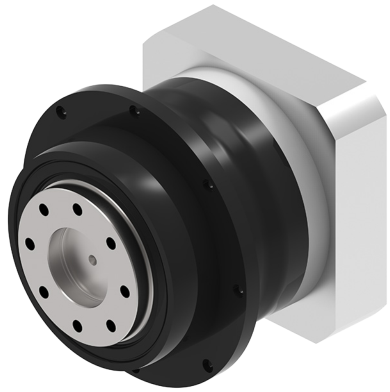
Beyond Backlash

Total Lost Motion in Gearboxes and Couplings



An application employing a servo motor for motion control will have specific requirements for performance and precision. The basic measurement for precision is backlash, but understanding of additional measurements can improve overall machine precision.

- **Backlash:** Movement in the output shaft position relative to the input shaft when the input is fixed. It is caused by clearance or play in the gears.
- **Torsional Stiffness:** Twisting angle due to external forces, "wind up" in the gearbox or coupling. It is a function of the overall rigidity of the gearbox.
- **Lost Motion:** Combination of backlash and torsional stiffness and is dependent on the applied torque.

In addition, these components of precision can stack up across components such as a drive using a gearbox with a coupling connection at the output. The backlash, stiffness, and lost motion of each component add up to the overall precision. Eliminating or improving a component can reduce the stack up of lost motion and improve precision.

We can compare mechanical motion control systems (gearboxes and couplings) by looking at the total lost motion at a specific torque including:

- Lost motion due to backlash
- Lost motion due to torsional stiffness

Total Lost Motion Calculation

Total Lost Motion is measured as an angle (usually arcminutes) and a combination of backlash and torsional stiffness

$$\text{Total Lost Motion} = \text{Gearbox Backlash} + \frac{\text{Applied Torque}}{\text{Gearbox Torsional Stiffness}} + \text{Coupling Backlash} + \frac{\text{Applied Torque}}{\text{Coupling Torsional Resistance}}$$

Where:

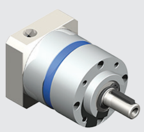
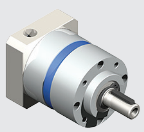
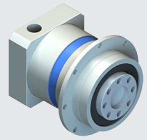
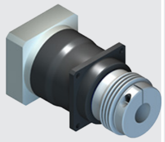
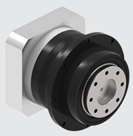
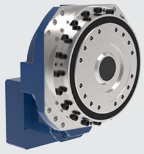
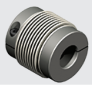
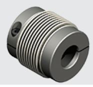
- **Backlash** (arcmin) and **Torsional Stiffness/Resistance** (Nm/arcmin) are provided by the gearbox manufacturer.
- **Applied Torque** (Nm) is the torque demand of the application.

Next, we will look a several gearbox comparisons.

1. Lost Motion Shows Performance of Different Gearboxes

In **Table 1**, we look at the total lost motion in GAM inline gearboxes. We use the maximum acceleration torque for each gearbox as the applied torque for a "worst case" scenario. Gearboxes are shown in order of decreasing total lost motion or increasing precision. The servo couplings are all zero backlash.

Table 1: Lost motion at Maximum Acceleration Torque

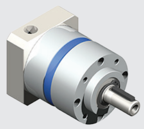
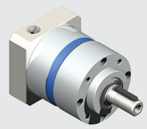
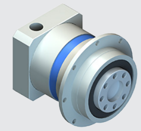
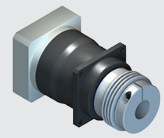
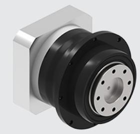
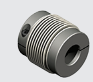
GEARBOX / COUPLING SELECTED							
Gearbox		EPL-W-084 	EPL-W-084 	EPL-F-090 	SPH-C-100 	SPH-F-100 	GPL-F-056 
Coupling at Output		EKM-150 	KLC-125 	Direct Connection	Integral 	Direct Connection	Direct Connection
GEARBOX DATA							
Gearing type		Straight Planetary			Helical Planetary		Robotic Planetary
Ratio		5:1	5:1	5:1	5:1	5:1	50:1
Frame size	mm	84	84	90	100	100	180
Torsional Stiffness	Nm/arcmin	7.1	7.1	7.1	20	82	165
COUPLING DATA							
Coupling Type		Elastomer	Bellows	-	Bellows	-	-
Torsional Resistance	Nm/arcmin	1.05	12	-	*Included with Gearbox*	-	-
APPLICATION DATA							
Applied Torque	Nm	100	100	100	375	375	625
LOST MOTION AT APPLIED TORQUE DUE TO:							
Gearbox backlash	arcmin	10	10	10	2.0	1.0	0.1
Gearbox Torsional Stiffness	arcmin	14.1	14.1	14.1	18.8	4.6	1.5
Coupling Torsional Resistance	arcmin	95.2	8.3	-	-	-	-
TOTAL LOST MOTION	arcmin	**119.3**	**32.4**	**24.1**	**20.8**	**5.6**	**1.6**
	degrees	**2.0**	**0.54**	**0.40**	**0.35**	**0.09**	**0.03**

Directly connecting a gearbox to the driven mechanism is more precise than using a coupling, and a bellows coupling is more precise that an elastomer coupling. In addition, the helical planetary gearbox outperforms the straight planetary gearbox of similar size, despite the higher applied torque.

