DESIGN OF THE AUTOMATIC ELECTROMAGNETIC RIVETING ASSEMBLY CELL

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ABSTRACT

Textron Aerostructures (formerly AVCO) was in search of a new technique to install wing to stringer rivets for the Airbus A330/A340 program. The conventional technique requires that stringers first be tacked to the wing plank in a floor assembly jig (FAJ). In the typical FAJ the wing plank is set vertical to permit convenient access to the part from both sides. The temporarily fastened assembly is then removed from the tack fixture, rotated to horizontal and placed on a second fixture which permits access to the part by the riveting machine. A third fixture is employed as a pickup station. Electroimpact proposed a travelling five axis yoke assembly system in which a lightweight yoke equipped with drill-insert-rivet-shave end effectors would travel along the FAJ using the FAJ as its base. In this fashion the entire assembly process can be completed in one fixture with minimum handling. Significant labor savings were anticipated. To permit the yoke to be lightweight the Low Voltage Electromagnetic Riveter (LVER) is employed for rivet upset.

Innovative features are incorporated in several areas. A unique clampup system is employed. An electronic depth stop and dwell mechanism is employed for both the drill and shaver. The Low Voltage Electromagnetic Riveter coaxially feeds a rivet and automatically senses rivet grip length before upset. All of the rivets required for riveting one panel are carried along with the yoke in cartridges. The cartridge rivet feeding system is uniquely compact, simple and reliable. An off-line rivet cartridge feeding cell is being provided by Electroimpact.

INTRODUCTION

The Automatic Electromagnetic Riveting Assembly Cell (AERAC) was developed to permit wing to stringer riveting in the panel jigs. By performing wing to stringer fastening operations in the floor assembly jigs (FAJ) much of the handling typical of wing to stringer operations is eliminated. In addition, many operations are also eliminated. For example, to accurately transfer wing components from jigs to conventional riveting stations a large number of temporary fasteners are typically required. These temporary fasteners must be replaced with permanent fasteners in a pickup station. These operations are completely eliminated

The enabling technology is the Low Voltage Electromagnetic Riveter (LVER). Textron engineers first learned about the LVER through a Fastec paper AD89-640 presented in 1986. When the Airbus A330/A340 wing to stringer upper wing panel project began at Textron these same engineers began to inquire about use of the LVER. In order to investigate the qualification of this process Textron purchased two sets of HH300 hand riveters. An extensive test program of fatigue and interference was conducted to compare results from the HH300 with conventional squeeze riveters. Fatigue specimens were run at Textron, Tennessee Tech and Electroimpact. Favorable results were achieved with the LVER (see Fastec paper AD89-640) and the process was accepted for use on the A330/A340 wings by British Aerospace. The HH300 hand riveters were accepted for the installation of slug fasteners into countersunk holes for the wing to stringer attachment. The handheld riveters have been heavily employed from the first shipset in production use. Simultaneous with the qualification process work was ongoing on the topology for incorporation of the LVER into a CNC tool. Ultimately two yoke nveters were purchased, one for the left wing FAJs and a second for the right wing FAJs.

YOKE DESIGN

On the A330/A340 wing planks are curved around two axes. In the Textron FAJS fixturing moves in and out of the centerline to accomodate the wing curvature. To minimize program cost a goal of the design was to employ the existing Textron FAJs as the machine base. The working envelope of the machine was established in cooperation with the Textron tooling department. To provide for accurate alignment of the skin and stringer side LVER actuators throughout the working envelope a solid yoke was proposed. The yoke is an aluminum weldment. The yoke can be seen undergoing fabrication in Plate 2. The yoke is attached to a crossarm which is attached at both end to spherical bearings. The crossarm can be seen attached to the frame in Plate 3. The spherical bearings permit both roll and yaw motion.

The yoke was designed to provide access to all points in the FAJ. The inside vertical dimension of the yoke to the toolpoint is 113”. The inside width dimension is 54”. The width expansion of the yoke when 800 pounds clampup is applied is under .037”. This small deflection keeps the tools concentric within .002”.

