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A Process for Delivering Extreme AFP Head Reliability

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Abstract

Every now and then a good idea happens. The Modular head was a great idea and enabled the use of multiple types of AFP heads, ATL, ply cutting, part probing, etc. with the use of a single machine and machining cell. At the time the modular head was developed by Electroimpact circa 2004, the industry assumed (and accepted) that AFP was an unreliable process. It still isn’t as reliable as we’d like. One way of coping with this lack of reliability is to stage more than one head in the AFP cell so that a spare head of the exact same type is ready to jump into action if the head out on the floor has an issue. If the reliability of the AFP process were to increase 10x or 50x, would there still be a business case for the multiple AFP head system? The modular head may still win the day, but the metrics change. For instance, if there was only 20 minutes of down time for every head load, it may no longer be advantageous to have 2 heads of the exact same type in the cell. It is our goal to eliminate AFP process unreliability to the point where this discussion has real meaning.

To address the #1 cause of reliability issues experienced in 777x we invented the Modular-Servo-Creel head. We built a full working prototype of this machine and demonstrated it to Boeing and others over the past year. What we learned was indeed we did fix the #1 cause of reliability issues that we see in production of the 777x spar (the loss of tension during large speed changes during the zero degree ply). In the process of using this head other causes for unreliability also came into view. They actually had nothing to do with the theory of operation of the head as we previously experienced with the old creel system, but more to do with preparation. These items are:

- Head Cleanliness
- Blade Sharpness
- A valve that is failing or leaking
- A seal that is worn or leaking
- A spring plate that failed

Each of these items caused an error on a part that we were trying to make and diagnosis took longer than acceptable causing even more issues on the part until the correct diagnosis and remedy was made. Because we identified these items as potential causes of mistakes on the part, we created a system described in detail in this paper. This section describes a process and method for cleaning the AFP head using a dishwasher, a method for checking blade sharpness and finally a method for checking the module functionality. We demonstrate this this system running our prototype AFP head building 16 plys of the 50’ spar, some stringer charges and then a hexagonal test part placing 100,000 individual tow strips without a process error, not even a slipped tow.

Introduction

AFP (Automated Fiber Placement) machines used in aerospace manufacturing spend much of their existence doing nothing. The challenge for next generation AFP cells is to increase layup time as a percentage of total cell time. Review of production data between 2 AFP cells shows that a well-managed cell can achieve double the layup time of a typical cell. Figure 1 shows a breakdown of cell use for a typical AFP cell. The machine spends only 19% of its time laying carbon. Figure 2 shows an example of a current cell that has exemplary layup time of 42%, more than double a typical cell.

The data also shows that a majority of cell time is used for activities that are NOT layup. This paper presents methods aimed to reduce time used for non-layup activities. A potential optimized time allocation is shown in Figure 3.

For the purposes of this paper, we will define utilization as Layup Time. If the Layup Time is 60%, we will say that the utilization is 60%. Layup Time is the time the machine spends actually running part programs that lay tow on the mold. This time includes all off part motion between courses and the time to move to the part from wherever the machine was at the beginning of the program.

As an AFP machine builder and vendor, we have some responsibility for current low levels of utilization. Our goal is to help our customers achieve machine utilizations in excess of 60% (more than doubling typical utilization). We see 4 critical areas:

- Increase reliability of the AFP process
- Reduce the need for non-real-time inspection

FIGURE 1 Typical Cell

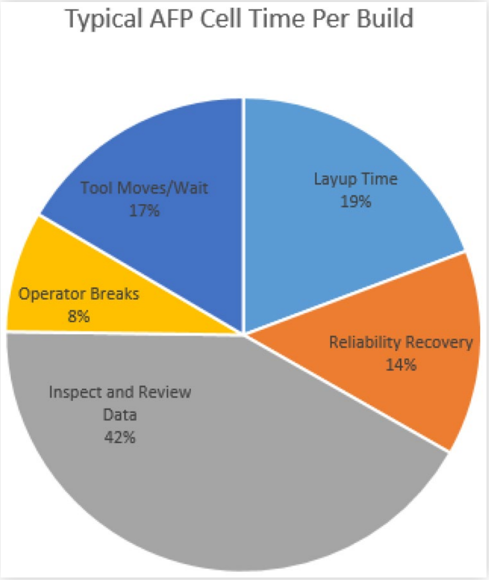

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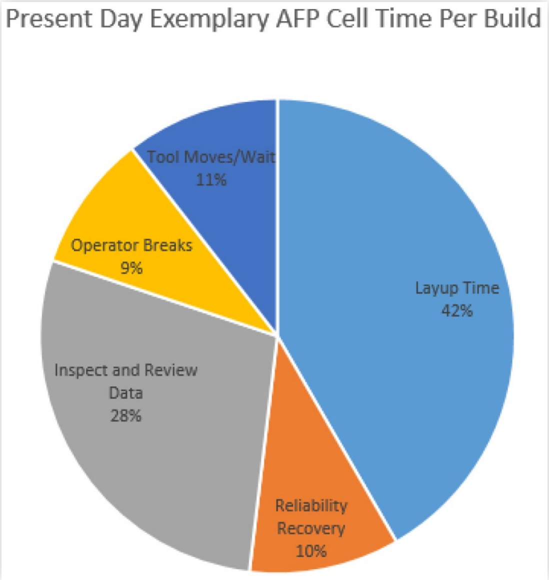
FIGURE 2 Exemplary Cell



