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Segment Manipulator Retrofit

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Abstract

The segment manipulator machine, a large custom-built apparatus, is used for assembling and disassembling heavy tooling, specifically carbon fiber forms. This complex yet slow-moving machine had been in service for nineteen years, with many control components becoming obsolete and difficult to replace. The customer engaged Electroimpact to upgrade the machine using the latest state-of-the-art controls, aiming to extend the system's operational life by at least another two decades. The program from the previous control system could not be reused, necessitating a complete overhaul.

Introduction

A "layup mandrel" is a form used to lay carbon fiber, essential in manufacturing wide-body aircraft fuselage sections. The layup mandrel consists of six segments: Crown, Upper Left, Upper Right, Lower Left, Lower Right, and Keel. These segments allow the mandrel to be assembled and disassembled from the inside, facilitating the manufacturing process. Each segment weighs approximately 3000 lbs and is handled by a segment manipulator machine.

The segments are initially assembled on a large manually guided vehicle (MGV) called a "ring cart." Once assembled, the segments are moved away from the manipulator to a separate machine known as an Automated Fiber Placement (AFP) machine, which lays the carbon fiber tape. After the tape is laid, the assembly is transferred to a large, pressurized oven called an autoclave, where the carbon fiber is cured. Following the curing process, the assembly is moved to a different segment manipulator for disassembly. The segments are then refurbished and prepared for the next build.

The segment manipulator machines, approximately 20 ft tall and 30 ft long, are equipped with 17 servo axes, 13 load cells, and 4 machine vision cameras. The customer's existing machine used outdated control components (CPU, motors, drives, HMI) that were difficult to replace. Electroimpact proposed upgrading to a Siemens PLC and Siemens drives and motors for compatibility and reliability. Siemens components were chosen because they are mainstream and widely supported from both service and spares perspectives. Additionally, the machine was in decent mechanical shape, with the main weldments, roller screws, linear rails, bearings, and rack and pinion in acceptable condition. This allowed for the motors to be swapped with new couplings and, in some cases, custom adapter plates. This upgrade also included replacing the load cells and machine vision cameras.

Controls Components

The segment manipulator is controlled by a Siemens S7-1515F PLC with integrated I/O. The Siemens PLC was selected for its robust motion control capabilities, industrial reliability, and integrated servo and I/O ecosystem. The 1500 series PLC, programmed using the TIA Portal V19 software package, provides comprehensive diagnostics information and factory connections for Industry 4.0, ensuring minimal downtime. The servo system is the Sinamics S210, which utilizes multiturn absolute encoders that do not require re-homing every time the power is cycled. Additionally, Cognex InSight vision cameras were used for machine vision. These cameras detect targets on the segments and send location data to the PLC, allowing for automatic adjustment of the grippers' position.

Test Bench

To minimize production downtime, a test bench was built to commission the Profinet and servos, test the new controls, and develop the programs. Typically, this testing and commissioning phase can take many weeks. However,

