Automated Coaxial Squeeze Riveter

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ABSTRACT

Electroimpact has developed a new automated squeeze riveting process. This process utilizes an innovative coaxial riveting head design in which the drill spindle and rivet driver share a common servo axis, with a simple toggle mechanism to switch which tool is active. This system has been optimized for the installation of headed solid rivets which can be automatically installed without the need for additional process tools beyond the drill and driver. By optimizing for the requirements of these rivets, Electroimpact has been able to eliminate much of the complexity typically seen on automated fastening equipment, resulting in an unprecedentedly simple and cost-effective design.

INTRODUCTION

An effort has been underway at Electroimpact to develop a new automated squeeze riveting process which enables the installation of several types of rivet which are not well suited for installation using the EMR technology [1] that Electroimpact has traditionally relied upon. The process is accomplished using a new coaxial riveting head design which is designed to be as simple as possible to minimize costs while achieving an exceptionally fast rate of fastener installation and meeting the quality requirements of aerospace manufacturers.

The coaxial riveting head is ideally suited for installing flush head rivets (e.g. NAS1097, MS20426) and universal head rivets (e.g. MS20470). It is limited to fasteners with a manufactured head that do not require the head to be shaved (milled off) after bucking.

SYSTEM OVERVIEW

Figure 1. Automated squeeze riveting machine utilizing the coaxial head design

The riveting machine consists of two riveting heads mounted to a supporting "U-frame" structure. Riveting is accomplished along a horizontal axis with the workpiece held in a predominantly vertical orientation. Compared to vertical-axis riveting, this approach provides better accessibility to the heads for manual tool change and maintenance. Additionally, by holding the panel vertically, any chips that are not collected by the vacuum system will tend to fall away rather than lingering on the workpiece surface.

The system is controlled by a Fanuc 31i CNC and its servo axes are powered by Fanuc Alpha motors. Secondary feedback is provided by Heidenhain LC493F encoders which utilize the Fanuc serial interface.

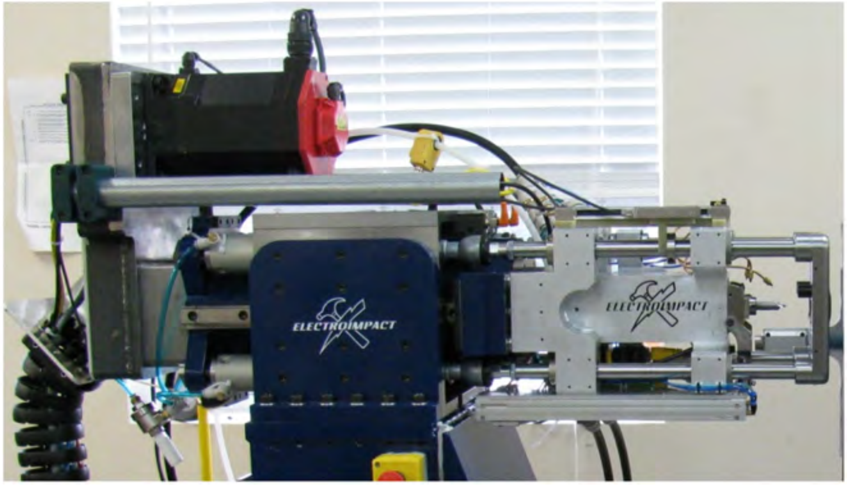

Figure 2. Coaxial riveting head

COAXIAL (OUTER) RIVETING HEAD

Spindle Housing and Floating Headstone

The spindle housing (Fig. 3) forms the main structure of the coaxial end effector. It is a machined out of a solid block of aluminum using a 5-axis CNC milling machine. The critical final machining steps are all performed in one setup to produce an end product that conforms to the tight tolerances required. The central feature of the housing is the bore into which the spindle is fitted. The housing is also equipped with a multitude of other machined features for mounting the various subassemblies that make up the end effector.

