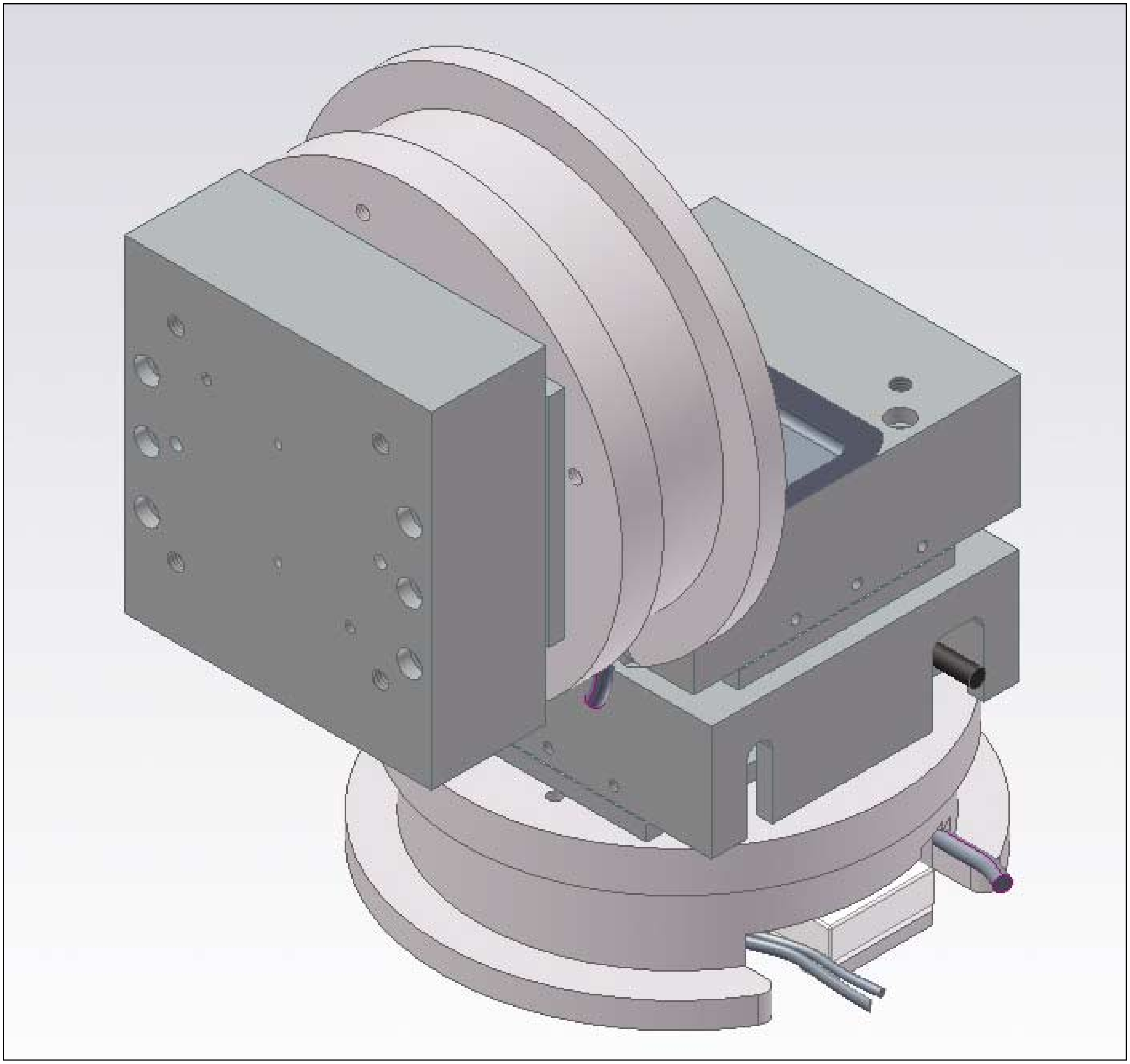

The Role of Precision Motion

In Fiber-Optic Manufacturing

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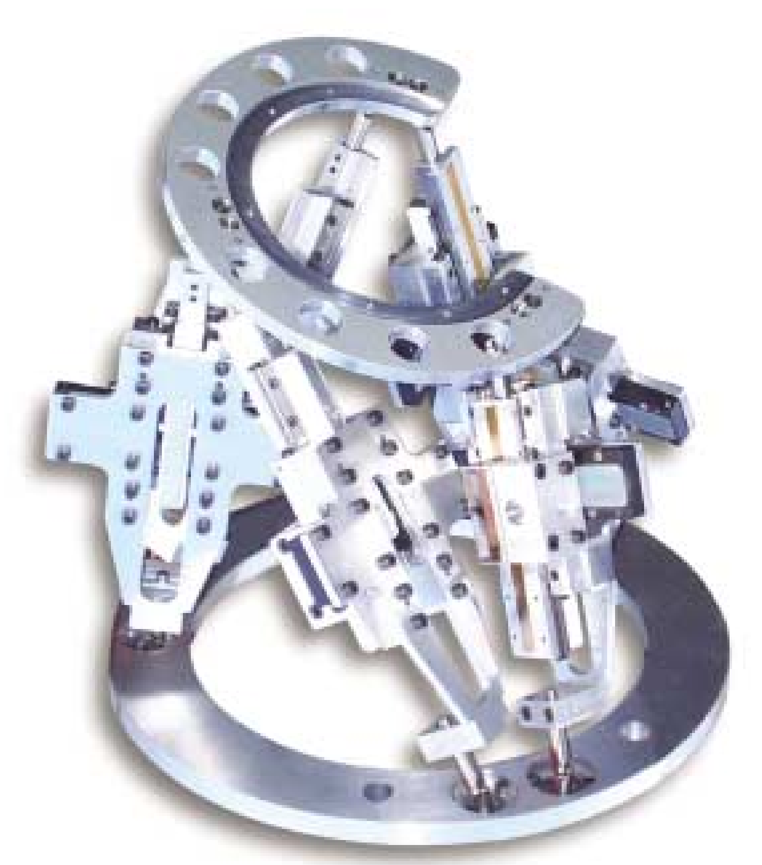

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Over the past several years, the fiber-optic industry has faced many challenges in the production of critical components. The lack of proven production techniques has led to exceptionally high failure rates for these components and contributed to financial struggles within the industry. One can argue that the downturn—by making it unnecessary to scramble to meet ambitious production quotas—offers a good opportunity to review current production methods. In this context, it is clear that many of the manual processes used in manufacturing fiber-optic components have significantly contributed to the present situation. In North America, only 5-10% of installed fiber-optic cable is actually being used to transmit data. A precursor to higher usage rates will be resolution of the production challenges the industry now faces.

One can attribute the industry's financial situation to a number of factors. From a manufacturing perspective, however, there's no getting away from the fact that a young industry, faced with rapid production requirements, has attempted to respond using manual R&D processes. As demand for component production grew, processes for alignment and assembly were developed on the factory floor. Without the luxury of **proving out** statistical reliability or providing a "factory-work-hardened" approach, manual and semi-manual tasks were used to provide precise motion control **(AQ1: What does proving out mean? Can you substitute another expression?)**.