FIGURE 1 Segment Manipulator

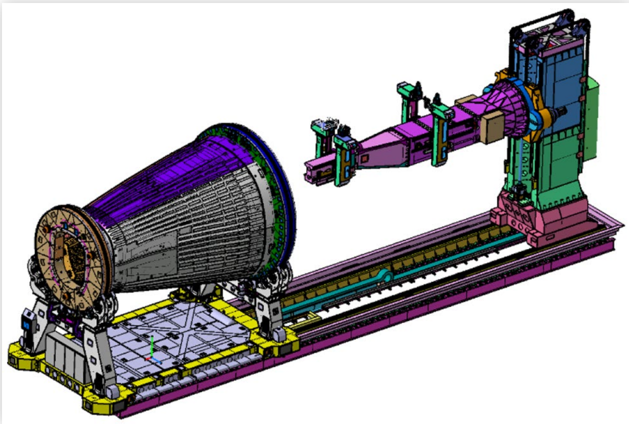
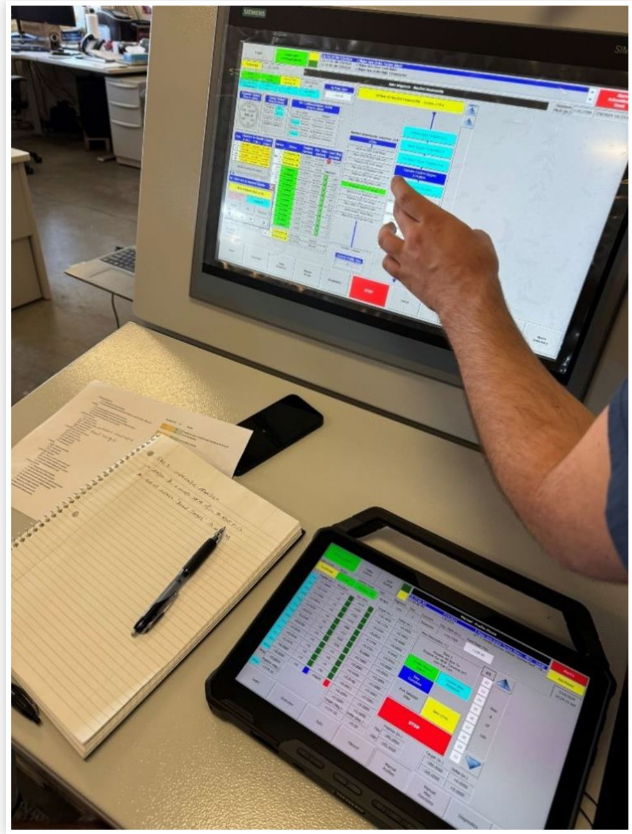


FIGURE 2 Segment Manipulator test bench.



the work done on the test bench saved months of time on the machine, significantly reducing downtime and onsite testing.

Profinet, the standard I/O protocol used by Siemens, was employed on this machine, which included a total of 44 Profinet devices. Each device required detection, configuration, and commissioning, all of which were accomplished on the test bench. Additionally, each of the 18 servo motors were tested. In the S210 system, each servo motor has its own servo drive, which must be configured with axis name, acceleration and speed profiles, as well as safety and braking logic.

Once all the motors were operational, it was possible to create and test complex coordinated motion. Although the motors were not connected to any mechanical load and were only spinning their shafts in the air, this simulated motion was extremely helpful. It provided valuable insights and saved extensive time on the actual machine. The two HMIs are shown in Figure 2, and the motors operated on the test bench are shown in Figure 3. The operating screens were recreated on the test bench and tested extensively, as shown in Figure 4. The test bench demonstrated its effectiveness, providing the necessary confidence to proceed with the retrofit.

FIGURE 3 Motors operated on test bench to run the Segment Manipulator.

Installation

Due to the height of the Segment Manipulator arm, which was well above the ground, scaffolding was contracted for the installation (Figure 5). This greatly facilitated the installation and improved safety. The arm was approximately 15 ft off the ground, requiring careful planning and execution to ensure a safe and efficient installation process.

A Rittal standing pedestal was used for the Main Control Panel (MCP). At the MCP, a 22" Siemens TP2200 Comfort Panel was installed for the Human Machine Interface (HMI) screens. Above the Comfort Panel, two arm-mounted PC monitors were positioned to display the overview cameras. There are four cameras, one for each machine gripper. The operator uses these cameras to ensure proper alignment while the machine clamps onto the segments.

Profile Testing

To automatically assemble and disassemble segments, the code utilized a complex set of instructions referred

FIGURE 4 Two Screens for Segment Manipulator.