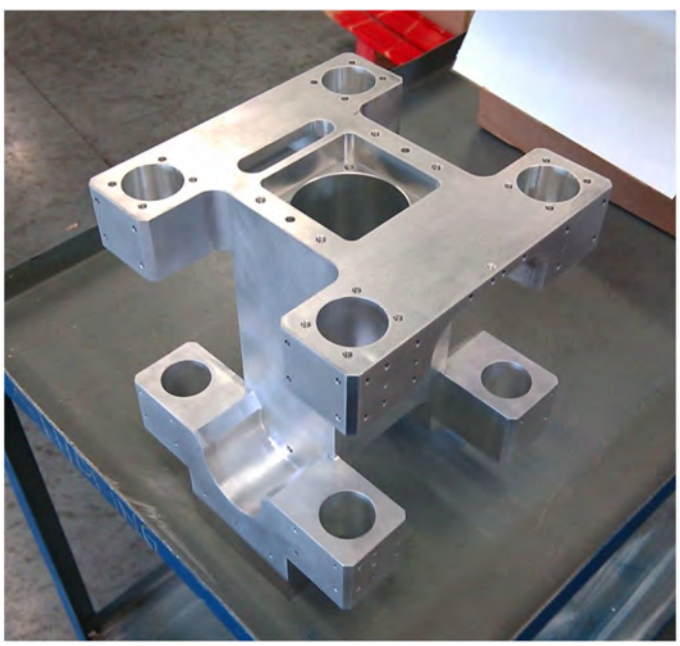

Figure 3. Spindle housing

The spindle housing is box-shaped and features four pairs of concentric bores, parallel to the spindle axis, located at the corners of the "box." These bores are fitted with linear ball bushings and support a set of four shafts. The shafts are connected at the rear to pneumatic cylinders and at the front to the headstone (clamp plate). Together, the air cylinders, shafts, and headstone comprise the floating headstone assembly (Fig. 4).

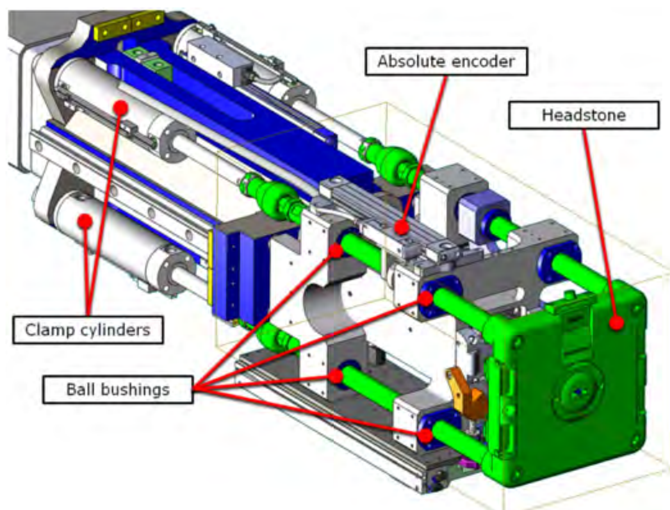

Figure 4. Floating headstone assembly

Mounted to one of the shafts is the read head of a Heidenhain absolute linear encoder. The body of the encoder is mounted to the spindle housing. As the floating headstone moves relative to the spindle housing, the encoder provides displacement feedback to the CNC.

The headstone is fitted with a set of four laser distance sensors used for normality correction as well as measurement of the distance between the contacting surface of the headstone and the part surface. This is a configuration which Electroimpact has successfully implemented on several recent automated fastening machines.

On many riveting machines, the outer (upper) clamp assembly is mounted directly to the supporting machine structure (typically a C-frame) and cannot be moved in the Z axis, thus creating a fixed working plane and requiring that the surface of the workpiece be brought to that plane before each cycle. On the coaxial head, the headstone is mounted to the outer head and moves along with it. This means that it is possible to clamp up and install a rivet at any point along the Z axis within a certain range. For some applications, this may eliminate the need for an independent Z axis on the part positioner.

