Integrating 20 Tow, 1.5 Inch AFP Heads on Large Part for High Deposition Rate Application

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Abstract

As carbon fiber reinforced plastics (CFRP) become more integrated into the design of large single piece aircraft structures, aircraft manufacturers are demanding higher speed and efficiency in Automated Fiber Placement (AFP) deposition systems. To facilitate the manufacturing of large surface area and low contour parts (wing skins, in this case) at a high production rate, Electroimpact has developed a new AFP head consisting of 20 1.5 inch wide pre-impregnated carbon tows. The new head design has been named the 'OH20', short for 'One and a Half Inch, 20 Tows'. This AFP head format creates a deposition swath over 30 inches wide when all 20 tows are active. A total of four of these AFP heads have been integrated with a quick change robotic tool changer on two high speed, high acceleration, and high accuracy moving beam gantries. All head CFRP spool loading, maintenance, and cleaning can be accomplished in a maintenance cell while the other AFP head is depositing CFRP in the part cell. This has greatly increased machine cell up time and hourly deposition rate. In addition to the implementation of a robotic tool changer for the AFP heads, a high power, large IR heater and in-process profilometer inspection assembly has been combined and integrated with separate automated robotic tool changer drop off routine. This allows for multiple heads to use the same heater/profilometer assembly which provides a reduction in expensive hardware quantity requirements and improves the safety for operators and equipment. The development and manufacture of this system has resulted in a greater than 900 pound per hour (PPH) layup rate during production part program execution.

Introduction

Cell uptime and production efficiency continue to improve for the OH20 machine cells. The OH20 heads are qualified at add and cut speeds of 1,200 inches per minute (IPM), with on part mid-course payout speed of 4,000 IPM. Minimum pieces and gaps are deposited at 600 IPM. Off part motion during transport between the part area and head change area are run at 6,000 IPM. Instantaneous deposition speed at 4,000 IPM is approximately 3,050 pounds per hour (PPH). Tow end placement for adds and cuts have been qualified to +/-0.150 inch at 1,200 IPM on a contoured part. The demonstrated high deposition rate is important for large surface area parts such, as aero-structure skins, because a single part has such a high mass of CFRP. Therefore, production time is decreased. Figure 1 shows the OH20 head during early prototype wing tool testing.

Figure 1. 20 Tow, 1.5 Inch AFP Head Depositing Carbon on Prototype Wing Tool during Development.

In addition to high payout rates, it is imperative that the material deposited meets the strict quality requirements of the manufacturer's specifications. Carbon location, lamination quality, lack of FOD or resin buildup, strict lap/gap statistics, and other layup quality requirements are inspected during and after each ply. If the layup does not meet the standards, it will have to be pulled up and re-laid. This means that creating a reliable process is important to creating a usable part within the manufacturing rate time requirements. This has been obtained on the OH20 by utilizing independent and retractable shuttle assemblies, which only place the compaction rollers in contact with the part when that tow is in use.

Because this system can deplete an entire load of carbon, approximately 600 pounds, in less than one hour, it is important to be able to clean, load, and otherwise prepare a second head while the other one is out laying tow on the part. We created a quick change head drop off system that uses an existing industrial robotic tool changer to switch between the two heads and single heater/profilometer unit in two minutes or less, this results in significantly lower machine down time due to head malfunctions.

Benefits of 1.5 Inch Tow

We have found that the use of 1.5 inch wide tow has several beneficial characteristics in application. First of all, the larger width of the tow allows for much higher deposition rate, as shown in Equation 1 and Table 1. The overall tow path width of over 20 inches allows for much larger area coverage. This combined with high layup speed creates unprecedented industry laydown rates.

$$R = \mathrm{W} \cdot \mathrm{n} \cdot \mathrm{T} \cdot \rho \cdot \mathrm{S} \cdot 60\,\frac{\mathrm{min}}{\mathrm{hr}}\;/16\,\frac{\mathrm{oz}}{\mathrm{lb}} \tag{1}$$

Where,

Instantaneous Payout Rate (R) in lb/hr

Tow Width (W): 1.50 in

Number of Tows (n): 20 each

Tow Thickness (T): 0.0075 in

Carbon Density (ρ): 0.905 oz/in^3

Layup Speed (S) in/min

Table 1. OH20 Operating Speeds During Layup and Off Part Motion.

