07-ATC-208

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

Ray Holden and Paul Haworth
Electroimpact, Inc.

Ian Kendrick and Andrew Smith
Airbus UK, Ltd.

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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 wing panels. The machine is based on existing Electroimpact technology but also incorporates numerous design modifications to process tools, fastener feed systems, machine structure and controls. In the first months of production these modifications have demonstrated clear advantages in reducing fastener installation cycle times and increasing component 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 A320 top surface wing panels. 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 system is a "stand-alone" workcell consisting of one machine and two wing panel fixtures. Early in the project we determined (with Airbus' concurrence) that this one-off machine would be a development platform combining:

- technologies transferred from non-LVER Electroimpact machines, such as cartridge spindles and the latest CNC systems;
- enhancements to the two-tower machine design, 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.

In these changes we saw significant opportunities for reducing cycle time and increasing reliability compared to previous machines. These design improvements are described in further detail below.

Figure 1. SA2 wing panel fastening machine.

LVER MACHINE OPERATION

On Electroimpact's wing panel LVERs, fastening heads operate on the skin and stringer sides of a vertically oriented wing panel assembly (Fig. 2). The heads clamp the panel to prevent component separation and burrs as fastening processes are performed. The larger skin side head carries most of the process tools on a transfer mechanism or “shuttle table.” These tools typically consist of an electromagnetic riveter (EMR), two spindles, a bolt inserter, a sealant inserter, and one or more probes 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, interchangeable clamp tooling, and interchangeable fastening hardware to swage lockbolt collars and form slug rivet tails.

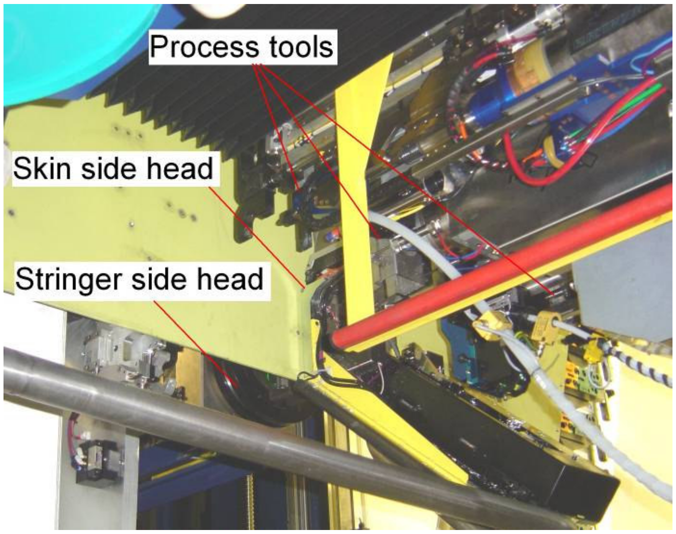


Figure 2. LVER machine fastening heads.

A slug rivet installation cycle on these machines consists of the following steps:

- Fastening heads clamp on panel and measure material thickness.
- Shuttle table moves to drill position; spindle drills hole.
- Shuttle to EMR; insert rivet; fire EMRs to form rivet.
- Shuttle to shave spindle; shave rivet head to net height (flush to +.002”)
- Unclamp and move to next fastener location.

A lockbolt installation cycle on these machines (without cold working) consists of the following steps:

- Fastening heads clamp on panel and measure material thickness.
- Shuttle to drill spindle; drill and countersink hole.
- Shuttle to sealant inserter; apply sealant to countersink.
- Shuttle to bolt inserter; drive bolt into hole.
- Place collar on protruding bolt tail. (Collar is placed before or after bolt driving, depending on which stringer side tool is used.)
- Shuttle to EMR; fire both EMRs to swage collar on bolt.
- Unclamp and move to next fastener location.

IMPROVEMENTS ON SA2 MACHINE

SIMPLIFY RIVET FEED MECHANISM AT EMR

Electroimpact’s wing riveters carry various diameters and grip lengths of slug rivets, lockbolts, and temporary fasteners in an on-board feed system utilizing coiled tube cassettes. Fasteners are released from the cassettes and fed through tubing to the fastening head. Slug rivets exit the feed tube through a U-turn mechanism, which guides them to a pneumatically-actuated gripper attached to the EMR (Fig. 3). The gripper places the rivet in the drilled hole, then retracts as the EMR advances to the panel.