Flip-up Rivet Buck Mechanism

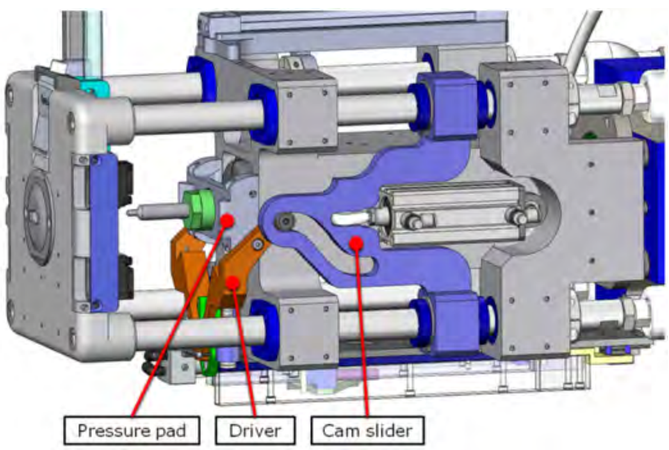

Figure 5. Pressure pad, driver, and cam slider (Driver in "feed" position)

The driver assembly consists of a wishbone-shaped body made of tool steel fitted with an anvil and a pair of rivet-gripping fingers. The driver pivots on the pressure pad assembly, which is a plate made of tool steel that is fixed to the front of the spindle housing. The driver is actuated between two positions: a flipped-down "feed" position and an upright "drive" position. In the "feed" position, the driver points downward, with the fingers positioned in front of the rivet injector, and the drill bit is fully exposed so that drilling can take place. In the "drive" position, the driver surrounds the drill bit and brings the anvil and rivet into alignment with the freshly-drilled hole.

The actuation between "feed" and "drive" is achieved via the cam slider assembly, which is a plate with a curved cam path that slides on two of the headstone shafts, powered by a small pneumatic cylinder. The curved shape of the cam path allows for some control of the acceleration and deceleration of the driver as it flips from position to position without the need of more complex and expensive methods of actuation such as a servomotor.

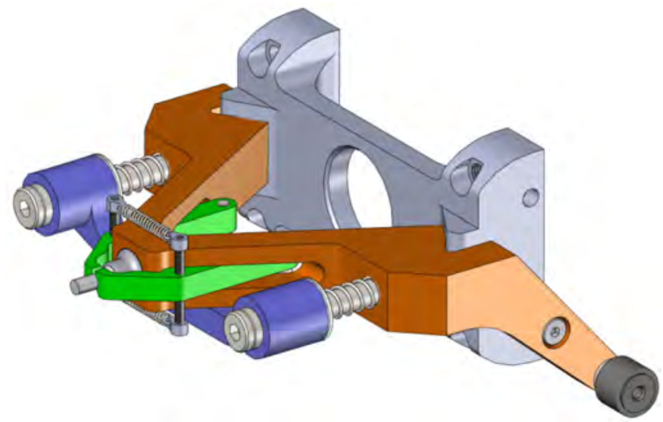

Figure 6. Driver and pressure pad, ready to insert rivet ("drive" position)

When the driver is in the "drive" position, it interfaces with the pressure pad at two locations (Figs. 6 and 7). The contact points on the pressure pad are concave, while the mating parts of the driver are convex. A curved Hertzian-contact interface was selected rather than a flat-to-flat interface to allow some compliance and avoid edge loading. Both parts are machined to very tight tolerances to ensure that they fit together properly, with wire EDM used to cut the critical curved interface features on both parts. Visual inspection of the first driver and pressure pad after installing several thousand rivets reveals a single linear mark on each of the pressure pad's "cup" faces where the Hertzian contact pressure reaches its maximum. The contact points are designed to be 100 mm apart, which was confirmed by measuring the separation between the marks on the worn-in pressure pad with a caliper.

The primary function of the pressure pad is to turning a spreading force into a predominantly compressive force (Fig. 7). The driver and pressure pad together form a highly stable triangle structure, with the middle portion of the pressure pad taking a tensile load. This reduces the severity of the stress concentrations induced in the spindle housing and allows for the use of aluminum for the housing's construction, saving a considerable amount of weight and making manufacturing much easier.

