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Autocalibration® technology *in Semiconductor Tools*

Downtime in semiconductor tools results in increased costs and reduced profits. Moog offers a proven and cost effective solution that substantially reduces downtime: Autocalibration® technology. This paper describes Autocalibration technology, and its benefits.

Semiconductor tools typicallyhave one or more wafer-handling robots capable of motion through multiple degrees of freedom. These robots rapidly transport semiconductor wafers often worth tens of thousands of dollars apiece between wafer cassettes, FOUPs, wafer aligners, process carriers, and process stations. Tools require precision to maintain process integrity, cleanliness to avoid wafer contamination, reliability to minimize downtime, and speed to maximize tool throughput.

To enable the fast and precise placement of wafers, robots are "taught," or calibrated to, the locations where they are to retrieve or deliver wafers. Such calibration is required upon tool integration, commissioning, maintenance, or repair of wafer-involved mechanical components. Actual or suspected performance deficiencies may also dictate recalibration. Calibration requires a qualified technician, in the clean room, to perform those physical contortions necessary to precisely view each tool's wafer pick-or-place locations, while using a "teach pendant" to slowly jog the robot's end effector to each location. When, in the technician's judgment, the required location is reached, robot arm position is stored in the controller. Such a process is by nature subjective, and likely to produce variable results. Physical intrusion into the tool also risks unacceptable contamination or harm to personnel. Meanwhile, manual calibration typically takes a tool out of productionfor several critical hours.

Moog's Autocalibration technology completely eliminates time-consuming and subjective manual robot calibration. This technology automates tool calibration, making it accurate, repeatable, and substantially faster.

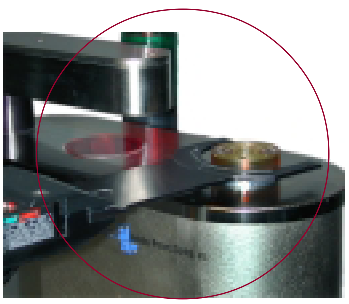
Autocalibration technology is enabled by the tight integration of a robot to the critical elements in its operational environment, under a highly capable machine controller. It is essential that the controller has the ability to detect changes quickly and precisely, and to respond instantaneously. The shared-state, multitasking architecture of Moog's BX-series motion-and-machine controller provides extraordinary integration and control responsiveness. Architectures employing multiple disparate controllers, and having common serial communications delays, cannot support the level of precision needed for comprehensive automatic calibration technology.

The Moog controller is programmed to drive the robot's motors to move its arms to a commanded position, and to process I/O data. High-resolution encoders provide feedback signals to the controller that indicate the present position of each motor. The controller software continuously compares the actual motor feedback position and the software commanded motor position to generate appropriate drive signals. The controller's integrated drives provide necessary motor drive current. Through this tight integration, the controller has intimate knowledge of the present velocity and torque of each of the robot's motors.

The controller simultaneously collects I/O data from the robot and associated connected sensors. One such sensor input may be from a laser wafer mapper, typically mounted on the backside of the robot's end effector. In the exceptional cases where

Downtime equals increased costs and reduced profits they may be required, reflective or thrubeam sensors may provide additional relevant state information.

Autocalibration technology is implemented through a variety of application-specific methods. Detailed mechanical attributes of the semiconductor tool are at the forefront of method selection. A single method or a mix of methods may be applied in any given tool design, and to any given pick-or-place location.



Touch is the most powerful Autocalibration technology implementation method. No added hardware or sensor is required. As stated earlier, the controller has intimate knowledge of the present velocity and torque of each robot motor and the present position of the robot's end effector. The controller also knows the approximate location of the controlled robot's pick-and-place location references, and the geometry of the end effector. The tool application developer supplies that information.

In touch calibration, the controller commands a robot axis to slowly move the robot's end effector into the predefined nominal location of a given pick-or-place reference. When the end effector makes light contact, that axis' motor torque change indicates physical contact. The controller instantly captures the encoder position as the calibration point.

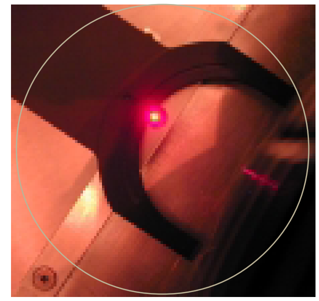
While simple in concept, a robust and reliable implementation of this calibration method is not within the capabilities of most robot controllers. Subtleties of touch calibration implementation require that the common non-uniform frictions that cause torque variations be separated from the torque change that occurs upon end effector touch contact. Suitable algorithms require control integration having excellent torque measurement sensitivity and minimal control latencies.

Autocalibration technology implemented via a robot's ubiquitous laser wafer mapper also has the appeal of requiring no additional hardware or sensors. Such mappers are normally used to accurately detect the edges of wafers in a wafer carrier or FOUP. Typically in this implementation, the robot moves the laser mapper a small distance up and down while moving it slowly toward the nominal reference location. Upon the mapper detection of the reference edge, the controller instantly captures encoder position data as the calibration point.

Autocalibration technology can also be implemented via added thrubeam or reflective optical sensors physically associated with pick-or-place targets. The approach is similar. The controller commands a robot axis to slowly move the robot's end effector into the optical path of a sensor for a given reference. As the end effecter crosses the optical path, the controller instantly captures encoder position data as the calibration point.