A recent discussion on beam profiling* included the statement: "In the fiber optics industry, one constantly hears that new markets will remain elusive unless production efficiency is improved." This assertion is confirmed by the excessive failure rates of critical components. Contacts with several prominent laser-diode manufacturers revealed that failure rates from manual alignment processes ranged from 35 to 40%. It's clear that failure rates at these levels make it virtually impossible to meet production requirements or control costs.

The complex process involved in the production of filters, optical switches, multiplexers, laser diodes, couplers, and a host of other components requires that a fiber be aligned to a lens, using fine alignment processes, and ultimately bonded in place. The motion control aspects of these processes require movement in the submicrometer range in order to maximize the strength of the light signal. This involves taking a 125-μm diameter fiber with cladding and moving it in steps ranging from 1 μm to 0.1 μm, (at times, moving only 50 nm). Once aligned, the fiber must be held absolutely stationary for either a laser weld or epoxy attachment .

Misalignment of fiber to a lens (or component) will result in dispersion or backreflection, a situation which has been occasionally addressed by use of a tip-and-tilt mirror. The mirror is manually adjusted to reflect light back through the fiber-lens pair until light strength is at its maximum. With mirror assemblies that must be positioned and fixed in place, a significant amount of time is required for the adjustment, calibration, and epoxy processes. Even 50 nm of servo dither will have a significant impact on the positioning of these devices, which must remain completely motionless during assembly.

