Selecting Steam Turbines for Pump Drives

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A Steam Turbine is an energy conversion device. It extracts heat energy from steam and converts it to velocity, or kinetic energy. The velocity energy, in turn, is used to produce rotary motion or useable shaft power.
What is a Steam Turbine?
Steam Cycle Terms

Non-Condensing:

"Non-condensing" cycle is used when the turbine exhaust pressure is above atmospheric (14.7 psia). The exhaust steam energy is usually utilized in the plant process (resulting in a high "Steam-Cycle" efficiency).
"Condensing" cycle is used when the turbine exhausts to a pressure lower than atmospheric (usually to a steam condenser). The steam is cooled in the condenser (by water or air cooling) and the resulting condensate is pumped back to the boiler. Condensing "Steam Cycle" efficiencies are usually very low since most of the exhaust steam energy is lost to the cooling medium and not recovered.
Steam Cycle Terms

Steam Rates:

_Theoretical Steam Rate_ (TSR) is based on "isentropic" turbine performance [no losses] or 100% efficiency.

_Actual Steam Rate_ (ASR) reflects turbine efficiency and is expressed in the same terms as the TSR. Lower ASR’s are indicative of higher turbine efficiencies.

Larger wheel sizes are often more efficient. Smaller wheels have lower windage losses and can be more efficient at low horsepowers than large wheels.

Typical single-stage turbine efficiencies range between 30 - 50%. Standard multistage turbine efficiencies range between 60 - 70%. Engineered multistage turbine efficiencies range between 70 - 80%.
Steam Turbines

Mollier Diagram

Saturation Line

Standard Atmosphere
Steam Cycle

- $P_1$: Inlet Pressure
- $T_1$: Inlet Temp
- $H_1$: Inlet Enthalpy
- $P_2$: Exhaust Pressure
- $H_2$: Actual Exhaust Enthalpy
- $H'_2$: Theoretical Exhaust Enthalpy
Steam Turbines For Pump Drives

Outline

• Why Steam Turbines?
• Steam Turbine construction
• Specifications
• Steam Turbine selection
• Prime movers are required as a drive for pumps, fans, blowers, generators, compressors, etc.

• Steam turbine drivers are prime movers that convert the thermal energy of steam into mechanical energy through the rotation of a shaft.
Steam Turbines Applications

- Pumps
- Generator Drives
- Compressors
- Fans
- Blowers
- Paper Mills
- Sugar Mills
- Palm Oil Mills
Steam Turbines

Advantages of Steam Turbine Drives

- High horsepower in a small package.
- Variable/optimal speed capability.
- Usually directly connected to driven equipment.
- Non Sparking - explosion proof.
- High starting torque capability.
- Will not stall or trip on overload.
- Can operate independently of plant electrical system.
- Quick start capability.
Why Steam Turbines?
## Why Steam Turbines?

### Variable Speeds

<table>
<thead>
<tr>
<th></th>
<th>Design speed</th>
<th>Maximum Continuous speed</th>
<th>Minimum speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple governors</td>
<td>100%</td>
<td>105%</td>
<td>85%</td>
</tr>
<tr>
<td>Advanced governors</td>
<td>100%</td>
<td>105%</td>
<td>65% or more</td>
</tr>
</tbody>
</table>
Why Steam Turbines?

Speed Capability

Typical pump speeds:
1500, 1800, 3000, 3600 RPM
Maximum speeds -To 12000 RPM
(and more)
Why Steam Turbines?
Quick Starting
Why Steam Turbines?

Availability of Steam

Exothermic processes
Why Steam Turbines?

Availability of Steam

Waste product for fuel
Why Steam Turbines?

Critical duties - power not required to operate a steam turbine

Generate power when power is not available
Why Steam Turbines?

Flexibility

Variety of duties, common design
Upgradeability
Steam Turbine Construction
Steam Turbine Construction

Follow the Steam
Steam Turbine Construction

Inlet
Trip Valve Types

Venturi Trip - single seated and piloted. Normally actuated through springs and linkages but also can be used in conjunction with bellows assemblies for low/air pressure trip functions. No throttling capability.

Built-in T &T Valve - The trip and governor valve are housed in the same inlet casing.

Separate T &T Valve - just as the name implies, it is separate from the turbine. Oil operated or latch type.
Steam Turbine Design - Components

Single Governor Valve & Venturi Trip
Steam Turbine Design - Components

Trip & Throttle Valve

Trip Valve

Governor Valve
Steam Turbine Design - Components

Rotor

Curtis 2 row wheel is standard but 1 Rateau wheel is available for high speed applications.

Single profiled disc with 2 rows of blades shrunk and keyed on to shaft is standard. Solid rotor construction is available for certain applications and API 612 machines.
Blades / Buckets

Turbine blades (buckets) are normally 403 stainless steel.

Lower stressed blades are made from stock drawn to foil shape. (Drawn Blades)
Blades / Buckets

Drawn Blades:

- Machined from extruded airfoil shaped stock.
- Cut to length, tenon and root machined.
- Packer piece (spacer) between each blade.
- Wedge/block locking piece at rim insertion point.
Blades / Buckets

Milled Blades:

As horsepower and speeds increase, stronger blades are needed. Also better shapes for efficiency.

Milled blades are machined from a rectangular piece of bar stock and are more expensive to produce because of the machining steps involved.

Milled blades do not require a packer piece between each blade.

