Automation1 & Laser Scan Head Material Processing

The Benefits of Controlling a Laser Scan Head and Servo Stages from a Single Motion Controller

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Many laser machine builders are experienced in building systems that incorporate both laser scan heads and direct- or screw-driven servo stages. In most cases, the laser-material interaction drives component selections and process control approaches. For example, a laser scan head is often selected based on process throughput considerations. However, laser scan heads typically use f-theta optics that affect beam quality - and therefore part quality and process performance - the farther from the center of the optic the beam is commanded. This throughput versus quality consideration lives under the broader envelope of applying laser energy to the surface when and where the user desires.

Fortunately for machine builders, there is a way to manage these tradeoffs and build a machine that optimizes process throughput while maintaining part quality: Aerotech's high-performance laser scan heads and controls, which use a single controller for scan head and servo motion control and offer controller features for precision process control.

High-Performance Laser Scan Heads and Controls

AGV-XPO High-Dynamic Laser Scan Heads are Aerotech's highest performance laser scan heads. These two-axis laser scan heads help to minimize the tradeoff between speed and precision. Their low-inertia, high-efficiency motors enable rapid acceleration profiles, while ultra-high resolution position feedback and optimized structural dynamics provide excellent part-profile tracking with minimal following error. As shown in Figure 1, AGV-XPO products provide an order of magnitude improvement to in-position jitter when compared to Aerotech's own AGV-HP 2D scan head - a specification that translates to improved tracking capabilities.

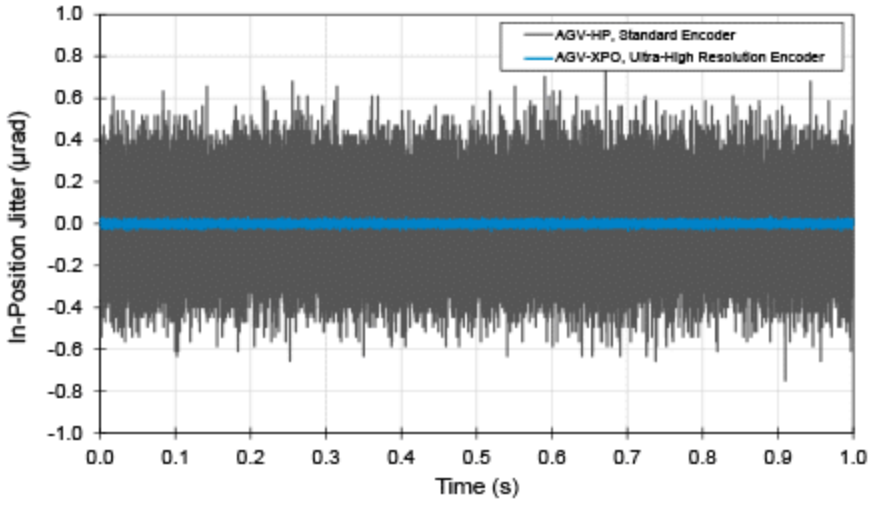

Figure 1. Ultra-high resolution feedback (-E2 option) provides the lowest noise levels for applications that require extremely fine trajectory accuracy or utilize long effective focal length optics.

These results come from pairing the AGV-XPO with Aerotech's Automation1 motion control platform. The AGV-XPO's control architecture is unique in that the amplifiers and servo control loops are not contained in the laser scan head. Instead, they are located remotely in the Automation1 GL4 Galvo Laser Scan Head Linear Drive. This architecture improves system performance in ways traditional scan heads with integrated controls cannot match. Removing the electronic heat source from the scan head ensures consistent performance over time - a must for any production material processing application. The GL4 uses linear amplifiers, which are the highest performance amplifier technology for driving galvanometric motors and provide improved velocity control and position stability (versus standard pulse width modulated (PWM) amplifier technology). See Figure 2.