To achieve this rigidity the yoke has a box beam cross section of 31.2 x15.2”. With the aid of finite element analysis the yoke was designed with internal baffling to enhance rigidity. The entire AERAC system was designed using computer aided design.

CNC TOOL CONFIGURATION

Figure 1 shows the yoke moving up and down in the Y (vertical) axis and rotating in the A (around the wing longitudinal axis). The Y axis has 85 inches of travel and the A axis is capable of plus and minus 10 degrees. The ball screw actuator which controls the A actuator can be seen in Plate 1. The Y axis is controlled by a split ball screw. One of the ball screws can be seen in Plate 3.

Figure 2 is a plan view which illustrates the B axis. One side of the yoke crossarm is connected to a fixed spherical bearing while the other side sits on crossed slide bearings. A ball screw actuator controls the position of the moving side. The B axis motion capability of the machine supplied to Textron is +8 to -4 degrees. Most of the B curvature is at the wing root. Therefore the two machines have opposite hand with respect to the B axis. Mounting holes are provided in both machines for mounting the B actuator on either side.

Figure 3 shows the general arrangement of AERAC on the FAJ. Note that the machine is supported by a frame which slides on ways along one side of the FAJ. This is the X axis. Cam rollers on the top of the FAJ keep the machine vertical. The machine slides on bearing track and ways on the bottom of the FAJ. The 4500 pound weight of AERAC is supported on an I beam adjacent to the FAJ. The I beam, bearing mount and rack can be seen in Plate 11. The bearing mount is a machined plate which holds the bearing and rack in accurate relation. The bearing mount is jacked into precise position on the support beam and epoxy poured. The rack is double width to permit the use of a split pinion. The pinion is split with opposing pairs of conical washers to provide 500 pounds of separating force. A zero backlash epicyclic gearbox is employed. All of the drive motors are brushless DC servo motors with resolver feedback. The extent of the X axis for each machine is 255 feet. Note in Figure 3 that the cable track is on top of the FAJ in order to carry electrical power, signal and pneumatic lines out to the riveter.

TOOL TABLES

The Z and W tool tables are shown in Plates 4, 5, 6 and 7. Both of the opposing Z and W tool tables have 29” of travel from the ball screws and short stroke air cylinder. Both the ball screw and the air cylinder advance the table on the same pair of slide bearings. An anti-torsion slider is mounted on the side of each table since the two drives do not share a common centerline. Brakes are provided in Z and W but these are not employed to achieve the 800 pounds clampup pressure. The motors have more than enough torque capability to provide the clampup. The air cylinders could be eliminated from the design if the customer specified controller supported current feedback. None of the six failsafe brakes in AERAC are closed except when the machine is shut off.

The long travel of the Z and W tables is required to clear formboards and pusher boards in the Textron FAJs. Initially AERAC will hop over boards and install permanent tack fasteners. Once this is completed form boards will be removed and the machine will again traverse the stringer installing the remainder of the fasteners.

In the wing to stringer application the two spindles as well as rivet feed are all deployed from the skin side. On the stringer side rivet heads are hidden behind the Z stringer cap. The tools on AERAC are all electric with pneumatics for positioning and chip blast. One of the four pneumatic valve blocks is shown in Plate 4. There are no hydraulics employed on AERAC. The Boelube applicator is also shown in Plate 4. Boelube is applied to both the drill and shave bits. The skin side actuators operate through a cantilevered clampup bushing. This provides an optimum amount of access to the tools. The clampup bushing also provides a depth stop for the shaver. A three position transfer table brings first the drill, then the feeder nose LVER and finally the shaver into the working position. Due to the low recoil force of LVER the transfer table can be lightweight and quite versatile. An arbitrary number of stop positions can be realized with a ball screw driven transfer. There are currently plans to increase the transfer table to five stops in order to accomodate a hard fastener cycle. A three ball normality sensor is also deployed from the Z side.

