Magnetic Safety Base for Automated Riveting and Bolting

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Abstract

There is an ever-present risk for the lower ram on a riveting machine to suffer a damaging collision with aircraft parts during automated fastening processes. The risk intensifies when part frame geometry is complex and fastener locations are close to part features. The lower anvil must be led through an obstructive environment, and there is need for crash protection during side-to-side and lowering motion. An additional requirement is stripping bolt collars using the downward motion of the lower ram, which can require as much as 2500 pounds of pulling force. The retention force on the lower anvil would therefore need to be in excess of 2500 pounds. To accomplish this a CNC controlled electromagnetic interface was developed, capable of pulling with 0-3400 pounds. This electromagnetic safety base releases when impact occurs from the sides or during downward motion (5 sided crash protection), and it retains all riveting and bolting functionality.

Introduction

While riveting and bolting on aircraft parts, for example on a C or D frame riveting machine, the upper head and lower ram move synchronously between fastener locations. While the upper head has few restrictions to motion, the lower ram and lower anvil must be navigated through an array of frames, stringers, clips, and shear ties which fasten the aircraft skin together, support it and provide mounting features.

Collisions during this process can be caused by inaccurate part models, faulty programming and manual operator mistakes. If the lower anvil is fixed and inflexible, the aircraft part can be badly damaged. The goal was to implement a flexible interface that would uncouple and minimize damage, while retaining all the previous functionality of the lower ram.

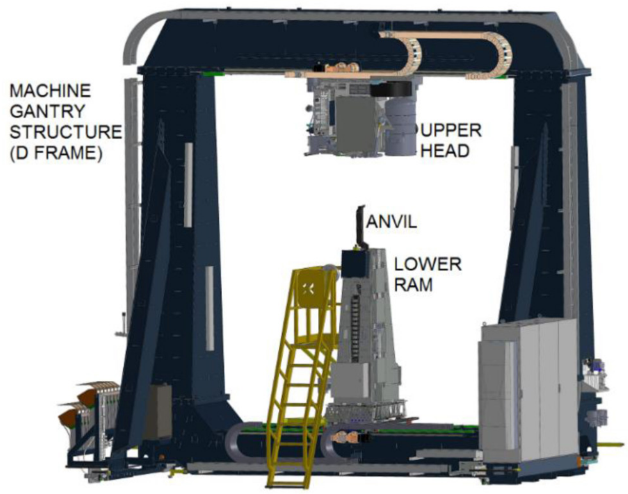

Figure 1. Example of an E7000 D frame riveting machine gantry

This level of crash protection is currently not present in the automated riveting industry, and its development involved functionalities that were counterintuitive. The envisioned safety base needed to seat and locate accurately while being able to rock from side to side and move vertically. It needed to move freely by rocking and moving upwards, but could not be removable. Lastly it was required to withstand tensile loads of 2500 pounds, but also be able to break loose when colliding with softer aluminum substructures.

After consideration, a full face electromagnet was chosen as the best option. The lower anvil sits inside of a shallow centering bore on the electromagnet. There is a clocking pin to orient the lower anvil, and micro switches all around that detect whether the anvil has tipped (indicating a collision). The tipped anvil sends a message to the CNC and puts the machine into feed hold. The retaining force is provided by the electromagnet.

An analog control is employed to turn the electromagnetic force up when stripping collars (90 volts DC provides 3400 pounds of pull) and down to a minimum when moving around a part (0 volts DC).

Due to residual magnetism in the steel, the lower anvil is attracted with about 200 pounds at 0 VDC. Pulses of inverted DC voltage are used to bring the force to zero.

The lower anvil baseplate is now the closing shunt of the electromagnet, which contains about 5000 turns of wire. By reducing the voltage the tool is pulled with less force; the force is readily controlled by the voltage. The highest force on the electromagnet will support stripping of the largest swage collars. Less force is required for riveting. Zero voltage is used when retracting the V axis to protect for the situation where the lower tool is hooked on the aircraft part. The shoulder screws shown in Figures 3 and 4 prevent removal of the anvil baseplate.

