AUTOMATION-ASSISTED WORK CELLS FOR COMPOSITE COMPONENT MANUFACTURE

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ABSTRACT

While composite fabrication technology continues to trend toward fully automated work cells, certain material systems, components, and/or processes are not good candidates for full automation. For example, some composite materials wrinkle too easily around tight tool radii or contours to be positioned by pick-and-place technology. Some component geometry is complex enough that an automated ply or fiber placement solution would be cost prohibitive. Such material systems, components, or processes may nevertheless benefit significantly from automation technologies that are integrated into manual operations through a robust human-machine interface (HMI). These 'Automation-Assisted Work Cells' are being developed and implemented to provide operators with adjustable, ergonomic and operator-specific tool positioning; laser projection and automatic inspection, both automatically coordinated with tool motion axes; ply backing accountability; workorder/recipe management including straightforward recipe generation and navigation; and integration with Manufacturing Information Systems. Work cell components, both hardware and software, and particulars of integration and implementation are described. An open-platform approach to accommodate future processes and component geometries is also discussed.

1. INTRODUCTION

While manufacturing process automation has been employed in multiple industries in many different forms for more than 70 years [1], this technology has matured and achieved broad application in each industry according to markedly different schedules [2]. For example, a vision for 'lights-out' automation reached a fever pitch in the 1970s and 1980s when US automobile manufacturers sought to compete with overseas manufacturers on price. In the aerospace industry, on the other hand, where airframe manufacturing volumes are several orders of magnitude lower than automobiles, manufacturing process automation has taken longer to reach widespread use as the business case – including but not limited to return on investment (ROI) – was not favorable.

Over the past 15 years, airframers and component manufacturers alike have begun to realize the advantages of automation solutions for the manufacture of composite aerospace components.

Portions of the composite component manufacturing value chain have seen significant deployment of process automation technology [3]. Resin and fiber manufacture, impregnation, and conversion; ply cutting; pick-and-place ply and tape lamination, CNC-controlled automated fiber and tape placement; and CNC net component trimming are just a few examples of manufacturing processes that have enjoyed significant throughput and quality advances through process automation [4]. Accudyne Systems and Aligned Vision have been involved in several first-of-a-kind automation solutions for these processes.

Even with significant advancements in manufacturing process automation for composite aerospace components manufacturing over the past several decades, many composite components continue to be manufactured via 100% manual hand-layup and inspection. For some of these components, a sound business case may not exist to support investment in full automation; for others, the material systems, components, and/or processes may not lend themselves to a completely automated technology solution. Accudyne Systems has developed several different automation-assisted work cells that address these challenges with cost-effective solutions that judiciously integrate automation technologies. The idea is to configure and program the equipment to do tasks that require more precision, repeatability, and/or heavy lifting, and enable operators, with minimal instructions, to accomplish tasks more suited to human capabilities. Operator instructions might take the form of text displayed from a recipe file on a Human-Machine Interface (HMI), or laser-projected ply templates displayed directly on the component/tooling by Aligned Vision laser projection hardware. With some creative thinking, these automation-assisted work cells can significantly increase throughput by allowing the work cell and operator to accomplish tasks simultaneously. This human-machine collaboration is a powerful theme, and one that resonates with operators of several automation-assisted work cells that Accudyne Systems has designed and built.

2. ESSENTIALS

To maximize effective and efficient collaboration of automation and operator in an automation-assisted work cell, the work cell design should ideally include the following five elements: 1) tool positioning; 2) laser projection ply templating; 3) ply backing accountability; 4) work order and recipe management; and 5) integration with manufacturing information systems. As warranted, a custom equipment solution provider like Accudyne may include additional features, such as pick-and-place systems or automatic inspection.

2.1 Tool Positioning

Tool positioning is the primary physical point of engagement for the operator through an entire work shift. Improperly positioned tooling can cause fatigue, muscle strain, and possible injury. Work cells with single axis tool positioning are designed such that the work position accommodates operators of different statures. Work cells with multi-axis tool positioning provide greater adjustability. To ensure the operators are comfortably standing or seated in a healthy posture, the work cell can be programmed to remember the appropriate tooling position for each operator based on their login or badge scan. Because of such functionality, an Environmental Health and Safety (EHS) representative can help individual operators develop correct work postures to be saved in the work cell software for recall each time they login.