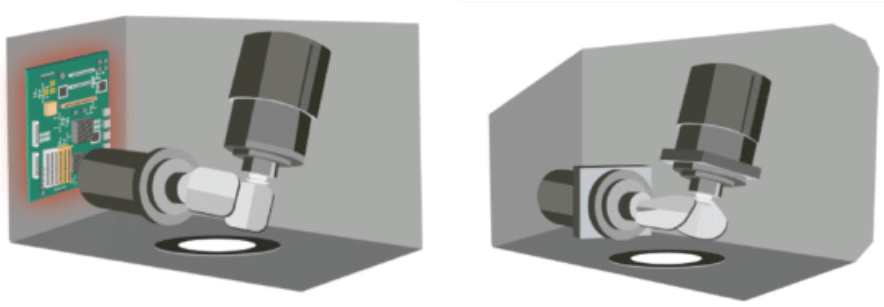

Figure 2. Many laser scan heads place the heat-dissipating electronics in close proximity to the scanner mechanics, which introduces thermal stability issues. Aerotech's AGV laser scan heads remove the heat dissipating electronics and place them in the control cabinet - enabling higher performance and decreasing thermal drift.

A Single Controller for Scan Head and Servo Motion Control

The Automation1 iSMC Intelligent Software-Based Motion Controller is a central motion engine capable of generating a single stream of motion control positions over the HyperWire® Motion Control Communication Bus to Automation1 laser scan head and servo motor drive electronics. The HyperWire bus runs at 2 gigabits per second (Gbps) with a position update rate of 100 kHz. The Automation-iSMC controller can generate and communicate 100,000 position command points per second for the laser scan head axes and 20,000 position command points per second for the servo axes. Over HyperWire, the Automation1-GL4 receives the 100 kHz stream of points and interpolates the number of points to 200 kHz for use in the 200 kHz two-axis laser scan head servo controller. A variety of Automation1 servo motor drives can be used, and each receives the 20 kHz stream of position command points over HyperWire and uses them directly in the drive's servo control loop. The trajectory points are 64-bit double-precision floating point values, and the drive-to-drive jitter is capable of being < 1 nanosecond even after adding 16 total axes on a single HyperWire port. Simply put, no superior motion control technology exists for coordinating the motion of precision laser scan heads and servo axes. Using a single controller drives the highest performance coordination of laser scan heads with servo axes for the most demanding laser processing applications. Aerotech's Automation1 controller platform is unique in that it enables not only a single configuration and programming environment for scan heads and servo axes, but it also enables higher performing systems due to some of the unique controller features addressed in the next section.

Controller Features for Precision Process Control

Automation1 has several controller features for those building precision laser material processing machines. A prime example is the Automation1 Studio application's Machine Setup wizard. As demonstrated in Figure 3, the Machine Setup wizard lets a user set up real-world electrical and mechanical devices and then interconnect these devices to form real axes of motion.