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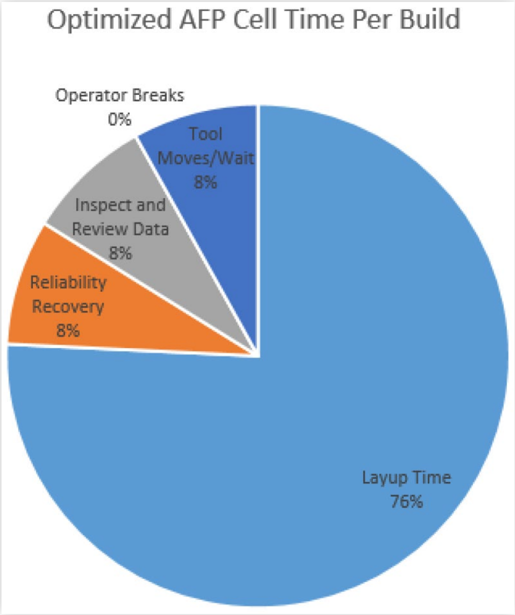
- Increase Visibility for Management, Maintenance and Operators with (E)I4.0
- Pace setting
- Utilization charts
- Predictive maintenance
- Standardize head readiness

Over the past 2 years we have declared an all-out war on resolving any reliability of process and reducing inspection time.

FIGURE 3 Optimized Cell Utilization



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Increasing Reliability of the AFP Process

Overview

Since we brought our recent 777x cells into production, the following new technologies have come into view and they are set to make a big impact on our goals of increasing utilization. We'll touch on them here and then explain in detail.

Although the 777x spar AFP system is achieving high reliability[1], the best we've ever seen, there is one system that is holding us back from getting to an MSBF (means strips before failure) of 10,000 or greater: the tow tensioning system. We decided to build an entire H16 (half inch, 16 lane) AFP head with our concept for a servo-actuated creel tensioning system as a pre-production prototype. This prototype contained:

- Modular-Servo-Creel AFP head
- New Modular-Head PLC enabling a significant control architecture change.

Those items yielded:

- Better AFP process reliability - expected from the servo creel
- Better AFP end placement accuracy - expected from the better control architecture
- Add placement measurement using process sensors on the AFP head - unexpected

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[1] The 777x spar machines build the world's first in situ-full length spar. This is an extremely difficult part. The system is meeting our contract goal of MSBF > 6000 while running at 100% FOV and very high speeds.

- Slipped tow measurement using process sensors on the AFP head - unexpected
- Cut placement measurement using process sensors on the AFP head - unexpected

Every now and then a leap in technology occurs in an industry. The introduction of the modular head was one of the leaps in technology for AFP and enabled the use of multiple types of AFP heads, ATL, ply cutting, part probing, etc. with the use of a single machine and machining cell. At the time the modular head was developed by Electroimpact circa 2004, the industry assumed (and accepted) that AFP was an unreliable process. It still isn't as reliable as we'd like. One way of coping with this lack of reliability is to stage more than one head in the AFP cell so that a spare head of the exact same type is ready to jump into action if the head currently on the machine has an issue.

If the reliability of the AFP process were to increase 10x or 50x, would there still be a business case for the multiple AFP head system? The modular head may still win the day, but the metrics change. For instance, if there were only 20 minutes of down time for every head load and no other source of process related downtime, it may no longer be advantageous to have 2 heads of the exact same type in the cell. It is our goal to improve AFP process reliability to the point where this discussion has real meaning. Higher utilization due to a near perfect AFP head process reliability and zero inspection time will be the next leap in AFP technology. We believe it is going to occur in the next generation of AFP equipment.

To address the primary cause of reliability issues experienced in 777x, we invented the Modular-Servo-Creel head. We built a full working prototype of this machine and demonstrated it to Boeing and others over the past year. We did indeed fix the primary cause of reliability issues that we see in production of the 777x spar (the loss of tension during large speed changes during the zero degree ply).

In the process of using this head, other causes for unreliability also came into view. They actually had nothing to do with the architecture of the head as we previously experienced with the old creel system, but more to do with preparation. These items are:

- Head Cleanliness
- Blade Sharpness
- A valve that is failing or leaking
- A seal that is worn or leaking
- A spring plate that failed

Each of these items caused an error on a part that we were trying to make, and diagnosis took longer than was acceptable, causing even more issues on the part until the correct diagnosis and remedy was made. Because we identified these items as potential causes of mistakes on the part, we prototyped a head preparation system described in more detail below. Basically, this section describes a process and method for cleaning the AFP head using a dishwasher, a method for checking blade sharpness, and finally a method for checking the module functionality. Our goal is to use this system to run our prototype AFP head building 16 plys of the 50' spar, some stringer charges and then a hexagonal test part placing 100,000 individual tow strips without a process error, not even a slipped tow.

Start of Add Cycle: While studying the characteristics of the servo-creel with the faster PLC and working out the details in our process, we realized that we can precisely detect when a feed event occurs with uncertainty on the order of 10us. We do this detection without the addition of a single sensor that is not dedicated to the process.

Slipped tows: Besides being able to accurately calculate when a tow feed starts, we can also accurately determine how much tow actually payed out during the add cycle. This capability allows us to determine exactly where the tow end is physically on the part, and determine how much slip occurred during the add cycle. A certain amount of slip occurs during every add cycle. Slip is the major contributor to tow placement uncertainty. It also indicates the cleanliness of the AFP head. The cleaner the head, the less slip that occurs.

Start of Cut Cycle: Similar to the Add Cycle start event, we can determine when a cut cycle occurs with an uncertainty on the order of 10us.

Improved Control Architecture: We implemented a new way of communicating position coordination to the AFP head PLC from the machine CNC. This method increases our update frequency from ~50ms and 20us uncertainty to ~1ms and 10 us uncertainty. Today's extremely high dynamic machines and fast lay down rates are not well supported by our old method. Our new method eliminates tow placement errors due to acceleration and deceleration during the feed and cut cycles.

