Lecture 13

Sliding Contact Bearings

Outline

• General Characteristics of Sliding Contact Bearings
• Typical Materials of Sliding Contact Bearing
• Gib Design
• Configurations for Sliding Contact Rotary Bearings
• Configurations for Sliding Contact Linear Bearings
Straight Talk on Ways

• Three basic types of ways exist: plain sliding (sliding contact bearing), rolling element and hydrostatic ways.

• In this design, the moving surfaces slide against each other assisted by a layer of lubrication which, when operating correctly, actually produces a hydro-dynamic bearing.

• That is a bearing which guides on a controlled layer of lubrication created by motion.

General Characteristics of Sliding Contact Bearings

• Sliding contact bearings are the oldest, simplest, least expensive bearing technology, and they still have a wide range of applications, from construction machinery to machines with atomic resolution.

• Sliding contact bearings utilize a variety of different types of lubricants between various interface materials. Lubricants range from light oil to grease to a solid lubricant such as graphite or a PTFE polymer. Because they often distribute loads over a large area, contact stresses and space requirements are often low while stiffness and damping are usually high.

• They are very robust and reliable.
• They are speed limited and have friction-induced servo limits.
• They are economical and for many applications will never be replaced.
General Characteristics of Sliding Contact Bearings

Advantages of Sliding Contact Bearing

- Have a good resistance to wear, fatigue and corrosion
- Have sufficient strength to support the load
- Have a fairly high melting point to reduce the tendency for creep in use
- Have suitable thermal properties to enable heat to be conducted away
- As metal to metal contact will be unavoidable in service the material should be selected to minimize seizure, fretting (corrosion), scoring and welding
- The bearing should be tolerant to dirt and foreign matter—e.g. soft surface
- Should be tolerant to misalignment
- Should be compatible to lubricant used—e.g. should not corrode if water is used
Dynamic Stiffness

- Many consider plain guides superior because of their high dynamic stiffness.
- In simple terms, **dynamic stiffness equals static stiffness times damping**.
- **Plain slides**, due to their long surface areas and oil film lubrication, develop much higher damping than rolling element bearings, which have very little surface area.
- **Rolling element bearings** do possess a **high static stiffness**. Taking a high static stiffness times a low damping factor results in **low dynamic stiffness**.
- **Plain slides**, on the other hand, have a high static stiffness and a higher damping, thus resulting in a much higher dynamic stiffness.
- **Plain slide ways** experience speed limitations due to their hydrodynamic nature.
Dynamic Stiffness

• The oil in the small gaps between the bearing surfaces acts like the oil in a shock absorber, and the small gap between the surfaces acts like the small hole that restricts oil flow in the shock absorber.

• This **viscous shear resistance** is very significant when you consider the surface area of the bearing and the small gap.

• Another **disadvantage of plain slides** is that the at-rest contact occurs between the bearing surfaces. This causes a **static friction higher than the dynamic friction** once the bearing surfaces generate an oil film during motion.

• The difference between static and dynamic coefficient of friction results in the phenomenon referred to as "**stick-slip**", and can make it difficult to position plain slides accurately when the application requires very small motions.

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General Characteristics Sliding Contact Bearings

• **Stiffness of various sliding contact bearings lubricated with light oil and after wear-in.** (After Dolbey and Bell.)

[Graph showing stiffness unit area (N/m²) as a function of contact pressure (MN/m²)]

<table>
<thead>
<tr>
<th>#</th>
<th>Way</th>
<th>Bearing</th>
<th>Stiffness/unit area (N/m²) as a function of contact pressure P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lapped cast iron</td>
<td>Ground cast iron</td>
<td>k/A = 6.2105 + 9.5538e-06P</td>
</tr>
<tr>
<td>2</td>
<td>Ground cast iron</td>
<td>Ground cast iron</td>
<td>k/A = 7.3247 + 2.3296e-06P - 3.44288e-10P² + 2.6426e-16P³</td>
</tr>
<tr>
<td>3</td>
<td>Ground cast iron</td>
<td>Scraped cast iron</td>
<td>k/A = 10.1294 + 1.3275e-04P</td>
</tr>
<tr>
<td>4</td>
<td>Ground cast iron</td>
<td>Ground ferroboron</td>
<td>k/A = 3.4576 + 9.7195e-06P - 5.5217e-11P² + 1.0544e-17P³</td>
</tr>
<tr>
<td>5</td>
<td>Ground cast iron</td>
<td>Ground plain DX</td>
<td>k/A = 3.8024 + 8.7459e-05P - 2.7094e-11P² + 1.6380e-17P³</td>
</tr>
<tr>
<td>6</td>
<td>Ground cast iron</td>
<td>Ground dimpled DX</td>
<td>k/A = 2.1344 + 7.5025e-05P - 3.8756e-11P² + 4.2546e-17P³</td>
</tr>
<tr>
<td>7</td>
<td>Ground cast iron</td>
<td>DU as received</td>
<td>k/A = 2.1064 + 6.1535e-05P - 3.0397e-11P² + 2.2446e-17P³</td>
</tr>
</tbody>
</table>
General Characteristics Sliding Contact Bearings

- Vibration and shock resistance
  - Excellent.
  - Matched only by hydrostatic and hydrodynamic bearings.

- Damping capability
  - Excellent normal to direction of motion due to squeeze film damping.
  - Matched only by hydrostatic and hydrodynamic bearings.
  - High along direction of motion.
  - Predict it using squeeze film damping theory.

