AN INTRODUCTION TO SLEW DRIVES

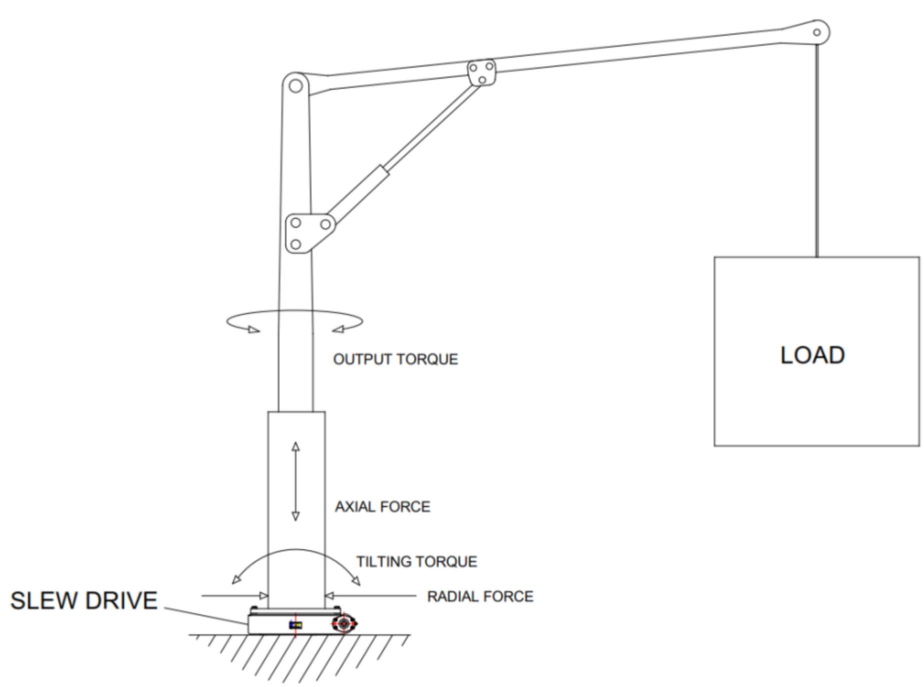
FROM THE EXPERTS AT KINEMATICS

www.kinematicsmfg.com

Introduction

Slew drives are commonly used compact rotary motion gear drives used in many applications ranging from state-of-the-art solar trackers to construction cranes and industrial automation. Chances are in your commute to work each day you pass many slew drives, all serving the function of applying rotating torque to generate and control the motion of objects or payloads. A slew drive is simply a gearbox, or self-contained drive unit consisting of one or more paired gears that can safely and dependably contain radial, axial, and moment loads and provide the necessary torque for moving heavy loads. Have you ever wondered how solar panels installed on solar trackers are precisely moved in relation to the sun's position to maximize energy production? The answer is, more times than not, a slew drive is the means for supplying this motion.

The rotational force supplied by the output of slew drives is described as torque, or put more simply, the force applied to the twisting of an object about an axis of rotation. When one is tightening or untightening the lid to a Mason Jar, one is applying torque. When we think about torsion in slew drives, there are two types to consider. There is torsion from external loads applied to the slew drive output bearing, creating an overturning moment, also called tilting torque. And, there is torsion taken from the slew drive output gear to rotate loads (also called output torque). In the picture example below, the load at some distance from the slew drive centerline is causing tilting torque on the slew bearing. The torsion required to rotate the mast (and the beam with the load) is output torque. Other slew drive forces will be explained a little later.



History

A slew drive is a pretty remarkable piece of machinery whose base elements have existed for hundreds of years, yet it's a machine that continues to evolve. The underlying technology found in these drive mechanisms is ancient, dating back to Ancient Greece and employed by Leonardo da Vinci in his Renaissance inventions.

