

Production Implementation of Multiple Machine, High Speed Fiber Placement for Large Structures

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ABSTRACT

A two machine Automated Fiber Placement (AFP) cell capable of laying $\frac{1}{2}$ " and $\frac{1}{4}$ " tow at rates up to 1800"/min (45.7m/min), including feeds and cuts, has been implemented for the manufacture of large primary aircraft structures.

The control architecture of the cell is such that part programs are machine independent and can run on either machine or simultaneously on both machines at the same time. A Central Cell Controller pushes part programs to each AFP machine and coordinates the cell.

Volumetric accuracy of the two machines is under 0.008" (0.2mm) radial error in the entire compensated envelop, which is approximately 64' × 21' × 14' (19.5m × 6.4m × 4.3m) for each machine. This is accomplished through optimization of volumetric kinematic compensation parameters using a linear numerical solver. The machines reference a common coordinate system which allows great flexibility in part programming.

A detachable head design was implemented which allows each machine to swap between $\frac{1}{4}$ " and $\frac{1}{2}$ " tow widths in 120 seconds. The creel is contained on the head which provides very short tow paths and isolates the AFP process to the detachable tool. This allows creel re-fills, AFP head maintenance, repair, and upgrade of AFP head to be performed off line without interrupting production.

INTRODUCTION

Electroimpact produced a cell built around a control architecture that permitted the use of two machines running simultaneously or independently using common programs which can be run on either machine, [Figure 1](#). Additionally, the machines are independent in that the failure of one

machine (e.g. dropped tow) does not interrupt the second machine laying tow. Furthermore, the use of detachable, modular AFP heads offered offline load, cleaning and maintenance for increased cell uptime, and provides a way to rapidly change tow widths during production.

Existing technology

Some knowledge of traditional AFP machine technology is helpful in understanding the unusual features of this machine. Typically, large AFP machines feature a "creel house" removed from the head which stores multiple spools of tow in an air conditioned environment and feeds them out to the head via a series of idle rollers along a 20'-30' (6.1m-9.1m) tow path. The most notable down side of this design is the very long tow path increases the chance of tows becoming twisted and makes threading tow difficult and time consuming. Changing tow widths is an involved process and most AFP path maintenance requires down time on the machine. The complex tow path may also preclude true bidirectional tow laydown in all tow directions, as the tow path must be twisted as the end effector rotates. In contrast, the Electroimpact AFP machines use a discrete AFP head that places all of the AFP elements - including the "creel house" - on the detachable head. The heads are interchangeable via a tool changer, allowing 120 second change-outs to a fresh head or a head of a different tow size.

Some multiple machine systems have a single CNC machine controlling the rotator and machines. If using two machines in such a cell it is very desirable to be able to quickly switch to a single machine or move work to an alternate machine. With a single CNC machine system, programmer intervention or multiple part programs are required to switch the number of running machines.