- Friction
  - Static friction never equals dynamic friction.
  - Most data is supplied for speed ranges from $10^{-6}$ m/s and 0.1 m/s, but what is important is the friction about at 0 m/s!
  - Stiction (Stick-Slip): when static $\mu$ is greater than dynamic $\mu$, cause stick-slip which causes position errors.

Boundary Lubrication

- Friction initially high, then lower, then increases (viscous effects): Strubeck curve:

Source: [http://www.bardyne.com/Documents/B3samp01.pdf](http://www.bardyne.com/Documents/B3samp01.pdf)
Boundary Lubrication

- **Boundary lubrication** is lubrication by a liquid under conditions where the solid surfaces are so close together that appreciable contact between opposing asperities is possible.
- The friction and wear in boundary lubrication are determined predominantly by interaction between the solids and between the solids and the liquid.
- The bulk flow properties of the liquid play little or no part in the friction and wear behavior.

General Characteristics Sliding Contact Bearings

- Static friction is always greater than dynamic friction.
- This effects the system’s controllability.
- With linear scales, as opposed to an encoder on a ballscrew, dimples will appear at velocity crossovers.
General Characteristics Sliding Contact Bearings

• Thermal performance
  
  ➢ *High friction coefficient generates heat.*
    - The bearings are so stiff, that when thermal errors (e.g., bowing), high points are created which wear and crash the bearing.
  
  ➢ *Heat changes oil viscosity.*
  
  ➢ *Large surface area efficiently transmits heat.*
  
  ➢ *In extreme cases, consider using a thermocentric design.*
    - Expansion in one direction relieves expansion in another direction.

General Characteristics Sliding Contact Bearings

• Environmental sensitiveness
  
  ➢ *Particles embed themselves in softer surface or roll out.*
  
  ➢ *Generally very tolerant of foreign matter.*
  
  ➢ *Water absorption can be dealt with the use of a sealant.*

• Seal-ability
  
  ➢ *Wiper seals are often sufficient and easily fitted.*
  
  ➢ *Don’t tempt fate, use way covers or bellows if possible.*

• Size and configuration
  
  ➢ *Thin profile.*
  
  ➢ *Virtually any configuration possible.*
General Characteristics Sliding Contact Bearings

• Support equipment
  ➢ *Automatic lubricator needed to periodically lubricate.*
  ➢ *Grooves are required to distribute the lubricant:*

  Longitudinal grooves can act as leakage paths and starve transverse grooves

"Pure" transverse grooves require deep hole drilling for supply

General Characteristics Sliding Contact Bearings

➢ *Scraped surfaces hold pockets of oil and are optimal for lubrication.*

➢ *Grinding with a cup wheel can also create an effective cross-hatch pattern.*

• Varying fluid resistances can cause straightness errors to be a function of lubricator cycle.

  ➢ *Controller can signal lubricator when machine is idling.*
Scraping Procedure in Sliding Way

1. A scraped surface without spot marks.
2. Scrapped way surface with spot marks (half moon marks) sometimes called flaking.
3. Scraping by hand.
4. Scraping with a power scraper.


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Scraping Procedure in Sliding Way

5. Application of blue marking compound to master flat.
6. Application of red marking compound.
7. Treated surfaces about to be rubbed together.
8. Letting surfaces mark on their own weight.

Scraping Procedure in Sliding Way

General Characteristics of Sliding Bearing

• Maintenance

➢ *Generally requires periodic lubrication.*
  ∞ Lubricators periodically send a squirt of oil that can cause a displacement if design is not done carefully.
  ∞ Differential flow to different bearings will cause a differential displacement.

➢ *Instrument grade bearings can often be run dry.*
General Characteristics of Sliding Bearing

- **Material Compatibility**
  - Sliding contact bearings have high stiffness to resist cutting forces but use low preloads to minimize starting forces: hence a small amount of differential thermal growth between bearing components can lead to loss of preload and in some cases opening of a bearing gap.
  - Maintains preload in the presence of uniform temperature changes
  - The surface finish of the interface components is very crucial to proper wear-in and long-term life. In general, one wants a surface finish on the order of 0.1-0.5 μm with a random pattern on the hard surface the bearing rides on. This provides fine grooves in which a lubricant can be trapped.
  - Rougher Finishes tend to cause the asperities to drag like grappling hooks, and finer surfaces cannot support a lubricating layer. The better the surface finish of the bearing material, the less time that is needed to wear-in the bearing and the less adjustment that is needed after wear-in.

- **Required Life**
  - A review of various manufacturers’ catalogs shows that when properly lubricated and not overloaded, after wear-in sliding bearings may wear at a rate of about $10^{-11}$ m/meter of travel.
  - Some PTFE bearings that ride on surfaces with nanometer-level surface finishes (so they are nanobrading) are thought to build up a film on the bearing way which transfers back and forth between the bearing pad, leading to essentially zero wear.
  - It used to be that machines were designed for a life of 5-10 years, with the intent that they could then be rebuilt over and over. It also used to be that sliding contact bearings often had to be hand scraped, which made them expensive, but modern accurate surface grinders make it possible to, in many instances, just assemble ground components and attain reasonable repeatability (on the order of 5-10 μm) after wear-in and readjustment of the gibs.
General Characteristics of Sliding Bearing

• Availability
  ➢ Modular sliding contact bearings or materials for custom manufacture are among the easiest items to procure.

• Designability
  ➢ Sliding contact bearings influence the design of a machine by often requiring the use of a gib and an automatic lubrication system. In general, sliding contact bearings are very easy to design.