Modern slew drives represent the current evolution of an ancient and highly effective machine, the worm drive, or endless screw. Slew drives have a vibrant history. The origin, many believe, has its roots in Archimedes' screw dating back to the 3rd century. The screw was used to transport materials, such as water or other light materials along a spiral chamber. The endless screw evolved into what became known as a worm drive. The worm drive became very popular for controlling speeds and applying torque from rudder control on sailing ships to steering automobiles to tuning strings on musical instruments.

By integrating the worm with the worm wheel, designers could control both speed and torque by using gear ratios. The worms provided the means, via high numeric gear ratios, to achieve speed reduction balanced with high torque production.

Modern Slew Drive Mechanics

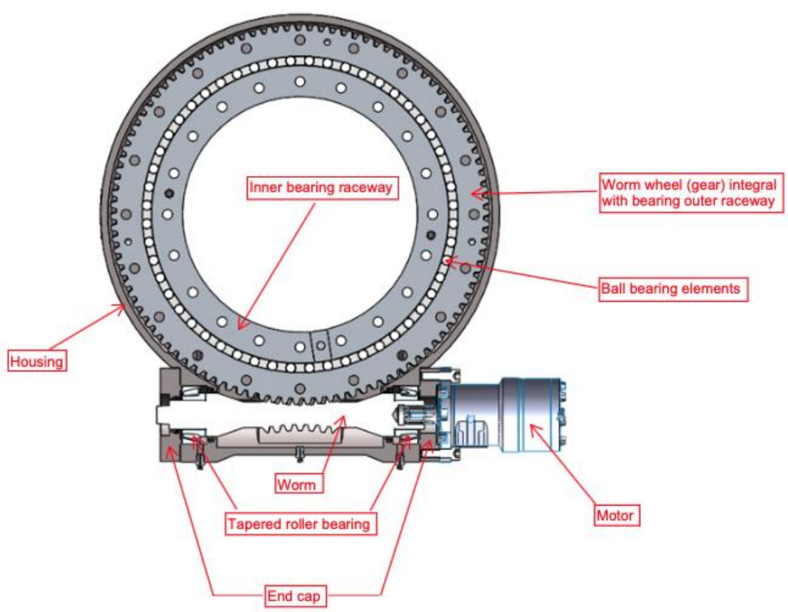
A quality modern slewing drive includes a sound and very reliable mounting structure or enclosure, a worm, a worm wheel, and an anti-friction slew bearing along with proper sealing from the environment and servicing lubrication hardware. In operation, the drive converts rotational input torque provided by a prime mover (electric or hydraulic motor) into rotary output torque. The output torque of the slew drive is the value of the input multiplied by the worm gear mesh ratio less the drive efficiency losses. The ratio is the tooth count of the output gear divided by the number of starts of the worm. Coincident with the torque multiplication is the drive output speed, which is reduced by the value of the gear mesh ratio. Power transmission through the drive is accomplished by the worm thread engagement with the output gear teeth slots. As the worm rotates, the gear (fixed on an axis perpendicular to the worm), rotates at the ratio value of multiplied torque and reduced speed. Both the worm and the gear are mounted and contained in the housing enclosure by anti-friction bearings.

Advances found in modern slew drives include the use of hourglass worm technology, which increases the number of gear teeth slots that engage with the teeth of the worm thread. This KMI innovation significantly improves tooth mesh load share, the drive's torque capacity, positioning accuracy, and rotational smoothness. Drives that are intended to deliver long-service lives in harsh environments are enclosed in rugged and thoroughly tested housings that protect crucial components from water, dust, or other particulates.

Slew drives are frequently the unsung heroes, delivering the positional accuracy and mechanical control that makes much of modern electro-mechanical technology possible. While a relatively small percentage of a typical complete system's bill-of-material, they play a mission-critical role in delivering the intended service. And like any precision engineering component, the effectiveness of a slewing drive is the direct result of selecting the right product for one's specific application requirements.

Modern Slew drives contain several vital components. The following is a list of key components found in slew drives and the function of each. See the image below for descriptions.