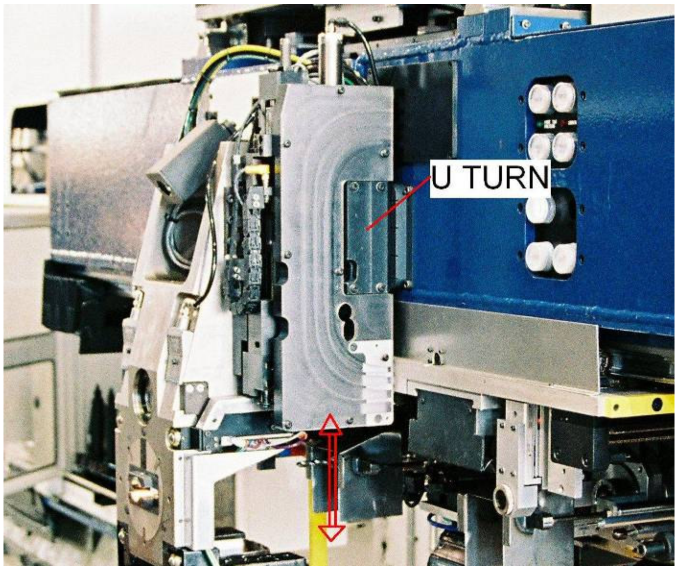


Figure 3. Rivet U-turn on pre-SA2 LVER machine.

The existing rivet feed system had several drawbacks which we wanted to address on SA2. First and foremost was the penalty imposed by shuttling to a fixed position for rivet feed. By design, hole drilling and rivet feed to the EMR occur at the same shuttle table position, so the two operations are nominally parallel. But the drilling operation is frequently completed first, and the next shuttle move is delayed until the rivet arrives at the gripper. Furthermore, if a rivet is rejected after being inserted in the hole (e.g. too long or too short), two additional shuttle moves are required to feed a new rivet.

Secondly, the gripper is radially compliant around the center of the rivet die. This design feature enables the gripper to insert the rivet in the hole without scraping, but the spring-centered mounting mechanism requires routine adjustment to maintain alignment to the rivet die.

Thirdly, the U-turn also requires routine alignment for reliable rivet feeding, both to the feed tube exits at top, and to the gripper at the bottom. 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.

The design goals that emerged for the SA2 rivet feed mechanism were (a) to replace the gripper with a passive device, self-aligning 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 SA2 rivet injector and gripper developed to meet these goals is presented in a separate paper (07-ATC-246) and described briefly here. A passive finger mechanism is attached to the driver bearing and centered on the driver shaft (Fig. 4). Two V-groove fingers ride in slots cut into the driver on opposite sides of the rivet die. 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.

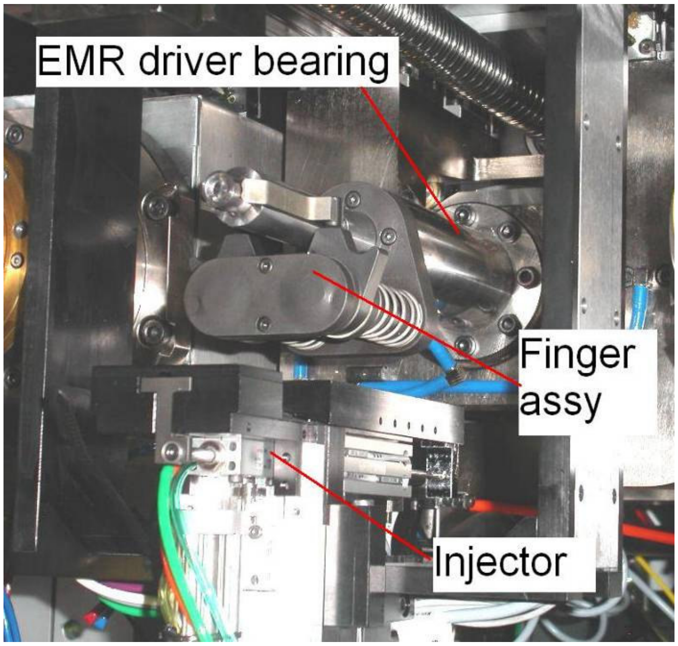


Figure 4. SA2 rivet finger mechanism and injector on EMR.

