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Incorporation of Laser Projectors in Machine Cell Controller Reduces Ply Boundary Inspection Time, On-Part Course Identification and Part Probing

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ABSTRACT

Incorporation of laser projectors in AFP machine cell controller reduces ply boundary inspection time, on-part course identification and part probing.

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INTRODUCTION

The entire process of AFP on large complex structures continues to leave large opportunities for improved efficiency. The focus of this paper is to identify three things that we decided to focus our efforts on in the past year:

1. Laser Projection for ply boundary verification
2. Course projection to aid the operator in identifying individual courses on the part.
3. Part probing.

All three of these items are addressed by tightly integrating our machine cell control and machine interface with the functionality provided by laser projectors.

BODY

Accurate laser projection for inspection applications

Laser projectors offer the possibility for efficient visual inspection of ply boundaries on complex composite parts. However, to project accurately on very large structures that move, the nuances of the device and the production cell need to be understood and accounted for.

The laser projector is a 2 degree-of-freedom device, but it can be used to project on a three-dimensional surface. In order to project accurately on a complex surface, the projector's relationship to the tool surface must be precisely known. Error is introduced into the projection when there is a discrepancy between the actual surface location and the nominal surface. This error increases linearly with the tangent of the angle of incidence of the laser on the surface.

To locate itself, the laser projector scans multiple retro-reflective targets that are valued in a known coordinate system. For simple setups, such as for parts made in a stationary mold, the entire part is always visible to the projector(s) and the targets can be placed directly on the surface of the part or the tooling. This works reliably to establish the location of the laser projector. However for more complex setups, such as large composite parts made on a rotating mandrel, establishing the relationship between the laser projector and the part becomes more difficult.

Current system

In a current production cell, the laser projectors can only project on a small portion of the barrel at a given rotator position. In total, twelve rotator positions, each with its own projection files, are required in order to inspect all 360 degrees of a barrel. Two laser projectors are utilized together and split the projections into their respective zones. With two projectors, the incidence angle still exceeds 45 degrees at regions of high curvature toward the nose of the part.

The projectors locate themselves by shooting into retro-reflective targets located on the edges of the rotators and at an intermediate point on the mandrel. These locations are valued in the part coordinate system, meaning the projectors are "bucked in" to airplane coordinates.

However, when the part rotates to additional inspection positions, the laser projectors are not bucked into the part. To account for this, the projection files in the additional rotations undergo a single rigid body transformation of the appropriate amount in degrees about the nominal rotator axis. This same type of transformation is applied to the additional inspection positions. This creates a “stacked” version of the projection files so that they occupy the correct region of space that is visible to the projectors associated with the assumed location of the mandrel in each of the 12 inspection positions. Unfortunately, this method for stacking the projection files does not reflect how the mandrel actually responds as it is rotated.

Electroimpact improvements

In reality, the loading of the mandrel is not consistent unit to unit nor is it consistent even between loadings of the same unit. Electroimpact's part probing process accounts for three things:

1. Location of part on the spin axis.
2. Location of spin axis in the FRC.
3. Motion of the part as it is rotated.

The part probing sequence is completed each time a new barrel is loaded in the rotators. It records tooling positions on the barrel in FRS coordinates and the mandrel's location; several of these tooling locations are measured in two different mandrel positions. Electroimpact's Barrel Transformer software uses this data to create the multi-rigid body transform (described above) between airplane and FRS coordinates. Each time a new barrel is loaded in the AFP cell, this process creates the transform that the machine uses to locate the part in the cell and perform lay-ups in the correct position. The part program commanded positions are transformed on-the-fly as they are executed on the control. Using only a single rigid body transform yields an overall fit of the probed points of .154″. While calculating a transform using Electroimpact's multi-rigid-body system yields a fit of .041″.

