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Maximizing Optical Alignment Precision by Choosing the Correct Positioning Architecture

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Advancements in silicon photonics and micro-optic technologies are driving automated alignment tolerances down to nanometer levels. Misalignment between optical components in today's photonic devices directly impacts the quality of light transmission, and only a few micrometers of misalignment can result in final device power losses of 50% or more (Figure 1).

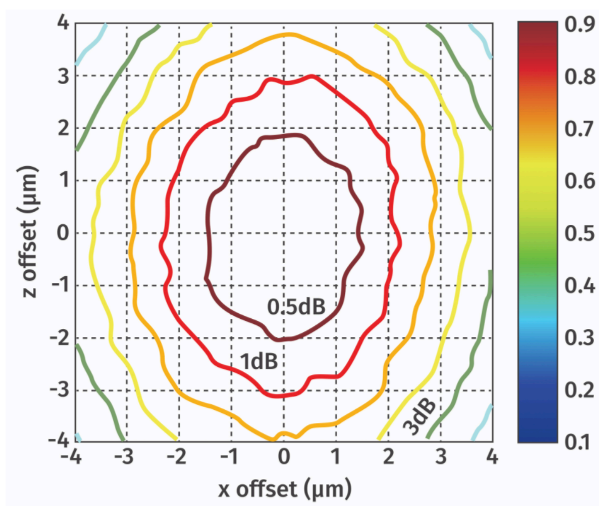

Figure 1. *Power loss between an optical fiber and silicon chip due to misalignment in 2D space.*

Photonic device manufacturers are rushing to develop new alignment techniques and hardware to keep up with spatial tolerance requirements between optical components. These spatial tolerances can be controlled during automated alignment processes by implementing the optimal positioning system architecture.

There are two types of architectures: serial kinematics and parallel kinematics. Both differ in spatial configuration, programming and required hardware, and choosing the ideal architecture can be challenging. The guidelines that follow shed light on the architectures available and when to implement each.

Architecture Choices – Serial vs. Parallel Kinematics

Serial positioning architectures use a single actuator to position an optical component in one direction in space. Serial systems can be stacked on top of each other to achieve positioning requirements in all six degrees of three-dimensional space (three linear and three rotational). Parallel positioning architectures use multiple actuators to position an optical component in one or more directions in space. They too can be configured to achieve positioning requirements in all six degrees of three-dimensional space. See Figure 2 for hardware examples of each kinematic approach.

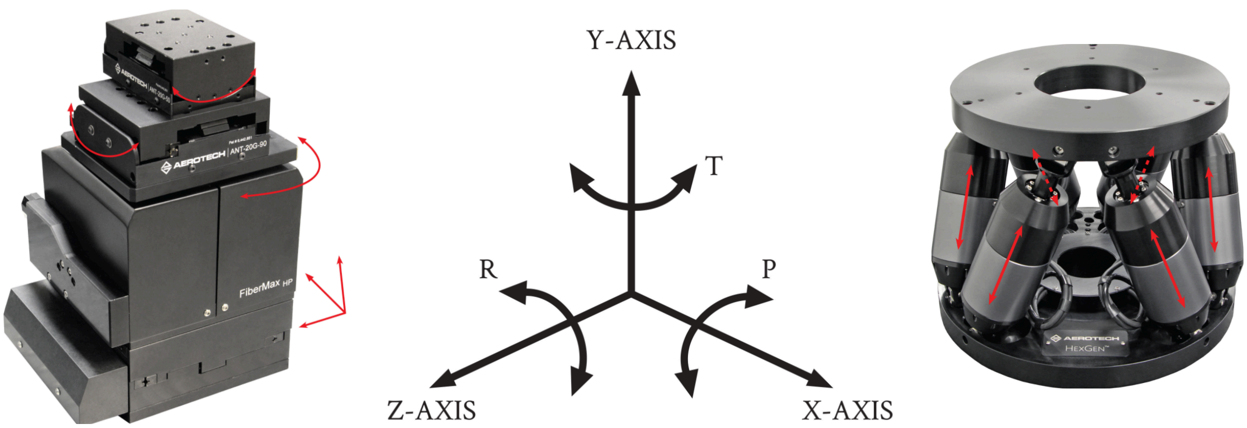

Figure 2. *An example of a 6-degree-of-freedom (DOF) serial motion platform in the form of stacked single axes of mechanics (left) and a 6-DOF parallel kinematic platform in the form of a hexapod (right). Each red arrow indicates the direction of motion for the actuator.*

Each architecture enables the user to program in three dimensional space. In addition, each allows for the selection and programming of a point in space about which rotations may be performed. This is useful for aligning arrays of components, such as a fiber block of multiple incoming fibers to a chip with multiple waveguides. There are limitations in terms of achievable precision between the two kinematic approaches, especially at the point of interest where the alignment process is being executed.

