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Automating AFP Tuning Using a Laser Sensor

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ABSTRACT

Electroimpact Automatic Fiber Placement (AFP) machines lay-up composite parts by accurately placing carbon fiber tow (strips of impregnated carbon fiber) on a mould. In order to achieve high accuracy at high speeds, the processes of feeding and cutting tows must be tuned. Historically, the tuning has been a time-consuming, manual process. This paper will present a methodology to replace manual measurements with an automated laser, improve measurement speed by an order of magnitude, improve accuracy from +/- 0.020" (manual) to +/- 0.015" (laser), and eliminate human error.

INTRODUCTION

Electroimpact AFP machines deliver carbon fiber tow from up to 16 different tow paths at speeds ranging from 5"/minute to 2000"/minute. Tow placement is influenced by mechanical variations between tow paths and surface speed. Tow tuning is a process of measuring variations and applying compensation to minimize tow placement error.

In the past, tuning has been accomplished by placing test patches on a tuning plate and using a digital micrometer to manually measure the placement of the beginning and end of each tow. This process typically involves 114 individual measurements, which is time consuming, and it adds variation due to human error.

Electroimpact has developed and implemented a methodology to replace manual tow tuning with automated laser tow tuning in order to reduce AFP machine down time and improve tow placement accuracy.

METHODS

TEST SETUP

Carbon fiber tow is placed on a part by an Electroimpact AFP machine. The AFP machine is a 6 axis machine controlled by a CNC. As an end effecter, the AFP has an Electroimpact Tapehead. The Tapehead is a self-contained tow delivery system that holds 16 spools of carbon fiber tow, which it feeds and cuts upon command. Each of the 16 tows is independently controlled, and the end placement targets are commanded by a part program. The tows are delivered to the part side-by-side such that a single pass of the machine can lay down a swath 16 tows wide.

Tow tuning is a process by which the beginning and end placement of each of the 16 tows is compensated to account process variations. The AFP machine places several patches of tows at various federates within the machine's working envelope, up to 2000 inches per minute. The tows are then measured to determine the error between the beginning and end placements and their respective targets. Each tuning patch is rectangular in shape, with a base 16 tows wide and a commanded length of 11.0 inches. Figure 1 shows 4 test patches placed side-by-side. A full set of measurement data includes the 3 sets of feed data and 4 sets of cut data, with each set composed of 16 tows. In addition, we measure 2 gaps between courses for a total of 114 measurements.

Figure 1 – Four test patches of carbon fiber tow. Each is 16 tows wide.

To measure tow placement data we use a single off-the-shelf laser sensor.

The sensor is wired into a PLC that communicates with the CNC that controls the motion of the AFP machine. In order to align laser data with machine position, the machine moves at a constant 100 inches per minute as it scans the laser across the tow edges. The PLC collects the laser measurement for each tow. When all of the data is collected the tow placement measurements are automatically input into an empirical model to adjust the timing of the feed and cut commands for each tow in order to make each tow land accurately at the target independent of the surface speed.

The laser sensor offers some advantages over a high resolution optical camera. Raw laser data is output from the unit and has a simple correlation to the intensity of reflected light. This leads to simple and straightforward calculation of tow position and provides full visibility of the data and calculation sequence. The simple solution offers few opportunities for errors, and enables straightforward automatic error detection.

The low cost of the sensor allows Electroimpact to permanently mount 1 sensor per each modular AFP head. It is mounted to the side of and slightly behind the roller so as to be close to the toolpoint without requiring any mechanical swapping between adding tow and laser measurement. There is no extra process time for setting up the laser measurement, and measurements can be run at any time between layers of a part build without swapping heads or taking time to setup or locate a camera. Beyond the laser measurement time (reported in Metrics) auto-tow tuning between part layers only adds the time it takes the machine to move to and from the tuning plate.

TUNING PROCEDURE

Before tow tuning, the laser is calibrated. The calibration procedure determines the laser's location and determines the translation from laser signal into tow position.

The tuning procedure begins by placing multiple courses of 16 tows. Next, the AFP machine moves the laser to scan the beginnings (feeds) and ends (cuts) of each course. The position of each tow is recorded and compared to the tow target. The error is then input into the empirical tuning model to update the tow compensation values.

Additional courses are placed and measured to verify the results. If tow placement needs additional tuning the process is repeated. The decision to repeat tuning is made by the machine operator. In addition, the tuning procedure notifies the operator if tow end placement variation violates an acceptable threshold.