• Manufacturability
  ➢ The comments for designability apply here as well.

• Cost
  ➢ The cost of sliding contact bearing materials themselves are negligible, and the cost of an automatic lubrication system is moderate. The principal cost associated with precision sliding contact bearings is that of attaining the desired accuracy and surface finish of the bearings and the surface they slide on. For example, it also takes considerable skill to make a tapered gib.

General Characteristics of Sliding Bearing

• Replicated bearings
  ➢ Only the replication master needs to be accurately finished.
    ☐ An exact fit is obtained, so gibs are usually not needed.
  ➢ The machine is easily rebuilt by casting a bearing.
    ☐ Replicated bearings generally do not have to be hand finished.
  ➢ Care must be taken to manage the heat generated during the cure process or else the system may harden in a warped state
    ☐ Part and master should have same thermal time constant to prevent gradients and warping.
  ➢ Replicants typically shrink about 0.2–0.3%, which is often referred to as "negligible" (e.g., 3mm*0.002 = 6 μm).
  ➢ The resin should be degassed before injection.
  ➢ Several manufacturing applications with replicated bearings are presented here to illustrate the technique.
Plastic Materials for Sliding Contact Bearings

Characteristics of Plastic Bearings

• Advantages
  - Self-lubricating
  - Low wear rates
  - Relatively high performance rating (PV) among sleeve bearing materials
  - Bearing O.D.’s compatible with standard sintered bronze sizes for upgrading existing equipment
  - Kinetic and static coefficient of friction virtually the same under heavy loads
  - Extremely low coefficient of friction
  - Lightweight
  - Ability to conform under load
  - Resistance to chemicals

• The design characteristics of plastic and nonmetallic bearings bear both similarities and differences relative to those of porous-metal bearings.
## Wear Rate, Coefficient of Friction and Limiting PV Data

<table>
<thead>
<tr>
<th>Acetal</th>
<th>Wear Factor &quot;k&quot; (1)</th>
<th>Comparative Wear Rate to Acetron® NS</th>
<th>Coefficient of Friction</th>
<th>Limiting PV (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetron® NS</td>
<td>48</td>
<td>1.0</td>
<td>.18 – .19</td>
<td>8750</td>
</tr>
<tr>
<td>Delrin AF Blend</td>
<td>57</td>
<td>1.2</td>
<td>.18 – .19</td>
<td>8300</td>
</tr>
<tr>
<td>Delrin AF</td>
<td>65</td>
<td>1.4</td>
<td>.18 – .19</td>
<td>11000</td>
</tr>
<tr>
<td>Delrin 500 CL (a)</td>
<td>176</td>
<td>3.7</td>
<td>.22 – .24</td>
<td>3500</td>
</tr>
<tr>
<td>Acetron® GP</td>
<td>200</td>
<td>4.2</td>
<td>.22 – .25</td>
<td>2700</td>
</tr>
<tr>
<td>Turcite A</td>
<td>213</td>
<td>4.4</td>
<td>.29 – .34</td>
<td>6560</td>
</tr>
</tbody>
</table>

1. Measured on 1/2" I.D. journal at 5000 PV (118 fpm & 42.2 psi)
   
   \[ K = \frac{h}{PVT} \times 10^{-19} \text{ (in^3 min/lb hr)} \]
   
   where:
   
   - \( h \) = radial wear (in)
   - \( P \) = normal pressure (psi)
   - \( V \) = sliding speed (fpm)
   - \( T \) = test duration (hrs)

2. Measured on thrust washer bearing under a normal load of 50 lbs. Gradually increasing torque was applied until the bearing completed a 90° rotation in about one second.

3. Measured on thrust washer testing machine, unlubricated @ 20 fpm & 250 psi.

4. Limiting PV (Test value — unlubricated @ 100 fpm (lb ft/min² min))

(a) Equivalent to DSM’s MC® 901.

### PV and Load Capacities of Different Plastic Materials

<table>
<thead>
<tr>
<th>Bearing Material</th>
<th>Load Capacity (psi)</th>
<th>Max. Temp. (°F)</th>
<th>Max. Speed (fpm)</th>
<th>PV Limit (Unlubricated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenolics</td>
<td>6000</td>
<td>200</td>
<td>2500</td>
<td>15000</td>
</tr>
<tr>
<td>Nylon</td>
<td>2000</td>
<td>200</td>
<td>600</td>
<td>3000</td>
</tr>
<tr>
<td>PTFE</td>
<td>500</td>
<td>500</td>
<td>50</td>
<td>1000</td>
</tr>
<tr>
<td>Filled PTFE</td>
<td>2500</td>
<td>500</td>
<td>1000</td>
<td>10000</td>
</tr>
<tr>
<td>PTFE fabric</td>
<td>60000</td>
<td>500</td>
<td>150</td>
<td>25000</td>
</tr>
<tr>
<td>Polycarbonate</td>
<td>1000</td>
<td>220</td>
<td>1000</td>
<td>3000</td>
</tr>
<tr>
<td>Acetel</td>
<td>2000</td>
<td>200</td>
<td>600</td>
<td>3000</td>
</tr>
<tr>
<td>Carbon-graphite</td>
<td>600</td>
<td>750</td>
<td>2500</td>
<td>15000</td>
</tr>
<tr>
<td>Rubber</td>
<td>50</td>
<td>150</td>
<td>4000</td>
<td>---</td>
</tr>
<tr>
<td>Wood</td>
<td>2000</td>
<td>160</td>
<td>2000</td>
<td>12000</td>
</tr>
</tbody>
</table>