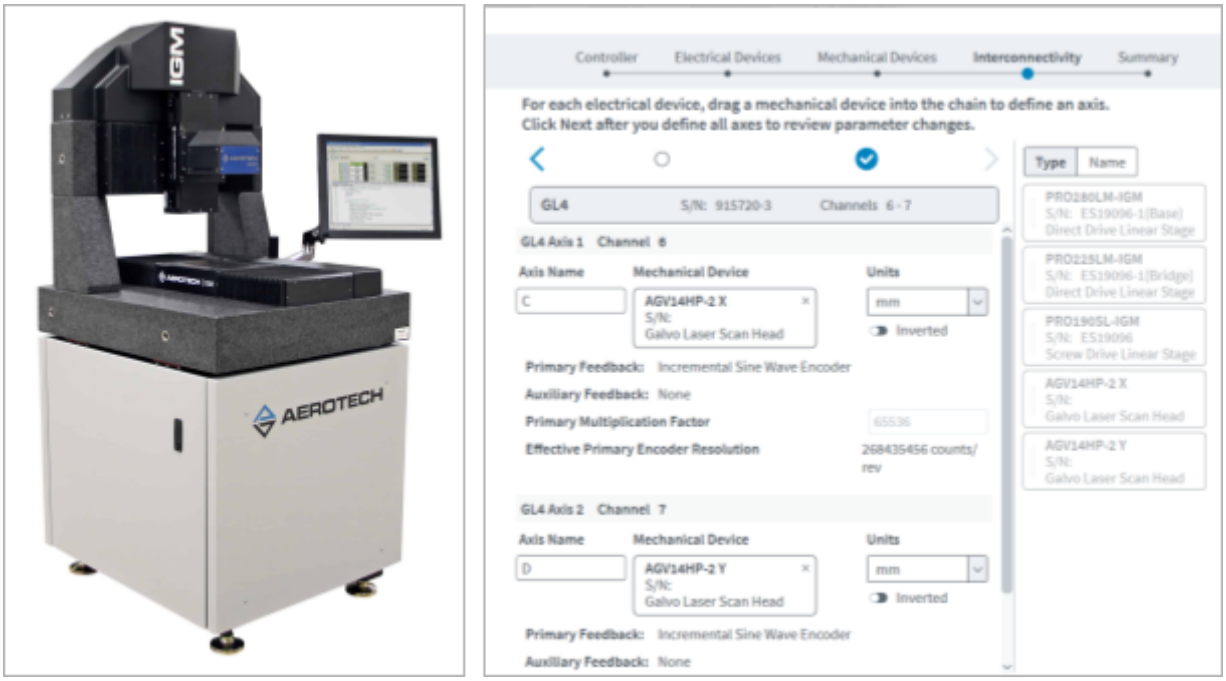

Figure 3. This example system, the Aerotech IGM with AGV-HP laser scan head, is configured in the Automation1 Studio's Machine Setup Wizard.

Factory optimization for the laser scan head is sufficient because laser scan head axes have a constant inertia (the scanner mirrors). However, many machine builders are placing custom loads on the servo axes, which often demands further optimization. Automation1 provides extensive encoder feedback tuning and servo tuning tools for optimizing these axes' performance.

Once axes are optimized at the servo control level, the commanded positions may not result in actual motion that achieves the desired position targets. This is a common issue resulting from optical distortion in laser scan heads and manufacturing tolerance-driven errors in optical feedback devices used to control both laser scan head and servo axes of motion. As long as the errors are repeatable, the solution to this problem is error mapping.

Both 1D and 2D calibration tables - based on error mapping - can be constructed and loaded into the Automation1 controller. Aerotech provides special services for error mapping of servo axes. However, machine builders can manage this process on their own. Similarly, laser scan head calibration is often handled by machine builders and the process is simplified with tools like Aerotech's GalvoCFC - Galvo Calibration File Converter (Figure 4).

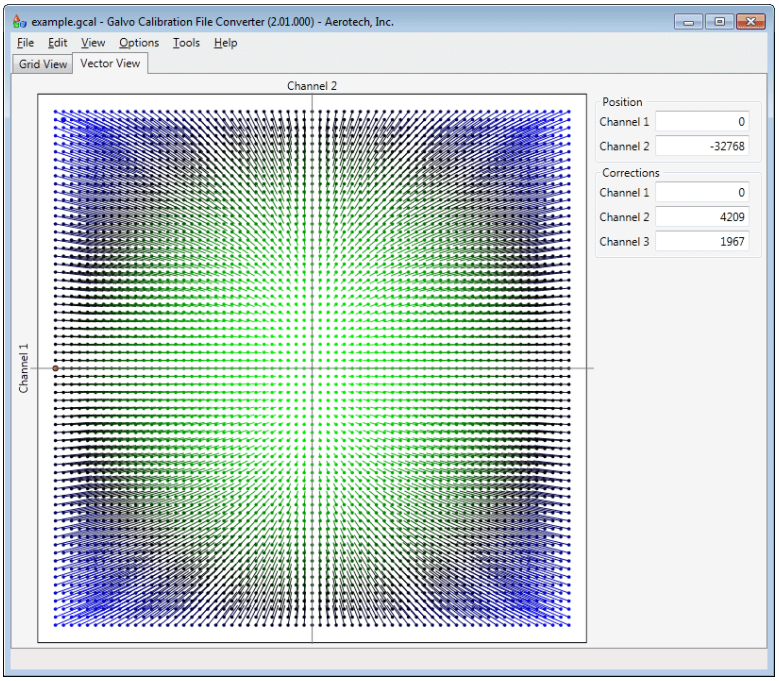

Figure 4. The Aerotech Galvo Calibration File Convertor tool enables users to create and modify a calibration file, scale calibration files to user units, interpolate calibration tables to higher resolutions and combine multiple calibration tables into a single file.

Once the positional accuracy is calibrated, another step can be taken to enhance throughput and part quality. Aerotech's Infinite Field of View (IFOV) feature enables users to directly program a part (or series of parts) that extend past the laser scan head's field of view (XY-motion constraints) with a single XY trajectory. IFOV does this by pre-processing a larger motion path and distributing the higher speed portion of that path to the laser scan head. IFOV distributes the lower speed portion to the servo axes, such that the scan head is always working within its field of view. Because IFOV eliminates step and scan motion, the laser remains on for a larger percentage of time and therefore increases process throughput.

