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Central Control of an Automated Riveting Machine and Robot Part Position with a Single CNC

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Abstract

There exists a demand in the aerospace industry for highly configurable and flexible automated riveting cells to manufacture small to medium sized panels of complex geometries. To meet this demand Electroimpact has developed a manufacturing system consisting of a stationary Electro-squeeze C-frame riveter, coupled with a robot part positioner to present the component to the process head tool point.

The C-frame can install a wide range of aerospace rivets and perform specialist functions including backside counter-sinking operations, giving potential for double flush fastening. The geometric limitations and high implementation costs of large cartesian based positioning barges or fixed jig tooling and moving gantry riveters are avoided when exchanged for a robot part positioner. To achieve the high levels of accuracy and repeatability required within the industry the robot part positioner is a KUKA KR1000L750 upgraded with EI proprietary Accurate Robot Technology (+/- 0.25 mm large volume global accuracy).

Critical to the success of the system is high speed and seamless communication between the robot and C-frame, it is the details of this that will be explored within the paper. In summary this is achieved by deploying a Siemens 840D CNC as the singular central controller handling the robot motion control, riveting process and cell safety features. With twenty-seven individual servo driven axis' working in harmony to perform the core manufacturing functions the single 840D controller allows for a more efficient and simplistic control architecture when compared to the typical methodology of integrating a separate motion controller. A critical capability enabled by this approach is the ability to position components normal to the fastening axis via live sensor feedback at the tool point in real time. In circumstances where the system is reliant on the integration of a separate motion controller this type of closed loop feedback simply would not be possible.

Introduction

As the drive for efficiency in aerospace manufacturing continues the requirement for high levels of advanced automation cascades down to smaller sized components. Automation is well established for large wing and fuselage panel assemblies, whilst semi-automated and manual methods remain favored for the production of smaller panel sizes. For the purposes of this paper small panels are considered as engine nacelles, cargo & pax doors, helicopter fuselage & doors, pressure bulkheads and various miscellaneous door/cover panels.

The single most important barrier to the automation of such assemblies is the initial investment cost. Typically fastening of a one-up build or pre-tacked panel requires a moving gantry fastening machine and either bespoke fixed jig tooling or a large cartesian based positioning barge. To penetrate this market Electroimpact have developed a highly configurable and flexible automated riveting cell consisting of a stationary C-frame riveter and robot part positioner. Utilizing a stationary C-frame greatly reduces the equipment and foundation cost, whilst the use of a robot positioner revolutionizes the part holding philosophy and allows for a high number of panel types to be manufactured with the same core equipment.

The high levels of accuracy and repeatability required within the aerospace industry are no less applicable to small panel assemblies which in fact are typically of highly complex geometries. The equipment shown and discussed within this paper is being built directly for a customer specification requiring +/- 0.25mm positional accuracy with +/- 0.1 repeatability on a small (1m x 1.9m) aircraft part. As such the robot part positioner incorporates Electroimpact proprietary Accurate Robot Technology achieving +/- 0.25mm large volume global accuracy [1,2].

The C-Frame riveter and robot part positioner represent a reconfiguration and optimized combination of existing Electroimpact technology. However, integrating a singular central controller handling all aspects of the fastening cell is truly unique.

Overview of Riveting Cell

Figure 1 shows the general layout and core components of the riveting cell. The compact 10m x 10m footprint neatly packages the automation which is all controlled by a single central CNC.

C-Frame Riveter

An Electroimpact E8000 C-Frame riveter with electro-squeeze incorporating fully automated tool changes, including sealant is utilized. Unique to this application is the development of backside countersink and shave functionality to enabling double flush fastening and further expanding the flexibility of the cell. Double flush fastening is a common requirement in the manufacturing of door panels and thus identified as a critical process for the equipment. Double flush fastening is achieved via a lower squeeze tool incorporating three spindles and a squeeze driver on a shuttle plate as shown in Figure 2. The upper and lower heads of the equipment (currently in build), clearly showing the two opposing process tool shuttle plates can be seen in Figure 3.

