WHITE PAPER

OPTICAL FIBER ALIGNMENT

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Most optical networks have many fiber couplings and even minor losses at these junctions will produce significant signal losses that cause problems in data transmission. Precise fiber alignment at the optical couplings in a network is therefore a prerequisite for accurate and reliable optical data transmission since it produces the least signal loss before assembly or packaging of an optical system. Minimal signal loss also results in the lowest optical power requirements which, in turn, means fewer repeaters, lower capital costs and reduced incidence of failure.

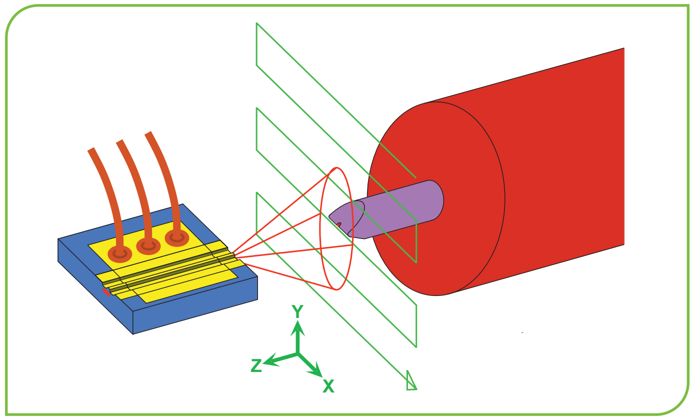

Figure 1. The operations and positional parameters of optical fiber alignment; (a) scan operations; (b) positional parameters for the optical fiber alignment.

Alignment Parameters and Procedures

Effective fiber alignment requires the precise adjustment of a precision motion control device and a suitable search algorithm that has been optimized for use in the alignment application. Figure 1 shows a typical search operation along with the positional parameters that are associated with optical fiber alignment. In the search procedure, the intensity of a well-characterized optical input beam (the laser diode in Figure 1) is compared against the output signal of the optical fiber being aligned.

Positional/Rotational Parameters

Motion controllers are employed that use a coordinate system in which an object is considered to have six degrees of freedom: three linear position parameters, along the X, Y, and Z-axes in a Cartesian co-ordinate system and three rotational parameters around those axes (see Figure 1(b)). All movements are defined in terms of translations along and/or rotations about the Cartesian axes. The fiber position is moved through a raster scan to detect first light - when the laser beam first enters the optical fiber (Figure 1(a)). Once first light is detected, the lateral, longitudinal, and angular coordinates of the fiber are incrementally adjusted to maximize the intensity of the optical signal output from the fiber. In the simplest case, only lateral (X, Y) adjustments are necessary, while in multi-channel cases, adjustments to all six degrees of freedom (X, Y, Z, θx,θy, and θz) may be required (Figure 1(b)).

Motion Control Parameters

Linear or rotary motion stages produce the controlled motions and trajectories that move objects during optical fiber alignment. The following parameters must be considered when selecting a motion system for optical fiber alignment:

- *Minimum Incremental Motion (MIM)* is the smallest increment of motion that a device can consistently and reliably deliver. It is the actual physical performance of the motion controller (as opposed to Resolution which is a theoretical capability and not a practical parameter) and can range from 100 nm to 1 nm. Smaller MIM comes at significant costs in terms of alignment speed and beam power increments. MKS Instruments’ XMS linear stages are capable of 1 nm MIM and 300 mm/s speed.

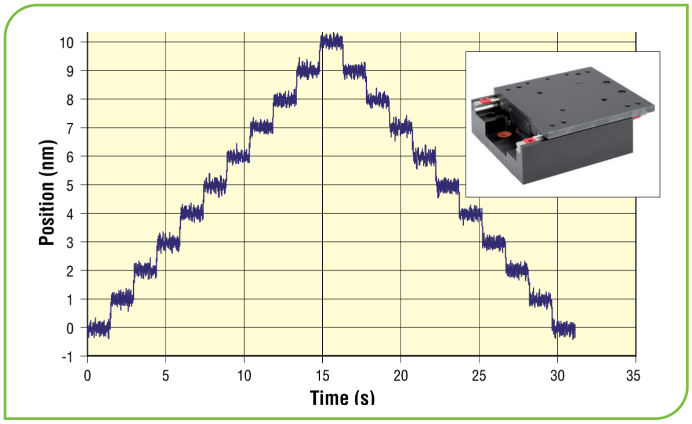

Figure 2. 1 nm MIM of an XMS linear stage;
Insert – MKS Instruments' XMS50-S Linear Motor Stage.