Since the stringer (W) side is often hidden from the operator cameras are provided as shown in Plate 6. A third camera looks down at the W side from the top. The working head on the W side is attached to and rotates around the LVER. Attached to and rotating with the offset clampup and anvil is a two axis tracer and actuator which brings a flat die in front of the ram. The two axis tracer positions the machine in Y. This tracer has a second position feedback which positions the machine in W. The Z position is controlled off of the normality sensor. For this reason AERAC is actually a six axis machine since the two opposing tables each independently fly along at a controlled height from the surface. This allows AERAC to accomodate motion of the wing panel in and out of the FAJ centerline as well as changes in the panel thickness. Since five of the six axes are on sensor control only the X axis needs to be programmed. Note in Plate 7 that the capacitor storage bank for LVER for each side is contained inside the yoke arm. The cover plate has been removed for this photograph.

The AERAC shaver is custom designed and built. A high quality milling machine spindle is coupled to a direct drive brushless DC motor. An electronic depth stop machanism was develooped to precisely control shaver depth. As of this writing the demonstrated cycle time for clamp-drill-insert-upset-shaveunclamp is 9.5 seconds. The tool sequence is shown in Figures 5 and 6.

RIVET UPSET

To achieve good fatigue results and interference in the A330/A340 application the riveting process needs to be carefully considered. The LVER has nearly unlimited forming pressure but this pressure must be wisely employed to achieve the desired results. One complication is the offset riveting anvil. The offset anvil needs to be dynamically balanced. This anvil also adds weight. It is generally advantageous to add weight to the driver on the skin side to balance the extra driver weight on the stringer side.

On AERAC 1/4” rivets up to a 29 grip length are installed into high interference. In addition the skin and stringer material is 7150, very high strength aluminum. Long rivets installed with high interference into high strength material are extremely susceptible to shanking. A rivet head is unacceptable due to shanking if a .002” feeler gage can be slid in under the head until it contacts the rivet shank. The solution employed on AERAC is to rotate a flat piece of metal into the centerline as shown in Figure 4. The LVERs are pulsed at a lower energy level in this second hit. In the first upset the cup dies focus force down into the holes to achieve high interference. Due to the anchoring effect of the countersunk head the rivet expansion resuls in a thin gap under the buckside head. In the second hit the flat plate allows radial expansion of the head which fills in the gap.

The feeder nose design must also be carefully tailored to the application. In the feeder nose metal fingers guide the rivet into the hole and then spring open to permit passage of the ram. The fingers are quite specific to the rivet style and clearance requirements.

CARTRIDGE RI VET’ FEEDING SYSTEM

Due to the long length of the cable track on top of the FAJ it was advisable to carry rivets on board AERAC. Plate 8 shows the 1/4” rivet cartridges mounted on the left side of AERAC. There are nineteen 1/4” rivet cartridges, each carrying 220 rivets. Plate 9 shows the 3/16” cartridges on the right side. There are ten 3/16” rivet cartridges each carrying 215 rivets. The cartridge feed system permits a large number of grip lengths to be carried in a compact and lightweight package. The individual escapements are of simple design and are in direct proximity to each other. It is still necessary to employ bowl feeders to load the cartridges but these are employed off-line. The inevitable jams then do not affect machine availability. The bowl feeders and rivet pumps supplied with AERAC are shown in Plate 10. The rivet pumps load the cartridges from the bottom until a sensor at the top indicates that the cartridges are full. By loading from the bottom the rivets do not have an opportunity to tumble and lose orientation.

CONTROLS

The control pendant and television monitors are shown in Plate 11. An Allen-Bradley 8200 AT controller was specified by the customer. The control pendant rides with the riveter while the actual computer and the bulk of the controls is mounted at a fixed location adjacent to the FAJ. Communications between the pendant and computer is through the cable track. A separate DOS based computer with hard disk drive is incorporated into the system for file storage and management functions.

A color monitor is mounted above the pendant. Any of the four camers can be selected to drive the monitor. The screen can also be split into quadrature to view all four cameras at once as shown in Plate 11. A miniature camera in the Z nosepiece provides a closeup view of the rivet being upset. A cross-hairs generator permits alignment to tack fasteners and spray dots.

