BEST PRACTICES FOR SELECTING & SIZING GUIDE WHEELS

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For over 40 years, Bishop-Wisecarver has been developing best practices for matching guide wheel systems to customer requirements, based on engineering and empirical experience. By sharing this knowledge and experience, selecting a guide wheel with the properties best-suited for a given application is easy and results in a system that reduces design costs and engineering changes, as well as lower warranty, assembly, installation and mounting costs.

Components

Manual Guides

Actuated Systems

Linear guide systems are chosen for an application based not only on their precision and speed characteristics, but also on a host of other operating conditions such as environment, length, speed, duty cycle, and temperature, to name a few. Guide wheel systems should not be overlooked; in many applications and environments they have notable advantages.

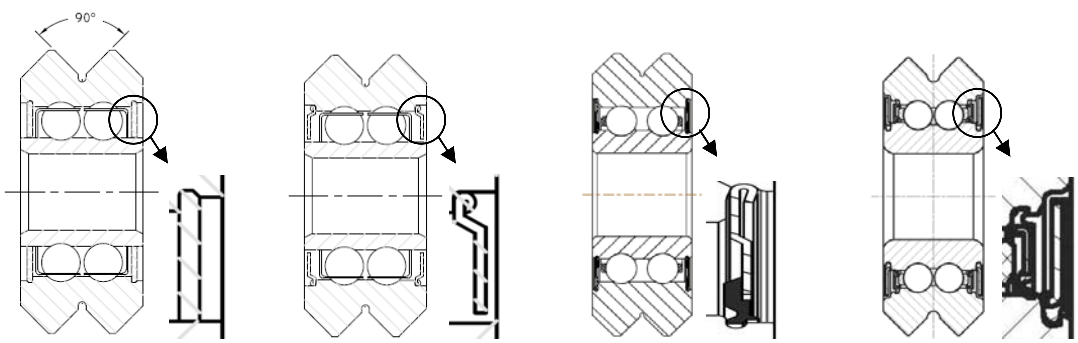
Well-known for their ability to outperform re-circulating ball technology in harsh environments due to their completely enclosed ball bearings and raceways, guide wheel systems also have other lesser known distinct advantages. They routinely operate in environments with low noise level requirements, high (up to 500°F) or low (as low as -94°F) operating temperatures, washdown practices, high humidity, or very long travel lengths. They can meet flatness, parallelism, and straightness tolerances as tight as +/- 0.001” (+/- 0.03mm), and compared to other linear guide systems, guide wheels have less friction, are much faster to assemble and very cost efficient.

By matching the component properties of a guide wheel system to a given application, engineers can ensure trouble-free operation over the system’s predicted lifespan, as well as reduced costs, lead time and field failures. The types of wheel and track selected must be matched to all application requirements, including environment, loads, accuracy, lifecycle and cost. Bishop-Wisecarver has developed the following process for ensuring the best match of guide wheel system to application, beginning with the operating environment to calculate the required size of the wheel.

The following is an overview of our best practices for bearing selection and sizing, which we have developed over time and find very useful for satisfying specific application requirements.

Bearing Type Selection

The environment determines the type of guide wheel bearing protection required.



Sealed | Shielded | Sealed/Shielded | Washdown

Sealed: Environments with heavy concentrations of liquid or fine/powdery particulates can displace and/or change the properties of the bearing lubricant, causing premature wear and failure of the bearing balls and raceways. Specifying a sealed bearing for this operating environment can prevent damage to the bearing elements, ensuring the predicted lifespan of the system.

Shielded: Generally, shielded bearings are used in environments with heavy concentrations of large particulates such as metal flakes that can work their way between the balls and bearing raceways. The larger debris can cause premature wear and damage such as brinelling or spalling.

Sealed and Shielded: Bearings that feature shields and seals combine the advantages of both sealed and shielded wheels. The shield protects the seal from damage by large particulates, while the seal protects the bearing elements from the fine particulate and liquid that the shield is less effective against.

Special configurations: The washdown bearing includes a patented inner seal and outer shield design. The design of the outer shield allows it to act as a momentary seal; while pressure from high velocity fluid causes the shield to deflect and conform to the wheel's metallic surface. When the pressure is removed, the shield returns to its normal position, allowing any liquid and debris that entered between the shield and seal to drain out or be spun out by centrifugal force.

