Feature

Robots improve the quality and cost-effectiveness of composite structures

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Abstract

Describes the benefits of using robots for advanced composite lay-up procedures. Particular emphasis is on aerospace structures. Argues that the use of robots now makes viable many fabrication operations that were previously too expensive, and highlights the improved quality afforded by consistent and rapid, automated lay-up procedures.

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Introduction

The superior qualities of composites have been well documented and demonstrated in the automotive, aerospace and marine industries, to name a few. There are, basically, two aspects to using composites, namely, the design, engineering and manufacturing of the tooling that defines the shape of a product, and the process which encompasses the engineering and lay-up by which a product is made.

Structural and cosmetic components, which may entail very complex geometry, can be manufactured with quality and reliability using composites. Aside from hybrid fabrics, various glass fibers, carbon fiber, Kevlar^{TM} and even ceramics provide the make-up of unidirectional and bidirectional cloth fabrics or weaves. With the advent of “prepregs” or pre-impregnated fabrics, quality and use of time have been greatly enhanced.

Until recently, the use of composites, outside that of military use, has been predominantly a task performed manually. In some aerospace applications, for example, once a design has been established, a plug is made. The shape is created via use of formers that are sectionalized geometric shapes located at designated stations, perpendicular to the long axis of the plug. Foam or a similar product fills the cavities between the formers and is then sculpted to conform to the desired shape. Filler is then used to smooth out imperfections prior to the application of composite material, fiberglass in many cases, which, then, completes the plug. From this plug, using a similar process, molds can now be produced. Recently, plugs or models have been made using an undersized core with the application of a machinable paste extruded over the surface. This has aided in the rapid prototyping of large, complex geometric master plugs.

Once molds are made the process of making parts can begin. The engineering behind the design dictates the lay-up and process for which a given part will be comprised. The factor of time can play a major role with some of these processes. Moldless methods of composite fabrication have also been developed. Yet both processes, for the most part, are performed by hand. Using such processes can, depending on the equipment employed, produce relatively accurate plugs, molds and parts.

Lay-up can be arduous and time-consuming. The mechanic must have a thorough understanding of the materials he or she is using. These products can cause serious injury if a healthy respect for them is not maintained. The mechanic must understand that the highest quality in craftsmanship should be practiced. Defects, especially within the aerospace industry, can contribute to the loss of life. Such mechanics are rare and their attention to detail is appreciated.

With regard to the fabrication and assembly of products such as air and fluid filtration components, which may entail layered or stacked composite matrixes, hard automation devices have proven to be limited in terms of speed, flexibility or both.

The need for faster methods of production and increased through-put, without compromising quality, is becoming a dilemma that must be overcome.

Post-lay-up processing

Post-processing, too, comes into play as the lay-up regime concludes. Vacuum bagging or the use of autoclaves, which may also be coupled with heat, are used to remove air pockets and symmetrically laminate and cure the lay-up around or within the mold. These processes ensure that the shape is properly transferred from the mold to the part with a high degree of lamination quality and cure being achieved. These processes are widely employed in the kit aircraft market.

Handling of such potentially large composite structures presents another issue. Use of wood formed stands or carts is typical and these are needed to support the structures until they can be assembled. The technology to handle, transport and assemble large and small parts, sequentially, in a practical manner, has been successfully demonstrated within the automotive, appliance and shipbuilding industries, to name a few.

The use of cubic footage within a manufacturing facility, instead of square footage, presents a viable, practical use of space, not unlike automatic storage and retrieval systems in use today. With such a system, handled composite components can be stored and supplied for ease of use in production.

Software

To design and develop aircraft made from composite materials, tools that enhance our understanding and use of composites are essential. Engineering software can now provide visual confirmation of reactions and effects that are inherent to a specific design. These allow for rapid refinement and validation.

Software allows various design and engineering disciplines including 3D CAD, CAM, solid and surface modeling, structural and fluid dynamics and kinematic modeling to work together seamlessly.

The use of CAM has enabled the machining and, in some cases, the fabrication and assembly of components direct from CAD, expediting the programming process on the factory floor. In addition, advances in CMM (coordinate measuring machine) technology have made real time quality control available. Use of laser measuring technology has greatly improved the generation of such data gathered directly from the finished product, where allowable tolerances can be confirmed. If an error is detected adjustments can be made rapidly and with ease.