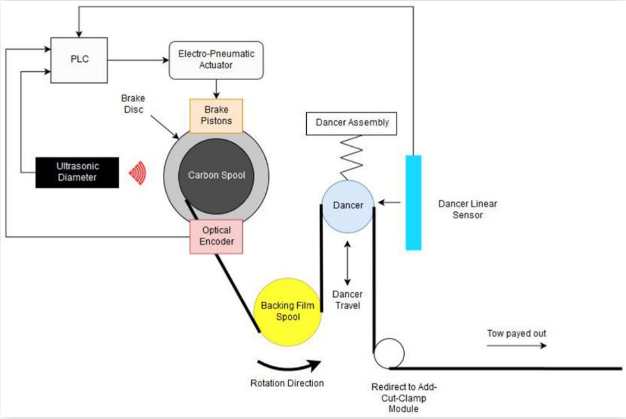
Testing, which includes building full scale 777x spar and stringer parts, shows we can 100% eliminate down time due to tow end placement inspection. It have also demonstrated extreme reliability of process, measured in mean-strips-between-failure (MSBF), in excess of 15,000.

Servo Pneumatic Creel

On the previous generation of Electroimpact AFP heads, a pneumatic braking system was used in order to control the tension of the tow. Tow is payed out by using a servo motor and pneumatic roller to pinch the tow and feed out at a controlled rate. Initially, the carbon spool is stationary and is accelerated by the tension generated from spring force. The braking system can then decrease the rate of material unspooling in order to change the dancer displacement during operation. Due to the nature of varying inertias, and diameters as well as using sliding friction to control the rate of payout from the spool, tuning this system is a complex task.

A disadvantage of this system is that the dancer spring must generate relatively high force in order to create sufficient acceleration in the spool. Also, if rapid acceleration cycles are present in the part program, it is possible that the dancer set point will creep upwards and, since the braking system cannot unwind the spool actively, this displacement will continue to build up into an over-travel. This high tension system can also cause large tow slips during high speed tow add events.

FIGURE 4 Pneumatic braking system



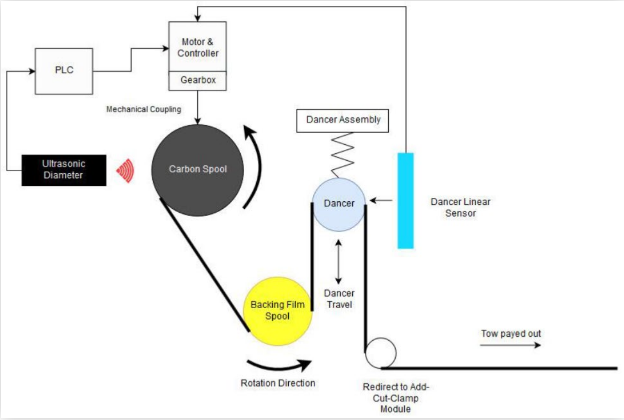
Another disadvantage is, to maintain a low tension, the dancer is only displaced a small amount. During high speed cuts, the dancer can completely stroke out causing slack tow.

Both of these disadvantages led to the most frequent forms of process errors we witnessed during the production of 777x spars where high speed lamination is required by our customer. We decided to change to another method. Instead of using servo-pneumatics, we switched over to servo motors which can not only provide tension, but can be used to actively accelerate the spools.

Servo Motor Creel

The main changes are that the brake disc is replaced with a servo/controller and gearbox combination. This allows the tensioning system to be completely controlled by the motor controller instead of the PLC. Figure 5 shows that the ultrasonic diameter sensor (in black) is passed through the PLC to the motor controller in order to get a good estimate of surface velocity. This is to offload sensor filtering to the PLC in order to get a more reliable diameter signal.

FIGURE 5 Servo Creel System, Patent Pending



Heater Developments

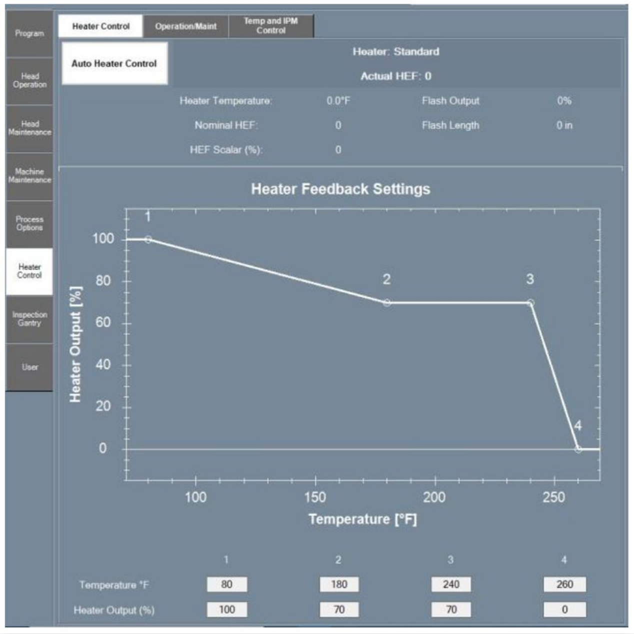
Current IR heater The IR heater was developed by Electroimpact in 2004. It has been refined since then, but remained largely unchanged. In general, the IR heater works extremely well after a warm up period. We identified some tow placement failures due to initial heat conditions:

- Cold Tow: tow that has sat in the cold area of the head for an excessive amount of time (30s or more) tends to not stick on the part.
- The heater tends to warm up over time. It turns out that the heater body (or specifically, the reflector area, also known as the backshell) tends to heat up with consistent use. This heat is then re-radiated and absorbed by the part. In fact, we find that this re-radiated heat is extremely effective in heating the part…more so than the IR bulbs themselves. During normal operation of the heater, the backshell reaches such a high temperature that no IR bulb output is required to achieve good tow tack.
- Even if we increase the bulb output to make up for the cold backshell, we still get untacked tows.

To obtain better results during the initial conditions of the heater an RTD (Resistance Temperature Detector) was added to the heater backshell. We use this device to control heater output and also to limit maximum federate, shown in Figure 6.