In the new cell that EI is designing, the laser inspection system will be integrated with the cell control and will take advantage of the multi-rigid body transform. Now, the laser projector's relative position is not dependent on the mandrel in the rotator, instead it is bucked into the FRC similar to the machine. In a test run on April 6, 2012 the following improvements were recorded on an actual part:

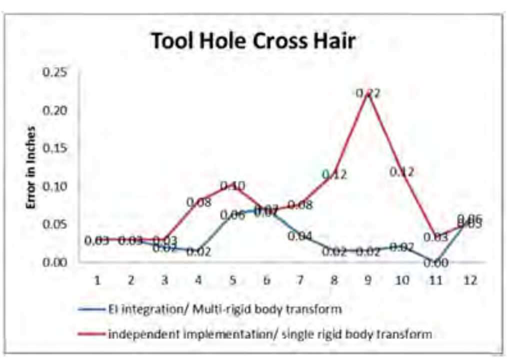

Figure 1. The above data shows the measured deviation of the projected cross-hair to the center of the hard tooling-hole location. This is largely in-line with our expectations based on the data gathered during probing.

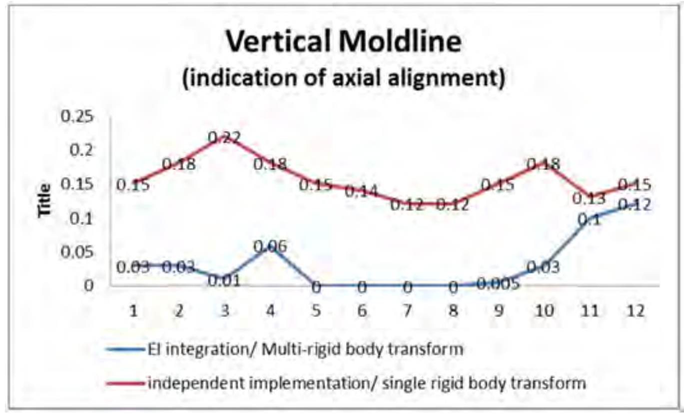

Figure 2. The above data shows the measured deviation of a mostly vertical (actually circumferential) line projected on a matching machined line on the part surface. This is an indication of the axial alignment of the laser projection to the mandrel.

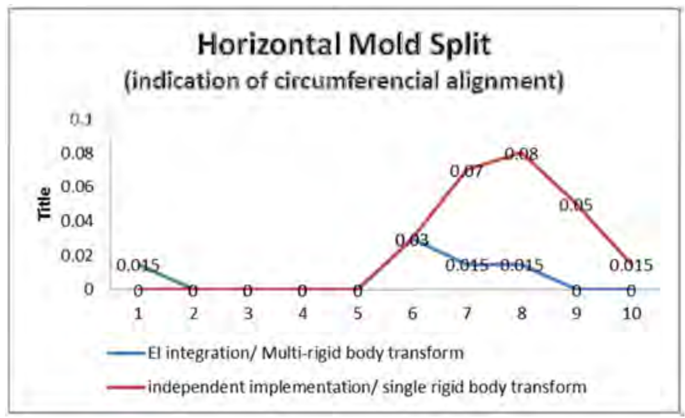

Figure 3. The above chart shows the circumferential alignment with the mandrel mold lines.

It is clear that utilizing Electroimpact's multi-rigid-body transform to transform projection data into the FRC and registering the laser projector in the FRC results in much more accurate projections. These projections better represent the design intent for this part. This improvement will greatly reduce the number of “repairs” required due to layup misalignment with projection alignment.

In addition to having a better method for locating the projection surface, four laser projectors will be implemented into the cell. This will keep the incidence below 30 degrees and will further limit error in the projections.

Instead of shooting into retro reflective targets on the surface, the projectors will locate themselves by shooting into portable target stands. Because these fiducials are not located on the projection surface, special attention needs to be paid to placing these portable stands, so that an accurate projection will be maintained.

Fiducial placement

A reliable fiducial placement process was developed by testing many setups. The process that works best is as follows. 3 portable stands are required, with each stand containing 2 nests for targets. The stands should be positioned as near to the projection surface as possible, in such a way as to capture the full envelope of the surface that will be projected on. The specific example for EI's new cell is illustrated below.

