Temperature Monitoring of PEEK Bearings

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Design Characteristics

PEEK

- High temperature resistance with excellent chemical and fatigue resistance plus thermal stability
- Retain mechanical properties at 250+°C
- Heat distortion temperature (HDT) up to 160°C virgin; up to 315°C with reinforcement
- Good wear resistance – low coefficient of friction and high limiting PV properties
- PEEK and PEEK lining can extend bearing operating limit

Forms and Applications of PEEK Bearings

- Combined polymer bearing for water-lubricated CHP turbine
- Polymer lined thrust bearing for oil-lubricated pumps
- Combined solid polymer bearing
- Polymer lined tilting journal pad
- Solid polymer thrust bearing for water pumps
- Polymer lined Flexural Pivot thrust bearing for steam turbines
Problem Statement

Bearing temperature is an important industry indicator of bearing health; however, traditional temperature monitoring methods used for babbitt bearings might not provide sufficient warning of bearing distress when used with PEEK bearings. Non-traditional methods of temperature monitoring is needed for PEEK bearings.
Goal

To identify effective temperature monitoring options for PEEK via polymer bearing tests and determine the best method for industrial application and lab testing.
Garner and Leopard, 1985: Review for Babbitt

- Discuss temperature sensor types, position, installation, and alarm/shutdown setting for babbitt (whitemetal) lined fluid film bearings
- Emphasize the importance of pad temperature, not only lubrication supply/discharge temperature
- Function of pad temperature is to provide safeguard of **gradual** changes
- No monitoring benefit of maximum temperature for industrial application
- Position sensors where film breakdown could occur
- Suggest placement of temperature sensors below the bond line

American Petroleum Institute (API)

- API standards address **babbitt only**
- API standards recommend **measuring bearing-metal temperature**
  - API 616 Gas turbine 4.8.5.5
  - API 617 Axial and Centrifugal compressors 2.7.1.2
  - API 617 Integrally geared compressors 2.7.1.3
  - “**Unless otherwise specified, thrust bearings and radial bearings shall be fitted with bearing-metal temperature sensors installed in accordance with API std 670**”
- API 670 specifies 75% location for sensors in tilt pad bearings
  - 6.1.8.1.2 (tilting pad journal bearings): Either one sensor at 50/75 or two sensors at 25/75 and 75/75
  - 6.1.8.2.2 (tilting pad thrust bearings): Temperature sensor at 75/75 location (75% radially and 75% circumferentially)
Ettles et al., 2003 (PTFE vs. babbitt)

- **Bearing 1**: 8-pad TPT, 464 mm OD; PTFE/OVA thickness: 5/40 mm
- **Test conditions**
  - Up to 10.2 MPa and 41 m/s
  - ISO VG32 oil, flooded lubrication
- **Temperature**
  - Measure lining temperature – thermocouples (TCs) in PTFE 3 mm below the surface
  - Later on, measure fluid film temperature using hole in pad surface
- **Results**
  - No significant film T difference between PTFE and babbitt
  - Higher power loss with PTFE

- **Bearing 2**: 8-pad TPT, 912 mm OD, spring supported; PTFE/OVA thickness: 2/38.1 mm
- **Test conditions**
  - Up to 10 MPa and 28 m/s
  - ISO VG32 oil, flooded lubrication
- **Temperature**
  - Measure pad metal temperature below bond line
- **Results**
Glavatskih, 2003: PTFE vs. Babbitt

- Bearing
  - 6-pad equalized TPT, babbitt and PTFE (15% glass fiber) lined pads, 228.6 mm OD
  - PTFE thickness: 1.5 mm

- Test conditions
  - Up to 2 MPa., 1500–3000 rpm
  - ISO VG68 oil, flooded lubrication

- Temperature
  - Measure metal temperature below bond line – TCs 4 mm below the PTFE surface; 3 mm below babbitt surface
  - Measure collar temperature

- Results
  - 1.5 mm thick PTFE layer leads to thermal insulation up to 23°C
  - Collar T similar for both bearings; T_PTFE slightly higher than T_babbitt
  - PTFE leads to up to 8% power loss reduction