Figure 2. Electromagnet base

The electromagnetic safety base pictured in Figure 3 was the first prototype. It was created for assembly of a military cargo plane, and was designed to allow vertical movement of 2 inches and a tip angle of 10 degrees. These dimensions came from predicted machine reaction time. The machine axis needs time to come to a stop before it binds up the lower anvil baseplate on the shoulder screws. Calculations were done to predict this, and tests were performed after the safety base was installed on the E7000 machine to confirm operability.

Figure 3. Safety base with anvil

During testing, the lower ram was driven at 200, 400 and 600 inches per minute into sample aircraft structures. The electromagnetic safety base and tool were installed, and voltages of 4.5V and 24V were applied. Each crash resulted in separation of the electromagnetic base, and no binding occurred. The sample aircraft parts were undamaged.

Background and Challenges

Figure 4. Anvil separating from base

For a D or C frame riveting/bolting machine, the fastening process occurs vertically. The lower ram extends to clamp the part between itself and the upper head clamp foot.

Figure 5. Extended lower ram hitting substructure

The fastener hole is drilled, and the fastener is inserted and either squeezed or torqued. This process is repeated at thousands of locations over the extent of an aircraft part. In this way large aluminum skins are spliced together, and frames, shear ties, and stringers are attached to the skins. These fasteners are located very close to all of the parts they are joining, and reaching these locations to fasten can be difficult and sometimes must be done by hand.

Intricate aircraft geometry can be a challenge to navigate. Any offest anvil used can have an overarching feature that can catch on the aircraft structure and pull it down. In Figure 6, the red lines indicate fastener axes, and for a tool to fasten on these axes, it must be able to reach around any structure to access the fastener. Getting in and out of the fastening location must be precisely controlled.

These geometries can be difficult to model perfectly in CAD. This, as well as CNC part programming errors and manual operator errors, can lead to a risk of damage.

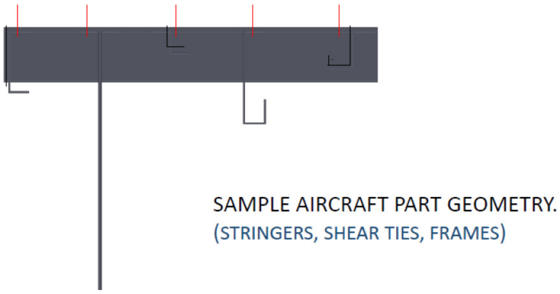

Figure 6. Sample aircraft part geometry

Similar issues came to light during the part programming for the military cargo plane aft fuselage panels. There were several errors where collisions between the lower tool and aircraft structure occurred. The electromagnetic safety base worked repeatedly, preventing damage which would have been costly and caused production delays.

The practical requirements of the safety base were challenging. Any process tool used on the lower head normally locates concentrically to within .002" of the central axis. The standard tool has a precise cylindrical boss that locates to a bore in the process head. The depth of the fit does not allow the tool to rotate out. In addition to this location fit, the tool is screwed down, and clocked radially with a dowel pin. Any safety base made needed to have the same accuracy of location, and maintain it while squeezing rivets at up to 20,000 pounds of force, and stripping the tool off of collars with 2,500 pounds of force.

Solutions

Arriving at a solution involved both prediction and testing of how the safety base would function in the factory. An open face electromagnet allowed use of variable amounts of force, making it capable of withstanding the 2,500 pounds of tensile force during collar swaging, and able to separate during a crash.

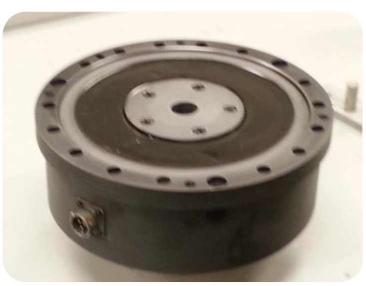

Figure 7. Electromagnet base

The voltage supplied to the electromagnet changes based on which process is occuring on the panel. With CNC control, the electromagnetic safety base could be programmed to operate as required. High force would be used for collar swaging and riveting, low force would be used for navigating the part, and it could be demagnetized for ease of lower anvil removal.

