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Improving AFP Cell Performance

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ABSTRACT

The Automated Fiber Placement (AFP) machine layup run time in large scale AFP layup cells consumes approximately 30% of the entire part build time. Consequentially, further reductions to the run time of the AFP machine part programs result in small improvements to the overall cycle time. This document discusses how Electroimpact's integrated system and cell design reduces the overall cycle time by reducing the time spent on non-machine processes.

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INTRODUCTION

Many different operations take place over the course of a part build. In order to increase the cell efficiency, all of these activities need to be understood. We compiled data from five recent part builds and analyzed this data to provide an image of what it takes to make a part. On average, each part is in the AFP cell for 3-4 days. Figure 1 shows where time is spent in the AFP cell during the production of the part.

From the data presented in Figure 1, we see that for this part, the machine only lays up approximately 30% of the time. The remaining time offers opportunities for improvements that can drastically increase overall efficiency and cell utilization. The right side of Figure 1 shows a representative gain from reduced tow errors and the subsequent improvement in repair time and inspection time.

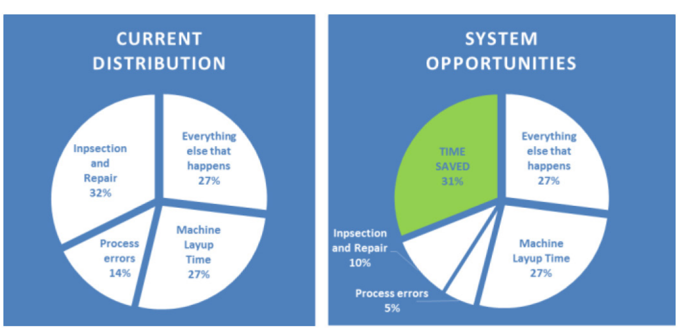

Figure 1. Time distribution During Part Build

Ways to Reduce Part Build Time for Process Errors

- Use appropriate speed for various ply geometries
- If an AFP head error occurs, do an AFP head swap
- Metric based head management system

Repair Time Reduction

- Less process errors mean less repair time (see above list)
- Show the repair person where the defects are

Inspection Time Reduction

- Less defects to inspect, see above two lists
- Boundary projections more accurate

The following sections describe improvements that were made for the second AFP cell (see Figure 2) and are in the process of being established elsewhere.

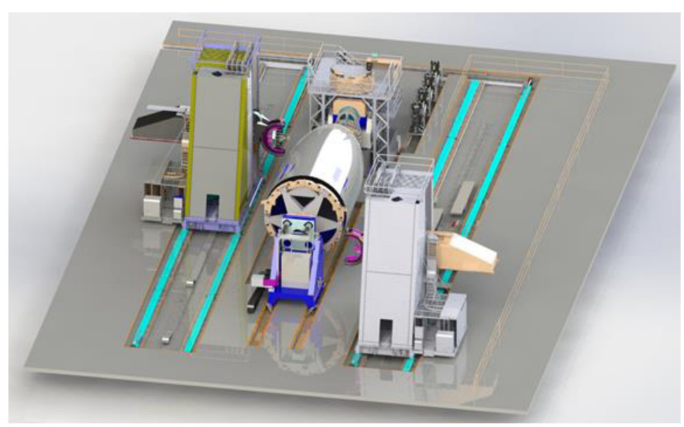

Figure 2. AFP Cell Utilized in Time Study

Process Error Recovery and Repairs

Process errors are a large contributor to the time in cell. They are also the most critical to solve because they add time in the following phases of the build:

- Process error recovery (unjam head, clean head, re-feed tow), 9 minutes/instance on average

- Repairs to the layup, approximately 15 min/instance
- Increase in the number of defects to inspect. The operators will likely always miss some percentage of the defects in the part. The more total defects, the more defects will be left when the inspector gets out there to do his job.

To illustrate the importance of this section, consider what is known today as a highly reliable AFP machine that regularly drops less than 60 tows in over 176,539 tow add events (approximately 1 failure in 3000 individual tow strips). If it takes on average 9 minutes to clear the AFP head this means that over 9 hours is dedicated to clearing the head during the part build. Considering that 9 hours is pretty close to all the work done by two shifts[1], eliminating these missed adds will reduce the overall floor-to-floor time by nearly two thirds of a day. On a 3 day build this is extremely significant. Remember that we have not yet accounted for the time required to actually make repairs to rectify the missed tow on the part. Let's assume that it takes 15 minutes to effect the repair on a missed or misplaced tow. For the case where there are 60 tow defects, that is 15 hours of repair. You can quickly see that it is easy to account for nearly 30% of the part cycle time simply by summing the process error recovery time and defect repair time.