With the use of kinematic engineering and modeling software, machines, including robots, can be modeled accurately as a stand-alone device or within a cell or factory environment. It provides the tools for the engineer/programmer to analyze critical information such as reach, paths, load limitations, collision avoidance and interaction with other machines or people. Because every aspect of a device or even a human can be generated within the environment, time studies can also be performed to identify through-put rates and safety issues.

Inserting a 3D solid or surface model into the kinematic modeling environment allows the programmer to teach a machine or robot the path and processes required to machine, fabricate and/or assemble a product. With such a modular and flexible environment infinite product and manufacturing scenarios can be generated and considered prior to equipment design or purchase and process selection.

Robots

The use of robots has been well documented in a variety of industries performing tasks including welding, cutting, assembly, painting, sealing and material handling, to name a few. Their use can be attributed to the flexibility, speed and accuracy for which they have been designed. In addition to advancements made mechanically, software development has provided simple programming and task options that enable process setups to be performed with relative ease.

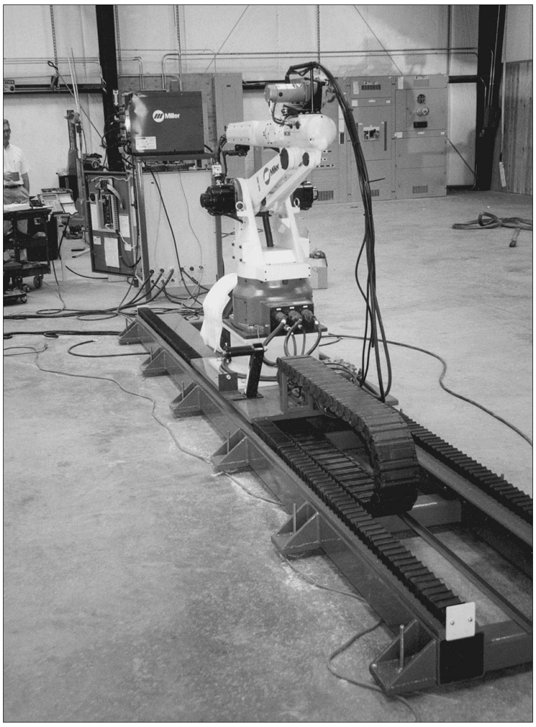
Cartesian, Scara and articulating electric robots are widely used in manufacturing. Electro-hydraulic and electro-pneumatic robots are traditionally employed where the environment in which they are used is harsh, requiring heavy load manipulation or minimal accuracy. These may be tele-operated devices. Activities may include decommission and decontamination tasks, foundry production or exploration.

Robots and robotic systems, as opposed to hard automation, are employed for their ability to accommodate change. If the cell is designed on a modular and flexible platform, systems can quickly adapt to size and product changes. Cartesian robots that employ tracks or shuttles and gantries are well suited to large product manufacturing and can easily accommodate such change (see Plates 1 and 2). With this type of robot additional axes may be integrated to the end of either the "Z" or vertical axis, or as a function of positioning equipment located within the working envelope.

Cartesian robots can also incorporate both articulated and/or Scara robots to provide additional reach and dexterity. They may be side mounted or inverted. These robots accompanied by positioning and part placement equipment within the work envelope can be tied together through cooperative or simultaneous motion. The integration of PLCs (programmable logic control) enables various process peripheral systems and equipment to be linked for use by the robot. With such flexibility, these systems, with as many as 24 axes of motion, can provide virtually infinite reach, positioning, dexterity and control.

