Condition Monitoring for Steam Turbines
and
Sleeve Bearing Diagnostics and Failure Analysis

Presented by:

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Condition Monitoring for Steam Turbines and Sleeve Bearing Diagnostics and Failure Analysis

- Part I - Condition Monitoring for Steam Turbines
  - What is today's definition?
    - We want an early warning so that when the operating condition of the turbine is changing, action can be taken to identify the failure mode. When the failure mode is properly identified, proper corrective action can be planned or taken to maintain or return the machine to reliable operation.

- Part II – Sleeve Bearing Diagnostics and Failure Analysis
  - What is today's definition?
    - Improve our understanding of sleeve bearings and their failure modes so that we can improve our monitoring techniques and failure analysis. Improvement in these areas will result in an improvement in the equipment's performance and reliability.

Sleeve Bearing Diagnostics and Failure Analysis

- Part II – Sleeve Bearing Diagnostics and Failure Analysis
  - What is today's definition?
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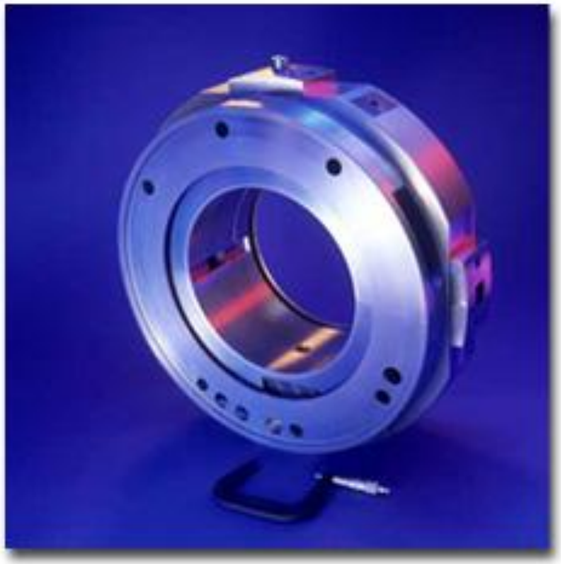


Part II - Sleeve Bearing Diagnostics and Failure Analysis

What is a journal bearing doing?

Take a look at this diagram.

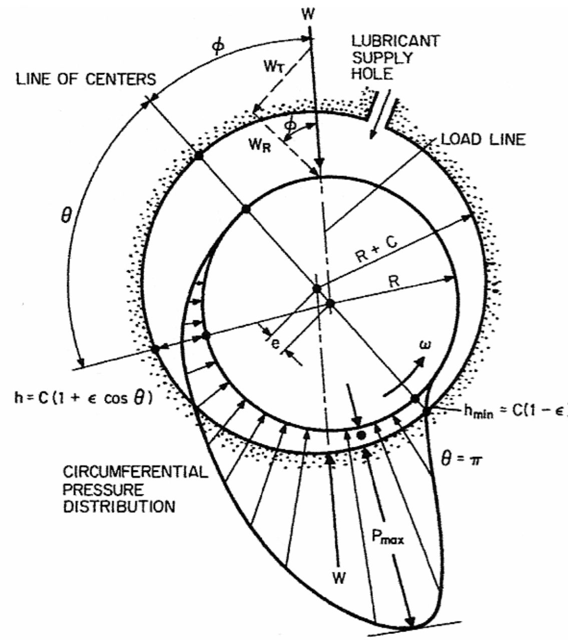


FIGURE 28.1 Journal and bearing notation.

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Variables that affect a bearing's design and operation:

- Fluid viscosity
  - Fluid viscosity – Is defined as shear stress/strain rate, internal friction, or, resistance to deformation when under a shearing stress.
  - Fluid viscosity is determined by
    - Dynamic viscosity
    - Temperature
  - Therefore, when there are any problems indicated we need to be sure of the following:
    - The proper fluid with the proper viscosity is being used.
    - The operating temperature of the fluid is within the design parameters that were expected by the OEM

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Variables that affect a bearing's design and operation:

- Shaft surface speed:
  - Shaft diameter
  - Which is determined/affected by:
    - Amount of horsepower transmitted by the shaft
    - Amount of static loading
    - Amount of dynamic loading

