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Understanding PV Panel-Scribing Motion Platforms**Introduction**

Second generation solar cells take advantage of improved materials that are applied as thin films to a variety of substrates. These new materials provide higher conversion efficiencies while lower-cost substrates significantly reduce manufacturing costs. Because of these efficiencies and cost savings, thin-film methods are increasingly popular with PV manufacturers.

Third-generation cells also take advantage of thin-film technologies and hold the promise of even greater conversion efficiencies and lower production costs. This cycle of continuous improvement is considered absolutely necessary to drive solar power to be cost-competitive with current non-renewable energy sources.

In the push for clean, renewable energy at a price point that is equivalent to current grid prices, photovoltaic (PV) manufacturers require production systems that provide exceptionally high throughput as well as the highest possible uptime. One process tool key to reducing cost by increasing throughput is the scribing platform. Focusing on key technologies and selecting a partner that is familiar with these technologies is vital to providing a scribing system with the lowest total cost of ownership.

Scribing Methods

The basic thin-film manufacturing operation relies on a process known as scribing. After application of individual thin-film layers, panel scribing is used to selectively remove material in areas that will be electrical interconnects or isolation areas. Because it is a key process step, scribing must be strictly controlled to ensure proper function of the finished panel.

Two methods are used for the scribing process -- mechanical and laser scribing. Each method provides specific benefits and presents unique challenges for material scribing. Mechanical scribing is less film-material-dependent than laser scribing but is limited in throughput as well as scribe quality, while lasers have throughput and quality advantages but their application is limited by the materials being scribed. Regardless of the method used, the scribing motion platform must accommodate the technology as well as provide extremely high throughput.

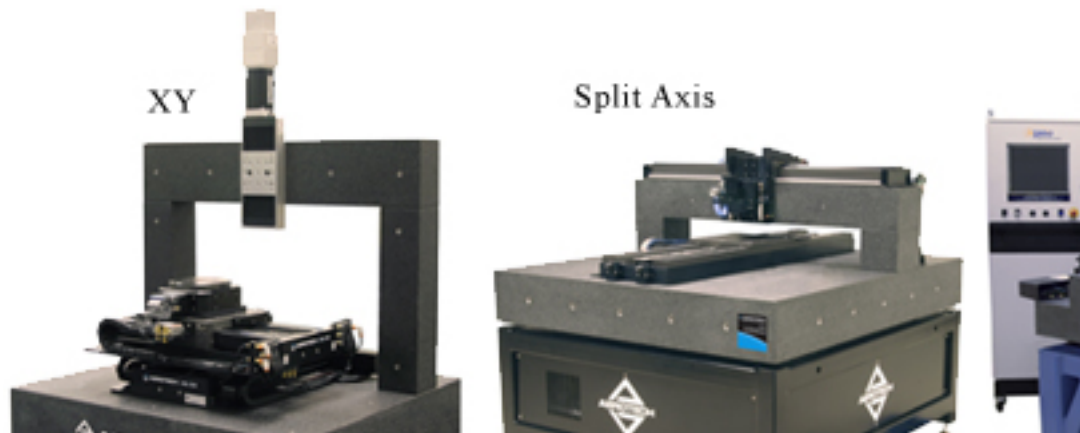
System Level Approach

The best approach for developing a solar panel scribing solution is to consider the scribing platform as a whole. Simply looking at the primary scan axis will only tell part of the story. While scan axis dynamic straightness, peak acceleration and peak velocity are very important, there are other design elements that come into play. Machine mounting/vibration isolation, scribe-axis configuration and design, chuck design, and motion controller technology all work together to provide maximum performance and throughput. If these items are not considered the system can be plagued by problems including:

- Acceleration-induced machine motion that negatively affects the dynamic straightness

and dynamic straightness repeatability of the scribing tool, which ultimately affects the straightness and parallelism of the scribe lines.

- Not maximizing the number of scribe heads increases processing time and scan axis duty cycle, thereby reducing scribe-tool life.
- Motors that are not correctly sized for the moving mass and throughput model. Too large a moving mass on the scan axis limits peak acceleration.
- Selection of a low performance motion controller that does not include throughput-enhancing advanced control capabilities.
- Not matching the proper axis configuration with the process objective (e.g., XY, split axis, or gantry).