To help with the cold-tow problem mentioned earlier, we set a time on the last time tow was fed out. If the time exceeds a threshold (nominally 30 seconds) then maximum feedrate is limited on the first placement of that tow so that the undesired untacked tow does not occur.

FIGURE 6 Heater feedback settings

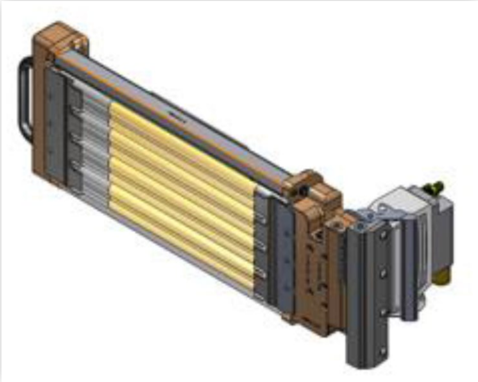


Heater: Standard
Actual HEF: 0

Heater Temperature: 0.0°F
Nominal HEF: 0
HEF Scalar (%): 0
Flash Output 0%
Flash Length 0 in

	1	2	3	4
Temperature °F	80	180	240	260
Heater Output (%)	100	70	70	0

FIGURE 7 IR Heater Assembly



Hands-off Operation of the Machine

- The AFP machine monitors the temperature of the heater body using an RTD. This feedback is used to scale the heater output and limit the maximum laydown speed to provide a more stable part temperature over the course of a ply. As the RTD reads higher values, the feedrate becomes unrestricted and the IR bulb output is reduced accordingly.

High Reliability of Error Detection

- The current carried by each emitter is continuously monitored. A deviation outside of a normal operating profile triggers an error.
- Standard Work includes a heater soak test procedure. The heater body must reach a target temperature within a pre-determined time window. This serves as a health check of the RTD and emitters.

Experimental Laser Heater We started research using a laser heater on the machine. Currently we have experience with the Laser Line laser. It works extremely well and does not have the problems associated with the IR heater. There are two drawbacks to the Laser Line laser. It does not package will with the modular head, and it poses a significant safety hazard. We are working with two companies to develop an IR laser diode heater that can package well on our equipment. We ultimately think that laser heat of some sort is the future of high-performance AFP machine and AFP machine reliability. To address the safety hazard we advocate for an enclosure that separates the machine from the operators, similar to the enclosures used on most modern milling machines. Laser power shuts off if the enclosure is breached by a human. The EI AFP facility has an enclosure surrounding our test machine which has an envelope of X: 60’, Y: 40’ and Z: 10’.

Inspection Improvements

Current Technology The currently deployed generation of Ply Boundary Inspection technology uses cameras to image tow ends and locate them in part coordinates. This serves a valuable purpose by generating terabytes of ply boundary data where no quantitative data has ever been gathered in large volume. However, the system is expensive and incurs a time cost to image the ply after layup.

Current Ply Boundary Inspection Capabilities:
Ply Boundary Inspection: +/- .060” 85% reliability.
Pros:

- Boeing certified
- Mostly automatic

Cons:

- Not real time
- Semi-automatic selection of tow ends is tedious
- Extremely hardware intensive and expensive

A real time ply boundary inspection system reduces inspection time and makes the cell available for layup. Implementing a ply boundary inspection system that inspects in parallel to layup is a key component to increasing layup utilization as data collected in previous cells, shown in Figure 8.

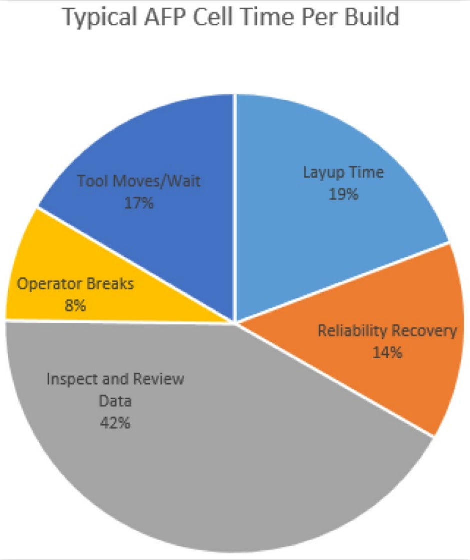
The current generation Lap/Gap system uses profilometers to measure surface features in real time. Data is processed in parallel with layup. The Lap/Gap system is expensive, but there is no time benefit in eliminating or improving the system.

Current Lap/Gap Inspection Capabilities:
Lap/GAP .005” - ~.125” gaps and .015” > ~.125” Laps.
Pros:

- Boeing Certified
- Reliable
- Real time

Cons: Expensive

FIGURE 8 Inspection and Data Review Cell Time



Rapid In-Process Inspection Technology (RIPIT)

For the past four years, Electroimpact put extensive effort into using an external sensor to collect lamination data for the purposes of detecting tow end data. This effort was fruitful in that we were able to develop a system that is Boeing certified and delivers a rich data set.

With this customer requirement complete, we were able to refocus our energy on improving the actual AFP process. First, we developed the servo creel system to increase reliability. The second improvement is a fundamental change in how we calculate and when we calculate the time to actuate a feed or cut cycle. The combination of these items yielded a method for accurately determining the placement of tow. It also allows us to determine whether a tow slipped, and how much it slipped during placement. The data is collected during the add or cut cycle and is fully processed before the next course begins. It is real-time. Results of this effort are:

- Servo controlled creel system provides highly repeatable and stable dancer motion and tow behavior.
- Electroimpact has developed a method using high performance sensors and precision processors to precisely detect the tow position on the aircraft part as the tow is payed out.
- Add and Cut position, as well as "tow slip" amount is provided by the system
- Tow slip is crucial information when understanding tow behavior as it is placed on the part. Causes of tow slip are incorrect normality of part program to actual part surface or dirty rolling elements in the feed module.
- Several weeks of trials indicate a good correlation between existing laser vision inspection and the in-process inspection system.
- In-process inspection is real-time, with 100% of tow end inspection measured in parallel with layup and the data

