Neighboring Mobile Robot Cell with Drilling and Fastening

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Abstract

Electroimpact, in collaboration with Boeing, has developed an advanced robotic assembly cell, dubbed “The Quadbots.” Using Electroimpact’s patented Accurate Robot technology and multi-function end effector (MFEE), each robot can drill, countersink, inspect hole quality, apply sealant, and insert fasteners into the part. The cell consists of 4 identical machines simultaneously working on a single section of the Boeing 787 fuselage, two on the left, and two on the right. These machines employ “collision avoidance” a new feature in their software to help them work more synchronously. The collision avoidance software uses positional feedback from external safety rated encoders mounted to the motors on the robot. From this feedback, safe spaces, in the form of virtual boundaries can be created. Such that a robot will stop and wait if the adjacent robot is in, or going to move into its programmed work envelope. Another feature of the collision avoidance is to limit robot speeds when they are occupying a zone slightly off the surface of the part. This allows the skin of the part to provide safe guarded space within the fuselage section, allowing a human element to be present. This is critical to the process as technicians run collars on each fastener before the machine moves onto the next hole to ensure adjacent hole clamp up for one up assembly. The production rate for this cell is so demanding, a 5th identical robot is required so that preventative maintenance can be done without interrupting production.

Introduction

In recent years the aerospace industry has begun to embrace the use of articulated arm robots in aircraft assembly as a flexible, cost effective way to incorporate automation into many aspects of aircraft production. Prior to this, robotic arms were often overlooked due to inadequacies in accuracy and repeatability. With advances in technology, including the development of the Accurate Robot, the aerospace industry’s view on robots has greatly changed. There is no longer the question of whether or not articulated arm robots can achieve required accuracies, as these Accurate Robots can hold positional accuracy of ±0.25mm. Now the aerospace industry is pushing the envelope on how they can be used to increase production rates, quality, and safety.

Earlier applications of Accurate Robots generally consisted of a single fixed robot, either stand alone or mounted on an external 7th axis, performing work on a part held in by a fixed or mobile jig. In later phases, the robot is mounted to a mobile platform with or without an external axis. These Mobile Robotic Platforms still had only a single robot performing work on a part or assembly. Enter, the Quadbots. A production cell consisting of 4 mobile robots, each equipped with an MFEE capable of drilling and fastening on the same section of the 787 fuselage simultaneously.

In order to meet production requirements of increased rate, improved quality, and provide a safe environment for employees; many new technologies and features were developed and implemented. This document will review the main components of the individual machines with an emphasis on new features. It will discuss how those innovations combine to produce an advanced automation cell to meet the requirements set forth.

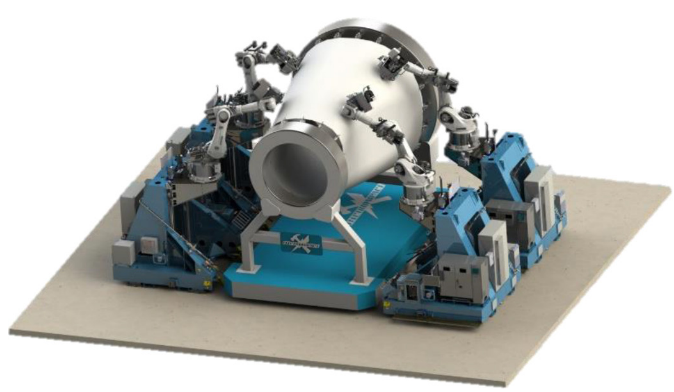

Figure 1. Quadbot Cell Layout

Machine Overview

The Quadbot is a 12.7 metric ton modular drilling and fastening machine. This self-contained machine boasts a rigid plate welded steel frame that supports an external vertical axis, Accurate Robot with MFEE, fastener feed cabinet, and automatic tool changer. The robot arm, MFEE, external axis, and tool changer are controlled by a single Siemens 840Dsl CNC located in the onboard electrical/drive cabinet.

Accurate Robot

Electroimpact's patented Accurate Robot uses an industrial standard 6 axis articulated arm with a 340kg payload. The robotic arm is then fitted with secondary feedback absolute encoders on the output of each axis. The addition of secondary feedback combined with compensation for geometric offsets, backlash, and deflection of the robot deliver accuracies of less than ±0.25mm over large work envelopes [1].

