Automated Alignment

A typical fiber-optic alignment application, fiber-to-fiber alignment, is shown in figure 8.29.

Usually one of the fibers is fixed in place, and the other fiber is mounted on a piezoactuated stage which moves the fiber in the horizontal and vertical axes. The goal is to have the fibers aligned so that laser light, propagating through the first fiber, is coupled efficiently into the second fiber and the transmission through the second fiber is maximized. Once the two fibers are clamped into their respective fixtures, the process should be automatic, without operator intervention.

A typical automated alignment setup is shown in figure 8.30. As an optical source, such as a laser, is coupled into the first fiber, an optical detector monitors laser throughput at the end of the second fiber. The power information is fed into an auto-alignment system which tells the piezoelectric controllers to drive the stage containing the first fiber into alignment.

There are two main steps to the complete process: first, a prealignment process locates the fibers close enough that some laser light propagates through the complete system, and then an autoalignment process maximizes the throughput, bringing the fibers into optimum alignment.

PREALIGNNMENT PROCESS

For the automated alignment system to work, a signal, however weak, must first be propagating through the complete system. Typically, fixturing is not sufficient to accomplish this task by itself, particularly with single-mode fibers. One way to prealign the system is to have the alignment system go through a blind raster scan of sufficient height and width that, at some point, a signal will be obtained. This technique works well for relatively simple, single-component alignment situations like that described above. For multiple-component situations (e.g., fiber array to waveguide to fiber array), the process can be quite time consuming and inefficient in a high-volume production application.

For high-volume applications, a prealignment process based on machine vision technology is the preferred option. Machine vision systems can identify all the components, determine their location, and provide relocation signals to the alignment system that are sufficiently precise to get a signal through the system. This is accomplished in a fraction of the time involved in the blind-raster approach.

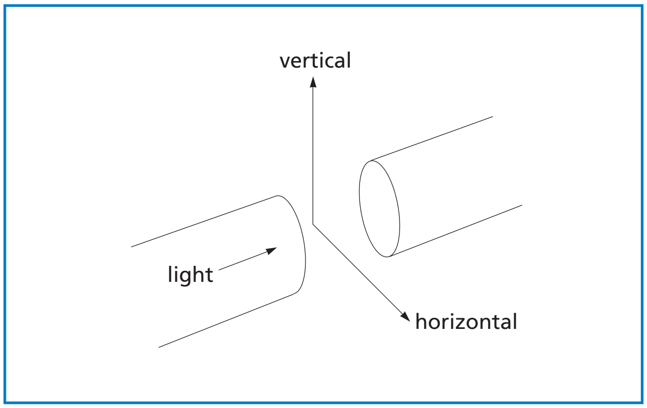

Figure 8.29 **Fiber-to-fiber alignment application**

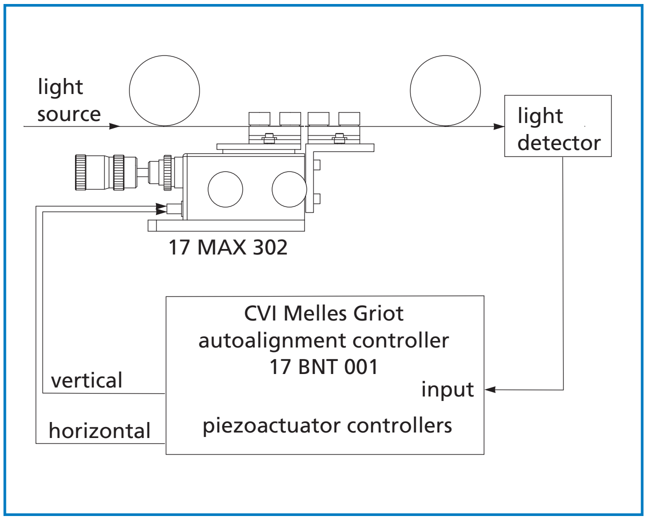

Figure 8.30 **Schematic of the automated alignment system**

AUTOMATED ALIGNMENT USING AN AUTOMATIC ALIGNMENT CONTROLLER

The CVI Melles Griot automatic alignment controller provides automated alignment among many types of optical components through scanning and tracking. For example, the automatic alignment controller can search for power over a given area coupled into a single-mode fiber from a laser diode, and then maximize the throughput.

