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New Jig Mounted Wing Panel Riveters, AERAC 2

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ABSTRACT

Electroimpact revisited a piece of automation history this year. In 1989, Electroimpact delivered its first ever Automated Electromagnetic Riveting and Assembly Cell or A.E.R.A.C. to Textron Aero Structures, now Vought Aircraft Industries. These machines produce upper wing panels for Airbus A330/340 aircraft. They were the precursor to the Low Voltage Electromagnetic Riveters or LVER's producing wing panels for Airbus single isle, A340 and A380 programs in Broughton, Wales, UK. In 2009, Electroimpact delivered two next generation AERAC machines to Vought Aircraft Industries. A significant design challenge was to hold the moving mass for the entire machine under 5220 kg without sacrificing performance of the LVER. These machines employ several new technologies to achieve this including Electroimpact's latest generation rivet injector, an integrated headstone load cell, and GE Fanuc's customer board. The new rivet injector grips the rivet axially and maintains positive control of the rivet from magazine to panel. PC based auxiliary controllers have been eliminated with the customer board.

INTRODUCTION

In 1989, Textron, was manually building upper panels for the Airbus A330/340. The panels are fixtured in a picture frame jig designed for manual assembly. Electroimpact had recently developed the Low Voltage Electromagnetic Riveter, but until this time, it was only being used in hand held applications. Electroimpact partnered with Textron to automate the manual assembly process and produced the first AERAC machines. This represented the first installation of Electroimpact EMR's on a CNC controlled machine. The AERAC machines were lightweight, simple, low cost automated riveting machines designed to run on the existing jigs. In the 20 years since, they have installed 2.1 million rivets in over 1000 ship sets.

In 2007, Vought partnered with Electroimpact again to replace the legacy machines. Goal was to improve on the legacy machines, taking advantage of technological advancements over the last 20 years to produce lightweight, simple riveting machines, that perform well, run on the existing beds and fixtures and keep costs to a minimum. Figure 1 show an overall layout of the new AERAC machines.

Improvements over the legacy machines include:

1. Fanuc 30i controller
2. Improved kinematics
3. Tool point control
4. Improved spindles
5. Addition of a rivet plucker
6. Position error compensation
7. Non contact normality
8. Tool point rotation
9. Non contact tracers
10. Automated stringer tooling orientation
11. Drives and controller mounted on machine

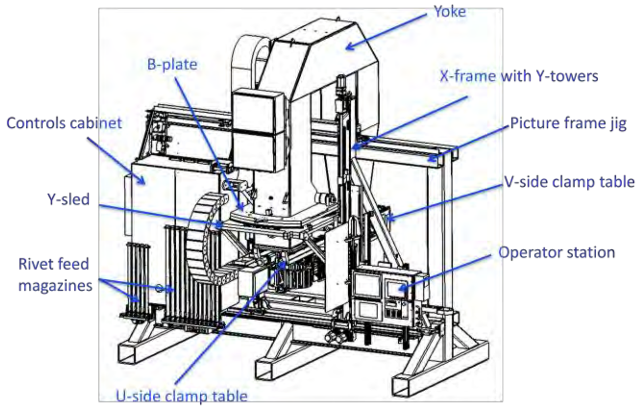

Figure 1 - AERAC2 machine

MAIN SECTION

BASELINE

The original AERAC Machines had aluminum yokes (or C-Frames). Figure 2 shows an image of one of the legacy machines. Aluminum presented some challenges in this application. Over the years, it has been shown to creep, which periodically requires re-alignment of the two heads using shims. Being an ultra light weight tool, if a severe crash occurs, the yoke would yield as much as few mm. For a period of months after such an event, it has shown a tendency to partially creep back to its original position.

The legacy machines are controlled with Allen Bradley 8200 CNC controllers, which are now obsolete. For weight and space concerns, these were installed on the floor and IO was run though a cable track to the machines and HMI. This was before the common use of serial busses, so there were a lot of conductors. Conductor breakage due to mechanical wear has required periodic replacement of this cabling. Servo feedback runs though these cable tracks and is subject to inductive noise over these long distances.

