertion tool.
- Shuttle table moves to sealant inserter position. Sealant inserter applies sealant to countersink.
- Shuttle table moves to bolt inserter position. Bolt inserter stakes lockbolt in hole and measures protruding length. If staked length is correct, bolt is driven into hole until head is flush with skin surface.
- Stringer side anvil tooling places collar on protruding bolt tail. (Collar is placed before or after bolt driving, depending on which anvil tool is used.)
- Shuttle table moves to EMR position. EMRs fire to swage collar on bolt.
- Fastening heads unclamp. Machine moves to next fastener location.

IMPROVEMENTS ON SA2 MACHINE

In the design phase of the SA2 project we identified several opportunities to improve the speed and reliability of the new machine compared to existing machines. Key areas of improvement are described in the sections below.

RIVET FEED TO EMR

On most Electroimpact LVERs, rivet feed tubes terminate at a U-turn mechanism attached to the side of the clamping foot (Fig. 3). The U-turn guides the rivet to a pneumatically-actuated gripper on the front of the EMR. The gripper places the rivet in the drilled hole, then opens and retracts as the EMR advances to the panel.

Although this system is generally reliable, several characteristics adversely affect long-term performance.

Most prominent is the cycle time penalty imposed by shuttling to a fixed position for rivet feed. By design, hole drilling and rivet feed from the U-turn occur at the same shuttle table position. The two operations occur nominally in parallel. But the drilling operation is often completed first, and the next shuttle move is delayed until the rivet passes through the U-turn and arrives at the gripper.

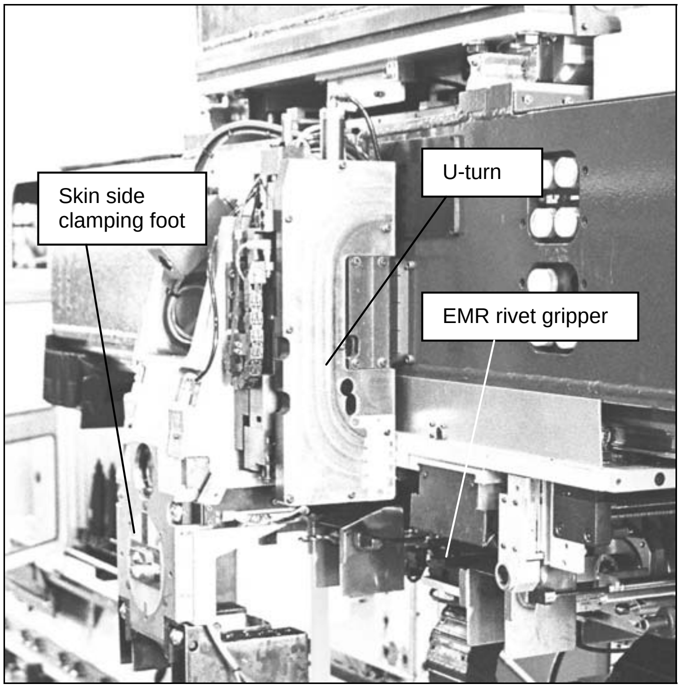

Figure 3. Rivet U-turn on pre-SA2 LVER machine.

Secondly, the rivet gripper is radially compliant around the rivet die, a design feature which enables the gripper to insert the rivet in the hole without scraping. However the spring-centered mounting mechanism requires routine adjustment to keep it centered on the die.

Finally, the U-turn is in an exposed location on the front of the skin side fastening head, where it can easily be damaged in collisions with tooling. It too requires routine alignment, with feed tube exits at top and with the gripper at the bottom.

For the SA2 rivet feed system, the design goals which emerged mechanism were (a) to replace the pneumatic gripper with a passive device, self-aligned to the rivet die, and (b) to incorporate all rivet feed hardware on the EMR or shuttle table, not at a fixed position on the fastening head.

The system developed to meet these goals is presented in a separate paper (2007-01-3783) and described briefly here. A pair of V-grooved fingers ride in slots cut into the driver shaft on either side of the rivet die (Fig. 4). The fingers are spring-loaded in the closed position, with the slot surfaces acting as stops. The slots allow the fingers a small amount of lateral travel when a rivet is gripped along its shank. If a gripped rivet is pushed too far off-center to be cleanly inserted in the hole (i.e. the EMR is misaligned to the hole) one finger runs out of lateral travel and the rivet drops out.