FIGURE 9 Laser Vision Inspection and In-Process Inspection

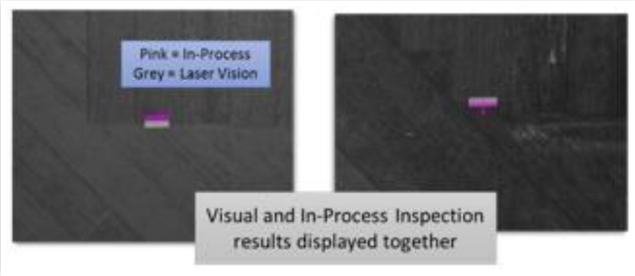


FIGURE 10 Correlation between independent inspection systems

FIGURE 11 This is a display from our Layup Image viewer. The Laser Vision images of the layup are arranged in part coordinate system. The tow end detection from our process based inspection system (RIPIT) is overlaid automatically and are represented by the pink horizontal lines. The ply boundary is also overlaid and is represented in the orange color.

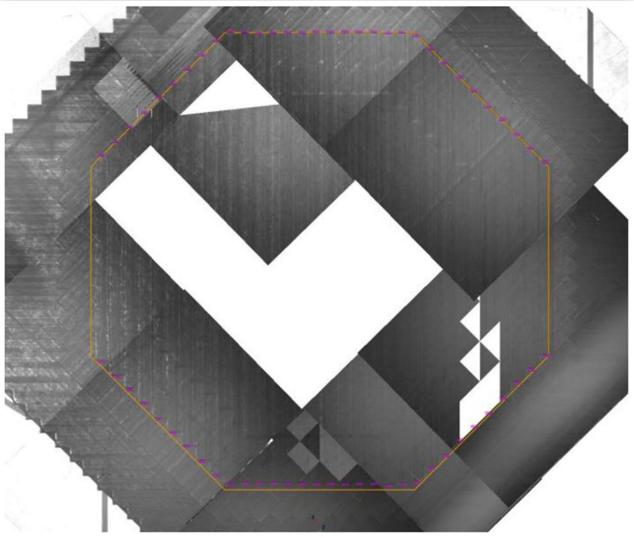


FIGURE 12 RIPIT tow end detection on adds.

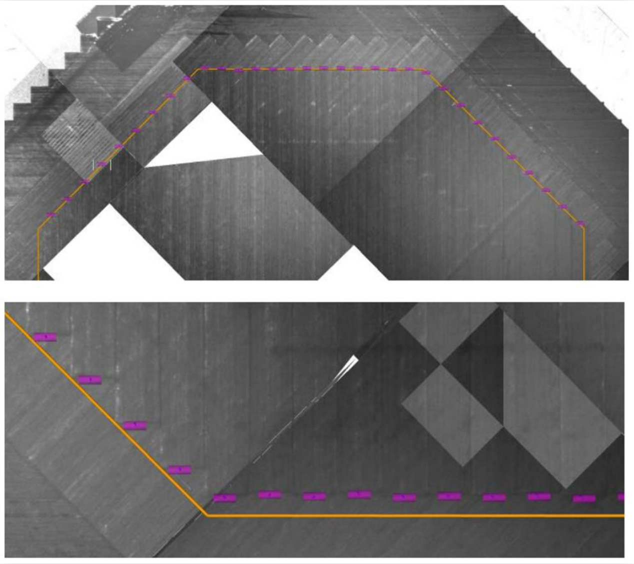


FIGURE 13 RIPIT tow end detection on cuts

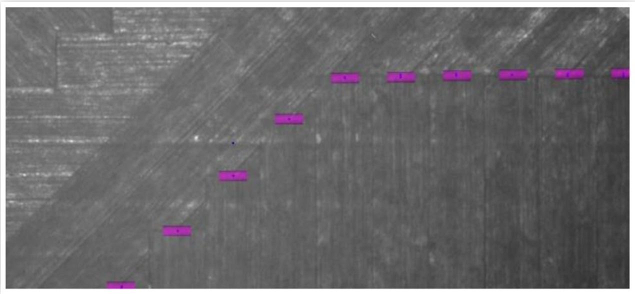
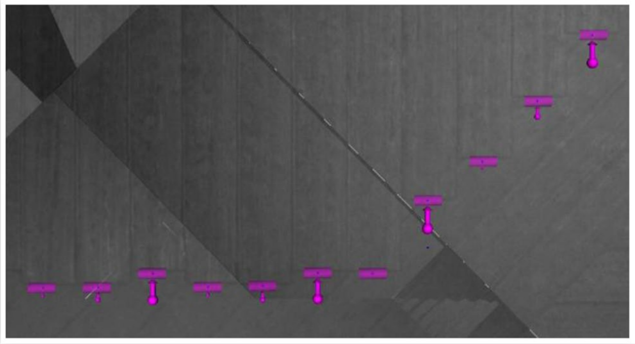


FIGURE 14 RIPIT detects not only tow location, but in the case of adds, can determine if the tow slipped during placement. The large bulb shows where the tow feed began and the cylinders represent the actual tow location. The difference (the arrow) depicts how much of the slip was a result of a tow slip. If tow slip persists, the system will notify the user that preventative maintenance is needed before the part falls out of spec. Also, note the blue dot in the image. This dot is where the visual based inspection thought it saw the tow. RIPIT has proven to be more reliable than the visual system at locating tows. RIPIT is not based on an image and not susceptible to being tricked by glare or other anomalies in the image.



is processed and available for the inspection interface before the beginning of the next course.

