

# Feature

## Robotic "layup" of composite materials

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### Keywords

Composite materials, Robots, Automation

### Abstract

This paper describes the history and current technology behind composite manufacturing and the development of a precision feed endeffector (PFE). The PFE is used on the end of a robot arm and performs many functions associated with the handling of prepreg and semipreg materials. The PFE helps to achieve higher levels of accuracy and productivity for automated layup systems.

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## History

With the advent of "composite materials", including cores, in its nearly limitless forms and characteristics that continues to evolve, new "application" technology has continued to be developed in concert with its use. With the improvements in plug and mold designs, engineers have been allowed to "assemble" complex parts. Of these many advances, lasers have assisted greatly in the verification of location and orientation of the materials used when layup is performed by hand. The use of water-jet systems has allowed for holes and cut outs to be performed after the "layup" has been completed and the part cured. Significant improvements in "XY cutting" systems and associated software has expedited the "profiling" or cutting of the materials prior to layup. In the "winding" regime, advances in fiber placement machines has provided increased throughput, although these systems are very "task specific". With the use of automated tape laying (ATL) machines, the placement of "unidirectional" tapes has been employed in a very limited group of aerospace and marine applications due to their expense, limited flexibility and limitations imposed by the specific materials that can be used by the systems.

Industries that are increasingly demanding both improved materials and methods for layup consists of the aerospace, automotive, marine, wind energy systems (blades), furniture, telecommunications, transportation (i.e. high speed rail, ship building, motor homes, sport boats, semi-trucks, trailers, shipping containers), residential homes, architectural applications, oil and gas exploration pipes and space systems, to name a few.

## Industry dilemma

A significant key to the growing use of composites, outside the benefits derived from the material characteristics themselves, is the ability to use such materials without, or at least limiting, the expense associated with the labor costs traditionally endured by the industry. To find qualified personnel, to perform the many and varied tasks associated with the "layup" or "placement" of such materials, can place limitations on which projects can be justified to use them. Herein



lies the dilemma for manufacturing. The expression "pounds-per-hour" is fundamental to the justification of the use of these advanced materials. These issues affect all programs employing "wet layup", "dry layup" (RTM applications) and prepreg or semipreg applications.

Current technology, until now, has limited this "number" in concert with the fact that the systems currently available limit the "types" and "sizes" of materials that can be *automatically* "laid up" or placed and the speed or amount of material that can be dispensed per hour of production. Typical methodology dictates that more personnel are simply required to get the "pounds-per-hour" required to justify the program. At some point of time, however, you reach a paradox.

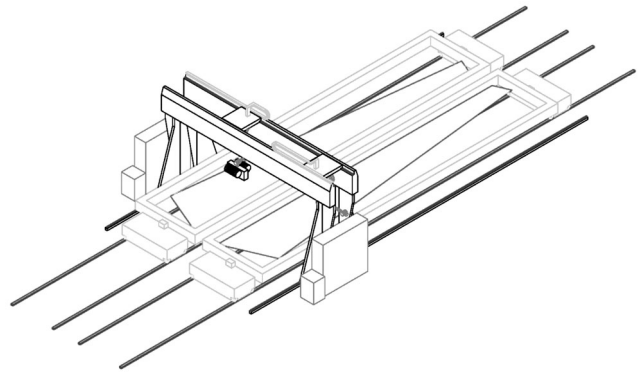
The placement of core is affected by such issues as well. These materials, too, are varied in makeup and shape and must also be "placed" in the proper position during the layup regime. The handling of such materials can be awkward, at times, due to the sizes and shapes and the specific location for it to be placed, as required by engineering. The issue of labor, again, plagues the process.

### Use of robotics

The use of robots to perform a variety of tasks is well documented. However, their use in the field of composites has been limited, to date, as the "end-of-arm" equipment has been limited to, for the most part, water-jet, drilling/tapping, material handling (limited), assembly and fiber placement applications. These advances have significantly improved quality and speeds at which these varied aspects of composite use are performed. Because of the flexibility associated with robots and the use of additional "axes" of motion that are commercially available as "auxiliary axis packages" from most commercial robot manufactures, increased "cell size" or work envelopes can be realized.

