QuinnTech
By Mike Quinn

Linear Bearings: A Comparison of Linear Ball Bearings and PTFE Self-Lubricating Bearings

Overview

Linear bearings are essential components in motion systems, and selecting the right type is critical for optimal performance. Two common types are **linear ball bearings** and **PTFE self-lubricating linear bearings**, each offering unique advantages based on their design and material properties. This report explores the differences, applications, and considerations for these bearings.

Key Concepts

- **Point Contact (Linear Ball Bearings):** Linear ball bearings utilize recirculating steel balls that make **point contact** with the shaft. This design allows for low friction and high precision but concentrates stress in small areas, which can limit the bearing's ability to handle high loads. Additionally, at higher speeds, the concentrated stress may lead to increased wear and potential shaft scoring if proper lubrication is not maintained. This design minimizes friction but concentrates stress at contact points, which can lead to shaft scoring if lubrication fails.
- **Line-to-Line Contact (PTFE Self-Lubricating Bearings):** PTFE bearings operate with a larger **line-to-line contact** area, spreading the load more evenly across the shaft. This reduces maintenance requirements compared to point contact systems, as the even load distribution minimizes wear and enhances the bearing's operational life. This design minimizes wear on both the bearing and the shaft, even under heavy or oscillatory loads.

- **PTFE Self-Lubricating Bearings:**
    - PTFE bearings are less forgiving of shaft misalignment because they are fixed in position. Although some PTFE bearings, such as those from LM76, offer up to 2 degrees of freedom, this flexibility is limited. When two bearings are mounted on the same shaft, they lock into position and lose their ability to self-align. This makes precise shaft alignment critical when using PTFE bearings to avoid uneven wear or operational issues.

Shaft Misalignment

- **Linear Ball Bearings:**
  - Linear ball bearings are inherently self-aligning due to their rolling ball design. This feature makes them more compliant and forgiving of shaft misalignment or lack of parallelism, ensuring smooth operation even with minor shaft deviations.
- **PTFE Self-Lubricating Bearings:**
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Key Concept 2:1 Ratio

The 2:1 ratio specifies that the distance from the applied force to the nearest bearing (load offset) should not exceed twice the distance between the two bearings (bearing span). In mathematical terms:

Load Offset (L) ≤ 2 × Bearing Span (S)

Where:

Load Offset (L): Distance from the center of the load to the nearest bearing.

Bearing Span (S): Distance between the centers of the two bearings.

Why It’s Important

Prevents Binding

Why It’s Important?

1. **Prevents Binding:**
   - When the load offset exceeds twice the bearing span, excessive torque can cause the shaft or bearings to bind,

2. **Reduces Uneven Wear:**

- Proper adherence to the 2:1 ratio ensures that moment loads are distributed more evenly across both bearings, reducing localized stress and extending bearing life.

3. **Maintains Alignment**
   - The guideline helps prevent shaft misalignment, which can degrade system performance and increase friction.

   - **Practical Example**

Imagine a horizontal shaft supported by two sleeve bearings, with a heavy load applied to one end:

If the distance from the load to the nearest bearing is 4 inches, the distance between the two bearings should be at least 2 inches to maintain the 2:1 ratio.

If the ratio is exceeded, the bearing nearest to the load may experience edge loading, leading to higher friction, PTFE liner deformation, ratcheting (stick-slip), and bearing failure.

Calculating Static Load for PTFE, Self-Lubricating Sleeve Bearings

NOTE: Sleeve bearings are rated by static load. Unlike ball or roller bearings, sleeve bearings are not optimal for handling overturning moment loads. Their fixed position design lacks the flexibility to compensate for uneven forces or torques, leading to concentrated stress that can cause uneven wear, increased friction, and potential binding issues.

To determine the static load capacity of a sleeve bearing, use the following formula:

Where: ID (Inner Diameter): The internal diameter of the bearing, measured in

inches. Length: The axial length of the bearing, measured in inches.

Material PSI Rating: The load-carrying capacity of the bearing material, measured in psi.