Source: [http://www.qbcbearings.com](http://www.qbcbearings.com)
## Properties of Bearing Materials

<table>
<thead>
<tr>
<th>Property</th>
<th>Graphitar (Carbon-Graphite)</th>
<th>Oillon PV® – 80 (TFE)</th>
<th>Rulon® (TFE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of friction</td>
<td>0.04 to 0.25</td>
<td>0.05 to 0.10</td>
<td>0.15 to 0.20</td>
</tr>
<tr>
<td>Temperature range</td>
<td>Cryogenic to 1000°F in some grades</td>
<td>−40°F to +250°F</td>
<td>−400°F to +550°F</td>
</tr>
<tr>
<td>Approx. max PV (unlubricated)</td>
<td>15000</td>
<td>18000</td>
<td>10000 (sleeve bearing)</td>
</tr>
<tr>
<td>Max. P</td>
<td>*</td>
<td>3000 psi</td>
<td>1000 psi</td>
</tr>
<tr>
<td>Max. V</td>
<td>*</td>
<td>1700 ft/min</td>
<td>400 ft/min</td>
</tr>
<tr>
<td>Recommended shaft surface finish</td>
<td>≤ 30 rms</td>
<td>*</td>
<td>8 to 32 rms</td>
</tr>
<tr>
<td>Recommended shaft clearance</td>
<td>0.003 in/in for most unlubricated applications</td>
<td>(tw)10⁻⁴ + 0.004&quot;</td>
<td>*</td>
</tr>
<tr>
<td>Typical elastic modulus</td>
<td>(0.5 to 3.5) 10⁰ psi</td>
<td>(3.5 – 3.8) 10⁰ psi</td>
<td>*</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>1000 – 9500 psi, depending on grade</td>
<td>7200 psi</td>
<td>*</td>
</tr>
</tbody>
</table>

* Consult manufacturer

Data reprinted with the permission of the following manufacturers:

(i) "Graphitar" Wickes, 1621 Holland Ave., Saginaw, MI 48631;
(ii) "Oillon PV® – 80 Design Guide", TFE Industries, 148 Parkway Kalamazoo, MI 49006

Source: [http://www.qbcbearings.com](http://www.qbcbearings.com)

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**The coefficient of friction varies with the bearing unit load.**

![Graph of Coefficient of Friction vs. Load](chart.png)

**Test conditions:**
- **Velocity:** 48 ft/min (360 rpm)
- **Load:** 140 lbs/in, addition applied at 10 min intervals
- **Dimensions of Test Specimen:** 6/8" OD x 3/8" ID x 3/8" long
- **Material:** Steel 113°F HRB 60.90

Source: [http://www.qbcbearings.com](http://www.qbcbearings.com)
Plastic Bearings

Example

- A shaft of 1/2” in diameter is supported by two plastic bearings. The force equals 10 lbs. The bearing length is 3/4”. The shaft rotates at 750 rpm.

\[
PV = \frac{0.262 \cdot F \cdot \text{rpm}}{l} = \frac{0.262 \times 10 \times 750}{0.75} = 2619 \text{ fpm} \cdot \text{psi}
\]

- From the tables showing the maximum PV values the proper material can be chosen.

The effect of lubrication on the factor of a particular material.

(Oilon PV–80)

Source: http://www.qbcbearings.com
Typical Materials of Sliding Contact Bearing

- **Turcite®**
  - *Ethylene-chlorotrifluoroethyene [ECTFE]*
- **Glacier DU®**
- **Castable Bearing Material**
  - *Zanite®*
  - *Moglice®*

**Turcite® Bearing Materials**

- **Turcite®** is a high-quality, internally lubricated material that is ideal for applications with demanding wear and friction requirements.
- Its low water absorption enables components made with Turcite® to retain their integrity over long periods.
- This material comes in two grades.
  - *Turcite® A* is a resilient formulation that performs well under vibratory and dynamic loading.
  - *Turcite® X* has minimal hygroscopic characteristics and low thermal expansion properties, resulting in a structurally stable material.
  - Both grades can be easily machined from rod and tube stock.
Characteristics of Turcite®

- Advantages
  - Excellent physical and mechanical properties
  - Self-lubricating with superior bearing performance
  - Good dimensional stability at operating conditions
  - Superior resistance to moisture absorption
  - High wear resistance
  - Low coefficient of friction
  - Outstanding chemical and corrosion resistance
  - Light weight and reduces noise chatter
  - Turcite® is oven annealed to reduce internal stresses
Characteristics of Turcite®

• MATERIAL PROPERTIES

<table>
<thead>
<tr>
<th>Turcite® TA</th>
<th>Turcite® TX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength @ Break .......... 7,600 psi</td>
<td>5,900 psi</td>
</tr>
<tr>
<td>Elongation @ Break .................. 15%</td>
<td>19%</td>
</tr>
<tr>
<td>Heat Deflection Temp. .............. 205 °F</td>
<td>203 °F</td>
</tr>
<tr>
<td>Max. Continuous Service Temp..180 °F</td>
<td>180 °F</td>
</tr>
<tr>
<td>Intermittent Service Temp. ........ 225 °F</td>
<td>225 °F</td>
</tr>
<tr>
<td>Linear Coef. of Thermal Exp.... 5.2 in/in °Fx10-5</td>
<td>5.2 in/in °Fx10-5</td>
</tr>
<tr>
<td>Coef. of Friction (Non-Lub)...... 0.30</td>
<td>0.22</td>
</tr>
<tr>
<td>Wear Factor ......................... 43 in/(psi<em>fpm</em>hr)</td>
<td>20 in/(psi<em>fpm</em>hr)</td>
</tr>
<tr>
<td>Limiting PV Value .............. 7,500 psi-fpm</td>
<td>42,000 psi-fpm</td>
</tr>
<tr>
<td>Water Absorption ................. .20%</td>
<td>20%</td>
</tr>
<tr>
<td>Color of Material ................ Turquoise</td>
<td>Red</td>
</tr>
</tbody>
</table>