2.2 Integrated Laser-Projected Ply Templates

Since the 1990s, laser-projected ply templates have replaced physical templates and/or measuring tools, improving accuracy, repeatability and efficiency in operator-placed ply operations. Laser projection systems directly utilize design data to generate laser patterns and project them accurately in three-dimensional space within the work cell. The systems are designed to advance from one ply pattern to the next, and they may also be programmed to instruct operators when to perform non-layup tasks, such as debulk or compaction [5].

In conventional work cells with fixed tooling, implementation of laser templating is well established and straightforward, as the reference frame for the laser projector doesn't change significantly if at all. However, a stand-alone laser templating system in an automation-assisted work cell would have to be realigned each time the work cell repositions the tool – a tedious and time-consuming process. Mere physical integration of the projection unit into the work cell does not eliminate this process.

Instead, to achieve promised efficiencies, an automation-assisted work cell needs to maintain a common coordinate system between the laser templating system and the tool, such that the templating system is able to calculate the tool's position anytime the tool is rotated and/or translated within the work cell. Achieving this level of integration via an application program may still require a separate interface, special operator training for the app, and more involved maintenance for the controls engineer. A software development kit (SDK), on the other hand, enables controls engineers to fully integrate the laser templating system at the driver level, so that this common coordinate system is maintained throughout the fabrication process, in a way that is invisible to the operator.

Recent developments in vision systems and image analysis technology has opened the door for automated inspection of plies as well [6]. The LASERVISION hardware utilizes the same reference frame for laser projection and ply inspection, further expanding the capabilities available in such automation-assisted work cells going forward.

2.3 Ply Backing Accountability

Ply backing accountability is a feature that helps prevent the inclusion of Foreign Object Debris (FOD) within components. FOD prevention is critical to composite fabrication processes because FOD interferes with interlaminar bonding, and often requires costly rework or even scrapping of components. 'Letter-box' style accountability systems are a simple and effective means of counting ply backing pieces. Recipe-based instructions on the HMI guide the operator through the process to verify that the ply backing material has been accounted for before moving to the next recipe step.

2.4 Work Order and Recipe Management

Work order and recipe management software ties all of the integrated automation technologies together and tracks the operators' progress in a database to ensure that steps are not missed due to scheduled or unscheduled manufacturing operations interruptions. Data commonly stored or identified in component recipe files may include: component and/or Part Number identification; step number; layer; ply; operation type and duration; component geometry references; laser projection geometry references; CNC G-Code references; and operator instructions and prompts.

The recipe as well as the component and laser projection geometry and CNC G-Code referenced therein can be stored on a protected network drive location to which only authorized users have edit access. This ensures that the production recipe cannot be altered once the manufacturing process has been approved and/or certified. The HMI itself has multiple user-levels (e.g. operator, engineer, maintenance, admin) that control access to the work cell HMI functions.

2.5 Manufacturing Information Systems (MIS) Integration

MIS integration connects the work cell to the enterprise. The benefits of an automation-assisted work cell to production control are severely limited if the work cell cannot communicate with the MIS. Close coordination between the automation-assisted work cell designer and the end-user Information Technology (IT) team ensures that integration of the work cell is seamless and straightforward. Many such solutions utilize SQL database architecture to ensure that the data is up-to-date and accurate.

3. IMPLEMENTATION

The three examples of automation-assisted work cell solutions outlined below provide a sample of the breadth of solutions available depending on the component type and size.