The use of floor or "wall mounted" tracks have given a single robot the ability to perform tasks in a variety of "work environments" along the track on which it rides. By using gantry systems, the robot(s) work envelope is substantially increased. These systems lend themselves to large work pieces where work is performed in all three "primary axes" (Figure 1).

**Figure 1** Robot on traveling overhead gantry provides X, Y, Z layup capabilities



In concert with these systems, additional axes may be employed within the "cell envelope" to position or manipulate the work piece in a "coordinated" movement to the system, thus adding flexibility to the cell.

### Precision feed endeffector technology

As mentioned, the requirement to precisely place or layup "pounds-per-hour" is critical to the justification of the use of composite materials, regardless of the process employed. To that end, precision feed endeffector (PFE) – patents pending and applied for worldwide – technology for commercial robots has immersed.

Commercially available material, whether dry or prepreg, is available in widths that range from 1.00 in. (25.4 mm) to excess of 60.00 in. (1,524 mm), with supply roll cores ranging from 3.00 in. (75 mm) to 12.00 in. (305 mm) in diameter, and outside diameter (OD) up to 26.00 in. (660 mm), of which the feed system has been designed to accommodate. With respect to prepreg or semipreg materials, they may be either unidirectional or woven in nature with varying amounts of resin impregnated to one or both sides of the material. Use of such materials is geared toward more control and uniformity in the layup regime, as both the resin type and volume and "fiber characteristics" lend themselves to be an "engineered" product.

PFE technology was developed to utilize the flexibility and ease of programming associated with commercial robots. It also addresses "justification" concerns to implement such technology for a given program.

## Prepreg/semipreg

The PFE device combines several aspects associated with the "handling" of prepreg and semipreg composite materials, namely, material feed, refrigeration of the material (Plate 1), the "peeling" of the protective film(s), "profiling" or cutting of the material on one or both edges simultaneously, discharge of the "waste" material, reactivation of the resin to the required temperature prior to placement (optional) and the ability to "absorb" the surface of the mold during layup, whether concave, convex or spline geometry, without requiring the programming of each "point" along a given "path".

Based upon a specific "process" selected, the roll of material is first loaded into the "feed" station on the PFE. The operator would perform this operation "offline" at a "tool crib" located adjacent to the robot cell. The tool crib may house several PFE devices, set up and configured for specific material types and widths. The tool crib would also house "end-of-arm" devices that may perform the placement of core material and imbeds

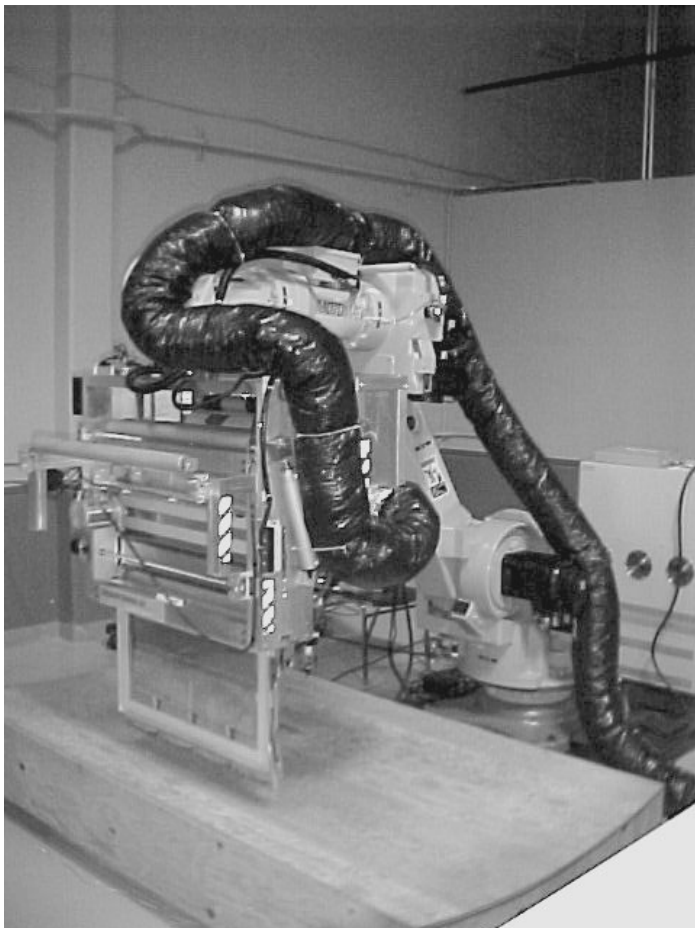
that may be part of a particular layup schedule. Further, such equipment may also include PFE devices configured to place "bagging" materials whether for "debulking" purposes during the layup regime or in preparation for curing. "Magazines" with core and imbed components may line the cells' exterior from which the robot or robots may draw from to satisfy an "assembly".