Note: In contaminated environments, a de-rating factor based on the severity of the contamination must be used for sizing. This is discussed in the section on Load/Life Equation – Sizing and Selection, page 6.

Selection of Bearing, Wheel & Track Material

Wheels: Wheels are available in a variety of materials to suit a wide range of applications. The most commonly used materials are 440C stainless steel, 52100 carbon steel and polymer. Stainless steel materials should be used in humid, liquid and corrosive environments. Although highly corrosion resistant, some corrosion can occur with stainless steel depending on the severity of the environment. Polymer wheels offer certain benefits including chemical resistance, low friction, and low noise. Polymer wheels have reduced load performance versus steel wheels, but polymer wheels provide an economical choice for light load applications and harsh chemical environments.

Track: Standard track materials include AISI 1045 carbon steel and AISI 420 stainless steel. Other track materials include aluminum, which can be used with polymer guide wheels. The 1045 is a medium carbon steel with good strength and hardness properties (53 HRC hardened; 22-25 HRC unhardened), which minimizes wear. The 420 stainless steel contains just enough chromium to limit corrosion, yet can be hardened up to 45 HRC (20-22 HRC unhardened).

Stainless or carbon steel track are equally effective in environments with heavy concentrations of large particulates and flakes, because contaminants are swept away when the wheel passes over the track. Since the wheel has a smaller diameter at its inner vee compared to its outer vee, the wheel's inner vee travels at a slower rate than the outer vee on the track, causing a velocity gradient that pushes the debris outward, resulting in especially clean track.

When selecting the track material, it is generally advised not to specify a material softer than the wheel material. This can result in the track material galling onto the wheel, damaging the track, wheel and payload, requiring time-consuming and expensive repair to be made to the system. However, A notable exception to this rule is that it is acceptable to use hardened steel track material with steel wheels despite the track having marginally less hardness than the wheels.

Operating Temperature and Lubrication

Guide wheels can accommodate up to 500°F for operation in environments with high temperatures, and as low as -94°F for operation in low temperature applications.
If accuracy is a crucial issue, stainless steel wheels can be heat treated to the point where it becomes very thermally stable, which minimizes growth. Carbon steel, stainless steel and polymer wheels all can withstand the temperature and duty cycle of an autoclave. (To sterilize instruments and equipment, an autoclave must reach a minimum of 121°C (250°F) for 30 minutes).

Lubrication is the key to maintaining a long service life and minimizing field failure. Internally, guide wheels are lubricated for life with an extreme pressure, corrosion resistant grease, but the lubrication of the wheel/track interface is the responsibility of the user. Lubricator assemblies prevent damage to bearings and help prevent corrosion, even in stainless steel systems. In our experience, most bearing failures are caused by inadequate, complete lack of and/or wrong type of lubricant.

In high temperature operating environments, lubrication is especially important. Friction caused by the wheels rolling across the track generates additional heat at their interface, which can lead to excessive heat buildup in the wheel, and cause the contact surfaces to gall. This can potentially lead to excessive brinelling or spalling on the rolling contact surfaces, eventually resulting in premature failure of the system. The use of guide wheels with high temperature grease and proper track lubrication will help decrease friction-generated heat buildup and protect against premature system failure.

Noise

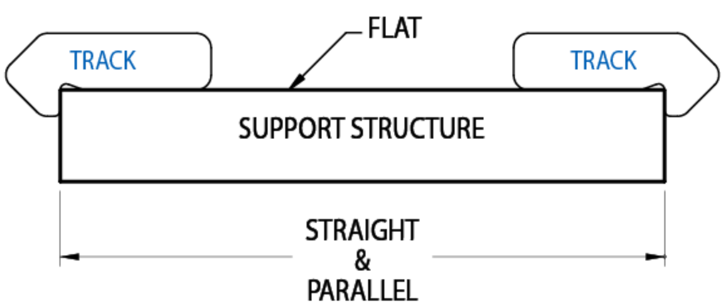
Industrial environments generally tend to be forgiving of loud noise. However, loud noise is an issue in applications that are in contact with the general public. For example, patients can be unnerved when in contact with noisy medical devices. Noisy guide way systems for CAT Scan and Magnetic Resonance Imaging equipment can make patients needlessly uncomfortable. Guide wheel technology can result in a 20% noise reduction compared to square rail or round rail systems.