Phase of Layup	Speed	Units	Payout Rate	Units
Add speed	1,200	[in/min]	916	[lb/hour]
Cut speed	1,200	[in/min]	916	[lb/hour]
Min gap speed	600	[in/min]	458	[lb/hour]
Min piece speed	600	[in/min]	458	[lb/hour]
Payout speed	4,000	[in/min]	3,054	[lb/hour]
Off part speed	6,000	[in/min]	N/A	[lb/hour]

The wider tow path allows for fewer total courses per program ply. Fewer courses creates fewer slow moves at add and cut speed, as well as fewer times lifting off of the part and turning the head around. All of these apects reduce the total program run time. These payout rates have been timed on a 110 foot long, 30 foot wide production wing skin tool with 77.3 lbs of carbon deposited in 4 minutes, 57 seconds in the 0 degree direction. This yields an average payout rate of over 936 PPH for the entire program execution. 45 degree and 90 degree full plies have been timed on the same tool at 903 and 767 PPH, respectively.

A second benefit of 1.5 inch tow is that a fewer number of tows are required to cover the same surface area of the part. This requires a lower total number of AFP process events. Because of the mechanical nature of each tow add and cut cycle, the reduced tow quantity decreases the statistical probability of tow drops or other failures. This is very important to the overall productivity of the AFP cell [1].

Beneficial Features of OH20 Head

The OH20 head was designed from scratch with cell uptime and efficiency as the primary design goals. With the reality that heads will occasionally need maintenance or have unexpected problems, a quick change drop off system was specified by the customer. The head drop off routine allows the loaded head to drop the heater assembly in a neutrally located stand, drop the head, pick up the opposite head, and load the heater in two minutes or less. This short amount of time spent changing heads substantially improves the up time of the machine. The OH20 head sitting in the drop off stand is shown in Figure 2.

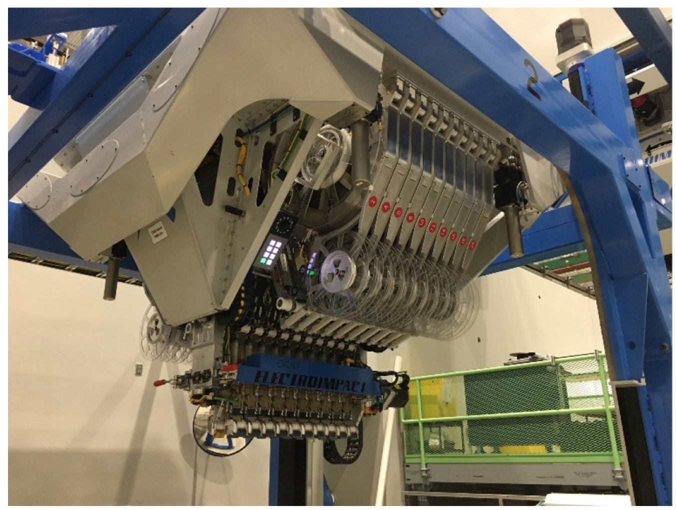

Figure 2. OH20 in Service Stand in Pickup Position

Due to the high unit price of the heater/profilometer assembly, the team decided that each machine cell should share a single heater/profilometer assembly between two AFP heads. We have used robotic tool changers on the heater/profilometer assembly to create an automatic drop off routine when heads are swapped. Using an automatic drop off ensures that the assembly is not damaged by inadvertent drops and lowers the risk of injury to the operators. The heater/profilometer assembly and tool changers is shown in Figure 3.

