Genmark Automation, Inc. - Technology Highlights

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Genmark Automation has been a leading designer and manufacturer of high-performance material handling and integrated systems, by introducing and implementing cutting edge technologies in robotics and automation. Highlights of these technologies and their benefits are provided below

Yaw-Axis

The "Yaw-axis" approach to the design of wafer handling robots came in response to the requirement for orthogonal arrangement of the wafer carriers and processing equipment. The first "Yaw-Axis" wafer handling robot was developed by Genmark, patented and introduced to the market in 1997. The manipulation dexterity introduced by the additional servo controlled axis allowed the tool builders not only to arrange their equipment in an orthogonal manner, but to optimize the performance of the material handler by planning a wide variety of smooth trajectories including straight-line segments in the Cartesian space. This wide variety of motion paths also allowed for motion optimization, flexibility in arranging wafer processing and metrology equipment, obstacle avoidance, and as a result - enhancing the overall performance and reducing the cost of the wafer processing tools. The introduction of the "Yaw-Axis" technology made it possible to perform the material handling with robots with stationary base (body) and to outperform and eliminate the more expensive, space consuming and less reliable "Robot on a Ttract Approach". The IP of the "Yaw-Axis" technology was protected by the following Genmark Automation Patents: US06121743, US06297611, US05789890, US06037733

Dual-Yaw

The "Dual-Yaw" technology is an extension of the "Yaw-axis" technology intended to provide a fast wafer swap with single arm robots. The two independently controlled "Yaw" axes and associated end-effectors make it possible to design smooth motion paths comprising straight-line segments for accessing orthogonally arranged equipment by the two end-effectors. The "Dual-Yaw" approach is a cost-effective alternative of the "Dual-Arm Robot on a Horizontal Track" approach and is especially applicable to scenarios with stronger constraints imposed on the operational area of the material handler (not enough space for a horizontal track, not enough swinging envelope at the end-stations, etc). Genmark Automation invented and introduced to the market the first "Dual-Yaw" robot in 1998. The IP associated with this technology was protected by the following patents: US06121743, US05789890, US06037733

GPR

In many wafer-handling applications, the robot is required to vertically move the wafer or to tilt it during motions with mechanical constraints imposed by the equipment (wafer carriers, process modules, etc.) This requirement becomes even stronger if there is an uncertainty in the equipment placement or if the robot-arm deflects due to the weight of the manipulated object. In order to precisely match the orientation of the equipment, the robot must be able to perform small "Roll" and "Pitch" motions in addition to the "Yaw" motion. "Roll" and "Pitch" motions in the range of ± 1.5 degrees cover the majority of the equipment placement deviations and arm-deflection ranges. In 1996, to combine the wide motion range and the dexterity of the serial manipulators with the preciseness of the parallel manipulator in small motion range, Genmark Automation, Inc. has introduced a hybrid "Parallel-Serial" manipulator called the "Global Positioning Robot", or "GPR". The GPR inheriting higher accuracy, increased stiffness, modularity and simpler inverse kinematics from the "Parallel Manipulators" meets the requirements for precise and fast wafer handling in the face of environmental uncertainties and arm deflections. The following Genmark patents cover the IP associated with the GPR Technology: US05954840, US06085670, US6489741.

Robots for Fast Wafer Swap

The fast wafer swap is considered to be one of the most important factors for increasing the performance of the wafer processing machines. The prerequisite for a fast wafer swap is the availability of a second independently driven arm ready to place an unprocessed wafer into the process chamber as soon as the first arm takes the processed wafer from the chamber. The dual-arm concept considerably shortens the wafer exchange time and eliminates the extra movements from the process chambers to the source cassettes as with the single arm concept. Similarly to the single arm robots, the dual arm robots can also be placed on linear tracks to serve in-line arranged equipment. A new design of a dual-arm robot from the GPR series, with less moving masses and better dynamic performance, was introduced in 1999 as an alternative to the dual-arm robots on a track. The new robot named the "GPR-Swap Master" inherits the stability of the GPR and the dexterity of the anthropomorphic robots. The robot combines the functionality of a three-link serial arm, which performs fast linear motion, with the motion of two lightweight arms for fast wafer swapping at the process chambers, source cassettes / FOUPs, prealigners, etc. The decoupled mechanics of the robot contribute to its modular design, simplified control, teaching, and programming. The "GPR Swap Master" technology is protected by US Patent 06297611

Motion Planning and Control

The performance of the substrate handling robots is exceedingly dependent on the way the motion is planned and executed. Genmark Motion Control Software implements advanced approaches to motion planning, coordination, transformation and execution in order to guarantee effective material transfer within the constraints of the processing tools. These approaches include but are not limited to:

- **Smooth motion profile generation via Bernstein-Bezier Curves (BB)** - Introduced in 1995 the motion profile generators based on BB-Curves guarantee smoothness at position, velocity, acceleration and jerk level. The inherent natural parametrization V(S) provided by the BB-Curves makes the quality of the motion planning insensitive to the real-time jitter, latency and variations in the system time-slice due to increased computational burden.