Example Calculation

If a sleeve bearing has:

An ID of 1 inch,

A length of 2 inches,

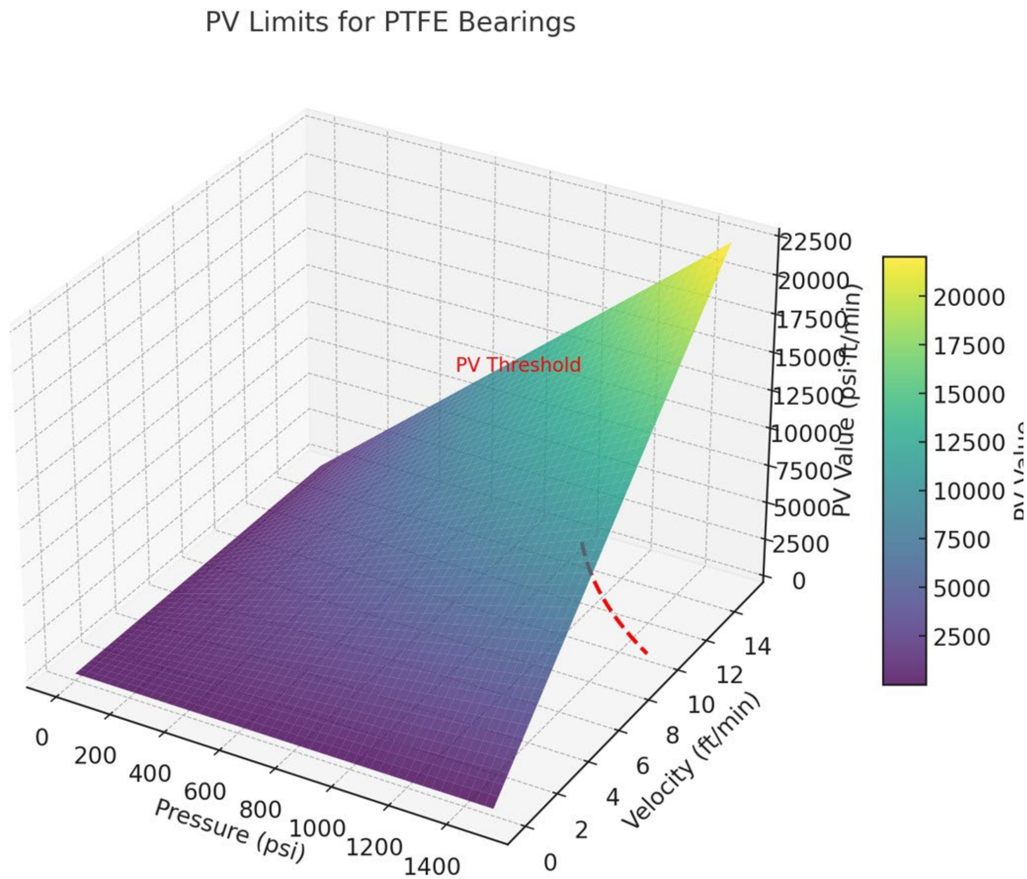
A material PSI rating (Please refer to material PSI rating)

1 x 2 = 2 square inches of material   2 x **5000 PSI** (LM76 PTFE Liner Material)

The static load capacity is: 10,000 Lbs. NOTE: This only applies to a bearing that is static, not in motion.

This calculation ensures that the selected bearing can handle the anticipated load without exceeding its material limits, ensuring safe and efficient operation.

PTFE Bearings are rated by PV:



PV Chart

3D representation:

To better visualize PV limits, consider the following 3D representation:

- Imagine a chart where the horizontal axes represent **Pressure (P)** and **Velocity (V)**, and the vertical axis represents the **PV Value**. The surface shows how different combinations of pressure and velocity contribute to the overall PV value.

- A critical threshold, typically around 15,000 psi·ft/min for PTFE bearings, is marked on the chart. Exceeding this threshold indicates conditions where heat generation and material degradation become significant concerns.
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This visualization reinforces the importance of balancing load and speed to operate within safe PV ranges.

The formula for calculating PV in sleeve bearings is:

- **Pressure (P):** The load on the bearing divided by the contact area (measured in psi).

- **Velocity (V):** The relative speed between the shaft and the bearing (measured in ft/min).

For example, if a sleeve bearing supports a load of 1000 psi and operates at a velocity of 10 ft/min, the PV value is:

This value must remain below the manufacturer's specified PV threshold to ensure safe operation.

