Research & News

ALIO News

Passion to push the envelope of today's precision, ALIO Industries, Inc., decided several years ago to build a novel Hexapod design to overcome serious precision issues with the Hexapod kinematic structure. The new Hexapod design is known today as a Hybrid Hexapod®. Scholars of the English language Merriam-Webster explain the word Hybrid as follows: : an animal or plant that is produced from two animals or plants of different kinds : something that is formed by combining two or more things Since the traditional definition of Hybrid does not fit the modern day electro-mechanical use from cars to boats and beyond the term Hybrid is widely accepted as combining technologies. ALIO used the term Hybrid when building a new and novel Hexapod since Hybrid has long been associated with novel designs and electro-mechanical devices that combine the best of new and old technologies as well as different new technologies.

Hybrid Hexapod® evolutionary or revolutionary? We like to think revolutionary due to its superior performance, precision and price. First we would like to debunk the traditional Hexapod manufacturers false statements. Yes, strong words for 20 to 30 years of printed and spoken sales hype. ALIO holds 2 patents for ceramic servo motor/piezo motor driven Hexapod. Building these devices for over 10 years we understand the challenges of Hexapod's thus statements from other manufacturers over error quotient, stiffness, precision, dynamic motion and footprint need to be challenged since they are not true! Stiffness: Hexapods have stiffness in only one axis, the Z axis which allows for all six legs to work as one but any movement in X,Y or rotation in X,Yor Z the stiffness is poor at best due to legs being in compression and tension when moved in multi-axes. In this world of 6 axis motion it is not conceivable that you would buy a Hexapod to move only in the vertical Z axis thus the statements on Hexapods having high stiffness is totally false!

Precision: Hexapods need to move all six legs/axes to make even simple moves. An X or Y move needs all six axes to move thus the error quotient is additive. Most Hexapod manufacturers will not give a data sheet numbers for precision of path even in a simple planar move since these numbers are in the 10's of microns. Again legs on a Hexapod go from tension to compression so the backlash numbers and repeatability numbers need to be added to get a representative path position repeatability. The challenge of data sheet calculations of which legs have moved from which direction and tension……which is almost impossible thus the data sheets do not represent true or even close numbers to actual precision.

Dynamic Motion: Traditional Hexapods are mostly built around screws and or piezo motors which neither on their own have great dynamic capability add to this parallel kinematics where many equations need to calculate position and look forward positions for all six legs to maintain coordination so they do not fight each other's motion. Dynamic Motion is not a screw motion systems advantage it is totally false. Footprint: Traditional Hexapods have a small footprint for 6 axis device but they also have a very small useable work zone. Hexapod data sheets give XYZ and Theta rotations in degrees but these number are not usable together since a work envelope for a Hexapod is shaped like an umbrella thus the cube of useable motion inside the umbrella is a fraction of maximum movement of each axis given on data sheets.

ALIO's patent pending Hybrid Hexapod® solves the inherent issues of the traditional Hexapod. The Hybrid Hexapod® system is an innovative motion system that does not just improve on existing hexapod technology, but completely eliminates inherent weaknesses of the traditional hexapod concept. As a result, the Hybrid Hexapod® achieves nanometer level performance with respect to accuracy, repeatability and geometric three-dimensional performance. Currently, there is a void in industry where hexapods have reached their performance limitations, but complex motion system needs have not stopped advancing – the Hybrid Hexapod fills this void. The ALIO patent pending Hybrid Hexapod® achieves nanometer order accuracy, nanometer order bidirectional repeatability, and high-integrity flatness and straightness of motion in a six degree of freedom motion system. The Hybrid has more than 2 orders of magnitude better precision, path motion performance and stiffness over traditional Hexapod designs. The name Hybrid Hexapod is indicative that the system supplies all the known six degree of freedom motion and existing functionality of a hexapod, but is a hybrid serial kinematic and parallel kinematic structure. It includes, a parallel kinematic tripod constructed of three links/actuators generating the Z, pitch, and roll motion. The tripod is integrated with a monolithic serial kinematic XY motion stage and a rotary (yaw) axis mounted into the top of the tripod (or underneath it depending on application needs). In this hybrid design, individual axes can be customized to provide flexible configurations and travel ranges from millimeters to over one meter, while maintaining nanometer levels of precision. The changes did not stop there, however, as the links and structure of the tripod parallel kinematic system were completely redesigned relative to existing hexapod links to enable nanometer order performance of the system. This hybrid concept remains a simple and elegant solution that draws on the best features of serial and parallel kinematic systems to enable a significant performance improvement over hexapods. The following sections break down some of the specific differences and how they help improve the overall system performance relative to traditional hexapods.

