High Path Accuracy, High Process Force Articulated Robot

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ABSTRACT

Spirit AeroSystems' process of producing carbon fiber nacelle panels requires heat and high force plus a high level of dynamic accuracy. Traditionally this would require large and expensive custom machines. A low cost robotic alternative was developed to perform the same operations utilizing an off-the-shelf 6-axis robot mated to a servo-controlled linear axis. Each of the 7 axes is enhanced with secondary position encoders and the entire system is controlled by a Siemens 840Dsl CNC. The CNC handles all process functions, robot motion, and executes software technologies developed for superior dynamic positional accuracy, including enhanced kinematics. The layout of the work cell allowed the robot to span two work zones so that parts can be loaded and unloaded while the robot continues working in the adjacent zone.

INTRODUCTION

Spirit AeroSystems, located in Wichita, Kansas USA, produces many aerospace components, ranging from fuselage sections to wings, and this includes parts for engine nacelles. The gantry systems used during a portion of the nacelle panel fabrication process were in need of significant upgrades, and replacement with similar equipment was deemed cost and schedule prohibitive due to sharp increases anticipated in production rate within an abbreviated time frame. Spirit needed to look for alternatives, and so the application of a robotic system was identified as a viable alternative.

The end effectors (EE) used on the two existing gantry systems are relatively simple and have been in production use for approximately 15 years. Advancements in modern CNC systems meant that the basic function of the old style EEs could be improved and additional process controls implemented. The new EE is required to maintain surface normality and experience no twisting or turning while in contact with the varying surface geometry under high loads. The force required in the production of the nacelle panels ranges from 500 to 1,500 pounds, and the existing machines provide limited feedback to the operator during operation. The new robotic system provided to Spirit offered several advantages:

1. Flexibility. By designing the new EE on the robotic system to use as small an envelope as possible the new system is increasingly flexible regarding which parts can be processed.

2. Low Cost. Robots provide great reliability at relatively low cost due to their high production volume. With a cost to implement of roughly half that of gantry style machines with similar capability, a robotic system was considerably more affordable.

3. Small machine footprint and large work envelope. The area that the robot is able to work on is large compared with the footprint that the uni-bed linear axis inhabits. Combining this with the dual-zoned work cell maximizes the machine's uptime and utilization.

BACKGROUND RESEARCH

Spirit's first step was to conduct a machine reach analysis to determine feasible cell configurations and proper robot sizing. Offline simulation software tools allowed Spirit to study multiple alternative robot models with various available test parts. A KUKA KR 500 L480-2 MT robot (figure 1) in Spirit's automation laboratory was found to have a working envelope sufficient to reach applicable portions of the identified test article.

Once the robot and test article were selected and prepared, Spirit tested the repeatability of the robot moving along a defined path at increasing levels of force. This was accomplished by using the robot (Figure X) to move an EE that applied a specified force normal to the surface of a rigid complex contour tool. The motion was measured at the EE using a six degree of freedom laser tracker system to provide both position and orientation data relative to the tool surface. The first path iteration was designed as the control run by ensuring contact between the EE and tool surface but with no applied force. All subsequent iterations ranging from 1,000 pounds to 2,000 pounds of applied force were treated as a deviation from this original path to determine path repeatability under increasing load.

The KUKA KR 500 L480-2 MT robot is designed for high process force applications up to 8,000 N (~1,800 pounds). Its major structural components are made of aluminum alloy, and it employs additional gear reducers on axes 1, 2, and, 3 for increased torque/force capability. Data collected indicated less than 0.2″ path repeatability deviation from 0 pounds to 2,000 pounds with less than 0.5° of orientation deviation in any direction. With actual production process force closer to 1,500 pounds, the decision was made to proceed with specification of a robotic system with identified improvements including use of a robot with steel construction for additional stiffness and a robot with increased torque/ force capability to provide a larger factor of safety and added system longevity.

Figure 1. KUKA KR 500 L480-2 MT laboratory robot

PRODUCTION SYSTEM

Spirit's intent was to obtain a system that matched the performance and control of a large custom engineered gantry machine but which had the flexibility and cost savings of an articulated robot. The Electroimpact EE and ancillary clamping components are all controlled by the same Siemens 840Dsl CNC that handles the positioning of the 7 axis robot system. This, combined with the use of traditional M and G codes gives the look and feel of a standard machine tool familiar to both operators and programmers[1].

POSITIONING SYSTEM

The primary positioner chosen for the application is a KUKA KR 1000 L750 Titan robot. The robot system is constructed entirely from steel linkages and uses nine drive units in total giving the Titan robot superior stiffness. Axes 1, 2 and 3 are driven by dual motors and gear units, and mechanical backlash on axis 1 is removed by maintaining a constant torque offset between each. The linear axis is of a mono-bed construction and also utilizes dual drives in order to eliminate backlash. Secondary position encoders are mounted on the output of each axis (figure 2) giving much tighter control of the actual axis position[2]. The addition of customized high-order kinematics allow for accuracies that approach equivalency with large custom machine tools. This kinematic modeling allows for unique values that better describe the actual physical attributes of each linkage and the system as a whole. Dynamic load compensation, applied when working on the part, positions the EE accurately under the high loads associated with this particular production process. The system delivered to Spirit demonstrated point-to-point accuracy of ±0.006″ (3σ) in each of the two work zones.