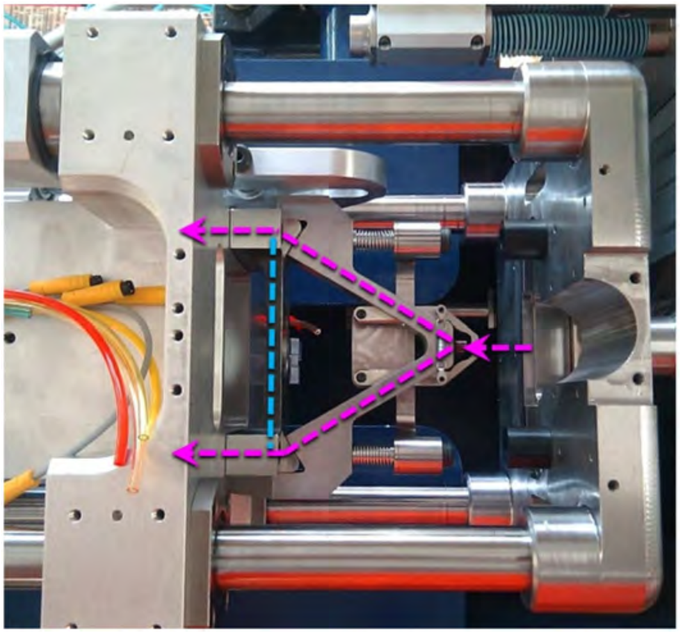

Figure 7. Driver and pressure pad, showing areas of compressive (magenta) and tensile stress (blue) during rivet upset

Rivet Fingers

The driver is fitted with a sliding part called the finger block, shown in blue in Fig. 8. The finger block is supported by a pair of ball bushings and rides on a pair of shoulder bolts. It is sprung forward by means of a spring on each shoulder bolt. Mounted to the finger block are a pair of fingers, which are tied together above and below by a pair of extension springs. As the driver moves toward the workpiece, a pair of hard stops on the back face of the headstone contact the finger block. As the driver continues to move forward, the finger block slides back relative to the anvil. Curved faces on the front of the driver come into contact with curved faces on the inside of the fingers, causing them to cam open and release the rivet (Fig. 8). The thickness of the hard stops which strike the finger block determines the timing of when the fingers release the rivet.

The fingertips are machined with a profile that is the inverse of the geometry of the rivet head. They are chamfered on one side to allow a rivet to be snapped into them laterally by the rivet injector (Figs. 9 and 10). The fingers engage with enough of the shank of the rivet and grip with enough force to maintain control over the rivet orientation during the flip-up motion and while inserting it into the hole. The surfaces on the fingers which contact the fastener are polished to reduce potential for making the rivet.

