EMR with High Reliability for Retrofit of E4100 Riveting Gantry Machines

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Abstract

Electroimpact has retrofitted two E4100 riveting gantry machines and two more are in process. These machines use the EMR (Electromagnetic Riveter) riveting process for the installation of slug rivets. We have improved the skin side EMR to provide fast and reliable results: reliability improved by eliminating a weekly shutdown of the machine. In paper 2015-01-2515 we showed the slug rivet injector using a Synchronized Parallel Gripper that provides good results over multiple rivet diameters. This injector is mounted to the skin side EMR so that the rivet injection can be done at any position of the shuttle table. The EMR is a challenging application for the fingers due to shock and vibration. In previous designs, fingers would occasionally be thrown out of the slots. To provide reliable results we redesigned the fingers retainer to capture the finger in a slotted plastic block which slides along the outside diameter of the driver bearing. The various size fingers are pinned to the block in such a fashion as to allow rotation and clamping on the rivet. The clamping action is provided by opposing wave springs. The design of the fingers and clamping unit are shown in detail. This improvement in the injector (already reported), combined with an improved finger design, has provided unprecedented reliability and rivet rate.

Introduction

The E4100 rivet gantry machines have been in production since 2000. These machines produce wing panels for Airbus A330 and A340 airplanes. Two out of four of the rivet gantry machines have been retrofitted with improved EMRs. The improved Electromagnetic riveters have reduced part counts over previous EMRs: 12 parts were combined in the new design into one part. With high shock and vibration forces the monolithic design has fewer parts to vibrate loose. Although this EMR is on the smallest of our standard design foot prints at 8.5” wide, it has a robust 20mm rail and a 32mm ball screw for strength and longer life. The recoil mass which absorbs the rivet forming force pulse is optimized based on years of empirical data.

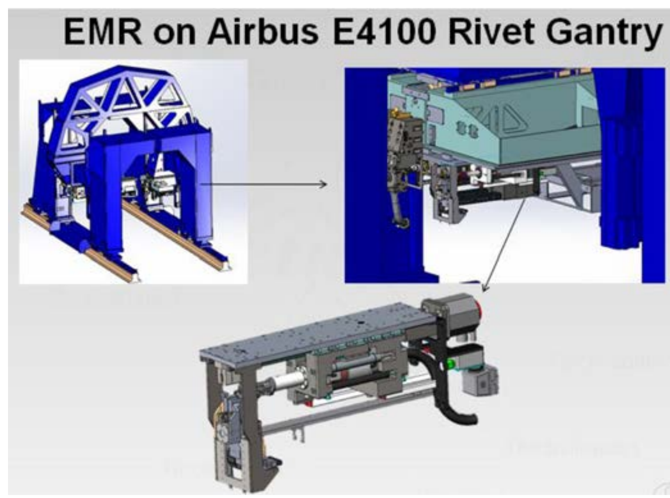

Figure 1. EMR on Airbus E4100 rivet gantry

Electromagnetic Riveter Summary

The electromagnetic riveters (EMRs) are the tools that form rivets. Two opposing EMRs work in unison, one on each side of the panel. They deliver a short-duration pulse of high mechanical force that forms the fastener.

Electromagnetic riveting is a single shot, electro-mechanical means of cold forming rivets. Energy for each riveting gun is stored in a bank of capacitors connected to the gun by a large coaxial cable. When the guns are fired, the discharge of stored energy creates a current that passes through the cables and into a custom-made pancake coil inside each gun. The resulting magnetic field generates eddy currents in a copper plate adjacent to the coil, repelling the plate from the coil with high force. This force is transmitted from the plate, through an attached tool steel bar and into the die that forms the fastener. The copper plate and attached bar are called the driver. Reaction force in the coil is absorbed in a mass that is allowed to recoil over a short distance. This results in very little force being transmitted to the external structure holding the guns. Force pulses of up to 32,000 lbf. can be attained, while typical external reaction forces are 300 lbf. or less.