CONCLUSION

The AERAC machine dramatically changes the procedure for stiffening wing panels. The riveting machine is brought to the wing panel in the floor assembly jig. With AERAC panel stiffening can be performed with less handling potentially yielding a more accurate and more economical product.

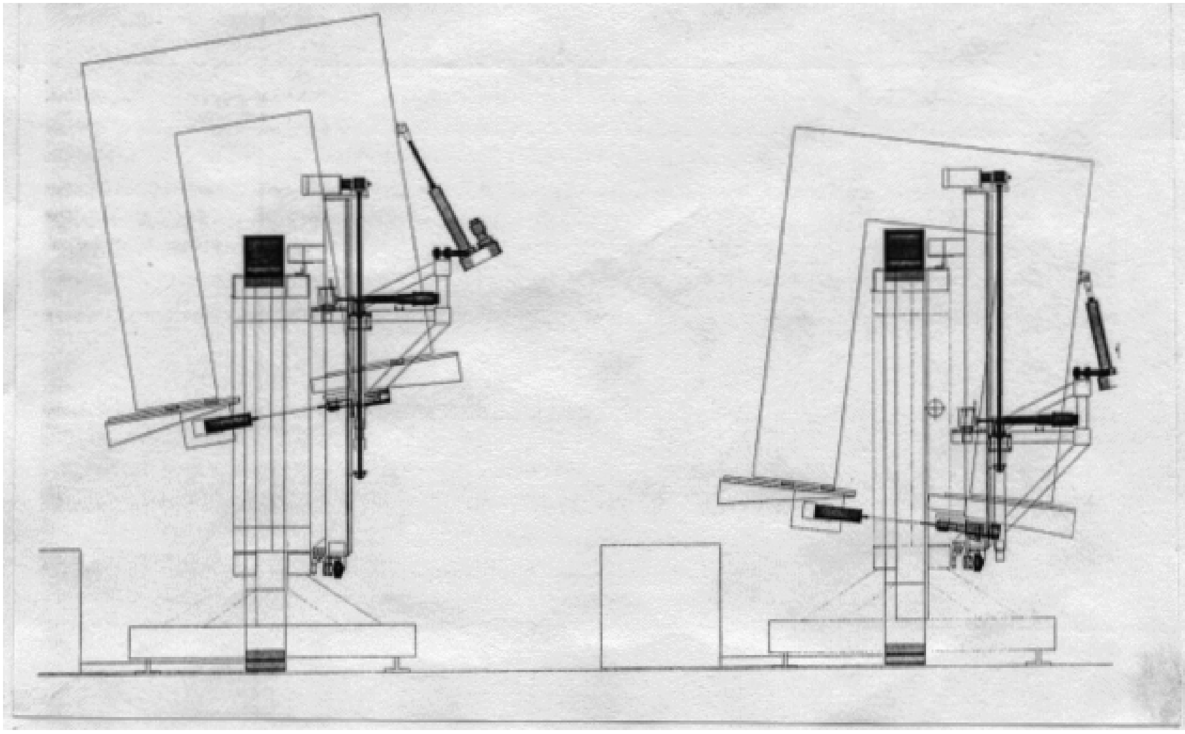


Figure 1 Illustrates the A and Y axes