- Shaft Rotational Speed:
  - Will depend on the process and the efficiencies desired from the equipment

- Bearing clearance:
  - Shaft diameter
  - Viscosity of the fluid
  - Flow amount of the fluid
  - Expected heat rejection rate of the fluid

Part II – Sleeve Bearing Diagnostics and Failure Analysis

Variables that affect a bearing's design and operation:

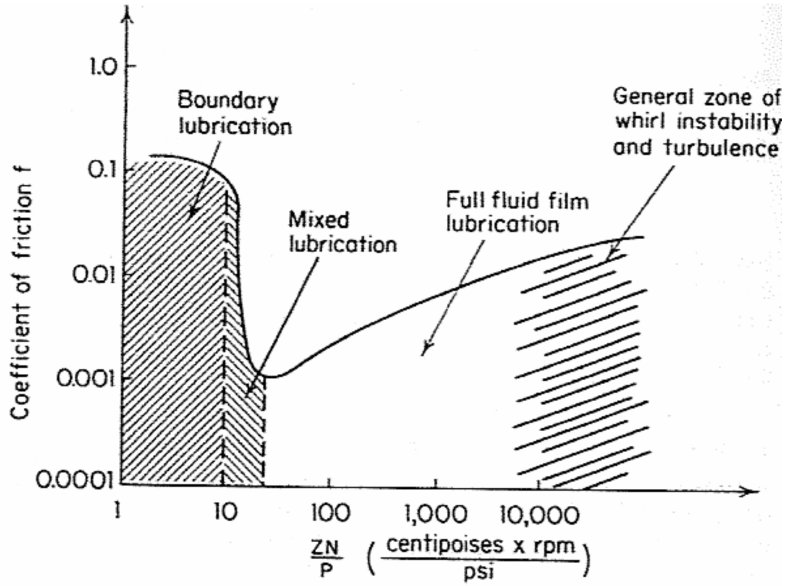


Fig. 8.4.5 Various zones of possible lubrication for a journal bearing.

Part II - Sleeve Bearing Diagnostics and Failure Analysis

What it comes down to is that all of the necessary parameters have to be chosen, so that a stable pressure distribution of the fluid film occurs, in the proper place, and that the oil film at the thinnest location is thick enough to ensure no contact between the rotating surface and the stationary surface.

Refurbishing a Babbitt bearing

What is Babbitt?

Table 6.4.28 Composition and Properties of Some Babbit Alloys (ASTM B23)

ASTM grade	Nominal composition, % Sn	Sb	Pb	Cu	Yield point,* ksi 68°F (20°C)	212°F (100°C)	Compressive strength,† ksi 68°F (20°C)	212°F (100°C)	Brinell hardness 68°F (20°C)	212°F (100°C)
1	91	4.5		4.5	4.4	2.7	12.9	7.0	17.0	8.0
2	89	7.5		3.5	6.1	3.0	14.9	8.7	24.5	12.0
3	84	8.0		8.0	6.6	3.2	17.6	9.9	27.0	14.5
7	10	15	75		3.6	1.6	15.7	6.2	22.5	10.5
8	5	15	80		3.4	1.8	15.7	6.2	20.0	9.5
				Other						
15	1.0	16	Bal.	1.4 As					21.0	13.0

ksi × 6.895 = MN/m^2.
*Based on 0.125 percent change in gage length.
†Compression test specimens were cylinder 1.5 in long and 0.5 in diam machined from chill castings. Compressive-strength values based on a deformation of 25 percent of specimen length.

Part II – Sleeve Bearing Diagnostics and FailureAnalysis

Refurbishing a Babbitt bearing; general process steps

- Cleaning of the shell.
- Setting up mandrels/molds for babbitting process.
- Prepping the shell for tinning.
- Performing the tinning process.
- Prepping the material for the pouring process.
- Controlling the pouring process.
- Controlling the cooling process.
- Rough machining.
- Checking the bond quality.
- Final Machining.