The part builds in this study experience about 1 tow drop every 1.5 hours of part build time or approximately 30 minutes of machine run time. This is extremely in-frequent in the AFP world, yet the impact on AFP cell productivity is huge.

REDUCING STOPPED TOW CAUSED BY MINIMUM-PIECE/MINIMUM-GAP SITUATIONS GEOMETRY

Although the Electroimpact AFP head system is reliable even at very high speeds of adding and cutting, we realized from our study that the process experiences a higher frequency of stopped tows if we attempt to place tows at very high speeds during small gap and minimum piece operations (see Figure 3). In fact, on a recent visit to the customer's facility the operator told me that our process didn't drop tows in any other locations (we believe this to be an exaggeration, but the point was taken). Our improved post-processor features the ability to automatically examine the part program for minimum pieces and small gaps. By inserting appropriate feed-rates for these features, we are able to gain very high reliability on these difficult placement situations. Efficient use of machine/part program execution performance requires detailed understanding of machine performance (acceleration/deceleration characteristics, interpolation of motors and discrete outputs, etc) and intimate knowledge of how blocks are executed on the CNC. Since we write our own CNC executive, our engineers have the critical knowledge that is necessary to accomplish this.

1. After accounting for lunch, breaks, shift change, etc. and break in the natural work flow.

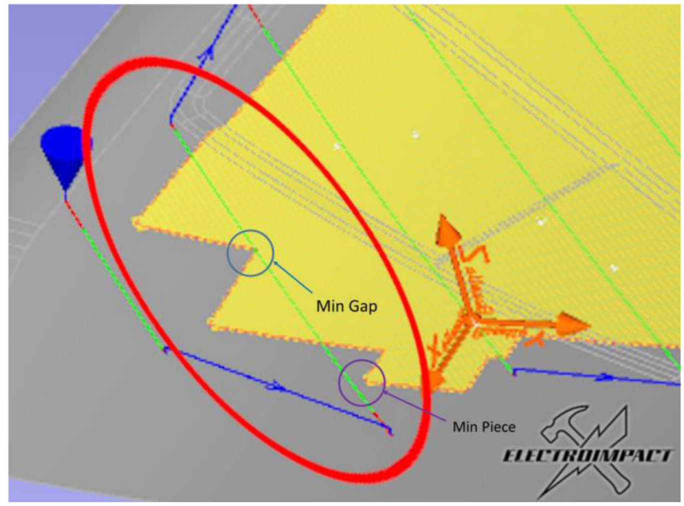

Figure 3. min gap and min piece in a layup. These occur regularly in 45 degree plys

DECREASING PROGRAM RUN TIME AND INCREASING RELIABILITY WITH FEED-RATE TOOL

Additionally, feed-rate affects stopped tow frequency and end-placement accuracy, as well as the floor-to-floor time. The two effects are in conflict with each other. The faster the machine feed-rate, the quicker the program runs. The faster the machine feed-rate, the more likely a tow placement defect will occur. Our machines are reliable and Boeing qualified up to 2000″/min for adds and cuts on-the-fly. However, we offer machines capable of feed-rates in excess of 3500″/min. On large volume AFP parts, we see no reason to not take advantage of these very high feed-rates. The feed-rate tool allows the customer to specify separate add/cut feed-rates and payout rates, for example, 1500″/min adds and payout rates of 3500″/min. This capability greatly reduces the number of stopped tows, missed placed tow ends and roller wraps because there is less transfer of resin to the feed system at these lower speeds, while decreasing overall program run-time because of the higher payout feed-rate. So to increase reliability, the machine uses lower speeds during the feed and cut event. The other benefit is that the machine is no longer limited by the add-on-the-fly speed during the entire laydown. This feature is new and currently being implemented in production.

OUR CURRENT RECOMMENDED FEEDS FOR LARGE VOLUME AFP AEROSTRUCTURES

When considering appropriate feed rates, we need to balance the impact to part program runtime, process reliability and machine performance. The values in Table 1 seem to work well.

Table 1.

