Types of Boiler Feedwater Pumps

- **Diffuser Casing Segmental Ring**
- **Volute Casing Horizontal Split**
- **Diffuser Casing High Speed Barrel Casing**
Volute vs. Diffuser Casings

Radial loads increase as the liquid flows through the volute and exits through the casing discharge. The result is an unbalanced radial load on the rotating element.
Volute vs. Diffuser Casings

A dual volute casing will have an additional passage way 180° from the main volute which will almost balances the generated radial forces.
Volute vs. Diffuser Casings

A diffuser style casing has multiple discharge passage ways with equal area distributed throughout the circumference resulting in radially balanced rotating element.

Diffuser Casing

\[ F_R = 0 \]
HPT Boiler Feed Pumps
Range Chart

HPT PEP

HPT PRO

H in m

Q in m³/h

Frame 1
Frame 2
Frame 3
Special design features which eliminate the need for pre-warming on most applications

Forged, low alloy steel barrel casing designed for long term cycling operation

Axial thrust compensation by balancing piston to avoid damage during transient conditions

Hydraulic tensioned case cover studs and nuts

Individually bolted stage casings

Swirl breaks at balancing piston to maintain rotor stability when internal clearances are worn

Fully rated double acting tilting pad thrust bearing

Full cartridge pull out for rapid changeover

Sliding pads to maintain alignment during thermal movements
HPT Boiler Feed Pumps
Installation (Removal of Cartridge)

**Advantage**
Quick and safe cartridge change

**Step 1**
Suspended and supported on rollers at DE

**Step 2**
Supported for re-rigging

**Step 3**
Final installation
HPT Boiler Feed Pumps
Alternative Arrangements

Double Suction Impeller
Intermediate Take Off
Kicker Stage
**Advantages:**
- Shrunken on parts allow for high rotor balancing quality
- Shrunken on parts avoid fretting corrosion and minimize stress concentrations
- Shrunken on parts avoid loose parts on shaft during operation and result in lower vibration
HPT Boiler Feed Pumps
Impeller and Diffuser Design

**Precision castings**
- high efficiency
- small hydraulic unbalance

**Thick shrouds**
- high strength for high head
- natural frequency away from resonance thus avoiding shroud breakage

**Continuous channel diffuser**
- high efficiency

**Advantages:**

- Precision castings
  - high efficiency
  - small hydraulic unbalance

- Thick shrouds
  - high strength for high head
  - natural frequency away from resonance thus avoiding shroud breakage

- Continuous channel diffuser
  - high efficiency
Sulzer Pumps

Pure Graphite Seal Rings
- up to 1000 bar
- up to 300 °C

Advantages:
- low gasket seating load required
- fully confined gasket
- metal to metal face
HPT Boiler Feed Pumps
Pressure Retaining Parts

**Analyzed with proven codes:**
- German vessel code AD, standard
- ASME section VIII, Division 1, option
- FE for selected cases

**Advantages:**
- proven codes provide high reliability
- hydro test (1.5 x or 1.3 x $p_D$) of each pressure casing provides high safety
HPT Boiler Feed Pumps
Tightening of Delivery Cover Studs

Air operated hydraulic oil pump

Advantages:
• accurate tensioning to required pre-load
• fast cartridge change

Hydraulic jacks
HPT Boiler Feed Pumps
Case Bolt Tensioning Tool

Stage 1: Set Up Tensioning Tool
Stage 2: Tighten Stud Bolt
Stage 3: Turn Nut
Stage 4: Release Tensioning Tool
Shaft seal with single mechanical seal

**Advantages:**

- High pump efficiency
- Air barrier and thermo sleeve insulates hot and cool area thus reduces thermal stratification. Avoids shaft bending due to thermal stratification
- Cooling jacket keeps elastomer seals cool during stand still
HPT Boiler Feed Pumps

Mechanical Sealing with Integral Cooler

- **Air- filled gaps**: Avoids the heat transfer coming from hydraulic pump parts to the sealing area.
- **Cooling water**: Decreases the temperature in the seal chamber.
- **Hot seal water**: Circulation produced by rotating part of the seal drives.
HPT Boiler Feed Pumps
Fixed Throttle Bushing

Advantages:
• simple design
• reliable
• temperature or differential temperature control avoids influx of cold water during stand still, hence avoiding thermally induced rotor bending

Disadvantages:
• lower efficiency (~2%)
• large leakage (50 gpm)
• risk of cold water entering pump (with pressure control)
• depends on CE availability
• auxiliary injection pump required during shutdown of CE pump

Cold condensate injection

Bleed-off for high suction pressures, without bleed-off for low suction pressures

Drain
Unbalanced pressure distribution on impellers results in a force termed thrust in the direction of suction.