FIGURE 1 Riveting cell overview

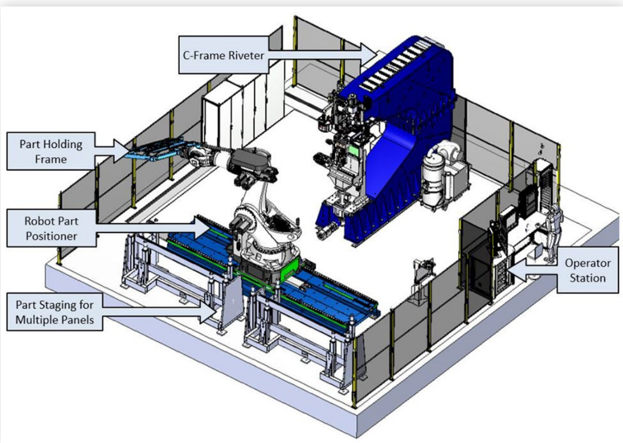


FIGURE 2 Lower tool servo axis' and process tools

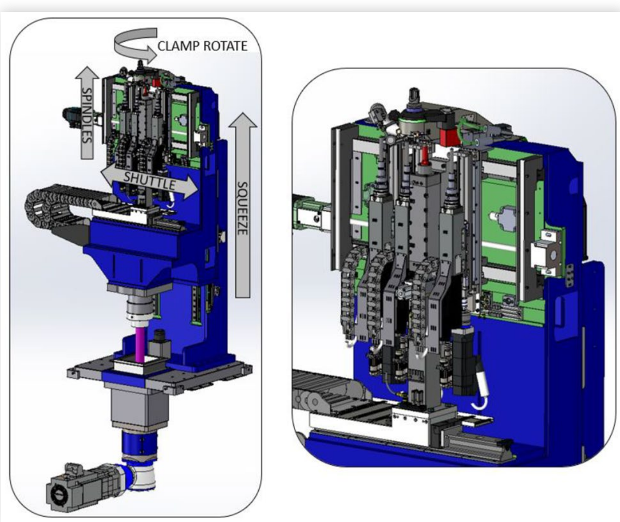
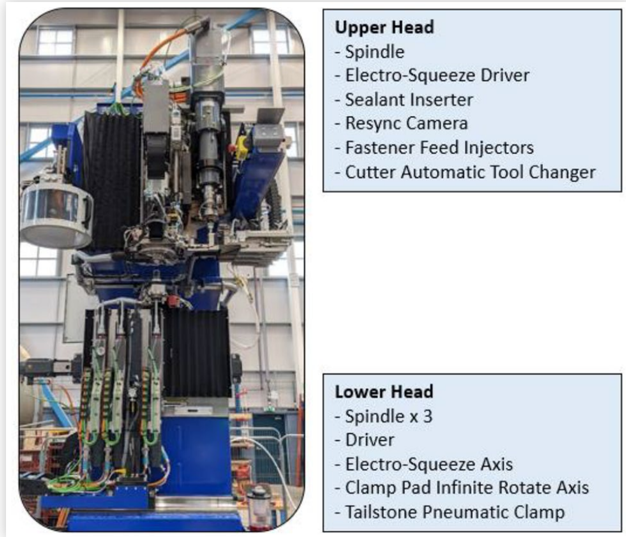


FIGURE 3 E8000 C-Frame riveter upper & lower heads



Robot Part Positioner

A KUKA KR1000L750 retrofitted with EI proprietary Accurate Robot Technology and mounted on a 7th Axis for optimal part positioning is utilized within the riveting cell as shown in Figure 4.

FIGURE 4 Robot part positioner

A panel holding frame is attached to the robot with an ATI tool change interface enabling the production of multiple panel types. Holding frames are stored in stands when not in use and are automatically picked up and dropped off by the robot as required. The riveting cell currently in build is being configured to manufacture 8 panel variants but has scope for expansion with the addition of more frames. Each holding frame is uniquely numbered and tracked throughout the process. In addition to the part frames a utility end effector has been developed to allow process test coupons to be completed as well as automatic replacement of the sealant cartridge through use of an integrated Schunk parallel gripper.

FIGURE 5 Panel Holding Frame Picked up by Robot

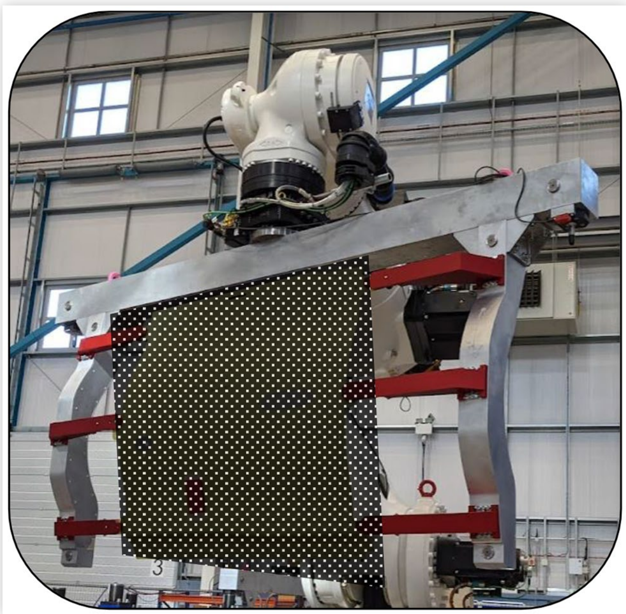


FIGURE 6 Panel Positioned in C-Frame During Machine Commissioning

Control Architecture

Separate Motion and Process Control

The industry standard for this type of automation typically utilizes two controllers, one for the part positioning and a separate controller for handling the fastening process. This is true for both robot and cartesian barge arrangements. It is especially common for robot part positioners to have this architecture due to them being supplied with OEM motion control hardware and software packages. A simplistic block diagram of this approach is given in Figure 7.