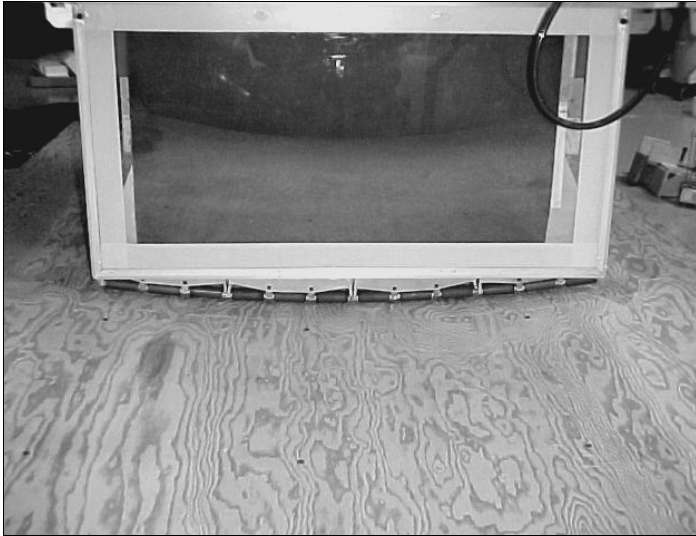
Once the material has been loaded, the operator would then peel a "leader" of the protective film(s). In that event the two films were to be removed, the "bottom" film leader would be wrapped around the supply roll, thus placing both film leaders on top for feed to the "take-up" reel. There, the films would be attached to an empty "core" for take up by the system.

The PFE has been designed for easy access and service and opens as a "clamshell" in the vertical orientation, with the hinge being at the top of the device. In the open position, the operator would pull the material down through a series of drive rollers that will both feed and provide "tension" in the "cutting or profiling" station. The drive system can be programmed to overcome specific "tackification" issues that are inherent to various prepreg and semipreg materials as they pass through the system. The profiling station has been designed to accommodate different methods of cutting that may include a "drag knife", slitting and ultrasonic devices. The waste material exit just below this station by means of a series of pneumatic venturies that are "linked" to the profiling system and apply bursts of air in two directions, one for retaining the material that is to be laid up and forcing it to continue through the tool, and a second, simultaneous burst of air in the opposite direction that directs the waste material out of the device where it is captured for removal by the operator once the PFE device returns to the tool crib.

One of the key elements to the PFE device is that of its "suspension system" (Plate 2). This allows the system to "absorb" the surface contours as the robot moves along the "path". The suspension system provides 100 percent contact with the surface regardless of the supply roll width, and can be programmed to provide a "specific force" so as not to crush core material that may be employed in the layup. Further, because the device provides such controlled "contact criteria", debulking,

**Plate 1** The PFE combines material feed, refrigeration, peeling and profiling



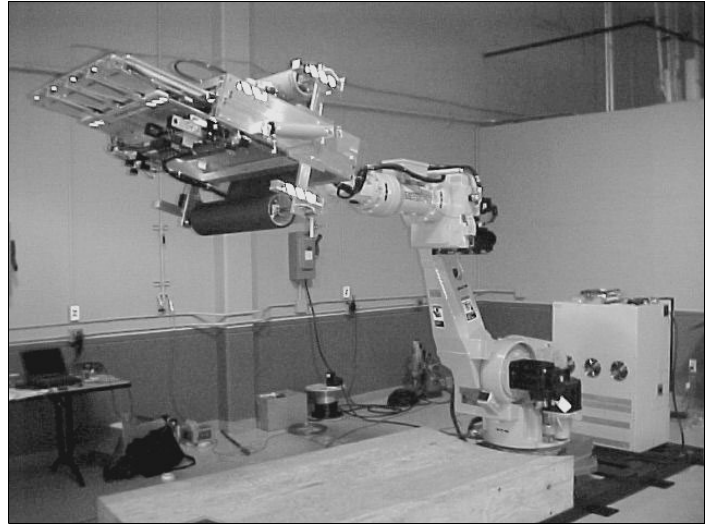
**Plate 2** The PFE has a suspension system to absorb surface contours