The entire finger mechanism is spring-loaded axially in the direction of EMR travel toward the panel. As the driver advances to the hole, the fingers contact the back of the clamping foot and are pushed back. The rivet die separates the fingers as it continues forward to the EMR firing position.

An injector attached to the EMR base plate below the driver 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.

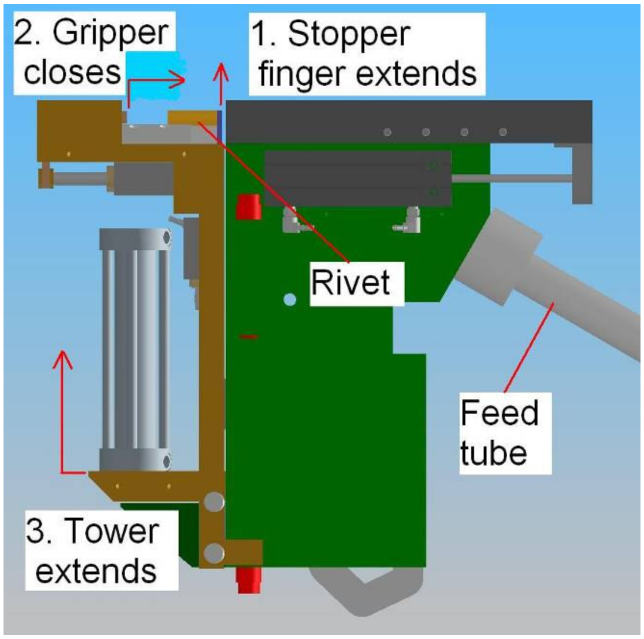


Figure 5a. Gripper holds rivet lengthwise when it is fed to injector.

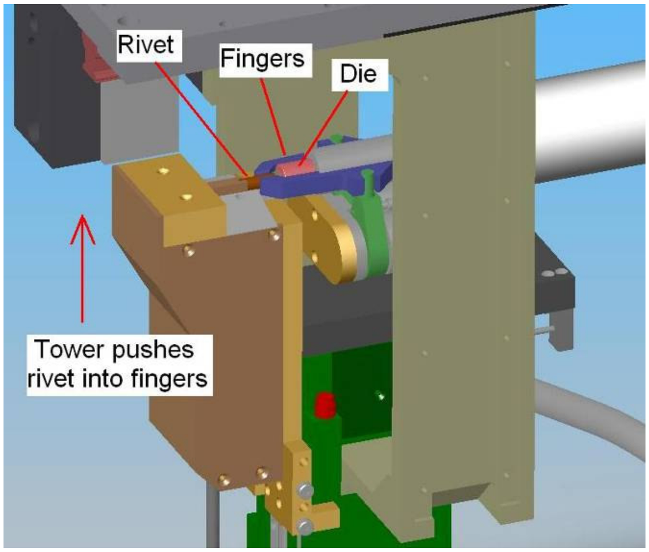


Figure 5b. Rivet is fed into EMR fingers.

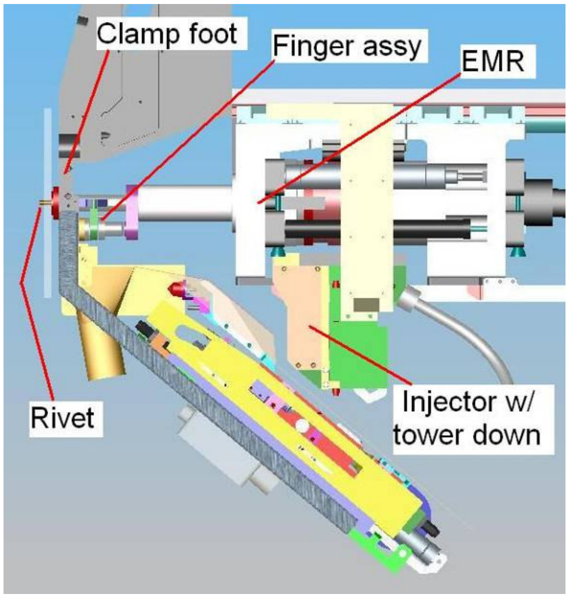


Figure 5c. Fingers insert rivet in hole as EMR moves to panel.

