



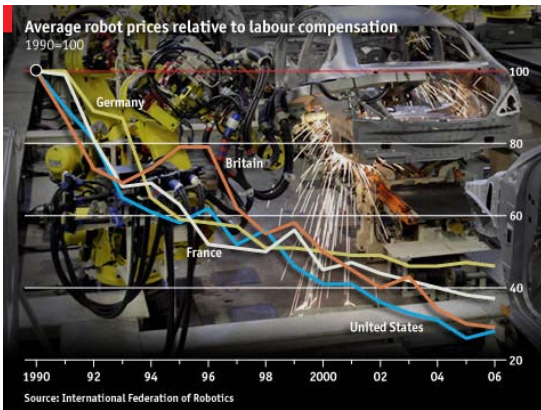
Solar Cell Manufacturing & Robot Automation: Right Fit / Right Robot

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The U.S. has set 2015 as a goal to reach grid parity (that point where solar electricity is equal to grid electricity) while other nations predict reaching it as soon as 2010. No matter your thoughts on regulatory involvement it is clear there will be a resurgence in investment, development and innovation within the PV manufacturing community throughout the world and it will largely be driven by technology. Finding the most effective tools and processes to gain more productivity and decrease costs within a set capital plan is paramount. While the significance of robot automation in the manufacturing of solar cells is obvious, which robot types and kinematics fit each unique process may not. Which solar manufacturing areas offer the greatest return opportunities for robotic automation? Which robot type is best for a given solar application task and how does vision fit it? This article should act as a primer targeting these issues and discusses how the solar industry can best maximize factory throughput, drive down costs and improve efficiencies with robotic automation.

Robotic Automation's Impact

Robots in the photovoltaic manufacturing process are important due to their ability to significantly reduce costs while continuing to increase their attractiveness compared to manual labor. Richard Swanson, the CTO of SunPower Corporation a leading manufacturer of solar technology, framed automation's impact in a very interesting light by discussing the economies of PV manufacturing in terms of labor. He explained



that to produce one gigawatt of solar power it requires 250 to 500 laborers to produce poly silicone, 250 to 500 laborers to process ingots, 3000 -6000 people to manufacture the cells, 1500-3000 for the panel lamination & associated applications and 2500-5000 for the solar system integration. In total that's 8000-16000 laborers required to produce 1 gigawatt of photovoltaic capacity. Therefore to produce 500 gigawatts of solar power per year that equates to roughly 4 million people who could be adding

tremendously more value in other capacities. With more automation, inclusive of appropriately applied robotics, the solar industry can cut that labor to 1 million people realizing a 75% savings in direct labor costs alone. Given this magnitude it is critical robots receive ample consideration in line design.

Considerations When Selecting the Right Kinematic Solution

A handful of considerations will provide good direction in selecting the correct robot. First and foremost, what is the payload requirement for the robot? Frequently people only consider the products that are being handled. However it is important to also consider the tooling solution or end of arm tool (EOAT).

Evaluating the motion requirements is also critical. Not only the simple motion of picking and placing but also what interferences exist between the robot, its linkages as well as other items that may be in dynamic motion within the cell.

Consideration must also be given to how parts are produced and throughput requirements. How repeatable does the robot need to be? It's also important here to recognize that robot manufacturers tend to speak in terms of repeatability while engineers and designers tend to look at it from the standpoint of accuracy. A robot's repeatability outlines the machine's ability, once taught, to return to that taught position. Accuracy, references the ability to input a given location digitally and have the robot move to that point in space "accurately". This encompasses offsets and other digitally inputted motion parameters and often varies within a given mechanical unit's work envelope. Thus, a good understanding of a process's requirements in combination with the capabilities of a given robotic solution requires careful evaluation.

Do your processes require special environmental considerations? Do you require a robot designed to eliminate the generation of particulates that might degrade the product? Or does the robot need to be protected from process specific elements like slurry ingot processing.

Major Robot Types

Robot kinematics can be divided into four major categories. The four groups are Cartesian, SCARA, Articulated and delta/parallel.

Cartesian

The Cartesian kinematic solution is highly configurable as the platform includes everything from a single degree of freedom or unidirectional travel to numerous axis of motion. Given the simplicity of this



kinematic, adjusting strokes or lengths and configuration is relatively easy when compared to this model's counterparts. Multiple drivetrains exist which are optimized to provide high throughput or precise motion as characterized by whether the drive might be a ball screw or a belt driven mechanism. Platforms exist that accommodate small part assembly to extremely large part transfer such as overhead cranes that might be observed overhead in a manufacturing facility.