Machine vision used in prealignment process

Beam acquisition and optimal alignment occur in less than a second. The speed is ultimately limited by the dynamic response of the flexure stage under piezoactuation. Parallel flexure stages have excellent dynamic response because of their low inertia and high stiffness; therefore, that tracking is extremely stable and can be performed even more rapidly than with serial stages.

CVI Melles Griot uses the automated alignment system to optimize component location and maximize throughput. The automatic alignment controller automatically aligns fibers to devices, dramatically simplifies waveguide characterization and pigtailing procedures, and ensures drift-free positioning and accurate data acquisition.

The automatic alignment controller modulates the coupled optical power between two components by applying a small circular oscillatory motion to one of the components in the y-z plane. The motion is achieved by imposing a small modulation voltage to the y and z piezoelectric actuators of the positioning device holding the component. The radiation transmitted to the next optical component and on through the optical system is constantly monitored for power, modulation intensity, and phase; normally a simple detector is adequate. Using phase-sensitive detection techniques, the automatic alignment controller provides output dc correction voltages which are amplified in the piezoelectric controller and applied to the device piezoelectric drives to drive the component into alignment.

Figure 8.31 illustrates a typical automatic alignment application with the CVI Melles Griot autoalignment system. Details of the controls and functions used in this process are described in the following paragraphs.

Track and Latch Mode Operations

There are two basic alignment modes: the track mode and the latch mode. In the track mode, once a signal is detected through the system, the automatic alignment controller drives the components into optimum alignment and then continues to actively monitor the alignment and make any corrections necessary to maintain optimum throughput. A low-pass filter within the control loop limits the minimum response frequency to 4 Hz, allowing tracking to be maintained in all normal circumstances. In this way, any sudden disturbances will not be tracked, and the last position of maximum coupling will be maintained. In the latch mode, once the system is optimized, active adjustment is discontinued, and the last recorded position is held until the power is removed or the unit is switched back to track mode.

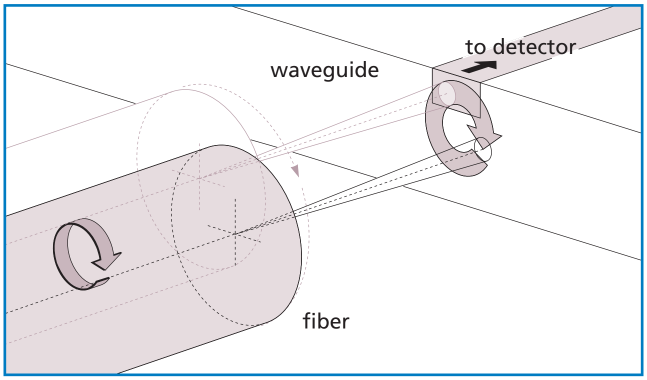

Figure 8.31 **Conical scan used in fiber-to-waveguide alignment**

The track mode is used for most applications, but there are occasions when the latch mode is appropriate. For example, when bonding fibers some users have found that the UV curing process can generate an erratic throughput signal, which, in the track mode, could cause the components to move out of alignment.

Scanning Circle Control

Two modes are used to control the diameter of the scanning circler: automatic and manual.

In the automatic mode, the scanning circle diameter is initially 15 percent of the maximum piezoactuator extension (MPE), approximately 3 μm for the standard 20-μm MPE piezoactuators. As the intensity of light coupled through the system increases, the diameter of the scanning circle decreases, inversely proportional to the transmitted power, to a minimum of 0.25 percent MPE (50 nm with 20-μm piezoactuators). This minimum has been chosen so that a good tracking signal is always maintained. In the manual mode, the user sets the scanning circle diameter, using software controls in the graphical user interface.