REDUCE LOCKBOLT CYCLE TIME

Early in the SA2 design phase we recognized two key changes that would speed up the lockbolt installation cycle. The first change was to remove the sealant inserter from the shuttle table and mount it on the clamp foot (Fig. 6), eliminating a shuttle move. The new sealant inserter operates during the shuttle move between drilling and bolt insertion positions, adding no time to the cycle. 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.

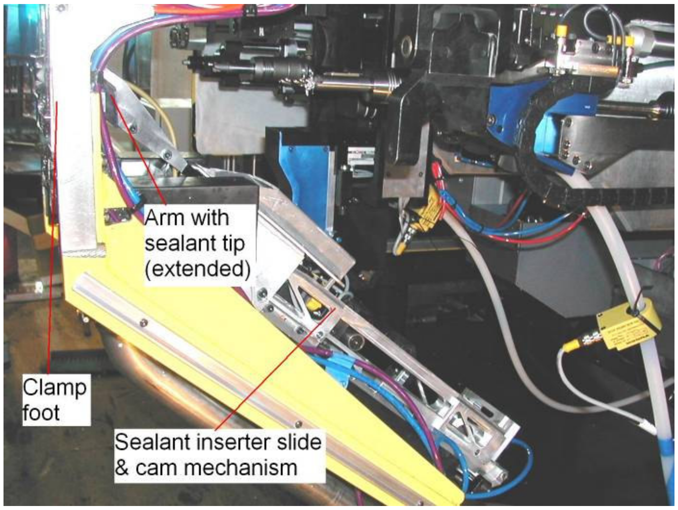


Figure 6. SA2 sealant inserter.

The other major improvement in bolt installation was to develop an 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 at the stringer either before or after the bolt is driven, depending on which stringer side tools 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.

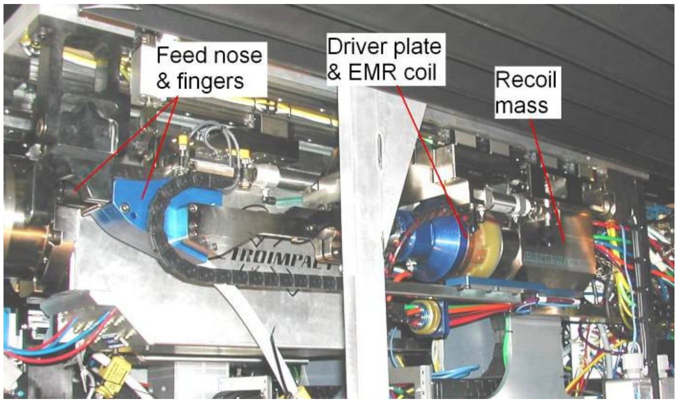


Figure 7. Electromagnetic bolt insertion tool (EMB).

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 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.

REDUCE FASTENER FEED DELAY

On pre-SA2 LVER machines a basic operating mode is “automatic fastener selection.” The fastening heads clamp on the wing panel and measure material thickness. Based on that measurement the appropriate fastener is then transmitted through the feed system. Feed tube length is a determining factor in installation cycle time. Delays can occur as the EMR or bolt inserter waits for the fastener to travel through some 70 feet of tubing.

Various techniques are used to mitigate this delay. A rivet or bolt can be fed prior to clamp-up and stack measurement, with grip length selection based on programmed length for the current fastener, or on the actual length of the previous fastener. Another workaround for rivets is to feed the next one as soon as the U-turn has delivered the current one. The "staged" rivet remains trapped behind the U-turn until the gripper is ready to receive it.

These techniques involve a certain degree of guesswork because they rely on grip length remaining constant from one fastener to the next. In areas of varying thickness, the machine frequently rejects fasteners of the wrong length and feeds the correct one. Rejected fasteners are dropped on the floor, creating a housekeeping nuisance, and the re-feed process has a detrimental effect on cycle time.

