Automated Fiber Alignment Engines

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Computer controlled fiber aligners help process engineers achieve higher throughput in photonics packaging applications

Before the telecom boom at the end of the last millennium, fiber alignment was a tedious manual task. Automated fiber aligners made a big difference. Here's a look back at the first devices and an outlook on what is possible with today's technology

Analog Gradient Search

This *analog phase demodulation* hill-climbing technique works for clean, quasi-Gaussian couplings already near optimal alignment. However it will lock-in on local maxima and "flat spots" which occur in multimode couplings, with imperfect devices, or far from optimum alignment. Nevertheless, instrumentation based on this principle was popular, though bulky and providing too little travel range for fully automated fiber-alignment.

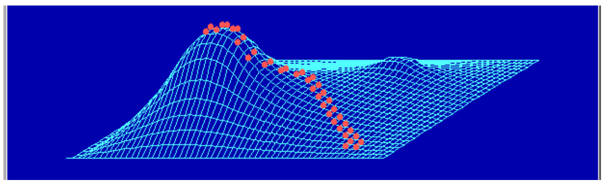

Figure 1. A digital gradient search optimizes coupling by iteratively sensing the local gradient and climbing the hill. It is one way to achieve fully automatic fiber alignment over long travel ranges.

Digital Alignment Algorithms

The first *digital* gradient search technique was introduced in the early 1990s to allow fiber optic devices to be efficiently aligned using motorized linear stages of the day, which were low in speed, resolution and synchronization capabilities compared to today's piezoelectric nanopositioners.

Flexibility was an advantage of this class of automatic fiber aligners, plus the massive motorized positioners on which these systems were built were a good match for the emerging industrial era of photonics.

Angular alignment

However, the architectures mentioned above did not cover angular alignment. Three new types of photonic devices made angular alignment a mainstream concern:

- Planar waveguides emerged as key players in switching and modulating in photonic networks. Angular alignment (especially in θ_z) needed to be automated.
- Optical switches based on steering of collimated beams necessitated throughput-optimized gimbaling alignment of collimators and other optical elements.

- Confocal optical trains (COTs) in photonic packages had sensitive angular alignment needs.

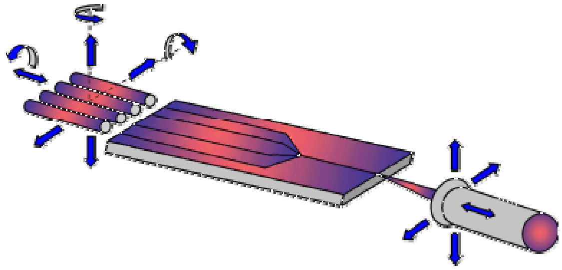

Figure 2. Waveguides are one of several classes of devices needing angular alignment.

These needs, in addition to unabated alignment requirements for high-throughput transverse alignment, drove the introduction of PI's F-206 hexapod 6-axis fiber alignment system. This instrument combined six ultra-precision actuators with a stictionless kinematic flexure coupling design.

Figure 3. The F-206 HexAlign hexapod micro-alignment system provides six degrees of freedom of 0.1µm-precision motion in a vastly more compact and responsive package than any equivalent stack of stages. Fiber-optic alignment animation at http://www.youtube.com/watch?v=vA0Zea4s9PQ

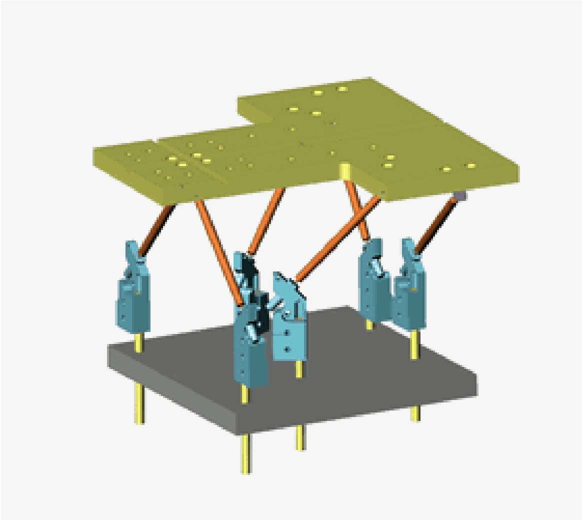

Figure 4 Motion engine of the F-206 parallel aligner. Animation available at www.youtube.com/watch?v=MEMQmtUCMeEA