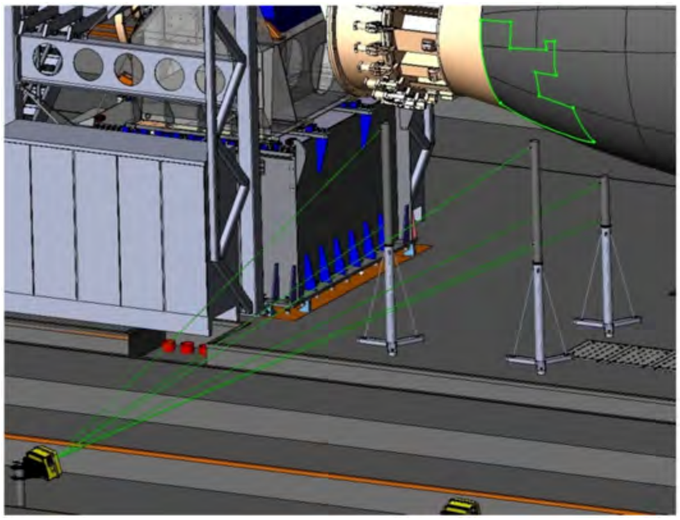

Figure 4. Laser Fiducial Stands used for locating the projector

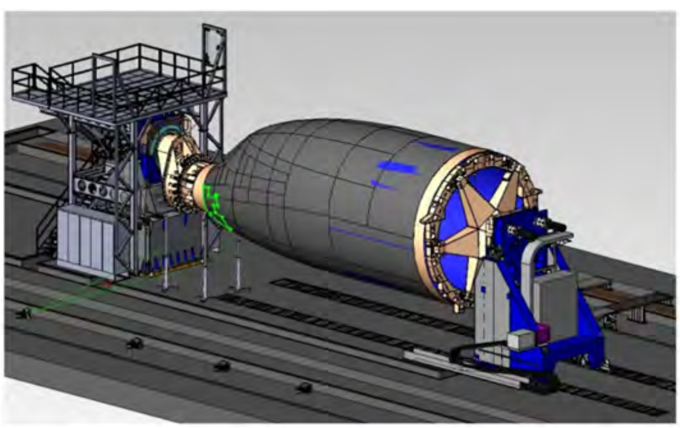

Figure 5. New EI-Cell Shoot-in Overview

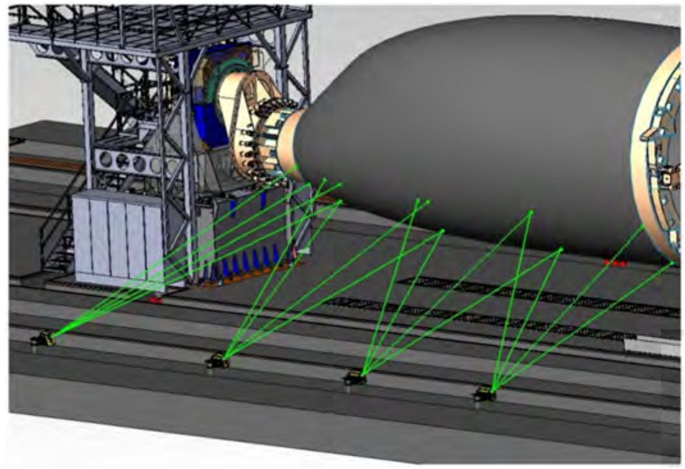

Figure 6. Total Projection Overview

Two fiducial stands, approximately 10′ tall, are positioned in front of the projection surface. On each stand, the two target nests are positioned in a vertical line. The laser projector has two galvanometers that control the angle that the beam exits the projector. One galvanometer controls the vertical angle and the other controls the horizontal angle. The vertical distance between targets encompasses the vertical angular range that the projector will actually utilize when projecting on the surface. The horizontal distance between the two tall fiducial stands encompasses the horizontal angular range that will be utilized when projecting on the surface. These tall stands are positioned as close to the projection surface as safely possible. The third stand is approximately 6′ tall and fits underneath the mandrel. It is positioned behind the projection surface to add depth to the locating algorithm. These fiducial locations create a three dimensional angular and depth envelope that encompasses the projection surface.

In this application, the retro-reflective target locations will be valued using a laser tracker. The same three stands can be moved and repositioned to locate each of the four laser projectors in the cell. Because the projectors maintain their position in the FRS, they will only need to be shot-in every 90 days.

Projecting a Point

A single point can be projected using the Electroimpact UI. This provides an interface to input a point's XYZ coordinates and coordinate system, which then get converted to the system the laser projector is registered to. The software behind the UI reads the point, converts the coordinates, and generates an “X” on the point in the desired coordinate frame. The 2 lines that describe the “X” are sent to a projector file, which is then loaded onto the projector to display the “X”.