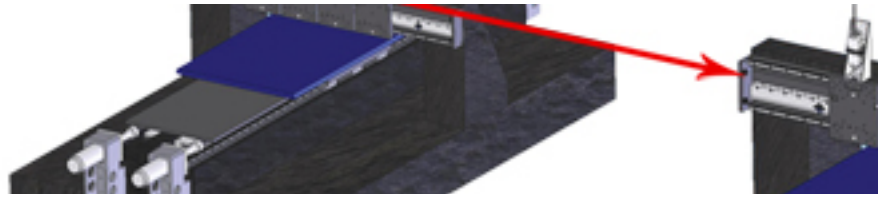
Key Features

For purposes of this article, the split-axis arrangement will be discussed in detail because it is the most common configuration for production-level PV scribing.

A key feature of a high throughput panel-scribing system is the use of a multi-head axis to carry the mechanical or laser scribe heads. Figure 2 illustrates this type of design. This configuration, which uses four or more scribing heads, provides much higher throughput because the number of passes required to scribe the entire panel is reduced in direct proportion to the number of heads. This reduction of passes directly increases throughput as well as proportionately increases the life of the system. It is important to note that to properly implement a multi-head arrangement will require the motion controller to independently position these axes and, for laser scribing, trigger the lasers simultaneously. Selecting the right partner to design the motion platform and integrate the controls, drives, lasers, motion axes, and machine base is critical to addressing these issues.

An important part of an efficient multi-head design is the use of customizable Z axes that allow the flexibility to create exactly the configuration required and that is most efficient. Either direct-drive or ball-screw Z stages are options, but the load and positioning requirements will be the determining factor. These axes must be configurable for the load as well as have a flexible cable management design that allows the system to integrate not only the laser scribe heads but also cameras and other elements that are needed for the system to operate as efficiently as possible.





Direct Drive

Direct-drive linear motors are used almost exclusively for a scribing tool's primary scan axis for a multitude of reasons. For instance, high duty-cycle applications where 24/7 operation is a reality require a noncontact drive mechanism that eliminates wear and increases reliability. Other drive mechanisms such as ball-screw either cannot provide the throughput or will quickly wear out in this strenuous environment. The inherent noncontact nature of linear motors means that they can provide precise dynamic motion, very high speeds, and a long, trouble-free life.

Linear motors also can be stacked together to generate the very high forces needed for high acceleration. The design shown in Figure 3 utilizes multiple linear motors stacked in parallel allowing them to generate 5 g acceleration on a 30 to 40 kg payload. The force capability of these motors is also important to minimize the turn-around time by quickly decelerating the payload and re-accelerating it to the full scan speed of 2.5 m/s.



One challenge when using linear motors is the issue of protecting them from process generated debris. This can be overcome by using creative mechanical designs that place the linear motor and bearing elements out of the direct path of falling debris. As an example, the design above places the linear motors so that they are protected by overhead horizontal structures that virtually eliminate exposure to processing debris.

When correctly applied, linear motor technology can provide dramatic throughput for scribing platforms. As an example, a top-tier solar panel manufacturer increased throughput by 300% using an Aerotech [SolarScribe](#) platform that utilized direct-drive linear motors. In a typical example, a single high-throughput scribing tool equipped with Aerotech [linear motors](#) replaces three or more standard scribing stations saving time, money, and manufacturing floor space.

Thermal Management

Because of the high accelerations and duty cycles, PV scribing applications require very high continuous currents in the linear-motor drive mechanism. These currents can generate a significant amount of heat that can affect both the accuracy and lifetime of the machine. To maximize the life of the motor when running in these conditions the system must incorporate thermal management techniques. A quick and efficient way to do this is to utilize air-cooled linear motor forcers that use a continuous stream of air over the coil to reduce its operating temperature.

In addition to active cooling of the motors, continuous temperature monitoring is also used. A typical installation will include thermal sensing devices that are connected to the system controller to provide real-time motor temperature data. This information can also be used by the

controller to shut the system down in the event that coil temperature becomes too high for safe operation. This helps to increase the life of the machine by providing failsafe operation and by providing the user with information that can be used to adjust the system parameters to optimize both the throughput and tool lifetime. Both active cooling and thermal sensing features support maximizing the life of the system.

Dynamic Performance

Beyond providing very high speeds and accelerations, the motion platform must provide good dynamic characteristics. Although all system geometric performance characteristics can be tested dynamically, PV panel-scribing applications are most concerned with scan-axis dynamic straightness and dynamic straightness repeatability.