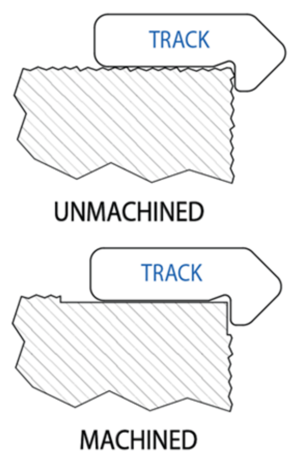
The ball bearings in a guide wheel follow a constant radius raceway path while the ball bearings in square rails follow an oval raceway path with widely varying radii. A square rail has straight sections with radii at the ends, which make a 180° arc. The ball bearings move along alternating straight and semi-circular paths to form a complete circuit. The sudden change in the ball's trajectory when transitioning from the straight to the semi-circular section causes increased noise and vibration. Sometimes polymer cages are used to reduce the noise of the ball bearings, but they are not completely effective.

Tolerances and Track Mounting

The track does not require additional and costly grinding and finishing operations to achieve tight tolerances.

Because the flatness, straightness, and parallelism of the support structure surface on which the track is mounted or bolted to determine the accuracy of the linear guide system, designs requiring less accuracy will require less surface preparation and therefore, can result in significant time and cost savings.





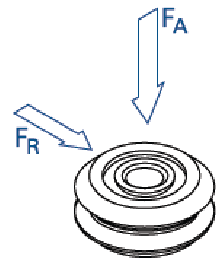
Cold finished or extruded bar plate is accurate enough to serve as the support structure for most applications. Greater accuracy can be obtained by machining the surfaces on the support structure used for mounting the track.

For example, if only +/-0.004 in. tolerances are required, a guide wheel system can be bolted to a semi uneven surface. Surface preparation is minimal and installation time and costs are low. However, for systems requiring +/-0.001 in., better mounting surface preparation will be required.

Loads

The service life of a properly designed guide wheel system is limited to that of the most heavily loaded wheel bearing. Therefore, loads must be evaluated to predict the lifespan, minimizing warranty and in-field repair costs. However, load evaluation can be fairly tricky, so it is extremely important to understand exactly the conditions under which the guide wheel will be used.

Generally, we start with determining whether the loads are radial and/or axial.



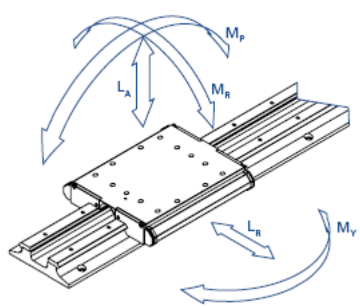
F_R: Radial load refers to the load applied in a direction perpendicular to the axis of rotation.

F_A: Axial load refers to the load applied in a direction parallel to the axis of rotation.

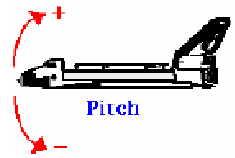
We use a formula based on empirical data, which is very easy to apply and reasonably accurate with regard to lifespan based on field experience. See section on Load/Life Equation – Sizing and Selection, page 6

Standard bearing equations will yield inaccurate data for wheels that are axially loaded because the axial load is not uniform on the wheel. Axial loading will, in fact, result in a moment load on the wheel, causing uneven loading on the ball bearings (unlike a thrust bearing where the load is distributed equally on all the balls). The wheel can accept higher moment loads by increasing the radial preload although this will result in a much higher wear rate.

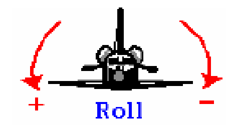
Systems with guide wheel-equipped wheel plates can be subjected to both linear and moment loading conditions. Moment loads on a wheel plate are forces that cause torque loading around the wheel plate's coordinate axes.



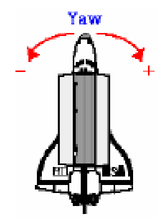
Another way to think about moment loading is in respect to an airplane in flight:



M_P is a moment load in the pitch direction. Pitch loading can be thought of as an airplane climbing or descending. Pitch moments take place when a force wants to tilt the wheel plate up or down.



M_R is called a roll moment. When an airplane banks left or right this is considered movement in the roll direction. A roll moment occurs when the wheel plate is subjected to a load that makes the wheel plate want to tilt like an airplane banking.



M_Y is a yaw moment. Yaw occurs when an airplane turns left or right. The wheel plate is subjected to loading that force the wheel plate to want to rotate to the left or right.