Plate 1 Robots mounted on overhead gantry

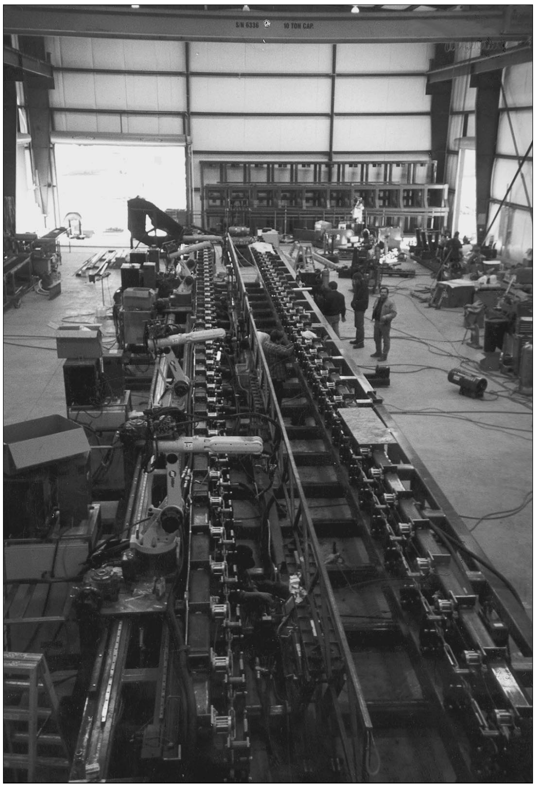
Plate 2 Robot mounted on linear track



Examination of robotic systems in various fields can provide further understanding as to how such technology can be implemented within composite manufacturing. Robotic welding systems (Plate 3) are among the most widely used. The technology to control and monitor in real time all aspects of the welding process is common. Quick-change end-effectors allow for torch change and tip cleaning as a function of the cell. Indexing or servo controlled positioning devices and part specific tooling allow for accurate part assembly and positioning.

In composite lay-up the end-effector used by the robot consists of a lightweight aluminum, flexible, roll feed system. This device employs drive rolls that draw pre-preg material, for example, from a power assisted supply roll. These sets of rolls work in concert with each other and are controlled as

Plate 3 Multiple robot welding system



additional axes to the robot. The advantage of such a device is that it places the material at the last physical axis of the robot allowing the flexibility of the robot arm to be optimized. The peeling of the separation liner, which separates the layers on the roll, is also accomplished in the reverse direction with the use of additional drive rollers. Both the source roll feed and the liner take-up rollers are equipped with force sensing to accommodate the layer increases and decreases as the pre-preg is fed out.

As the pre-preg is fed out on to or in a mold, placement is the next event for the robot and tooling. This is accomplished via a series of short length and small diameter powered drive rolls that, as the pre-preg is fed out, apply a constant pressure to the surface of the plug or mold. These shaped rolls are configured by means of an adjustable plate platform that accommodates X and Y placement, including overlap of these rolls. The Z direction is accomplished using air assisted, flexible joints, that employ force feedback and develop pressure zones which provide constant pressure to the surface of the plug or mold creating a uniform lay-up. Cutting of the material is accomplished via use of a flying knife synchronized with the fabric flow speed. This end-effector is traditionally built with a specific product or products in mind. However, it is designed on a modular and flexible premise and can be out-fitted for a variety of plug/mold configurations.

Communication and feedback is done directly through the quick-change device located at the last axis of the robot. Any additional support and peripheral equipment required in the lay-up regime is attached to the forearm, third and fourth axes, of the robot.

The difference between the pre-preg end-effector and that used with fabric is the additional requirement for the application of resin and the method by which the robot “squeegees” or forces the resin into and through the fabric. Since the resin, usually two-part and in some cases three, does not become active until mixed, individual supply of each can be accomplished with pots containing the material mounted on the primary structure of the track or gantry. When the resin is to be applied, materials are pumped to the robot and mixing occurs prior to passing through the quick-change device. This ensures that it is properly mixed and gives the robot all the time it needs to perform the lay-up process.

As far as the squeegee process is concerned, it performs the same as that of the pre-preg process, in that the shaped rollers employ force feedback that can be adjusted and controlled in real time. Since the robot can be programmed to position the end-effector exactly where it needs to be, uneven and/or complex surface geometry, including joints or breaks, is accommodated. As sensed viscosity of the resin fluctuates, so does the force feedback system, thus ensuring a constant, even lay-up. This system is practical for its ability to dispense only the required amount of resin and fabric or pre-preg as required by the product.