A limiting factor in the performance of this type of control architecture is the speed of communication between the process and the motion controllers. Time is added to each drilling/fastening cycle while this handshake of information occurs and the process and motion control elements communicate their status to each other. A reasonable worse case estimate for this additional communication time is 20-30ms. Whilst only measurable in milliseconds this soon adds up to an appreciable amount when processing high numbers of fasteners or geometrically complex parts. Aerospace manufacturing tolerances usually necessitate the use of closed loop positional feedback rather than rely on nominal NC positions derived from the CAD representation to achieve the required accuracy. Positional feedback typically takes the form of component edge margin sensing and/or detection of surface normality to the tool axis. The importance of surface normality to drill spindle vector is discussed in Holt, S. and Clauss, R., "Robotic Drilling and Countersinking on Highly Curved Surfaces" SAE Technical Paper 2015-01-2517, 2015, doi:10.4271/2015-01-2517 [3]. A system with closed loop positional feedback may require several communication cycles between the motion and process controller whilst the correct position is iterated and as such magnifies the limitation of this control architecture.

A further limiting factor is only the robot positional accuracy as supplied from the OEM (typically +/- 0.5mm) will be achievable in the configuration shown in Figure 7. Use of extensive on part local resync or other means of secondary positional feedback monitoring (for example laser metrology)

FIGURE 7 System with separate motion controller

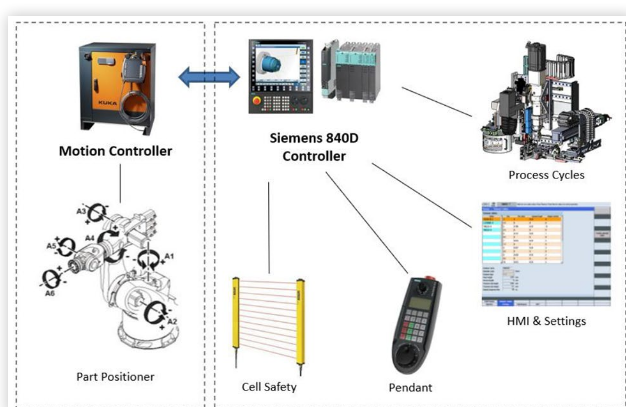
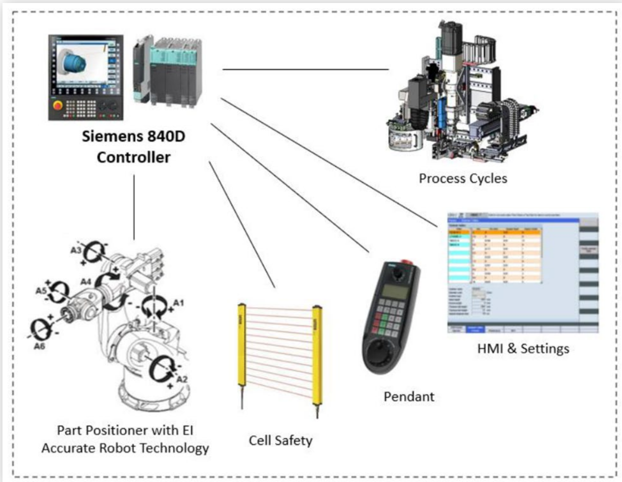


FIGURE 8 System with single central CNC



would be required to achieve a tighter positional accuracy, all of which adds to the part processing time and system complexity.