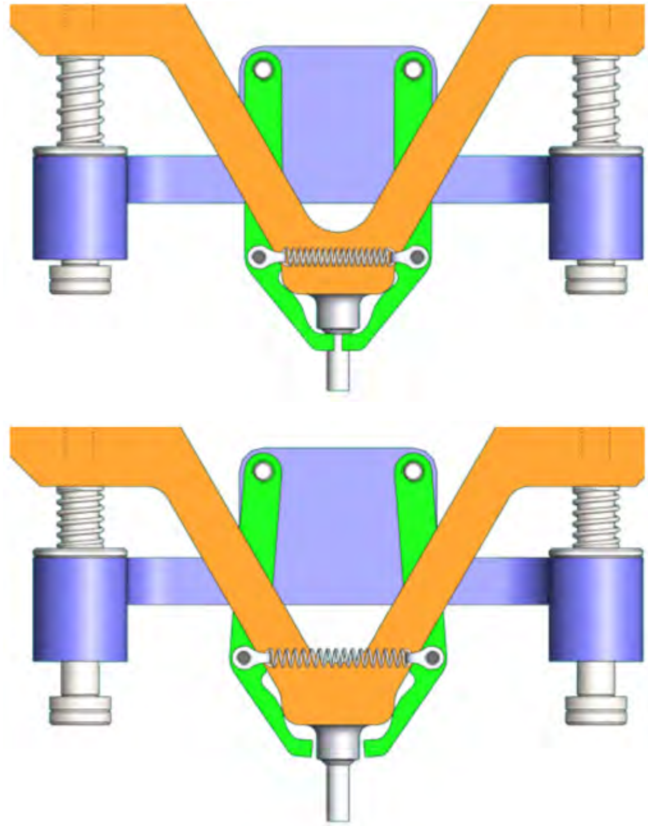

Figure 8. Fingers releasing their grip on a rivet

*Figure 9. NAS1097**6 rivet finger tip detail*

Rivet Injector

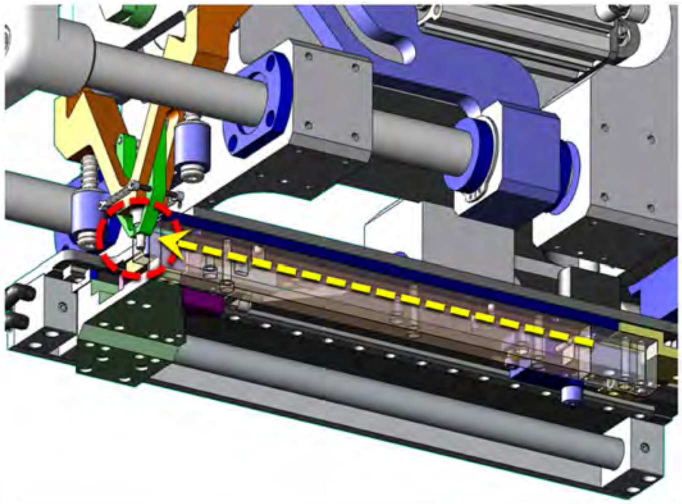

Figure 10. Rivet injector showing feed path and rivet being snapped into fingers (circled)

The rivet injector receives incoming rivets from the fastener feed system and delivers them into the waiting fingers of the driver while the driver is in the "feed" position (Fig. 10). The injector is mounted to the underside of the spindle housing. The feed tube which delivers the rivet to the injector passes behind the spindle and blows the fastener into a machined slot, catching it by the underside of the head and allowing the tail to hang freely downward. A proximity switch detects when the rivet has arrived, triggering the action of an arm mechanism which slides down the slot, pushing the rivet forward and into the fingers. The 90° rotation of the driver allows the rivet to be fed in the preferred tail-first orientation into the injector and handled in the preferred tail-down orientation as it is delivered into the fingers, while at the same time allowing riveting to be accomplished along a horizontal axis.

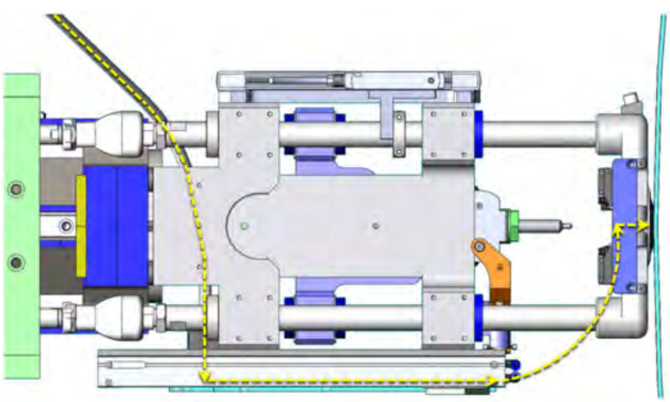

Figure 11. Fastener feed path

INNER RIVETING HEAD

The inner riveting head (Fig. 12) is a very simple mechanism compared to the coaxial outer head. Its two functions are to provide clamp pressure and to buck the tail of the rivet. This is accomplished by means of a donut air cylinder which surrounds a central driver shaft, with an anvil fitted to the end of the shaft. A clamp foot is attached to the rod of the air cylinder. During most of the riveting cycle, the air cylinder is continuously pressurized and the clamp foot does not move relative to the anvil. After the rivet is inserted into the hole, the inner servo axis drives forward and through the clamp, briefly increasing the clamp-up pressure as the tail of the rivet is formed.

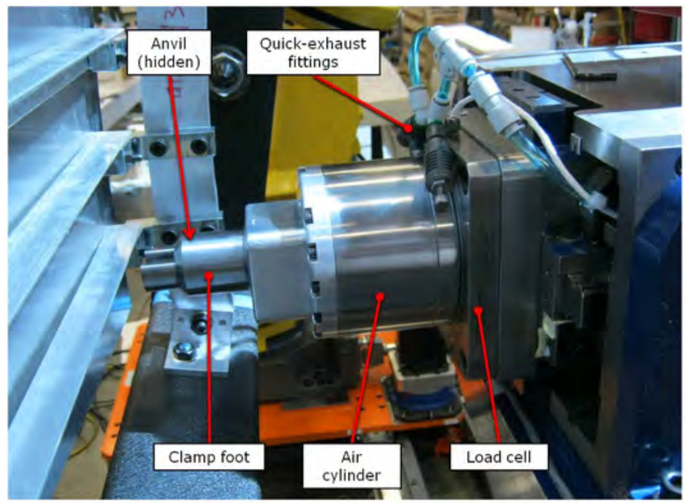

Figure 12. Inner head end effector

The inner head was designed to be as simple as possible for the first-generation proof-of-concept coaxial squeeze riveting machine. Future improvements to make the inner head production-ready include Y- and Z-axis laser tracers, a rotating servo C-axis, and a quick tool change socket. These are standard features on Electroimpact inner tooling, but were omitted at this stage.