An optimum tool implementation of Autocalibration technology might find a mix of methods applied across the several possible wafer locations, and indeed a mix of methods used to calibrate the three-dimensional location of a particular wafer station. Such an implementation exists in Moog's WaferServer™ XL wet-bench front end. In this thirteen-axis front end, a single command initiates a calibration sequence that concludes less that six minutes later in a fully calibrated wafer-handling system. (The implementation of Autocalibration technology in the WaferServer XL is described later in this document.)

Yields, defect incidence, downtime, and tool throughput are critical factors in achieving acceptable return on investment given the lofty cost of building 300mm fabs and the high unit value of each wafer. High levels of wafer- and FOUP-handling automation introduce new preventive maintenance and time-to-repair challenges. Legacy manual calibration techniques are unsuitable to this new environment as



they demand lengthy tool downtimes, produce variable results, and risk tool contamination and personnel injury. Autocalibration technology produces extremely fast and repeatable tool calibrations. Manual calibration that took hours is reduced to just minutes. Tool commissioning, maintenance, and repair times are dramatically reduced. Autocalibration technology offers the remarkable benefit of reducing semiconductor tool downtime— resulting in reduced costs and increased profitability.

Autocalibration technology reduces downtime

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Autocalibration technology

value calculation example

Autocalibration technology substantially reduces the time needed for tool calibration. This produces significant labor and capital savings resulting in lower total cost of ownership.

Total savings over five years with Autocalibration technology **$39,039**

	input assumption	calculatio	result
time savings			
Manual calibration of wafer transfer syste	5.0 hrs		
Calibration by Autocalibration technology	0.1 hrs		
savings per calibration		5.0-0.1	4.9 hrs
factory calibration labor savings			
Calibrations during factory test	2	2 X 4.9	9.8 hrs
Factory labor rate (burdened)	$100		
total		$100 X 9.8	**$980**
field calibration labor savings			
During tool set-up and commissioning	1	1 X 4.9	4.9 hrs
Due to failures over 5 years	5	5 X 4.9	24.5
For preventative maintenance, 5 years	20	20 X 4.9	98.0
For tool reconfiguration, 5 years	1	1 X 4.9	4.9
Total field labor hours		sum	132.3
Field labor rate (burdened)	$200		
total		$200 X 132.3	**$26,460**
capital cost savings			
Hours of fab downtime over 5 years		from above	132.3 hrs
Average tool cost	$2,000,000		
Per day capital cost over 5 year life		$2M/365 X	$1,096
Cost of downtime over 5 years		132.3/24 X $1,096	$5,799
Cost of ownership multiple to capital cost		2	
Reduced total cost of ownership over 5 years		2 X $5,799	**$11,599**

total savings over 5 years
WITH Autocalibration technology **$39,039**

Lost potential revenue without Autocalibration technology **$14,700,000**

When a bottleneck tool requires calibration, the downtime for that calibration results in lost production. Manual calibration requires far more downtime than using Autocalibration technology, resulting in far greater loss of production and revenue.

	input assumption	calculatio	result
cost of lost capacity on bottleneck tool for ONE manual calibration			
Time savings per calibration		above	4.9 hrs
Operating throughput (wafers per hour)	300		
Value of a finished wafer	$10,000		
lost potential revenue		4.9 X 300 X $10,000	

WITHOUT Autocalibration technology **$14,700,000**

Autocalibration Technology in the

WaferServer™ XL

Moog's WaferServer XL is a high-throughput 300 mm wet bench front end. It provides an instructive example of Autocalibration technology implementation and performance. The two RTZ robots (Input and Output) are automatically calibrated to all the objects with which they interface during normal operation. As is the case for normal WaferServer XL operation, the calibration routines involve coordination across three Ethernet-networked controllers. State information is available to all controllers, and motion is fully coordinated. With Autocalibration technology, this thirteen-axis front end is calibrated in less than six minutes, with a very high level of consistency from calibration to calibration. WaferServer XL calibration is rapidly and precisely achieved through the following sequence of steps:

1. The Input robot is calibrated to a backlash reference using both thrubeam-optical and touch calibration methods. This provides information on robot performance, available for e-Diagnostics, and a calculation of robot backlash for use in fine-tuning the positions found in touch calibration for the remainder of the calibration routine.

2. A master FOUP is clamped on the input PDO. The robot's laser wafer mapper is scanned past a reference block on the master FOUP to determine Z position. The robot touch calibrates to a reference post in the master FOUP that represents the correct wafer center in a FOUP.

3. The robot is calibrated to the single-axis notch aligner. The robot's laser wafer mapper is scanned past the edge of the wafer chuck to determine its Z position. The robot then touch calibrates to the notch aligner chuck and a reference post associated with the notch aligner's CCD sensor.

4. The robot is calibrated to the Twist-and-Rotate (T&R) robot handoff position. The robot's laser wafer mapper is scanned past a T&R reference plate to determine the target Z position. Theta and radial position calibration is to an optical sensor reference located on the T&R reference plate.

5. The Output robot uses the same calibration techniques for the T&R, backlash reference, and PDO in its operational realm.

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Thirteen axis front end calibrated in less than six minutes

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Moog has been awarded four U.S. Patents for its Autocalibration technology. Other Moog patents are pending. Autocalibration® technology is a registered trademark of Moog Inc.