3.1 Recipe Driven Pick/Place/Form/Compact Work Cell

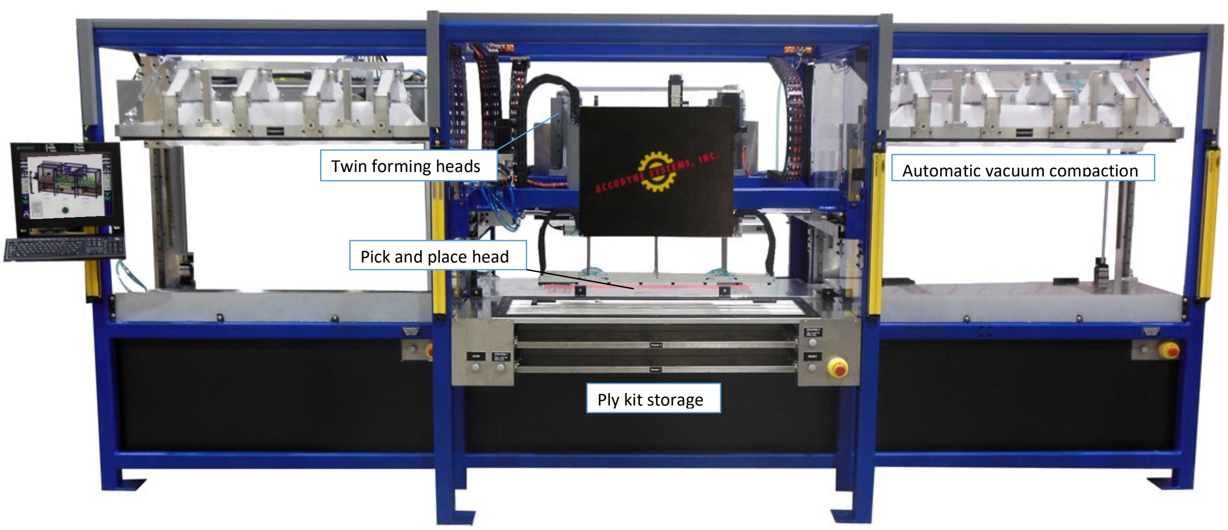

Figure 1: Small Parts Pick/Place/Form Laminator Work Cell

The Small Parts "Pick/Place/Form Laminator" is designed to eliminate operator wait-time by enabling simultaneously manufacture of two constant-cross-section composite components on two independent tools. The system accommodates components less than 48" long, 3" tall, and 10" wide in a machine footprint about 16 ft wide and 6 ft deep. Multiple component cross sections can be accommodated in the machine to include 'C,' 'T,' 'Z,' 'L,' and others. The work cell has a single, fixed 'pick' position on which the operator places plies retrieved from the appropriate drawer, which is identified by an indicator light and unlock mechanism. If desired, the cell can be configured with a barcode reader or camera in order to validate ply identification and/or orientation before picking up plies. As directed by the HMI, the operator picks and prepares plies for placement alternately on each tool.

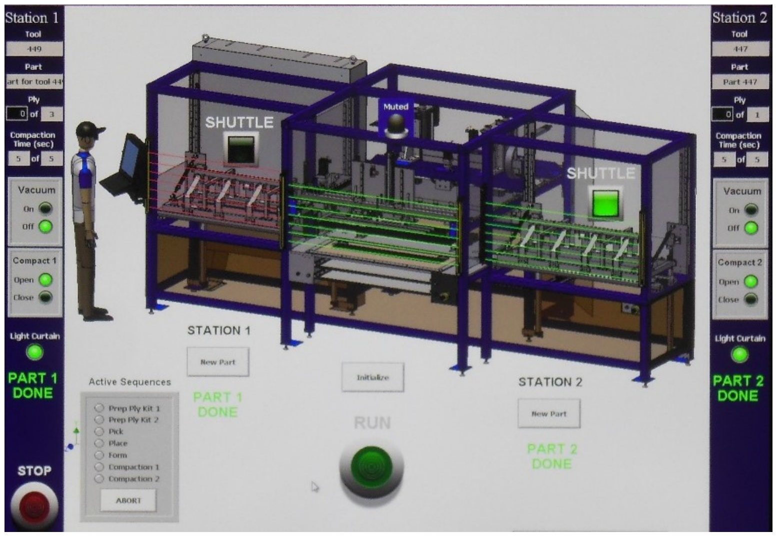

Figure 2: HMI Screen Layout

The cell automatically places a ply on top of the first tool and tacks it in place with light pressure. Two forming bars follow pre-programmed paths to precisely form the ply onto the layup tool. The forming bars are retracted and the tooling table shuttles the tool with this new ply under a compaction bladder. Simultaneously, the second layup tool moves into position for ply placement and forming. As one tool undergoes placement and forming, the operator is retrieving the next ply for the other tool, peeling the poly backing, and placing it on the work cell pick location.