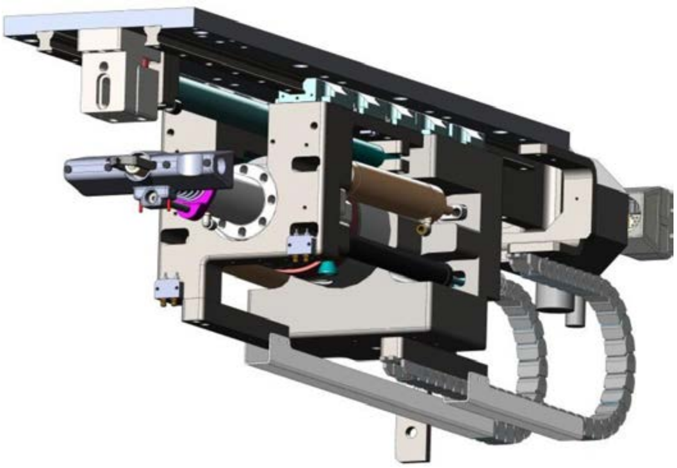

Figure 2. Electromagnetic riveter

EMR guns consist of five major assemblies: the base assembly, driver assembly, front moving mass assembly, recoil mass assembly and the drive train assembly. The front plate and recoil assemblies are mounted on linear bearings. The servo motor and ball screw of the drive train assembly attach to the front moving assembly of the UEMR. The machine installs slug rivets, which must be positioned to the correct depth in the hole before forming. The UEMR axis position is used for feeding the rivets and controlling the rivet length protruding from each side of the panel. The driver delivers mechanical force from the copper plate to the fastener. The recoil assembly slows and stops the recoil mass in a short distance, and returns it to the firing position for the next fastener.

Slug rivets are fed to the UEMR via a pneumatic rivet injector assembly. The injector pushes the rivet into fingers attached to the driver bearing on the front moving assembly. The drive train then moves the UEMR forward to a calculated position, pushing the rivet into the drilled hole. The fingers release the rivet as the rivet enters the hole. Sensors on the injector and the UEMR verify rivet length and protrusion.

The EMRs are operated under computer control from the Fanuc CNC. Capacitors for each gun are located in dedicated electrical boxes near the Operator platforms on both the U and V side.

EMR Components

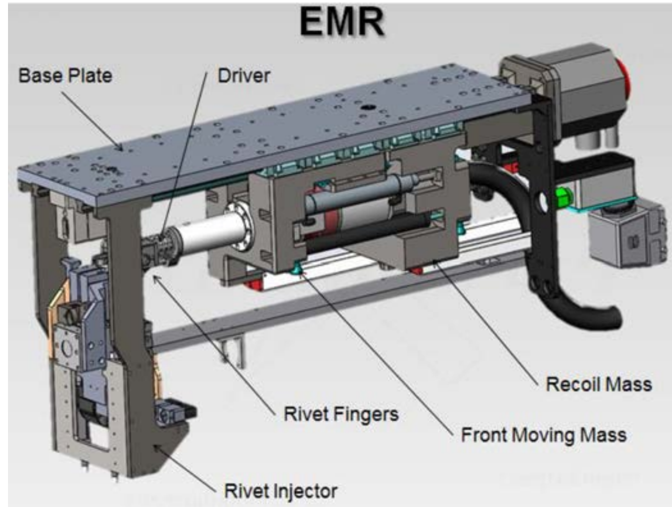

Figure 3. Electromagnetic riveter retracted

Table 1. EMR components

- Base Plate
- Front Moving Mass
- Recoil Mass
- Driver
- Rivet Fingers
- Rivet Injector (separate process tool assembly)