For the SA2 machine, the design goal was to shorten the feed path for all 30+ combinations of fastener type, diameter, and grip length, no matter which fastener was the next one selected. To accomplish this, one of each fastener is staged in a multi-fastener buffer on the back of the yoke, just behind and above the skin side fastening head (Fig. 8). The buffer is 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, a distance of approximately eight feet. Travel time over this distance does not contribute to overall cycle time; when the EMR or EMB is in operating position the fastener has already arrived.

As on previous LVER machines, fasteners on SA2 are stored in coiled-tube cassettes on a large rack. Feed tubes from this rack lead to entrance ports on top of the buffer's shuttle mechanism. When the selected fastener is sent from the buffer to the tool, another identical fastener is released from the appropriate cassette to replace it. The replacement fastener travels through feed tubing and drops into the escapement. Buffer replenishment occurs in the "background" of the fastening cycle and does not add any delay.

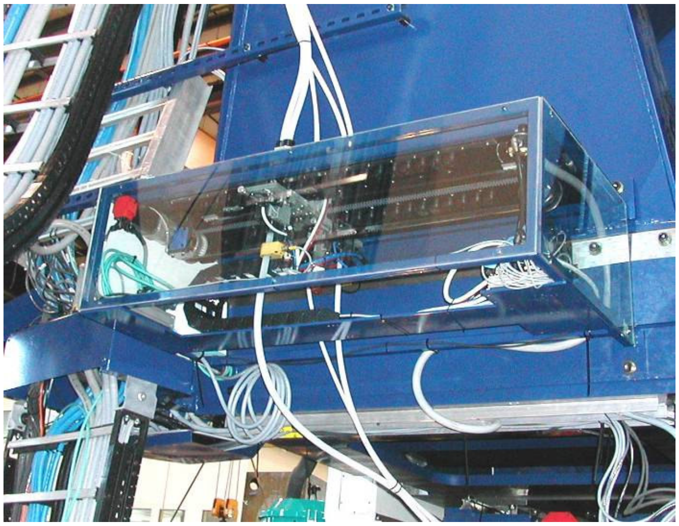


Figure 8. SA2 fastener buffer.

SIMPLIFY COLLAR FEED SYSTEM

The collar feed systems originally supplied with pre-SA2 LVER machines include coiled-tube cartridges similar to those used for rivets and bolts. The collar is fed axially through round tubing to the anvil, where a small 2-axis gripper presents it to the swaging die.

This system presents several challenges. Precise alignment is required between the gripper and the die. Therefore dedicated anvils are needed for each size of collar, as well as for straight or offset collar installation. The axial collar orientation of collars in the cartridge contributes to damaged collar ends. Collar advancement in the cartridge is inconsistent, due to loss of air pressure through the collar bores.

The SA2 machine uses improved collar feed technology which Electroimpact has developed in the last three years and deployed on several Airbus LVERS. 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 stringer locations requiring offset tooling (Fig. 9). Collars are fed sideways through rectangular tubing to the anvil, where the final segment of the feed path to the swaging die is defined by the fixed features on the anvil and ram. A plastic sleeve on the die stops the collar, and the ram then moves forward slightly to trap the collar between the bell-mouth of the die and the stringer surface. 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.