To better understand PV limits, consider this everyday analogy:

- Imagine rollerblading on a hot summer day. The **pressure (P)** is like your body weight pressing down on the wheels, and the **velocity (V)** is how fast you're skating. If you skate too fast or weigh too much, the friction generates heat, making the wheels soften and lose efficiency. Similarly, exceeding PV limits in bearings generates excessive heat, which can degrade materials like PTFE.
- Linear ball bearings are not typically constrained by PV (Pressure-Velocity) limits. Their design allows for high-speed operation and can handle significant loads without exceeding thermal or mechanical thresholds, provided proper lubrication and alignment are maintained.

- **PTFE Self-Lubricating Bearing PV:**
  - PTFE bearings are subject to PV limits due to their sliding contact design. PV represents the combination of load (Pressure, P) and speed (Velocity, V) that a bearing can withstand without overheating or excessive wear. The **PV threshold** is defined as:
    - **Pressure (P):** Load distributed over the contact area.
    - **Velocity (V):** The relative speed between the bearing and the shaft.
    - PTFE materials have a finite ability to dissipate heat generated by friction. Exceeding the PV threshold causes the bearing to

overheat, leading to softening or degradation of the PTFE layer. The sled analogy highlights how controlling weight (pressure) and speed (velocity) of the system ensures smooth and efficient operation. For this reason, operating within the manufacturer's specified PV limits is essential for long-term reliability.

- **Typical PV Thresholds for PTFE Bearings:** PTFE bearings often have PV limits ranging between 1,000 to 15,000 psi·ft/min, depending on the specific material formulation and operating conditions.
- To mitigate high PV conditions:
    - Reduce the load (P) by increasing the contact area.
    - Decrease the relative speed (V) between the shaft and bearing.
    - Improve heat dissipation using external cooling or more efficient lubrication.

Typical Applications

1. **Linear Ball Bearings:**
    - **High-Speed Automation:** Used in CNC machines, 3D printers, and robotic arms due to their low friction and high precision.
    - **Precision Equipment:** Essential in optical alignment systems and semiconductor manufacturing, where accuracy is critical.
    - **Medical Devices:** Found in imaging machines and laboratory automation where smooth, reliable motion is necessary.
    - **Long Bed 4 Color Printing Systems**
    - **Linear Actuators**

2. **PTFE Self-Lubricating Bearings:**
    - **Heavy-Load Applications:** Ideal for conveyor systems, packaging systems, FDA process systems where FDA Compliance and Corrosion resistance are critical, and industrial machinery where durability and maintenance-free operation are required.
    - **Food Process/Bio/Pharma/Medical:** where FDA compliance is a requisite and chemical wash-down is routine (Caustic Foaming Agents).
    - **Oscillatory Motion:** Suitable for pivot points in automation, automotive, and aerospace applications, where consistent performance under repetitive, short strokes is critical.
    - **Dirty or Harsh Environments:** Common in food processing, agriculture, and marine applications due to their corrosion resistance and ability to operate without external lubrication.

Everyday Analogy

To better understand the differences between linear ball bearings and PTFE self-lubricating bearings, consider this analogy:

- **Linear Ball Bearings:** Imagine rolling a shopping cart with ball-bearing wheels across a smooth tile floor. The balls inside the wheels make rolling motion efficient, low-friction, and precise. However, if the wheels encounter dirt or lose lubrication, they may wear out quickly or become damaged.
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- **PTFE Self-Lubricating Bearings:** Now, think of sliding a heavy box with a felt pad underneath across the same floor. The felt pad distributes the load evenly, protects the floor, and reduces friction, but over time, the pad wears down, especially if the box is slid repeatedly over a long distance.

This analogy illustrates how linear ball bearings are optimized for speed and precision, while PTFE bearings excel in durability and maintenance-free operation under heavy loads or challenging environments.

Material Comparisons

1. **Linear Ball Bearings:**
    - **Material:** Typically made from hardened steel or stainless steel.
    - **Advantages:** Low friction, high precision, and suitable for high-speed applications.
    - **Limitations:** Requires continuous lubrication, susceptible to contamination, and can score shafts. Balls can freeze, and similar to a glass cutter, can score shafting - brinelling (permanent surface deformation that occurs when a shaft's material is stressed beyond its yield point. **NOTE:** bearings are made to be the sacrificial component. Replacing shafting is expensive and time-consuming.