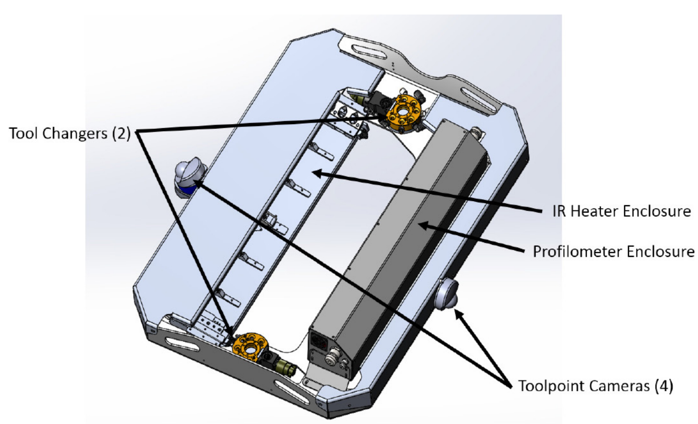

Figure 3. Heater/Profilometer Assembly with Tool Changers

The stands that receive the OH20 heads can then lower using servo actuation to a horizontal position designed for ergonomic access, maintenance, and CFRP loading. This final lowered position can also be adjusted to accommodate particularly short or tall operators. Access to the opened spools and business end of the head are possible from one standing position on each side of the head, as shown in Figure 4.

Full head process function when detached from the machine CNC is integral to a seamless transition between the maintenance area and working in the part area. All of the critical head process functions are available to the operator on each side via the button panel attached to the head. These functions include feed, cut, and cool. Head power, air, and communication are provided through tool changer modules attached to the industrial drop off clamps.

All maintenance area functions and operations are handled at a separate operator console from the main machine. This allows people working in the maintenance area to complete tasks separate from those who are laying up CFRP in the part cell. When the reloading personnel have completed their work, they simply raise the head into the pickup position and press a button letting the machine operators know that the head is ready and available for pickup.

Finally, an array of eleven laser profilometers installed on the same assembly as the IR heater [2] allows us to measure and verify the lap/gap specification provided by the customer, which is a nominal gap between each adjacent tow [3]. In reality, these gaps creates a nominal course width slightly over 30.1inches. When the OH20 heads are initially assembled, the gaps are measured with nominal shims installed and a one-time adjustment is made to bring each tow's lateral positions and gaps into the required specification.

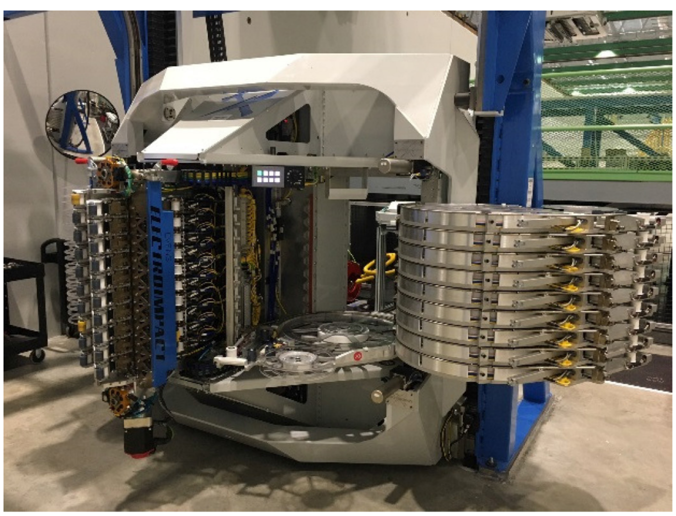

Figure 4. OH20 in Maintenance Position with Open Creels

A secondary design goal was to allow operators and maintenance personnel to complete typical access tasks, maintenance, and cleaning on the head without the use of tools. This is both for speed of access and to decrease the risk of FOD on the part from tools being left in the head. All of the commonly removed parts have finger release mechanisms and are positively located so that they cannot be installed incorrectly. The same is true for the cassette loading mechanism, it is released and pivots out with the push of a button. The retainers for the spools and backer take-up are button released as well. This way, the operator is able to unload, reload, and thread the cassette while standing in one position and without any tools. The cassette layout and tow path is shown in Figure 5.