Repeatability is the ability to repeatably position an object. It can be unidirectional (always approaching the target position from the same direction) or bidirectional (approaching the target position from either direction). This parameter is important for quickly finding the peak power location for similar device designs. The XMS stage shown in the insert in Figure 2 has 80 nm bi-directional repeatability.

- *Position stability* is the ability to maintain a position within specified tolerances over a specified time interval. It is the sum of drift and vibrations, which typically varies between 0.5 and a few microns. Aligning fibers for assembly steps such as bonding

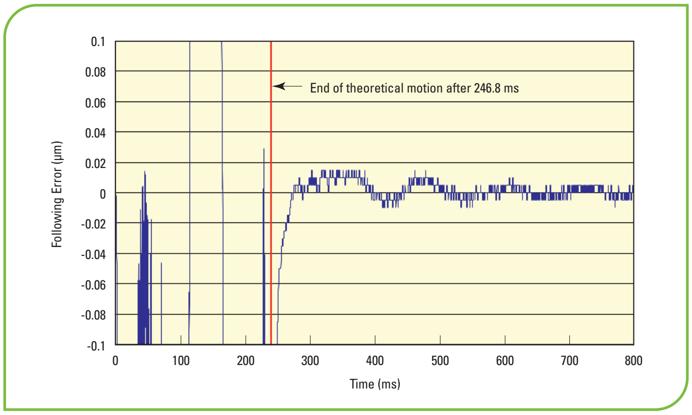

Figure 3. Step and settle characteristics of an MKS linear motion stage 250 ms after being moved.

  relies on the positional stability of the motion system. Figure 3 shows the positional stability of an MKS Instruments linear motion stage 250 ms after movement. The stage exhibits less than 20 nm variation in position stability after settling.

- *Other motion* parameters include: axis alignment, location of the gimbal point, system stiffness, pitch/yaw, thermal considerations, fixture design, Abbe error, etc.

Representative Search Algorithms

- Effective optical fiber alignment can only be achieved using a positional search algorithm appropriate to both the application and the step in the alignment procedure. Search algorithms can be classified into two categories: 1) those most effective for finding the first light; 2) faster and more precise algorithms for peak power location.

First Light Searches

There are two primary approaches for first light searches, raster scans and spiral scans. Raster scans, the simplest search method, scan a defined distance along one axis, index the position by a defined distance along another axis, then repeat the cycle. Raster scans, shown in Figure 1, are one of the quickest methods for finding the first light of the beam. Spiral scans are another approach used for first light searches. This method searches the general area of the beam by using a spiral motion generated by synchronizing controlled motion in the X and Y axes.

Peak Power Searches

After first light has been located, search algorithms other than raster or spiral scans are better for finding the peak power location. The choice of the peak power search algorithm depends on whether the beam has a Gaussian distribution or top hat profile having multiple peaks. The following examples are representative; a number of other methods exist:

- *Hill climb* is a simple 2D search for the highest power. It is most effective for beams that have a Gaussian profile and when the optical power quickly increases. The hill climb method, by itself, is not effective in finding peak power with flat beam profiles.

- *Centroid Search* moves along one axis and finds a peak then moves along a second axis to find the final peak. Centroid searches are useful with top-hat or multi-peak profiles.
- *Dichotomy Search* explores one axis at a time in large increments until a peak is identified. Within this peak, another search cycle is performed using finer steps to find the peak maximum.