- Housing: The housing is an enclosure that structurally supports all gears and bearings and protects them from the environment.
- Worm: The worm is a screw-threaded shaft whose function is to apply axial translation through its rotating screw thread about its input axis to impart rotational motion to the worm wheel about its output axis.
- Worm Wheel: The worm wheel's (sometimes called the output gear) function is to impart rotational motion to the desired payload with amplified torque and reduced speed compared to the input. The payload is attached to the worm wheel output by means of a drive coupling.
- The Inner Raceway: The inside portion of the bearing raceway in the shape of a trough that comprises one-half of the roller bearing elements support. It is typically integral to the mounting structure of the slew drive.
- The Outer Raceway: The outside portion of the bearing raceway in the shape of a trough that comprises the other half of the roller bearing elements support. It is typically integral to the output gear (worm wheel) side of the slew drive.
- Oil Seals: Sealing elements that keep the gear and bearing lubricant inside the slew drive housing and also keep contaminating particulates from the environment out of the slew drive.
- Bearings: Rolling elements of the slew drive bearing, typically spherical ball bearings.



Sizes and Performance Metrics

Slew drives come in many sizes and shapes. It's not a one size fits all scenario. Slew Drives come as single-axis or dual-axis. Dual-axis drives are capable of driving two distinct but connected gears to deliver motion range along two perpendicular output axes, versus one. Slew Drives are frequently first described by their size. Size measurements are listed by the diameter of what is called the "raceway" bearing mean diameter. In general, the smaller the drive that can deliver the required performance for the application, the better. However, other considerations go into picking the right slew drive, as described later.

An area that is often confusing, even for engineers, is the different performance metrics provided by manufacturers. Suppliers often report different numbers or even different terms to describe a measurement. There are several key performance metrics to consider:

Maximum Torque: Maximum Torque is the amount of output torque that a slew drive can generate as measured in Newton Meters or foot-pounds. This rating is intended to be a very short interval duration. It is sometimes called "intermittent torque rating" or "3-second torque rating."

Back-Holding Torque (BHT): "Back-drive" occurs when the external load drives the worm gear backward. BHT is the rating for maximum non-back driving or static torque that is near but inside the threshold of the breaking strength capacity of the drive.

Nominal Torque: Nominal torque is the maximum output torque rating for continuous operation. It is sometimes called operating torque. It is given in units of Newton-meters or foot-pounds.

Tilting Torque: Tilting torque is the maximum static rating of the slew bearing to support a load at some distance from the output axis that creates a "tipping" torsion on the raceway bearing's axis (see above illustration). This rating means the drive can absorb the rated moment loading without deformation of the raceway from the rolling elements. It is given in units of Newton-meters or foot-pounds.

Static Radial Rating: Static radial rating is a capacity rating for the raceway bearing when the load direction is oriented in the radial direction on the bearing, perpendicular to the axis of rotation (see above illustration). This rating accounts for the radial load capacity of the bearing that can be absorbed without denting deformation of the raceway by the rolling elements. It is given in units of Newtons or pounds. Note that it is the rating for pure radial load and not in combination with any other load parameters.

Static Axial Rating: Static axial rating is a capacity rating for the raceway bearing when the load direction is oriented in the axial direction on the bearing, along the axis of rotation (see above illustration). This rating accounts for the axial load capacity of the bearing that can be absorbed without denting deformation of the raceway by the rolling elements. It is given in units of Newtons or pounds. Note that it is the rating for pure axial load and not in combination with any other load parameters.

Dynamic Radial Rating: Dynamic radial rating is the amount of radial load that can be applied to the raceway bearing and the bearing achieve a fatigue life of 1,000,000 cycles with 90% reliability. This fatigue life is in reference to raceway pitting fatigue. The load orientation is in the radial direction and perpendicular to the axis of rotation (see above illustration). This rating is for pure radial load and not in combination with any other load parameters.

Dynamic Axial Rating: Dynamic axial rating is the amount of axial load that can be applied to the raceway bearing and the bearing achieve a fatigue life of 1,000,000 cycles with 90% reliability. This fatigue life is in reference to raceway pitting fatigue. The load orientation is in the axial direction on the bearing along the axis of rotation (see above illustration). This rating is for pure axial load and not in combination with any other load parameters.