2. **PTFE Self-Lubricating Bearings:**
    - **Material:** Ceramic Coated Aluminum Shell with a bonded PTFE Liner. (LM76)
    - **Advantages:** Self-lubricating, corrosion-resistant, and maintenance-free. Operates well in dirty or dry environments.
    - **Limitations:** Lower speed capacity compared to ball bearings. PTFE material loss during operation can reduce bearing life, especially under long-stroke conditions.

Contact and Load Distribution

- **Linear Ball Bearings:**
  - Balls recirculate in closed loops, redistributing the load and spreading lubrication. This closed-loop design aids in thermal management by ensuring that heat generated during operation is distributed and dissipated effectively. Under high-load conditions, the motion of the balls continuously refreshes the lubricant, preventing localized overheating and maintaining consistent performance. This continuous motion not only maintains even lubricant distribution but also aids in carrying heat away from the shaft and bearing contact areas, preventing localized overheating.
  - To ensure proper lubrication transfer between the bearing and shaft interface, linear ball bearings require a stroke length of 1 to 1.5 times the bearing length to ensure complete ball circulation.
  - Point contact concentrates stress, requiring careful shaft surface preparation and lubrication.

- **PTFE Bearings:**
  - Line-to-line contact distributes the load evenly across the shaft. To ensure proper performance when moment loads are present, a 2:1 ratio requirement should be observed. This means the distance from the applied load to the nearest bearing should not exceed twice the spacing between the two bearings. Following this guideline helps distribute forces evenly, minimizing uneven wear or binding issues.
  - The self-lubricating PTFE material deposits microscopic flecks of PTFE into the shaft's surface disparities, reducing friction and enhancing smooth operation. However, this is a **loss process** since the PTFE liner gradually wears down over time. Bearings with longer strokes, exceeding the wear capacity of the PTFE layer (approximately 0.025" - 0.035"), experience reduced operational life.

Friction and Lubrication

- **Linear Ball Bearings:**
  - Requires lubrication to reduce friction and dissipate heat.
  - Recirculation ensures even lubricant distribution and enhances thermal management, extending bearing life.

- **PTFE Bearings:**

- No need for external lubrication; PTFE's self-lubricating properties reduce maintenance and operating costs.
- Operates quietly and efficiently, even in challenging environments, but the gradual loss of PTFE material limits long-term use under certain conditions.

Common Materials for Sleeve Bearings

- **Bronze:** High load capacity, wear resistance, and suitability for lubricated applications.
- **Plastic/Polymer Composites (PTFE):** Lightweight, corrosion-resistant, and self-lubricating.
- **Babbitt:** Low-speed, high-load capabilities with excellent embed-ability for contaminants.
- **Cast Iron:** Durable and cost-effective for heavy-duty, low-speed use.
- **Steel:** High strength and durability, often with coatings to improve wear resistance.

Application Considerations

- **Linear Ball Bearings:**
  - Best for high-speed, low-friction, and precise motion.
  - Suitable for environments with regular maintenance and minimal contamination.

- **PTFE Bearings:**
  - Ideal for heavy loads, oscillatory motion, or environments with dust, corrosive media, or debris.
  - Preferred where maintenance access is limited or lubrication systems are impractical. However, applications involving long strokes can significantly reduce the lifespan of the PTFE liner due to material wear.

Closing Summary

Linear ball bearings and PTFE self-lubricating bearings cater to different performance needs. Linear ball bearings excel in high-speed, precision applications, such as CNC machines, robotic arms, and 3D printers, but require careful lubrication and maintenance to avoid shaft damage. PTFE bearings, with their self-lubricating, shaft-friendly design, are ideal for heavy loads and challenging environments. However, the gradual loss of PTFE material and reduced lifespan under long-stroke conditions must be considered during design. Shaft alignment is another critical factor, as linear ball bearings are self-aligning and more tolerant of misalignment, whereas PTFE bearings are fixed and require precise shaft parallelism. Additionally, PV limits must be considered for PTFE bearings to avoid overheating and wear, while linear ball bearings remain less constrained in this aspect. The choice depends on application requirements, balancing speed, load, environmental factors, and maintenance constraints.

For more information or engineering assistance, contact Mike Quinn 617-538-8756 Email: quinntech@quinntech.solutions Web: www.quinntechsolution.com