RIVETING HEAD AXES

The inner and outer heads are each mounted to an actuator assembly which is nearly identical between the two sides. The actuator's core components are a servomotor, a recirculating roller screw, and a set of bearings that transfer the force between the screw and the body of the actuator. Linear bearings are used for guidance. Heidenhain absolute linear encoders are used for position feedback.

Each actuator is fitted with a load cell. On the outer head, the load cell is mounted at the nut and measures the force transmitted out through the nut into the supporting structure of the riveting machine. On the inner head, the load cell is mounted to the front face of the actuator, and the anvil transmits rivet upset loads directly into and through it.

PROCESS

OVERVIEW

The following steps briefly describe the process of automatically installing a rivet into a workpiece using the coaxial squeeze riveting head.

1. The riveting heads are in their default positions (retracted).

2. The inner head approaches the inner surface of the workpiece and makes contact. Because the clamp nose is backed up by an air cylinder, the force applied to the part is limited by the pressure of the air supplied to the cylinder.

3. The outer head approaches the workpiece and makes contact. The outer head then moves forward an additional nominal distance to the clamp-up position after making contact. Because the outer clamp force is lower than the inner, the workpiece does not move, and the headstone is displaced relative to the outer head.

4. Stack thickness is measured using a combination of the two actuator encoders and the headstone encoder. Once stack thickness is known, the correct length rivet can be fed.*

5. The drill spindle is turned on and the outer head moves rapidly toward the panel to bring the drill bit to a standby position.

6. The outer head moves forward at the appropriate drill feed rate. Cutting fluid mist is sprayed on the toolpoint.

7. While drilling is underway, the fastener arrives at the injector from the fastener feed system and is transferred into the fingers of the driver.

8. Using feedback from the headstone encoder, the outer head stops when the correct countersink depth has been reached and retracts back to the clamp-up position.

9. The driver is actuated upward into the “drive” position with the rivet gripped in its fingers.

10. The outer head moves forward and inserts the rivet into the hole. The fingers cam open passively as they pass through the headstone, releasing the rivet at the last possible moment.

11. The inner and outer heads move in a coordinated fashion to bring the inner and outer anvils into contact with the rivet and form an upset tail.

12. When the desired tail thickness is reached, both heads stop. The heads can also be programmed to stop when the desired upset force has been reached via feedback from load cells.

13. The air supply to the inner clamp cylinder is shut off and a set of quick-exhaust valves cause it to rapidly lose pressure. Because the fastener is still securely held between the anvils, the workpiece does not move.

14. The outer head retracts to its default position, pulling the headstone away from the workpiece. Because the inner clamp pressure is zero, the inner clamp foot does not extend, so the workpiece remains stationary.

15. The inner head retracts to its default position, pulling the anvil and clamp foot away from the workpiece.

16. The air supply to the inner clamp cylinder is restored.

CYCLE TIME

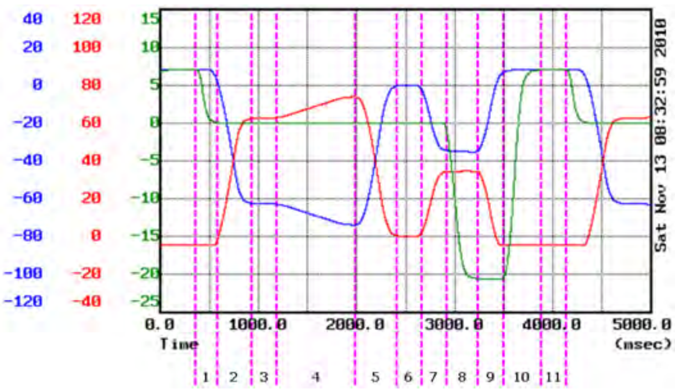

Figure 13. Plot from CNC showing axis positions during a full cycle

Cycle time was measured by riveting a coupon consisting of two sheets of 1/8″ 7075-T6 aluminum using NAS1097AD6-9 flush head rivets with 25 mm spacing. Figure 13 shows a plot of axis positions taken from the CNC during one of these cycles. Total cycle time from hole to hole is 3.8 seconds, or 15.8 rivets per minute. Table 1 gives a breakdown of what is happening at each of the numbered phases of the plot.