Motion Control Systems

Different kinds of motion control systems can be employed in fiber alignment, ranging from simple manual stages suitable for small scale and R&D applications to fully automated production systems with high precision motorized stages, pick and place automation, dispensing and curing systems, machine vision, etc. The following are representative of the manual and motorized motion control systems employed in fiber alignment operations:

- *Manual stages* are the simplest and the least costly motion control systems for precise linear or rotational motion. They are used in R&D and low volume production environments. Figure 4(a) shows an MKS ULTRAlignTM 562 manual stage that has been motorized through the addition of TRA actuators.
- *Piezoelectric stages*, Figure 4(b), are compact, four to six axis alignment systems driven by piezoelectric actuators. They allow high-resolution (<30 nm) adjustment for different combinations of X, Y, Z, θx, θy, and θz and can hold their position without applied power.
- *Linear motor stages with direct read encoder* are the highest precision standard stages. They have 1 nm MIM capability when used with precision motion controllers. MKS Instruments' XMS linear motor stage, Figure 4(c), can quickly and easily search within a 10 µm diameter area of a beam region exhibiting the highest power.
- *XYZ assembly with ball screw drives* are compact stages available with either a 100 nm or 10 nm MIM and in left and right versions for single or double-ended configurations. Figure 4(d) shows MKS Instruments' 100 nm VP-25XA-XYZ.

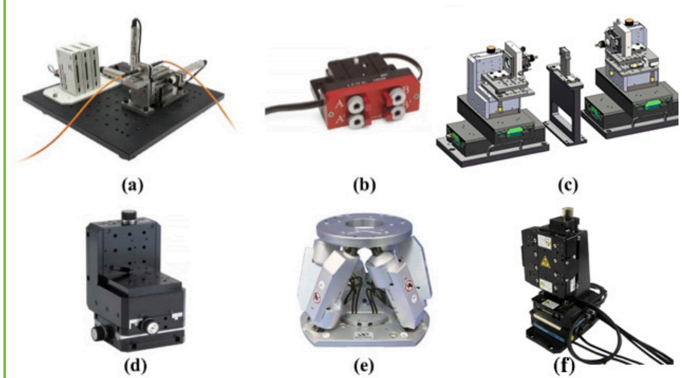

Figure 4. Manual and motorized motion stages: (a) Single fiber, single-end configuration with MKS 562 manual stages and CONEX-TRA actuators; (b) MKS 8071 4-axis aligner driven by PicomotorTM piezo actuators; (c) Double-sided configuration with MKS VP-25 and XMS stages; (d) MKS VP-25XA-XYZL integrated specifically for fiber alignment; (e) MKS HXP50 hexapod with horizontal and vertical beam paths; (f) MKS MLT-25XYZL/R integrated direct drive stages designed for fiber alignment.

- *XYZ assembly with direct drive motor*, providing 5 nm MIM. Also available in left and right handed configurations.
- *Hexapods* are mechanical devices that use six actuators, all moving in parallel, to provide 6-axis range of motion in a Cartesian coordinate system. Hexapods are more compact than stacked stages and capable of complex combinations of linear and angular motions useful for critical rotation adjustments. Figure 4(e) shows MKS Instruments' HXP50 hexapod. hexapods incorporate advanced innovations that are advantageous in fiber alignment applications:
- MKS Instruments' hexapods employ Work and Tool Coordinate Systems. These are programmable coordinate systems, shown in Figure 5(a), that enable independent manipulation of the Work (sample or device) or Tool (cutter or beam). Using this system, the user can simply send positioning commands in the Cartesian coordinate system.

- Hexapods can encounter difficulties in scanning applications that require a specific linear, rotational or arc path to be followed. Figure 5(b), shows the motion of a standard hexapod when commanded to move from one point to another in the X-axis (blue line). The deviation from a straight line in the path can be up to a millimeter. MKS Instruments' hexapods use RightPath Trajectory Control to minimize the run-out to a couple of microns, enabling the hexapod to more precisely follow specified linear, rotational or arc trajectories.
- *HexaViz simulation* – HexaViz is free, downloadable simulation software that allows customers to simulate loads, motions and potential collision for all MKS HXP hexapods.

