KAYDON®

MSD MOTION SYSTEM DESIGN

Gearing up your bearings

Slewing ring bearings — the bearings that find use on cranes, wind turbines, and other smaller designs — are sometimes cut with teeth to double as gears. Let's review the benefits and challenges of applying these units.

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Drive systems can be simplified by incorporating a gear on either the inner or outer bearing race of a slewing ring. These gear details can take on many styles and features: Fellows stubs, full-depth involutes, straight, helical, hardened or unhardened, and ground or unground, but what factors make for a good slewing-ring gear? Gear static strength, resistance to pitting, gear fatigue, and gear/pinion interfaces, or mesh.

A pressure angle of 20° is most common because 20° cutters are standard, but 14.5°, 25°, and special pressure angles are also used. Machine designers select slewing ring bearings based on load capacities. (See attached load charts.)

Gearing

The tooth size and form is then selected using the following Lewis equation:

$L = SFY\,P$

Where L = Tangential tooth load

S = Allowable bending stress

Y = Tooth form factor (from tables — *see last page*)

P = Diametral pitch

F = Face width

The *stub* tooth form is often used in large gears; economics is the main reason. The form requires less material in the ring forging and less gear cutting time. *Full depth* tooth forms, on the other hand, provide greater contact ratio for smoother operation, but have lower bending strength.

With core hardness of 23 to 30 Rc, allowable bending stress is 34,000 psi. With 262 to 302 BHN (27 to 32 Rc) this is 37,000 psi, and 29 to 34 Rc allows 40,000 psi. These stress approximations are for maximum or stall torque conditions — so when shock is included in the loading, higher stresses may occur.

Induction-hardened gear teeth with a minimum surface hardness of 55 Rc should be considered when high tooth surface pressures are constant. One example is an excavator or logger that undergoes high acceleration rates and rapid deceleration during a swing cycle.

A slewing ring bearing has rolling elements designed to create a reactive moment within the bearing's dimensions envelope, to oppose applied (overturning) moment load. The use of one bearing instead of two reduces the height required for an application and can improve performance.

A full root radius with root hardening is also recommended; the tooth pattern and depth of hardness are critical here.

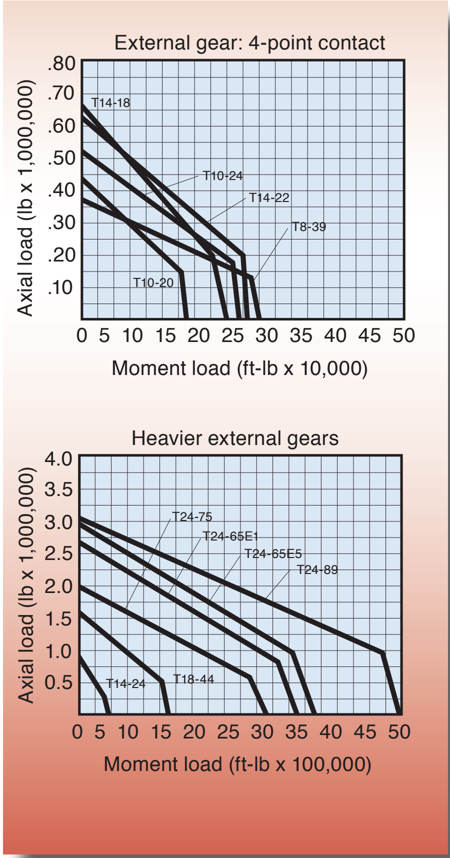
Backlash

All gears need backlash room. This is especially true of bearing gears, in which large diameters and large center distances require greater manufacturing tolerances. Other factors can determine whether adjusting the center distance between gear and pinion is appropriate to make room for backlash. The cost advantages of adjustment should be kept in mind: Gear size tolerance can be greater (and life extended) with take-up for wear.

Installation

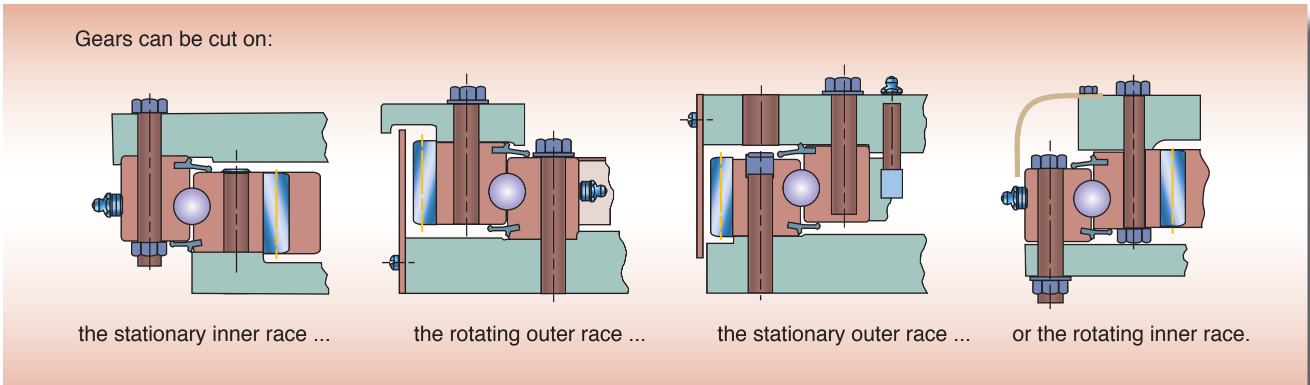
Installation of bearing/gear assemblies should be done in a clean, dry, well-lit area. Housing mounting surfaces and pilots should be unpainted and wiped clean of chips, dirt, and lint, because even soft materials make high spots when entrapped. Any weld spatter, nicks, and burrs should be removed.