The process assemblies in the business end are designed to be interchangeable on all 20 lanes as well as quick release. This allows for quick debug by swapping modules and checking to see if a particular issue follows the hardware. Additionally, spare assemblies can be provided to quickly switch out defective or resin contaminated modules.

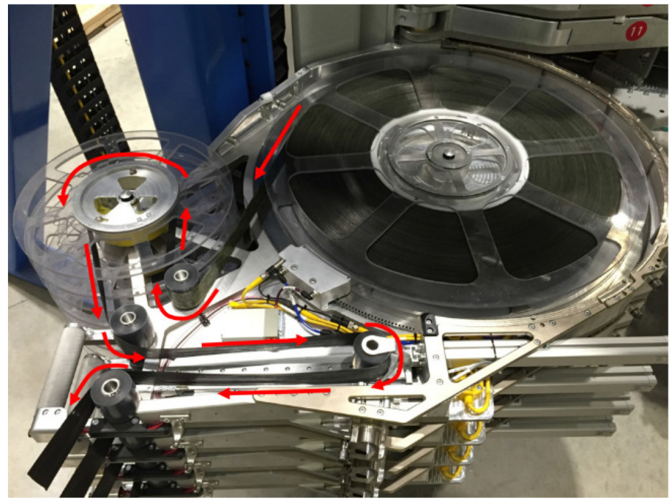

Figure 5. OH20 Cassette with Tow Routing Shown

Figure 6 shows the robotic tool changer that supplies all of the signal, power, and high/low pressure air services for the process head while on the main gantry. The tool changer is connected to the machine with a ring type torque motor and pneumatic and electrical slip rings that gives the head's rotation axis unlimited travel. This functionality has been made standard on all Electroimpact AFP machines and robots.

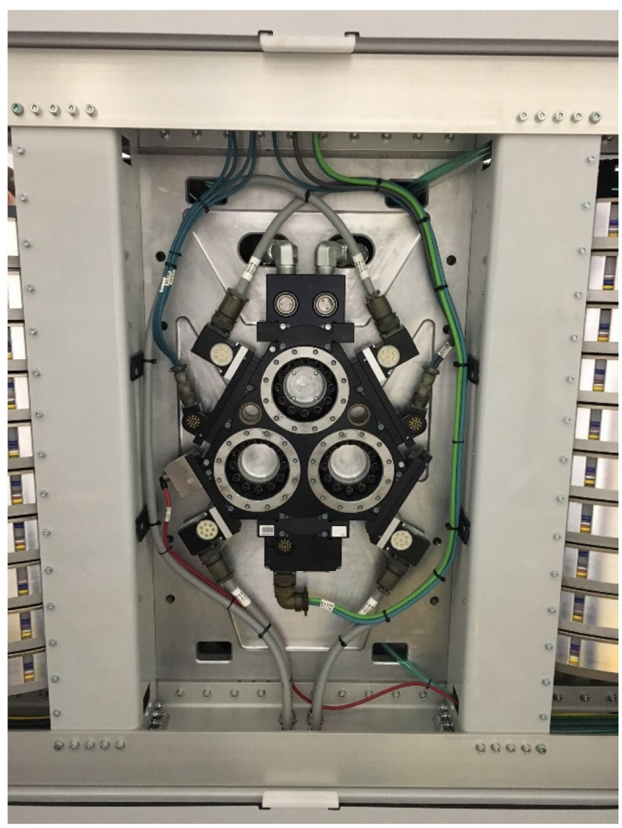

Figure 6. OH20 Tool Changer and Air/Power/Signal Interfaces

Challenges of 1.5 Inch Tow

The use of 1.5 inch wide tow presents several new challenges for the AFP process that do not exist for narrower tow format. Because of the higher width to thickness ratio, the ability to steer the tow becomes much more difficult. This can make part programing for highly contoured parts more time consuming and complex. Because the tow has so much directional stability. The alignment of the creel and business end components within the AFP head becomes critical. Misalignment can cause rolled tow edges, folded tows, and internal tow jams. Good design and assembly practices must be employed to ensure that the tow does not experience unnecessary lateral steering in the head prior to contact with the part.