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Refurbishing a Babbitt bearing; general process steps

- Cleaning of the shell.
  - Several methods can be successful.
  - Have to remove old material
  - Have to remove contaminants from shell surface

- Prepping the shell for tinning.
  - May need a pre-tin material
  - Preheat of shell
  - Proper temperature of tin

- Setting up mandrels/molds for babbitting process.
  - Depending on process you may may need molds for obtaining proper babbitt thickness and shape

- Prepping the material for the pouring process.
  - New (virgin) material only
  - Proper temperature
  - Method for pouring
  - Preheat of shell

Part II – Sleeve Bearing Diagnostics and Failure Analysis

Refurbishing a Babbitt bearing; general process steps

- Performing the tinning process.
  - Maintaining proper temperatures
  - Ensuring quality bond
- Controlling the cooling process.
  - Minimize porosity
  - Minimize separation of materials
- Controlling the pouring process.
  - Rate of pour
  - Controlling temperature
- Rough machining.
  - Ensure no large porosity pockets
  - Prep for UT bond testing

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Refurbishing a Babbitt bearing; general process steps

- Checking the bond quality.
  - Can depend on the bonding method
    - Mechanical
    - Adhesive
  - UT Testing
  - PT Testing

- Final Machining.
  - Proper diameter for the shaft
  - Proper design shape and type
  - Location for any thermocouples for temperature monitoring

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Bearing Types

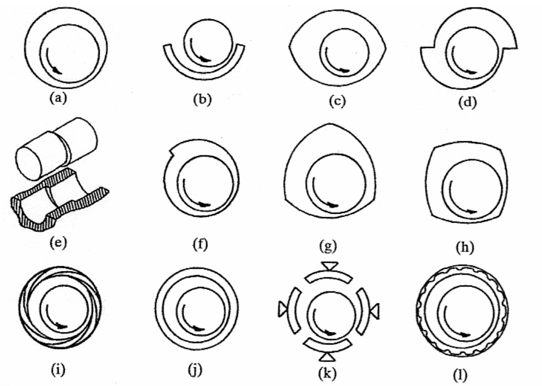
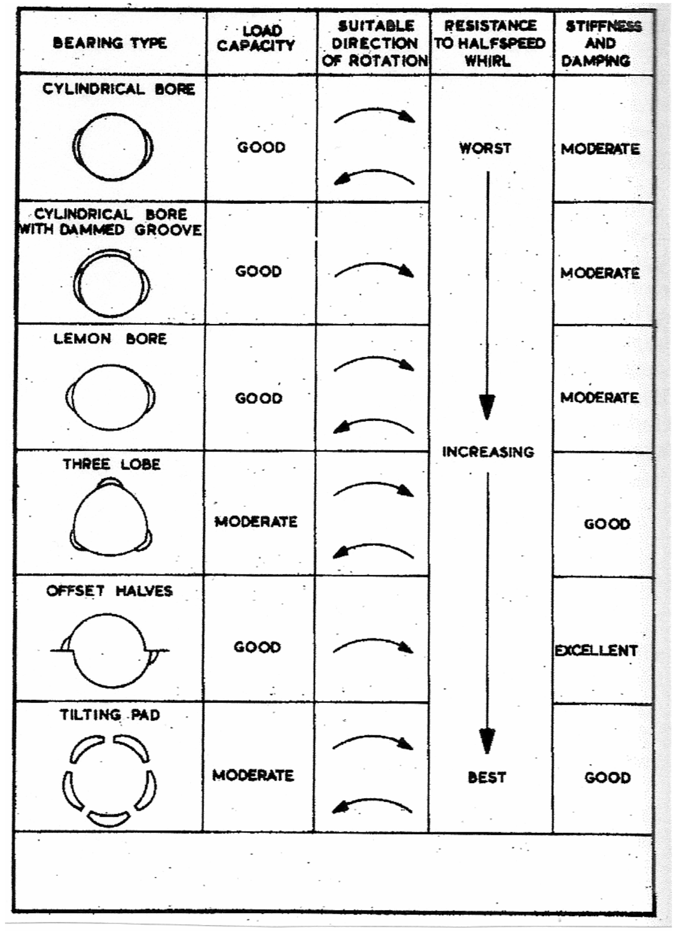


FIGURE 28.3 Journal bearing geometries. (*a*) Full bearing; (*b*) partial bearing; (*c*) elliptical, or lemon, bearing; (*d*) offset bearing; (*e*) rocking journal bearing; (*f*) pressure dam bearing; (*g*) three-lobe bearing; (*h*) four-lobe bearing; (*i*) multileaf bearing; (*j*) floating-ring bearing; (*k*) tilting- or pivoted-pad bearing; (*l*) foil bearing.