Opposed impeller design offsets the unbalanced pressure distribution (thrust) effectively completely balancing axial thrust. Since axial thrust is not completely balanced or when there are odd number of stages residual thrust is handled by a thrust bearing.
Unbalanced pressure distribution on impellers results in a force termed thrust in the direction of suction.

Stacked impeller design results in adding of (thrust) in the direction of suction.

Developed thrust must be compensated by a hydraulic balancing device. Residual thrust is handled by a thrust bearing.
Balances 85 - 90% of generated thrust. Residual thrust handled by a thrust bearing.

Most reliable design for transient conditions (start up and run down, quick temperature changes, daily starts and stops).

Easy and safe axial rotor setting because of the radial gap as compared to axial sealing.

Rotor is fixed in the axially position.

Higher amount of leakage - less efficient.
Axial Thrust Compensation – Balance Disk

- Balances 100% of the generated thrust.
- No thrust bearing required.
- Rotor floats axially for proper operation.
- Least amount of leakage - higher efficiency.
- Disk lift off device required for frequent starts and stops.
According to EPRI Statistics 1):

- Out of 533 pumps balanced by disks, there were 310 failures (58%).
- Out of 511 pumps balanced by pistons, there were 27 failures. (5%)
- Balance disks are not suitable for DSS-operation. (daily start & stop)

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1) E. Makay, O. Szamody  
Survey of Feed Pump Outages (EPRI FP-754)  
Electric Research Institute, Palo Alto, California,  
April 1978
Product Description
Thrust Compensation Design

- Total thrust on impellers without balancing drum
- Area of unbalanced thrusts, which depends on differential wearing of impeller wear rings/drum, coupling reactions, impeller/diffuser positions
- Resulting unbalanced thrusts
- Driven End
- Flow
- BEP
- One side thrust bearing capacity
- Opposite side thrust bearing capacity

Total thrust by balancing drum without impellers

+100%
~ +20%
~ -20%
-100%
HPT Boiler Feed Pumps
Journal and Thrust Bearing Arrangement

Advantages:

Thrust bearing
- low power loss
- high safety against overload

Journal bearing
- high damping
- good rotor stability

Oil seal
- provides positive oil seal to atmosphere

Split bearing housing
- allows bearing inspection without pump disassembly

Non contacting oil seal (INPRO)

Double acting high capacity tilting pad thrust bearing, direct lubricated

Split bearing housing

Four lobe fixed arc journal bearing
Thrust Bearing Lubrication

A “wedge” of oil builds up between each stationary thrust pad and the rotating collar, and no metal-to-metal contact takes place during normal operation.

The white metal lining of the pads are designed to be tolerant of any minute particles of grit that may get through.
Journal and Thrust Bearing Arrangement

Double Acting Tilting Pad Thrust Bearing
Forced Oil Lube Systems
During normal operation, “wedges” of oil build up between the shaft and the bearing surfaces, providing rotor dynamic stability, known as a hydrodynamic effect.
Journal and Thrust Bearing Arrangement

Sleeve Bearings
HPT Boiler Feed Pumps
Design of Close Running Clearances

Design of close running clearances

Advantages

Optimized labyrinth
- high efficiency
- good rotor dynamic behavior

Radial grooves
- increased radial stiffness
- reduced effect on rotor tilting
- good rotor dynamic behavior

Swirl brakes
- high rotor stability even with worn clearances
Swirl Break Advantages:

- High rotor stability even with worn clearances
- Prevents pre-rotation of fluid
NPSH Considerations - Cavitation

The NPSHₐ must exceed the pump’s NPSHₐ or the liquid will vaporize within the pump impeller. This vaporization of the liquid is called **cavitation**.

**Cavitation** can occur in many areas of the pump. The most common and significant is within the impeller.

In an area on the vane commencing a short distance from the vane tip, the static pressure can fall sharply, before rising again further along the vane.