Tool point control was not feasible with these controllers. Each servo axis was commanded rather than using the modern tool point axis control scheme.

The legacy machines had three tools: a drill, EMR and shaver. Shuttling was actuated entirely pneumatically, with a three position air cylinder set up.

Figure 2 - Legacy AERAC machine

Normality sensing, which positions the headstone square to the panel, was accomplished with pneumatically actuated ball contact sensors. Feedback is via linear potentiometers. Figure 3 below shows the head stone and normality sensor arrangement.

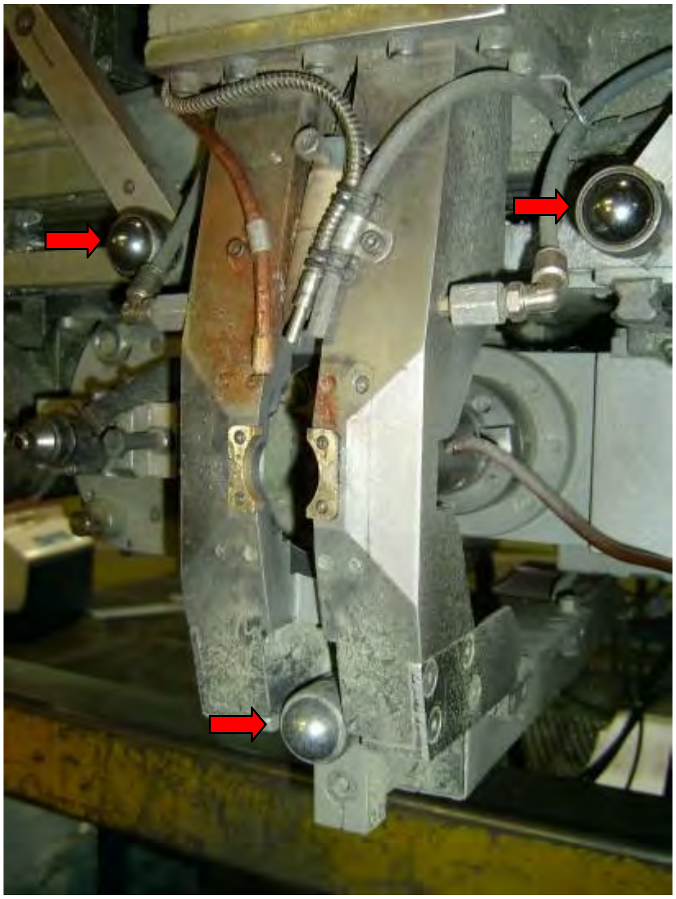

Figure 3 - Head stone with normality sensors

Stringer tracers are used in tracer mode, to position the machine relative to the string in 2 axes. The legacy machines used a mushroom shaped contact head, which was actuated with air cylinders and sensed with linear potentiometers. The top of the mushroom slides along the underside of the tracer sensing the Y position and the circumference rolls along the flange sensing distance from the flange. The former is set to control the edge margin and the latter controls the flying height to avoid obstacles such as tack fasteners. Figure 4 shows a legacy machine tail stone with the mushroom tracer.

The kinematics of the legacy machine combined with lack of modern controller made the tool point more difficult to control than modern machines. The rotational axes on the legacy machines were not mechanically independent. They had a linkage interaction, which produced side-effect axis motions. For instance, commanding a B axis rotation would induce an A axis rotation that would need to be compensated for.