This concept was then combined with the practical requirements for joining the lower anvil to the lower head.

A minimally overlapping hole and shaft interface allowed the lower anvil baseplate to both locate concentrically and rotate out. This was termed a shallow dish. Using a dowel pin that protruded only a couple of millimeters also allowed this baseplate to be clocked radially. To allow separation without interference or binding, the overlap was kept small, and the fit was toleranced within a determined range.

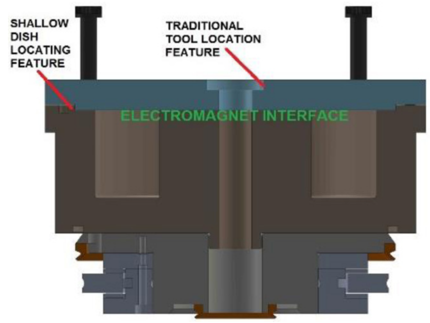

Figure 8. Shallow locating bore detail

These features provided accuracy of location with the ability to disengage, and the programmable electromagnet allowed force variability. The next step was to guide free motion to the point where the machine axis could stop, and then constrain the base. It was desirable to prevent the lower anvil from falling out.

The tipping motion that occurs when the electromagnetic safety base crashes into a stationary structure is detected by shielded microswitches on the face of the electromagnet. A signal is sent to the CNC which commands a feed hold on all axes in motion.

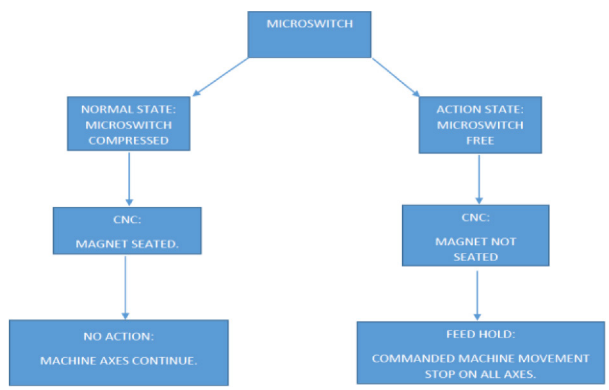

Figure 9. Microswitch feeback during crash

The time it takes for a complete stop includes signal time, process time and deceleration time. During this time, the machine axis still moves a small distance. This distance plus a safety factor was used to give the safety base a range of free motion. The lower anvil can tilt 10 degrees off of the electromagnet face. The simple solution for constraint at the limit of this dimension was to use shoulder screws.

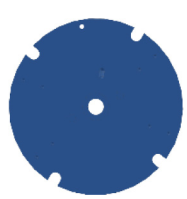

Figure 10. Shoulder screw slots on baseplate

Adding clearance slots allowed the shoulder screws to run through maintained space for the baseplate to move freely. With this setup, the functionality of the electromagnetic safety base met initial goals. While moving underneath an aircraft part the lower ram anvil could potentially collide with a part. The base of the tool will separate by either tipping or moving up, exposing the microswitches, which signals the machine to stop before damage occurs. Once the machine has stopped, the operator can reverse motion, the tool base will fall back into its locating bore, and the part program can be resumed after the error has been corrected.