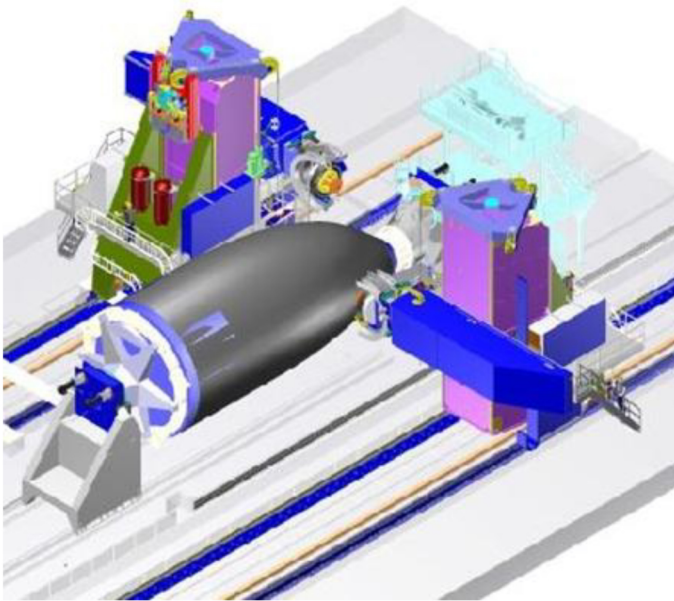


Figure 1. Machine Cell

MAIN SECTION

This section is divided into three sub-sections

- Cell Description
- Accuracy and Compensation
- Control Architecture

CELL DESCRIPTION

The cell consists of two machines, a rotator, a maintenance area and a control station. The cell is specifically designed for lay-up of forward section wide body composite fuselage, including the cockpit region, [Figure 2](#). Additionally, three ½" heads, two ¼" heads, and one probe head were delivered with the cell. The heads attach to the machine using a robotic tool changer. The maintenance area contains four head transfer stands and head transfer carts.

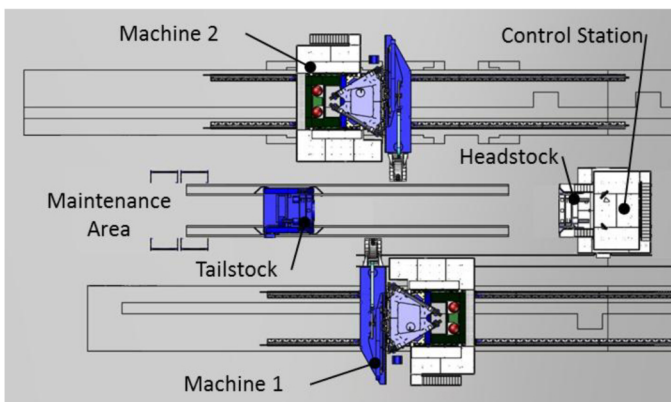


Figure 2. Cell Layout

Major Machine

Two moving column floor mill or "post" style machines were implemented on either side of the part, [Figure 3](#) and [Figure 4](#). The very large part diameter and customer specifications drove the machine envelope of 22.2' (6.77m) of Y axis travel and 14.2' (4.35m) of Z axis travel, along with X travel to address the 48' (14.6m) longer proposed derivatives. 135 degrees of "A" rotation at 2700 degrees/minute, 90 degrees of "B" rotation at 1800 degrees/minute and an infinite "C" axis at 12000 degrees/minute permit maintaining normality to the part at any position in the work envelope. Linear axes move at 2000"/minute (50.8m/min) with accelerations of 0.18g. High acceleration is critical to machine performance where many short courses exist, which turns out to be the case even for parts as large as this fuselage.

Rotators

A large and accurate rotator was required for rotational (U axis) positioning of the mandrel assemblies. The rotator consists of an independently driven headstock and tailstock, [Figure 2](#). The tailstock X axis travel allows it to accommodate a variety of tools.