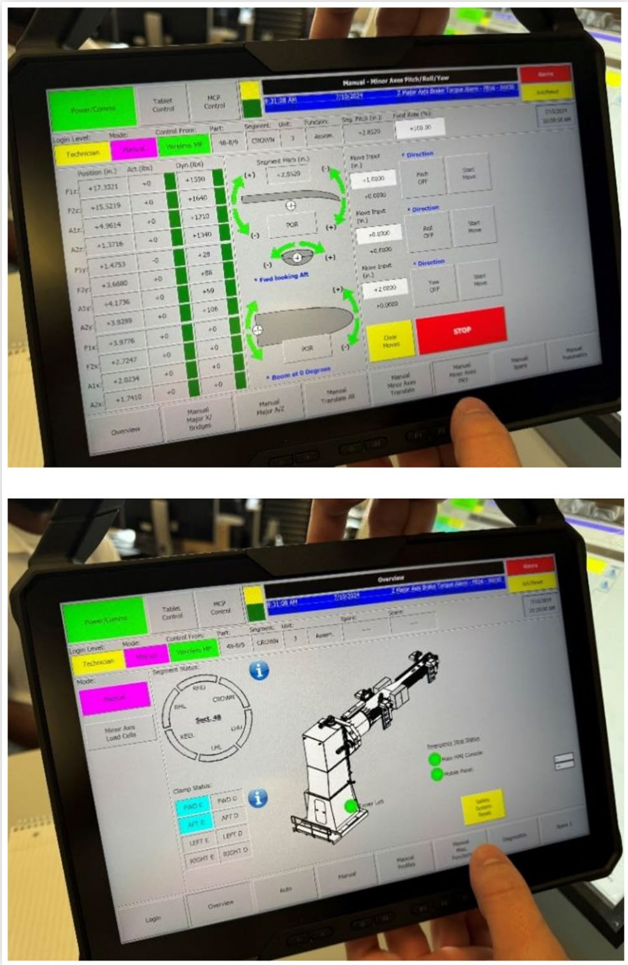


FIGURE 5 Scaffolding erected to facilitate installation on Segment Manipulator.

to as a "profile." These profiles include the following steps: moving each gripper to its nominal location, driving down to the segment, using vision cameras to detect and adjust the grippers, moving to engage the grippers, locking the grippers, using the load cells to induce sideways preload

FIGURE 6 Console installed for the Comfort Panel and camera screens.

FIGURE 7 The Segment Manipulator during testing of an assembly profile.

into the grippers, picking up the segment, rotating and performing many small movements to navigate the segment into place, engaging clamps, and finally releasing the grippers. Some segments have only a few steps due to minimal clearance issues, while others require many small, complex movements to avoid obstructions. These steps are dictated by the geometry and sequencing of the segments.

An Electroimpact controls engineer worked with experienced operators to develop 12 profiles (6 for assembly and 6 for disassembly) within 2 weeks which is considered highly efficient. This method ensured accurate and reliable profile creation, enabling nearly fully automatic operation.

Additionally, logic was incorporated to allow the operator to more easily reverse the sequence if necessary, a significant improvement over the old machine controls.

Conclusion

The retrofit of the segment manipulator machine using Siemens PLC and drives proved to be highly effective, extending the system's operational life by at least 20 years. This project faced unique challenges, including the unknown state of existing components, limited downtime windows, and the need to learn and recreate functionality. These challenges were mitigated through a comprehensive approach that included the use of a test bench, careful planning, and the selection of widely supported Siemens components.

The test bench allowed for extensive testing and commissioning of the Profinet devices and servo motors, significantly reducing downtime and onsite testing. The use of multiturn absolute encoders in the S210 servo motors eliminated the need for re-homing after power cycles, and the Cognex InSight vision cameras provided precise target detection and automatic adjustment of the grippers.

During installation, scaffolding was used to ensure safe and efficient access to the high-mounted components. A Rittal standing pedestal was employed for the Main Control Panel, featuring a 22" Siemens TP2200 Comfort Panel for HMI screens and arm-mounted PC monitors for camera displays. This setup enabled operators to ensure proper alignment while clamping segments.

Profile testing involved creating detailed instructions for each motor, allowing for dynamic and coordinated movements. The development of 12 profiles within 2 weeks was highly efficient, and the incorporation of logic to facilitate sequence reversal was a significant improvement over the old controls.

Overall, this retrofit project demonstrated the benefits of upgrading control systems, including extended system life, reduced downtime, and improved reliability. The approach taken in this project can be applied to other retrofits, highlighting the importance of thorough testing, careful planning, and the use of reliable components.

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