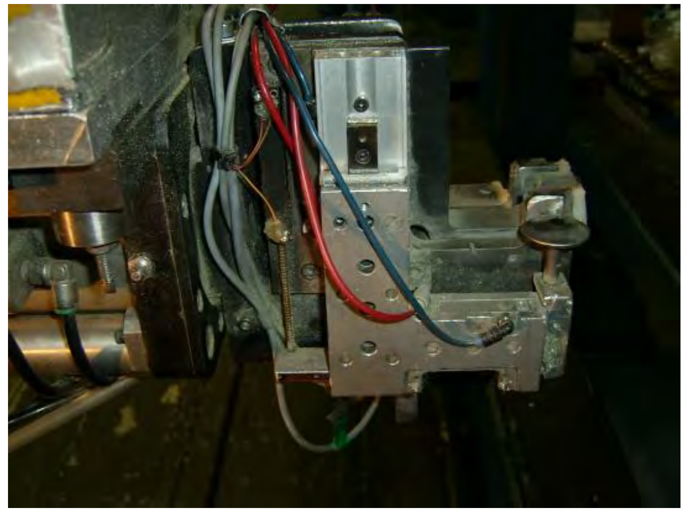

Figure 4 Tail stone with tracer mechanism

MINIMAL MASS

The site at Vought Aircraft Industries goes back to the 1930's. In fact it was originally the final assembly site of the Vultee Vengeance dive bomber. It does not have an adequate foundation for a typical riveting machine and over half of each fixture is located over a basement. As a result, one of the major design constraints was keeping the mass low. The mass of the original AERAC machines is not precisely known, but is thought to be 6000 pounds. The AERAC2 machines were specified with a maximum moving weight of 11,500 pounds. While the legacy machines had the controller and servo drives remotely located, the new machines were specified to have the controller included in the moving mass to improve reliability and reduce inductive signal noise problems.

For perspective the Single Isle LVER's (a318/319/320) weighed in at 160,000 pounds and the A380 LVER's weighed in at 240,000 pounds of moving mass.

The C-frame or "Yoke" was given a weight budget of 1600 pounds, about half the mass of the average compact car. Aluminum, carbon fiber and steel were all considered. Aluminum was excluded because the original aluminum yokes showed a tendency to creep. Carbon fiber was researched and partially prototyped, but eventually excluded because the expected 20% increase in specific stiffness came at a cost of approximately 5 times that of steel yoke. Spares were another concern. In a pinch, A steel yoke could be fabricated much more quickly than a CFRP yoke. The final yoke was made of a steel space truss with steel exterior panels. The truss primarily provided a jig for assembly of the thin exterior panels. The exterior panels range in thickness from .07 inches to .19 inches. Deflection under a 2000 pound clamp load is approximately 3mm. This is approximately 50% of the clamp deflection seen on the legacy machines. With the servo - loadcell clamping method, yoke stiffness correlates with clamping speed

KINEMATICS

The legacy machines have a linkage interaction which caused undesirable side effect axis motions which had to be compensated for. At the time, bearing components that would permit true independent linkages were not as readily available as they are today.

With mass at a fraction of a traditional LVER, kinematics was especially important. The new LVER's were designed to keep the yoke cg close to the centers of rotation and coincident with the drill axis, while attempting to avoid the linkage interaction on the previous machines. Using curvilinear accomplished this It has the benefits of linear ball rail - stiffness, accuracy, low friction, and zero backlash. Figure shows the Y - A - B assembly and Figure 6 shows the B axis bearing arrangement.