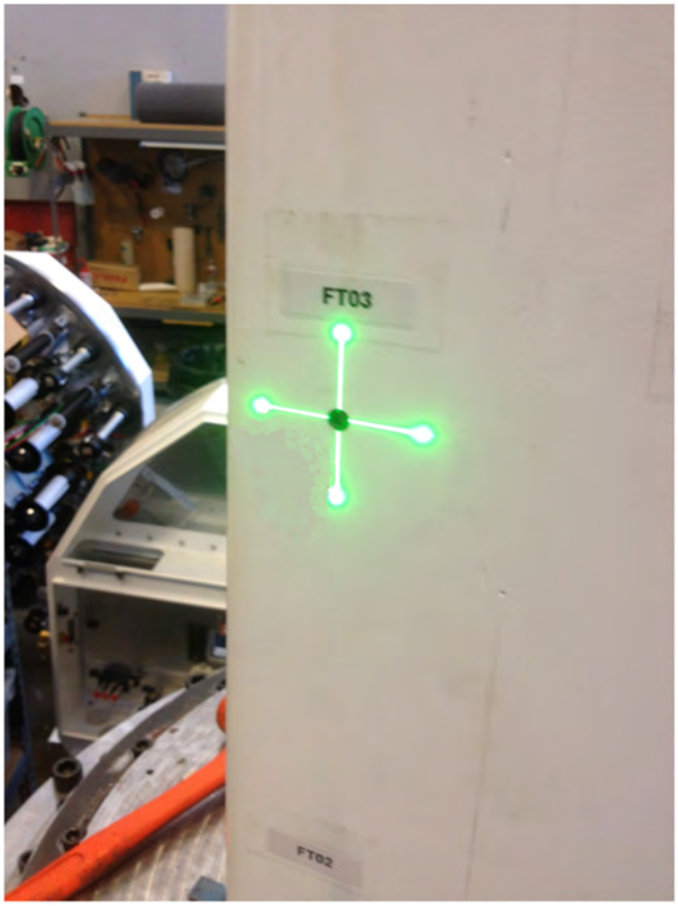

Figure 7. Projecting a Point

Projecting a Course

Part inspectors and machine operators often need to inspect an individual course or determine to which course misplaced tows belong. Locating a single course on an all-black AFP part can be difficult, confusing, and time consuming.

Electroimpact has developed a software interface to project individual courses within a part program. To do so, the operator selects a course in the Electroimpact UI and clicks on the “project course” button.

EI software reads the part program and isolates the desired course, which gets processed and exported to a file the laser projector can use. If the course is programmed for a mandrel, then the course is rotated to locate the course at the current mandrel position. The file is trimmed to contain only points visible to the projector. The projector is then automatically commanded to project the course. The end result is a sequence of line segments that run down the center of the course on the part.

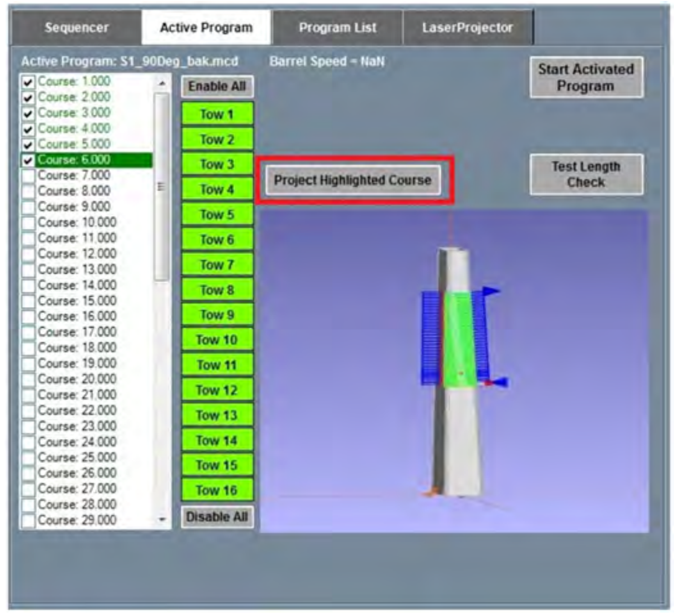

Figure 8. Electroimpact Part Program Display

In addition to projecting the centerline, EI software can optionally project the course outline.