The Quadbots take this a step further by adding Siemens safety rated absolute rotary encoders to the Siemens motors on all 6 robot axis. The encoder replaces the existing 2 pole resolver as the primary feedback for the axis. These additional encoders mount externally and bypass the resolver without the need to remove it, therefore the motors are not physically altered.

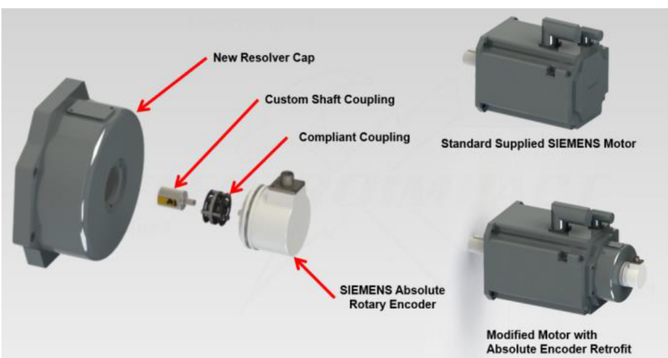

Figure 2. Absolute Encoder Retrofit

Multi-Function End Effector

The Quadbot's MFEE consists of a clamp axis with a load cell and shuttle axis that carries 4 process tools, a resync camera, spindle, hole probe, and bolt inserter. Each of these tools are presented to the tool center point (TCP) via the servo positioned shuttle table. The resync camera on this system, like many others, is used to locate existing features on the part in order to increase local accuracy. The spindle has a servo driven feed axis and uses an absolute linear encoder for secondary feedback. New to the Quadbot's spindle feed axis is the integration of an inline load cell for drill thrust feedback. Monitoring thrust feedback allows for cutter life tracking and in-process broken bit detection. The drill thrust load cell provides higher resolution than of the clamp load cell for process verification, specifically for use on carbon fiber reinforced polymer (CFRP).

Previously the hole probe measured hole and countersink diameter at two orientations, usually at 0° and 90°, hole measurement was limited to a single diameter without manually changing the probe tip assembly. Additionally, the probe re-calibrates off of a proving ring (that also required a manual change) before every hole is measured.

The current probe, developed for this project can take 360° measurements. This, in combination with the probe feed axis, allows for a helical profile to be measured to verify circularity. The current probe design also includes new hardware to eliminate manual tool changes of the probe tips and proving rings by means of the automatic tool changer (ATC).

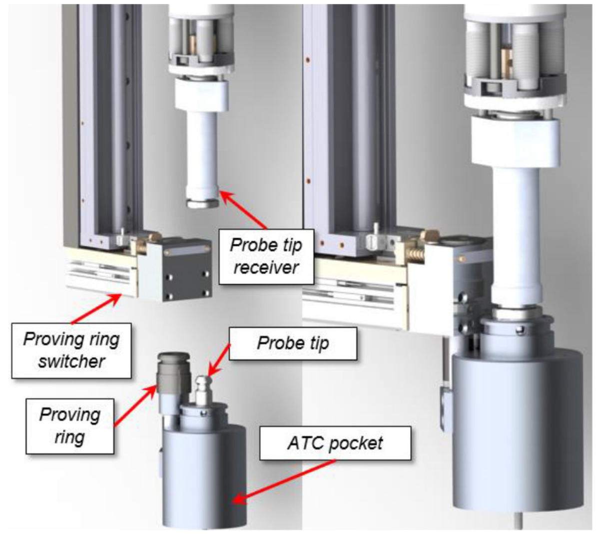

Figure 3. Auto probe and proving ring change

Finally, a new bolt inserter was designed for the Quadbots. Key changes from previous inserters include the use of a servo-driven feed axis and the incorporation of features and hardware to facilitate automatic feed nose changes. A servo feed axis was chosen over the pneumatic chipping hammer style due to the clearance fit of the fasteners during installation. Use of the servo axis yielded additional beneficial features, such as measuring fastener flushness, fastener length, and the ability to apply sealant methods 1, 2, and 3 to the fasteners. Positional accuracy of ±0.013mm is achieved through the use of the servo motor, precision ball screw, and compensation from the MFEE clamp load cell. Further, the resolution that the servo motor provides in combination with clamp load, allows real time monitoring of insertion force and collar installation detection.