Testing

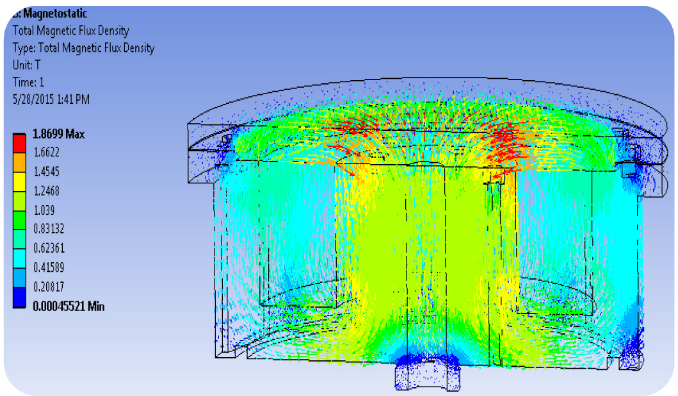

Figure 11. Magnetic flux density analysis

Testing at Electroimpact as well as field testing at a defense contractor facility demonstrated that this is a simple, robust and effective solution to a pesistent issue.

The initial design of the electromagnetic circuit was completed, giving a rough idea of what we could achieve within the available space. From that model a prototype was made and tested with load cells to confirm the range of force that could be used. Results showed that at full power for the gauge wire used, 90V DC and .5 Amp, the electromagnetic interface would remain closed up until a limit of 3400 pounds.

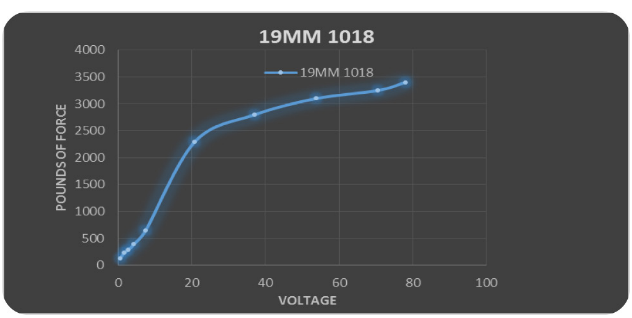

Figure 12. Magnet tension test

Considering the 2500 pounds of force to resist, the safety factor was 1.36 for the worst case scenario collar. This result and the ability to program the voltage supply were the first confirmation that this would be a capable solution to the problem. Efforts were then put into making a production model to be installed on a riveting machine for factory testing.

Crash tests were performed at Electroimpact on the E7000 D frame riveting machine. A sample aircraft structure was fixed to the part positioning frame, which is the part holding frame on the machine. During these tests a production tool was used and wrapped in foam for protection. The results were not effected by the foam wrapping; goals included separation of the base upon impact, no binding at the electromagnetic safety base interface, and no damage/yielding beyond marring of the aluminum structure. At speeds of 200, 400 and 600 inches per minute, the anvil was crashed into the aluminum frame. The same was done for downward motion of the lower anvil.

Figure 13. Lower ram hitting part structure during testing

The electromagnet was set to 4V (100 pounds force) and 24V (2400 pounds force) for each test. Separation occurred during all runs, and no damage to the parts was observed. From visual inspection of the video, the 4V setting was chosen as the ideal level for crash protection for when the lower ram moves around the part frame. The electromagnetic interface uncouples readily in this setting, and for moves that do not involve fastening, the lower anvil retention force is less critical.

Once the machine moved to the defense contractor facility, more testing began when production aircraft parts were loaded into Electroimpact's E7000 riveting machine. During the initial stages of production part models, part programs and operators can all be a source of error. The operators found that Electroimpact's electromagnetic safety base was crucial during this process. There were several instances where procedures went wrong and the lower anvil collided with the aircraft structure. The safety base tilted and stopped the machine.

Any damage and schedule loss that would have occurred was prevented. It proved to be of practical value in a manufacturing environment.

Conclusion

The guarding of aircraft parts during riveting processes where the lower ram must navigate part frames or substructure without damaging that substructure is accomplished through the use of an electromagnetic safety base that will disjoin in the event of a collision. Collisions of this type can be caused by inacurrate part CAD, faulty programming, or operator error during manual jogging of axes. They occur on the underside of an aircraft part where the lower anvil is navigated through shear ties, stringers, clips and fastener heads. By employing an electromagnetic safety interface at the base of lower anvil tools, the machine gains the ability to sense a collision and stop before damage is done.

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