Dynamic straightness and dynamic straightness repeatability show both the error motion that is transverse to the primary scan axis direction as well as the repeatability of that motion when scanning forward and reverse. The dynamic straightness number provides insight into what the form of the overall scribe lines will look like. This is an important parameter as this form will be repeated each time a scribe is made. Dynamic straightness repeatability will further quantify the amount of line-to-line variability or line parallelism across the panel. Dynamic straightness numbers are typically tens of microns with dynamic straightness repeatabilities less than 10 microns over a typical 1300 mm panel length. The key to providing this level of accuracy is to utilize high quality, precision machined components along with precision assembly methods. A well-versed motion partner will have the infrastructure as well as the experience to be successful in these areas.

Motion Controller

Another feature that is essential for increasing panel throughput and dynamic performance is the [motion controller](#). Although most modern controllers can produce the basic trajectories necessary for solar-scribing applications, they typically do not have a full suite of tools necessary to optimize that motion for both quality and throughput.

For example, development of the optimum motion profiles must be simple and effective. To that end Aerotech employs technologies like [Motion Designer](#) which provides a way to graphically generate needed trajectories as well as provide users with a full suite of data analysis capabilities. Motion Designer's standard toolkit allows trajectories to be generated using predefined building blocks that provide rapid motion prototyping. Once the motion profile has been generated the user can perform data analysis (such as FFT, max, min, average, rms, and standard deviation) from an existing trajectory to diagnose system performance. In throughput-dependent applications like scribing, motion profile optimization is absolutely critical.

Another key feature is the controller's ability to trigger and control the laser (in the case of laser scribing) based on position. Aerotech's motion control platform utilizes Position Synchronized Output (PSO) which uses a combination of both hardware and software to trigger the output based on the actual position of the axis. Triggering on the actual position eliminates effects that external disturbances may have on the process. For example, velocity regulation and settle values become unimportant since the process is not affected by their uncertainty. Also, the latency between when the axis is at the target position and the actual triggering of the output is very low, in the sub-microsecond range. This allows for much higher speeds than traditional high-latency tracking methods because the chance of missed or overlapping events is avoided. Combined with the low latency of PSO is its ability to trigger multiple pulses in close succession. Trigger rates can be up to 10 MHz, allowing not only high-speed tracking but also the ability to directly control the output pulses of a laser or perform high-speed data acquisition. PSO is an extremely versatile tool, offering a number of tracking and firing options, as well as easy programming.

Other supporting technologies also help to maximize system throughput and reliability. In

particular, Aerotech's Dynamic Controls Toolbox includes performance enhancing options like Iterative Learning Control and [Enhanced Throughput Module \(ETM\)](#) that enable the highest level of system performance from the hardware investment. The ETM helps improve the positioning performance by directly measuring the unwanted motion of the machine base and communicating it back to the controller. By working in concert with the Dynamic Controls Toolbox and Aerotech controllers, the ETM significantly improves move-and-settle time and contouring performance, increases throughput of existing and new machines, and greatly reduces the effects of frame motion on the servo system.

Conclusion

Lowering manufacturing costs of photovoltaic panels is absolutely critical in the push for grid parity. To make this a reality, PV manufacturers must seek out technologies and capable partners that can provide the highest throughput, most reliable motion platforms. The right partner can provide the system-level knowledge as well as the mechatronic platform that will maximize system performance and provide reliable operation well into the future. Understanding the issues as well as the solutions presented will provide manufacturers with the tools necessary to develop the best possible scribing platform.

Registration Now Open for ASPE Spring Meeting: Control of Precision Systems

[Join us](#) at the Massachusetts Institute of Technology April 11 - 13, 2010 for the American Society for Precision Engineering's (ASPE) third meeting on the [Control of Precision Systems](#). This conference will promote a broader understanding of the principles and techniques applicable for precision control and highlight the challenges and achievements unique to our field. Practitioners from industry, government, and academia will exchange ideas and identify topics for further research. The conference schedule will also include unstructured time for technical and social interactions.

The control of precision systems encompasses a wide range of applications in high-speed, high-accuracy manufacturing and automation. The growth of [nanotechnology and nanoscale manufacturing](#) has further raised the positioning requirements for machine designers. The performance of such systems, instruments, devices, and processes depends upon the innovative application of feedback principles due to the large dynamic range of controlled variables and the sensitivity to effects which might be ignorable in conventional systems.