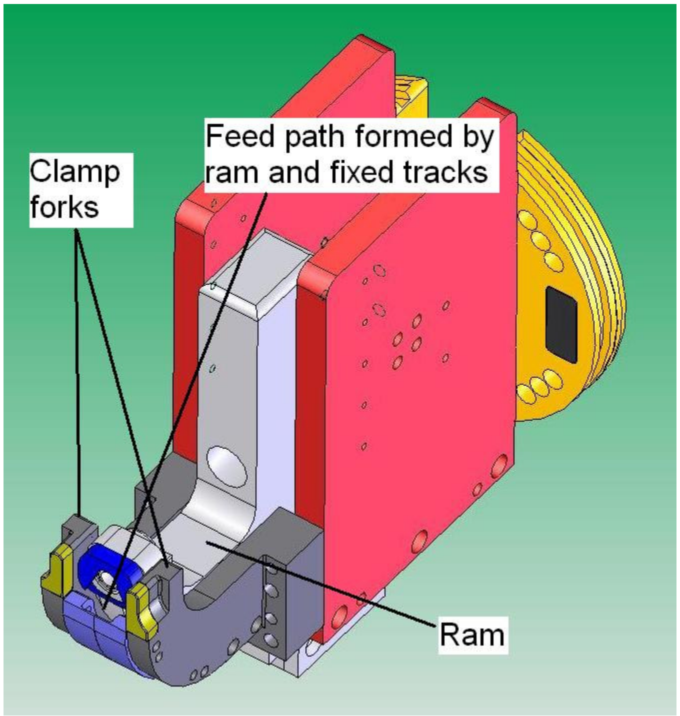


Figure 9. Anvil for offset collar installation.

We have 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 well-defined feed path all the way to the die makes it almost impossible for collars to become cocked. Detection of missing collars is straightforward on both tools. The straight tool ahs a proximity switch to detect the collar on the pin. For the offset tool, the ram LVDT on the stringer side EMR (also used to measure rivet protrusion) indicates when the ram is in the correct “trap” position, with the collar held between the swage die and the stringer flange. The ram being too far forward indicates that there is no collar. For either tool, a misfeed or missing collar initiates a sequence in which air is blown down the feed tube to clears the mis-fed collar or any debris, followed by another collar being fed.

A key feature of the new tools is that collars are oriented sideways for feeding. Storage is in coiled-tube cartridges, as in the old system, but the new cartridges have tubing with rectangular cross section and the collars are oriented sideways. Compared to axially-oriented collars in round tubing, this arrangement reduces damage to the collar ends as the collars work their way around the coiled tube, and allows collars to be fed more efficiently with less air flow.

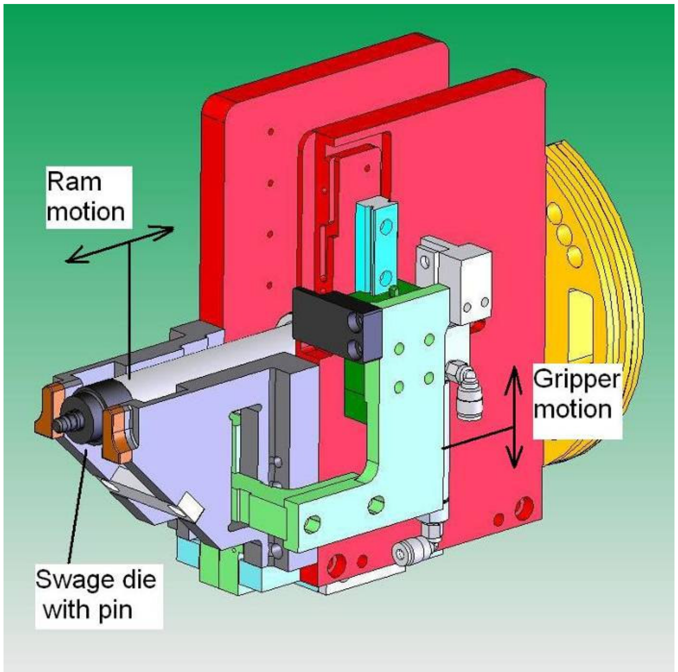


Figure 10a. Anvil for straight collar installation (ram in swaging position).

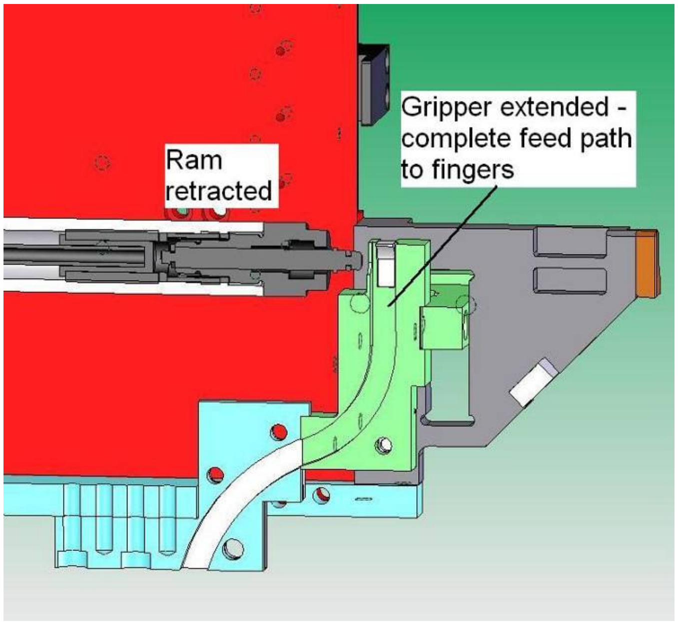


Figure 10b. Anvil for straight collar installation ram and gripper in feed position).