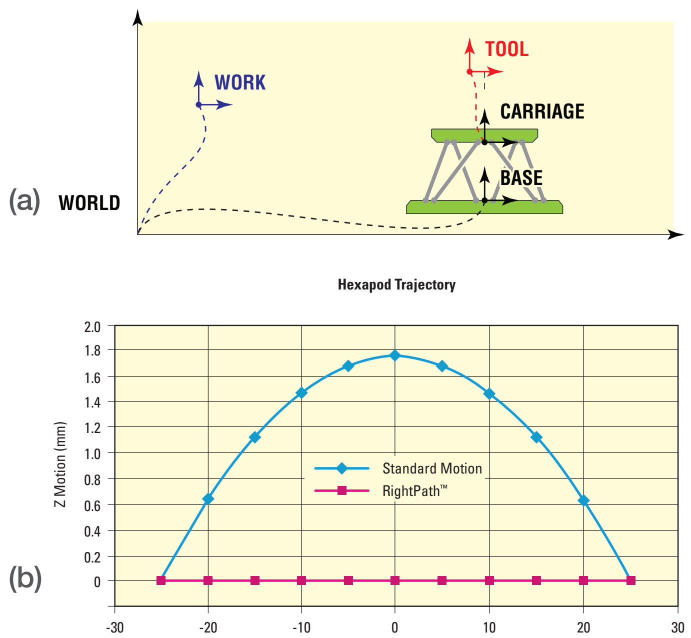

Figure 5. (a). MKS Instruments' HXP hexapod Work and Tool coordinate systems transformation of axes; (b) RightPath™ trajectory showing runout.

Other Fiber Alignment System Components

A complete fiber alignment system consists of the receiver or transmitter device, the device fixture or holder, a light source, a motion control system, and ancillary components. These latter components, some detailed in Table 1, include:

- Detectors that measure beam power; coupled with a power meter, they monitor the optical signal to determine the highest transmitted power. A beam profiler may also be needed to characterize the shape of the beam.
- Power meters, matched with detectors for the specific wavelength, the power range measured, and a minimum data transfer rate of 2 kHz for fast alignment and productivity.
- Vision systems that detect the proximity of devices and the rough alignment of fiber ends. A vision system allows a very small gap, so that the fiber ends are almost touching, maximizing the transmitted power.
- Dispensing/bonding systems that dispense an accurate volume of liquid epoxy, apply it evenly over the interface of two materials and cure it using UV light.
- Laser welding that employs highly localized heating to attach two parts together. This is typically an automated process used to attach the output fiber, lenses and the laser diode in a package.
- Pick-and-place automation for high volume, high speed production.

Table 1. MKS Instruments Components for Fiber Alignment Systems.

Reference Guide for MKS Instrument Component Selection in Fiber Alignment Systems			
	Research & Development	**Assembly/Production**	**Final Test**
Laser Source	LDC3726 and LDM Mounts	LDC3908/LDC3916 Modular LD Controller	N/A
Motion	CONEX-TRA/CONEX-LTA 562 Ultra Align Precision XYZ Manual Stages	XMS/VP/MLT Linear Stages HXP50 Hexapod	N/A
Power Detector	3A-IS-IRG 818-SL/DB	PD300-IRG 918-IS-IG	PD300-IRG 918-IS-IG
Power Meter	StarBright 1938-R	Juno and 844-PE-USB 1830-R	StarLite 2938-R
Wave Meter	OMM 6810B	OMM 6810B	N/A
Beam Profiler	LBP2 XC-130	N/A	LBP2 XC-130
Photoreceiver	N/A	N/A	1544 1474-A

Conclusion

Fast, accurate, and precise optical fiber alignment is critically important to the efficient operation of optical communication networks. Poorly aligned junctions between fibers and between fibers and optical devices result in excessive signal losses in a network which, in turn, results in higher equipment costs to avoid excessive incidence of failure. MKS Instruments provides a suite of motion control systems, search software, and ancillary system components that are ideal for use in optical fiber alignment applications. MKS Instruments' motion control components enable optical fiber alignment applications with accuracy and precision requirements ranging from low nanometer to sub-micron scale and with throughput requirements ranging from R&D to volume production.

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