Scan Circle Position

The software display gives a real-time representation of the alignment of the two fibers or optical components. The position of the circle on the screen represents the degree of extension of the two piezoactuators. The bottom left corner of the screen represents zero extension for both vertical and horizontal piezoactuators; the upper right corner of the screen represents full extension of both the vertical and horizontal piezoactuators. The actual alignment position may fall anywhere on the screen. However, it is most desirable that this position be near the center (50 percent MPE) to provide the greatest range of extension available to compensate for relative positional changes of the components. Without interfering with the automatic tracking, the user can adjust the mechanical drives on the positioning stage to center the alignment position.

Programmable Scanning

The built-in conical scanning algorithms meet a wide range of needs, especially when using single-mode fibers. However, in other situations (e.g., longer-extension piezoactuators, multimode fibers, integrated optical devices), it may be desirable to have more influence on the scanning operation or to use custom scanning routines. This can be accomplished through the USB interface with software included with the automatic alignment controller.

With software control, the scan circle diameter can be adjusted to match any piezoactuator MPE or fiber diameter. A simple command sets the circle diameter at any stage of the alignment process. Three separate diameters are usually sufficient: (a) a large circle to acquire the signal, (b) an intermediate circle to optimize the alignment, and (c) a small circle that is large enough to maintain optimization but small enough that it will not interfere with device characterization.

Computer control also can be used to develop custom scan and search routines. For example, the symmetrical square spiral shown in figure 8.32 is one basic search pattern. This pattern increases the capture range of the scanning circle by deflecting it over the full field of the piezoactuators, providing a larger area for the coupling surfaces to overlap.

Consider the vertical component of the fiber motion. Plotted over time, this will produce a sine wave. However, at t_0, although the vertical motion is a maximum, the power only reaches a maximum at t_1. Similarly, the minimum motion is at t_2, whereas the minimum power is not reached until t_3 (see figure 8.34).

By detecting the phase of the optical power signal, (see figure 8.35) the automatic alignment controller directs the fiber to the maximum point. Once it has found the maximum, it locks onto it. Even if one of the fibers is moved slightly, the automatic alignment controller directs the piezoactuators to correct for the movement to maintain the maximum power.