Load ratings



Gear-related slewing ring bearing ratings are determined by tooth geometry.

Gear where?



Gear teeth can be cut into a number of slewing ring bearing surfaces, to accommodate different application requirements.

The bearing can be lifted or hoisted into position using eye bolts in mounting holes (or nonmetallic slings) which can prevent damage to bearing surfaces and gear teeth.

Inherent to the hardening process of most turntable bearings is a small gap at one point in the raceway; loading holes are drilled through this gap. These gaps (and load hole plugs, in races with through holes) should be positioned at minimum load points if possible. Load hole plugs in races with tapped holes or weld rings must be so positioned. With the rotating race, this is done by placing the loading hole 90° off the maximum load zone from moment loading. With the stationary race, this position depends upon the location of the lightest load relative to the lower structure of the machine.

For good internal load distribution and smooth, low-torque

Arrangements

Slewing ring bearing options abound. Unfortunately, there is no one best design for all applications. Selecting the right one depends on requirements for load, stiffness, speed, size, and smoothness of rotation. Traditional king-post bearing mounting arrangements (used to support radial, thrust, and moment loads) consist of two ball or roller bearings spaced along a common axis. Their moment capacity is boosted by spacing the bearings further apart and by using heavier sections. But their significant space and mounting complications means they do not lend themselves to many new applications.

A better solution nowadays is a single four-point contact ball bearing. This bearing utilizes gothic arch race construction for the inner and outer race ball paths to generate four points of contact for each ball. This in turn generates intersecting contact angles that create a large effective pitch diameter to offset any overturning moment load. The use of a single larger diameter bearing allows for wiring and plumbing through the bore of the bearing. This can simplify overall design, improve appearance, and help to protect components.

Four-point contact bearings have been used for many years in the construction equipment industry for cranes, backhoes, and excavators, and now these bearings are also used in specialty equipment: Robotics, lift-and-rotate tables, machine tools, aerial baskets, aerial platforms, and radar pedestals.

Though load vs. capacity considerations dominate bearing cross section and diameter selection, other parameters also influence which design is best. Torque considerations may indicate the use of a two-row ball bearing in place of a four-point contact bearing. Increased moment stiffness may require a two-row roller or a cross-roller bearing. Deflections, or use of an aluminum mounting structure, may dictate the need for an aluminum wire race version of a steel ball or roller bearing. The use of aluminum bearing rings with hardened steel wires not only matches the coefficient of expansion of aluminum mounting structures, but can also provide the flexibility needed to compensate for mounting distortions.

Smaller-bore bearings may be necessary in weight-sensitive applications such as robotics and manipulators; these enable smaller mounting structures, and overall weight reductions that reduce moments of inertia — to allow for faster movements with fewer structural deflections.

Standard turntable bearings are available in bore sizes to more than 800 mm. Some manufacturers also offer standard slewing ring bearings in bore sizes as small as 50 mm. The relatively high capacity of these bearings make them suitable in the joint positions of articulated systems.

Surface hardness

Case depth-induction hardened gears

Diametral pitch	Flank depth	Root depth
4.00	0.040	0.030
3.50	0.050	0.035
3.00	0.060	0.040
2.50	0.075	0.050
2.00	0.100	0.070
1.75	0.125	0.080
1.50	0.150	0.100

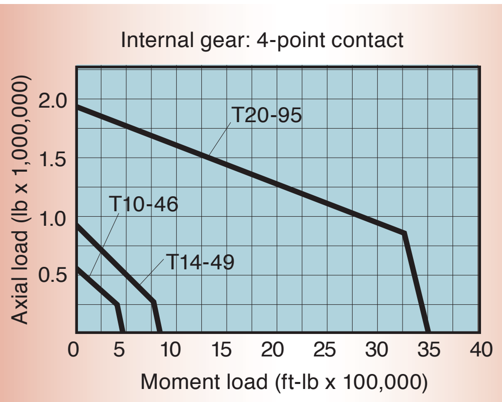
Gear teeth are hardened through to their full root radius resist high surface pressures.