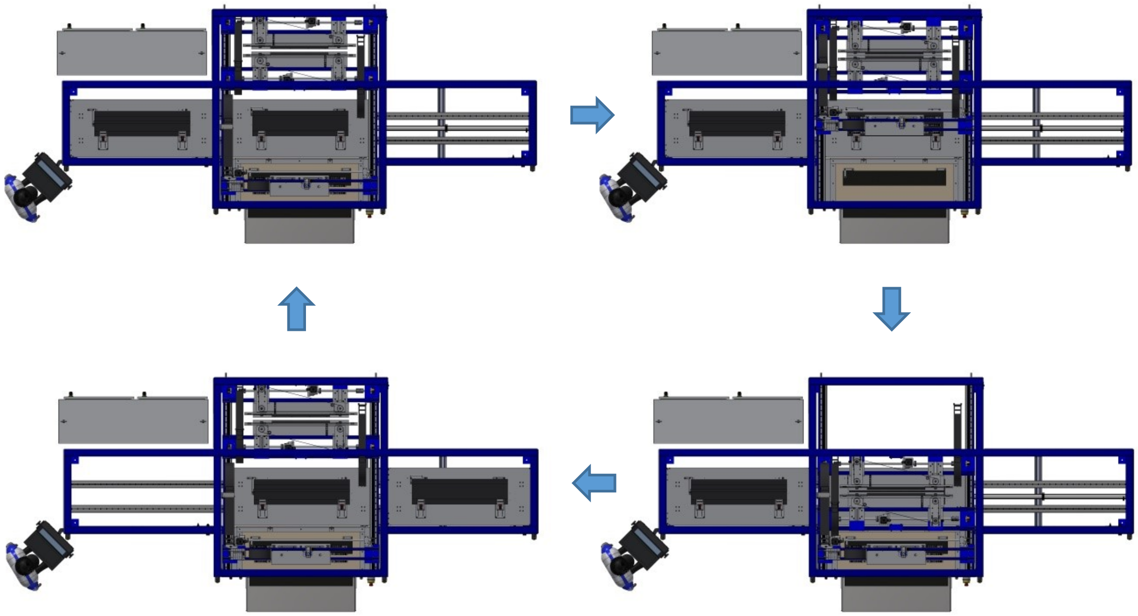

Figure 3: Process flow showing placement, forming, tool shifting and compaction

The cell alternately performs placement, forming and compaction for each tool, and cycle is repeated until layup is complete. The HMI tracks the progress on both component builds and provides instructions to the operator based on the recipe. Once the components are complete, the tooling is removed from the modular tooling platens and replaced with the tooling required for the next component manufacture. The operator scans the next work order(s) and the appropriate recipe(s) is(are) loaded into the HMI.