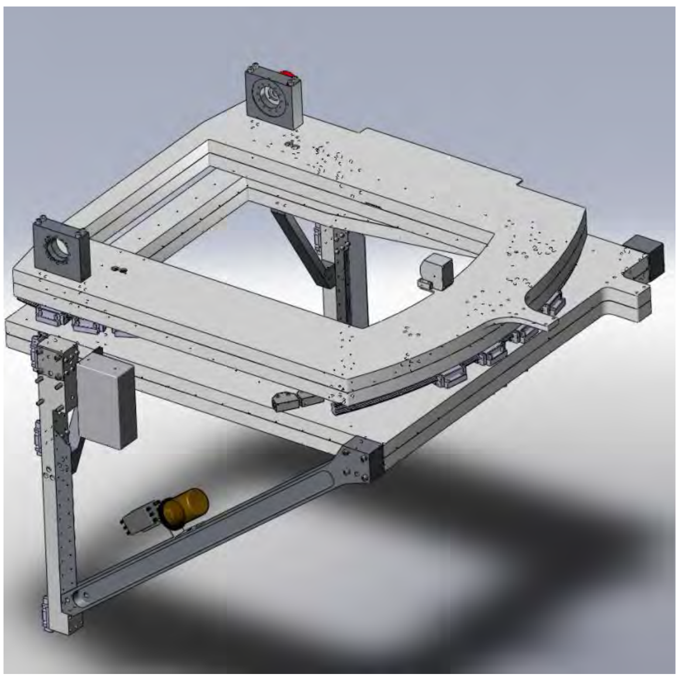

Figure 5 - A-B-Y Assembly

Figure 6 - B axis bearing arrangement

CONTROLS

In recent years it has become common to control complex machines by marrying a PC and Fanuc controller. This presents a reliability problem, because PC's have a much shorter MTBF than CNC's. The new AERAC machines are controlled entirely with a Fanuc 30i CNC controller. This represents multiple steps forward in controller evolution. The legacy AERAC machines didn't have advanced tool point positioning with normality and tracer functions. More recent machines do, but with the assistance of a PC. With the Fanuc 30i controller, these machines have these advanced functions without an auxiliary PC. The new generation AERAC machines have a PC for data collection and diagnostics, but the machine will still install fasteners should it fail.

Self Calibration - The new AERAC machines have a self calibration routine that is run at the start of each day. In the park zone at the panel 1 end of the jigs, there is a coupon stand and calibration plate. The self calibration routine is a macro that manipulates the axes, clamping and positioning around various features of known dimension on the calibration plate. Self calibrated parameters include, stack thickness, normality, rivet protrusion and stringer tracer scaling.

COMPENSATION

The new generation AERAC machines use the same compensation software developed for Electroimpact's high accuracy robots[i]. Each axis has 6 (3 rotational, 3 prismatic) potential degrees of freedom in the kinematic model allowing compensation and characterization of deflection under know loads. At setup, laser trackers are used to measure actual position through series of programmed exercises. The data is used to calibrate the machine, mathematically correcting the various sources of error. Corrected errors include deviations between real and design kinematic lengths angles, manufacturing tolerances, deflection due to payload and thermal effects.

CLAMPING AND NORMALITY

Headstone Doughnut Load Cell - The AERAC2 machine clamps the panel with a prescribed force prior to drilling to facilitate one up assembly. The clamp force is provided with servo motors driving ball screws. Prior art relied on ball screw mounted load cells. In this configuration, the measured load must transfer from the wing panel and through multiple machine parts before arriving at the load cell which introduced hysteresis.

Electroimpact's latest designs utilize a custom thin, spherical doughnut loadcell mounted immediately behind the skin side clamp pad. Clamp load is directly and immediately measured, reducing clamp up time and improving clamp accuracy. The loadcell measures up to 3500 pound-force clamp loads standard and can handle up to 10000 pound-force without replacement in the event of a crash. Additionally, the design handles shear loads resulting from shuttle table motion as well as non-normal clamping. The headstone load cell is also easier to replace than the ballscrew cell in the event of a failure.

Eddy Current Normality Sensors - Electroimpact integrated non-contact normality sensors to address shortcomings of contact sensors. The prior art was subject to collisions with objects protruding from the OML such as temporary fasteners, wear of mechanical components and hysteresis.

For the AERAC2 non-contact sensors, Electroimpact chose Eddy Current sensors and KμDA amplifiers from Kaman. Four sensors are arranged around the tool point. This quad arrangement allows normalization in A or B even when panel conditions (such as edge of panel or bulkhead opening) require one or two sensors to be turned off. With all sensors turned on, redundant sensor permits a planarity calculation which helps to anticipate problems with the sensors or panel geometry. These sensors are immune to light swarf. Figure 8 shows the headstone assembly. The normality sensors are indicated with red arrows. The nose piece assembly is indicated with a blue arrow.