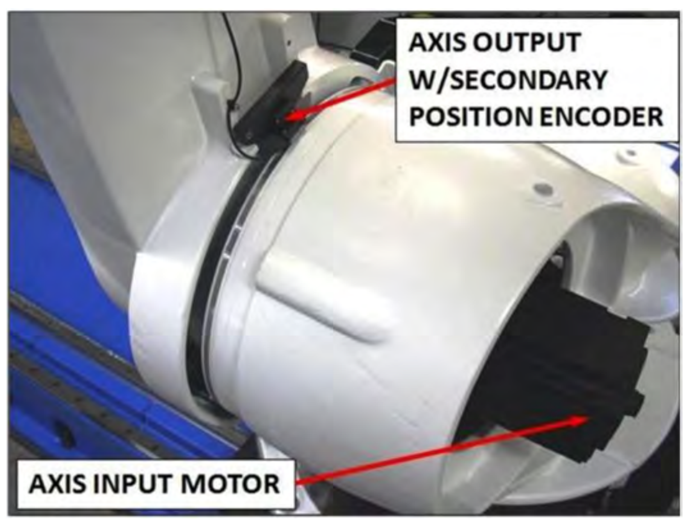

Figure 2. Secondary encoder mounted to output of a robot axis (KR500 shown)

END EFFECTOR

The EE utilizes two 100mm bore SMC pneumatic cylinders, each capable of over 1200lbs, to apply up to 1,500 pounds of load. The low-friction pneumatic cylinders can conform to any abnormalities in the panels' surfaces, maintaining CNC-commanded load at all times. The travel of the compaction axis is measured using a Balluff photoelectric sensor, and a graphic of the compaction axis position relative to the total travel limit is displayed on the CNC. Dual 2,000 pound load cells are used for feedback and to give a read-out of the actual applied force versus the CNC commanded force. The positioning of these load cells is such that they are able to provide protection against accidental crashing of the EE during off part moves as well as feedback in case the EE experiences unexpected side loads during operation.

Three tools along with a Renishaw RMP60 touch probe are able to be automatically exchanged during a single part. This provides the operator with the ability to perform other tasks while the machine is working. The use of inductive proximity sensors and another Balluff photoelectric sensor allow the CNC to track which of the four tools is loaded at all times. Each of the four tools' tool center point (TCP) is located in axial alignment with axis 6 of the robot. The EE is bi-directional, considerably reducing time taken between operational paths. Having the TCP of the touch probe in line with axis 6 gives the ability to orient the EE in order to eliminate the run-out when probing. This prevents the need to set the position of the probe ruby every time it is automatically exchanged or replaced. The primary purpose for the Renishaw RMP60 touch probe is for calibration of the off-axis resync camera, however it is also possible to perform tool resync with the touch probe.

Careful consideration was required during the design phase to make service and repair of the EE convenient and straightforward. Individual components are able to be replaced if damaged without extensively breaking down or detaching the EE from the robotic system, saving on time when realigning the EE. This removes the need for the TCP to be realigned with Axis 6 anytime a single part is replaced during the machine's lifetime.

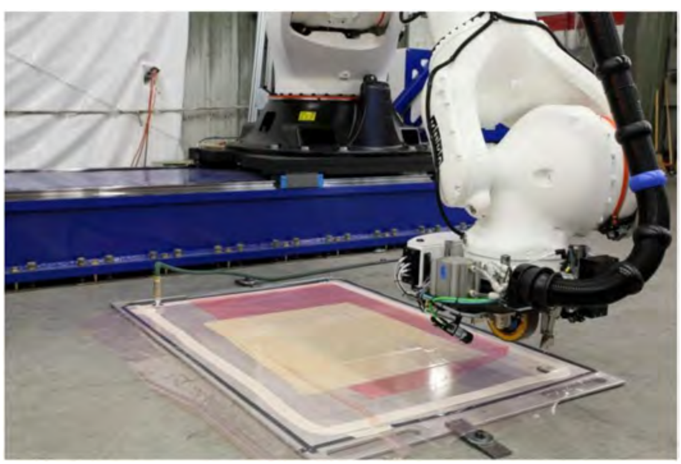

Figure 3. Robot and EE working on a test panel

PRODUCTION CELL

The robotic system is mounted on a 30′ servo-controlled linear axis, spanning two separate working zones (Figure 4). The work pieces are moved in to each cell via forklift and clamped using an automated tool clamping system. This system is used to rough align the tools before the robot performs its automated resync procedure. While the robot is working on one of the parts, the other cell can be accessed safely by personnel to perform the unloading and reloading tasks (figure 5, 6, 7 shows the configuration of the 2 cell system and the position of the laser scanners). The tool clamping is pneumatically driven using air motors controlled with the same Siemens CNC. This allows for seamless integration between the safety system, tool holding and robotic system.