Backlash allowances

Gear pitch diameter	Minimum backlash (in.)	Maximum backlash (in.) Diametral pitch 1.5	1.75	2	2.5	3,4,5
20	0.014	0.029	0.027	0.025	0.023	0.022
30	0.015	0.030	0.028	0.026	0.024	0.023
40	0.016	0.031	0.029	0.027	0.025	0.024
60	0.018	0.033	0.031	0.029	0.027	0.026
80	0.020	0.035	0.033	0.031	0.029	0.028
100	0.022	0.037	0.035	0.033	0.031	0.030
120	0.024	0.039	0.037	0.035	0.033	0.032

The large center distances and (often) big diameters of slewing ring bearings require tighter tolerances, so gear teeth must be designed to allow for backlash.

Axial and moment load



Slewing ring bearings withstand loading from multiple directions.

Tooth form factor
The tooth form factor is used in the Lewis equation to determine the right gear size.

Tooth form factor (Y)						
Number of teeth	20° full depth involute system	20° stub tooth system	Fellows stub tooth system			Internal gears 20° full depth system
12	0.245	0.311	0.301	0.349	0.320	
13	0.261	0.324	0.317	0.361	0.336	
14	0.276	0.339	0.330	0.374	0.352	
15	0.289	0.348	0.339	0.386	0.361	
16	0.295	0.361	0.349	0.396	0.374	
17	0.302	0.367	0.358	0.405	0.383	
18	0.308	0.377	0.367	0.411	0.389	
19	0.314	0.386	0.374	0.412	0.399	
20	0.320	0.393	0.380	0.424	0.405	
21	0.327	0.399	0.386	0.430	0.411	
22	0.330	0.405	0.393	0.437	0.412	
24	0.336	0.415	0.402	0.446	0.427	
26	0.346	0.424	0.408	0.455	0.437	
28	0.352	0.430	0.418	0.462	0.443	0.691
30	0.358	0.437	0.424	0.468	0.449	0.678
34	0.371	0.446	0.437	0.480	0.461	0.660
38	0.383	0.456	0.440	0.484	0.468	0.644
43	0.396	0.462	0.452	0.446	0.480	0.628
50	0.408	0.474	0.462	0.506	0.490	0.613
60	0.421	0.484	0.471	0.515	0.499	0.597
75	0.434	0.496	0.484	0.525	0.509	0.581
100	0.446	0.506	0.496	0.537	0.521	0.565
150	0.459	0.518	0.509	0.547	0.534	0.550
300	0.471	0.534	0.525	0.563	0.550	0.534
Use in Lewis Formula for P			4	5	6	

operation, the bearing should be as round as possible when the bolts are tightened. If one race is doweled or piloted, it should be mounted first when possible.

On unpiloted gear bearings the gear/pinion backlash should be checked and adjusted. The minimum backlash point of the gear is often identified by yellow paint in the tooth space.

When installing:

• Leave all mounting bolts loose until both mating parts are attached to the bearing.

• While applying a moderate centered thrust load to the bearing, measure the torque to rotate the bearing. Then tighten all bolts to the level prescribed by the bolt manufacturer. This is very important; improperly tightened bolts can fail due to fatigue and can harm equipment and workers.

• Again measure the torque required to rotate the bearing. If greater than the first measurement, the bearing is being distorted. Determine and correct the cause.

Team player
The teeth of slewing ring bearings can be tailored to designs just as regular gears.

After these steps, gears on fixed centers can be checked for backlash, and pinions on adjustable centers set for proper backlash.

When all backlash checks are completed, the gear should be coated with grease suitable for the operating conditions, and rotated to ensure coverage of all contacting surfaces with the pinions.

Complete installation of all rotating components of significant weight, and check bearing for freedom of rotation. Again, excessive torque or variations are indicative of an unsatisfactory installation condition.

Beyond backhoes: Small designs

Significant changes are taking place in the use of slewing ring bearings. The traditional perception of slewing ring bearings as large-diameter, heavy-section, low-precision bearings with bolt holes and gears for construction equipment applications is no longer valid; these bearings are increasingly used in smaller, precise applications.

Improved manufacturing methods and design concepts are behind this trend. Smaller, off-the-shelf slewing ring bearings (preloaded to eliminate clearance and improve stiffness) have become standard in the machine tool industry; runout and diameter tolerances for these bearings can be specified in ten-thousandths of an inch, vs. thousandths.

Big and small
Slewing ring bearings are no longer limited to large, heavy applications. Their versatility is boosting performance in smaller designs as well.

The design is useful in even small designs because it's simple to bolt a rotating structure to a stationary base.

For more information, contact KAYDON Bearings Division at 1-800-514-3066 or visit kaydonbearings.com or motionsystemdesign.com and click on the Component Zone links for bearings and gears.