Figure 7 - Doughnut load cell in partially assembled headstone

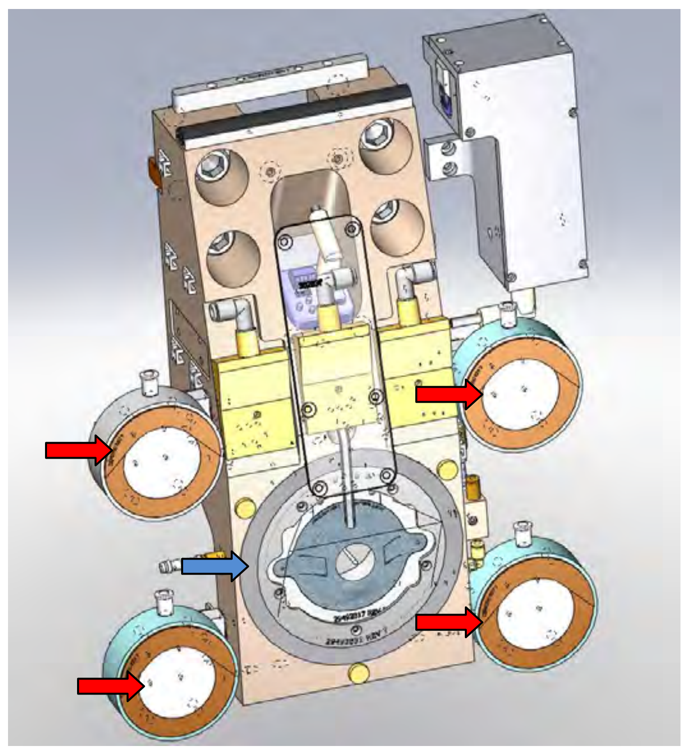

Figure 8 Headstone assembly

TRACERS

Y and Z (chord wise and normal distance from panel) machine positions are typically controlled in relation to the stringer. The position feedback comes from a set of tracers mounted on the back side tool. The prior art used mechanical sensing devices. The new generation AERAC machines use non contact lasers to sense stringer position.

Figure 9 Stringer side EMR offset anvil with laser

PROCESS TOOLS

Spindles - The new generation AERAC machine use a 120 mm Precise spindle cartridge with an HSK 40 tool holder. These spindles offer remarkable thermal stability affording Vought the ability to easily meet shave height and countersink depth tolerances.

EMR (Electromagnetic riveter) - An enabling technology for the lightweight AERACs is the use of (low voltage) electromagnetic riveting. EMR's generate large forces without transferring the riveting forces back to the C-frame or yoke. The EMR's use gas-springs and hydraulic dampers to lessen recoil forces. For instances, the AERAC2 EMR's can generate 100,000 N (22,500 lb.) to form 3/8" rivets, but only 890 N (200 lb.) force is transmitted back to the yoke.

The AERAC2 machines install mostly Ø¼", 2117 alloy rivets, 8-14 through 8-24. (NAS1097AD8-xx, where xx is length in 16th of an inch.) Please refer to references 2 and 3 for more detailed descriptions of the electromagnetic riveting process.

The skin-side EMR is mounted on a shuttle table between the drill and shave spindles. A linear servo-motor drive and linear bearings provide rapid and accurate positioning between these tools.

The skin-side EMR features a Ø32mm, 10mm lead, ballscrew drive for servo controlled motion along the axis of the rivet. This EMR servo motor drive works in tandem with the rivet injector mounted below the rivet axis for fast and reliable rivet insertion into the drill hole. Please see the photograph below.

