A New Paradigm for Free-Space Optical Alignment of Telecom Devices

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Introduction:

The alignment of free-space optical elements of devices for the optical telecommunications industry has been going through many changes in the past few years. During 2000 the manufacture of optical components was mainly manual, with rows of microscopes and workstations manned by hundreds of human workers. As demand grew in late 2000 and early 2001, pipe dreams of high throughput automated systems danced in the heads of manufacturing managers and factory general managers. But alas, it was not to be. When the demand for the components abruptly slowed in the second quarter of 2001, it became clear that the need for high throughput was fading away into the distant future. Nonetheless, it was abundantly clear that the manual-manufacture model was also severely flawed. After the layoffs of so many trained workers that the slowdown demanded, it was obvious that assembling large populations of these workers again when demand resurfaced was unlikely. Automation would still be necessary even if the high throughput requirement were no longer the driving force. Reproducible, high-quality parts needed to be built without the need to train armies of workers, and they needed to be manufacturable without the variable quality that manual piecework introduced into the process.

As the demand for bandwidth and the increased technological complexity of optical networks continues, low-loss, high quality components are critical. Migrating the manufacturing processes used in manual assembly and alignment to automation has many pitfalls. Machines are very good at doing repeatable steps routinely and with extreme accuracy, but they are not as flexible as human workers. Steps that are simple feedback loops to the human being are often difficult to program into vision systems, motion controllers and computers. Parts that were being manufactured by hand were never designed for automation. They lack the indices and reference marks that are routine in the highly automated semiconductor industry. Free space optical alignment is further complicated by the need to understand the beam emanating from the device, and how the beam's shape affects the coupling of light between devices.

Free-Space Optical Alignment Challenges

Free-space optical components, as the name implies, are those components from which light beams are sent between optical components through free space as opposed to through waveguides or fibers. These can be either single or multiple beam devices. In any case, it is normally necessary to focus a lens to the source or bare fiber to collimate the light beam, enabling the coupling of the beam into the other device with minimal signal losses. Alignment of the lens-fiber (or source) pair for focus and pointing, aligning the resulting beam into another lens, and then aligning that lens to a receiving fiber is perhaps the most common free space alignment challenge in the telecom industry. Most free-space optical devices are built this way and in this order. Often some filter or other beam-modifying element is inserted between the two lens elements to create a final device, such as an add/drop multiplexer. Array devices, such as transceivers and MEMS switch fabrics, need arrays of lenses to be collimated, further complicating the process. In order to build the extremely low-loss devices demanded by telecom applications, these lens-fiber alignments must be very precise in both pointing direction and beam collimation. Variations of as much as 10nm can result in unacceptable losses.[i] Depending on the application it may be desirable to create a waist in the beam(s) at a precise working distance, or it may be better to collimate the beam to as nearly parallel as possible.

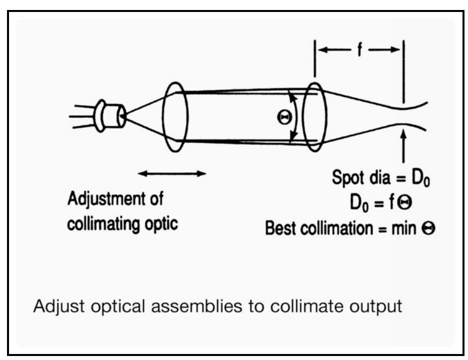

Fig.1: Beam diameter one focal length from a test lens can be used to optimize collimation

The Current Automation Model

Basing the automation process on the manual methods of device alignment has led to the use of multiple six-axis motion stages. Six axes mimic the degrees of freedom found in the human hand-wrist linkage. Starting from one side of the device-under-construction, a six-axis stage is employed to align the first lens-fiber pair. Simultaneously, another six-axis stage performs a search pattern to find "first light."[ii] Once light is found, these twelve axes adjust the device until an acceptable loss level is achieved, and then the device is secured with glue or welded. Although this process solves the problem of creating reproducible parts without human intervention, it is far less efficient than it should be. The programs for finding first light are slow and require a combination of vision systems, complex search patterns and very expensive multi-axis stages. It is also possible that after a significant alignment time, acceptable loss levels may not be achieved, and the part will have to be rejected without understanding what caused the problem.

New Paradigm Solution

As is often the case with automation, copying the human process may not be the best approach. The manufacture of free-space devices can be made more efficient by dividing the process into its two parts. Collimation of the lens-fiber pairs and the alignment of these assemblies into finished devices are really two separate processes. It is much more efficient to approach them as such. If you create well-characterized collimation devices first, aligning them into low-loss devices becomes much easier. If the lenses, fibers or array v-grooves are defective, they can be rejected before the value-added step of attempting alignment.