One limitation of the course projection is that the update process is not fast enough to track a spinning mandrel in real time. As the mandrel spins the updating projection lags in time, but will align properly when the mandrel stops.

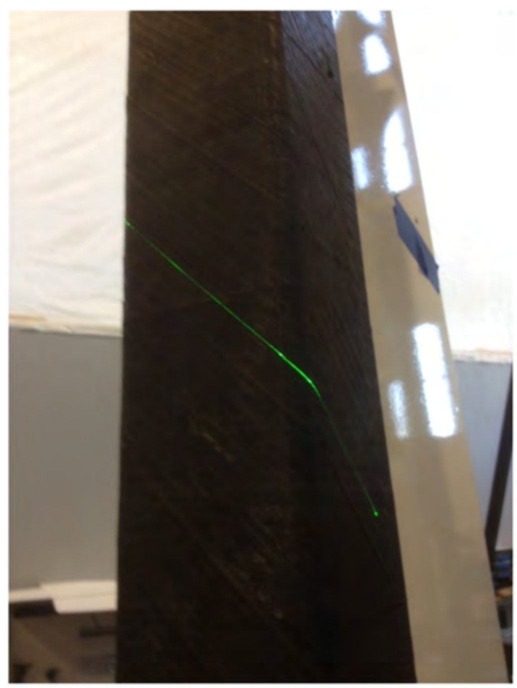

Figure 9. Course Projection on a Part

Part Probing

Electroimpact offers Part probing with a Renishaw touch probe. This system is used in all forms of our part transformations, whether it is a single 6 degree of freedom (6DOF) rigid body transformation or the more in depth barrel transforming system described earlier. For all Electroimpact systems, the exact tool location is not important as the Electroimpact control offers a true 6 axis tool tip programming interface. Probing with the Renishaw touch probe has proven to be a reliable way to get tooling datum values in the machining envelope and calculate transforms from tool space into machine space. However, the machine must pick up a touch probe and engage a part whose position is necessarily well known. This requires the operator to be careful during the process and pay close attention to the machine as it engages the part's tooling datums; which takes time. The result is that the number of points probed are minimized which reduces our ability to characterize the part's location.

Using an Assembly Guidance Long Throw laser projector system, we are able to collect data on individual points using a wide scan size and do so very quickly. This mitigates the risk of engaging a part of unknown location and the time it takes to find the tooling datums by allowing us to probe tooling datums with a touchless laser with a wide scan window and do it very quickly. Now for very large structures we are able to collect more data since there isn't a time penalty for doing so. For very large structures there are on the order of 50 tooling datums. Instead of collecting information on only a few of these, we now intend to collect positional data on all of them, greatly increasing our ability to characterize the part's location as it is moved rotated.

As we all know a laser projector is a 2D device that is used to draw lines on parts in 3D. The laser projector does this by assuming it knows the location of the part's surface and directing a ray to strike the surface at a certain point along the ray. Fairly accurate projections are achieved using this process; the typical claim is .015″ at 15′ although better results have been documented by ASG.

Since the device is able to register on a tool and project parts accurately, it is easy for one to assume there must be a way to use this same hardware to collect information about a retro-reflector in space and calculate its position.

It turns out that this assumption is true. By recording the mirror angles of the center of mass of a retro-reflector and doing so from more than one perspective, the 3D location of the point can be calculated. Although our system is still in the prototype stage, we have taken a significant amount of data and have proven to ourselves that we can value points in space to an accuracy of .030″ TIR as long as the point is within 15′ of the projector. This is roughly double the error we expect and we expect with some effort our ability to value points in space will eventually reduce to the .015″ TIR we predict.

However, for the very large structures we are considering even the .030″ TIR is acceptable since a fit of 50 or more points taken from multiple perspectives with an average .030″ TIR is more desirable than 12 points with a .005″ TIR. When .030″ TIR does not provide enough resolution to manufacture the part, we intend to use this process to locate a tool well enough so that touch probing with the renishaw touch probe is not a risky process.

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