to some extent, is provided as a consequence of the layup itself.

The "path" described herein, consists of two elements to the robot system. This proprietary "link" between the robot and the PFE device allows for the coordinated "feed of material" with the travel of the robot. The path is combined with the "average offset" that the robot will maintain over the surface and the "nominal centerline" assigned to the direction in which it is moving. This "centerline" is given to the system offline from software capable of producing a "flat blank" or pattern, established at the engineering level and typically supplied to "XY cutting" systems.

The robot, the PFE device and the roll of material supplied within it shares this same "centerline". Laser systems monitor the "alignment" of all of these components to ensure that the "edge" of the material is placed where it is desired. The cutting system receives the "pattern" information in relationship to the path the robot is programmed to take. The system does not require complex algorithms to perform the layup. Verification of dimensional length is provided at the suspension system level of the PFE, just prior to the placement of the material. This is significant where "ply drop-offs" or "field build-ups" are critical to a given layup.

By incorporating robot tracts or gantry systems, layup may be performed over or within large mold tooling. The PFE device is capable of being inverted (material/process specific – Plate 3) and may be "daisy-chained" or connected together, end-to-end, for large part layup such as wings, hulls of boats or ships, cylinders as well as flat

**Plate 3** The PFE can be inverted for layup of angled surfaces

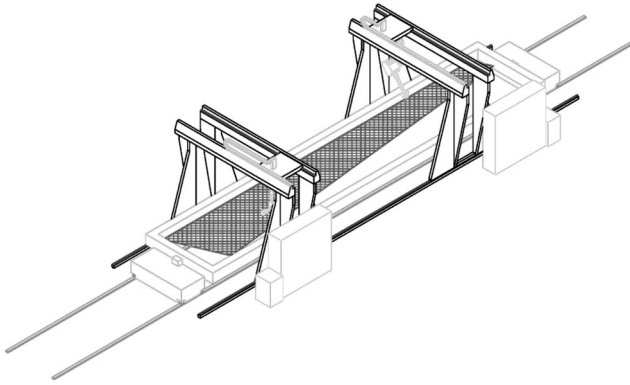
panels. Additional axes to the robot system can provide the ability to "manipulate" the mold so as to provide "in-position", or within gravity, layups, depending upon the material tackification.

In applications where two molds will be worked together and provide the "mirror" part, or the other half, gantry systems that employ at least two robots that share a common bridge can greatly reduce the amount of time involved in such layups, thereby, at least, doubling the throughput rate. This becomes evident when a large portion of the programming is shared by both robots, thus synchronizing speed down the long axis of the system.

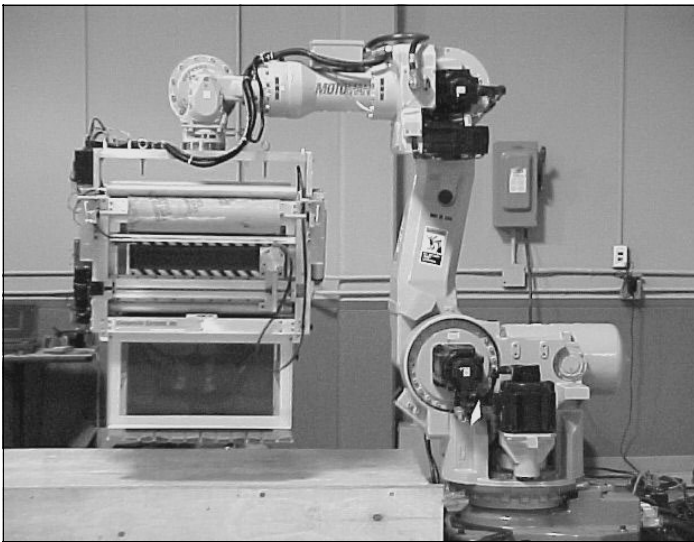
As to the speed of the ten axis PFE device, feed rates of material may exceed 1,200' in. ipm (30.48 mpm), based upon material limitations. The gantry system or track system employed in the cell will perform these speeds, where the robot need to make only minimal adjustments within its speed range to maintain the path and relative perpendicularity to the surface of the mold (Figure 2).