Roll widths best suited for this end-effector range in 6.00in (152mm) increments, from 6.00in (152mm) through 24.00in (610mm) and roll diameters up to 8.00in (203mm). Longer lengths can be accommodated if required. This is made possible by the linear adjustment system within the end-effector. Adjustments must be made, at this time, manually, prior to the lay-up regime. However, here is where the use of quick-change end-effectors comes into play. Having several setups for various size rolls or types of fabric or both, located at a docking station, allows the robot to perform in-process changes without halting the lay-up regime. Multiple types and make-ups of resin may also be accommodated in a similar fashion.

Material handling is another area where robot reach and dexterity has proven beneficial. These robots are designed for manipulating materials, in some cases heavy loads, precisely and with great speed. They accomplish this with a variety of process support peripheral equipment such as vision, force sensing and specialized end-effectors.

To provide a constant flow of product application, depending on the plug or mold size requires a method by which the robot can replenish its supply during the lay-up regime. This is accomplished with the use of material handling robots or devices. In some lay-ups hard points or imbeds, such as motor mounts and landing gear mounts, are required to be incorporated within the lay-up at a given layer and location and orientation. These parts are supplied to the system via magazines drawn out by the material handing robot. This is accomplished by adding "teeth" or pins to the back of the imbed or hard point. This allows the material handling robot to accurately place it in the proper location while the lay-up robot makes it part of the product.

Since the system can continually run, rolls of fabric, fiber or pre-preg must be ingested within the robot's domain. Magazine devices feed this material to the material-handling robot for placement on the end-effector tooling or tooling located at the docking station. Additional subassembly components made from composites may also be provided to the system by such devices.

The application of paint and various finishes for a number of products demands control and monitoring of every aspect of the process. Distance from the product, the pattern in which the material is applied along with volume of material must be accurately coordinated to meet desired finish requirements. Intrinsic safety may play a role, as some of the materials applied robotically can be highly combustible. The application of composite materials robotically requires similar control and accuracy.

Inverting articulated robots, in a gantry configuration (Figure 1) within a composite lay-up cell, provides virtually infinite flexibility. They share the "X" and "Y" axes and can thus work in concert with each other at a given station along the plug or mold. This system can double the productivity of the lay-up regime providing faster through-put rates while maintaining quality. The configuration of the robot cell affords easy egress and exiting of the modular mold or plug tooling. Program changes are accomplished simply by identifying three known points on the plug tooling and orientating the robot to them after the program has been downloaded.

Tooling

With the use of computer numerically controlled (CNC) profiling and machining equipment, precision tooling has been realized. Such tooling, depending on its complexity and makeup, can be very expensive.

Tooling has been developed that enables the "winding" of fibers about a rotating mandrel. The robot is responsible for not only the dispensing of the fiber and resin (if required) but also the generation of a weave or pattern along the long axis of the mandrel. In this, tension, variable feed rates and robot traverse speeds must be monitored in real time. The factor of time may also play a role depending on the fiber and resin used. By using a robot in this capacity repeatability of accuracy can be monitored and reproduced. Aircraft fuselages, wing structure components and flying surfaces have been successfully manufactured with this type of system.

Use of plugs and molds to produce composite parts also facilitates the employment of robotic systems. The spraying of fibers is a common method of manufacturing bathtubs and similar products. Tooling, such as plugs and molds, can be manipulated within a cell environment as additional axes to the robot. Specialized tooling now allows for flexible fiber and fabric "manipulation" and "placement" as an extension of the robot in non-winding systems. Tension and speed of fabric or fiber feed, placement and cutting, viscosity, temperature and placement of resin along with part orientation are accurately controlled as a function of the process.

Positioning mechanisms such as head and tail stock positioners are ideal for placement of large, complex plugs or molds within the work envelope of the robot system (see Plate 4). This eliminates any manual intervention during the lay-up regime. These positioners are not unlike