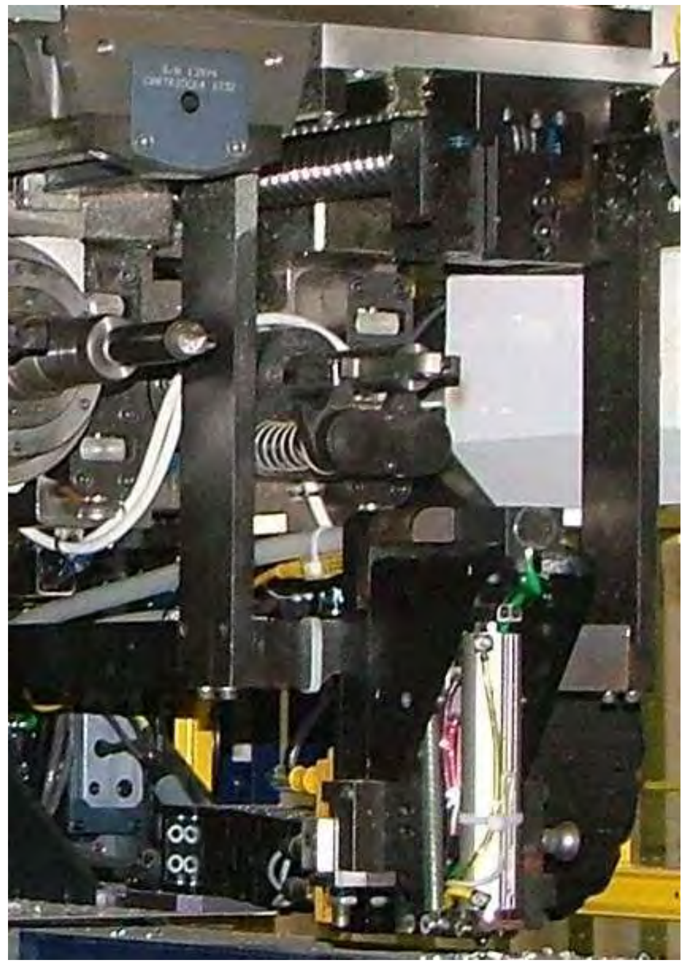

Figure 10 Skin-side UEMR and injector

There are a set of integral rivet fingers mounted alongside the driver on the skin-side EMR. This design keeps the rivets concentric with the skin-side EMR axis and ensure correct insertion into the drilled hole. Please refer to Figure 11. The red arrow indicates the fingers.

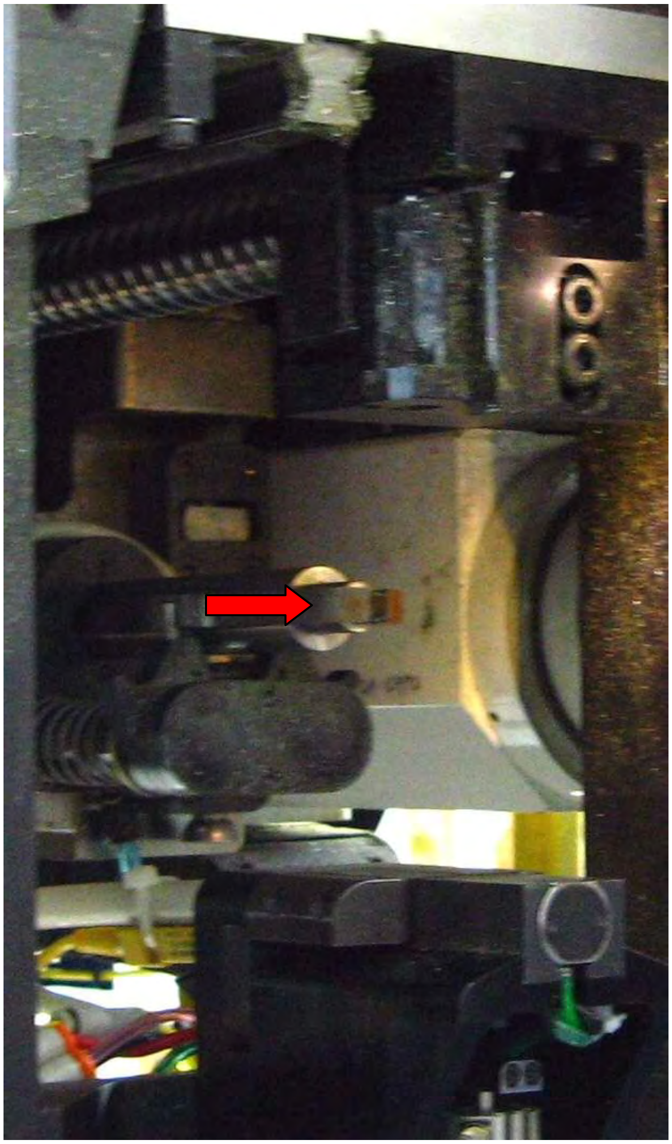

Figure 11 Skin-side EMR driver, die and rivet fingers

Plucker - Due to the height of the jigs, and the difficulty inherent in physically reaching the panel, a rivet plucker, which pulls any incorrect/incorrectly inserted rivets from the wing panel, was added to these machines. The plucker is a simple tool consisting of two pneumatically actuated axes. The first axis is the positioner, simply moving the tool into/away from the panel. The second axis is the grip axis. Due to the small angle of the finger assembly, the large cylinder area and long cylinder travel, the fingers are capable of gripping extremely tightly. The plucker is capable of pulling with approximately 170 pound-force. The plucker is cycled automatically as part of a rivet eject cycle.