The PFE is manufactured in standard module widths, typically in 6.00 in. (152 mm) increments, assembled at the factory to 60.00 in. (1,524 mm) in width standard (Plate 4 – 24.00 in. /610 mm PFE shown). However, special length configurations and systems may be provided on request. Further, "combination" PFE systems can be provided affording "angled" layups, where, for example, a 6.00 in. PFE and a 24.00 in. PFE can be mounted at a right angle (90°) to each other. This configuration would be applicable to where corners could be done in a single

**Figure 2** The gantry system tracks the robots at constant speeds over large surfaces



**Plate 4** The PFE can be manufactured for different widths of layup materials



pass. For example, when two planes or surfaces come together, creating a corner, as in the case of a box, where the 'side' meets the 'bottom'. The PFE will place both the 'side wall' and the 'bottom' at the same time. In addition, "cross configurations" may be employed where the layup of unidirectional material could be placed at a right angle to a linear path of woven material in a given layup, thus eliminating an additional pass by the system. Configurations, such as these examples, could be designed into the "process" at the engineering level.

The PFE systems come fully integrated to the robot and system configuration is selected by the customer. These systems are designed to be expanded as the need arises.

### Wet layup

For "wet" layup applications, such as those associated with boat building, among others,

the PFE device performs a very similar set of functions with only a few additions, which are optional devices to the "base" PFE platform.

The dry materials (fabric) are loaded and fed in the same manner as prepreg materials, with the exception of the take-up system, as no protective films need to be removed. The profiling and waste removal stations are the same. However, the additional attachments include resin supply and feed systems, which provide for temperature control as well as the mixing of materials. The feed system provides resin to both sides of the material as it is being fed, just prior to placement, with the ability to "meter" volume and viscosity on each side.

The addition of a flexible "squeegee" attachment to the suspension system allows for the spreading and "bleeding" of the resin through the material as it is being placed. Excess resin is "recycled" and metered so that the "new resin supply" may be cut back accordingly, in "real time", so as to "balance" the resin/material feed.

### Control

Control to the PFE system is PC/PLC based incorporating both digital and analog inputs and outputs to monitor speed/feed criteria in concert with the robot movement. This is done by means of a proprietary "chip" which "negotiates" with both of the devices in real time so that they work together seamlessly. This hardware "rides" with the PFE device so that when exchanges of tooling occur, each device carries what it needs to perform the tasks it is assigned.

Patterns that the profiling system will perform are simply fed to the system offline and verified through "offline programming software" that is supplied with the robot system. The operator has the option to program on the floor or call predefined programs from archived files.

These "turn-key" systems are typically equipped with an human machine interface (HMI) that includes a customized touch screen, incorporating icons that allow the operator to test and cycle individual aspects of the system. The HMI is located adjacent to the tool crib, as the operator will use it to communicate with individual PFE devices or other "end-of-arm" tooling located within for setup and testing prior to telling the "robot system" that a particular device is ready for use.

The HMI also monitors what is happening during layup, which may include cameras that monitor aspects of the layup regime to ensure quality and provide documentation for various uses internally. The screen can be tailored to the customer's requirements, based upon existing processes. Training for the operator personnel is part of the packaged system.

### **Conclusion**

Without question, the use of robots to perform arduous and even dangerous tasks, precisely, has been well established. With

the demand for faster, accurate, methods for the layup of composite materials, PFE technology fills these demands economically. Working in concert with track or gantry systems that may include "positioning" devices within the cell, rapid, accurate, automated layup can be realized.

For further information on PFE technology and the layup systems please contact:  
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