Figure 1 Front view of overhead gantry "lay-up" robots

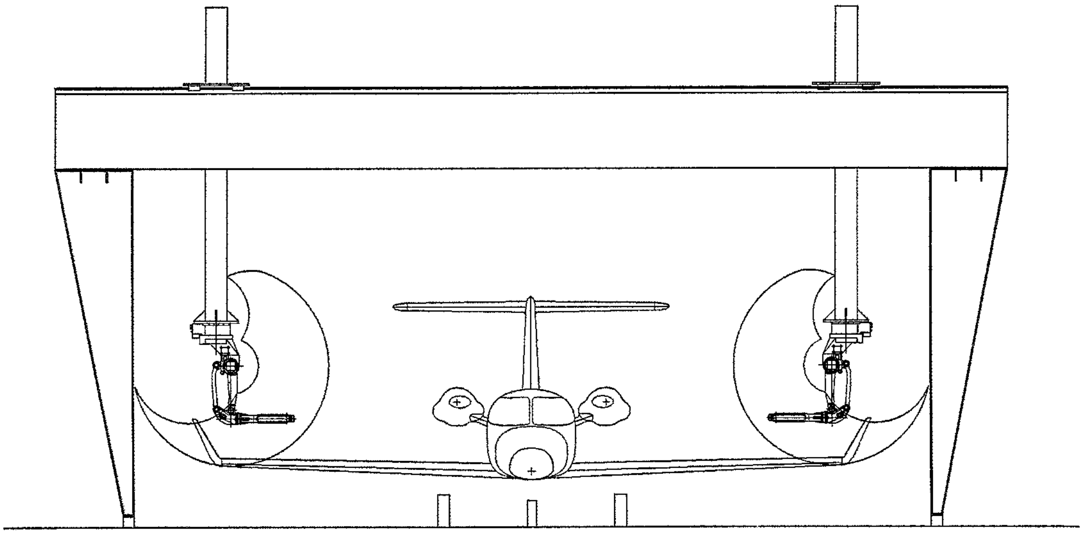


Plate 4 Positioning mechanisms allow rapid jigging of complex components

those employed in the winding process except that they may employ multiple axes of motion to more accurately position the plug or mold. With such flexibility lay-up can be performed with gravity as an aid since the plug or mold can be manipulated to provide for "in position" placement of the composite material.

Robots, in some applications due to the use of force sensing and specialized end-effectors, can perform the machining process as well, due to the fact that the plugs and molds can be made using foams and similar products that are easily machinable. This is possible because the harmonics and resonance generated by the machining regime are minimal, provided that the robot and positioning system are stable. This practice is common in deburring and complex geometric machining and finishing of metal, wood, plastic and glass products. With such capabilities, robotic gantry systems can perform both the manufacturing and finish of the plug or mold as well as the lay-up and finish of the part, all within the same cell environment. Employing pallet transfer systems within the robots work envelope can assist manufactures with rapid setups.

Use of robots in concert with hard automation devices or in cell environments makes possible a quick change over from small batch manufacturing to large-scale production within the same system. In this way the robot may simply be an upgrade to an already proven and reliable process.

Off-line programming of these systems enables change and setup to be accommodated with relative ease as all the process tooling and equipment can be contained within the cell with the employment of docking stations, similar to that of automated tool changers for machining centers. It also enables a system to be programmed for other projects without having to shut the system down to do so. This can be advantageous when part families need to be produced in rapid succession to accommodate manufacturing through-put requirements. Just-in-time automation is a prime example.

Systems integration

Companies like Composite Systems, Arnold, California, USA, provide manufacturers of composite tooling and products with consulting services, system concepts, cost analysis, design, engineering, manufacturing and implementation of these robotic systems. They employ the use of pre-engineered modular and flexible track and gantry modules. These modules allow for standard size gantry robot systems with up to 300ft (91.440m) of "X" (long) axis travel, 40ft (12.192 m) of "Y" (cross – horizontal) axis travel, and 40ft (12.192m) of "Z" (vertical – telescopic) axis travel. Multiple "Z" axes may be employed to double production rates depending on the product being manufactured. For long, linear manufacturing applications, servo powered tracks or shuttles that transport robots can be employed using the same module based concept. The specialized end-effectors discussed are also available from this supplier.

What makes these systems unique and straightforward is the integration of design and engineering software, simplified programming of the robot system and peripheral equipment, combined with modular and flexible tooling and positioning equipment, providing a "turn-key" manufacturing package solution.

Conclusion

Robots and their support systems are well suited for composite fabrication and lay-up regimes. This technology exists and is commercially available. These machines need not be defined as "custom" robotic systems as the integration of the various technologies discussed is common in many other industries. With such modularity and flexibility already available, the robotic manufacturing of composites for the aerospace and other industries is ready for the twenty-first century.

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