The initial R&D processes—which were ultimately applied to manufacturing—primarily used manual adjustment to provide such tight motion parameters. Because it is difficult to quantify the optimal position, the one resulting in the least amount of loss, search algorithms have failed to provide an effective solution for the automation of some of these processes. On the other hand, however, while the ability to turn a mechanical leadscrew provides a degree of high resolution, it remains very difficult to pinpoint the optimum location. Additionally, any locking action to hold that position will often result in slight, but unacceptable, change of locus.

The use of manual or even semi-automatic processes has led to exceptionally high failure rates, making it virtually impossible to support high volume production and limiting the application base of fiber optics. Specifically, in processes such as active alignment, fiber manipulation, attachment, and MEMs manufacturing, producers have struggled to implement automation, in the form of automatic motion control equipment, that can run seamlessly with the requisite fiber-search

* Peterman, Fleischer, and Swain.

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algorithms and data-collection devices. The net result is that, in a classic "chicken and egg" scenario, the industry is faced with the lack of financial resources to provide this automation

Other financial issues contributing to the slowdown of the telecommunications industry should not be ignored. In 1999 and 2000, aggressive capital spending on fiber-optic systems expanded at rates well beyond what reasonable returns could support. From 1999 to 2000, for example, the laser-diode market expanded by 91%, to a level of $4.17 billion in revenues. In 2001, however, the market was off 40%, to $2.5 billion. Some industry observers predict there will be a moderate rebound in 2002, estimating an increase of 16%, to $2.9 billion. If producers are going to be able to meet new demand, they have no choice but to improve the manufacturing process through automation.

Today, major manufacturers are moving toward the implementation of automated processes that can provide the next level of performance, assuring greater component quality and reliability. The big question is what type of automated equipment, i.e., what type of motion control technology, will meet the need.

The road to automation

A variety of tools are used in the production process: motion systems are configured to perform fine and coarse positioning; search algorithms are used to sense light strength and determine the precise location at which fiber and component should be joined; testing processes, often coupled with **SPC**, are used to verify the process and collect data **(AQ2: please spell out SPC the first time it is used. Thanks.)**

In many of today's component-alignment platforms, the process involves moving a component to a predetermined location using an "open-loop" method: once the component is in position, an algorithm **runs a spiral route at the** motion system to identify the ideal location and angle for joining fiber to component. In the semi-automatic modes used today, there is a significant amount of human intervention, involving slight manual adjustments or searching for proper location, as well as the engagement of measurement tools. High failure rates during these processes are primarily a result of misalignment.

Automation requires the seamless integration of each alignment and testing process. The ability to operate complete, closed-loop servo motion tied to search algorithms, ultimately providing all testing and data collection without any limiting human intervention, is critical to maximizing production yield. Additionally, if the search algorithms are not sufficient to characterize all aspects of proper alignment, adjustment capability should be built into the motion system in order to provide nanometer levels of motion. This effectively eliminates the need for tilting mirrors to control backreflections.

The basics of successful alignment

In terms of process requirements, the diversity of components translates into a wide range of performance specifications. While there are basic alignment processes that can be satisfied with traditional motion control, as the required degrees of freedom increase beyond the simple X/Y/Z Cartesian, the effects of stacking additional axes creates errors. Generally, the processes of alignment and attachment will dictate four to six degrees of freedom: four axis being X/Y/Z and tilt (pitch), while six axis includes roll and rotation.

Typical Cartesian Stacked Axes

In addition to varying the number of axes, the performance of each axis differs based on the particular component. In a coarse or low-end process, resolution may range between 100 and 500 nm, with position repeatability in the range of a few micrometers. The opposite end of the spectrum uses 10-nm resolution and position repeatability in the 50-nm (or better) region. Each manufacturer must define its own performance requirements and evaluate how errors within these parameters affect the manufacturing process and subsequent component performance.

In an industry facing such stringent production requirements, and with no standardized tooling, a number of mechanisms have evolved to allow attainment of higher levels of performance. Most solutions have been derivatives of standard motion control axes, configured to meet the form factor of a production machine. In an attempt to create the ideal tool for a variety of applications, others have started with a "blank sheet."

In the simplest approach, several motion control manufacturers have configured very basic, stacked Cartesian axes, often driven by mechanical leadscrews and step motors. Because this approach presents limitations in terms of position resolution and repeatability, these systems are typically coupled with a fine positioning mechanism, which duplicates an axis of motion with a limited travel, high-resolution device. Although capable of meeting the performance criteria, this method creates a duplication of axes, resulting in higher costs, more process time, and the potential to create additional errors.