Another unique advantage of using IFOV is that the actual servo stage position is known by the Automation1 GL4 laser scan head controller immediately prior to the servo control loop. This allows the laser scan head to compensate for dynamic position errors in real time. Approaching combined scan head and servo stage motion in this manner helps to manage servo stage position errors that can be orders of magnitude larger than the scan head position errors. See Figure 5 for an example IFOV system configuration.

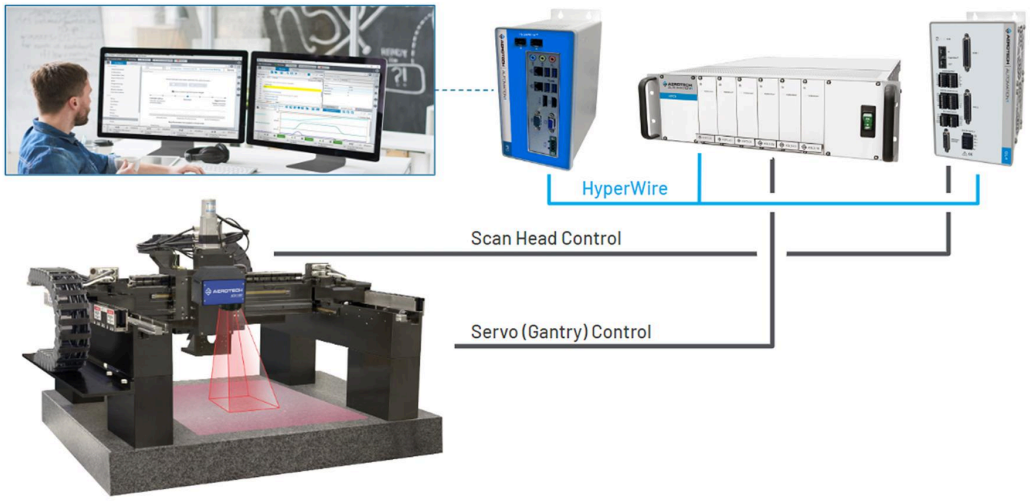

Figure 5. Aerotech's Infinite Field of View (IFOV) feature enables laser material processing of workpieces that are larger than a laser scan head's field of view by taking into consideration servo stage motion to eliminate step-and-scan operations.

IFOV has an additional unexpected benefit – improving part quality. By depending more heavily on stage motion during the process, it is possible to limit the laser scan head travel to the center of the scan head's optic. The center of the optic is the portion where the least amount of laser spot distortion occurs. Because increased spot distortion lowers process quality, using IFOV to command motion helps to improve overall part quality. If limiting scan head travel does not provide a sufficient solution, Automation1 also offers galvo power correction tables. Based on the position of a laser scan head's axes, the user can scale the voltage of an analog output. Because laser spot distortion changes the power density, this power correction can be used to adjust for laser power to ensure consistent laser-material interaction.

When each mechanical device is set up to be controlled properly by each electrical device, all axes of motion are calibrated and the laser power is calibrated over the XY laser scan head field of view, it is time to start managing laser-material interactions that occur during motion – in other words, managing how laser energy is applied to the material while axes are moving. Laser processes that occur during motion must take into account, at a minimum, the following:

- Will the laser firing be continuously on or pulsed?
- Can the laser's power be modulated and how quickly?
- How sensitive is the laser-material interaction to process speed?

Aerotech's Position Synchronized Output (PSO) tool provides precision laser machine builders with a flexible toolset for managing laser-material interactions. For pulsed lasers, the pulse spacing (Figure 6) can be managed by tracking actual distance traveled and generating a firing event based on a fixed or variable distance.

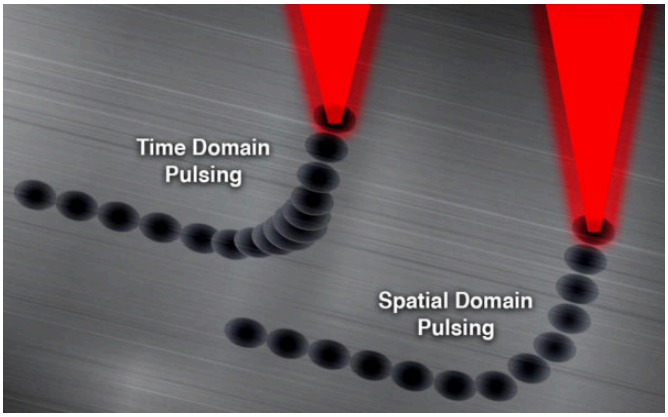

Figure 6. One highlight of fixed-distance firing is that changes in velocity (acceleration) do not affect the pulse-to-pulse laser spacing. This type of control increases part quality and throughput in high-dynamic precision processes.