Link Design – First, traditional hexapod link or actuator designs are generally designed primarily to support the load against gravity, with precision of the link motion a secondary priority. The motors are driven by mechanical contact mechanisms, such as a micrometer leadscrew paired with a rotary motor or a friction drive motor (typically piezoelectric motor), which are not considered high precision motor solutions and introduce heat gradients and vibration into the links.

Additionally, screw driven actuators are characterized by backlash and employ rotary encoders from which linear position is calculated, not measured. Furthermore, as any hexapod moves, the forces on each joint of the actuator will vary greatly in magnitude and angular direction. The link designs, some of which are simply off-the-shelf linear actuators, are not designed to maintain the location of the end joint of the cantilevered actuator with high precision under such varied loading. The varying loads can also cause motor forces, and thus motor heat generation to vary drastically, adversely affecting precision. Most hexapod links or actuators would not be used in a precision single axis stage, for the reasons mentioned, but when coupled together in the form of a hexapod they are billed as a precise six degree of freedom motion system. The new Hybrid Hexapod links were designed from the ground up with optimum precision as the primary focus. The links utilize brushless, non-contact, linear servo-motors oriented along the link axis eliminating any mechanical coupling. There is no friction or wear to adversely affect precision or create backlash, while minimizing vibration and heat generation. Heat variation is minimized by coupling the motor with near frictionless pneumatic cylinders (or non-contact magnetic springs) in each link to counter balance (i.e. zero-out) the strut load against gravity. This allows for high payload capabilities. Aside from the inertia of the payload, there is very little force (and thus little heat) that the motor needs to generate to move the system because the counterbalance supports the mass. Lastly, all axes of the Hybrid Hexapod use non-contact optical linear encoders that eliminate backlash and rotary encoder errors. Optimized sensor locations ensure the position feedback reflects the actual position of each link/axis. The Hybrid Hexapod link design provides Stiffness – The tripod structure was selected for its stiffness benefits compared to traditional hexapods. Traditional hexapod's high Z stiffness is well publicized, and is a result of all six links being oriented in the near vertical angle. However, the XY (horizontal) stiffness is relatively weak. A review of hexapod manufacturers' websites will show XY to Z stiffness ratios ranging from 1:10 to 1:32. Poor horizontal stiffness, combined with links that carry varying loads at varying angles, correlates to poor repeatability and positioning performance of the common hexapod top ring. A motion system in three-dimensional space needs to have high and equivalent stiffness in all directions to be able to supply precise motion in all directions. The tripod parallel kinematic structure offers both excellent Z stiffness from motors aligned in each link vertically, and excellent XY stiffness from mechanical stiffness of the tripod link joints. Specifically, the tripod joint between the link and base plate has only one rotational degree of freedom (i.e. hinge). This design allows the link rotation in one direction only, but provides mechanical stiffness in other rotational loading directions. Mechanically rigid joints positioned 120 degrees apart, the tripod can provide equivalent XY stiffness in any vector direction in the XY plane, even without servo-power.

