Fluid Film Thrust Bearings: Fundamentals, Damage Evaluation, & Repair

VIBRATION INSTITUTE MEETING CHARLOTTE, NC

Pioneer Motor Bearing
May 2006

Outline
- Basic Design Criteria
- Thrust Bearing Monitoring
- Damage investigation
- Damage mechanisms
- Inspection
- Repair

History
- Without question the most significant mechanical invention in the world was:
  - The Wheel

History
- However, almost immediately upon discovery of the wheel, the need for bearings was also discovered:

History
- Which has led to one of the most elusive searches in human history

History
- As one can observe from this wooden wheel dating to 2700 BC, axles where used to allow support by radial and thrust bearings:
Load Orientations: radial/thrust

Thrust Bearing
- Support axial load from the process
  - e.g. Water or steam pressure
- Thrust runner surface
  - Generally flat (<13 µm = 0.0005")
  - 16 µin RMS
- Thrust bearing
  - Generally circumferential segments
    - Tend to be "square" - length=width
  - Trade-off
    - Larger loaded area gives more friction loss

Thrust Clearance
- Typical operating clearance
  - Human hair about 75 µm (0.003") diameter
  - Typical operating clearance about 25 µm (0.001").

Thrust Load
- Load capacity based on
  - Hydrodynamic pressure profile
  - Pad area
    - Nominally $Area = 0.25 \pi (OD^2 - ID^2)$
    - Reduced by grooving

Thrust Bearing Designs
- Flat Washer
- Flat Babbitted Face With Grooves
- Taper-Land Babbitted Face
- Tilting Pad Thrust Bearing
- Equalized Tilting Pad Thrust Bearing

Flat Washers
- Simple but useful only with minimal speed and load conditions
- Grease lubricated
“Bumper” Thrust

Babbitted axial surfaces to resist motion of shaft collars. Babbitted surface may have radial pockets or grooving.

Flat Babbitted Thrust Face with Grooves

- Useful as a bumper, or locating bearing
- Oil or grease lubricated
- No theoretical load capacity
- Practical capacity around 50 to 75 PSI

“Bumper” Thrust

Radial grooves enhance load capacity.

Taper-Land Thrust Bearing

- Optimized for only one speed and load combination
- Taper for oil wedge formation is machined into the bearing surface
- Alignment is critical to operation
- Practical load limit 150 to 225 PSI

Simple Tapered-Land Thrust

Taper is steeper at the inner diameter than at the outer diameter. Taper is generally 0.003” - 0.007”. Land region is visible.

Compound Tapered-Land Thrust
Fluid-film Thrust Bearing

- Annulus controls axial position.
- Maximum load capacity

Tilting Pad Thrust Bearing

- Self Optimizing based on applied load and speed
- Maximum Flexibility re: potential modifications
- Alignment is critical
- Load Capacity in excess of 600 PSI

Tilting Pad Thrust Bearings

Equalizing linkages correct for housing skew. Equalizing linkages do not correct for rotating collar skew.

Non-Equalizing Support

Ref: Constantinescu, p. 354.

Non-Equalized Bearing

Self Equalizing Tilting Pad Thrust Bearings

- Maximum capacity in given space
- Self optimizing oil film
- Can accommodate collar to housing misalignment
- Not designed for dynamic misalignment
- Load Capacity in excess of 600 PSI
Equalizing Linkages

Intent is to equally load each of the thrust pads in spite of variations in pad thickness or misalignment of the housing to the runner.

Ref: Constantinescu, p. 354.

Anti-Rotation Pins

Provides:
- Locates shell in housing
- Circumferential
- Prevent rotation of the cage in the housing.

Combined Journal Thrust

Lobed journal bearing
Tapered thrust bearing

Oil Distribution Geometry

Axial groove
Radial groove

Thrust Bearing Flows

Ref: Kingsbury sales literature, EOC-1.

Tilting Pad Thrust Bearings

Ref: Kingsbury literature
So, how much load can my bearing take?

- This depends on where you are operating within the regime of the bearing performance parameters
- No, I am not a lawyer

What can be done to increase load capacity?

- First, understand the shortcomings of the existing bearing
- Second, consider modifications to the operating parameters
- Third, consider an upgrade to the basic bearing design

Deal with low speed wear

- Hydrostatic lift system to provide hydrostatic oil films where hydrodynamic oil films may not otherwise be present
  - Start up operation
  - Turning gear operation
  - Some emergency conditions
  - Per DIN 31652 part 3 consider hydrostatic lift where startup loads exceed 2.5-3.0 MPa (363-435 psi)
    - May be required for lower loads

Hydrostatic Lift Systems

- Inject high pressure oil (typically > 1000 psi) at the location of the highest loading
- Hydrostatic film is developed through pressure, film thickness is controlled by flow
- Quite often, many bearings are fed by a common high pressure header

Hydrostatic Lift System

- Introduce externally-pressurized oil into bearing cavity for operation at low surface speeds and high loads
  - Forms hydrostatic bearing on lower half

Hydrostatic lift in tilting pad thrust shoes.
Sample Hydrostatic Lift Oil System

Each radial bearing #3-8 has a separate pressurized hydrostatic lift supply (1500 psig), separate supply pump with a gravity or slight vacuum drain back to the reservoir.