RESULTS

EVALUATION OF ACCURACY

To evaluate the accuracy of laser measurements, tow end placement is independently measured using a loupe, which is an optical magnifying glass marked with units of length in increments of 0.005". Loupe measurements are the standard against which both the laser measurements and caliper measurements are evaluated. Loupe measurements are used only for initial development and evaluation of the laser auto-tune procedure, and they are not a part of the deployed solution.

METRICS

Figure 2 shows the manual caliper measurement error of 30 tow measurements. The error for this sample is bounded within +/- 0.020 inches. The standard deviation is 0.007, which suggests a 6σ error of +/-0.021 inches.

Figure 3 shows the laser measurement error of 30 tow measurements. The error for this sample is bounded within +/- 0.010 inches. The standard deviation is 0.005 inches, which suggests a 6σ error of +/-0.015 inches.

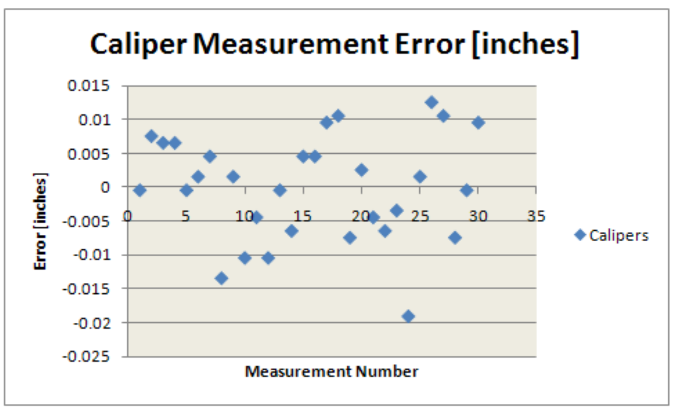

Figure 2 – Manual Caliper Measured Error for 30 samples.

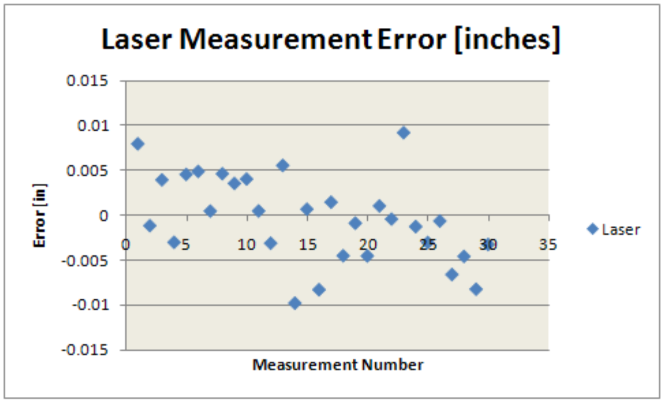

Figure 3 – Automated Laser Measured Error for 30 samples.

To obtain the 114 measurements needed for complete tuning, manual caliper measurement takes approximately 25 minutes. In contrast to this, the automated laser measurement takes only 2 minutes. In addition to the time disadvantage, manual measurement can be tedious, occupy 2 human operators, and it is vulnerable to data misalignments that can add gross error to multiple measurements. In a production cell that operates 24 hours a day, the time savings and ease of use gained by automatic measurement translates into significant cost savings.

Table 1 summarizes the time and accuracy results for manual vs. automated laser measurement techniques.

Table 1 – Manual vs. Automated Measurement Results

Manual Measurement Error	+/- 0.020 inches
Manual Standard Deviation	0.007 inches
Manual Measurement Time	25 minutes
Laser Measurement Error	+/- 0.010 inches
Laser Standard Deviation	0.005 inches
Laser Measurement Time	2 minutes

SUMMARY/CONCLUSIONS

The automated laser measurement method presents a distinct advantage over historical methods of measuring tow placement manually. The laser improves accuracy by 25% or more, achieving tow measurement error better than +/- 0.015 inches. Furthermore, the laser reduces measurement time from 25 minutes to 2 minutes, resulting in reduction in costly machine down-time.

The human operator is removed from measurement, which eliminates inconsistencies between operators and prevents outlying data caused by operator error. Unacceptable tuning performance is automatically detected by laser verification. In addition, the time savings and ease of use encourages more frequent tow tuning, which leads to more consistent parts.

Automated laser tow tuning is faster and more reliable than manual tow tuning, and it improves part accuracy and consistency.

CONTACT INFORMATION

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DEFINITIONS/ABBREVIATIONS

AFP	Automatic Fiber Placement
Tapehead	Modular end effecter that acts as creel and fiber delivery system
Tow	A single strip of carbon fiber
Course	A single pass of 1-16 tows