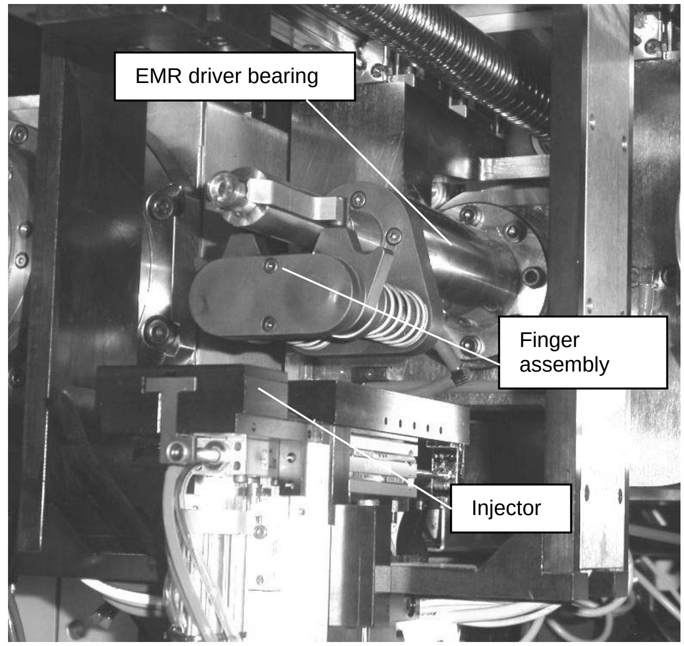

Figure 4. SA2 rivet fingers and injector on EMR.

The entire finger mechanism is spring-loaded axially in the direction of EMR travel. As the EMR advances to the panel, a plate contacts the back of the clamping foot and the fingers are pushed back. The rivet die separates the fingers as the EMR moves forward to the firing position.

An injector attached to the EMR base plate inserts rivets into the fingers. The rivet enters the injector through a feed tube at the rear. A lengthwise gripper traps the rivet against a stopper pin, and a slide moves upward to snap the rivet into the fingers (Figs. 5a-5c). The lengthwise gripper then releases the rivet and the slide retracts.

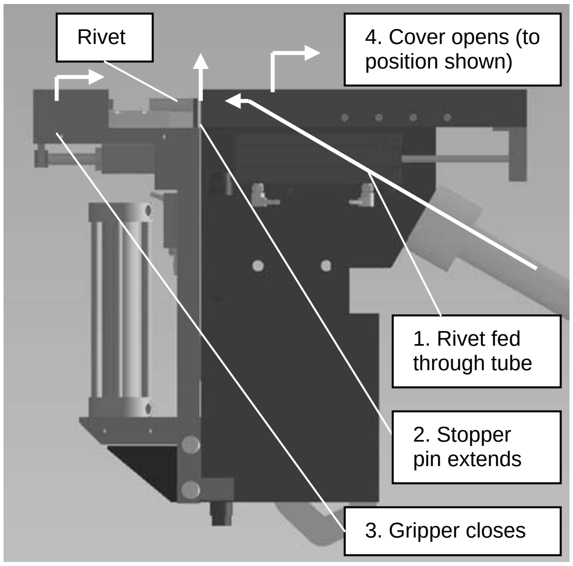

Figure 5a. Rivet feed sequence to injector.

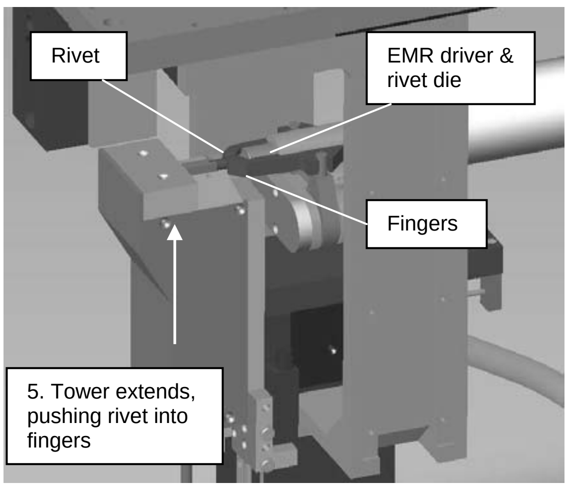

Figure 5b. Rivet is fed into EMR fingers.