If the local static pressure falls below the vapor pressure of the liquid being pumped, bubbles (cavities) form and travel along the vane. As soon as they reach an area of higher pressure, the bubbles collapse suddenly. **This is cavitation.**
**NPSH available** is a function of the system in which the pump operates. It is the excess pressure of the liquid over its vapor pressure as it arrives at the pump suction.

\[ \text{NPSH}_A = p + L_H - (V_p + h_f) \]

Where:

- \( p \) = pressure in suction vessel
- \( L_H \) = static height of liquid in suction vessel to centerline pump
- \( V_p \) = vapor pressure of liquid at pump suction
- \( h_f \) = frictional losses of liquid in suction piping
NPSH Required

NPSH Required is physical design property of each pump. It is dependent on the design of the suction casing, impeller, capacities and speeds. In Boiler Feedwater applications the greater the margin between NPSH available to required the better the pump can handle suction transients occurrences.

NPSH Required can be identified in various ways:

- Incipient cavitation
- Head decrease by a certain percentage (0%, 1%, 3%...)
- Efficiency loss by a certain amount
- Erosion of a specific material quantity in a unit of time
- Exceeding of a certain noise level
- Maintenance of a certain vibration level
- Collapse of the flow, i.e. total cavitation
NPSH Required

NPSH required is measured on the test stand by reducing the suction pressure and measuring discharge pressure.

Incipient values represent the very onslaught of bubble formation with no reduction in head.

NPSH 0% values represent the beginning of bubble formation but with no reduction in head.

NPSH 1% values represent a larger and more bubbles with a reduction of discharge head of 1%.

NPSH 3% values represent increasing bubble size and amount with a reduction of discharge head of 3%.

NPSH tot represents a pump in full cavitation with a significant reduction in discharge head, heavy vibration and noise.

The point to note is that you do not want to operate a pump at or near the reported NPSH required value since this already represents a pump which is cavitating.
Approximate Safety Margins for the Determination of NPSH Available (t = 170°C – 190°C)

\[ \text{NPSH av} > S_A \times \text{NPSH} \text{ 3\%} \]

- \( S_A = \frac{\pi(D_1)n}{60} \)
  - \( D_1 = \text{Imp Eye Dia.} \)

Valid for High Cavitation Resistance Impeller Material (e.g. 13/4 Chrome Steel)

- \( U_1 > 65 \text{ m/s} \)
- \( \text{bubble length} < 4\text{mm} \)

- \( N_5 = 1340 \)
  - \( 42 \text{ m/s} \) at \( 240 \text{ m} \)
  - \( 52 \text{ m/s} \) at \( 370 \text{ m} \)
  - \( 60 \text{ m/s} \) at \( 490 \text{ m} \)
  - \( 67 \text{ m/s} \) at \( 610 \text{ m} \)
  - \( 73 \text{ m/s} \) at \( 730 \text{ m} \)

- \( U_1 \) Head/Stg
HPT Boiler Feed Pumps
NPSH Considerations

If the load reduction > NPSH margin and occurs in a time frame which is shorter than the time required for the liquid to travel to the pump suction flashing in the piping will occur. The greater the NPSH margin the better able the system is in handling suction transients.

Common Transient Condition

- Full Load Operation
- Load Reduction
- Part Load Operation
- Pressure/Temperature decay
- \(\Delta \text{NPSH}_{\text{available}}\)

\(\text{DT} = \text{Time needed by the water to flow from deaerator to pump suction}\)

- Static Pressure at Pump Suction
- Vapor Pressure at Pump Suction
- Load Change
- Vapor Formation at Pump Suction
HPT Boiler Feed Pumps
NPSH Considerations

Because of the high operating speeds the required NPSH is high and requires either a double suction first stage as a minimum or a separate booster pump.