Standard Handbook of Machine Design – Shigley/Mischke



BEARING TYPE	LOAD CAPACITY	SUITABLE DIRECTION OF ROTATION	RESISTANCE TO HALFSPEED WHIRL	STIFFNESS AND DAMPING
CYLINDRICAL BORE	GOOD		WORST	MODERATE
CYLINDRICAL BORE WITH DAMMED GROOVE	GOOD			MODERATE
LEMON BORE	GOOD			MODERATE
THREE LOBE	MODERATE		INCREASING	GOOD
OFFSET HALVES	GOOD			EXCELLENT
TILTING PAD	MODERATE		BEST	GOOD

Centrifugal Compressors – Dr. Boyce

Bearing Types

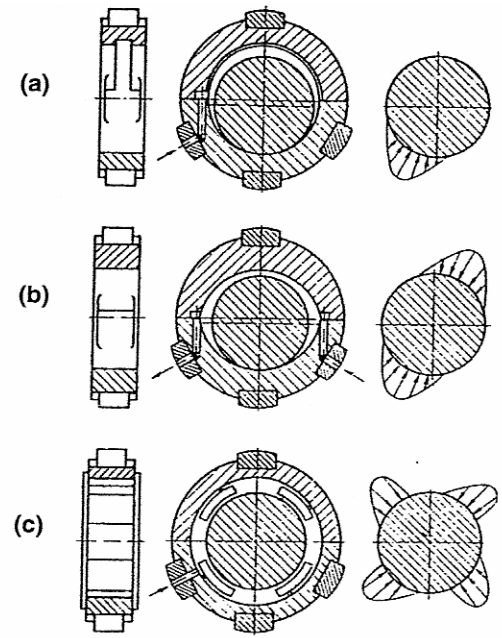


Figure 6.118 Main types of journal bearing shells: single-wedge *(a)*, double-wedge *(b)*, and multi-wedge *(c)*. (From A. D. Trukhny [T33].)

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Failure Modes

- Excessive Bearing to Shaft Clearance
  - Loss of lubrication
  - Lubrication Contamination
  - Increased operational load
    - Static load increase
    - Dynamic load increase
  - Improper assembly or manufacture
    - Bearing improperly sized
    - Shaft improperly measured
    - Bearing not aligned to shaft
    - Improper preload on bearing shell
    - Babbitt not poured properly
- Excessive Bearing Shell to Housing Clearance
  - Improper assembly
    - Measurements not checked
    - Improper preload on bearing shell
    - Bolting has loosened

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Failure Modes - Babbitt Damage

- Loss of lubrication
- Abrasion or damage from foreign matter or dirt in the lube oil system
- Moisture contamination of the lube oil system
- Fatigue cracking
- Corrosion
- Cavitation erosion
- Electrical discharge
- Faulty assembly
- Pivot fatigue and wear
- Loss of babbitt to shell bond
- Overheating
- Misalignment
- Tin migration
- Scab formation
- Spherical seat fretting

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Failure Modes

- The failure modes on the previous page typically mean one of a couple of items is occurring:

Loss of babbitt material or Loss of babbitt bond to shell

The page before that even stated that we could have a mechanical looseness issue develop as a problem.

What possible effects do the failure modes cause?

- Loss of babbitt material from the bearing
- Possible scoring of the shaft and loss of shaft material
- Increased bearing temperature
- Change in shaft position
- Increased mechanical looseness between the shaft and bearing or bearing and housing

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Failure Modes

What different tools do we have available to monitor for those failure modes?

