



[<< Return to Main Page](#) | [Print](#)

From the pages of Design News

Backlash vs. lost motion

By John Landry, BSME, Account Manager, alpha gear drives -- 8/5/2002

High performance servomechanisms capable of dynamic precision movement improve industrial productivity by increasing machine cycle times and throughputs. Precision planetary servo gearheads, often an essential component of a servo system, provide mechanical advantage through speed reduction and torque manipulation to control relatively large loads with relatively small motors by reducing reflected load inertia on the motor. Smaller motors, cables, drives, controls, and amplifiers consume less power to reduce the system's operating costs.

Because lost motion is one of the principal causes of positional uncertainty in a motion system, understanding the difference between backlash and lost motion, and their impact on repeatability and precision, are key to choosing the correct servo gearhead to achieve a given rotational accuracy. Unfortunately, differences in semantics and methods of measurement confuse the matter. In particular, backlash and lost motion are often erroneously believed to be synonymous in describing the relative motion of the gearhead output position in relation to the input movement.

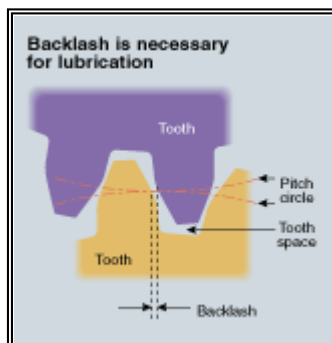
In fact, gearbox backlash is a component of lost motion, which describes the condition in which an input to a mechanism yields no corresponding displacement at the output. Simply stated, all mechanical devices, even a bar of solid steel, have some elasticity. Thus, a small torque and rotation can be applied to the output of a device (or one end of the bar) and be absorbed in the windup of the device or bar, with no movement at the input (or other end of the bar).

Lost motion for transmissions is a measurement of the angle of movement in both directions before movement at the input occurs while applying a load at the output, while backlash is the amount by which the width of a gear's tooth space exceeds the thickness of an engaging tooth measured at the pitch circle of the gears.

Backlash, which is sometimes termed slop, lash, free-play, or simply play, is an angular quantity due to the gear's circular geometry. This can be termed clearance backlash, which is necessary to accommodate manufacturing errors, provide space for lubrication, and allow for thermal expansion of components.

Measuring backlash. In servo-mechanical transmissions, backlash is measured at the output shaft of the gearhead while holding the input shaft rigid. Lack of measuring standards for determining backlash makes the ambiguity in published values from various manufacturers no surprise. Is the specified value the maximum value or average? Is it a plus or minus value, or the total? Is any force used to rotate the output in order to insure full-face contact on the gears and the bearing rollers?

For example, if a manufacturer claims 10 arc-min of torsional backlash, and this is a plus/minus clearance backlash value, the actual torsional backlash will be about 35 arc-min (10 in each direction + 15 with a small load applied to the output). Quality manufacturers will apply some amount of torque when measuring backlash and call the result torsional backlash in order to insure that designers take this into account when trying to achieve a given



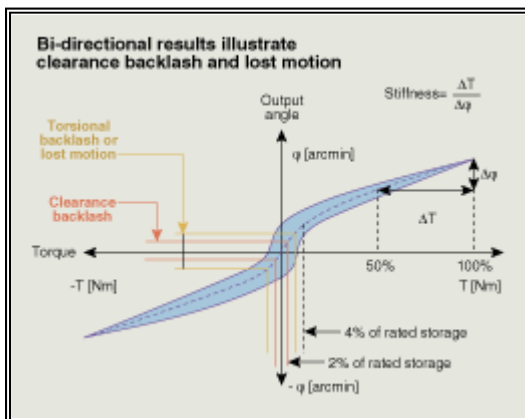
Backlash accommodates manufacturing errors and provides clearance for a lubricating film between meshing teeth. However, poor manufacturing and/or incorrect lubrication can increase a

rotational accuracy.

This is where the terminology gets confusing. Because a force is applied, some manufacturers will call torsional backlash lost motion because it involves rotating the output with no rotation at the input. The torsional backlash includes the clearance backlash, deflection of the gear teeth for full-face contact, motion as a result of bearing clearances, and friction. Torsional backlash is synonymous with lost motion, and common sense tells us that the amount of force applied will greatly affect the values of lost motion or torsional backlash.

gearhead's backlash over time because smaller tooth contact areas mean greater contact pressures. If these exceed the lubrication's allowable pressure, metal-to-metal contact will cause greater wear.

Lost motion and stiffness. Lost motion is not typically specified as such, since it is a function of the torque applied in a particular application. However, a useful alternative is the stiffness of the gearhead, sometimes termed torsional rigidity or torsional stiffness. This characteristic, in units of torque over an angle (Nm/arc-min or inch-lb/degree), denotes a gearhead's "spring effect" or stiffness. Input and output shaft diameter and gearing tooth pitch have the largest impact on a gearbox's torsional rigidity.



Manufacturing the ring gear integral to the housing provides a gearhead with maximum stiffness and torque capacity because it allows for the largest internal component size for a given envelope size. The higher the stiffness, the easier it is to control a system's accuracy of movement.

Stiffness of the gearhead is determined by rigidly mounting the unit, locking the input, applying a series of unidirectional torque loads to the output and, for each value, measuring the angular displacement at a number of positions about the circumference of the output shaft. The resulting data series is linear when the torque load nears the capacity of the gearhead.