A beam profiler will make it possible to create lens-fiber collimation for single sources or arrays for which the precise character of the beam is known.[iii] If the final device calls for a beam or beams with a 100 µm beam waist at 15mm from the lens, the beam profiler will allow its precise measurement. In addition, it will show the pointing position of the beam. Once this is known, two such collimated beams can be easily positioned to couple the light. It should only require minor adjustments, rather than six-degree “first light” searches to get the light from one device to the other. By eliminating the need to make the first light search pattern, the coupling losses of the device can be minimized more quickly. Two devices to be coupled can be positioned based on the knowledge of the beam profile. Since each collimated device has been built to a certain specification, both waist position and pointing direction are known. They then can be positioned so that there will be detectable light to use in the final alignment. The key to making these free space devices is to create some reference surfaces for automated alignment, and the beam profiler provides a method of creating such an indexed device. The beam can be thought of as part of the device. The free space beam has a physical dimension that can be aligned in relation to the index reference of the actual part.

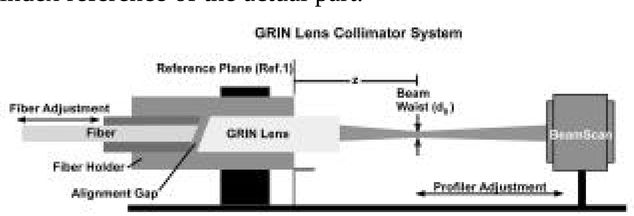

Fig 2: Adjusting the lens-to-profiler-distance allows beam waist mapping of a device

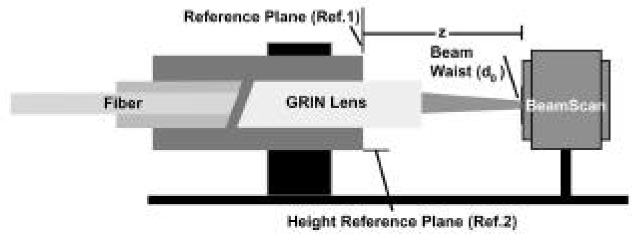

Fig. 3: Placing the profiler at the intended waist location allows the direct measurement of the focusing adjustments to the device

The new paradigm of this approach is the creation of a piece with the light beam as part of the part. The beam’s precise shape and location are no different than the physical dimensions of precision machined parts. Combined with the proper index reference marks, two of these parts can be precisely positioned to couple light without the need for time-consuming “first light” searches. Much simpler feedback systems can tune up the coupling for minimal loss.

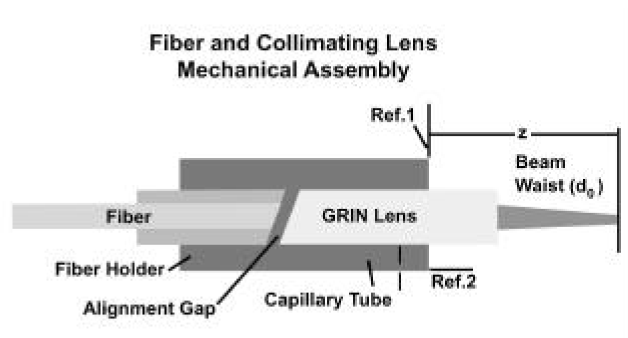

Fig 4: Optical device with characterized light beam as part of the part

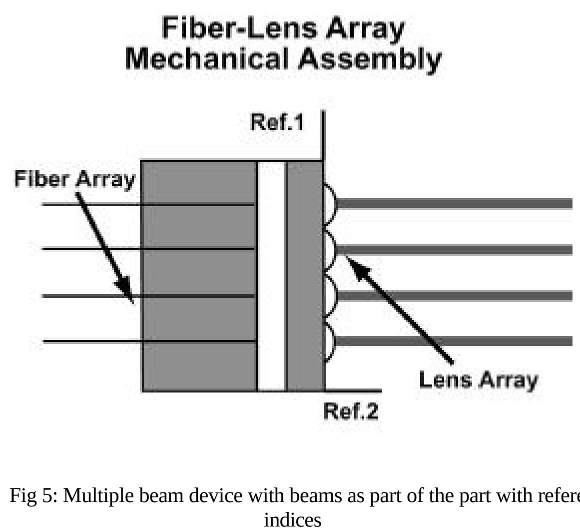

Fig 5: Multiple beam device with beams as part of the part with reference indices

Multiple beam arrays provide additional challenges because the beams’ positions in 3-dimensional space must be accurately characterized. Multiple beam arrays need to have the spacing, pointing, and beam waists properly aligned to ensure that they do not overlap. In order to line up two such arrays, all the beam locations need to be identical. Once positions are known, however, there is no difference in the concepts of a multi-beam array or a single beam part. If the beams are understood relative to reference alignment indices on the physical part, the part can be quickly and accurately aligned to another device to create a final light coupling.

The challenge for this approach be able to measure the beam precisely enough to guarantee light coupling when the two parts are initially positioned. We believe that new developments in profiler design allow this level of precision to be easily achieved. Combined with the much-touted nano-positioning capability of currently available positioning stages, this precision will allow much more efficient assembly of passive optical devices. Using this approach, automation can start to move forward to streamline optical manufacturing processes.

References

[i] personal communication

[ii] Matt Sargent, Exfo Electro-Optical Engineering, Inc. and Mike Formica, Axsys Technologies, Personal Communication

[iii] Peterman, D.W. PhD, Fleischer, J.M., Swain, D.C., “Beam Profiling Aids Fiber Optics Manufacturing,” *Photonics Spectra* **36,** 2, pp.72-77, February 2002