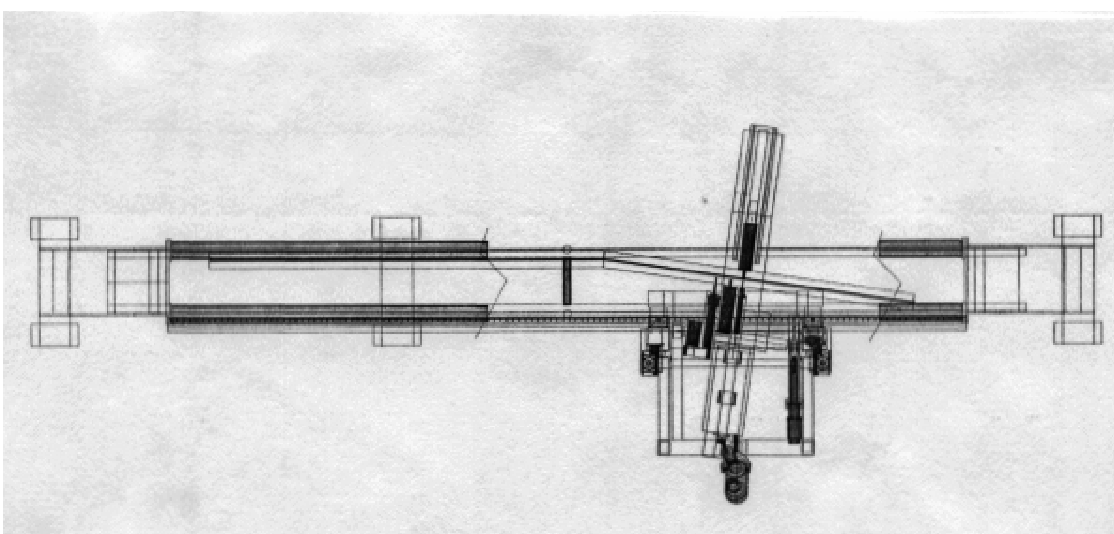


Figure 2 Illustrates the B axis

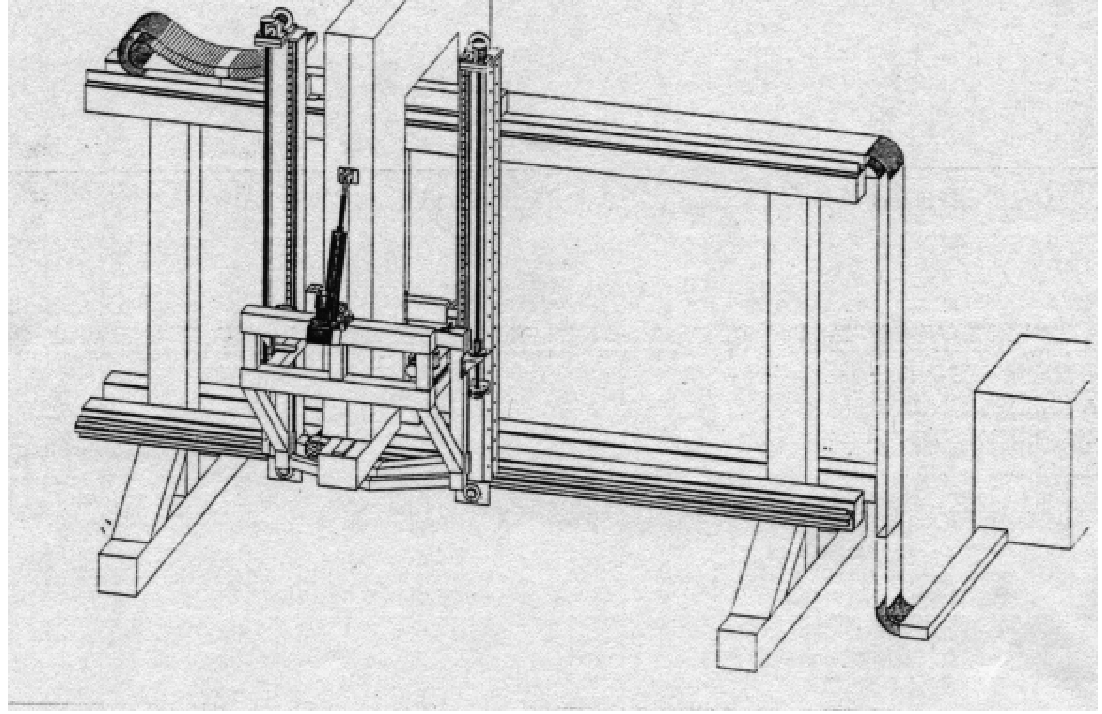
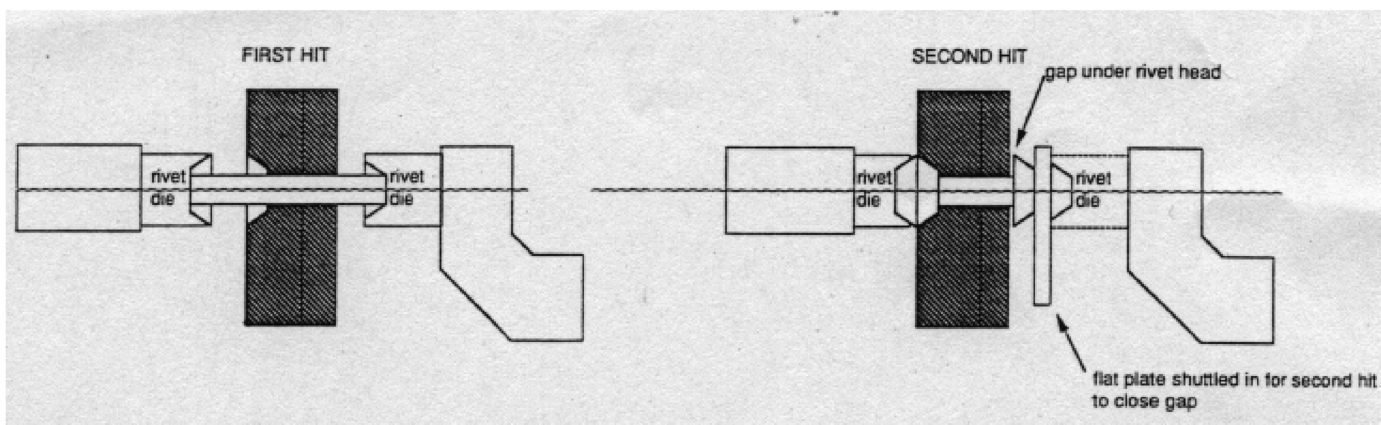
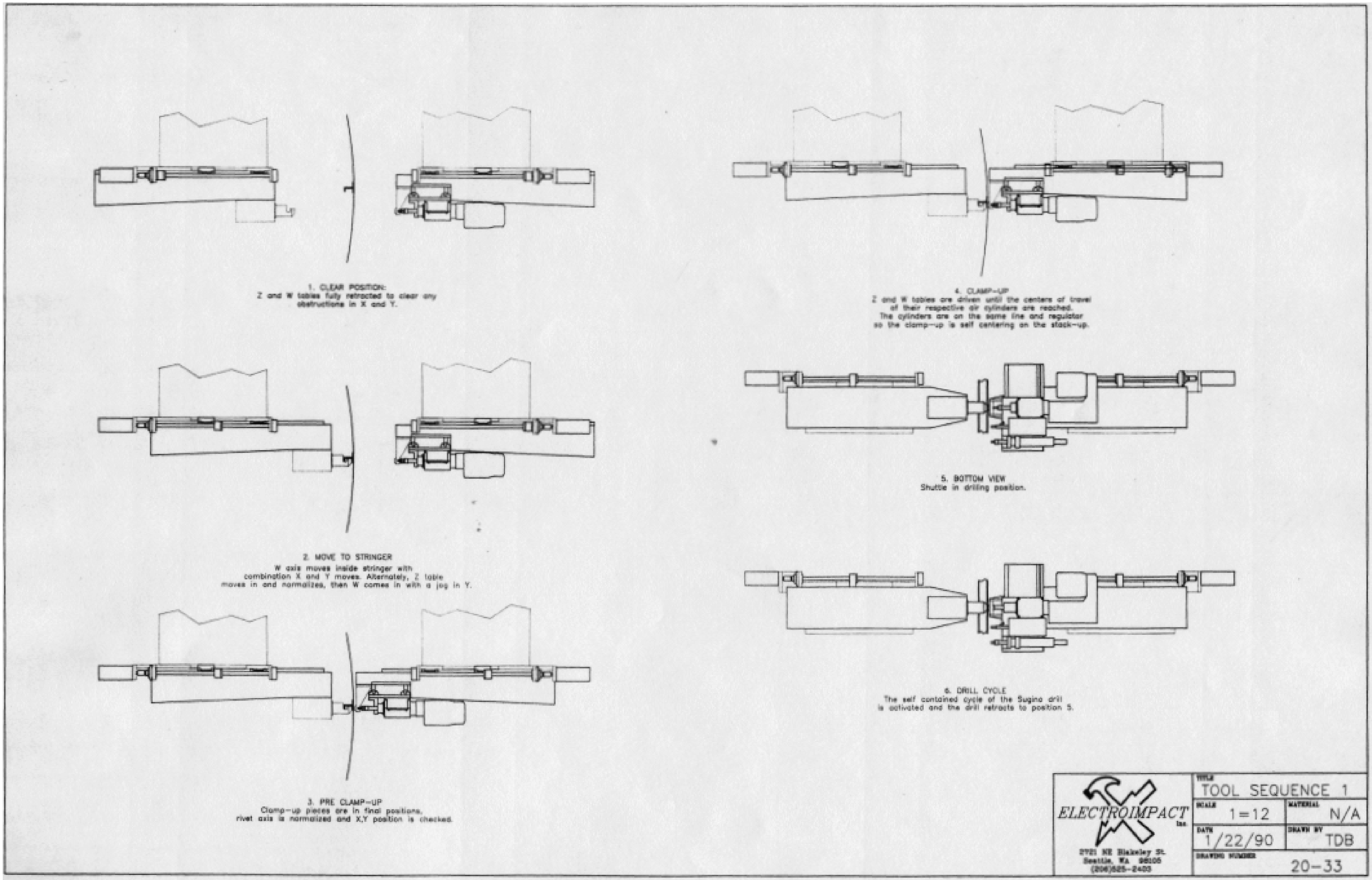