Phase of layup	Value	Units
Add speed	1500	[in/min]
Cut speed	2000	[in/min]
Small gap speed	1200	[in/min]
Min piece speed	1000	[in/min]
Payout speed	3500	[in/min]

Even though the add speed, small gap speed, and min piece speed are lower than the capability of the equipment during qualification, the gain in payout speed and process reliability WAY more than makes up for this difference.

REDUCING STOPPED TOWS WITH METRIC BASED HEAD MANAGEMENT SYSTEM IN MAINTENANCE AREA

The following is under development for a recent AFP system order we received. A head management system which automatically displays in real time the number of sequences, part programs, and estimated run time the machine has remaining with the current head will further improve maintenance area operations. This information will help prevent the AFP head from running out of tow during a layup and minimize waste from under-utilized spools of tow. For all heads in in the AFP cell the following information will also be shown:

1. The time the head was last cleaned relative to the required cleaning interval to maximize head reliability.
2. Guide chute cleaning based on the number of tow add events that have occurred or by the amount of tow dispensed.
3. Number of cuts until cutters need to be serviced or replaced.
4. The amount of material on the head in each lane relative to the material required in each lane for upcoming part programs. Indicates minimum amount of run time until the critical lane will be depleted. This efficiently communicates to maintenance personnel when to change spools and when the head currently on the machine will need to be changed.

We plan to show this information on large displays mounted in the maintenance area. When considering a shift change the efficiency gained from this system is exemplified. Rather than operators communicating the status of all heads and what urgently needs to be done, this is automatically displayed on monitors for all heads.

A well cleaned head is almost 100% reliable if given reasonable feed-rate profiles.

REDUCING THE IMPACT OF INEVITABLE DEFECTS

Leverage Quick Change Modular AFP Heads When Tow Faults Occur

All Electroimpact AFP machines have modular AFP heads which allows off line tow error resolution and maintenance. For a head change in the study, the time from on-part laying tow to on-part laying tow with a different head is 2 minutes and 45 seconds. However, the time from on-part laying tow to on-part laying tow while fixing a tow error on the head takes an average of 9 minutes. Fully utilizing the quick change head ability minimizes time spent fixing tow errors when the machine should be running. For a savings of 6.25 minutes per event, if there are 60 events for a ship set, this saves about 6.25 hours per part build. The tow error can then be resolved with the head on a stand in the maintenance area while the machine continues to run. This head will then be ready when the next head change is required.

Repair of Known Tow Errors, Operator Interface

Although the Electroimpact AFP head system is uniquely reliable even at very high speeds of adding and cutting, there is still a small number of missed adds and feed roller wraps that will inevitably occur. Our control system is very good at catching most errors that occur during a layup, but due to the very large envelope of the twin aisle aerostructure parts we are producing it can be difficult for an operator to identify where exactly on the part these problems are. Our new control system provides a simple utility to project known errors on the part surface. This quickly guides the operator to the exact location of the error (see Figure 4 and Figure 5). This reduces repair time drastically as the exact location of an error is easy to locate.

Figure 4. Laser projection of course containing logged error or user specified course

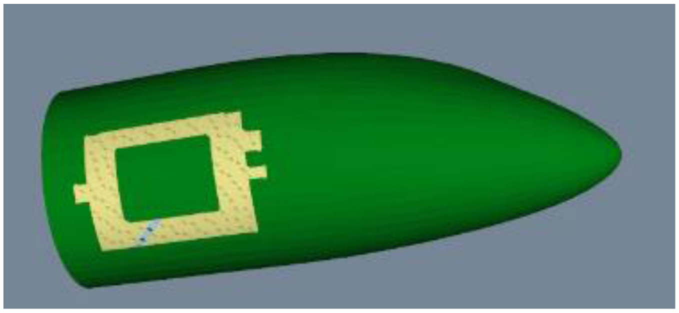

Figure 5. Operator display highlights course laser is projecting

INSPECTION

Inspection Ply Boundary Discrepancy for Barrel Systems

Repairs must be made where ply boundaries do not match the laser ply boundary and where process errors have occurred. Due to the size of the AFP cell, repairs take a long time to complete. Therefore, reductions in both the number of repairs that need to be made and the time needed to complete them help reduce the overall cycle time.

We noticed that the ply boundaries projected by the industry standard OLT systems did not match the ply boundaries of the part in all positions of the part, with errors of up to 0.3″. The single rigid body transform utilized by the OLT system could not account for the part-to-spindle mounting deviations that occur in reality.