The slope of the line in this area defines the torsional stiffness in units of force per angle increment. When this test is performed with bi-directional rotation and torque application, backlash contributes to the results. The difference between the data upon reversal indicates the lost motion or torsional backlash as a function of

the applied torque.

Backlash, or lost motion, is not an issue in the case of continuous single direction motion. Here, the resistance of the load forces the meshing gear teeth into contact that is maintained by constant unidirectional gear rotation. However, any reversal of motion or cyclical single direction applications require that the teeth first disengage then re-engage on the opposite tooth surfaces.

Impact on repeatability and precision. For cyclical motion systems, where low backlash is necessary, the drivetrain's torsional stiffness is critical for meeting duty cycle objectives. Consider a unidirectional rotary mechanism for cut-off applications. The intermittent cutting forces result in instantaneous high torque demands. These torque "spikes" through the gearhead input cause the gear teeth to deflect or move, and the output shaft to twist, which may produce erroneous cuts.

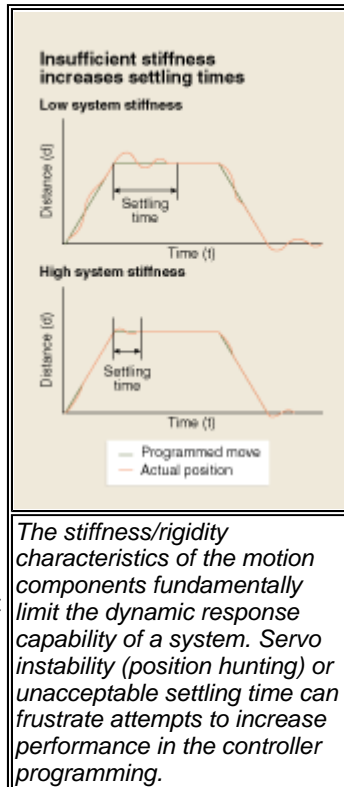
The inertia of the knife is very important here, because the higher the inertia, the greater influence stiffness has in control of the system. In these dynamic applications, the gearhead ratio decreases the inertia mismatch by a factor of the ratio squared. This allows a motor to use its energy to move the load quickly as opposed to using its energy to rotate its stator.

A controlled motion profile for this cut-off system entails accelerating and decelerating the knife. If the drivetrain isn't rigid enough to resist deflections due to the dynamic loads from accelerating and decelerating the knife's mass, then the output shaft will lag the motor shaft and its feedback transducer (resolver or encoder). The more torsionally rigid the gearhead, the more accurate the input to output readings will be.

Duty cycles must be limited to allow the system time to reach stability, which compromises throughput capacity. Otherwise, unacceptably large position uncertainty will result due to the torsional rigidity. For example, increasing the rigidity of a gearhead may allow processing speed of a paper processor to increase from 450 to 600 sheets/min.

Designers must realize what is important; precision, position, repeatability, or reliability. The combination of these factors will determine the most suitable gearbox for the application. In practice, price difference between gearhead suppliers tends to be miniscule compared to the costs of replacement in the field and the impact a faulty design or failure has on customers.

Keep in mind that gearhead catalogs are sales tools. Ask your vendor to supply test or inspectional data if precision and reliability are important. Make sure to compare equivalent specs. Clearance backlash is different from torsional backlash and lost motion, which are different names for the same thing. And remember that zero backlash does not result in exact positional location. The rigidity, lost motion, and dynamics of the control system as a whole will determine how close the system can come to perfect positioning.



For more information

Go to www.designnews.com/info or enter the number on the Reader Service Card:

Precision gearheads from alpha gear drives, www.alphagear.com: Enter 545

How much backlash is too much?

Well, that depends on repeatability, accuracy, and precision requirements. Repeatability is the degree to which the positioning accuracy for a given move performed repetitively can be duplicated. Accuracy is the difference between the expected position and the actual position. Backlash and lost motion play a minor role in this. The largest impact is the accuracy of your gear teeth or cam profile, as well as the accuracy of the positional feedback device on your servomotor.

Precision relates to repeatability, speed, and the ability to cycle at peak loads in opposite directions. If the inaccuracies of the gear teeth, backlash in the system, or manufacturing tolerances are great, the gearhead will overheat, misindex, or fatigue to failure. In contrast, a torsionally rigid gearbox with minimal torsional backlash allows the greatest precision.

It is essential to keep in mind the objectives of the motion system and the gearhead's significant influence in determining system performance. A common misconception is believing an application requires zero backlash, or that a transmission can be manufactured with zero backlash, when the reality may be that backlash readings of 2 arc-min or less will do.

For example, this amount of angular error in a gearhead that is rotating an 8 inch diameter roll equates to a maximum of 0.001 inch of movement at the roll surface, as calculated using the following equation:

$2 \pi \text{D} \text{ } \mu\text{A} \text{ radius} / 360 / 60 \text{ } \mu\text{A} \text{ backlash in arcmin} = \text{positional error in the same units as the radius.}$

However, it's important to consider the torsional rigidity of all components between the output shaft of the gearhead and the load to get a true measurement of the lost motion in a system. The types of couplings and line-shafting also have a large impact on the system stiffness and dynamic response, as these components are available in a variety of designs with different stiffness and damping characteristics. Even if compromised throughput is tolerable, a lack of stiffness can result in oscillations that may cause premature system failure due to fatigue of gears, shafts, couplings, or some other component.

© 2006, Reed Business Information, a division of Reed Elsevier Inc. All Rights Reserved.