Figure 3 Overall machine configuration





1. CLEAR POSITION:
Z and W tables fully retracted to clear any obstructions in X and Y.
2. MOVE TO STRINGER
W axis moves inside stringer with combination X and Y moves. Alternately, Z table moves in and normalizes, then W comes in with a jog in Y.
3. PRE CLAMP-UP
Clamp-up pieces are in final positions, rivet axis is normalized and X,Y position is checked.
4. CLAMP-UP
Z and W tables are driven until the centers of travel of their respective air cylinders are reached.
The cylinders are on the same line and regulator so the clamp-up is self centering on the stack-up.
5. BOTTOM VIEW
Shuttle in drilling position.
6. DRILL CYCLE
The self contained cycle of the Sugino drill is activated and the drill retracts to position 5.
ELECTROIMPACT Inc.
2721 NE Blakeley St.
Seattle, WA 98105
(206)525-2403
TITLE
TOOL SEQUENCE 1
SCALE
1=12
MATERIAL
N/A
DATE
1/22/90
DRAWN BY
TDB
DRAWING NUMBER
20-33

Figure 5

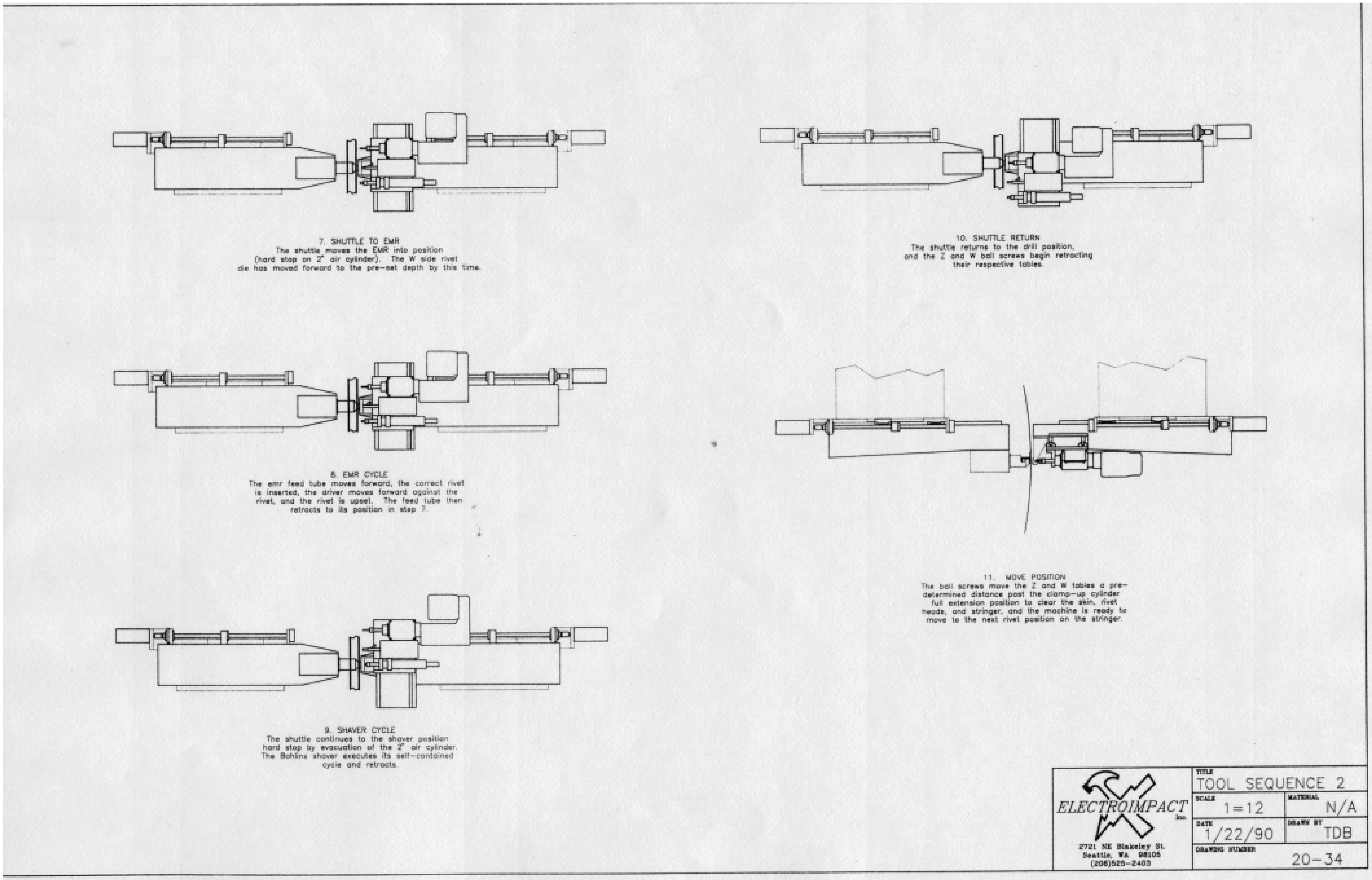

7. SHUTTLE TO EMR
The shuttle moves the EMR into position
(hard stop on 2" air cylinder). The W side rivet
die has moved forward to the pre-set depth by this time.
10. SHUTTLE RETURN
The shuttle returns to the drill position,
and the Z and W ball screws begin retracting
their respective tables.
8. EMR CYCLE
The emr feed tube moves forward, the correct rivet
is inserted, the driver moves forward against the
rivet, and the rivet is upset. The feed tube then
retracts to its position in step 7.
11. MOVE POSITION
The ball screws move the Z and W tables a pre-
determined distance past the clamp-up cylinder
full extension position to clear the skin, rivet
heads, and stringer, and the machine is ready to
move to the next rivet position on the stringer.
9. SHAVER CYCLE
The shuttle continues to the shaver position
hard stop by evacuation of the 2" air cylinder.
The Bohlins shaver executes its self-contained
cycle and retracts.
ELECTROIMPACT Inc.
2721 NE Blakeley St.
Seattle, Wa 98105
(206)525-2403
TITLE
TOOL SEQUENCE 2
SCALE
1=12
MATERIAL
N/A
DATE
1/22/90
DRAWN BY
TDB
DRAWING NUMBER
20-34

Figure 6