Another Form of Actuators - Linear

A Slew drive is a type of actuator, a component of a machine that creates and controls mechanical motion. A slew drive generates rotary motion and does so very efficiently and reliably. But there are other types of actuators as well. One of the most common is the linear actuator, which is simply an actuator that creates motion in a straight line. There are many underlying technologies available to build a linear actuator.

Linear actuators are one of the options that can be used in Utility-Scale solar tracker applications. The linear actuator is attached to an anchor on one end and an offset lever on the other end to provide rotary motion to the solar tracker. One fundamental question is, how should users compare and contrast slew drives to linear actuators?

Because slew drives sit at the very center of the rotation axis located on what is known as the torque tube driveline, the applied torque is independent of the tracker angle, and the tracker can be positioned relatively close to the ground. This allows the shortest, strongest, and least expensive support structure, which can have a significant impact on overall costs. By contrast, linear actuators, because of their push and pull nature, act only on a point along the chord of the external panel. The device must be mounted at some distance from the panels such that they can be pushed and pulled around the center axis of rotation of the torque tubes. Due to the geometry of converting linear motion to rotary torque, the applied torque varies with the angle of the tracker table. The physics of this solution requires taller, more expensive support structures.

From a complexity perspective, slew drives have the benefit of being a turnkey unit, comprising a single product to order. Linear Actuator configurations typically have a more complicated bill of material, requiring multiple purchase orders from different suppliers. With respect to installation, linear actuators must be bracketed, measured, and aligned, in what is already a challenging fieldwork environment. The number of linear actuators per tracker row (and associated installation labor) is also significantly higher than the number of slew drives.

Does this mean that linear actuators are always a poor choice over slew drives? No, there are situations where the use of linear actuators makes sense. These usually are cases where the land supporting the solar trackers is on very uneven topologies, and the ability to use standard trackers and underlying infrastructure is prohibited.

Factors when Considering Slew Drives

Many factors must be considered when selecting the optimal slew drive for an application. Answering some basic questions is the best place to start:

What are the actual performance requirements? The most cost-effective and reliable drive design will be the one that fits a minimum size profile while also meeting particular structural, power, duty cycle, and survivability holding torque values. Fully appreciating your actual operating requirements is critical when evaluating slew drive designs intended to meet them.

What are the expected environmental conditions? A slew drive's protective outer casing must be sufficient to ensure a long mechanical life, reliable performance, and adequate defense against the surrounding elements. Will the drive be exposed to dust, dirt, or other particulate contaminants? Will water or other liquids be a concern? If so, one should make sure that the housing is rated to support the conditions the drive will operate in (e.g., IP55, IP65, IP66). At the other end of the spectrum, where there are little to no environmental threats, there are fully exposed, open slew drive architectures.

What are the expected axes of rotation and motion ranges? A best-fit slew drive design will quickly and smoothly accommodate a specified range of motion about one or two rotation axes.

What will be the required backlash tolerances? Backlash, also called play or lash, refers to the slew drive's stop/start position accuracy. Backlash is a measure of the clearance existing between the meshed gear teeth, gaps that result in lost motion potential in the drive. Backlash is required for the exiting side of the tooth flank to prevent double-flank mesh interference and allow for smooth meshing operation. Manufacturing tolerances and the size of a given drive dictate how much backlash is required. Gear design, quality standards, and customer requirements dictate how much backlash is designed into a given drive.