Central Control with a single CNC

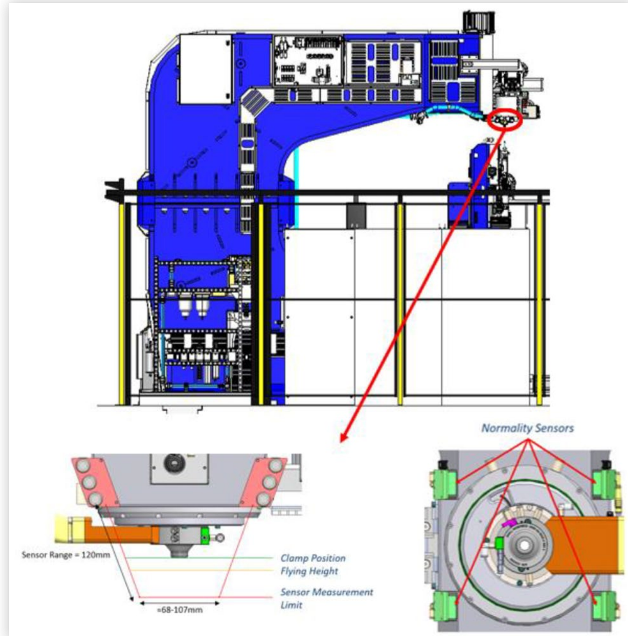
By deploying a single central controller handling all aspects of the riveting cell high speed seamless communications between robot part positioning and C-frame can be achieved. With the single controller handling all aspects and any communications being internal the handshake and hence time delay between separate controllers is eliminated. The Robot manufacturers motion control hardware and software is removed and replaced with a Siemens 840D CNC, enabling the addition of the Electroimpact proprietary Accurate Robot Technology upgrades [1].

This more efficient and simplistic control architecture enables the critical capability of positioning components normal to the fastening axis via live sensor feedback at the tool point in real time utilizing laser normality sensors mounted to the stationary C-Frame, Figure 9. Both the ability to implement Electroimpact proprietary Accurate Robot Technology and eliminating the communications lag are critical to this functionality.

Impact on Part Position Sensing

A system with separate motion controller and therefore only Robot OEM levels of positional accuracy as per Figure 7 would result in a slow normalisation process. The communication time between the two elements and lower positional accuracy result in the system response being theoretically under dampened. Therefore, there is a hunting/settling time required between each part motion, the cycle will need to wait until the position of the part stabilizes sufficiently before it can continue with the next process. It should be noted that the

FIGURE 9 C-Frame headstone normality sensors



importance of this is dependant on the required part normality tolerance, the tighter the tolerance the slower the process.

The issue of under dampening becomes worse if the requirement to travers a part whilst under normality sensor control is necessary. This is because the control loop will continually be out of step with the reality of the panel geometry, especially while moving through areas of high curvature. This function would be prone to error and must run at a reduced feedrate to prevent potential for collisions as the motion platform overshoots and oscillates. As an alternative turning normality sensor control off while traversing complex geometries is possible however this relies on a series of intermediate programmed positions and retracting the process heads. Resulting in a slow process and more onerous requirements for offline programming and simulation.

To address the limitations described above it is typical for part positioning to be completed as a multistage process, NC programmed move to location, stop and then normalise.

Conversely all of the aforementioned limitations are avoided with the single central CNC as per figure 8 as the communications time lag is effectively eliminated and a higher positional accuracy is achieved allowing for a system response more akin to one with critical damping and zero or minimal positional overshoot. Therefore, allowing the robot part positioner to smoothly track the contours of the panel geometry without danger of collision with the process heads. Furthermore, the hole to hole normalisation process can be made integral to the positional move and as such is a quicker single step process.

Whilst we are not in a position to present quantitative date to allow for a direct comparison between the two control system architectures the riveting cell as shown in Figure 1 has recently completed commissioning tests with some pertinent performance information given below.

FIGURE 10 On part positional accuracy and normality sensing verification

On Part Positional Accuracy Check (mm)						
	Machine Position x	CMM Measured x	Delta	Machine Position y	CMM Measured y	Delta
Hole 1	579.960	579.957	0.003	-222.481	-222.48	-0.001
Hole 2	1050.78	1050.823	-0.043	-222.482	-222.484	0.002
Hole 3	1050.78	1050.853	-0.073	208.209	208.224	-0.015
Hole 4	597.960	597.972	-0.012	208.209	208.295	-0.086

Normality Measurement (tol. +/- 0.5 deg)		
	X	**Y**
DTI measurement delta	0.69	0.97
Angle (deg)	0.104	0.146

Impact on Maintenance

Beyond the discussed performance benefits there is also a positive impact on equipment maintenance by implementing a single central CNC. Reducing the overall system complexity leads to a reduced spares holding requirement of often expensive motion control hardware components. Furthermore, training requirements or dependance on 3rd party OEMs for maintenance are reduced as all diagnosis can be done from the Siemens 840D control without the need for knowledge or equipment to access multiple control interfaces.

Conclusions

In conclusion the implementation of a single central CNC allows for:

- A simplified control infrastructure with reduced communications time between process and motion control functions.
- Enables the implementation of Electroimpact accurate robot technology within the part positioner
- Resulting in ability for dynamic in process part position sensing.

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Definitions/Abbreviations

CAD - Computer Aided Design

CNC - Computer numeric control

NC - Numeric Control

OEM - Original equipment manufacturer

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