- Vibration analysis
- Bearing Temperature/Housing temperature
- Bearing Oil Drain Temperature
- Oil analysis
- If it is a water-cooled bearing, we could also use water discharge temperature

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Monitoring for Failure Modes

Early stages of babbitt damage may only be identified by spectrographic oil analysis

- Fatigue cracking
- Corrosion
- Cavitation erosion
- Electrical discharge
- Scab formation

For the oil analysis to be successful, several items have to be correct:

- Sampling procedure
- Sampling location
- And knowledge of the bearing and shaft materials

By the time bearing wear materials have caused enough damage to be seen in vibration data, the damage will probably be extremely severe

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Monitoring for Failure Modes

Later stages of bearing wear could result in increased shaft to bearing clearance, this may be seen with:

- Vibration data may show the following:
  - Increased 1X
  - Increase in oil whirl ~ 1/2X frequencies
- If permanent proximity probes are installed, shaft position change will be shown by:
  - Change in gap voltage when machine is at rest
  - Change in gap voltage when machine is at steady stable load
- If permanent temperature probes are installed:
  - Increase in babbitt temperature if probe is in the load zone

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Monitoring for Failure Modes

- The following issues are problems driven from the lubrication system
  - Abrasion or damage from foreign matter or dirt in the lube oil system
  - Moisture contamination of the lube oil system
  - Corrosion
- For the items on the previous slide and these, the oil analysis program needs to monitor the following items:
  - High or changing particulate levels
  - High or changing moisture levels
  - High acid levels
  - A drop in the results of an oxidation stability test
- Scab formation will probably show both bearing wear metals and shaft wear metals in the oil analysis.

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Monitoring for Failure Modes

For the remaining failure modes:

- Bearing shell to housing looseness
- Faulty assembly
- Pivot fatigue and wear – Tilt pad bearings
- Loss of babbitt to shell bond
- Overheating
- Misalignment – Bearing to shaft
- Tin migration
- Spherical seat fretting

Multiple tools may be used and necessary to determine the mode that is occurring.

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Monitoring for Failure Modes

Looseness of the shell to the housing will typically show up as multiples of running speed.

- Verify whether the looseness is inside or outside the bearing housing.
- The looseness may gradually increase in amplitude
- The looseness may also result in babbitt wear metals showing up in the oil analysis.

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Monitoring for Failure Modes

- Faulty assembly
- Pivot fatigue and wear
- Spherical seat fretting
- Misalignment – bearing to shaft

Can all end up with showing:

- Mechanical looseness and
- Excessive temperatures

If conditions are bad enough, they can also end up with showing babbitt wear metals in the oil analysis.

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Monitoring for Failure Modes

Pivot Wear

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Monitoring for Failure Modes

Loss of babbitt to shell bond can cause the following:

- Air pockets between the babbitt and the shell. These pockets may cause localized hot spots and weakening of the babbitt material in those locations.
- Vibration of the babbitt material in the unsupported areas could cause earlier fatigue or cracking failures earlier than anticipated.

Significant changes in bearing temperature (especially ones with probes embedded in the bearing babbitt) may indicate a very serious concern. Before stating that there is an issue, sure that you understand the typical variations that occur during normal operational conditions and load changes.

Note: Tin migration will eventually result in a loss of the Babbitt bond

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Monitoring for Failure Modes

Overheating – Can be caused by several things, all of which should show up in temperature monitoring before damage is caused

- Increased load
  - Static
  - Dynamic
- Increased lube oil inlet temperature
  - Cooler fouling
  - Increased ambient temperatures
- Loss of bond between babbitt and housing decreases cooling of babbitt
- Loss of cooling water flow
- Increase of cooling water temperature

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Monitoring Summary:

- Oil analysis for:
  - Contamination
  - Shaft scoring
  - Babbitt material loss
- Vibration monitoring for:
  - Excessive bearing to shaft clearance
  - Support structure looseness
- Temperature monitoring:
  - Bearing babbitt temperature
  - Bearing housing or shell temperature
  - Lube oil drain temperature
  - Cooling water temperature

Part II - Sleeve Bearing Diagnostics and Failure Analysis

Before closing,

We have focused on journal bearings, but nearly all of this applies also to babbitted tilt pad and tapered land thrust bearings.

THERMOMETRICS

PRECISION TEMPERATURE SENSORS