ELECTRICAL

One of the technological improvements in the 20 years since AERAC1 is the size and mass of digital servo drives and controllers. The original machines had an Allen Bradley 8200 controller and was simply too large to run on the machine. It was mounted in a large electrical enclosure on the wall with all of the cabling running through the primary cable track. This resulted in a very large cable track which requires periodic repairs due to worn conductors. It also increases the tendency to pickup inductive noise in signal cables.

The new machines use light weight Fanuc 400 volt drives and a 30i controller mounted on the machine. IO was reduced from 100 to 24v. The new machines also incorporated distributed I/O to save space & weight. Fanuc I/O was used in the main cabinet, B&R Profibus I/O was used for general I/O around the machine, and SMC IP67 valve blocks were used for general pneumatics. This located I/O close to where it was required and eliminated a great deal of cabling and intermediate terminations.

The new machine has only two power feed cables and an Ethernet cable in the main track. An isolation transformer is located off of the machine. The new machine uses a 400/240VAC system so that 240V equipment (such as EMR power) could be fed directly, without need for additional transformers.

CONCLUSION

The goal of this project was to improve on the legacy machines, taking advantage of technological advancements over the last 20 years to produce lightweight, simple riveting machines, that perform well, run on the existing beds and fixtures and keep costs to a minimum.

Initial estimates indicate that floor rate was improved by approximately 40%. (Floor rate in this context is defined as the amount of time the panel spends in the jig.)

The 30i controller afforded many improvements, including 5 axis tool point positioning, tool point rotation, and advanced positional accuracy compensation. Tool point positioning cuts down on the number of concessions caused by operator error when returning to a hole location. It also eases the burden on part programmers, because all transformations are done in the background. Tool point rotation permits the machine to trace a panel under 5 axis CNC control while maintaining flying heights and tool point normality.

The plucker helped to improve floor rate. The prior machines required an operator to drive the machine away from the work area, climb up on the jig and manually remove the fastener. The plucker accomplishes this in a matter of seconds.

Positional accuracy compensation in the new machines is expected to reduce concessions. The jigs originally converted from manual work jigs and do not enjoy the benefits of having been designed to have a precision machine tool operating on them. The uncompensated machines on the production jigs demonstrated approximately .38 inch radial accuracy (3 sigma) over an 8 foot section. Compensated, that number was reduced to .021 and .022 inches radial (3 sigma) for each of the machines.

Non contact normality sensors and tracers are expected to improve reliability. The prior art is relatively delicate and subject to mechanical wear. Quantitative data on sensor and tracer repair history was unavailable.

The prior machines required an operator to walk around the jig to rotate the tooling. Automating the stringer tooling rotation is estimated to save about 36 minutes per panel.

Mounting the control cabinets on the machine is anticipated to cut down on maintenance costs. The legacy machines had several hundred conductors running in the main cable track. Quantitative data for repairs to the legacy machine cable tracks is unavailable, but cutting down on the number of conductors in the main track was identified as a goal due to maintenance concerns.

These improvements happily achieve the goals of this project.

ACKNOWLEDGMENTS

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

AERAC: Automated Electromagnetic Riveting and Assembly Cell
CNC: Computer Numerically Controlled
EMR: (Low Voltage) Electro-magnetic Riveter
DCS: Data Collection System
KμDA: Kaman Micro Digital Advantage
LVER: Low Voltage Electro-Magnetic Riveter
MTBF: Mean Time Between Failure
OML: Outer Mold Line
PC: Personal Computer