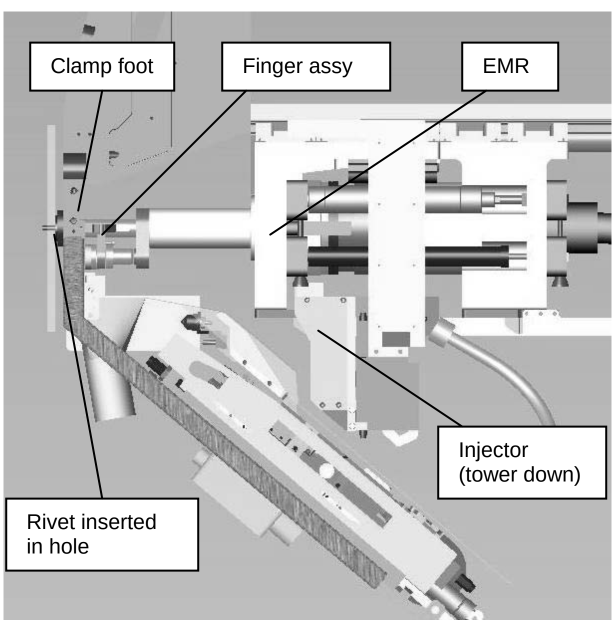

Figure 5c. Fingers insert rivet as EMR moves to panel.

LOCKBOLT CYCLE TIME

Early in the SA2 design phase we recognized that bolt cycle time improvement required two new process tools. The first is a sealant inserter mounted on the clamp foot, instead of on the shuttle table (Fig. 6). A pneumatic slide drives the sealant cartridge and tip toward the hole at an angle. Near the end of travel a cam mechanism redirects the sealant tip motion so it is normal to the panel surface. Sealant is applied as the tip dwells briefly in the countersunk hole. The slide mechanism then retracts. The new sealant inserter operates during the shuttle move between the drilling and bolt insertion positions. This eliminates sealant application and a “shuttle to sealant” move from overall bolt cycle time.

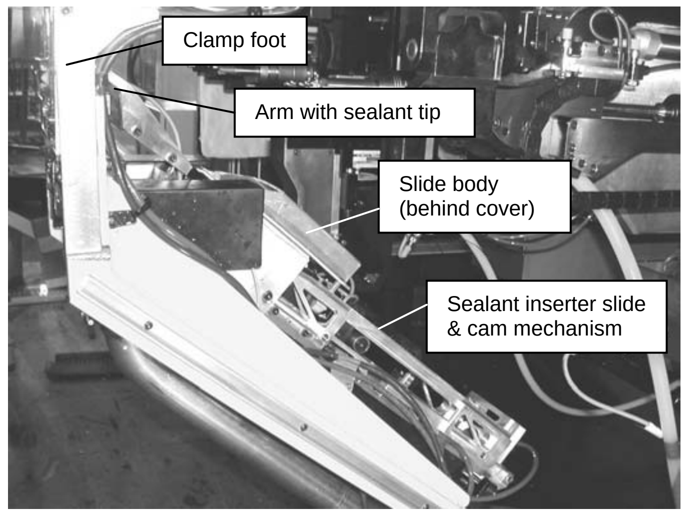

Figure 6. SA2 sealant inserter.

The other major improvement in the bolt installation cycle was the Electromagnetic Bolt Inserter (EMB), which combines a rattle-gun hammer with an EMR (Fig. 7). A bolt delivered through the feed tube is received in plastic fingers at the front of the tool. After a length check the bolt is staked in the hole and measured again. The hammer drives the bolt flush with the panel. The collar is placed on the bolt tail either before or after the bolt is driven, depending on which stringer side anvil tool is used. Immediately upon completion of bolt driving and collar placement, the EMB and stringer side EMR fire simultaneously to swage the collar. The EMB eliminates a shuttle move from the bolt inserter to the EMR for collar swaging, further reducing overall bolt cycle time.

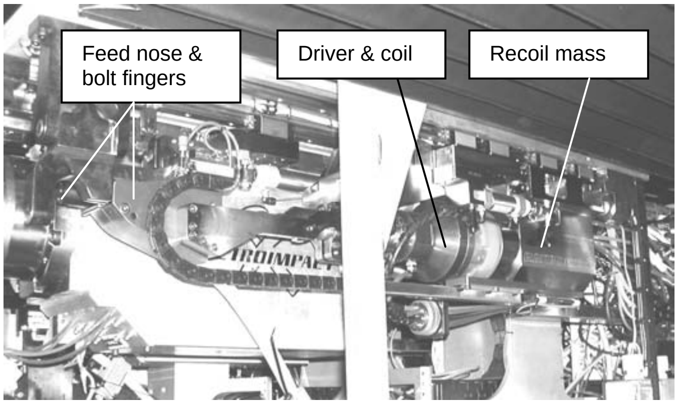

Figure 7. Electromagnetic bolt insertion tool (EMB).