As performance requirements increase, some manufacturers have applied better drive/feedback technologies, such as brushless linear motors with high-resolution linear encoders (10-nm to 20-nm resolution). While this still requires stacking a series of Cartesian axes, speed and position repeatability are greatly improved.

In these applications, however, there are issues involved with using non-contact drives like linear motors. In many instances, position-stability requirements dictate that the motor be turned off and a brake activated to eliminate all motion. Aside from adding components and driving the cost up, mechanical hysteresis resulting from brake engagement can easily cause a change in position. Additionally, if power is lost, the axes are free to slide and change position.

While the ability to construct Cartesian axes to overcome conventional shortcomings is a step forward, the ideal is to configure an alignment platform that eliminates many of the aforementioned potentials for error. A "hexapod" configuration, deriving from machine tool and robotic development, provides a single-point tool centered about multiple axes which eliminates stacked (accumulated) errors, and provides equal rigidity in all directions.

The Alio Industries' Fiber Alignment Hexapod design provides six degrees of freedom, all about one common center point; X/Y/Z/theta/pitch/roll. All six legs of the hexapod support the moving surface, eliminating stiffness disparity and stacked position errors.

Each leg is controlled by two opposing Nanomotion piezo-servo motors and high resolution Renishaw encoders.

- The Nanomotion piezo motors provide velocity up to 200 mm/s and the ability for discrete movement within 1 nm of resolution.
- Standard feedback is available with 10-nm resolution.

The hexapod provides an unobstructed work surface and the ability to feed tooling through the center. It can be mounted in any orientation while providing equal rigidity in all directions.The ability to place a component on the hexapod, for active alignment, fiber manipulation, or MEM manufacturing, makes this a simple solution for component manufacturing. Alio's hexapod approach is seamlessly integrated with National Instruments, and offers simple, single-point coordinate control.

Please add caption...

Besides the hexapod, another approach to alignment tasks is to use traditional Cartesian axes, with drive technology that supports the required performance. Many motion control companies, such as Alio, Anorad, Bayside Motion Group, Newport, New Focus, Nutec, and Schneeberger build assemblies with the same piezo-servo motor technology, avoiding the problems created by brushless linear motors or leadscrews and rotary motors.

These machines use Nanomotion's motors to provide the ultrahigh-resolution, high speed, and absolute position stability required for fiber-optic component manufacturing.The motor is easily applied to rotary and tilt, as well as linear, axes.

The motor technology is a derivative of the "reversed piezo" effect and it overcomes issues of bi-directional hysteresis and drift.

To facilitate using search algorithms to locate the apparent optimum and then 'tweak' the system based on testing, without having to use tilt mirrors or manual screw adjustments, piezo-servo motor technology can operate in three distinct modes: closed-loop servo, stepping, and dc piezo mode for nanometer resolution. This allows for the simplest electro-mechanical configuration, with one technology per axis, thereby eliminating separate course and fine positioners or manual intervention.

In use with traditional Cartesian stages or the hexapod design, the motor's primary mode of operation is closed-loop servo. Encoder feedback is used to control position to the level of required resolution. Motion is provided in this mode, with unlimited travel and velocity up to 250 mm/s. The motor technology can be adapted to a variety of mechanical structures to provide simple linear, rotary, or tilting motion.

The motor can also operate in a pulsing mode, providing voltage in bursts to take incremental steps. This can be used for coarse positioning and is easily controlled at an operator interface, while being viewed via high magnification imaging.

Last, the motor technology can be put into a dc piezo mode, enabling traditional piezo operation. This allows for discrete motion from 1 nm to 300 nm. This mode can be operated in an open- or closed-loop manner and will allow for the final "fine tuning" of fiber alignment. This approach completely eliminates the need to manually adjust leadscrews or develop mirror assemblies to compensate for inferior positioning capability.

Triangle wave1 Hz frequency With 90 V PTP **(AQ3: What does PTP stand for?)**When operating in theUltrahigh-resolution dcmode, this graph depictsperfect tracing of a triangularwave, with a 1-nm resolutionencoder.

Future prospects

As the need to increase production and high-quality yield continues to increase, automated platforms are being developed around a variety of technologies. Motion control platforms providing the simplest and most cost-effective configurations will come to dominate processes such as active alignment and fiber manipulation. The ability to use one-drive technology to achieve all manufacturing requirements should prove a boon to equipment producers who must integrate motion with fiber-assembly processes.

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