The integrated laser system we use in the second cell uses a multi-rigid body transform that accounts for part-to-spindle location and spindle to machine location. It also accounts for select non-rigid body deflections at different rotation positions. This system was proven to reduce OLT ply boundary errors by a factor of five [1].

Elimination of Extra Interface

Typically in an AFP cell there is a stand-alone interface used for the OLT. Learning to use and operating this extra interface requires an overhead of time (see Figure 6). Our new system automatically loads the correct laser data files for the given sequence and the click of a single button shows the correct ply boundary inspection data. By making the transition from operating a machine to operating the inspection system seamless, there is no break in the work flow.

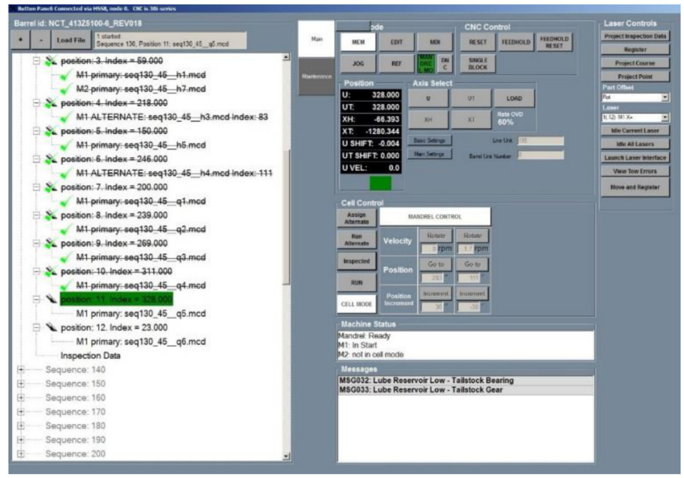

Figure 6. Part program sequence including inspection data in each sequence

Planned Laps/Gaps

Planned laps and gaps are frequently mistaken for errors rather than programmed features. An error in identification can cause down time as inspectors need to query NC programming to approve these laps and gaps. Our integrated laser system quickly and accurately displays NC programmed laps and gaps on the part eliminating the possibility that these planned features will be erroneously suspected of being actual errors.

The Future: In Process Inspection

The above inspection related technologies mentioned so far have been put into practice in several AFP cells around the world. Additional, automated, in-process technologies are currently in development and will be implemented in future Electroimpact AFP cells to further increase overall cell efficiency and quality. Although it would be appropriate to include with this paper, this technology will be presented in a future paper.

SUMMARY/CONCLUSIONS

Given the current distribution of time spent building large scale AFP aerostructures reductions in part program execution will have only marginal gains in productivity, all other things being equal. This is because so much of the time spent producing AFP aerostructures is spent doing other tasks. 46% of this time is spent conducting correcting process errors, repairs on the part due to process errors and during inspection. Reducing the chance of AFP defects (tow placement errors, add failures and untacked tows) by using a highly reliable feed-rate for particular ply-boundary geometries greatly reduces the number of automatically placed defects. Since these defects are part of an event cascade that includes time spent re-threading and cleaning the AFP head, time repairing defects and the instance of inspection failures it is easy to see how we can recover a huge percentage of the time in the part build process. For the cases where inevitable defects will occur, it is beneficial to project the defects directly onto the part so that little time is wasted searching for the defect. Because there are less defects, the operator will have fewer opportunities to leave a defect for an inspector to find. Lastly, using a single interface to choreograph the build of the part and inspection sequence makes the work flow smoother.

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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.

Tow - a single strip of carbon fiber. The system in the study features ½″ tow. There are 16 lines per head.

Layup - strips of tow placed on a part either by hand or machine.

Defect - any anomaly in a layup that must be repaired.

Repair - when an anomaly is present in a layup, the operator must remove the anomaly by removing the damaged section and replacing the section so that it will pass inspection.

Inspection - after completion of a layup, an independent person is dispatched to inspect the layup to ensure quality before another layer is added, covering up the layup just completed.

Process Error Recovery - during the AFP process occasionally the process fails. The act of resetting the equipment is the process error recovery.

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.

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.

Payout - the time where tow is being added to the part. This occurs between adds and cuts.

Feed-rate - the speed which the part program is executed by the AFP machine. Typically it is quoted in inches/min.

Post Processor - in this case where a computer program reads in a part program, examines it, makes decisions about feed-rate and outputs a new program to be consumed by the AFP machine.