Typical Applications of Turcite®

• Cams and cam followers
• Bearings
• Rollers
• Valve seats
• Insulators
• Liners
DU® Bearing Material

• Structure
  ➢ Steel + porous bronze sinter + PTFE + Pb

DU® Bearing Material

• Usage: Dry Good Oil lubricated Good Grease lubricated Fair Water lubricated Fair Process fluid lubricated Fair Availability:
  ➢ Ex stock:
• Standard cylindrical bushes, flanged bushes, thrust washers, flanged washers, strip
  ➢ To order: Non-standard parts
• Features:
  ➢ Dry bearing material with good wear and friction performance over, speed and temperature conditions
  ➢ DU also performs well with lubrication
  ➢ Available from stock in a wide range of standard sizes
• Possible Applications:
  ➢ Automotive:
    ☐ McPherson struts and shock absorbers, door, bonnet and tailgate hinges, steering columns, clutches, gearbox selector forks guides, wiper arms, power steering pumps, pedal bushes, ABS equipment, etc.
  • Industrial:
    ➢ Lifting equipment, hydraulic pumps and motors, pneumatic equipment, medical equipment, textile machinery, agricultural equipment, scientific equipment, drying ovens, office equipment, etc.
Properties of Glacier DU® bearing material available as bushings or in sheet form. (Courtesy of The Glacier Metal Company Ltd.)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum load</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>140 N/mm²</td>
</tr>
<tr>
<td>Special circumstances</td>
<td>250 N/mm²</td>
</tr>
<tr>
<td>Compressive yield strength</td>
<td>310 N/mm²</td>
</tr>
<tr>
<td>Maximum rubbing velocity</td>
<td>2.5 m/s</td>
</tr>
<tr>
<td>Specific load x rubbing velocity (PV factor)</td>
<td></td>
</tr>
<tr>
<td>Continuous</td>
<td>1.75 N/mm² x m/s</td>
</tr>
<tr>
<td>Short periods</td>
<td>3.5 N/mm² x m/s</td>
</tr>
<tr>
<td>Minimum operating temperature</td>
<td>-200°C</td>
</tr>
<tr>
<td>Maximum operating temperature</td>
<td>280°C</td>
</tr>
<tr>
<td>Coefficient of friction (un lubricated)</td>
<td>From 0.02 to 0.2, depending on load</td>
</tr>
<tr>
<td>Electrical resistance</td>
<td>1 to 10 ohms/cm²</td>
</tr>
<tr>
<td>Nuclear radiation resistance</td>
<td>Unaffected by gamma-ray dose of 10^8 rad</td>
</tr>
</tbody>
</table>

Glacier Garlock Bearings (GGB)


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Glacier DU® Bearing Material

- **The DU® Bearing** is the ultimate in oilless bearing design, using lead and tetrafluoroethylene (Teflon) having excellent wear resistance which optimizes metal properties such as strength and dimensional stability.

- **Coefficients of static and dynamics friction** are so small that the bearing surfaces run smoothly without lubrication, while at the same time eliminating sticking and slipping.
Glacier DU® Bearing Material

- The bearing surfaces have such low coefficients of static and dynamic friction that they require no lubrication.
- The operating temperature range extends from -200 to 280 °C.
- DU® bearing operate smoothly under loads which exert high levels of resistance, impact, intermittent motion, and thrust.
- DU® bearing are free from electrostatic induction. When installed, each DU®

Glacier DU® Bearing Material

- Glacier Garlock is one of the world's primary sources for plain industrial bearings and bearing materials. Covering all manner of industrial, aerospace and specialist technologies, Glacier has a long established history in this field and provides an enormous range of products to suit many applications.
- The range includes bearing materials designed to operate dry, under conditions of marginal lubrication, and continuously at temperatures up to 280°C. None of materials rely on the build-up of a hydrodynamic oil film to operate correctly, and they are particularly suitable for oscillating, frequent stop/start, or high-load/low-speed conditions.
- The materials do not absorb water or swell in the presence of moisture, so there is little danger of seizure (鎖住) in a humid atmosphere due to reduction in clearance.
The Frictional Characteristics of a Castable Bearing Material

- **One surface must be very rough**, while the other surface should be **smooth** and covered with mold release. To prevent porosity, the replicant must be thoroughly vacuum degassed before application.