- **Generation of complex smooth motion paths based on Bezier Curves** - Vast variety of motion paths, based on Bezier curves provided to the user in order to optimally fit the motion paths to the tool-geometry.

- **Motion overlapping for enhanced performance** - typically the motion path of the robot consists of segments with zero velocities and accelerations of the robot axes at the segment end-points. Having the robot to completely stop at the end of each segment is not always necessary and segment overlapping is typically allowed by the geometry of the tool. The resulting motion is a superposition of the moves along adjacent segments, which it turn leads to a significant time-saving (in the range of 30%).

- **Uninterrupted Trajectory Motion** (Blending PUT and GET commands) - When the sequence of motions is known in advance based on deterministic process recipes one can overlap successive "GET" and "PUT" commands and to minimize the motion stops necessary to synchronize with processing equipment.

- **Singularity Consistent Motion Planning** - this approach is applicable when the configuration of the robot arm gets in a close vicinity of a singular configuration. In such a vicinity the execution of the planned motion typically requires high-enough velocities / accelerations of the motors, which may exceed their operational limits. In order to preserve the planned motion path, the planned velocities and accelerations get "intelligently scaled" based on the "distance to the singularity".

- **Collision prevention software -** based on elaborate geometrical analysis of the constraints imposed on the robot motion, the collision prevention software monitors the robot motions for compliance with the constraints and prevents collisions due to operator "mistakes" during the robot teaching process.

- **Optimal PID tuning -** facilitates the process of tuning the PID filter parameters and guarantee optimal servo-loop performance in compliance with constraints imposed on the PID filter coefficients or on selected characteristics of the motion. This approach is based on the Constraint Optimization Method of Jeeves and Hooks, which does not require knowledge about the robot model (normally not available with the required degree of accuracy) and derives PID filter coefficients that minimize user-defined performance target. The method guarantees optimal PID tuning in the face of complex loading, motion geometry and kinematics.

- **Motion Optimization** - this is an extension of the Optimal PID Tuning approach based on Hooke and Jeeves method, to more general motion optimization tasks such as determining motion parameters that guarantee smallest cycle time; optimal calibration of measurement equipment (e.g. wafer aligners); optimal substrate-aligning; automatic teaching, etc.

- **Centralized, Multi-Axis Motion Controllers** - capable of controlling up to 24 DC brush/brushless servo axes

- **True-Absolute, Multi-Turn Enco**linear**der Interface Support** - the absolute position of the motors is permanently available and there is no need for dedicated homing hardware. Eliminating the homing hardware and having the servo-loop closed on absolute motor positions contributes to increased reliability of the robotic system.

- **Distributed Control Architecture Option** - allows to place single axis control nodes next to the motors, allowing to significantly simplify the wiring of the robot.

- **Advanced Kinematics and Dynamic Control Schemes** - allow for kinematic support of a wide variety of mechanisms and for improving the motion tracking performance by introducing model based dynamic compensations

“On-the-fly” Wafer Centering and Automatic Motion Path Correction

In a variety of wafer handling applications, there is no need for orienting the wafer but only to center it so as the last can be safely inserted into wafer carriers or process stations. Orienting the wafer requires a dedicated wafer aligning device (wafer prealigner) but wafer centering is fully within the capabilities of the robot, provided information about the wafer center misplacement with respect to the end-effector of the robot becomes available. The most effective way for acquiring the subject information is to use through-beams and fast robot position capturing based on the beam-breakage by the wafer. Genmark has designed and implemented, fast, computationally effective and robust computational schemes for calculating the wafer offsets during the motion of the robot. This allows for “on-the-fly” wafer offset compensation through pre-planning the motion path so as to deliver the wafer centered at the final destination and to comply with the motion constraints. The effect of the on-the-fly wafer centering is significant throughput increase. The beam-based wafer centering approach is also used for auto-calibration of the robot and automatic station teaching.