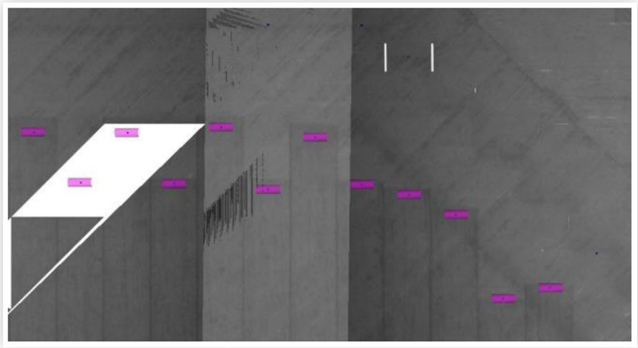
- Electroimpact is continuing to develop this system in concert with visual inspection to provide solid, verifiable performance.

Slipped Tow, Missing Tow, Tow Length Paid Out

Because of the stability of the servo-creel, we are able to capture tow feed anomalies. For instance, we can reliably catch a tow slip of >= .100”. Not only can we capture the event, we can predict the magnitude of the slip within about +/-.030”. Using the same circuit that measures the magnitude of the slip, we are also measuring the total amount of tow paid out. By knowing that the tow didn’t slip, or that it slipped <= a certain amount, we can be pretty confident that enough of the tow is actually on the part to meet engineering’s needs.

In addition to making our slipped tow detection accurate, we can use the same logic to predict the total amount of tow paid out by the AFP head.

FIGURE 15 In this case the system was setup with crazy parameters to cause massively early cuts. Even in this extreme case RIPIT is able to locate the tow ends and do so much more reliably than the visual system. The visual system thought it found four ends that simply do not exist (look for the blue dots, when you find them, you will see why the visual system thought it “saw” a tow end).



Servo Creel Based In Process Inspection Goals/Claims

Use the Servo-Creel Head and New Control Method to:

Detect Tow Slips > .050”

Detect Add Placement +/- .050”

Detect Cut Placement +/- .050”

Pathway to Real Time Inspection: Calibrate Probe -> Machine Axis Check -> Probe Part -> Tune Head

Increase Visibility for Management, Maintenance and Operators

Overview

EI is actively developing a data analysis tool, originally called the Data-Worm and now designated EI4.0, that generates and presents reports that will assist managers, operators, and maintenance personnel in maximizing layup utilization and efficiency.

The software offers a suite of features to empower employees at several levels of an organization to improve utilization. Operators receive real time feedback of build rates, pace, and reliability. Maintenance staff receives reliability data to help them identify problematic components. Part programmers receive build data to help them identify areas for programming improvement. Managers receive cell usage reports to help them decide how to manage resources to improve overall performance.

Management Visibility: Cell Usage Report

The Cell usage report in Figure 16 is created from 100% automatically collected data. It is passive and requires no human input. It does lack some granularity. However, we use this data to determine if a change we made works well or to predict the next system change we should make to improve our machines' performance.

An option to gain more granularity may prove to be worthwhile for some organizations. For them we have an option that requires parties with work to do in the machine cell use a form on the HMI to assign and accept cell custody when starting their work. This will allow the OEE software to provide reports on the average time per ply that the cell was in custody of each party at work in the cell. An example of the system behavior might be: an operator finishes a ply and the inspection data is ready, the operator releases himself from the system clock by tasking the quality person with buying off the part. The quality person would then accept responsibility (giving us a response time) and buy off the part. The quality person would then task the operator with starting the next sequence. The operator would accept the task, thus allowing us to calculate a response time. For persons not co-located with the cell, we have used pagers, cell phones, email and lights to indicate they have been assigned a task.

Another example of how we use this automatically collected data is in Figure 17. If a manager wanted to compare the performance of two shifts, the manager can make the following comparisons.

FIGURE 16 Cell Usage Report

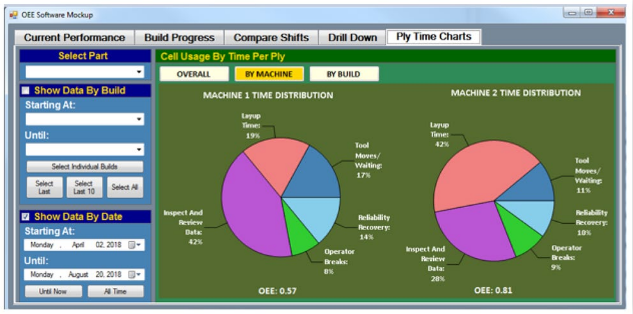
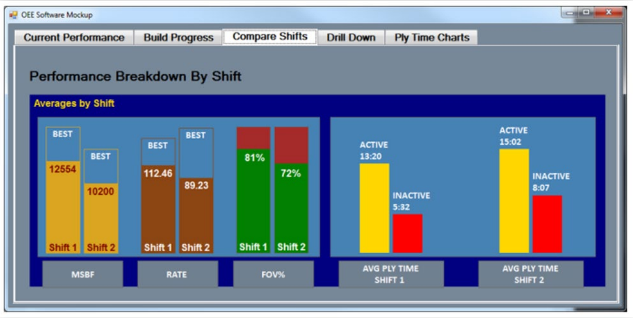


FIGURE 17 Shift Performance Report, MSBF - mean strips before failure, Rate - lbs./hr. for example, FOV% - feedrate override, AVG PLY TIME - shows both active and in-active time.

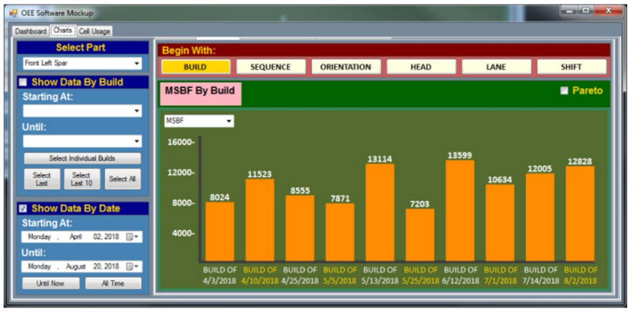


Maintenance Visibility: Machine Performance Charts

The OEE software reads machine logs and prepare charts summarizing the machine's performance. Navigating the data is simple, as the user can drill down through the data into increasing levels of specificity.