Load/Life Relationship

Several factors influence the service life of a guide wheel system. We have devised a simple method to estimate the load/life relationship for a specific guide wheel system under defined loading conditions. This methodology accounts for the size of the bearing elements, relative spacing; and the orientation, location and magnitude of the load. The equation is based on clean and well-lubricated track conditions; so for applications where lubrication is prohibitive, a derating factor must be applied.

It is important to note that secondary considerations such as maximum velocity, acceleration rates, duty cycle, stroke length, environmental conditions, the presence of shock and vibration, and extreme temperature ranges can all impact service life to varying degrees. As such, this sizing method is considered only as a guideline for guide wheel components and assemblies.

Load/Life Equation – Sizing and Selection

The load/life estimation requires a basic understanding of the principles of statics, the ability to work with free-body diagrams, and the capacity to resolve externally applied forces on a wheel plate into the radial and axial reaction forces at each guide wheel in the design. The life of a guide wheel system is limited to the life of the most heavily loaded bearing in the design.

Step 1: Calculate the resultant radial (F_R) and axial (F_A) loads reflected to each bearing element in the linear guide design.

All standard considerations involved in statics calculations must be accounted for, including inertial forces, gravitational forces, external forces such as tool pressure, bearing element spacing, and magnitude and direction of the payload. Any external forces that generate a reaction through the wheel/track interface must be considered:

Step 2: Calculate the load factor for the most heavily loaded bearing.

$$L_F = \frac{F_A}{F_{A(max)}} + \frac{F_R}{F_{R(max)}}$$

Where :	L_F	=	Load Factor
	F_A	=	Resultant axial load on guide wheel
	F_{Amax}	=	The maximum axial working load capacity of guide wheel
	F_R	=	Resultant radial load on guide wheel
	F_{Rmax}	=	The maximum radial working load capacity of guide wheel

- Bearings should be sized such that $L_F \leq 1$
- The most heavily loaded bearing will have the highest load factor

Typical Guide Wheel Load Capacities: Steel & Stainless Steel							
Size		**0**	**1**	**2**	**3**	**4**	**4XL**
Axial F_A	N	123	252	625	1701	4001	6552
	lbf	28	57	141	382	900	1473
Radial F_R	N	650	1220	2650	5900	9700	14300
	lbf	146	274	596	1326	2181	3215

Step 3: Calculate life by applying the load factor to the load/life equation below:

Due to varying application load and speed parameters and environmental conditions, an appropriate adjustment factor must be applied to the life equation.

Adjustment Factor (A_F)	**Application Conditions**
1.0 – 0.7	Clean, low speed, low shock, low duty
0.7 – 0.4	Moderate contaminants, medium duty, medium shock, low to medium vibration, moderate speed
0.4 – 0.1	Heavy contamination, high acceleration, high speed, medium to high shock, high vibration, high duty cycle

Wheel Size	Life Constant (L_C)	
	Inches of Travel life	Kilometers of Travel Life
0	1.65×10^6	41
1	2.19×10^6	55
2	3.47×10^6	87
3	5.19×10^6	130
4	6.84×10^6	171
4XL	8.58×10^6	215

$$\text{Life} = \left(\frac{L_C}{(L_F)^3} \right) A_F$$

Where : L_F = Load Factor

L_C = Life Constant

A_F = Adjustment Factor

Calculation Example:

F_A = 50 lbf

F_R = 200 lbf

Wheel Size = 2

Environment = Moderate shock loading and contamination with intermittent motion

Following the outlined procedure, we know the information from Step 1, radial (F_R) and axial (F_A) loads on each wheel, therefore we are ready to calculate:

F_A = 50 lbf

F_{Amax} = 141 lbf

F_R = 200 lbf

F_{Rmax} = 596 lbf

L_F = 50/141 + 200/596 = .69

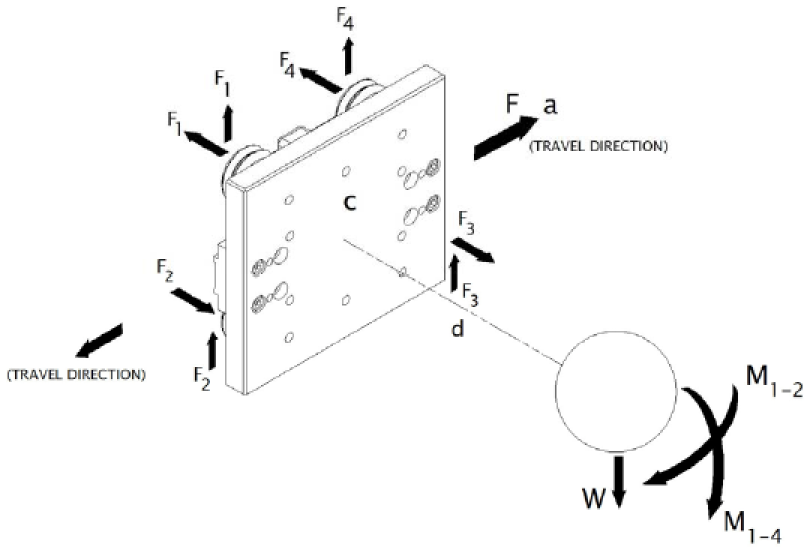
Life = $3.47 \times 10^6 / (.69)^3 \times 0.6 = 6.33 \times 10^6$ Inches of travel

Note that an adjustment factor of 0.6 was used due to the environmental influences.

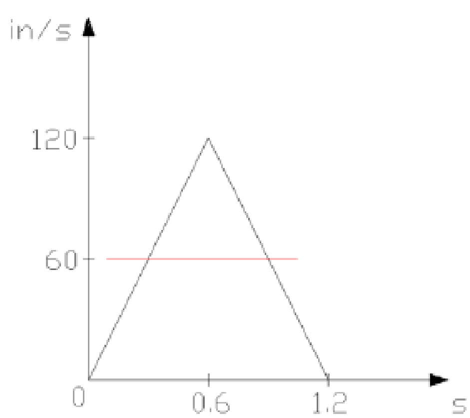
How to Size DualVee Guide Wheels

The versatility of DualVee allows for an infinite number of wheel plate sizes, for this example we will restrict the size to a particular dimension. Many applications entail size limitations due to space constraints.

Example Application:



- Move 250 lb mass (24” x 12” x 12”)
- Center of Gravity (CG) centered, d = 12.0
- 72” of travel in 1.2 seconds with a triangular velocity profile
- Orientation as shown with movement along the Y-axis
- Wheel spacing cannot be any larger than 10” apart in Y and Z-axis



V_{AVG} = 60 in/s

V_{MAX} = 120 in/s

Acceleration = (120 in/s) /(0.6 s) = 200 in/s^2 (0.52 G’s)

Force Due to Load

$\Sigma M_{1,4}$ = 10"($F_{2,3}$) + 12"(250lbf) = 0

$F_{2,3}$ = 300 lbf →

F_2 = F_3 = 150 lbf (axial)

ΣF_X = $F_{2,3}$ + $F_{1,4}$ = 0

$F_{1,4}$ = 300 lbf ←

F_1 = F_4 = 150 lbf (axial)

ΣF_Z = 250 lbf + $F_{1,4}$ = 0

$F_{1,4}$ = 250 lbf ↑

F_1 = F_4 = 125 lbf (radial)

Force Due to Acceleration

$\Sigma M_{1,2}$ = 12" (250lbs)(0.52 G) + 10" ($F_{3,4}$) = 0

$F_{3,4}$ = 156 lbf ←

F_3 = F_4 = 78 lbf (axial)

Σ_{FX} = $F_{3,4}$ + $F_{1,2}$ = 0

$F_{1,2}$ = 156 lbf →

F_1 = F_2 = 78 lbf (axial)

Total Force on Highest Loaded Wheel

F_4 = 125 lbf (radial)

F_4 = 150 lbf (static loading) + 78 lbf (force due to acceleration) = 228 lbf (axial)

Estimated Wheel Life Under Ideal Environmental Conditions

L_F = $L_A / L_{Amax} + L_R / L_{Rmax}$

Life = $L_C / (L_F)^3$

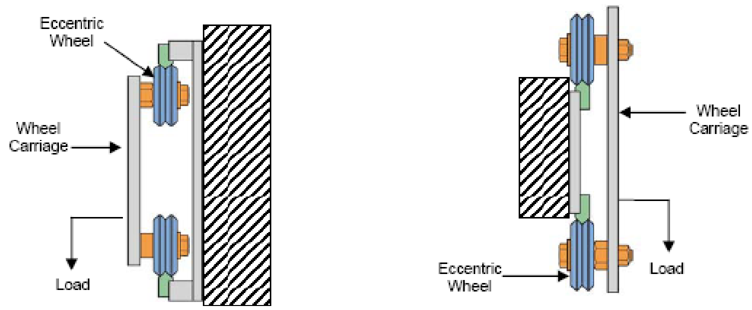
For a Size 3 Wheel (Given Working Load Capacity: L_A=382, L_R=1326)