OK smart guy, I've already got a tilting pad thrust bearing, Now what?
- Consider upgrading specific design features of the assembly
- Directed lubrication
- Alternative materials
- Offset pivots

Effect of Pivot Offset

Effect of Chrome-Copper Alloy Backing Material

Thrust Bearing Monitoring
- Temperature
- Load
- Thrust Collar Position

Thrust Temperature Monitoring
- Embedded Sensors
- Thermocouples
- RTD’s
- Oil Inlet and Exit Temperature
**Tilt-Pad Thrust Profiles**

Temperature profiles show influence of pressure peak over the pivot (dashed circle), as well as radial and circumferential flow.

---

**Embedded Sensors**

- Proper Location

---

**Thrust Load Measurement**

- Basic Bearing Design

---

**Thrust Load Measurement**

- Leveling Plates

---

**Thrust Load Measurement**

- Strain Gage Load Cell

---

**Thrust Position Measurement**

- Eddy Current Probes
- Dual Voting
Thrust Position Measurement

Damage Investigation
- Generic Elements
  - Visual examination
  - Background information
  - Photographic records
  - Event reconstruction
  - Laboratory analysis

Damage Investigation
- Visual Examination

“Say, is all that babbitt supposed to be on the bottom of the bearing housing like that?”

Damage Investigation
- Generic Elements
  - Visual examination
  - Background information
  - Photographic records
  - Event reconstruction
  - Laboratory analysis

Visual Examination

Where is the damage?
- Babbitt Surface
  - Centered over pivot
  - More toward trailing edge
  - More toward leading edge
- Supporting structure
  - Leveling plates
- Thrust collar
Damage located primarily along the trailing edge is indicative of debris, electrolysis, or other trauma that occurred while the bearing was otherwise operating in a normal condition.

Damage located primarily opposite the pivot is indicative of the bearing operating in an overloaded condition.

Damage located primarily along the leading edge is indicative of a lack of lubrication, either during start up, or during operation.

Damage to the leveling plates, base ring, or other support structure is usually indicative of thrust collar runout problems. Collar may be installed improperly, or may have come loose in service.

Circumferential scoring or scratching of the thrust collar is usually indicative of debris in the oil system.

Mechanisms are the same as those covered earlier by Dr. Branagan. Specific thrust bearing photographs may help.
Minor Overload

Babbitt Fatigue

Overheating

Gross Overheating

Anisotropy

Tin / Copper Migration
Pivot Fretting

Leveling Plate Fretting

Babbitt Erosion

Bearing Inspection

Bearing Surface
Bearing Subsurface
Thrust Collar
Assembled End Play

Thrust Bearing Surface

- Portion of bearing designed to carry the load must be clean and flat
- Inspect for embedded debris with a single edged razor blade
- Inspect surface with straight edge
- Inspect contact with Prussian bluing with a calibrated plate and finally with the mating thrust collar

Thrust Bearing Subsurface

- Ultrasonic Inspection
- Dye Pen Inspection
- Brass Dowel Ring Test
Thrust Collar Inspection
- Surface finish 16 RMS or better
- Surface flatness less than .001 inch
- Assembled runout less than .001 TIR

Assembled Runout Check
- Can not be measured with a single indicator as rotor float will impact measurement
- Temporary blocking may be required to limit rotor float during inspection
- Requires 2 Mag base indicators with sufficient travel to stay in contact with collar face

Indicator position

Typical Measurement record

Assembled End Play
- Best to first measure available space and stacked height of the bearing assemblies
- Difference should be the assembled end play
- After assembly, bump test the rotor to confirm measurement

Repairs
- Many minor thrust bearing repairs can be accomplished on site
- The level of repair that should be attempted is directly proportional to the experience level of the technicians available
**Babbitt Surface Repairs**

- Minor imperfections can be removed by lapping or scraping.
- Larger scratches can be repaired by first locally puddling babbitt and followed by peening and then lapping or scraping.

**Babbitt Puddling**

**Hand Scraping**

**Power Scraping**

**Thrust Collar Repair**

- Minor damage and glazing can be repaired by hand stoning.
- Use a fine 600 grit oil stone.
- More serious repairs can be corrected by turning, lapping, or grinding.
- Many of these operations can be conducted in place.

**Conclusions**

- Remember that the babbitt surface is a SOFT, sacrificial layer.
- Look at your babbitt surface to better understand the likely cause of the bearing damage and reduce re-occurrence.
- Remanufacture (repair) or redesign bearing depending on the nature, severity, and probability of future damage.