The Case for Serial Architectures

In general, the highest level of alignment precision can be achieved with a serial design because serial systems provide the following:

1. Better positional accuracy at the work point where the component being aligned is held
2. Smaller incremental step sizes in each direction of motion
3. Better repeatability when returning to previous positions

Serial systems exhibit these advantages because they limit the number of actuators moving at any given time. For example, in the parallel hexapod system shown in Figure 2, all six actuators move at the same time to move the payload in a single direction of motion. This means error motions from the individual actuators are compounded. A serial system simplifies the motion requirements since each axis moves independently of the others and only moves when needed. This allows serial systems to align optical components with less motion-induced error.

Furthermore, the joints required by parallel kinematic systems add motion-related error due to mechanical compliance. Serializing the motion eliminates these additional joints and leads to serial devices capable of individual motions, or step sizes, of less than 10 nanometers while providing travels of hundreds of millimeters. This long travel is useful for ancillary processes like part loading and tool changing.

Other notable advantages of serial platforms are increased design modularity and simplified programming. As shown in Figure 3, the axes can be separated, reducing the working height while still allowing the user to program in all six degrees of freedom.

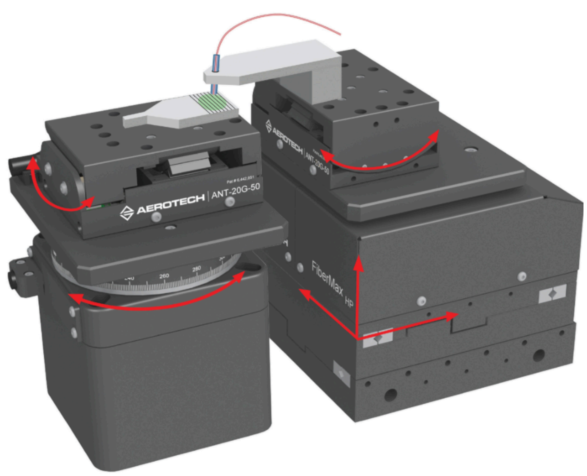

Figure 3. *A split serial kinematic system capable of positioning in all 6 degrees of freedom.*

This flexibility is often lost with parallel kinematic systems due to the need for mechanical linkages between the actuators. Additionally, the linkages between parallel-kinematic actuators require transformational code to be written into the motion controller so the user can program in familiar coordinates (for example, Cartesian space). These transformations make simple operations such as finding home references for each axis very complicated. Serial architecture eliminates the need for these more complex transformations.

The Case for Parallel-Kinematic Architectures

Parallel-kinematic designs generally cannot achieve the positioning precision of serial designs. However, they are better-suited for use in some cases. Primarily, if the physical footprint of the alignment station is of concern, or if there is limited space to add motion control, parallel-kinematic approaches can help. The actuators do not have to be stacked on one another as with serial systems, and can be placed much closer to each other. This means that the footprint of the motion system can be reduced up to 50% in the vertical direction. Another advantage of a parallel architecture is the freedom to place actuators where needed to improve stiffness and rigidity. If designed correctly, multiple actuators can share the burden of the payload simultaneously. This allows users to position heavier payloads without concern for positional stability while the components are bonded into place.

Commercially-available parallel-kinematic systems are capable of high accuracies and resolutions, as shown by the XY plane positional error plot in Figure 4.

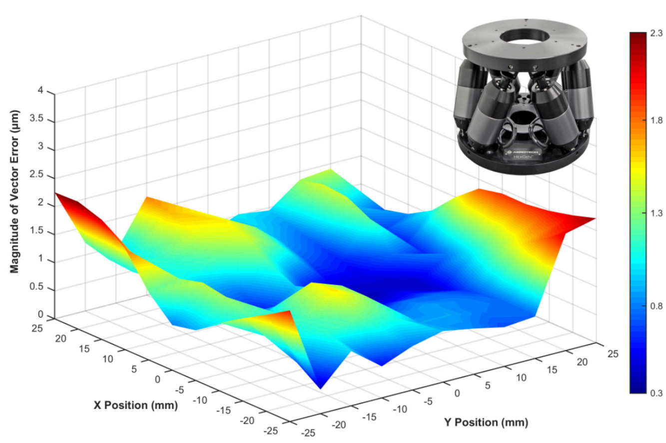

Figure 4. *A plot of the XY plane position error using an Aerotech HEX300-230 six axis hexapod.*

High-precision mechanics, alignments and advanced calibrations are required for parallel-kinematic devices to achieve similar results as serial systems. However, an experienced supplier of parallel-kinematic motion systems can do this in a way that is essentially transparent to the user.