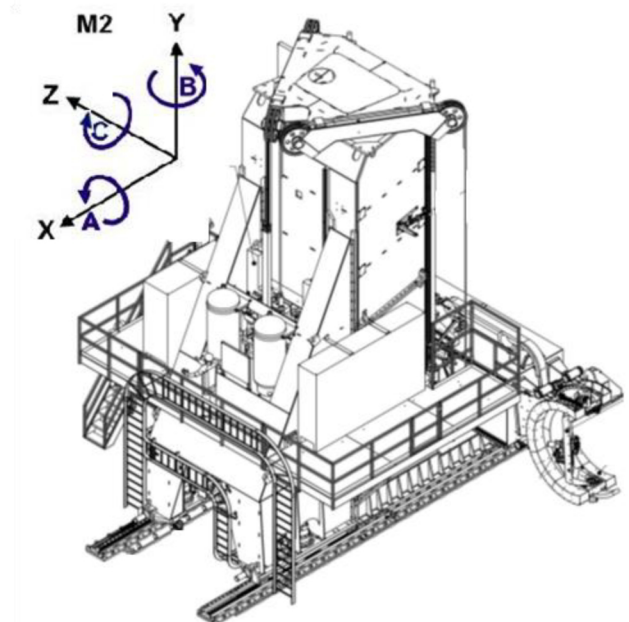


Figure 3. Major Machine



Figure 4. Major Machine

Modular AFP Heads

The machines are equipped with both $\frac{1}{4}$ " and $\frac{1}{2}$ " tow widths. The ability to lay multiple tow widths is accomplished by implementing quick change AFP heads. The AFP process is completely contained on each head. Each head contains 16 spools of tow, an infrared heater for highly controllable and responsive heating and air for cooling, [Figure 5](#). A high speed local PLC provides head control with minimal delays for the AFP process (e.g. cutters, feed rollers, heater, etc.). All AFP process elements are designed for the very rapid response required by the design laydown speed of 2000 inches/minute.

Modular AFP Head Advantages

The removable modular head offers several advantages specific to this design.

The head offers 360 degree positioning about the C axis and therefore true bidirectional layups. Because the fiber placement system is independent of the machine, the head does not "care" which way it is oriented and the tow path is not influenced by head orientation considerations.

The removable head offers a multiplicity of tow widths with a 120 second change. Each head uses exactly one tow size, with 16 spools. To date, $\frac{1}{8}$ ", $\frac{1}{4}$ " and $\frac{1}{2}$ " heads have been implemented (the $\frac{1}{8}$ " on other machine cells). Other tow widths and other materials are possible with the removable head concept.

The very short tow path (approximately 3' (1m) long) offers significant advantages whenever threading new tow is required. All the fiber placement elements are located within arm's reach of the operator and any operations - tow stringing, cleaning, diagnosis, cutter replacement, etc. are greatly simplified.

The rapid head change means that nearly all fiber placement maintenance tasks (loading new tow, cleaning, cutter replacement, etc.) can take place offline while another head is attached to the machine and laying tow.

Future developments in head design are easier to implement. A new generation of head has already been developed. Such improved heads may be brought online and used alongside the existing heads, as desired.

Other special use heads are possible. Currently a probe head is used for locating the mold and for machine compensation purposes. The possibilities exist for other heads, such as an NDI head or an ultrasonic profiler.

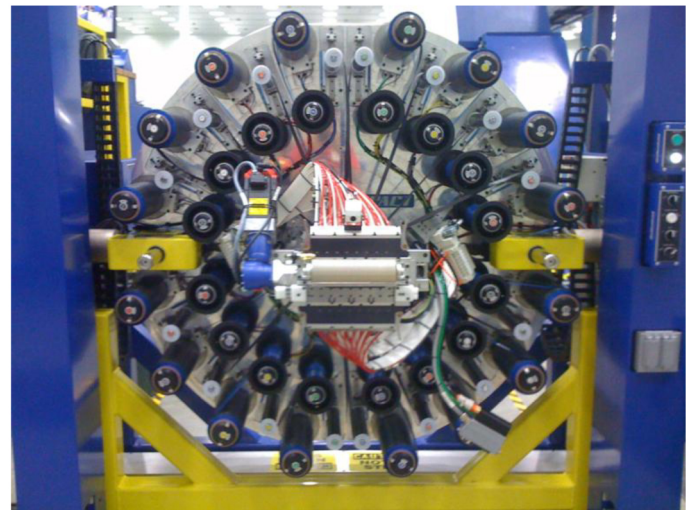


Figure 5. AFP Head

Transfer Stands

Transfer stands allow for the rapid change-out of a head. They are positioned at the maintenance area for ease of access to head maintenance tools and spools of tow. The transfer stands provide fully automated safe and secure head swap and provide a staging position for newly ready heads. Additionally, the transfer stands provide power and air to the heads for full off-machine functionality. [Figure 5](#) shows a head in a transfer stand in the lowered position.