In contrast to the lockbolt cycle mentioned above, the new cycle is as follows:

- Fastening heads clamp on panel and measure stack thickness.
- Shuttle to drill spindle; drill / countersink hole.
- (Apply sealant to countersink while shuttle table moves to EMB position.)
- (Feed collar on stringer side, before or after driving bolt, depending on which anvil tooling is used.)
- Shuttle to EMB; drive bolt into hole; immediately fire EMB and stringer side EMR to swage collar.
- Unclamp and move to next fastener location.

FASTENER BUFFER

On pre-SA2 LVER machines a basic operating mode is “automatic fastener selection” or AFS. The fastening heads clamp on the wing panel and measure material thickness. The appropriate fastener is then released from its cassette and transmitted through the feed system. The feed process can be a limiting factor in speed of the overall fastening cycle. For smaller diameters and short grip lengths, hole drilling occurs quickly and the cycle is delayed until the fastener arrives at the EMR or bolt inserter. Delays on the order of 10-20% of the overall cycle time are typical.

Fastener feed delay can be mitigated by programming the grip length for each fastener location, based on actual thickness measurements or 3-D part models. The programmed fastener is fed immediately at the start of each fastening cycle. Another method for reducing delay time is to feed another fastener of the same length as soon as the current one is installed. The fastener is “staged” at the bolt inserter or U-turn until installed in the next fastening cycle. This scheme assumes that material thickness remains constant from one fastener location to the next.

These techniques reduce but typically do not eliminate cycle delay, and involve a certain degree of guesswork. Programmed grip length is not always the correct one, due to manufacturing tolerance stackups, or if NC programs originally based on 3-D models are not verified on the shop floor. Predictably, the constant-thickness assumption is sometimes wrong. When the fastening heads clamp and measure the panel thickness, the machine controller determines the grip length actually required. A new fastener is fed and the incorrect one is rejected. Rejected fasteners are dropped on the floor, creating a housekeeping nuisance. Re-feeds have a detrimental effect on cycle time, essentially negating any rate gains from the fastener-staging method. As the NC programs become better developed, fastener staging can be selectively disabled in areas where material thickness varies widely, and the machine reverts to the relatively slower AFS mode.

The design goal for SA2 was to minimize fastener feed delay for all fasteners by feeding them over the shortest possible distance. A multi-fastener buffer was developed to hold all (approximately 30) combinations of fastener type, diameter, and grip length. The buffer is mounted on the yoke, just behind the skin side fastening head, a short distance from the process tools (Fig. 8). The buffer consists of an array of escapements, each one holding a different fastener. A servo-driven shuttle mechanism traverses the escapements. Immediately upon machine clamp-up and panel thickness measurement, the shuttle moves to the appropriate escapement and actuates it. The correct fastener is sent directly to the EMR or EMB through an exit tube at the bottom of the shuttle. Feed distance is approximately eight feet and fastener travel time is negligible. When the EMR or EMB reaches its operating position, the fastener has already arrived.

Fasteners on SA2 are stored in coiled-tube cassettes on a large rack, as on previous LVER machines. Feed tubes from this rack lead to entrance ports on top of the buffer’s shuttle mechanism. When a buffered fastener is sent to the tool, an identical fastener is released from the appropriate cassette to replace it. Buffer replenishment occurs in the “background” and adds no time to the fastening cycle.

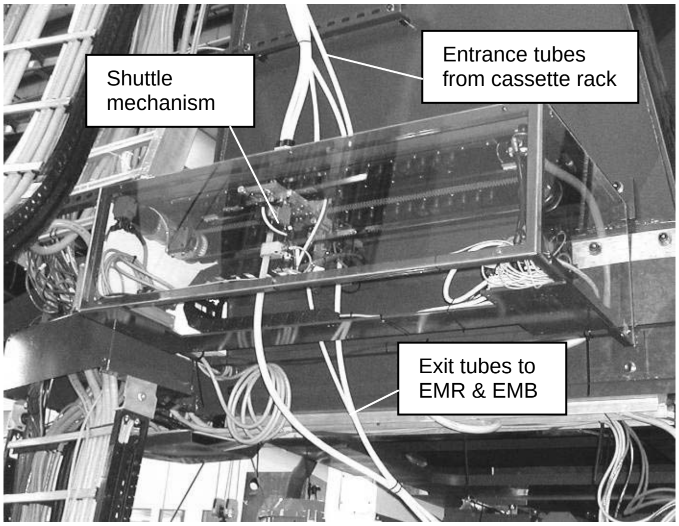

Figure 8. SA2 fastener buffer.