- Replication greatly **decreases the cost** of bearing surfaces for the following reasons:
  - *Only the replication master needs to be accurately finished.*
  - *An exact Fit is obtained, so gibs are not needed.*
  - *The machine is easily rebuilt.*
  - *Replicated bearings are less sensitive to dirt and they generally do not have to be scraped.*
General Characteristics of Castable Bearing Material

- Speed and acceleration limits
  - $< 15$ m/min (600 ipm) and 0.1 g.
- Applied loads
  - Large surface area allows for high load capacity.
  - Virtually insensitive to crashes.
- Accuracy
  - Axial: 5 - 10 microns depending on the drive system.
  - Lateral (straightness): 0.1 - 10 microns depending on the rails.
  - Special designs can yield nanometer accuracy.
- Repeatability
  - Axial: 2 - 10 microns depending on the drive system.
  - Lateral (straightness): 0.1 - 10 microns depending on the rails.
- Resolution
  - Axial: 1 - 10 microns depending on the drive system.
- Preload
  - 5-10% of the allowable load.
- Stiffness
  - Easily made many times greater than other components in the machine.

Properties of a typical castable high lubricity polymer.
(Courtesy of ITW-Philadelphia Resins.)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength</td>
<td>96.5 MPa</td>
</tr>
<tr>
<td>Shear strength</td>
<td>31.7 MPa</td>
</tr>
<tr>
<td>Compressive modulus</td>
<td>4.0 GPa</td>
</tr>
<tr>
<td>Shear modulus</td>
<td>0.8 GPa</td>
</tr>
<tr>
<td>Shrinkage</td>
<td>400 micron/m</td>
</tr>
<tr>
<td>Coefficient of thermal expansion</td>
<td>42.5 micron/m/°C</td>
</tr>
<tr>
<td>Lubricated static coefficient of friction</td>
<td>Approx. 0.11</td>
</tr>
<tr>
<td>Lubricated dynamic coefficient of friction</td>
<td>Approx. 0.09</td>
</tr>
<tr>
<td>Density</td>
<td>2.1 g/cm³</td>
</tr>
<tr>
<td>Pot life</td>
<td>45 minutes</td>
</tr>
<tr>
<td>Cure time</td>
<td>40 hours</td>
</tr>
</tbody>
</table>
Zanite® Polymer Composite

• Zanite® polymer composite is a blend of pure silicon dioxide ceramic (99.8%) quartz aggregate, specially formulated high strength epoxy resin and selected additives.
• The natural elliptical shape of quartz is ideal for casting intricate structures.

Zanite® Polymer Composite

• Zanite® polymer composite is a formulated composite material designed for casting machine bases and other structural components. It is a combination of epoxy, quartz aggregate and selected additives.
• Zanite® replaces traditional materials, such as iron, aluminum and steel, used in the manufacture of machine bases. Castings can be manufactured to finished tolerances, and the resulting item outperforms alternative materials. Zanite® provides many advantages over metals.
• Zanite® applications include a variety of other special equipment and machinery where vibration damping, chemical resistance and design flexibility is a consideration.
The Properties of Zanite®

<table>
<thead>
<tr>
<th>Properties</th>
<th>U.S. Units</th>
<th>S.I. (Metric)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damping ratio</td>
<td>0.157</td>
<td>0.157</td>
</tr>
<tr>
<td>Specific heat</td>
<td>0.23BTU/Lb°F</td>
<td>960J/kg°C</td>
</tr>
<tr>
<td>Chemical resistance</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>20,000 psi</td>
<td>137 N/mm²</td>
</tr>
<tr>
<td>Density</td>
<td>0.084 lb/in³</td>
<td>2.3 kg/dm³</td>
</tr>
<tr>
<td>Flexure strength</td>
<td>3,800 psi</td>
<td>26 N/mm²</td>
</tr>
<tr>
<td>Modulus of elasticity</td>
<td>4.5 x 106 psi</td>
<td>31 KN/mm²</td>
</tr>
<tr>
<td>Poisson ratio</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Temperature limits</td>
<td>-50°F to 220°F</td>
<td>-45°C to 104°C</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>2,100 psi</td>
<td>14.5 N/mm²</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>11.09 Btu/(h.ft²,F/ft)</td>
<td>0.191 W/(cm²,°C/cm)</td>
</tr>
<tr>
<td>Water absorption</td>
<td>0.01%</td>
<td>0.01%</td>
</tr>
<tr>
<td>Thermal expansion</td>
<td>10.8 x 10^-6 in/in°F</td>
<td>2.0 x 10^-5 /°C</td>
</tr>
<tr>
<td>Flame spread index</td>
<td>Class A (Class I) – 25 or under flame spread per ASTM E84</td>
<td></td>
</tr>
</tbody>
</table>

The Advantages of Zanite®

- **Vibration**: Zanite® dampens vibration approximately 10 times better than cast iron and 45 times better than steel due to its higher dynamic stiffness. Reduction of vibration means improved system performance and tool life. Zanite® also deadens sound.

- **Flexibility**: Custom linear ways, hydraulic fluid tanks, threaded inserts, cutting fluid and conduit piping can all be integrated into the polymer base. In addition, Zanite®
The Advantages of Zanite®

- **Cost**: Zanite® is cast to finish tolerances while cast iron requires secondary machining. Zanite® polymer bases cost significantly less than metallic castings when compared to finished, ready to assemble parts. In addition, inventory costs are significantly reduced because of the short lead times.

- **Zanite® is environmentally friendly.** Zanite® bases are created using a cold casting process, requiring a minimal amount of

The Advantages of Zanite®

- **Zanite® replaces traditional materials such as iron, aluminum, and steel** used in the manufacture of machine bases. Castings are manufactured to finish tolerances, and the resulting base outperforms alternative material in many areas.