We also encourage presentations of a tutorial nature that elaborate principles essential to achieving high performance in precision control systems. One such session, [Tutorial on Industrial Motion Control](#), will be presented on the first day of the summit. This proceeding is a refresher course on the main aspects in the application of motion control for precision systems. From the broad field of control theory, those theories most often used in industry will be introduced, explained, and applied. This focus will help engineers from diverse backgrounds familiarize themselves with some of the most common theories.

To [register](#) and view a copy of the complete conference program, please [visit ASPE's registration home page](#).



Motion Control and Positioning Library

This resource provides a short summary and a link to articles, tutorials, white papers, and other materials that discuss problems and solutions involving motion control and positioning equipment and systems.

[Explore Aerotech's Online Library of Product Catalogs and Brochures](#)

Browse our motion solutions for applications in aerospace, semiconductor, medical device fabrication, laser processing, micromachining, electronic manufacturing, test and inspection, data storage, and more. Request a hard copy of any brochure or catalog, or download a PDF today.

[Solar Nears Tipping Point](#)

As solar cell production gains momentum, manufacturers are focused on higher efficiency, sustainable quality, and incorporating more automation. Gain insight into how solar cell manufacturers are leveraging the latest precision motion control technologies, robotics, networked automation inspection stations, and automation solutions to make more units at a lower cost.

[Controller Retrofit Solutions](#)

The high cost of new machine tools has many manufacturers considering *re-control* of their existing machinery. Re-control projects allow manufacturers to realize significant cost savings while modernizing the control system, which is typically the backbone of the machine tool itself. The Aerotech A3200 Digital Automation Platform has played a key role in accomplishing these objectives for many large global manufacturers.

[Laser Processing in Stent Production](#)

The diameter of a human hair is approximately 100 microns, while the entire wall thickness of the material in a stent is 25% the thickness of a human hair. By reviewing these numbers, it is easy to understand the difficulties of ensuring quality stent manufacturing. But what is the best method of production to meet these tight tolerances?

[The Need for Speed](#)

Packaging OEMs look to advanced software solutions and linear servos to boost system performance.

[Machine Vision Speeds PCB Solder-Joint Inspection](#)

The system combines servo motion, continuity testing, and solder-joint inspection in one unit for processing of automotive connectors.

[Resolution Resolved](#)

System or stage resolution is often spelled out for motion controls as well as in vendor catalogs and Web site specifications. However, many misinterpret what the term truly means.

[Linear Motor Basics](#)

A steady increase in practical industrial applications has secured a place for linear motors. Here's an overview of the various types of linear motors and what differentiates them from their rotary counterparts.

[How to Select and Install Air Bearing Stages](#)

Air bearing stages are noted for their smooth, frictionless motion. A few tips and techniques will ensure you benefit from their advantages.

[Micropositioning Meets Mechatronics](#)

Compared to traditional methods, the mechatronic design approach is more of a holistic approach to product design, where the tradeoffs between different functional components (software, hardware, user interface, etc.) are carefully considered for their impact on overall performance.

[Motion Control Requirements for Hermetic Seam Welding](#)

A discussion of the motion control platform in regard to [hermetic seam welding](#) of sophisticated electronic devices implanted in the human body.

[Digitizing a Century of Astronomical Images](#)

Aerotech's ABL9000 air-bearing stage is put to use to efficiently digitize more than 500,000 photonegatives.

[Two-Photon Polymerization: A New Approach to Micromachining](#)

Femtosecond lasers enable microfabrication with resolution beyond the diffraction limit.

[Precise Triggering of External Events Based on Axis Position](#)

An axis-based trigger in the controller can significantly improve part quality, reduce cycle time, and eliminate processing problems. This article discusses Aerotech's unique PSO (Position Synchronized Output) option, and how any application that requires precise data acquisition or process action linked to axis position can benefit from it.

[Applications Dictate Gimbal Selection](#)

The choice between direct-drive and gear-driven gimbals and optical mounts presents an opportunity for a comparison of the pros and cons for each.

[Linear Motors Application Guide](#)

A tutorial guide to the history, design, and application of linear motors.

Latest Software Releases (Red indicates a new release)

A3200 Digital Automation Platform	Version 3.00.001
Ensemble Multi-Axis Controller	Version 3.00.001
Soloist Single-Axis Controller	Version 3.00.001

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