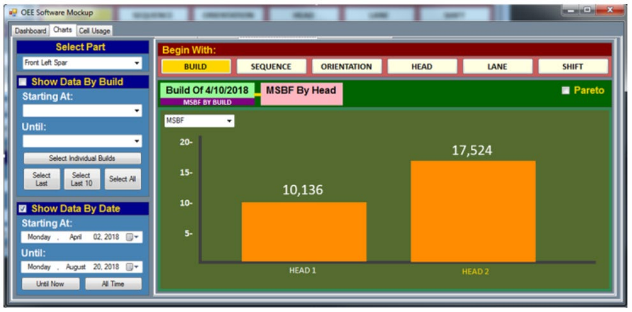
For example, in Figure 18, the user might begin by looking at MSBF over the last ten builds:

FIGURE 18 Mockup of Build Data Display, level 1



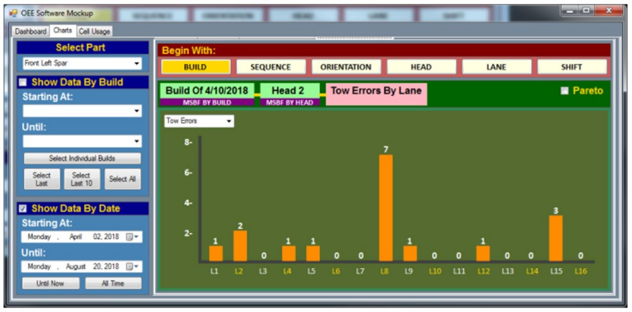
Clicking on the bar corresponding to a particular build would allow the user to choose a series of charts relevant to that build. The user might choose to look at MSBF per head for that build, seen in Figure 19:

FIGURE 19 Build Data Display, level 2



Then, the user might drill down further to look at tow errors for that build just on Head 2, seen in Figure 20:

FIGURE 20 Build Data Display, level 3. Here a maintenance person should deduce that something is askew with lane 8.

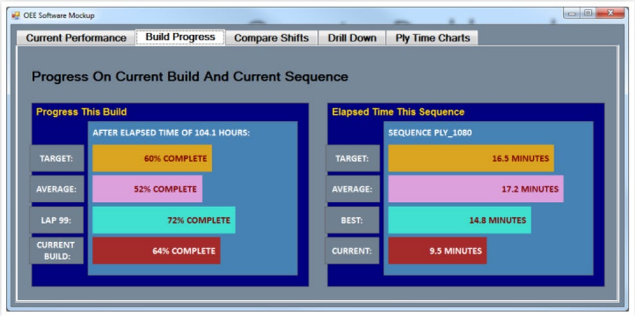


The range of data displayed in the current chart is stated in the chart title bar, with clear links showing the previous charts in the chain. The user can return to a previous chart by clicking that chart's box in the title bar.

Operator Visibility: In-Process Dashboard

Progress and performance in the current build can be viewed from the dashboard:

FIGURE 21 OEE Dashboard



Progress On Current Build And Current Sequence

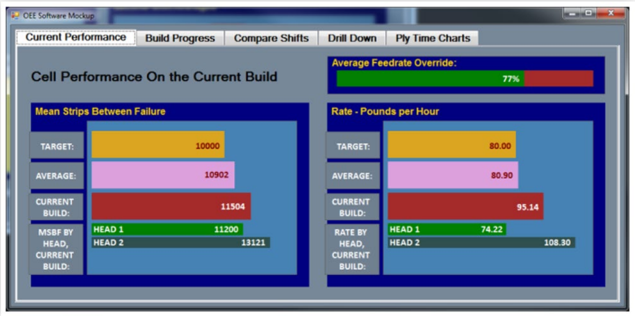
Progress This Build

AFTER ELAPSED TIME OF 104.1 HOURS:	
TARGET:	60% COMPLETE
AVERAGE:	52% COMPLETE
LAP 99:	72% COMPLETE
CURRENT BUILD:	64% COMPLETE

Elapsed Time This Sequence

SEQUENCE PLY_1080	
TARGET:	16.5 MINUTES
AVERAGE:	17.2 MINUTES
BEST:	14.8 MINUTES
CURRENT:	9.5 MINUTES

FIGURE 22 OEE Dashboard



Cell Performance On the Current Build

Average Feedrate Override: 77%

Mean Strips Between Failure

TARGET:	10000
AVERAGE:	10902
CURRENT BUILD:	11504
MSBF BY HEAD, CURRENT BUILD:	HEAD 1 11200 HEAD 2 13121

Rate - Pounds per Hour

TARGET:	80.00
AVERAGE:	80.90
CURRENT BUILD:	95.14
RATE BY HEAD, CURRENT BUILD:	HEAD 1 74.22 HEAD 2 108.30

Standardizing Head Readiness

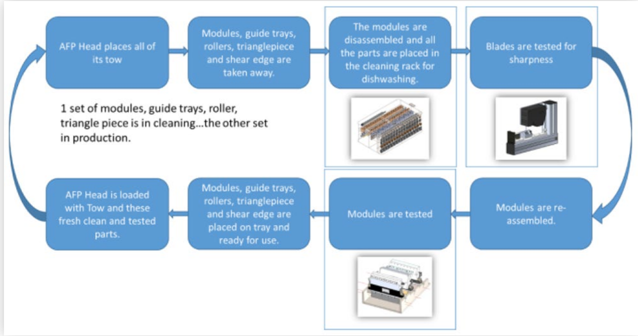
AFP Module Cycle

Our main goal for AFP equipment is to maintain an MSBF reliability in the production environment of 10,000:1. We will demonstrate this ability at Electroimpact by achieving 100,000:1 reliability. The AFP module cycle addresses a few problems that we noticed in the course of running our own prototype servo-creel head. The main problems this system will eliminate are: leaky valves, leaky or worn piston seals, dull blades and inconsistent cleaning.