- **Zanite® polymer composite is accepted by design engineers throughout the world** as an alternative material due to its excellent design flexibility, mechanical properties, and short production time.
The Advantages of Zanite®

Typical Industry Use of Zanite®

- Filled Structures:
  - Zanite® Polymer Composite Filled Weldments and Iron Castings
- Standard and Custom Designed Inserts
- Molds and Tooling
- Machine Tool
- Medical

- Typical applications include: frame supports for MRI machines, X-ray equipment, CAT-Scanners, and blood testing & analysis machines.
Moglice® Bearing Material

• The coefficient of friction for the combination C.I./Moglice® is only approx. 1/7 of the combination C.I/ steel.
Properties of Moglice® high lubricity castable bearing replication material. (Courtesy of "DIAMANT" Metallplastic GmbH.)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific weight</td>
<td>1.6 g/cm³</td>
</tr>
<tr>
<td>Dynamic strength</td>
<td>1450 N/cm²</td>
</tr>
<tr>
<td>Static strength</td>
<td>14,000 N/cm²</td>
</tr>
<tr>
<td>Minimum operating temperature</td>
<td>-40°C</td>
</tr>
<tr>
<td>Maximum operating temperature</td>
<td>125°C</td>
</tr>
<tr>
<td>Shrinkage</td>
<td>About 1/4%</td>
</tr>
<tr>
<td>Moisture absorption</td>
<td>Very good resistance</td>
</tr>
</tbody>
</table>

Frictional properties of Moglice® castable bearing material: contact pressure 5 daN/cm² with mineral oil having a viscosity of 25 centistokes at 50°C. (Courtesy of "DIAMANT" Metallplastic GmbH.)

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The Benefits of Moglice®

• Moulded in place
• Applicable without special knowledge,
• With highest precision
• Just putty, pour or inject - ready! (After cure)

Fields of Application of Moglice®

• Round guideways, bushings
• Bearings of any kind for large machine tools
• Hydraulic pistons
• Taper gibs
• Column guidings
• Carriage slideways
• Tooth racks
• Ram guideways
• Hydrostatic guideways
• Support guideways
• Aerostatic guideways
• Quill bushings
Use of Castable Bearings in RepRap


Gib Design
Gib Design

• In order to allow the preload to be adjusted easily, particularly after the wear-in period has been completed, a machine element called a gib should be used with linear sliding contact bearings.

![Diagram of gibs with preload mechanisms]

| Tapered gib with in-line screw preload (not shown) | Straight gib with setscrew preload | Straight gib with locking bolts and setscrew preload | Straight gib with locking bolts and roller/wedge preload |

Gib Design

• Straight gibs are preloaded using setscrews along their length or with a roller.
• Tapered gibs are preloaded by a single screw that pushes them along a matching taper, thereby creating uniform lateral displacement along the length of the gibs.
• The former is easy to manufacture, while the latter requires more complicated machine setups and considerable skill if it is to be hand scraped.
• Still, tapered gibs provide the highest degree of stiffness. Note that gibs for dovetails that are locked in place with retaining bolts can provide twice the stiffness to overturning moments than do tapered gibs.
Gib Design

• For the T carriage design shown in Figure 8.2.5, a straight gib is used to control the lateral clearance between the saddle and rail.

• Note that lateral motion is restricted by one rail only. To use both rails for lateral restraint would overconstrain the system, increase the likelihood that Poisson expansion of the bolted rails would create straighiness errors, and increase manufacturing costs considerably.

\[
 t_{\text{gib}} = \left( \frac{2a\eta ab^3 P_{\text{max}}}{\delta E} \right)^{1/3}
\]
For example, assume that a brass gib is used and $E=110$ GPa ($16 \times 10^6$ psi), $\delta = 10^{-6}$ m, $a = 0.1$ m, $b = 0.05$ m, $P_{\text{max}} = 0.5$ Mpa (75 psi) and $\eta = 0.3$: then $t = 0.0183$ m (0.72 in).
Configurations of Sliding Contact Rotary Bearing

- Sliding contact rotary bearings are not often used in precision machines because ball bearings are so inexpensive and easy to use.
- However, sliding contact bearings may be needed where high loads may be encountered, or extreme accuracy requirements warrant lapping a shaft and sliding contact bearing to fit each other perfectly.

Various Configurations for Sliding Contact Rotary Bearings

Various configurations for rotary sliding contact modular bearings. (Courtesy of Thomson Industries, Inc.)
Jewel Bearing

• For very high precision applications, such as instruments where the friction torque is to be minimized, one should consider using a jewel bearing (synthetic sapphire or ruby).

• The high surface finish, high compressive strength, high modulus, and chemical inertness of a jewel bearing usually ensures dimensional stability.

• These properties also allow jewel bearings to be used with a small-diameter or pointed shaft, thereby minimizing tare torque.

Jewel Bearing

• The synthesizing process dates back to the early 1900’s and has changed little since then. Aluminum ammonium sulfate is calcined at a temperature between 1200°C and 1500°C.

• The resulting alumina or corundum is fed as a powder into an oxyhydrogen flame of about 2050°C centigrade temperature.

