Motion Control Tech Briefs

Specifying Fiber Alignment System Performance:

Coupling Loss Offers An Alternative to Motion Capability

One of the most difficult assembly tasks ever introduced into commercial manufacturing is the sub-micron alignment and attachment of a fiber-optic to a laser diode or other optical waveguide. Consequently, many questions arise about how to specify and ultimately verify the performance of the positioning system(s) that will guide these microscopic elements successfully into alignment. Proper alignment is critical to assuring the long-term performance of fiber-optic components.

Precision motion performance is usually discussed in terms of "resolution," but in fact there are multiple performance attributes that must be addressed in order to be consistently successful in fiber-optic device alignment applications. This article defines key terms for motion systems, discusses the importance of each with respect to this very demanding process, and offers a method for specifying motion systems in terms of coupling loss rather than motion capability.

Fundamental Motion Terminology

There are four important figures of merit for motion stages. They are resolution, minimal incremental motion (MIM), repeatability, and stability.

Resolution is used for Encoder Feedback Resolution (EFR) and is the smallest increment for determining the position of a stage. EFR describes only position reading and is not the same as the Minimum Incremental Motion.

Minimum Incremental Motion (MIM) is the smallest motion a positioning device is capable of reliably moving. MIM describes actual motion and is influenced by several factors like encoder resolution, stage, and controller closed loop quality.

Repeatability is the ability of a motion system to reliably achieve a commanded position over many attempts. There are two types of repeatability, uni-directional (UDR) and bi-directional (BDR). BDR is more stringent, and for fiber-optic alignment applications requires closed-loop positioning control with direct drive and on-axis encoder feedback. As it turns out, BDR and MIM are linked which allows us to use the approximation: BDR= +/- *MIM*

Stability is the ability to maintain a constant position over a specified period of time.

Of these four parameters, MIM (and so BDR) is the most significant when defining a motion system to achieve maximum fiber coupling. Because MIM relates to the ability of the motion system to take smaller steps while searching for the optimal location, a stage with a smaller MIM will theoretically find the highest coupling point. In practice however, most fiber-optic devices have coupling maxima that are of much greater width than the MIM of the alignment system. This means that decreasing MIM beyond a certain point will no longer have a measurable effect on the overall alignment efficiency. The importance of BDR is necessitated by the device attachment application, which requires the alignment system to (repeatedly) return a fiber to the position of maximum coupling during the attachment process.

Stability is also essential because after alignment the remaining steps, such as attachment, require the coupling efficiency to be held constant over the period of time needed for completion. Although resolution contributes to MIM, it is not a critical parameter in fiber-optic device alignment applications. If a stage cannot move in very small steps (MIM), even very high-resolution readings of position become irrelevant.

Stage specifications such as MIM, stability and resolution are typically given per stage axis as if the stage was used by itself. Since fiber alignment systems are composed of many stages stacked together, the motion system must be spec-

Motion systems for fiber-optic device alignment & attachment, such as the Newport AutoAlign™-MDX, are being specified in terms of coupling loss (dB).

ified rather than a single stage axis. Furthermore, the true MIM, stability, and resolution at the tool point (where the fiber meets the device) are much different than at the stage encoder. In order to establish the exact MIM at the tool point, sophisticated experimental setups are needed, normally using non-contact measurements. Although interferometric measurements would be the most precise, it's relatively difficult to implement for the typical user. A simpler alternative is to use the power coupling efficiency of two single-mode fibers.

A Simpler Alternative

Achieving the maximum coupling point during alignment is a function of the previously outlined parameters, the alignment algorithm and its ability to search out and seek the maximum point, and other factors including environmental characteristics. So rather than specifying a motion system in terms of MIM, resolution, and other motion related criteria, specifications should be defined in terms of power coupling efficiency.

All specifications should be easily measurable by both the customer and the vendor. They should also relate to the performance characteristics of the system in a way that is understood to the user. Lastly, part of the specification should address overall system performance rather than the performance of its individual parts. This is particularly important since alignment systems are complex systems consisting of motion stages, vibration isolation, optical power measurements, and alignment algorithms. The following method for specifying alignment systems addresses these criteria.

The experimental setup to verify these specifications is quite simple and consists of two single-mode fibers. Light passes through one fiber into the other. The alignment system will align these two fibers so that there is maximum light coupling. The test conditions are as follows:

System Setup: Two single-mode fibers are separated by a specified distance z in the optical axis. One fiber is on a stationary stage. The other is on the alignment system to be tested.

Load on the System: The load on the system is *W*.

Temperature Range: The system will operate within a temperature range *K* and achieve the above specifications, except for stability (*S*) specification, which has its own specified range.

Number of Measurements: The range and standard deviation of each specification is measured using at least 50 observations.

The Specifications

Motion Repeatability is defined by R_σ (dB). It is determined by achieving alignment, recording the motion coordinates and the coupling power, and then commanding the system to return to the same coordinates and record the power for at least 50 more repetitions. R_σ is the standard deviation of these measurements. This measurement is a system level measurement that takes into account all the system parameters.

Maximum Coupling Efficiency is defined by two parameters. The average coupling-loss *C* (dB). This specification is a measure of how good the coupling is, and is determined by achieving alignment, recording coupling efficiency, then moving all axes (except Z) away from the aligned position, and then aligning again and recording power.

Alignment Repeatability is defined by the coupling loss standard deviation C_σ (dB) measured as described above. *C* and C_σ are also system level performance measurements that take into account all the system parameters including the alignment algorithm.

Alignment Stability is defined by the drift, *S* (dB), in coupling loss recorded over a period of *t* minutes after alignment has been achieved, while the temperature fluctuation is limited to a range *K(s)*. When determining this specification, the alignment system is kept idle.

Alignment Time is defined by the average time, *T* in seconds, required by the alignment system to reach maximum coupling efficiency from observation of first light.

Fiber-to-fiber alignment does not cover all applications. Since single-mode fibers are standard, it provides a universal apparatus to test alignment systems. The user may have other applications where they are aligning lasers to fibers or waveguides to fibers, but those applications are dependent on the device in question and do not provide a universal means for system specification.

How will MIM effect the coupling efficiency specifications? If two fibers are in perfect alignment, movement in the *X* or *Y*-axes will result in lower coupling between them. Based on theoretical models, a 50nm movement in *X* or *Y* will only result in <0.001 dB additional loss. This difference cannot usually be measured but is calculated from a theoretical model. In general, 50nm MIM is sufficient for most alignment applications.

As standards emerge in the fiber-optic industry for performance of components, similar set of standards are needed for the performance of automation systems, particularly alignment systems. Both the user and the vendor can easily measure the suggested performance criteria. It can also be used as acceptance level tests or used to compare the performance of different systems.

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