Glavatskih, 2004: PTFE vs. Babbitt

- Same bearing as in Glasvatskih, 2003
- Present a new method: Measure fluid film temperature via hole in pad surface and with bypassing hole
  
  - “…. compared to conventional industrial methods of temperature monitoring, provided higher sensitivity to oil film temperature in both steady state and transient operating conditions “
  
  - “Existing methods of temperature measurement are inadequate if applied to PTFE-faced bearings”

Glavatskih, 2004: Transient Plot for PTFE and Babbitt Bearing

- $T_H$ (fluid film) and $T_{75/75}$ (metal) generally follow the same trend
Henssler et al., 2015: PEEK with 50% Carbon Fiber

- Solid PEEK (50% carbon fiber) pads
- Journal bearing
  - 5-pad TPJ, flooded water lubrication
  - 1500–6000 rpm, 0.5 MPa
- Thrust bearing
  - 8-pad TPT, flooded water/glycol lubrication
  - 1500–6000 rpm with 500 rpm step, Up to 3.8 MPa
- Measure fluid film temperature via hole in pad surface, 75/75
- Results: pass the test

Sumi et al., 2014: PEEK vs. babbitt

- **Bearing**
  - 14-pad TPT, 727 mm OD, PEEK lined (3 mm) and babbitt lined

- **Test conditions**
  - 12 MPa (steady), 20 MPa (4 seconds); 3600 rpm
  - Measure fluid film temperature via hole(?) in pad surface (near pad surface)

- **Results**
  - No damage after test
  - Compared to babbitt lined bearing, no significant temperature or power loss difference

PEEK Long-term Test

- **Bearing used in MHI internal plant since 2007**
  - 10-pad TPT, 553 mm OD; PEEK lined (3 mm)

- **Test Conditions**
  - 3600 rpm, 0.8 MPa,

- **Temperature**
  - Metal temperature
  - Photos also suggest fluid film temperature (hole in pad surface)

- **Results**
  - 631 start-up/shutdown, total 20,462 hours
  - Surface looks good

Zhou et al., 2015: PEEK

- **Bearing**
  - 8-pad 60% offset self-equalized TPT, PEEK lined, 279 mm OD

- **Test conditions**
  - ISO VG32 oil, ‘Directed Lubrication’,
  - Load up to 16.2 MPa at 6000 and 11,000 rpm
  - Performance study at 1000–13,000 rpm, 0.69–6.9 MPa, max 147 m/s

- **Temperature**
  - **Metal temperature**, TC at pivot location below bond line

- **Results**
  - PEEK lined thrust bearings can operate at higher bearing unit loads than babbitt lined bearings
  - PEEK lined thrust bearings can be designed up to 8.0 MPa for modern turbomachinery’s demanding load and speed requirements
  - No significant power loss difference between PEEK and babbitt (1-6%)
  - Observed small range of temperature variation with PEEK lined pads
  - Recommend PEEK for high speed/high load applications when babbitt cannot meet the need


## Literature Review Summary

<table>
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<tr>
<th>Material</th>
<th>Max MPa</th>
<th>Max m/s</th>
<th>Pad / metal</th>
<th>Pad / lining</th>
<th>Fluid film /hole</th>
<th>Fluid film /hole with bypass flow</th>
<th>Fluid film / flush with surface</th>
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- **Babbitt bearing temperature monitoring:**
  - Pad metal temperature is industrial standard practice; lab tests also use fluid film temperature
- **Polymer bearing temperature monitoring:**
  - Measuring pad fluid film temperature deviates from standard practice
  - Measuring temperature using fluid film with instrument flush to bearing surface has not been published
  - No published data relating temperature to bearing distress
The Current Study

- Present fluid film temperature in PEEK bearings using sensor flush with pad surface
- Present fluid film temperature in PEEK bearings using hole in pad surface located below surface
- Study options for indicating bearing distress
Test Rig

- 750 kW total power
- ISO VG32 oil
- 5678 L reservoir
- 1136 lpm oil pump
- Individual oil control to all bearings
Test Trial 1:
Measuring Pad Fluid Film Temperature Via Sensor Flush with Pad Surface
PEEK Lined Pocket Feed TPT