The Case for a Combination Approach

Since each positioning architecture has unique benefits for optical alignment systems, it makes the most sense to combine them where appropriate. Using serial architectures for high-precision processes and parallel architectures for reducing platform footprints and increasing load capacities will maximize performance of the total alignment process. It is then important to choose an automation supplier who can easily combine both serial and parallel architectures in a single package. This gives the designer more hardware tools to implement and offers the programmer a single platform with which to develop the application software.

Aerotech supplies both serial and parallel-kinematic alignment solutions. Our control system is architecture-agnostic, so we can implement the appropriate solution depending on the application requirements (see Figure 5).

Figure 5. *Aerotech's Automation1 software-based machine controller combines serial and parallel-kinematic architectures into one user interface.*

Applying this approach allows the user to maximize the precision and functionality of any optical alignment process.

Case Study: A Combined Alignment System

Due to the immature industrial supply chain for automated photonics alignment machines, users of these machines often ask for purpose-built platforms based on the optical components being aligned. This spurs flexibility and allows the machine builder to select automation and positioning systems that fit the exact needs of the application. One case where this flexibility has been used was to align a semiconductor laser source to a microlens and then to an integrated waveguide on a photonics integrated circuit. In this situation, there were multiple components that needed to be aligned simultaneously and precisely to each other in order to transmit a sufficient amount of light into the photonics integrated chip. Each of these photonic components required multiple small positional translations with respect to each other, and they also needed to be translated in a space-constrained environment because of limited accessible working volume. To further complicate the machine design, a high-speed automated parts loading step was required.

A combined serial and parallel kinematic positioning system solved the multiple variables and constraints this application presented. A high-speed overhead gantry platform was implemented for the loading and unloading of optical components (Figure 6).

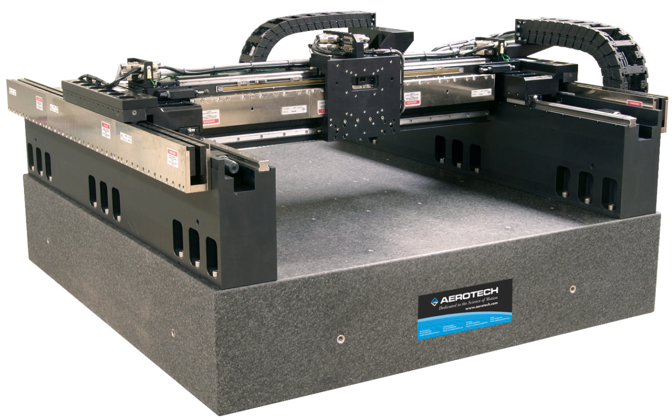

Figure 6. *An Aerotech AGS15000 gantry used for overhead high speed pick and place loading and unloading operations.*

Its throughput depended on a reduced and stiff payload, so a parallel kinematic six degree of freedom hexapod was added between the gantry's moving carriage and the part gripping tools. Finally, to enable the highest possible light transmission between the laser, lens and waveguide, a high-precision serial architecture system was placed on the base below the overhead gantry. This serial system was separated into two modules to allow the photonic integrated chip and laser source to move independently. This also provided enough working volume in between the laser source and chip for the parallel kinematic hexapod to manipulate the microlens into its optimal position. Ultimately, all components could be aligned simultaneously with sub-100 nanometer precision, which allowed for reduced transmission light loss supplied to the photonics chip.

Overall, this system was designed and purpose-built for the specific components that needed to be aligned. The flexibility allowed the design team to choose the best positioning architectures that were available. After the machine was built, the ability to control and program the parallel kinematic hexapod simultaneously with two separate serial positioning systems and gantry was beneficial. This functionality allowed the design and implementation teams to reduce the control system's complexity and software development's timeline, which brought the product to market faster. When building an automated optical alignment station, both serial and parallel positioning architectures should be considered in order to take advantage of their individual strengths.

About the Author

RJ Hardt is the President of Peak Metrology, an Aerotech company focused on surface metrology equipment. He has over a decade of experience working directly with customers implementing motion control and automation technologies.