Compact and swift, it integrated a fast photodetector and a flexible assortment of sophisticated digital algorithms for autonomous fiber alignment automation in up to six degrees of freedom. It has been continuously improved over a decade with updates in mechanics, controller design and software.

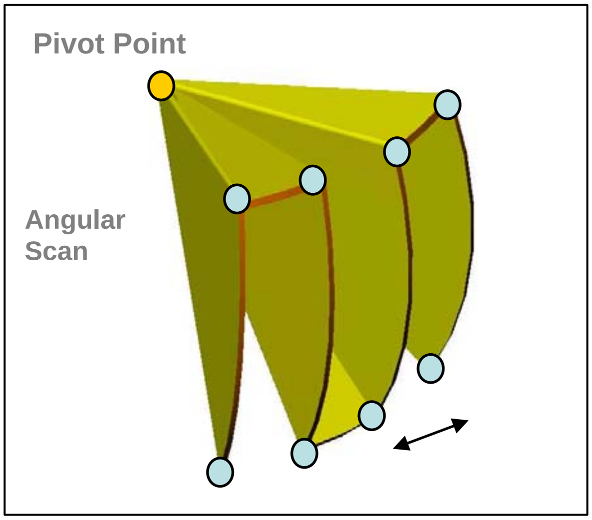

Figure 5 Angular scans around the tip of a fiber or focal point of a fiber optic device can be programmed with a few commands .

Significant Advantages

A key advantage of the *hexapod* parallel kinematic approach is the ability to cast the rotational pivot point anywhere in space. Conventional stage-stacks are limited to rotating about the fixed mechanical centerpoint of their rotation stages and goniometers. This is defined by their bearings and fixturing structures and cannot readily be moved around. With the hexapod, process engineers gained the capability to place the rotation point about an optical sweet-spot with a single software command, a significant advantage for alignment of complex fiber-optic components. Examples include:

- For multichannel waveguide alignments, the rotation can be about the first optical channel.
- In collimator-collimator alignments, the rotation can be centered on either collimator's face.
- For COT alignment, the alignment can pivot about its focal point, which might be buried inside a package and only blindly accessible by tweezers.

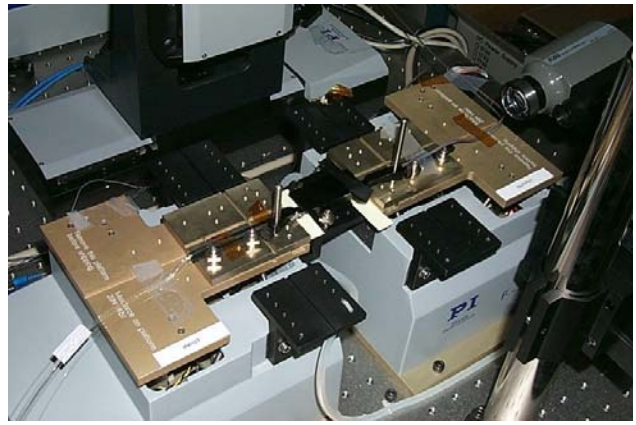

Figure 6. By integrating six degrees of freedom, F-206 facilitates complex alignments like this 10-DOF waveguide MUX/DEMUX packaging.