SIMPLIFIED COLLAR FEED SYSTEM

The collar feed systems originally supplied with pre-SA2 LVER machines utilize coiled-tube cassettes similar to those which store rivets and bolts. Collars are fed axially through round tubing to the stringer side fastening head. They pass through an intermediate device called a “spinner,” which carries them from the fixed end of the feed tube to the anvil which can rotate ±180°. At the anvil, a small gripper on a 2-axis stage presents the collar to the swaging die.

Reliability issues with this system affect cycle time over the long term. In the cassette, collar advancement is erratic due to air flow through the collar bores. The collars collide repeatedly in start-stop motion as they advance, which can deform the collar ends until they do not fit on a bolt. On the anvils, precise alignment is required between the gripper, feed tube exit, and the swage die. Gripper misalignment at the die causes cocked collars or misfeeds, for which the machine operator’s common remedy is to reject the collar and feed another one. The rejected collar is dropped on the floor or into the stringer.

The SA2 machine uses improved collar feed technology which Electroimpact has developed in the last three years and deployed on several Airbus LVER machines. Paper # 2005-01-3300, “Sideways Collar Anvil For Use on A340-600,” presented at the 2005 SAE AMAF conference, provides details of a “gripperless” collar feed system for use under stringer flanges, where offset tooling is required (Fig. 9). Collars are fed directly to the anvil sideways through rectangular tubing. The final segment of the feed path is defined by machined features on the anvil and ram. A plastic sleeve stops the collar at the swaging die, whereupon the ram moves forward slightly to trap the collar between the stringer surface and the bell-mouth of the swage die. This system has no moving parts other than the ram, and requires no alignment except the setting of correct ram position relative to the stringer.

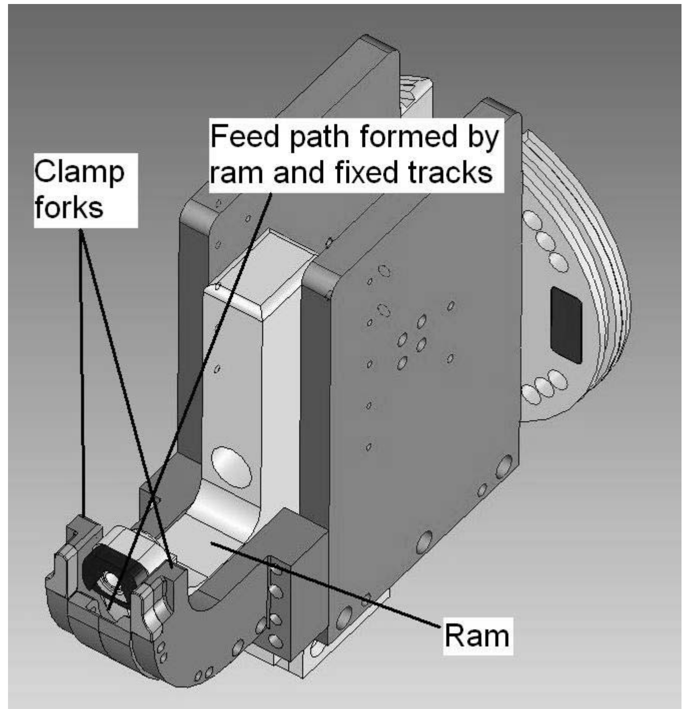

Figure 9. Anvil for offset collar installation.

Electroimpact has also developed a straight tool for collar installation (Fig. 10). This tool utilizes a single-axis gripper with compliant fingers, which presents the collar to the swage die. A spring-loaded pin in the die stabs the collar as the ram moves forward. The gripper then retracts, releasing the collar, and the ram moves forward to the stringer to present the collar to the hole. When the bolt is driven into the hole and through the collar, it displaces the spring loaded pin which retracts into the die. The EMRs then fire, swaging the collar normally with no interference from the pin.