The longest step of the process, by far, is drilling, taking approximately 0.8 seconds. During this testing, the coaxial head was fitted with a pneumatic spindle which was underpowered (0.8 kW / 1.1 HP). A feed rate of 900 mm/min was used in order to maintain acceptable hole quality. Equipped with a faster and more powerful spindle, it is likely that the drilling step could be completed much more quickly. A 50% reduction in drilling time would give an overall cycle time of 3.4 seconds, or 17.6 rivets per minute.

*Stack thickness can also be programmed such that the predicted correct length rivet can be fed as soon as the previous cycle is complete, and if the measured thickness deviates too much from the programmed thickness, the bad rivet can be ejected and the correct length rivet fed instead.

Table 1. Rivet cycle breakdown

	Operation	Start	Duration
1	Clamp-up approach	0.4	0.2
2	Rapid move to drill standby	0.6	0.3
3	Wait for vibration to settle	0.9	0.3
4	Drill and countersink	1.2	0.8
5	Rapid move back to clamp-up	2.0	0.4
6	Driver flip up	2.4	0.3
7	Insert rivet	2.7	0.2
8	Upset	2.9	0.3
9	Unclamp/retract	3.2	0.3
10	Retract & coupon movement	3.5	0.3
11	Wait for coupon to finish moving	3.8	0.4
12	Begin next cycle	4.2	
	Total cycle time		3.8 sec

In addition to upgrading the drill, another way that this process could be sped up would be to use a larger servomotor and a higher pitch screw for the riveting head axes, which would allow for faster acceleration and deceleration during each step of the process and bring the overall hole-to-hole rate closer to 20 rivets per minute.

PRODUCT

Figures 14 and 15 show a specimen of a 3/16″ flush head rivet (NAS1097KE6-9) which was installed in a 1/4″ thick coupon of 7075-T6 aluminum. The specimen was potted in epoxy, turned on a lathe, and polished to reveal the interface between the rivet and the countersunk hole.

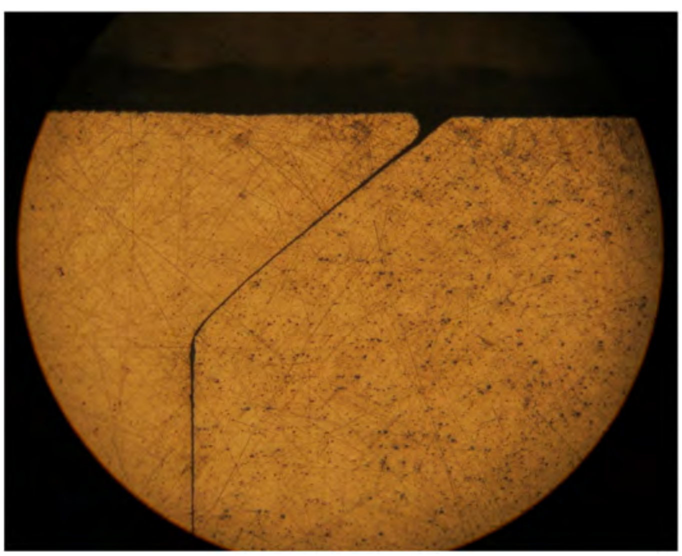

Figure 14. Rivet head (5x magnification)

A tapered gap is visible under the head in Fig. 14. The gap was measured to be between 0.001″ and 0.002″ at its widest, which is typically considered acceptable. With optimization of the die geometry, it is likely that this gap could be reduced or eliminated altogether. The formed tail of the rivet has no gapping, as shown in Fig. 15.