A firing event typically creates a physical change in state for a PSO output pin on a specified Automation1 servo motor drive. How this output functions is configurable. The output can be held "on" for a specific amount of time, a specific waveform can be generated or a series of pulses can be generated. In addition, an analog output can be modified with each firing event.

When operating an Automation1 GL4 or Automation1 GI4 laser scan head controller, the user also has access to a series of laser output control functions that control three digital outputs (Figure 7).

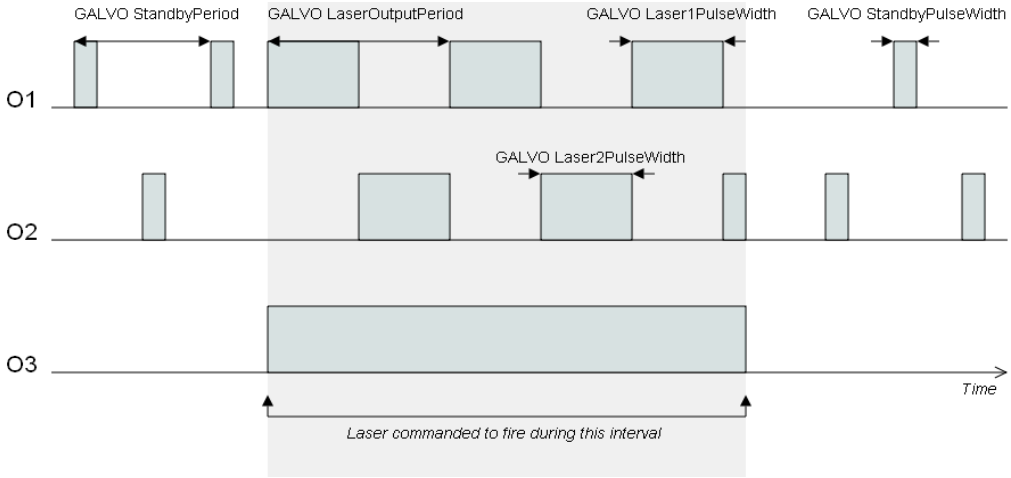

Figure 7. In this standard galvo laser mode control configuration, when the laser is firing, O1 and O2 are modulation signals with a configurable frequency and a fixed 180° phase shift. When the laser is not firing, O1 and O2 outputs can be configured to output standby pulses.

These three outputs operate in different modes, each meant to work with specific types of industrial lasers. The first laser digital output (O1) typically controls laser firing. The second laser digital output (O2) is used either to suppress the first requested laser pulse or is an inverted or phase-shifted version of the first output. The third laser digital output (O3) is typically used to

control the laser's gate, and it is always on during a laser firing period. Some industrial lasers require a 'tickle' pulse. For this reason, O1 and O2 can be configured with a standby periodic output pulse when the laser gate control is off. This can be turned off by configuring the standby pulse length to 0 microseconds.

IFOV, PSO and laser output control functions are all powerful features in the Automation1 motion control platform, and are even more powerful when used together. The Automation1 GL4, when configured for use in an IFOV system, has access to both scan head and servo stage encoder feedback. It uses this information to enable IFOV and execute a version of two-axis PSO that combines one servo X and one galvo X axis into a single axis and combines one servo Y and one galvo Y axis into a single axis. This allows the GL4 controller to command laser output firing events in real time based on actual laser spot distance traveled along the part. When both PSO and laser output control functions are configured properly, the O1 laser output becomes PSO-controlled while the O2 and O3 outputs maintain the Galvo mode operation. See Figure 8.