STRUCTUAL IMPROVEMENTS

The SA2 machine incorporates a number of design improvements to the previous generation of two-tower

LVER machines. We wanted to address two key issues with the older machines:

- Tower twist and axial yoke deflection during clamp-up causes stringer side oscillation, slowing the clamp sequence.
- Shuttle table acceleration / deceleration causes lateral deflection at the tool point, even when the machine is clamped on the panel.

We took several steps to mitigate these problems, some of which are visible in Figures 11 and 12.

(1) The yoke cross-section was increased to increase stiffness in the clamp direction.

(2) Tower dimensions and internal stiffeners were modified to increase torsional stiffness.

(3) The A/B pivot structure was nested inside the yoke, instead of wrapping around it. This increased stiffness in both the clamp and lateral directions.

(4) The A pivots were redesigned with a tapered roller bearing package at each corner, and larger turntable bearings were used for the B pivots.

(5) Heavy components previously mounted on the clamp table were relocated to the yoke, to reduce clamp table mass. 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 shuttle table speeds. Clamping time has decreased from approximately 700 msec on previous machines to 450 msec on SA2. The SA2 shuttle table operates approximately 13% faster, but deflection at the tool point has been reduced by half (from .001” to .0005”).

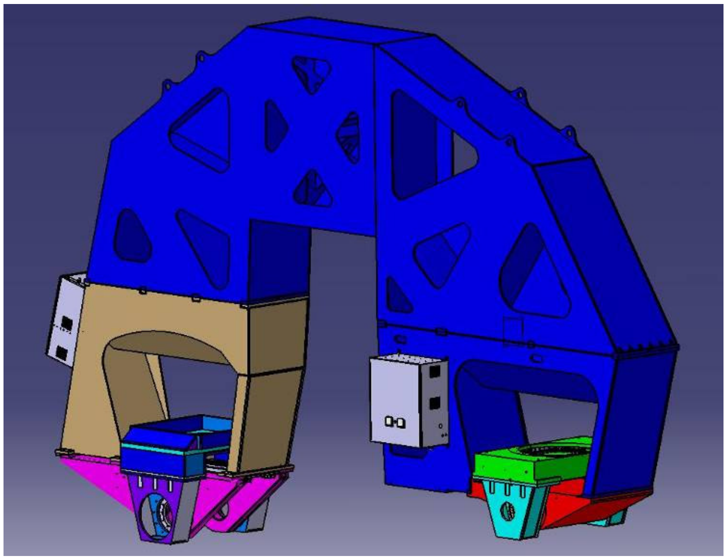


Figure 11. LVER yoke, generation 4 (pre-SA2).