Cartesian Solutions within the PV Industry

Cartesian solutions have numerous applications within the PV industry. They can be applied to both small and large workspaces. Cartesians are typically called upon to serve applications where the substrate remains in the same plane. This is to say that if you were to pick a product off of a table or a conveyor it does not need to be flipped or change its configuration other than a rotation in the same plane as the table or conveyor (X-Y plane). An example of a job using a small Cartesian might be dispensing sealing material on the flange of a junction box. The sorting and placement of solar cells in a large rectangular is also an optimal application for a Cartesian solution. Solar cell sorting into multiple stacks in a large work area and processes such as stringing up and lay up within a large cubic area where robots are required to reach with good repeatability are optimum applications for Cartesian.

SCARA Robots

The next robot is the SCARA robot. SCARA stands for Selective Compliance Assembly Robot Arm. It offers a cylindrical work envelope and this category of robot typically provides higher speeds for picking, placing & handling processes when compared to Cartesian and articulated robotic solutions. They also deliver greater repeatability by offering positional capabilities that are superior in many cases than articulated arms. This class of robot is usually used for lighter payloads in the sub 10 kilogram category for applications such as assembly, packaging and material handling.



SCARA Solutions within the PV Industry

Within solar manufacturing processes these robots are best suited for high speed and high repeatability handling of cells in smaller workspaces. Where the workspace is constrained sufficiently the SCARA is an excellent selection. For example, junction box handling and assembly of panels are good applications for this robot group. Stringing is a process that with its increasingly tight tolerances is unmanageable with manual labor. As wafers migrate to thicknesses of 150 micron and thinner, the propensity for damage is greatest when labor is applied. As wafer thicknesses decrease over time as forecasted, the thermal expansion of the silicon will also become an issue while soldering. So it's going to become increasingly important to maintain yields in stringing by controlling and automating the soldering operations even in low cost labor markets through the use of mechanisms such as SCARA robots.

Articulated Robots

Articulated robots comprise the third robot group. They have a spherical work envelope. These arms offer the greatest level of flexibility due to their articulation and increased numbers of degrees of freedom (DOF). This is the largest segment of robots available on the market and therefore offers a very wide range of solutions from tabletops to very large 1000 kilogram plus solutions. Articulated robots are frequently applied to process intensive applications where they can utilize their full articulation and

dexterity for applications such as welding, painting, dispensing, loading, assembly and material handling.



Articulated Robots within the PV Industry

Articulated robots are applied to a wide variety of solar applications. Examples include handling heavy silicon ingots which are also in an area where the robots might require industrial protection and handling wafer cassettes where the orientation of the carrier might differ from pick to place utilizing the full dexterity of the robot. Handling glass, sub assemblies and assemblies where the products are introduced to the cell in a different configuration than they are presented to the system again take advantage of an articulated arm's flexibility. This is to say that articulated robots permit the optimum introduction of product into a cell which may be in a vertical orientation to maximize floor space while the

assembly process is most efficient in a horizontal orientation. Edge trimming and module assembly where tool change and other process considerations dictate the use of articulated arms is yet another use of this class of robots within the PV manufacturing process.

Delta/Parallel Robots

Parallel robots round out the fourth classification of robots. This kinematic solution provides a cylindrical work envelope and is most frequently applied to applications where the product again remains in the same plane from pick to place. The design utilizes a parallelogram and produces three purely



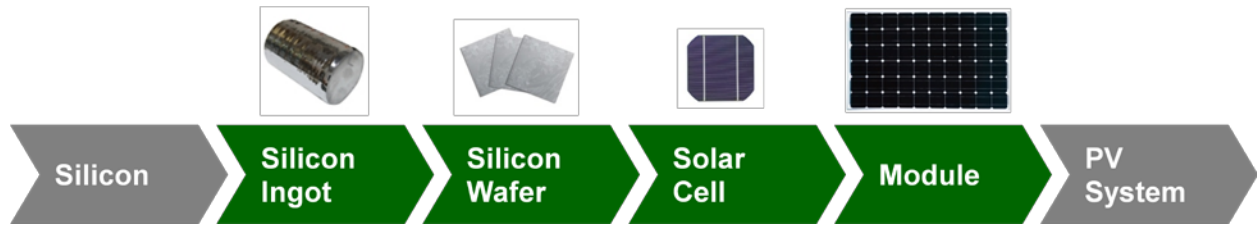
translational degrees of freedom driving the requirement to work within the same plane. Base mounted motors and low mass links allow for exceptionally fast accelerations and therefore greater throughput when compared to their peer groups. The robot is an overhead mounted solution which maximizes its access but also minimizes footprint. These units are designed for high speed handling of lightweight products and offer lower maintenance due to the elimination of cable harnesses and cyclical loading.