New Hexapod Options, New Fiber-Optic Alignment Power

Recent advancements in hexapod design and controls has now enabled a host of robust, high-load, long-travel hexapods to be deployed for high-throughput industrial alignment applications. Building on established designs featuring high stiffness, highly triangulated geometries, these systems offer travel ranges of several centimeters while accommodating loads of many kilograms. These designs are suitable for use in any mounting orientation and offer up to 50% higher acceleration than previously possible. In addition to integrating optical metrology with the hexapods' six degrees of freedom plus two additional linear or rotary axes of motion, their powerful new controllers integrate data recorders for precise correlation of optical power with position. 100x100μm scans can be achieved in as little as 650msec with these speedy mechanisms.

Interfacing options have also expanded and improved, with standard TCP/IP and USB ports offering high-speed communications and compatibility with factory automation architectures. New, optional remote-control pad/displays offer hands-off manual operation. A thoughtfully designed software suite offers GUI setup and configuration tools as well as Windows and Linux libraries and a comprehensive, well-documented, native and open-source LabVIEW library— an unusually broad and deep software architecture in a field more typified by hasty wrappers constructed as an afterthought around some single-platform implementation.

Figure 7. Advanced new hexapod options offer reduced size, longer travels, higher load capacities and faster alignment throughput for demanding industrial packaging applications. More information on hexapods at www.hexapods.net

A Modular Piezo Fiber Alignment Engine for Transverse Alignments and Tracking

As the telecom boom crested in the early 2000s, we were approached by a leading player to provide an especially cost-effective, robust and flexible fiber alignment platform for coarse/fine transverse alignment. The customer specified a simple stack of stages including our NanoCube XYZ nanopositioning stage, which provides 100 microns of travel in three orthogonal axes with 2nm resolution.

Figure 8. The CyberAligner fiber aligner coarse/fine stack provides up to 25mm standard travel with 2nm resolution. Modular construction means any travel range or configuration needs can readily be accommodated.

Three motorized stages would allow many millimeters of coarse positioning to accommodate different devices in the customer's production. The system was to be software-based, would take advantage of a new generation of fast analog I/O interfaces, and was to be modular, open-source and based on LabVIEW. We reviewed this and similar applications, noting challenges like fiber-through-tube package designs (which complicate the search for first-light) and irregular coupling cross-sections, which can impede gradient searches. We decided that comprehensive application coverage together with highly time-efficient throughput was possible with a two-step sequence:

1) A unique, space-efficient double-spiral-scan, using motorized long-travel stages, for first-light capture and rough optimization, followed by

2) An extremely fast raster scan (previously impossible without modern piezoelectric positioners and advanced controls), combined with synchronous data acquisition to compile the transverse coupling cross-section and identify the global maximum. This approach would literally align virtually anything in a flash.

The raster scan approach offers insensitivity to local maxima. The global maximum can always be observed and selected. This option had been unavailable a decade earlier due to the limitations of the motion devices of that day. Put plainly: since our piezo devices are so fast, why not collect lots of data to localize the global maximum directly rather than inferring the vector to it from the limited data older architectures could provide?

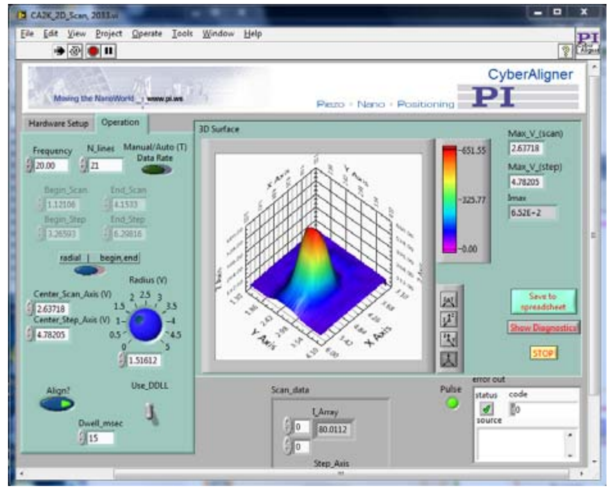

Figure 9. The CyberAligner graphical user interface, showing a device profile captured in a full-field scan in ~400msec.