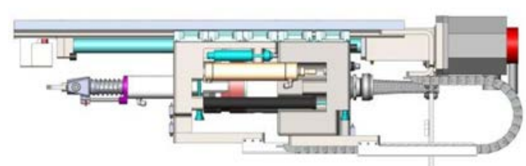

Figure 4. Electromagnetic riveter retracted

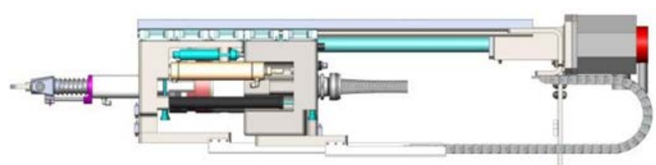

Figure 5. Electromagnetic riveter extended

Figure 6. EMR assembly on bench with shipping frame

EMR Rivet Finger Closer Design

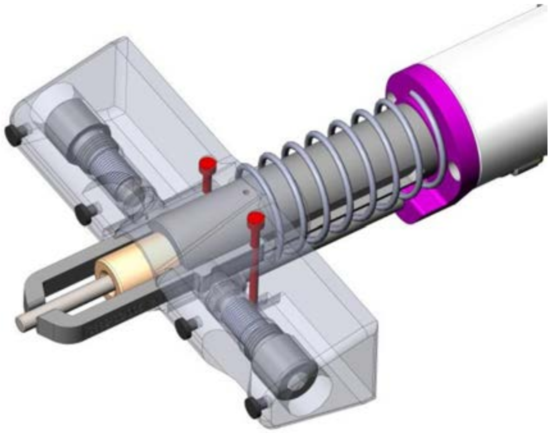

Figure 7. EMR finger closer transparent body

The conventional arrangement for the finger closer that worked on hydraulic riveters was problematic on EMR-based riveters. That arrangement is two rotating rods pulled together by an extension spring. The rods engage a receiving slot on the fingers. It was impossible to make the rods effective over the full exercise range of the fingers.

Our design is to pry the fingers open .010” with the rivet inserted in the fingers. This meant that the tip of the slug rivets is within .010” of center and is easily able to enter the hole. This implies that the fingers need to be changed out by rivet diameter.

Also note that the fingers are stripped back over the rivet die at full insertion (see Figure 10). The rivet die diameter is .75”, considerably larger than the .25” rivet. The closer mechanism must cope with this wide range of conditions. The problem with the conventional design was that the shock of firing the EMR would occasionally cause the rivet fingers to jump out of the slots and fall on the floor. This happened about once a week, shutting down production.

As part of the redesign, we sought to capture the fingers in a plastic block that would need to be lightweight due to its fast motion (see Figure 7). The plastic block has two opposing bores with wave springs to give the desired closing force. The fingers are captured with pins that drop in from the top surface. Figure 7 illustrates the capture of the fingers by the pins which stay in the holes by gravity. As previously stated we need to change the fingers according to the rivet diameter.

With the new design we had set 2.5 lbf as the target for the grip on the rivet. This is higher than we had achieved previously. Our target force on the springs that apply the force on the rivet fingers was therefore 10 lbf. There is a 4 to 1 force reduction from the springs to the rivet finger tips.

To achieve this forces we used an off-the-shelf wave spring (see Figure 11). We set up a test bench and cycle tested the rivet finger closer assembly. After 25,000 cycles the off-the-shelf wave springs started to fail. We were compressing the wave springs to the maximum recommended compressed height which resulted in a shorter wave spring life. We worked directly with a wave spring manufacturer to design a custom wave spring that would achieve the forces we needed over the travel distances we required, while also achieving life cycles at the maximum million cycle range that the manufacturer will calculate. Electroimpact’s tests of the improved custom wave spring lasted more than 100,000 cycles before the test was concluded for time constraint reasons.

EMR Rivet Finger Closer Implementation

After the cycle testing was successfully completed at Electroimpact, the new finger closer was shipped to our installation team and retrofitted onto the E4100 machine inside the factory. They ran thousands of rivet installation cycles as part of the testing routine in the factory. They found we had a completely different problem that we had not anticipated.

Figure 10 shows that the fingers are pulled back over the .75” diameter die when the rivet is inserted. Due to spring rate the force on the finger tips increases to 3.8 lbf. The increased friction of sliding the fingers along the die was problematic. Occasionally the extension spring on the driver shaft was not able to push the finger closer forward. This is referred to as reset of the fingers. We had designed the rivet pinch so well that occasionally the fingers would not reset.