2. Comparing Gearboxes with Lost Motion

Next, we compare the inline servo gearboxes at the same torque (100 Nm). In this case, the SPH helical planetary gearbox outperforms an EPL straight gear planetary gearbox of a similar frame size (**Table 2**)

Table 2: Lost Motion at a Set Torque

GEARBOX / COUPLING SELECTED						
Gearbox		**EPL-W-084** 	**EPL-W-084** 	**EPL-F-090** 	**SPH-C-100** 	**SPH-F-100** 
Coupling at Output		**EKM-150** 	**KLC-125** 	**Direct Connection**	**Integral** 	**Direct Connection**
GEARBOX DATA						
Gearing type		Straight Planetary			Helical Planetary	
Ratio		5:1	5:1	5:1	5:1	5:1
Frame size	mm	84	84	90	100	100
Torsional Stiffness	**Nm/arcmin**	7.1	7.1	7.1	20	82
COUPLING DATA						
Coupling Used at Output		Elastomer	Bellows	-	Bellows	-
Torsional Resistance	Nm/arcmin	1.05	12	-	*Included with Gearbox*	-
APPLICATION DATA						
Applied Torque	Nm	100	100	100	100	100
LOST MOTION AT APPLIED TORQUE DUE TO:						
Gearbox backlash	arcmin	10	10	10	2.0	1.0
Gearbox Torsional Stiffness	arcmin	14.1	14.1	14.1	5.0	1.2
Coupling Torsional Resistance	arcmin	95.2	8.3	-	-	-
TOTAL LOST MOTION	**arcmin**	**119.3**	**32.4**	**24.1**	**7.5**	**2.2**
	degrees	**2.0**	**0.54**	**0.40**	**0.13**	**0.04**

Inline Gearing Technology

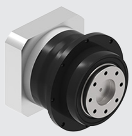
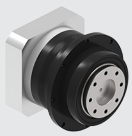
Gearing technologies each have their own advantage beyond precision.

Gearing Type	Gearbox type	Advantages
Straight Planetary	Servo	High precision, best value, many options, easily customized
Helical Planetary	Servo	Highest precision servo gearbox, quiet operation
Robotic Planetary	Robotic	Zero backlash for the life of the gearbox, vibration-free operation
Strain Wave (Harmonic)	Robotic	Zero backlash with high ratios in a small, compact gearbox

3. Looking Beyond Backlash

Looking at gear technologies, zero-backlash robotic gearboxes can seem like the obvious choice for precision motion control. But not all zero-backlash is the same. In **Table 3**, we compare the SPH helical planetary gearbox with the GSL strain wave (harmonic) gearbox. While strain wave gearing provides zero-backlash, it can be "spongy" resulting in greater lost motion than a helical planetary gearbox.

Table 3: Using Total Lost Motion to Compare Gearing Technologies

GEARBOX DATA					
Gearbox		SPH-F-075 	SPH-F-100 	GSL-HS-A-020 	GSL-HS-A-025 
Gearing type		Helical Planetary		Strain Wave (Harmonic)	
Ratio		50:1	50:1	50:1	50:1
Frame size (dia.)	mm	75	100	90	110
Torsional Stiffness	Nm/arcmin	30	74	4.9	9.2
APPLICATION DATA					
Applied Torque	Nm	35	35	35	35
LOST MOTION AT APPLIED TORQUE DUE TO:					
Backlash	arcmin	2.0	1.0	0.5	0.5
Torsional Stiffness	arcmin	1.2	.5	7.2	3.8
TOTAL LOST MOTION	**arcmin**	**3.2**	**1.5**	**7.7**	**4.3**
	degrees	**0.05**	**0.02**	**0.13**	**0.07**

The lost motion in a strain wave gearbox is not always a factor in an application. These gearboxes have the advantage of providing high ratios in a compact package. When applying strain wave gearboxes, lost motion comes into play during acceleration or with an overhung load.

Conclusion

Lost motion combines the effect of backlash and torsional stiffness on the precision of a gearbox system. It can be used as a factor in comparing and select the best motion control system for an application when precision is critical.