The gripper on this tool is contained between the anvil plates, and has no adjustable stops that may loosen up over time. The well-defined feed path on both tools virtually eliminates cocked collars, and correct collar feed is verified by robust methods. On the straight tool a proximity switch detects the collar’s presence on the pin. For the offset tool, the LVDT which measures rivet protrusion on the EMR also serves as a collar detection device. The LVDT indicates whether the ram is in the correct “trap” position, (collar held between the swage die and the stringer flange), too close to the stringer (indicating no collar), or too far from the stringer (indicating debris or a second collar in the feed path).

A key feature of the new tools is that collars are stored and fed in a sideways orientation. Storage is in coiled-tube cassettes, as in the old system, but the new cassettes and feed lines utilize rectangular tubing. Compared to axially-oriented collars in round tubing, this arrangement provides more consistent collar feed with low air flow, and reduces damage to the collar ends as the collars work their way around the coiled tube.

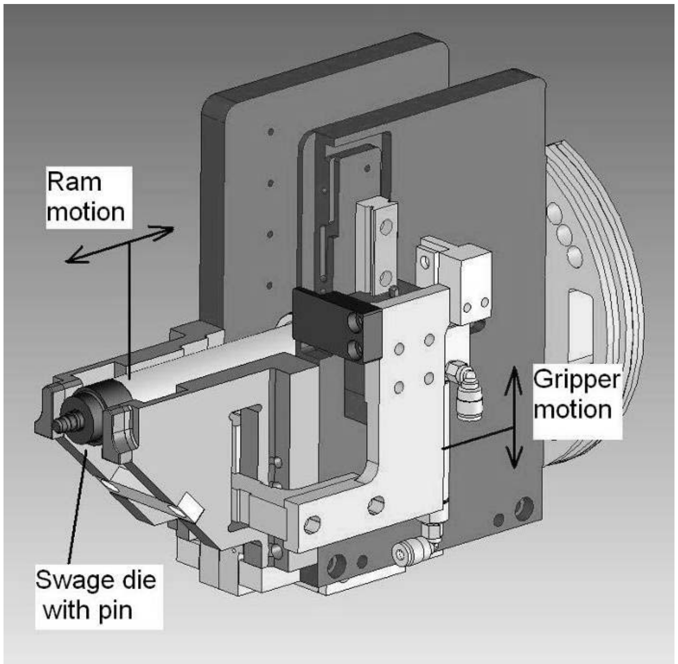

Figure 10a. Anvil for straight collar installation (ram in swaging position).

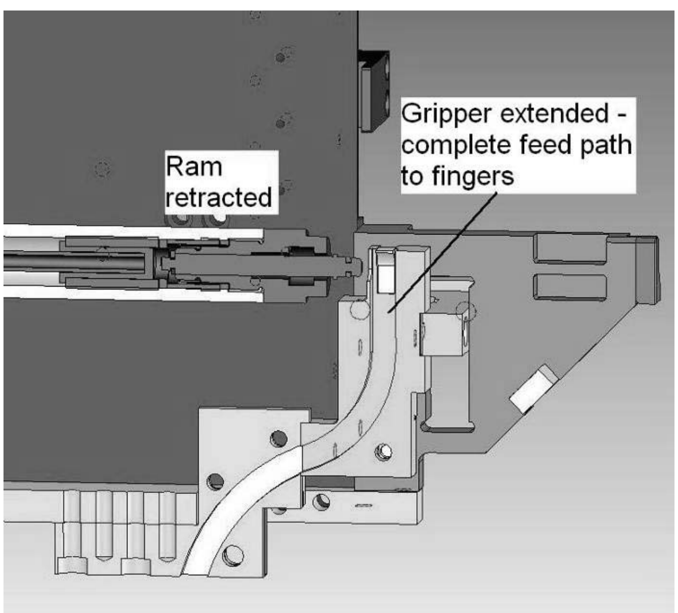

Figure 10b. Anvil for straight collar installation ram and gripper in feed position).

MACHINE STRUCTURE IMPROVEMENTS

The SA2 machine is a slightly scaled-down version of the previous generation of LVER machines. While adapting the design to smaller wing panels we also wanted to address two performance-related problems:

- During a clamping move the yoke deflects axially and the skin side tower twists, causing the stringer side of the yoke to oscillate. The programmed clamping sequence has built-in delay to allow this oscillation to settle.

- Shuttle table acceleration / deceleration causes lateral motion of the skin side clamping foot, even when the machine is clamped on the panel.

To alleviate these problems we made several improvements to the SA2 design, most of which are shown in Figures 11 and 12.