Deflection Compensation

The “Deflection Compensation” is patented Genmark technology primarily attributed to the GPR robots. As the last have the ability to tilt and to accommodate for equipment misalignment and deflection of the arm due to the load of the manipulated object, the task for maintaining the orientation of the object during the constraint motion of the robot becomes of significant importance. To this end, the straight-line (X, Y) motion of the center of the object is synchronized with the vertical (Z) motion of the robot so as the wafer remains in one and the same plane (coincident with the plane of the respective slot of the wafer carrier/process station) during the constrained motion. The deflection compensation technology is very effective in high-payload applications, such as carrying multiple wafer platens, bonding-fixtures, flat-panel-displays, solar panels, etc. The “Deflection Compensation” IP is protected by US Patent 6489741.

Automatic Calibration, Teaching (EZTeach) and Diagnostics

The goal of the auto-calibration is to derive calibration parameters of the robot or associated equipment without or with minimum participation of the operator. To this purpose, dedicated sensor-arrays, based on through-beams, CCD, etc., are used to correlate reference positions with actual positions of the robot and to identify respective calibration parameters. Similarly, the coordinates of stations associated with equipment can be automatically derived if the physical position of these stations is acquired by the robot through appropriate sensor-array.

The station coordinates are represented in terms of robot axes positions and therefore they are robot dependent. The robot is used as an instrumstockersent for measuring and calculating the Cartesian coordinates of dedicated beams from the auto teaching sensor-array. These coordinates are used to calculate the displacement (position and orientation) of the equipment coordinate frame with respect to the world coordinate frame. The result is then transformed into robot axes positions to obtain the pickup coordinates of the station.

In addition to auto-calibration and auto-teaching provisions, Genmark provides effective means for diagnostics, monitoring and recording of the robot-state, and tools for facilitating the operator interface and interaction with the robot. Dedicated diagnostics scripts residing in intelligent PDA based Teach-Pendant-Terminals or in the host-computer make the diagnostics process effective and less-dependent on the qualification of the servicing personnel. Equipment specific teaching wizards, streamline the teaching process and make it uniform and less dependent on operator's teaching skills. Last but not least, a dedicated "Black-Box" device embedded in the robot monitors and records the most important state-parameters of the robot, keeps robot specific calibration data, registers critical exceptions thus facilitating the robot diagnostics, maintenance and support.

Vacuum Technologies

Genmark designs and manufactures a wide spectrum of vacuum robots, covering all possible needs for material handling in vacuum. The enhanced payload capabilities (up to 30 lbs) and extended vertical travel (up to 9") widens the application scope of these robot from being single wafer handlers to manipulating heavy wafer-platens for LED applications. The extended vertical travel of the robots provides for effective wafer indexing thus eliminating the need for vacuum elevators for a wide range of applications. GPR vacuum elevators, with extended vertical travel (16") and high payload (150 lbs) provide excellent indexing (with 0.0002" resolution) of heavy equipment. Two different vacuum robot families - "Swap Master Vacuum" and "GPR Vacuum Swap Master" guarantee fast wafer swap in vacuum ($<$ 4 sec). The "Swap Master Vacuum" is one of the very few robots in the market employing "true absolute multi-turn" encodstockerser interface, no-homing provisions and endless global rotation.

In addition to the substrate handlers in vacuum, Genmark designs and manufactures turn-key cluster-tool solutions comprising various geometry and sides vacuum transfer chambers, load-locks, buffers, vacuum prealigners, etc. The integration and control software provides means for path and motion sequencing optimization, collision avoidance, material monitoring and auto teaching through dedicated sensor arrays located on the vacuum transfer chamber.

450 mm Wafer Handlers

Having invested in the development of high-payload material handling systems and approaches to effectively control the motion of these systems Genmark acknowledges its readiness to fully support the 450 mm wafer handling both in atmosphere and vacuum. Genmark's GB8YP robot was recognized as the best performance and reliability 450 mm wafer handled by the Sematech ISMI 450 mm Test Bed.

GRex

In an attempt to optimize the price-performance ratio of its material handling robots Genmark, in 2008, Genmark introduced its GRex robot series, characterized by

- Extremely simple mechanics and actuation and highly reduced part count
- Light weight - weight less than a half compared to equivalent competitive products
- High reliability, serviceability and maintainability

The IP of GRex is protected by US 2008/0121064 A1

Batch Handling

This is an effective approach to increasing the performance of the wafer handling systems carrying simultaneously multiple wafers with constant or variable (servo-controlled) pitch. The last is especially effective for vertical furnaces equipped with wafer-boats with various pitch.

Extended Vertical Travel Material Handling

In order to optimally use the expensive real-estate in the FAB, Genmark has developed a series of extended vertical travel material handling systems allowing for equipment stack up, building high-performance vertical furnaces, FOUP stockers, substrate stockers and sorters, etc. The extended vertical travel material handling systems are typically based on vertical tracks combining the vertical motion of the last with the one of the robot.