Accuracy and Repeatability – In a traditional hexapod, all six links move for any motion command. Therefore, for any single axis move, whether it is a rotation or linear move, the error of the top ring is a summation of the error sources from all six links. This includes errors due to miscalibration of each joint location, backlash, link translation errors, and even servo dither. Furthermore, the complex kinematic structure of the hexapod makes these errors hard to isolate or calibrate, and thus, a hexapod's accuracy is limited to the 10s of micrometers and repeatability limited to several micrometers. While the new Hybrid link design presented above improves accuracy and repeatability significantly, the hybrid serial and parallel kinematic concept enables motion in each degree of freedom to be performed with the minimal amount of error sources affecting its precision. The three link tripod kinematic structure is simpler and symmetric, and therefore, provides simple methods of calibration and compensation to ensure the Z, pitch and roll motion degrees of freedom can be performed with sub-micron accuracy. The hybrid concept, joining the tripod with monolithic XY and rotary stages, decouples error sources of other axes from affecting the XY and yaw motions. Furthermore, with this simplified hybrid approach, all axes, both linear and rotational, can be easily calibrated for accuracy and orthogonality to optimize performance in three-dimensional space. As a result, multi-axis motion will also be more precise, because the error sources from each axis, orthogonality, will have all been minimized.

Motion Trajectory/Straightness/Flatness – Continuing the discussion above, motion trajectory, or straightness and flatness of motion performance, is relatively poor for hexapods due to the multitude of error sources and difficulty of calibration. In fact, a quick review of hexapod manufacturer specifications will show that virtually none mention straightness or flatness at all in specifications for their hexapods. Specifically, many standard precision hexapods will have straightness on the order of 100 micrometers per 100 millimeters of travel. Again, the hybrid serial and kinematic approach of the Hybrid Hexapod enables optimized geometric (flatness and straightness) motion errors for all axes. In many applications, the Z, pitch and roll are utilized for alignment of a device or substrate, and a process (such as a raster scan) is performed in the XY plane. The precision XY stage, which is designed specifically for accurate and straight planar motion, can perform the raster scan with straightness error of less than +/-1 micron per 100mm of linear travel – two orders of magnitude better than typical hexapod performance. Non-linear or multi-axis motion trajectories (i.e. circles) are also performed with single-digit or sub-micrometer precision.

System Flexibility and Ranges of Travel – Lastly, standard traditional hexapods provide a limited range of travel for all six degrees of freedom for any given design. If an end user requires any more travel in any one axis, an entire new hexapod model or design is required. Additionally, yaw rotation is typically limited to +/- 5 degrees maximum. With the Hybrid, axes can be optimized for range of travel and cost. For example, XY travels of over one meter can be paired with any tripod sub-assembly. The yaw rotary stage can have limited travel or 360 degree continuous rotation. The overall flexibility of the concept allows for a myriad of efficiently configured assemblies to fit any and all six degree of freedom motion system applications.

Summarizing the ALIO Patent Pending Hybrid Hexapod® Advantages Conventional hexapods we initially designed for amusement rides and later more widely known as flight simulators where 6 axis of motion was needed and not precision. The past 25 to 30 years the Hexapod platforms are commonly used, and have their place in applications requiring 10s of microns of precision, but they do not meet the high precision motion requirements of 6-D Nano Precision®

applications. 6-D Nano Precision is a term used to describe motion systems with verifiable nanometer order motion performance for all six degrees of freedom of a body in motion. The patent-pending Hybrid Hexapod was developed with the 6-D Nano Precision concept at the forefront of every decision. It combines precise serial XY and rotary (i.e. yaw) stages with a novel parallel kinematic tripod design to provide six degrees of freedom of motion at performance levels two orders of magnitude beyond current traditional hexapods. The accuracy, repeatability, stiffness and geometric accuracy performance makes the Hybrid Hexapod the ideal motion solution for many leading nanotechnology companies in the optical, semiconductor, manufacturing, metrology, laser processing and micro-machining industries. The Hybrid Hexapod continues to open up a new realm of possibilities for 6-DOF motion systems.