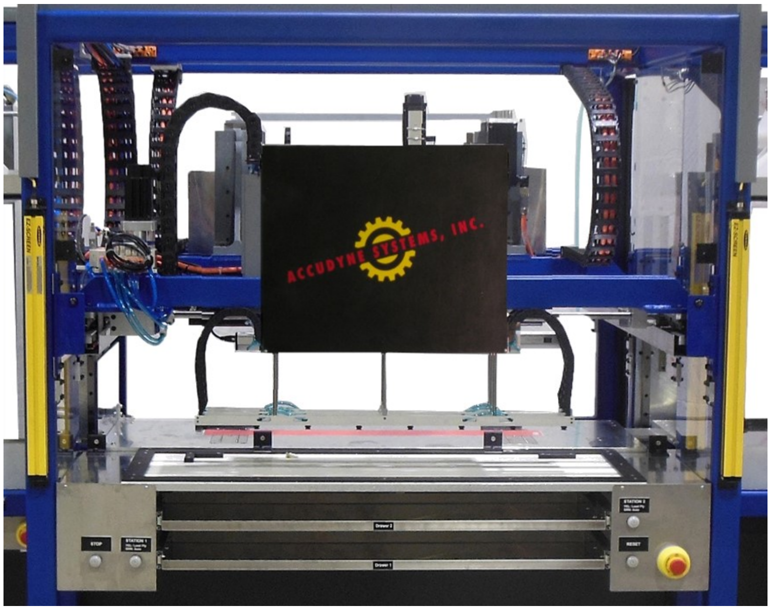

Figure 4: Operator Station

Although it is typically an essential feature, laser projection integration is not necessary for this work cell as the plies are all rectangular and placed in the same location. However, this work cell could easily be adapted to incorporate laser projection if complex ply shapes are necessary to facilitate the manufacture of components with more complicated geometry. The end user reports a 75% demonstrated reduction in manufacturing time per component.

3.2 Recipe Driven Position/Project/Form/Compact/Trim Work Cell

Figure 5: Stringer Former and Trim Cell

Similar to the small parts laminator described above, the "Stringer Former and Trim Cell" accommodates two tools at once. However, due to the larger size of this work cell (30 ft x 35 ft) to accommodate long slender components, two operators are necessary – one working on each side of the machine at their respective 'Prep Stations.' Two Aligned Vision laser projectors are mounted high above the Prep Stations to facilitate fully integrated recipe driven laser ply templating with machine axis coordination. The laser projected data includes not only the ply outline, but also the ply number and the fiber orientation (0/90 or +/-45). Because of the number and size of the plies, the operators are kept busy while the work cell forms and compacts each ply and then trims the Net-Edge-of-Part.

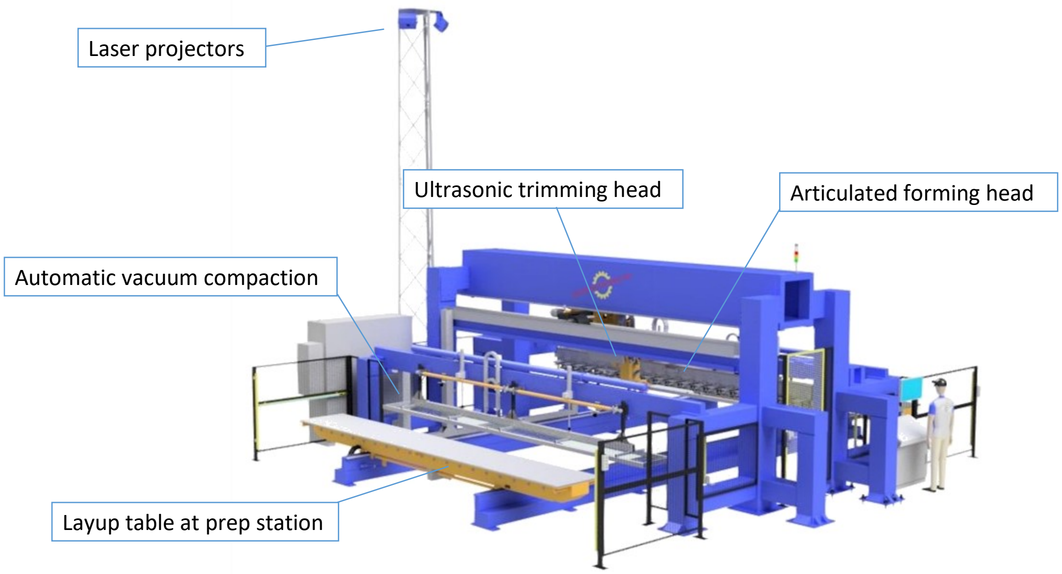

Figure 6: Stringer Former and Trim Cell Laser Projector Tower Configuration

To begin component manufacture, the operators log on and select the correct part numbers and tools for the work orders (bar code capable). The component manufacturing recipes (including machine and human instructions) are loaded from the network drive, and startup instructions are provided to the operators. Following prompts on the HMI displays, operators alternate between laser-projection-guided ply placement and formed ply inspection until the component build is complete.