The dual work zones allow the robot to operate continuously without any machine idle time, greatly increasing throughput. Four programmable SICK laser safety scanners throughout and a single-beam safety switch at the rear of the cell are used to ensure personnel working around the machine maintain a safe distance. A single user-friendly operator console with cell overview and graphic display of the EE performance provides the necessary process feedback and control.

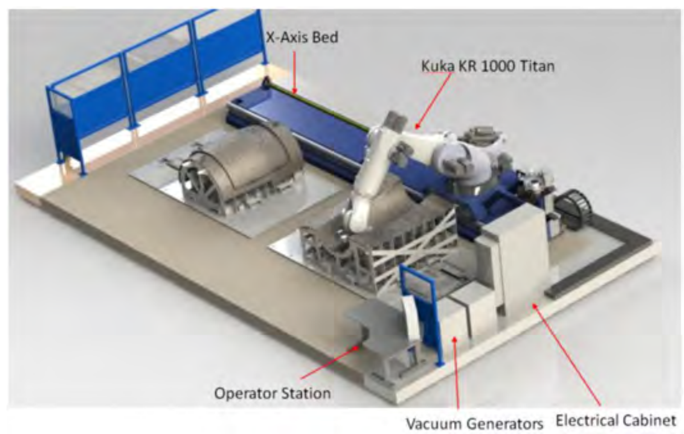

Figure 4. Overall Cell Layout

Figure 5. Both Zones Active

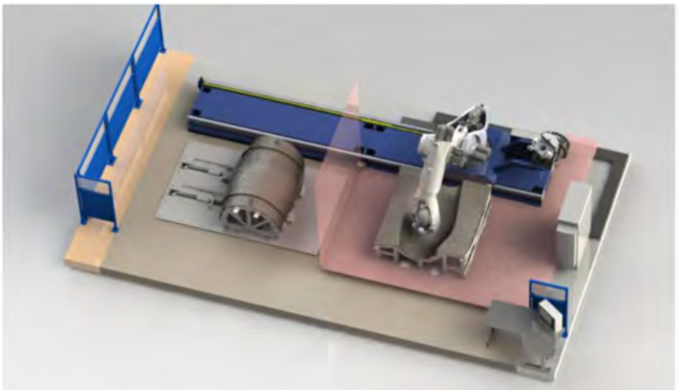

Figure 6. Right Zone Active

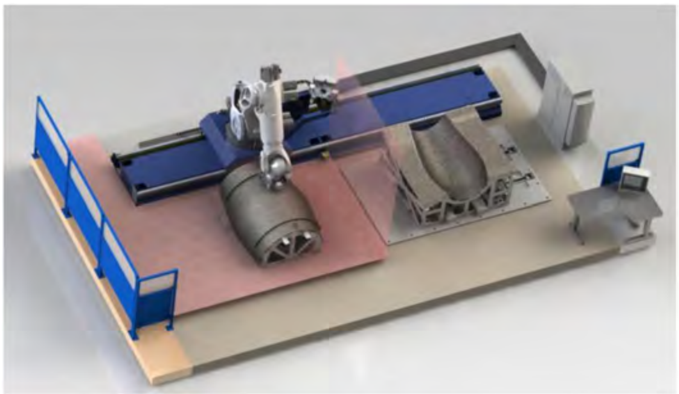

Figure 7. Left Zone Active

A test similar to the initial KUKA KR 500 L480-2 MT feasibility trial was conducted with the production system to quantify path repeatability under applicable production process loads using a production configuration complex contour tool. Six degree of freedom data was collected to compare a baseline no-load path to resulting robot path iterations with applied forces ranging from 750 pounds to 1,500 pounds. The system demonstrated path deviations of less than 0.010″ and orientation deviations of less than 0.05° in any direction at 1,500 pounds of applied force, thus validating the comparatively higher performance of the KUKA KR 1000 L750 Titan robot in combination with the additional Electroimpact engineered enhancements.

CONCLUSION

Spirit AeroSystems required a cost-effective alternative to existing gantry machines used in the production of composite nacelle panels, driven by aging machinery and increasing production rates. An initial study provided evidence of the feasibility of their concept. The production robotic solution offered by Electroimpact offered distinct advantages: high dynamic performance, a small machine footprint with high-efficiency utilization, and at a relatively low cost. The entire system was designed to require minimal human input through automation of tool management, dual working zones and intuitive display of the machine's real-time performance. The ability of the Titan robot to apply high levels of force, combined with the Electroimpact "Accurate Robot" package was particularly well-suited to Spirit's specific needs. The ability to maintain accuracy while operating under high loads has great potential for other applications in the aerospace industry.

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ADDITIONAL SOURCES

KUKA Robotics, www.kukarobotics.com

DEFINITIONS, ABBREVIATIONS

EE - End Effector

TCP - Tool Center Point

CNC - Computer Numerical Control

3σ - Measure of Accuracy, +/− (average +3*Stdev)

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