• The powder melts and is crystallized on a ceramic pedestal to form a small, single crystal boule form which blanks are cut for the manufacture of various designs of jewel bearings and other products.
# Synthetic Sapphire Properties

## General Properties of Sapphire

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Formula</td>
<td>Al₂O₃</td>
</tr>
<tr>
<td><strong>Mechanical</strong></td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>3.97 gm/cm³</td>
</tr>
<tr>
<td>Compressive Strength</td>
<td>300,000 psi</td>
</tr>
<tr>
<td>Young Modulus</td>
<td>50-55 x 10⁶ psi</td>
</tr>
<tr>
<td>Flexural Strength</td>
<td>~100,000 psi</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>~60,000 psi (at approx. 25°C)</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>0.28-0.33</td>
</tr>
<tr>
<td>Porosity</td>
<td>0%</td>
</tr>
<tr>
<td>Hardness</td>
<td>9 mohs 1800 Knoop parallel to c-axis</td>
</tr>
<tr>
<td></td>
<td>2200 Knoop perpendicular to c-axis</td>
</tr>
<tr>
<td>Coefficient of Friction</td>
<td>0.15 against steel</td>
</tr>
<tr>
<td><strong>Optical</strong></td>
<td></td>
</tr>
<tr>
<td>Index of Refraction</td>
<td>No: 1.768(c-axis) Ne: 1.760(c-axis)</td>
</tr>
<tr>
<td>Birefringence</td>
<td>(No-Ne) 0.008</td>
</tr>
<tr>
<td>Dielectric Strength</td>
<td>480,000 v/cm</td>
</tr>
<tr>
<td>Dielectric Constant</td>
<td>average 11.5 (parallel to c-axis)</td>
</tr>
<tr>
<td></td>
<td>average 9.3 (perpendicular to c-axis)</td>
</tr>
<tr>
<td>Volume Resistivity</td>
<td>&gt;1014 ohm-cm²</td>
</tr>
<tr>
<td><strong>Electrical</strong></td>
<td></td>
</tr>
<tr>
<td>Thermal</td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>9 mohs 1800 Knoop parallel to c-axis</td>
</tr>
<tr>
<td></td>
<td>2200 Knoop perpendicular to c-axis</td>
</tr>
<tr>
<td>Coefficient of Expansion</td>
<td>5.3 x 10⁻⁶ (parallel to c-axis)</td>
</tr>
<tr>
<td></td>
<td>4.5 x 10⁻⁶ (perpendicular to c-axis)</td>
</tr>
<tr>
<td>Conductivity</td>
<td>0.086 cal/gm</td>
</tr>
<tr>
<td>Heat Capacity</td>
<td>77.8 joules/deg. Mole</td>
</tr>
<tr>
<td><strong>Thermal</strong></td>
<td></td>
</tr>
<tr>
<td>Melting Point</td>
<td>2,050 °C</td>
</tr>
<tr>
<td><strong>Optical</strong></td>
<td></td>
</tr>
<tr>
<td>Index of Refraction</td>
<td>No: 1.768(c-axis) Ne: 1.760(c-axis)</td>
</tr>
<tr>
<td>Birefringence</td>
<td>(No-Ne) 0.008</td>
</tr>
<tr>
<td><strong>Electrical</strong></td>
<td></td>
</tr>
<tr>
<td>Thermal</td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>9 mohs 1800 Knoop parallel to c-axis</td>
</tr>
<tr>
<td></td>
<td>2200 Knoop perpendicular to c-axis</td>
</tr>
<tr>
<td>Coefficient of Expansion</td>
<td>5.3 x 10⁻⁶ (parallel to c-axis)</td>
</tr>
<tr>
<td></td>
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</tr>
</tbody>
</table>

Source: [http://www.swissjewel.com/synthetic_sapphire_properties.htm](http://www.swissjewel.com/synthetic_sapphire_properties.htm)
Jewel Bearing Designs

Standard jewel bearing designs. (Courtesy of Swiss Jewel Co.)

Jewel Bearing

- Ring Jewels serve as radical or sleeve bearings used with a straight cylindrical shaft.
- Typical Applications: General Instrumentation, Flow Meters, Gauges, Indicators, Watches, Clocks, Potentiometers, Gyros, Aircraft Instruments, Spacer, Insulator

Source: http://www.swissjewel.com/sapphire_ring_jewels.htm
Closed Rectangular Liner Bearing Configuration

- It is an overconstrained design, but if well made and preloaded, it can provide exceptional stiffness and damping capability.
- Note that the full wraparound design of the carriage means that the bearing rail is subject to bending loads.
Open Rectangular (T) Linear Bearing Configuration

- T configurations are the most common type of sliding bearing configuration seen in machine tools.
- It is overconstrained but provides very high stiffness. Wear among the bearing surfaces is usually symmetric, so alignment of the carriage does not change much with wear. With careful design and manufacturing quality control, machines with 5 to 10 μm repeatability or better can be built using this bearing design.

Vee and Flat Linear Bearing Configuration

- The vee and flat is a true kinematic bearing configuration.
- A vee and flat supported carriage is generally preloaded by the weight of the machine, so it is often acceleration and speed limited.
- It is possible to preload a vee and flat supported carriage with a friction drive roller, but then the preload force on the bearings becomes a function of carriage position.
- Vee and flat supported carriages are also prone to walking problems should the center of mass of the system change dramatically, as when a heavy part is put on one side of the carriage.
- When the center of mass changes, the distance from the axial motion guiding the vee to the center of mass changes: hence the distribution of frictional forces changes, which causes a yaw motion on the carriage.
- This causes the carriage to yaw differently when different weights are applied at different positions.
Double-Vee Linear Bearing Configuration

- The double vee is quasi-kinematic: It is more kinematic than the dovetail but not as kinematic as the vee and flat; however, it has been found to be easier to manufacture than a dovetail, and a carriage supported by twin vees is less susceptible to walking than is the vee and flat when heavy off-center loads are applied.