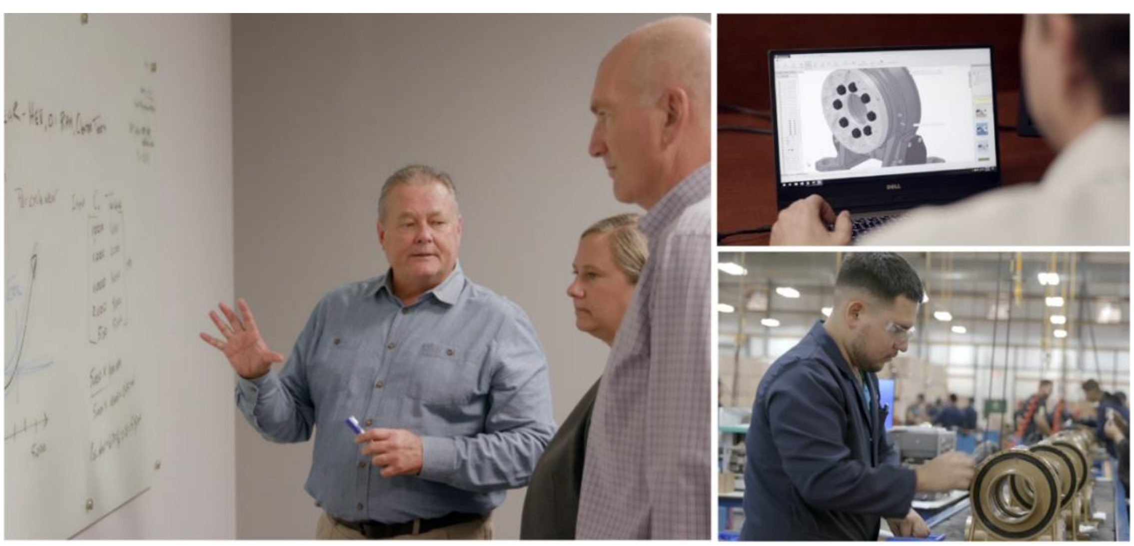
Should one acquire Self-Locking or Non-Self-Locking slew drives? As a general practice, low helix angle slew drives are self-locking. This means that while the worm drive can transmit torque to the gear, and the gear to the load, the gear can't back drive the worm. This implies that the drive is "self-locking," i.e., when the worm stops transmitting torque, the payload induced torque will not be able to back-drive the worm gear. For many applications, this is the desired effect. For others, it may not be. When not desired, a higher helix angle worm drive configuration might be the solution. With higher helix worms with sufficiently high enough helix angle, the drive can relatively easily be back-driven. Dual-start and multi-start worm designs are are typically not self-locking. But note also that single start designs can have a high enough helix angle to permit back-driving.

What are the input power requirements? A slew drive can be designed using one of many different common types of input power systems, such as electric (DC brushed/brushless and AC motors), hydraulic, and hand rotation power controls.

Determining the right combination of slewing drive design factors can be a detailed and complicated process, but it doesn't have to be a difficult one, and one doesn't need to tackle it alone. One needs to make sure that their chosen supplier has the engineering skills to help pick the right solution. Reputable vendors should have an engineering staff that can quickly understand one's application objectives and makes the right recommendations.

The KMI Difference

Kinematics slew drives incorporate the load bearings, rotational torque, and motion control needed, all inside of one compact, quality manufactured housing. They are available in a myriad of options for electric motors, reduction ratios, output power, and mounting options to suit all types of industrial equipment. Kinematics is the leading slew driver supplier to the Utility-Scale solar industry. The company has over one million slew drives installed in field applications throughout the world. The Kinematics difference can be summarized in three ways: Continuous innovation in torque technology, a Sales and Support team made up of technical application experts and a company that can scale



operationally to meet the growing demands of the Utility-Scale solar industry and other industrial application needs.

Summary

In this introduction to slew drives, we've provided the reader with some essential background. We've described what slew drives are and how they work. We shared the rich history and the innovation that continues to enhance the form, function, and economics of slew drives. We provided some primary performance metric definitions and why these metrics are important. We also provided some basic questions to ask when considering using slew drives. Slew drives are highly configurable and come in different sizes and performance characteristics. Lastly, we shared the KMI difference. We're proud to be the world's leading supplier of slew drives and were also pleased to have a committed team of technically competent professionals whose passion is to partner with our customers to make their applications better and produce positive change.