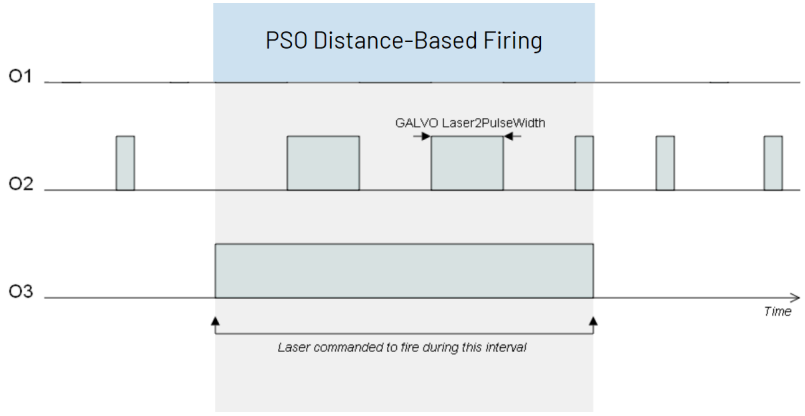

Figure 8. When both Position Synchronized Output (PSO) and Galvo functions are configured properly, the O1 output (see Figure 7 above) is overrode by the PSO configuration, while O2 and O3 still function as per the Galvo function configuration.

After the precision laser process is set up and ready to go on the industrial machine, a part path (or profile) must be developed. Because the Automation1 controller processes G-code by default, part paths can be generated by any computer-aided manufacturing (CAM) tool that outputs G-code syntax. Aerotech offers its own solution, targeted at 2D-contoured motion applications such as glass cutting or via hole drilling. This tool, CADFusion®, lowers implementation risk and ensures the best performance and accuracy possible with the Automation1 controller. It delivers dramatic improvements in part quality by helping users implement laser processing features such as PSO and IFOV. With CADFusion, the user can import an existing DWG or DXF file or start the design from scratch.

In order to deal with some of the realities of laser processes, CADFusion has a series of part path planning features that optimize performance. As seen in Figure 9 below, a user can create a part

path in CADFusion and do much more: apply tools such as lead-in and lead-out moves, create transitional moves such as skywriting, set up repeated sections of the part path, and use the Catalog Manager to apply process tool control syntax, including PSO, automatically. Then, exporting the AeroScript program file to run on the Automation1 controller is a simple click of a button.

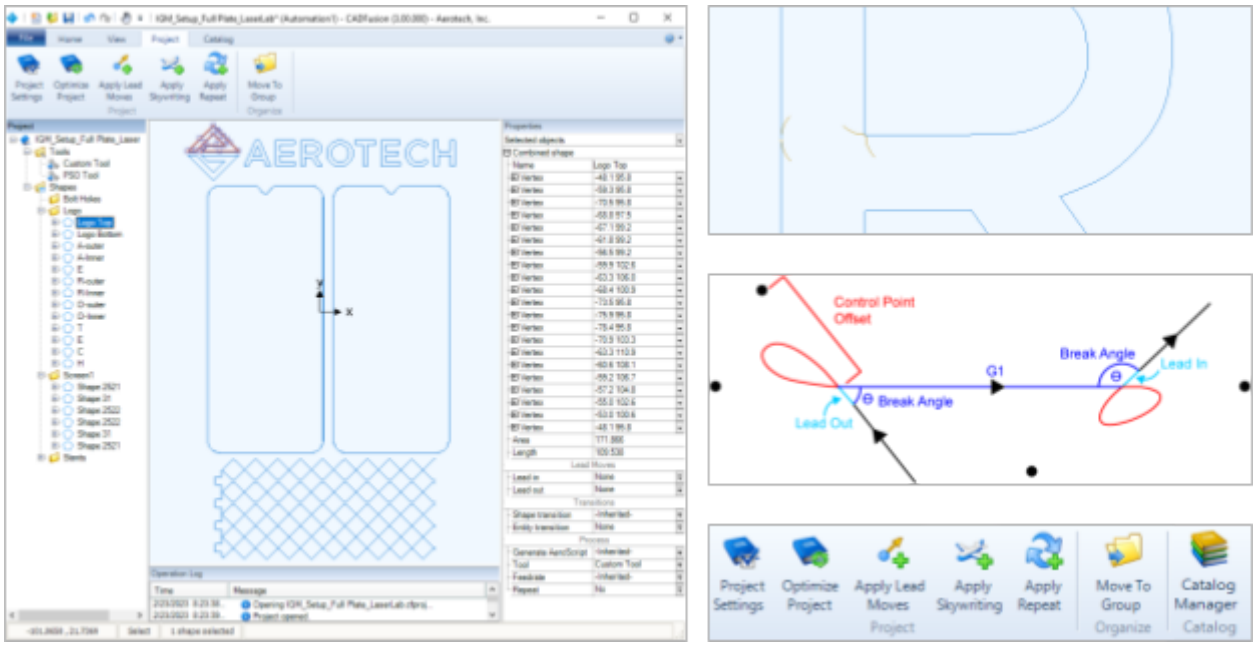

Figure 9. In CADFusion, users can develop a new project from scratch or import existing DWG or DXF files. Using CADFusion's drawing canvas (left) and tools such as lead-on and lead-off moves (right, top), skywriting (right, middle) and other toolbar items (right, bottom) optimizes the part path.