To achieve extreme reliability EI prescribes the following AFP module cycle sequence:

1. Swap out head hardware at each material reload.
2. Dirty hardware is placed in a dishwasher for cleaning.
3. Cutting blades are tested for sharpness

FIGURE 23 Head Cleaning Workflow



4. Feed, cut, and clamp modules are functionaly tested prior to swapping onto the head.

This AFP module cycle and head cleaning workflow are shown in Figure 23.

Hot Swap Kit

The Hot Swap Kit consists of an additional set of the following items. These items go through the "AFP Module Cycle" described earlier.

Dishwasher

The dishwasher cleans modules and other hardware after a head change.

The workflow for cleaning hardware is as follows:

Once the AFP head has deposited its load of AFP, it is recalled to the maintenance area.

The modules, guide trays, triangle piece, and rollers are removed and placed in a cart.

Clean hardware is installed on the head.

Dirty hardware is further disassembled and placed on a custom dishwasher rack.

The rack is submerged into an ultrasonic tank. In the current implementation the tank uses a 10:1 water to Simple Green solution.

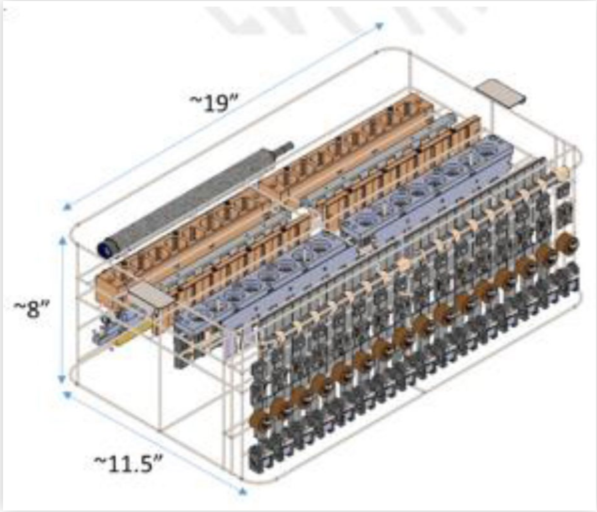
After the cleansing cycle, the rack is placed into a rinse and dry station.

Clean hardware is ready for testing at the Blade Test Station and Module Test Station.

TABLE 1 Hot Swap Kit.

Hot Swap Kit:
Feed, Cut, Clamp Modules
Guide Trays
Triangle Piece & Shear Edge
Add Rollers
Spring Plates
Clamp Rollers

FIGURE 24 Dishwasher rack with loaded hardware.



Blade Test Station

After cleaning, cut blades are tested in a blade test station, which measures the surface profile of the blades and determines whether they are suitable for reuse. The test clearly indicates whether the blades should be reused or thrown out.

Module Test Station

After cleaning and assembly, Feed, Cut, and Clamp modules will be tested at a module test station prior to be loaded on a production head.

FIGURE 25 Blade Test Station.

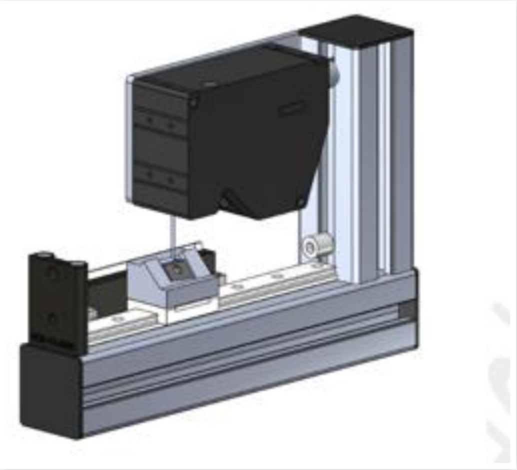
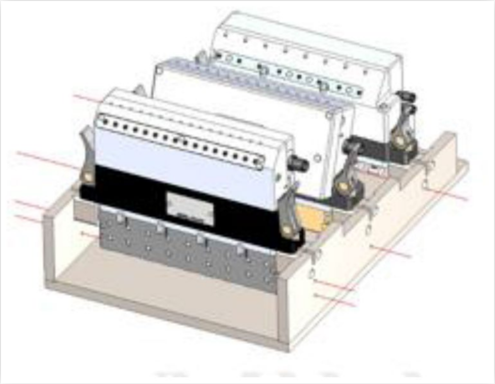


FIGURE 26 Module Test Station



The module tester actuates every valve and measures the actuation time.

From the actuation time we derive:

Mean actuation time for each actuator
Standard deviation of actuation time for each actuator

These are compared to a limit and, if the system exceeds the limit, a decision chart directs maintenance staff to quickly resolve the issue.

Once the modules all pass the test they are moved to the production area and are ready for installation when the next AFP had comes in dirty and ready for cleaning.

Conclusion

AFP (Automated Fiber Placement) machines used in aerospace manufacturing spend much of their existence doing nothing. The challenge for next generation AFP cells is to increase layup time as a percentage of total cell time.

AFP machine suppliers have an obligation to their current and future customers to increase utilization rates for these capital-intensive and space-intensive machine cells. We have already seen the first revolution in AFP; the next revolution is improving reliability, reducing the need for non-real-time inspection, increasing visibility for management into the process and standardizing machine readiness through process improvements in head readiness.

Our research and development is focused on improving the customer's machine utilization and we have made great progress. Further work is needed; further development and migration from experiments to production machinery will reduce costs and significantly improve utilization

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