A separate booster pump provides the ability to provide a high margin between available and required NPSH which helps during certain suction transient conditions.
## Typical Materials

<table>
<thead>
<tr>
<th>Part</th>
<th>Material</th>
<th>Advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrel casing</td>
<td>10 Cr Mo 9 10, forged (A182 Gr F22)</td>
<td>▪ high erosion resistance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ good thermal transient properties</td>
</tr>
<tr>
<td>Delivery cover</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impeller</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diffuser</td>
<td>G - X 5 Cr Ni 13 4 (A743, Gr .CA-6MN)</td>
<td>▪ high erosion resistance</td>
</tr>
<tr>
<td>Stage casing</td>
<td></td>
<td>▪ good cavitation resistance</td>
</tr>
<tr>
<td>Suction casing</td>
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<tr>
<td>Shaft</td>
<td>X 4 Cr Ni 13 4 (A182 Gr F6MN)</td>
<td>▪ high strength</td>
</tr>
<tr>
<td>Balance drum</td>
<td>X 20 Cr Ni 17 2 (A276 Type 431)</td>
<td>▪ at least 50 HB hardness difference</td>
</tr>
<tr>
<td>Stationary wear parts</td>
<td>X 20 Cr Ni 17 2 (A276 Type 431)</td>
<td>▪ high erosion resistance</td>
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<tr>
<td>Stud</td>
<td>34 Cr Ni Mo 6 (A322 Gr 4340)</td>
<td>▪ high strength</td>
</tr>
<tr>
<td>Static seals</td>
<td>Pure graphite</td>
<td>▪ good pressure / thermal resilience</td>
</tr>
</tbody>
</table>

HPT Boiler Feed Pumps

[Image: Sulzer Pumps logo]
HPT Boiler Feed Pumps
Recommended Instrumentation

- Shaft vibration
- Bearing temperature
- Balance water flow
- Shaft vibration
- Bearing temperature
- Axial rotor position, possible
- Guide Keys
- Bearing housing vibration, possible
- Bearing housing vibration, possible
HPT Boiler Feed Pumps
Recommended Instrumentation

Drop in efficiency
Function of increased labyrinth gaps for different specific speed

- **New**
- **Worn**
- **Worn max**

**Drop in Efficiency**
**Delta eta %**

- nq 33
- nq 26
- nq 22

**Leakage %**

**Operating limit**

- Normal operating range
- Danger
- Forbidden range

**Labyrinth gap**

- Operating limit
- Recommended overhaul

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Most Sulzer Diffuser Style Barrel Pumps do not require warm-up. On the very largest sizes, the warm-up flow back into the discharge surrounds the inner case, making warm-up faster and more uniform.

On some of those very largest sizes, additional warm-up flow is injected into the bottom of the suction chamber and barrel drain, as well as the discharge.
Typical Thermal Deformations

Section through a barrel type feed pump with thermally driven flows after shut-down.

Thermal deformations of shaft and casing after shut-down (shaft is shown turned by half a revolution).
Asymmetrical Casing Insulation

Sulzer standard casing design provides insulation on the bottom half to retain heat. The top half casing has perforated metal cover but no insulation to let heat escape. The result is a more uniform temperature throughout the top and bottom of the casing which minimizes the thermal deformations.
HPT Boiler Feed Pumps

Speed Control

This type of pump is designed to operate at speeds above standard 2 pole motor speeds, typically 6000 rpm.

Typical speed control devices are:

- Geared Fluid Coupling
- Fixed Speed Coupling
- Variable Frequency Drives (VFD)
- Steam Turbine
HPT Boiler Feed Pumps
Typical Layout

- TP1
- TP2
- TP3
- TP4
- Booster Pump
- Electric Motor
- Lub System Coolers
- Pressure Stage Pump
- Speed Increasing Gearbox
- Lub Oil System

Dimensions:
- G
- T
- K
- M
- R
- D
- E
- F
- C
- A

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Sulzer Leeds, UK Test Facility

- 10 MW Electric Motor at Full Speed
- Electric Capacity to 16 MW
- Speed Increasing Gearbox with Multiple Ratios
- 30 MW Gas Turbine Drive
- 365,000 Gallon Wet Sump, 30 Feet Deep
- 50 Ton Crane Capacity
- NPSH Testing
- Hot or Cold Testing
# Typical HPT Maintenance Inspection Frequency

<table>
<thead>
<tr>
<th>Operating Time</th>
<th>MEASUREMENTS Without Disassembling</th>
<th>MEASUREMENTS With Disassembling</th>
<th>REPLACEMENTS</th>
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<tbody>
<tr>
<td>2500</td>
<td>1</td>
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