- Yoke cross-section was enlarged to increase stiffness in the clamp direction.

- Tower dimensions and internal stiffeners were modified to increase torsional stiffness.

- The previous A/B pivot structures were saddle-shaped assemblies wrapping around the bottom of the yoke on each side. The new A/B pivot structures are box weldments nested inside the yoke.

- For the A pivots, axial/radial turntable bearings were replaced with dual, preloaded, tapered roller bearing assemblies. The B pivot bearing on the skin side is a larger turntable bearing than previously used.

- To reduce clamp table mass, certain heavy components previously mounted on the clamp table were relocated to the yoke. The new yoke and A/B pivot structure freed up ample yoke surface space for these components.

The improved stiffness resulting from these design changes allows higher clamping and shuttling speeds. Clamping time decreased from approximately 700 ms on previous machines to 450 ms on SA2. Shuttle table speed on SA2 is approximately 13% higher, but maximum lateral tool point deflection during a shuttle move is reduced by half, from .001” to .0005”.

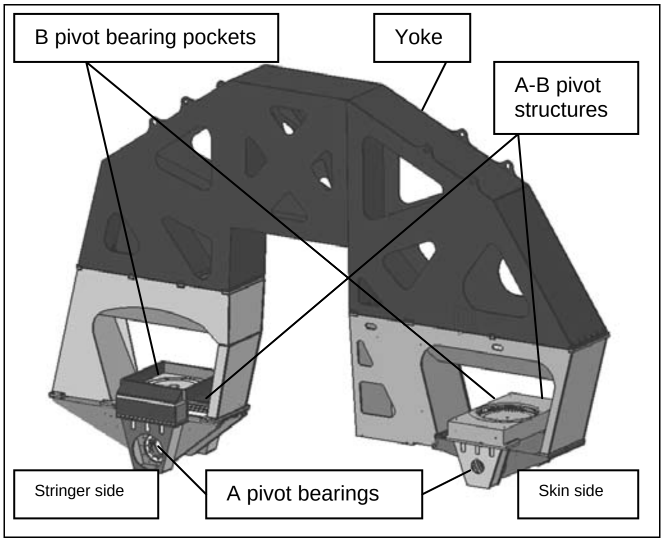

Figure 11. LVER yoke, generation 4 (pre-SA2).

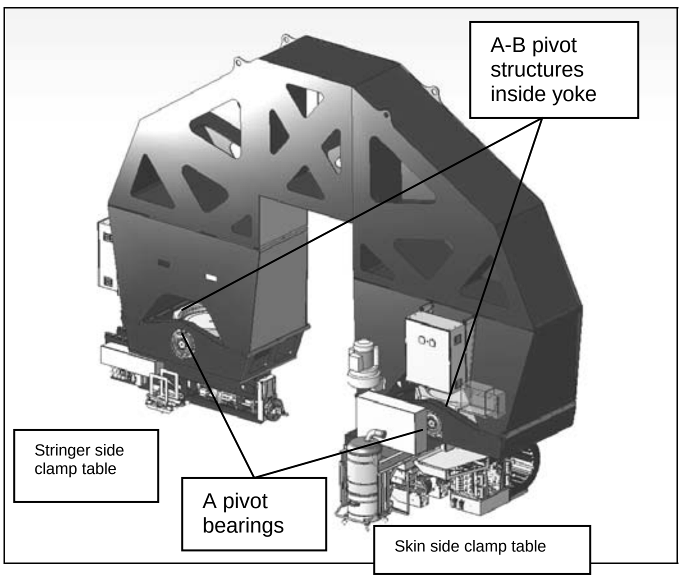

Figure 12. LVER yoke, generation 5 (SA2).

CONTROL SYSTEM IMPROVEMENTS

On previous LVER machines, software control of the fastening process is distributed among several interconnected control components (CNC with central and remote I/O; PLC's) running independently. This can make fault diagnosis a difficult and complex process. The SA2 machine utilizes an advanced CNC system, the FANUC model 30i, for more centralized control. I/O capacity is sufficient for all machine operations and remote PLC's have been eliminated, improving maintainability and performance. PMC axis control in the 30i also permits a high level of parallel, asynchronous operation. For example, drilling, fastener feed, and hole probe calibration all occur simultaneously in the cycle, under PMC axis and I/O control.

Like its immediate LVER predecessors, the SA2 has a front-end PC which runs applications for the operator interface, management of cutter and fastener data, machine kinematics, and axis compensation. The customized display (Fig. 13) allows ease of use and provides a range of operator aids, such as routines to recover interrupted cycles that would otherwise result in an empty hole.