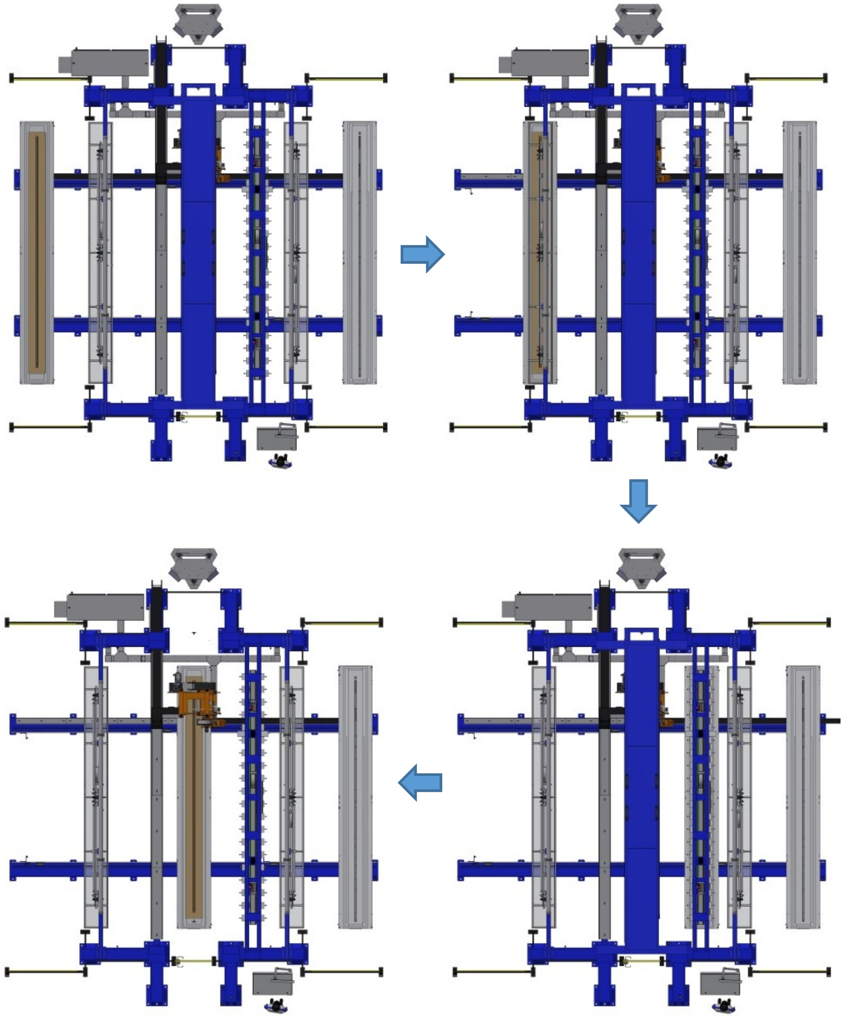

Figure 7: Process flow showing ply placement, compaction, forming and trimming

Once the component is fully laminated, formed, and compacted one last time, the operators initiate the Ultrasonic CNC Net-Edge-Of-Part trim sequence. A custom 6-axis CNC cutting system executes the trim program in a fraction of the time it took to trim manually, and at a precision of +/- 0.015". The end user reports a significant reduction in manufacturing time, labor, and re-work utilizing this automation-assisted work cell.