Parallel Robots within the PV Industry

Parallel robots are deployed into many solar cell processing steps. Again they offer high speed transfer of solar cells through manufacturer lines and a multitude of processes. Three examples are diffusion of process equipment, wet benches and PECVD anti-reflective coating machines. In these applications the tables and trays have large placement opportunities which could be equally serviced by a Cartesian however the parallel robot out performs the Cartesian from a throughput standpoint. The Quattro parallel linked product from Adept Technology, Inc recently achieved 300 cycles per minute illustrating the capabilities for this class of machine to handle products at high rates.

Where Robots are Deployed within the Solar Process

The diagram below shows typical PV process steps. The steps are broken into four basic groups where high concentrations of robots are deployed. The ingot processing step predominantly uses Cartesian gantries and large articulated arms due to the requirement for heavier payloads and large workspace optimization. Wafer manufacturing uses a variety of arm types depending on volume and process requirements. Cell processing tends to use gantries, SCARAs and parallel linked robots and the decision usually lies with the reach and repeatability considerations. Module build uses a variety of arms with a high concentration of articulated and Cartesian arms for reach and flexibility, but some specific tasks utilize the services of SCARAs and parallel robots.



Robot Comparison Example: Anti-Reflective Coating Load/Unload Process.

Following is a comparison of the four robot categories when considering their use in an anti-reflective coating load/unload process. If we look at a Cartesian robot it is optimized from a reach standpoint. However, the majority of solutions here would prove too slow and would require in excess of a single head EOAT. This complication would drive the need for pre-alignment and further complications in pre-conditioning the product and therefore may prove a Cartesian solution to be considered less flexible.

Cartesian Robots

- Too slow for loading/unloading using a single-head EOAT
- Because multi-head EOAT is often used, cells require pre-alignment
- Less flexible when reconfiguring for different size wafers is required

SCARA robots would give us increased speeds and prove more flexible than a Cartesian. However if we look at a traditional table top version it would limit the workspace and therefore may not be optimal in reaching all points on the load and unload areas of this machine.

SCARA Robots

- Faster and more flexible than Cartesian robots when used with vision guidance
- Table mounted versions could limit work space and multiple robots may required to cover pallet/matrix

Articulated robots would be pedestal mount and may prove too slow in increasing complexity of the installation.

Articulated Robots

- Too slow for loading/unloading with single-head EOAT
- Spherical work envelope isn't ideal for covering pallet/matrix

Therefore a delta or parallel style robot might be optimal for a number of reasons. First the overhead mount is ideal in reducing the footprint of the automation cell. We can reach all places on the PECVD pallets. And when we combine the benefits of the delta with vision it gives us an exceedingly flexible solution that will meet the throughput requirements. As noted below, vision is an enabler not only for parallel linked robots but provides the same benefits to all categories of robots.

Delta / Parallel Robots

- Overhead mount design ideal for loading/unloading equipment
- Larger delta robots can cover the width of most PECVD pallets
- When used with vision guidance, enables extremely good positioning
- Excellent flexibility and quickly reconfigurable
- Robot design optimal for handling cells (lightweight) at high speeds

Flexibility with Vision

Vision has become a highly adopted tool to improve the productivity of robot automation in all industries



and all facets of placement. Vision systems offer tremendous flexibility for applications that don't require fixtures or trays for part location. Vision-guidance is a feature that allows the vision system to take a picture and compute a part's location and orientation and guide the robot to the part using a computed robot-to-camera transformation obtained through an automated calibration

process. It allows tremendous flexibility and cost-savings because parts don't have to be fixtured. Parts can be randomly presented to the robot without pre-orientation or alignment or put into a tray which also reduces cost. These systems frequently incorporate line tracking which enables the robot to pick these parts from a moving belt which further optimizes the production process. Robot integrated vision allows inspection to be incorporated into the handling process. This puts the inspection or quality control process in parallel with handling, further reducing the overall cycle time and increasing throughput. Different part geometries only require vision re-training or the selection of a recipe instead of manual changes in fixtures and tooling. This increases the overall lifetime profit of the equipment by virtue of its optimization and improved throughput. Most robot manufacturers offer packages with multiple cameras and tracking

solutions for integration into a single cell. This offers tremendous power and flexibility for solar manufacturing.

Robotic Solar Manufacturing Summary

The common goal for solar manufacturers is to drive down the cost per watt. As the solar industry strives to achieve grid parity, manufacturers need to be knowledgeable about modern robotics and automation technologies and the value they contribute to helping reduce the cost of solar cells.

History has shown that automation has played a significant role in reducing manufacturing costs in many manufacturing industries, and when the costs associated with higher quality and yields are considered, the benefits of automation offer an even more appealing value proposition. While robotics and automation may be viewed by some industries as mature technologies, industry leaders are continuing to develop innovative products and new technologies that are ideal for solar manufacturing processes.

It would be prudent for solar manufacturers to look outside of their industry for the best practices in high volume manufacturing with automation and robotics to achieve their cost reduction initiatives.

More information:

Adept Technology, Inc. www.adept.com