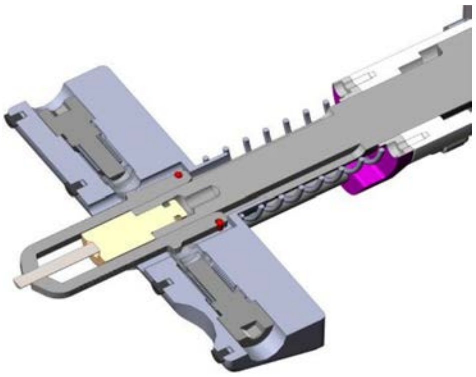

Figure 8. EMR finger assembly section

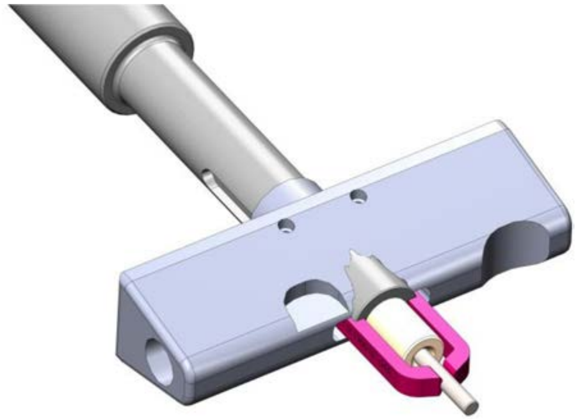

Figure 9. EMR fingers fully forward

The installation engineers modified the closing plugs to increase the rest length of the wave spring (see Figure 11). They found 2.4 mm longer spring rest length was effective. With a spring rate of 43 lb./in, the 2.4 mm increase equates to a force reduction on the spring that results in a new wave spring force of 6 lbf. After the 4:1 force reduction of the lever arm of the rivet fingers, the final forces on the rivets at the rivet finger tips are 1.5 lbf. That turned out to be the right compromise. The force was adequate to securely hold the rivet and the fingers would reliably reset. This final design is now in reliable production on the E4100 machine, and we have eliminated the weekly rivet finger detachments the machine had experienced for increased reliability.