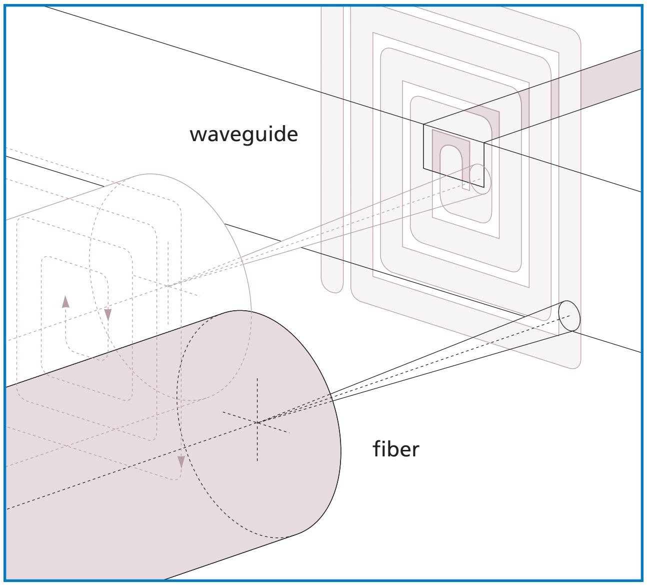

Figure 8.32 **Symmetrical square spiral scan**

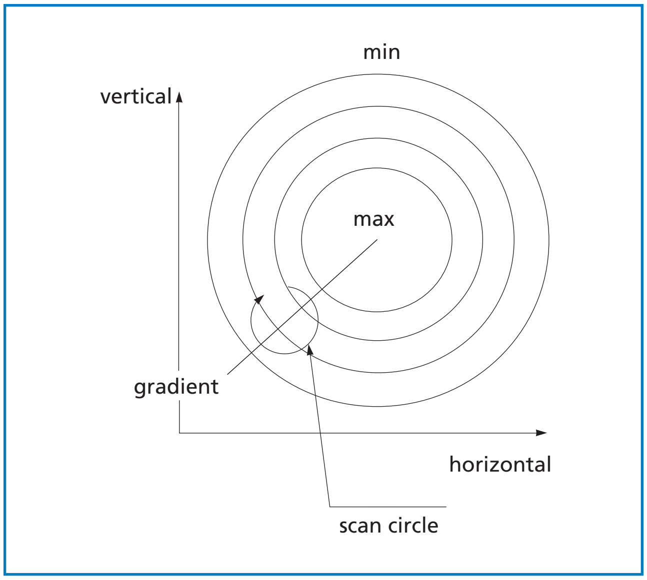

Figure 8.33 **Scanning the power gradient**

HOW THE AUTOMATIC ALIGNMENT CONTROLLER MAXIMIZES OPTICAL POWER

Optical power transmission through the fiber can be plotted as a function of any two axial positions of the moving fiber and shown as a series of concentric circles. These concentric circles represent the power contours and can be thought of as the contours on a map. The automatic alignment controller must guide the fiber to the summit. By detecting the gradient of power at a given position, it can adjust that position until the power is maximized and the gradient becomes zero. The automatic alignment controller calculates the gradient by moving the fiber in a small circle and scanning the change in power over the motion (see figure 8.33).

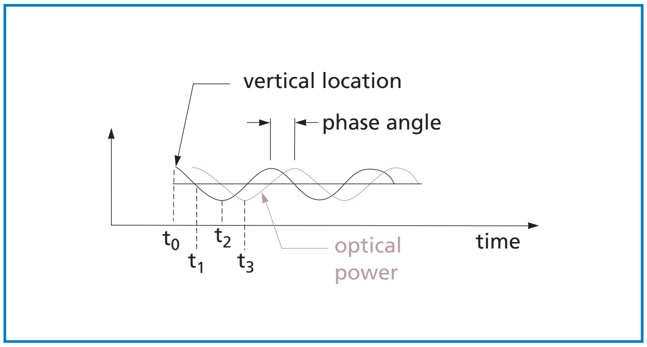

Figure 8.34 **Optical power as a function of vertical position**

The process time for an autoalignment system depends upon the number and complexity of operations to be performed. As a benchmark, CVI Melles Griot has provided systems for aligning and pigtailing input and output fiber bundles to a four-channel waveguide. Using the machine vision prealignment process and autoalignment, the cycle time for the complete operation is less than 2 minutes per completed component.

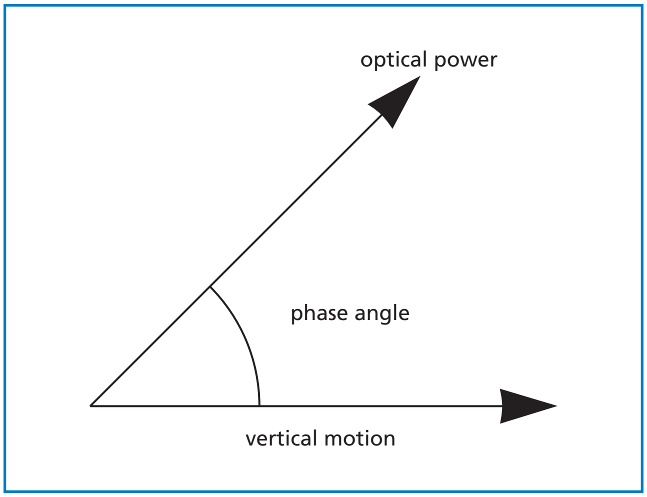

Figure 8.35 **Phase angle between optical power and vertical motion**

Drive Options

CVI Melles Griot offers a comprehensive selection of thumbscrew, differential micrometer, stepper-motor, and piezoelectric drives for manual or automated positioning. Thumbscrew drives provide high-resolution movement at an economical price. Differential micrometers offer both long travel and high-resolution adjustment in one actuator. Stepper-motor drives provide high-speed actuation with excellent repeatability. Piezoelectric drives are used for applications where automated, ultrahigh-resolution movement is required.

Thumbscrew drives

Stepper-motor drives

Differential micrometer drives

Piezoelectric drives