Figure 8: Stringer Former and Trim Cell Ultrasonic Trim Head

3.3 Recipe Driven Multi-Axis Position/Project Work Cell

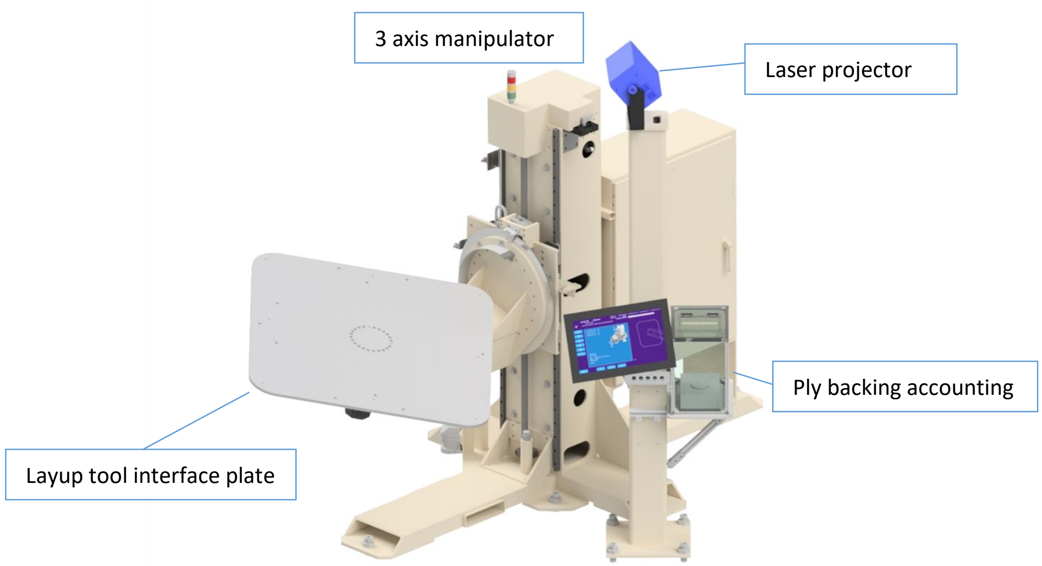

Figure 9: Multi-Axis Automation-Assisted Layup Cell

The Multi-Axis Layup Cell integrates five main features of the automation-assisted work cell concept in a compact form. It can be programmed for a broad array of component geometries – cube-like, sphere-like, or cylindrical.

The Multi-Axis Layup Cell has 3 axes of motion, 1 linear (Z) and 2 rotary (a, c). Using the laser projector, the kinematics of the system can be discovered by on-machine calibration. With each axis characterized, the frame of the end effector in any pose can be realized. Note that this calibration only needs to be done once at setup – the values are stored in configuration files on the HMI.

Layup tools are likewise only 'calibrated' once. The tools can be mounted with fixture pins, and the offsets that are calculated between the tool and baseplate are also stored in a file on the HMI. Because the operators do not have to register the laser for each setup, they are free to re-orient the layup tool for every ply, which is a significant time saving and operator fatigue reducing feature.

The part build recipe is created on or off the machine and starts by importing all of the ply projection data from the end user's choice of source file types. This populates the recipe file with all the plies to be projected, as well as one or more of the positioner's axes.

The recipe files can be edited easily in text editors or Excel to add more part routing information. Equipment configuration options are available for automatic compaction, forming or trimming cycles. Each recipe step can include a line of text for an operator instruction or informational display.

As the recipe is run on the machine, the positioner moves the part into the ideal/ergonomic location, automatically checks the appropriate laser target locations, and projects the ply boundary with minimal delays. The operator places the ply, discards the backer/carrier materials and presses a button to continue to the next ply. The work cell automatically repositions the tool for the next ply placement. When the part is finished, the log files are backed up and sent to the end user's network, and the tool is removed and replaced with the next layup tool.

4. CONCLUSION

Although the aerospace industry is likely to continue moving toward full automation of fabrication processes for many composite components, it is equally likely that a significant number of composite components will be most efficiently and cost-effectively manufactured with manual processes into the foreseeable future. Automation technologies can nevertheless benefit fabricators of these manually processed components. Automation assisted work cells have been demonstrated to improve process accuracy, decrease cycle time, and reduce rework and scrap rates. They are also designed with some extensibility so that more features can be added as new functionality is needed and/or becomes available. One example is automatic inspection; laser projection systems have recently evolved into full automatic inspection systems. Automation-assisted work cells will support automatic inspection and other new features without requiring major changes.

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