Recently this architecture, called CyberAligner, has enjoyed many advancements:

- An upgrade to updated versions of LabVIEW,
- Leveraging the latest I/O capabilities provided by today's multifunction analog/digital hardware, including incredibly fast USB units,
- Motion code based on PI's GCS General Command Set, allowing any type of motorized stages to be used for first-light seek and coarse alignment: cost-effective stepper-motor, robust DC servo-motor, stiff and stable PiezoWalk® motor stages, or high-speed ultrasonic motor positioners and whatever will come next.

The updates further magnify CyberAligner's speed advantages. The coupling cross-section data produced during the alignment scan can be saved to a local or network drive, providing valuable process and device diagnostics in production. All-USB configurations are featured, cabling is simplified, and multiple workstations can be run off of one PC. Support for double-sided waveguide alignments is standard.

Combining the Best of Both Worlds

Recently a new search capability was integrated into the CyberAligner system. *CyberTrack,* an efficient implementation of the very latest gradient search algorithm, is based on a patented[i] technique for performing a digital gradient search on-the-fly. This has proven to be an ideal addition and enhancement of the fast CyberAligner double-spiral first-light search and fast raster scan:

1) For applications with worse than 100µm fixturing tolerances, PI motorized stages can perform a space- and time-efficient double-spiral scan to achieve first-light coupling.
2) A full-field (100x100µm) fast raster scan is performed by the Nanocube, building a detailed optical profile and selecting the global maximum for fine alignment.
3) The CyberTrack digital gradient search is then activated, quickly peaking up the coupling and tracking to accommodate any drift or disturbance.

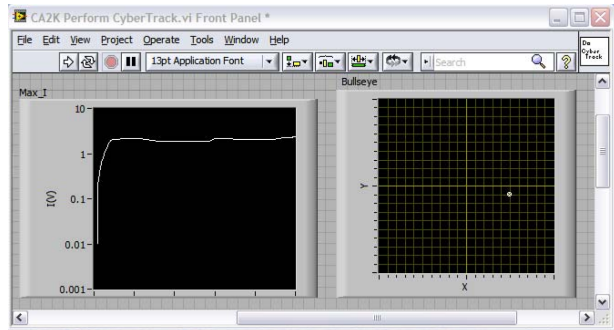

Figure 10. CyberTrack is a new capability for Nanocube and our other PZT mechanisms. Based on the latest digital gradient search, it offers high speed optimization and tracking and is easily integrated into production applications.

Implemented in platform-independent LabVIEW, this functionality is also readily accessed via ActiveX or MatLab. The combination of the fast raster-scan and gradient search offers remarkable speed for transverse alignments.

Figure 11. Quick, find the ping-pong ball.

The performance of the combined coarse/fine alignment is similar to finding a ping-pong ball in a basketball court and aligning it to better than the width of a dime in under two seconds… then tracking it as it rolls.

Summary: A Wealth of Solutions to Meet Every Need

The industry enters its renaissance with no shortage of production applications needing high throughput and high uptime. Fortunately, the photonics engineer's toolbox is well-stuffed with industrial-class solutions to meet all needs. From the H-206 flexure based fiber aligner and the new miniature H-811 hexapod and other robust hexapod solutions to the CyberAligner/CyberTrack modular software/hardware aligners, virtually any need and budget can be accommodated. The industry can look forward to enabling a new generation of applications challenges with these tools. For more information visit www.pi-usa.us/products/Photonics_Alignment_Solutions/index.php

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[i] "Aligning apparatus and method using on-the-fly determination of throughput-profile gradient for current positioning of radiated influence supplier and/or receiver," U.S. Patent #7,236,680