Additionally, with an approximately 30 inch wide course, a single, full width compaction roller with enough compliance to match part contour was not feasible. For this reason, we developed independently actuating shuttles with sufficient travel to satisfy the customer's minimum part radius requirement. They contain their own compaction roller, cut module, clamp module, cooling components and routing, and tow alignment hardware. The shuttles are pneumatically controlled and can extend or retract as needed to make contact with the part only when desired. They also control compaction force within a range specified by the customer and as commanded by the operator.

Compaction travel requirements are dependent on the minimum contour radius of the tool being used. We designed the shuttle assembly travel to be longer than the nominal compaction distance to ensure adequate contour compliance. Equations 2, 3 and 4 and Figure 7 show the calculation for required compaction travel based on part radius. The shuttle assembly is shown in Figure 8.

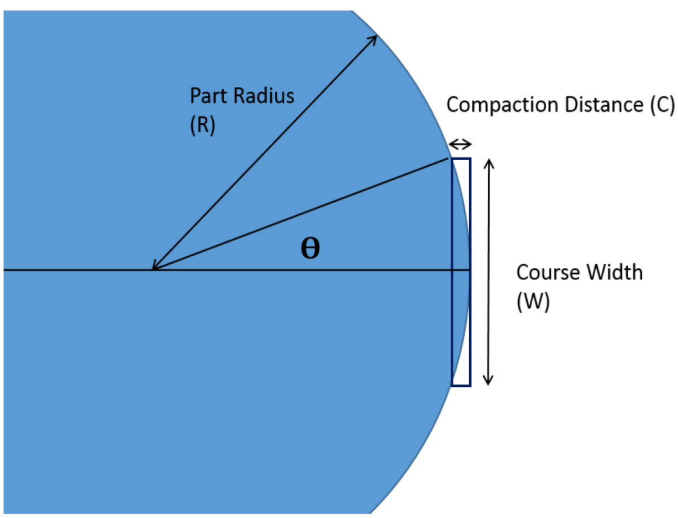

Figure 7. Compaction Travel Calculation Diagram

$$\theta = \sin^{-1}(W/2R) \tag{2}$$

$$C = (R\text{-}(R \cdot \cos(\boldsymbol{\theta})) \tag{3}$$

$$C_t = C_n + C \tag{4}$$

Where,

Part Radius Course Centerline Angle (**θ**): degrees

Part Contour Radius (R): 200 inches

Course Width (W): 30 inches

Delta Compaction Distance (C): inches

Nominal Programmed Compaction Distance (C_n): inches

Total Required Compaction Distance (C_t): inches

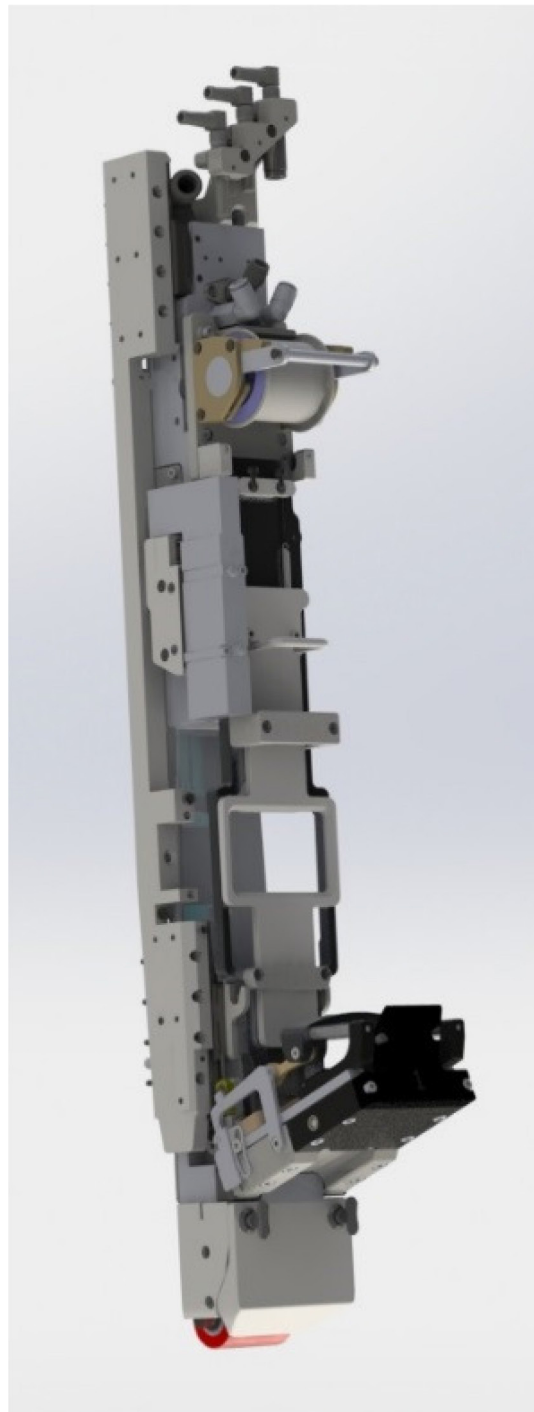

Figure 8. Modular Clamp/Cut/Compaction Shuttle Assembly

Summary/Conclusions

Electroimpact's new OH20 AFP head is a fresh approach to manufacturing large, low contour CFRP parts. Because of the wider tow format, a new and much different head layout was successfully designed and qualified to the customer's specifications. High AFP process reliability combined with an extremely high performance gantry type moving platform, the OH20 AFP heads have proven to produce unprecedented laydown rates and machine up time. Also, the specially designed quick head change allows the machine cell to keep despoiting CFRP on the tool at high rates. All of this in conjunction with an easily serviceable process module layout and quick change modular components creates the most efficient possible production process. The result is not only a requirement for a lower number of machines and capital investment for the manufacturer, but also a lower overall factory footprint.