- Pocket Feed TPT with 8 PEEK lined steel pads
- Bearing OD 279 mm
- 4 pads with **TC flush with pad surface**, measuring fluid film T
- 4 pads with **TC embedded in pad backing material**, measuring pad metal T
Temperature During Performance Test

- Steady state test from 1000 to 13,000 rpm
- Both fluid film T and metal T changed with load and speed, as expected

*PEEK lined pads*
Performance Test: 13,000 rpm

- **Fluid Film, 75/75, Pad 1**
- **Bearing Load**
- **Metal, 75/75, Pad 7**

*PEEK lined pads*
Performance Test: 1000 rpm

Elapse Time (second)

Temperature Rise (F)

Bearing Load Factor (%)

Fluid Film T, 75/75, Pad 1

Bearing Load

Metal T, 75/75, Pad 7
Temperature During Ultimate Load Test
Summary: Test Trial 1

- Temperature Monitoring
  - Both fluid film temperature and metal temperature tracked the gradual change of bearing load and speed
  - Fluid film temperature (flush with pad surface) swiftly tracked the sudden load change (in 1000 rpm test)

- Distress Indication
  - Caution advised if planning to use fluid film sensor flush w/ pad surface under very high load
  - Capability of metal temperature of PEEK lined bearing to indicate stress
    - Film temperature sensor resulted in test stopping
Test Trial 2: Measuring Pad Fluid Film Temperature Via Hole in Pad Surface
PEEK Lined CQDL TPT with Hole

- CQDL (Self-Equalizing ‘Directed Lubrication’) TPT with 8 PEEK lined steel pads
- 4 pads with TC measuring metal T
- 1 pad with 75/75 TC measuring fluid film T with hole in pad surface
- 11,000 rpm
Performance Test: 11,000 rpm
Performance Test: Transient Change in Oil Inlet Temperature During ‘Warm-up’

CQDL Pad Temperature at 8400 rpm & 26% Load

- Fluid film (hole) T, 75/75
- Metal T, 75/75
- Inlet T
Summary: Test Trial 2

- Temperature Monitoring
  - Both fluid film(hole) temperature and metal temperature tracked the gradual change of bearing load
  - Fluid film (hole) temperature had a shorter response time than metal temperature, as expected

- Distress Indication
  - Caution advised if instrument exposed to fluid film pressure
  - Not tested yet (prior to annual meeting)
Test Trial 3: Bearing Distress Indication
Distress Indication

- Using pad fluid film temperature to indicate bearing distress has not been demonstrated
  - Fluid film (flush with pad surface):
    - TC localized, misleading temperature reading; TC inaccurately indicated unacceptable temperature change
    - Measuring fluid film (flush surface) temperature not a reliable solution for high load application
  - Fluid film (hole):
    - Initial trial sensor unreliable
    - No test data indicating bearing distress
- Next: Distress indication using pad metal temperature
  - Ultimate load test of CQDL TPT with 8 PEEK lined steel pads
  - 4 pads with TC in **metal only**
  - Transient date from ‘ultimate’ load test at 6000 and 11,000 rpm
PEEK Lined CQDL TPT: Ultimate Load Test at 6000 rpm
PEEK Lined CQDL TPT: Ultimate Load Test at 11,000 rpm

- PEEK lined pad metal temperature can track change of operating conditions, as in Pocket Feed TPT
- Metal temperature indicated distress and the test rig was shut down to prevent rig damage
Summary and Conclusions

- Polymer pad temperature measurement:
  - Two options: material temperature and fluid film temperature
  - Five methods: lining material, metal backing material, fluid film (flush with pad), fluid film (hole), and fluid film (hole) with bypass flow

- Both material temperature and fluid film temperature can be used to monitor PEEK pads and track gradual change of operating condition, based on published test data

- Fluid film (flush with pad surface) method offer fast response, but not suggest for very high load/high speed application.

- Fluid film (hole) method also has quick response. Distress indication to be validated via additional testing

- Pad metal temperature can indicate bearing distress, as validated by test

Recommendation

- Industrial applications: pad metal temperature is a reliable method for bearing health monitoring and an indication of bearing distress
- Lab testing: combination of metal temperature method (ultimate load) and fluid film temperature method (fast response)