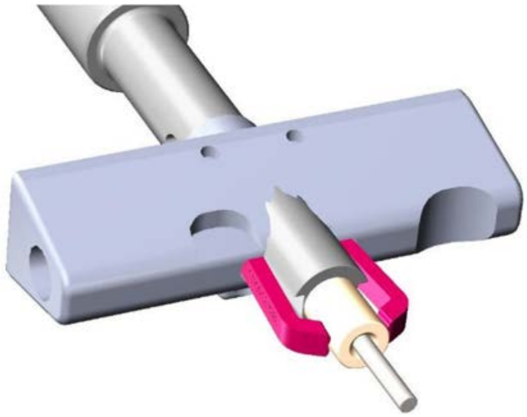

Figure 10. EMR fingers stripped back over the die

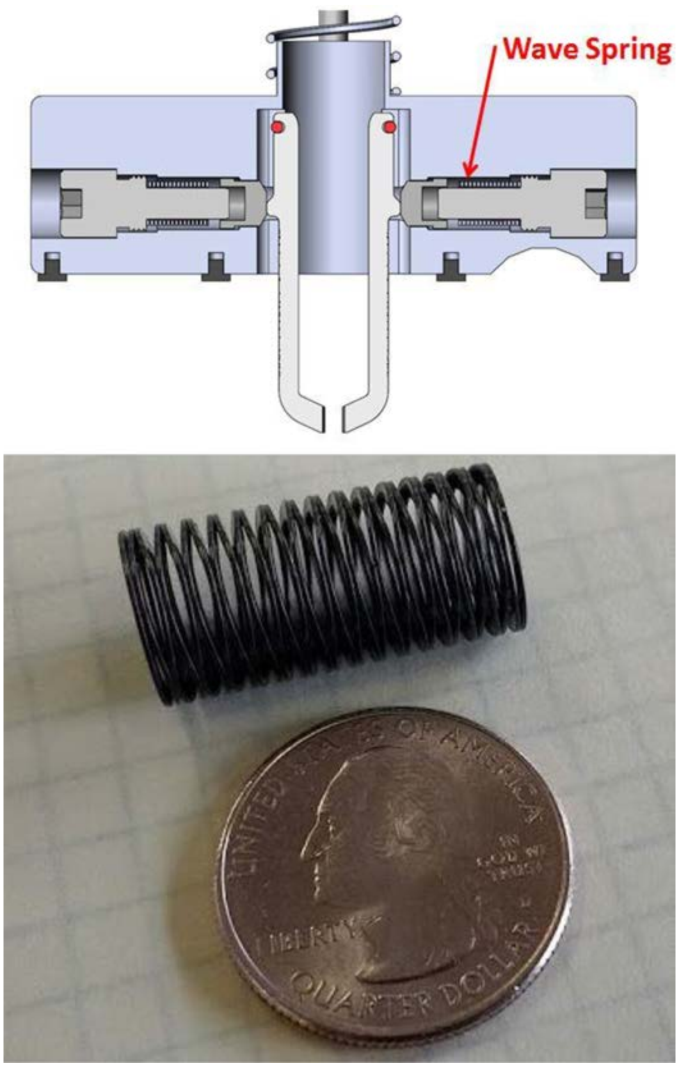

Figure 11. Wave spring pushes fingers closed

Summary/Conclusions

The EMR had greatly increased the rate and reliability of the E4100 machines. The improved EMR helped us improve the rivet rate from 4 rivets per minute to 7.5 rivets per minute after refurbishment.

Figure 12. LVER machine

Figure 13. LVER machine with wing panel

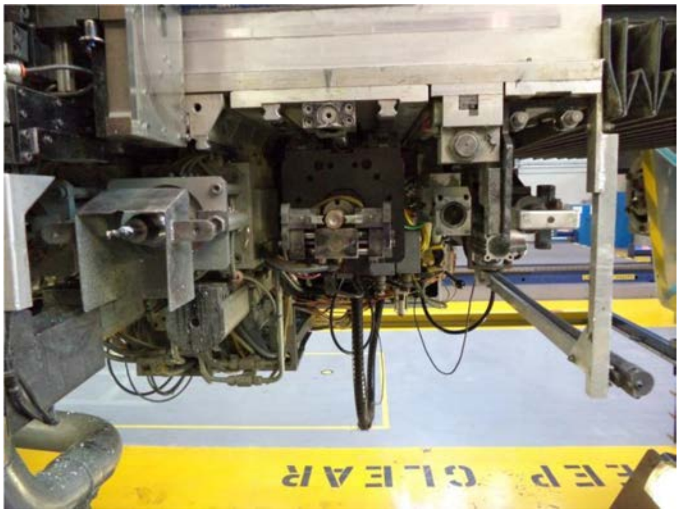

Figure 14. EMR before refurb of LVER

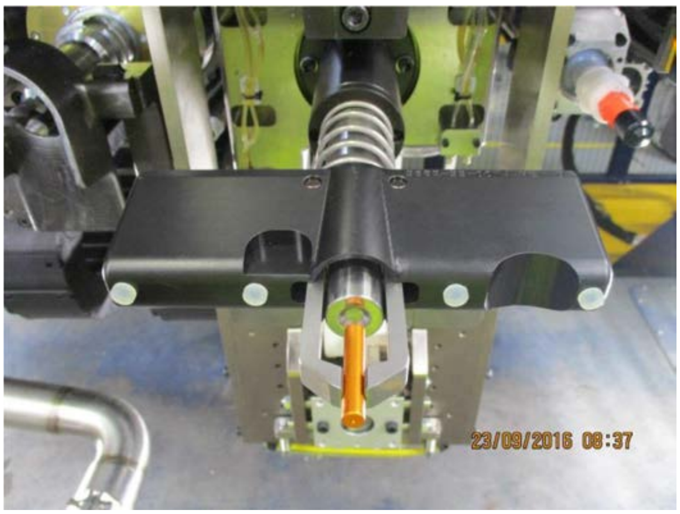

Figure 15. EMR after refurbishment of LVER

Table 2. EMR specifications

Width	8.5 Inches, 216mm
Length	43.7 Inches, 1110mm
Height	12 Inches, 305mm
Total Mass	250 Lbs., 113 kg
Rivet Diameter Sizes	1/4, 5/16, and 3/8 Inch

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Definitions/Abbreviations

EMR - Electromagnetic Riveter

Driver - Rivet Driver

UEMR - Skin side Electromagnetic Riveter

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