Now that Electroimpact has proven the feasibility and reliability of the OH20 design, it's structural and creel layout can be easily scaled down to facilitate layup of tighter curvature parts and integration with smaller machines and robots alongside 16 tow AFP heads. Design and testing is now in progress for an eight tow variant. That version of the 1.5 inch tow AFP head is scheduled to enter service in 2018.

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Definitions/Abbreviations

AFP - Automated Fiber Placement Where a machine, similar to a milling machine, deploys a process head made to deposit strips on carbon fiber impregnated with epoxy onto a layup mandrel.[1]

CFRP - Carbon Fiber Reinforced Plastic

PPH - Pounds per Hour

IPM - Inches per Minute

tow - A single strip of carbon fiber. The system in the study features 1.5″ tow. There are 20 lanes per head.[1]

FOD - Foreign Object Damage

OH20 - One and a Half Inch, 20 Tow AFP Head

add - The AFP process first adds tow, pays it out and then cuts it. The automation that causes tow to be placed accurately on the part is referred to as an add.[1]

cut - The AFP process first adds tow, pays it out and then cuts it. The automation that causes tow payout to terminate is referred to as a cut.[1]

payout - The time where tow is being added to the part. This occurs between adds and cuts.[1]

min gap - The shortest distance that the AFP head can reliably make a cut, subsequent gap, and add a new tow.

min piece - The shortest length of tow that the AFP head can reliably deposit.

course - A single path of motion made by the AFP platform that may use one or all tows.

ply - A single layer of CFRP as defined by the part designers.

cassette - Assembly that contains the carbon spool, tension mechanism, and redirects to the business end

business end - Nose ection of AFP head that handles tow processes and interfaces with the tool.

slip ring - An electromechanical device that allows the transmission of power and electrical signals from a stationary to a rotating structure. [4]

IR Heater - Medium Wave Infrared Heater for High-Speed Fiber Placement [2]

The Engineering Meetings Board has approved this paper for publication. It has successfully completed SAE's peer review process under the supervision of the session organizer. The process requires a minimum of three (3) reviews by industry experts.

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