L_F = 228 / 382 + 125 / 1326 = 0.691

Life = $5.19\text{x}10^6$ in / $(0.691)^3$ = $1.57\text{x}10^7$ in

Wheel Plate Configurations:

In designing a wheel plate, it is important to use the right combination of eccentric and concentric guide wheels depending on the configuration. The linear systems should always have two concentric wheels while the remaining guide wheels should be eccentric. The eccentric wheels are used to eliminate play (clearance) between the wheels and tracks and allow preloading of all the wheels so that they roll smoothly instead of sliding or skipping on the track. If the wheel plate is loaded in the radial direction, the concentric wheel should support as much of the radial load as possible.



It is important to note that the optimal locations of the eccentric and concentric wheels relative to an applied radial load are dependent on whether the tracks are between or outside of the wheel plate's two rows of wheels.

Below are several wheel plate configurations (examples given for image above, right):

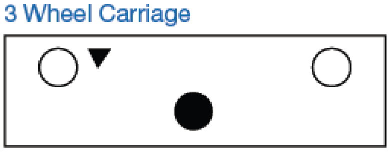
Diagram Symbols:

○ = Concentric guide wheel

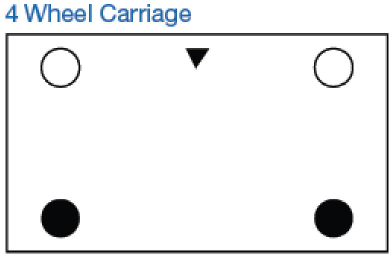
● = Eccentric guide wheels

▼ = Radial loading directions

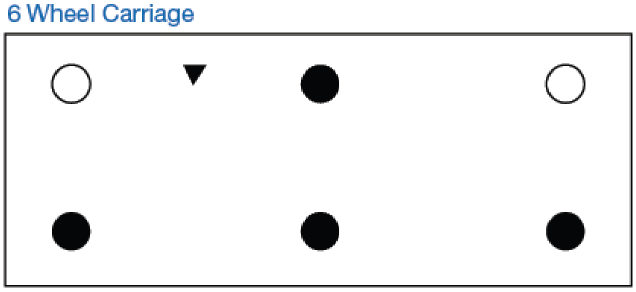
3 Wheel Carriage



4 Wheel Carriage



6 Wheel Carriage



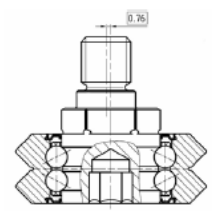
Preload

Wheel plate preloading creates radial loading between the wheels and tracks that exists when the system is not loaded by another outside force, and serves to eliminate play between the wheel and track.

Preload can be determined by:

Preload = Measured Wheel Plate Breakaway Force / (# of Wheels X Coefficient of Friction)

Wheel Carriage on Track



Guide Wheel with Integral Eccentric Fastener for Setting Preload

During assembly of the system, the wheel plate should be placed on the tracks, without any load attached, and with the concentric wheels fully tightened and the eccentric wheels tightened just sufficiently to permit adjustment.

Preload adjustment is accomplished by gradually rotating the eccentric wheel bushing(s) until the tracks are held captive by the two sets of wheels on each side of the wheel plate, with no apparent clearance between the tracks and wheels and very light preload. Once this is accomplished, fasten the eccentric wheel(s) so that they hold their positions. Next, check each wheel for correct preload by rotating the wheel with your fingers, while holding the track stationary. The wheel should skid against the track with a small amount of resistance, but should still turn without much difficulty. If rotation is not possible, the preload should be reduced accordingly by readjusting the eccentric wheel(s).

Caution must be used when applying preload because too much preload on the wheels can cause premature failure. The rated radial load should never be exceeded by the preload and subsequent radial loads applied to the wheel when in service. Note that preloading cannot compensate for large variations in track parallelism tolerances, which can occur in long travel length systems.