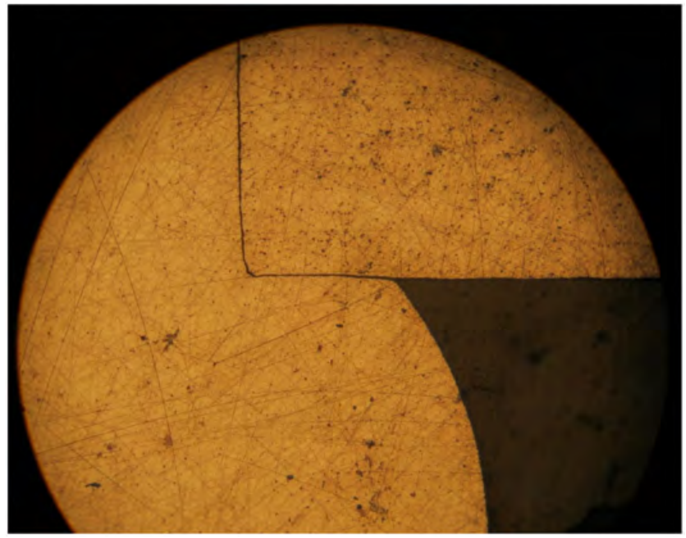

Figure 15. Rivet tail (5x magnification)

Flushness, tail height, and tail diameter were measured for a full coupon of 42 rivets (1/4″ stack, NAS1097D6-9). The results are summarized in Table 2. The complete set of data for the coupon measured is provided in the appendix (Table A1).

Table 2. Dimensions of formed rivets (inches)

	Flushness	Tail diameter	Tail height
Avg	0.0005	0.2897	0.0952
Stdev	0.00021	0.0010	0.0003
Max	0.0009	0.2920	0.0960
Min	-0.0001	0.2880	0.0945
Range	0.0010	0.0040	0.0015

SUMMARY/CONCLUSIONS

The coaxial squeeze riveter is a fast and simple approach to automated fastening. Although its range of capabilities is limited, it can provide excellent performance in terms of speed and quality when it is applied to the installation of the types of rivets it is designed to handle. Future improvements will focus on increasing cycle speed while maintaining or improving rivet installation quality.

REFERENCES

1. Zieve, Peter. “Low Voltage Electromagnetic Riveter”, SME paper # AD86-680, 10/21/1986

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DEFINITIONS/ABBREVIATIONS

EMR
[Low-voltage] Electromagnetic riveter

EDM
Electrical discharge machining

APPENDIX

Table A1. Data from a 1/4" thick 7075-T6 coupon, NAS1097D6-9 rivets (inches)

Rivet	Flushness	Tail diameter	Tail height	Rivet	Flushness	Tail diameter	Tail height
1	0.0007	0.2900	0.0955	22	0.0008	0.2890	0.0960
2	0.0006	0.2905	0.0955	23	0.0007	0.2905	0.0950
3	0.0004	0.2890	0.0950	24	0.0006	0.2920	0.0945
4	0.0006	0.2910	0.0950	25	0.0007	0.2900	0.0955
5	0.0005	0.2880	0.0955	26	0.0005	0.2905	0.0950
6	0.0009	0.2900	0.0950	27	0.0005	0.2900	0.0955
7	0.0009	0.2895	0.0955	28	0.0003	0.2905	0.0955
8	0.0004	0.2895	0.0955	29	0.0006	0.2910	0.0950
9	0.0006	0.2880	0.0955	30	0.0005	0.2890	0.0950
10	0.0005	0.2910	0.0950	31	0.0003	0.2890	0.0950
11	0.0006	0.2905	0.0950	32	0.0007	0.2905	0.0950
12	0.0007	0.2895	0.0955	33	0.0005	0.2910	0.0950
13	0.0007	0.2880	0.0955	34	0.0003	0.2910	0.0950
14	0.0007	0.2890	0.0950	35	0.0004	0.2900	0.0950
15	0.0005	0.2890	0.0955	36	0.0004	0.2890	0.0950
16	0.0005	0.2900	0.0950	37	-0.0001	0.2885	0.0950
17	0.0009	0.2900	0.0950	38	0.0001	0.2895	0.0950
18	0.0008	0.2885	0.0955	39	0.0006	0.2905	0.0950
19	0.0008	0.2880	0.0955	40	0.0003	0.2910	0.0955
20	0.0006	0.2885	0.0955	41	0.0002	0.2895	0.0950
21	0.0006	0.2880	0.0955	42	0.0006	0.2890	0.0955

Note: Positive flushness values indicate the rivet head stands proud of the panel.

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