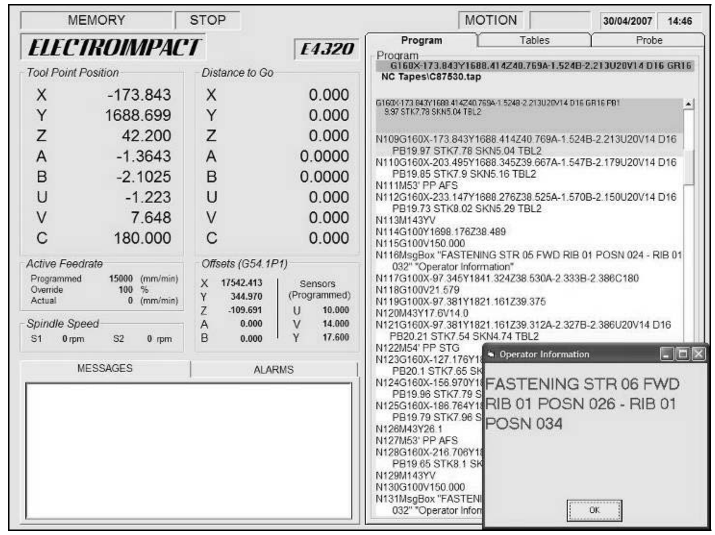

Figure 13. SA2 operator interface screen.

SA2 MACHINE PERFORMANCE

The improvements described above are now proven in production use, and have yielded significant reductions in fastening cycle times. Compared to a typical rivet cycle time of 7-8 seconds on other machines, the SA2 machine typically operates at a 6-second rate and has achieved 5 seconds in speed tests. Similarly, lockbolt cycle times have been reduced from 12-14 seconds for comparable bolt sizes on other machines, to 8 seconds on SA2.

In its limited production time to date, the SA2 machine's overall reliability compares favorably to that of older, "mature" machines. Breakdown reports for fastener-feed related causes were compiled for six highly-utilized LVER machines in calendar year 2005, and for SA2 in the first six months of 2007. Average downtime ranged from 0.5 to 5 hr/machine/month for all breakdown categories. SA2 downtime per month compares to the other machines as follows:

- For rivet-feed related breakdowns, 11% higher over 6 months; 3% higher in the last 3 months.
- For bolt-feed related breakdowns, 30% lower over 6 months; 82% lower in the last 3 months.
- For collar-feed related breakdowns, 20% higher over 6 months; 49% lower in the last 3 months.

The SA2 workcell has been in production since November 2006 and its availability for production use exceeds 95%. The first wing panel set was manufactured in 32 days. At present this has been reduced to set of wing panels every 3-1/2 days, equivalent to an average fastener time of 30 seconds, and an average cell throughput of ~103 sets per year at full rate.

CONCLUSION

The SA2 LVER machine encompasses a series of enhancements to process tools, fastener feed systems, machine structure and controls. Production use has proven these changes to be beneficial in reducing fastening cycle times and increasing reliability. A rivet and bolt buffer near the clamping head negates cycle delays due to fastener travel time. A rivet feed system incorporating an injector and passive fingers significantly reduces the need for manual alignment, and permits rivet feeding to the EMR at any shuttle table position. Redesigned bolt installation and sealant dispensing tools eliminate two shuttle moves from the fastening cycle. Anvil tooling with gripperless collar feed technology significantly reduces collar misfeeds. Improvements in the machine structure and control system have resulted in faster clamping, shuttling, and overall cycle speeds. Rivet cycles are approximately 20% faster and bolt cycles 39% faster than for comparable machines.

ACKNOWLEDGMENTS

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CONTACTS

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DEFINITIONS

The following acronyms are used in this paper.

EMR – Electromagnetic Riveter. A tool on the fastening machine which converts stored electrical energy to a high-force pulse to upset a slug rivet.

EMB – Electromagnetic Bolt Inserter. A tool on the fastening machine which combines a pneumatic chipping hammer (rattle gun) with an EMR.

LVER – Low Voltage Electromagnetic Riveter. A 5-axis CNC machine tool utilizing drill spindles, an EMR, a bolt inserter, and other process tools to install rivets and lockbolts in wing panel assemblies.

SA2 – Single Aisle LVER machine #2. The second Electroimpact LVER system installed at Airbus UK for assembly of A320 upper skin panels.