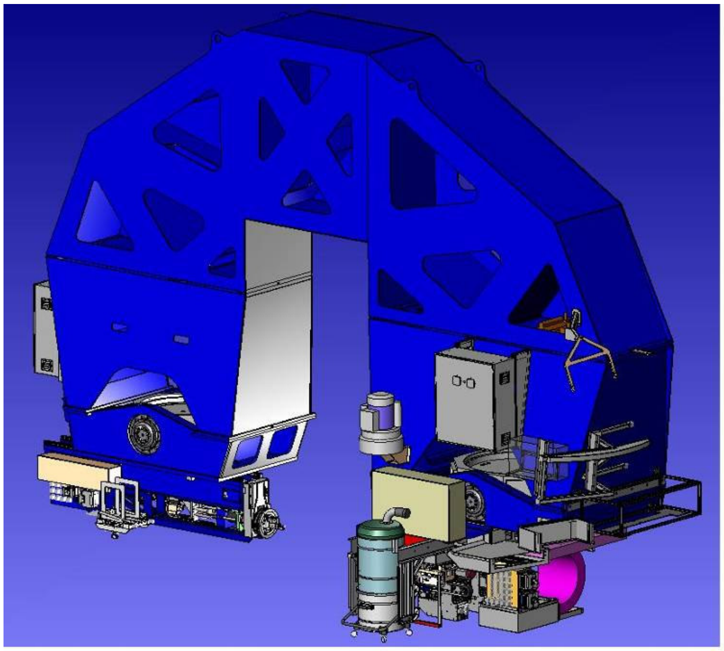
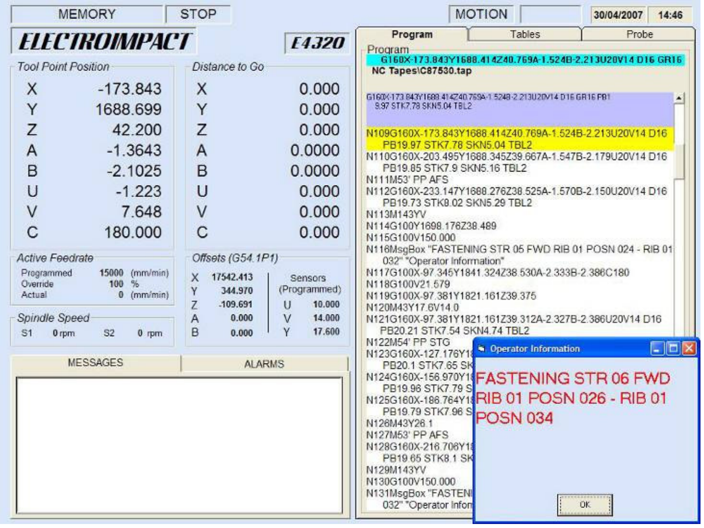


Figure 12. LVER yoke, generation 5 (SA2).

CONTROL SYSTEM IMPROVEMENTS

On previous LVER machines, software control of the fastening process is distributed among several interconnected control components (CNC with 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. Through PMC axis control 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.



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Y	1688.699
Z	42.200
A	-1.3643
B	-2.1025
U	-1.223
V	7.648
C	180.000

Distance to Go

X	0.000
Y	0.000
Z	0.000
A	0.0000
B	0.0000
U	0.000
V	0.000
C	0.000

Active Feedrate

Programmed	15000	(mm/min)
Override	100	%
Actual	0	(mm/min)

Spindle Speed

S1 0 rpm S2 0 rpm

Offsets (G54.1P1)

X	17542.413
Y	344.970
Z	-109.691
A	0.000
B	0.000

Sensors (Programmed)

U	10.000
V	14.000
Y	17.600

Program

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NC Tapes\C87530.tap
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Figure 13. SA2 operator interface screen.

SA2 MACHINE PERFORMANCE

The improvements described above have been tested in production use, and have yielded significant reductions in riveting and bolting cycle times. Compared to a typical rivet cycle time of 7-8 seconds on other machines, the SA2 machine typically runs at a 6-second pace 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 9 seconds on SA2.

Machine reliability has been improved as well. Compared to other Electroimpact machines at a similar level of utilization, repair and service hours on SA2 in the first six months of production have been reduced by

- 80% for rivet-feed related hardware;
- 40% for bolt-feed related hardware;
- 15% for collar-feed related hardware.

The SA2 workcell has been in production since November 2006 and its availability for production use exceeds 95%. At present it completes one set of wing panels every four days.

CONCLUSION

The SA2 LVER machine encompasses a series of enhancments to process tools, fastener feed systems, machine structure and controls. Production use has shown 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 gripper reduces misfeeds and the need for alignment. 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 31% faster than for comparable machines.

ACKNOWLEDGMENTS

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CONTACTS

Ray Holden is a mechanical engineer and project manager, and Paul Haworth is a controls engineer, at Electroimpact, Inc. For more information about SA2 and other custom machine tools for aerospace automation, contact the authors at rayh@electroimpact.com or paulh@electroimpact.com. More information about Electroimpact’s automation and tooling can be found at http://www.electroimpact.com.