Figure 4. Servo-driven bolt inserter

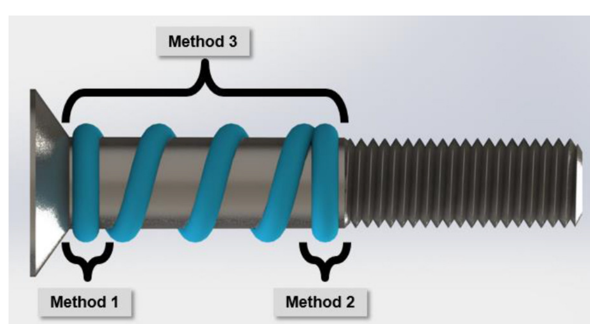

Figure 5. Sealant Methods

Cell Innovation

While the individual Quadbot adds more innovative features over previous versions of mobile robots, the most advantageous are found when integrated into the production cell. The Quadbot cell consists of 4 mobile robots drilling and installing fasteners in 4 positions around the same section of 787 fuselage. One forward and one aft on both the left and right side. Previously the work on this section was performed by a single end effector machine and was physically limited completing later iterations of the aircraft. The Quadbots place 4 MFEEs on the part simultaneously and substantially improving throughput will increasing installed fasteners by approximately 30%. In order to maintain production rate and the machines over time, redundancies were added, such as a second vacuum unit and a 5th Quadbot. The vacuum units are sized such that individually they can supply vacuum to the entire cell. The 5th Quadbot, which sounds counterintuitive, is crucial to cell production. All 5 of the Quadbots are identical and are rotated through each position the cell. The 5th or spare machine allows for testing and preventative maintenance to be performed without impacting production, while also protecting for lengthy, unplanned maintenance issues.

When 4 mobile robots are working in close proximity with one another, the aircraft part, and factory personnel; safety is crucial. Without question, personnel safety is the top priority, although not the only one. Use of Siemens safety integrated controls software combined with the safety rated rotary encoders mentioned previously, complies with ANSI/RIA R15.06-2012 Section 5.2 [2] and provides the following features:

- Safety Rated Feed Hold
- Safety Rated Axis Velocity Monitoring
- Safety Rated Axis Speed Limiting
- Safety Rated Axis Position Monitoring
- Safety Rated Axis Position Limiting

Through the use of these features not only are personnel protected but the robots and the part are too. Virtual barriers are created around the fuselage section and MFEE through position limiting. These barriers are slightly larger than the physical components they surround, determined by the distance it takes the robot to stop moving when an E-stop is triggered. By limiting speed the stopping distance can be decreased, thus decreasing the size of the barrier. Once the barrier surrounding the MFEE enters the fuselage barrier the speed is reduced to protect the part from accidental collision, which in turn protects the personnel performing work inside the fuselage. If the MFEE barrier enters the neighboring robots barrier, a feed stop is initiated. In order to reduce unwanted stoppage of adjacent robots due to overlapping work envelopes in part programming, collision avoidance software was developed. Collision avoidance software predicts robot motion and, stops the robots before they occupy each other's safe zones. Upon acknowledgment, allow its neighbor to finish working in the occupied zone and move out of the way.

Summary

Use of robotic assembly in aerospace structures has expanded significantly through the use of highly specialized machines and advances in technology along with increased demand for interaction between humans and robotic systems. Despite the added complexities and customization, these systems remain a cost effective and flexible solution. The Quadbots increased productivity, improved quality; they provide a safe production environment for factory personnel and the customer's equipment and product. The inherent flexibility of these mobile robots has allowed for the production of 3 different iterations of the 787 fuselage and also make it possible to expand the applications within the cell to allow manufacture of additional products.

References

1. Devlieg, R., "Expanding the Use of Robotics in Airframe Assembly Via Accurate Robot Technology," *SAE Int. J. Aerosp.* 3(1):198-203, 2010, doi:10.4271/2010-01-1846.
2. American National Standards Institute, "American National Standard for Industrial Robots and Robot", ANSI/RIA R15.06-2012

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Acknowledgments

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Siemens

Definitions/Abbreviations

MFEE - Multi-function end effector

Process Tool(s) - Sub-assemblies of MFEE that perform a specific manufacturing process.

Quadbot - A single mobile robot in the Quadbot Cell

CFRP - Carbon fiber reinforced polymer

Feed nose - Fastener holding assembly of the bolt inserter.

E-stop - Emergency stop

The Engineering Meetings Board has approved this paper for publication. It has successfully completed SAE's peer review process under the supervision of the session organizer. The process requires a minimum of three (3) reviews by industry experts.

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