Results

The final result is a world-class precision automation machine that delivers all the advantages of the Automation Motion Development Kit (MDK), including the Studio application, the Automation1 APIs and the Automation1 MachineApps Windows-based custom HMI tool. The Automation1 Studio application (Figure 10) is a single application for configuring, programming, commissioning and optimizing the system.

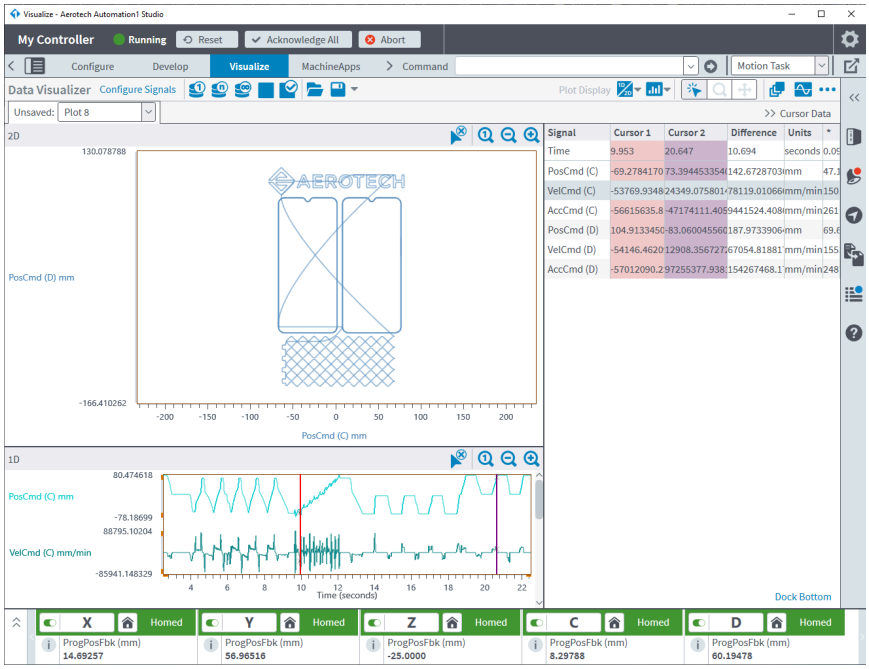

Figure 10. The Automation1 Studio application includes the Machine Setup wizard, MachineApps HMI builder, modern AeroScript™ programming language and a digital oscilloscope (Data Visualizer) to enable the user to set up, program and optimize servo and stepper motors, precision stages, galvo scanning systems and more in one development environment.

Automation1 Studio has a powerful programming IDE as well as a Data Visualizer tool that enables viewing 1D and 2D data concurrently. Automation1 APIs include .NET, C and Python. Finally, users can build their own custom HMI with MachineApps - a tool that quickly develops custom, effective HMI screens for the machine or motion system. MachineApps lets machine builders apply their brand to a machine interface and uses a module-based approach for quickly laying out a user interface.

These tools make Automation1 a single-motion control environment for machine builders who want to lead their industry in precision laser material processing applications.

About the Authors

As a Senior Product Manager, Patrick Wheeler oversees Aerotech's complete controls product line including software, controls and drive electronics. He earned a bachelor's degree in electrical engineering from Lehigh University and a master's degree in electrical engineering from the University of Southern California. His 16+ years of industrial experience spans operations, project management, sales and marketing. Throughout his career, he has specified and interfaced with controls and industrial automation.

Aerotech Product Manager Bryan Germann focuses on light manipulation products, including Aerotech's AGV laser scan heads and associated Automation1 drives and software control features. He has hands-on experience designing and managing the production of high-precision motion control and automation machinery and products. Germann earned his bachelor's and master's degrees in mechanical engineering from the University of South Carolina. He holds 17 U.S. and international patents.