Wedge/block locking piece at rim insertion point.
Steam Turbine Construction
Steam End
Steam Turbine Construction
Exhaust end
Steam Turbine Construction

Casing Support
Steam Turbine Construction

Rotor
Steam Turbine Construction

Rotor
Bearing Housings

SST bearing housings are cast separate from the casing and are bolted on to the casing during assembly. They are cast with integral cooling water passages for lube oil cooling and are horizontally split to allow bearing removal with the rotor and casing in place. The following NON-STANDARD options are available:

- Steel material
- INPRO seals
- Air purge connections
- Oil mist connections
Steam Turbine Construction

Bearings

Journal bearings
  Sleeve, ball

Thrust bearing
  Rotor locating ball
  Tilting pad
Turbine Bearings

The Journal Bearings support the turbine rotor.

Two types

Sleeve type bearings
Tilt-pad type bearings

Note: Ball radial bearings have been supplied on some turbines for ExxonMobil.
Turbine Bearings

The Thrust Bearing locates the turbine rotor in relation to the nozzle ring.

Two types

Ball type thrust bearings
- 3311XR (Simple Bearing Case)(MRC)
- 9310 - U (Hi-Cap Bearing Case) (MRC)

Tilt-pad type bearings - Glacier
Steam Turbine Construction
Ring-Oiled Bearings
Steam Turbine Construction

When Pressure Lubrication?

• Higher speeds
• Tilt-pad thrust bearing
• High exhaust temperatures
• Needed for other items
  – Trip and Throttle valve
  – Gear
Steam Turbine Design - Components

Lubrication

Options:

“SP” circulating oil system (non-pressurized)
- Saddle pump with oil tank, level indicator, carbon steel interconnecting tubing and sight flow indicator. Cooler and filter available as options.

F.F. lube feed and drain manifolds

Complete F.F. lube system
Lubrication

All standard ball thrust bearing applications are ring oiled unless:

- Turbine speed is over 5000 RPM
- Limits on allowable Exhaust temperature are exceeded.

All 9310-U (oversize ball thrust) and tilt-pad thrust bearing applications require a force feed lube oil system.
Steam Turbine Construction

Shaft Seals

Carbon rings
most common
Steam Turbine Construction

Seal Leakage

Carbon Rings
Turbine Seals

Seals prevent steam from leaking out of the casing along the turbine shaft, and potentially contaminating the bearing oil.

Three types
Carbon Ring
Labyrinth
Mechanical
Steam Turbine Construction

Seal Alternatives

Gas Face Seal
– Don’t let the steam out

Water accumulation
Growth
Cost
Steam Turbine Construction
Bearing Isolators

Keep the oil in and the steam out
## Steam Turbine Construction
### Controls – Speed definitions

<table>
<thead>
<tr>
<th>Class of Governing System</th>
<th>Maximum Speed Regulation %</th>
<th>Maximum Speed Variation %</th>
<th>Maximum Speed Rise %</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10</td>
<td>0.75</td>
<td>13</td>
</tr>
<tr>
<td>B</td>
<td>6</td>
<td>0.50</td>
<td>7</td>
</tr>
<tr>
<td>C</td>
<td>4</td>
<td>0.25</td>
<td>7</td>
</tr>
<tr>
<td>D</td>
<td>0.50</td>
<td>0.25</td>
<td>7</td>
</tr>
</tbody>
</table>
Governors

The standard governor is the Woodward TG-13.

The following mechanical-hydraulic governors are available:

- TG-13L
- PG-D
- PG-PL
- UG-10
- UG-40
Steam Turbine Construction
Controls – Mechanical-Hydraulic
Governors

The following electronic governors are available:

- Woodward Peak 150
- Woodward 505
- Tri-Sen TS-110
- Tri-Sen TS-310
- Dynalco

Actuators - Fisher, Valtek and Woodward

- Pneumatic and hydraulic
Woodward ProTech 203

Triconex TurboSentry
Control components considerations -
  Reliable
  Versatile
  Remote signal
  Redundant trip
Steam Turbine Selection

When to use a Multistage Turbine

Larger exhausts needed than available on single stage turbines (typically condensing)

Steam rate improvement

Power too high for single stage turbine
## Steam Turbine Selection: Multistage Comparison

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<th>Annual cost of steam (millions)</th>
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<tr>
<td>Min/Max design without Hand Valves</td>
<td>58.7</td>
<td>$1.81</td>
</tr>
<tr>
<td>Multistage</td>
<td>40</td>
<td>$1.23</td>
</tr>
</tbody>
</table>
Steam Turbine Specifications
Steam Turbine Specifications

• NEMA SM23
  - Controls
  - Velocity limits
  - Piping loads
  - Excursions
  - Purity
• API 611 General Purpose
• API 612 Special Purpose
**Mechanical Differences**

API 611
- Cast iron bearing housing
- Sleeve journal bearings
- Ball or tilt-pad thrust bearing
- Carbon ring steam seals
- Keyed shaft
- Nema A or D governor

API 612
- Steel bearing housing
- Sleeve or tilt-pad journal bearings
- Tilt-pad thrust bearing
- Labyrinth end seals
- Nema D governor
- Oil operated T&T valve
- 2 out of 3 voting electronic trip
- No mechanical trip
- Casing field rotor balance provision
- Rotor shafts must be degaussed
API 611
- 1-hour uninterrupted mechanical test
- Measure Oil Temperature (IN)
- Measure Oil Pressure (IN)
- Measure Steam Pressure
  - Inlet and Exhaust
- Measure Steam Temperature
  - Inlet and Exhaust
- Standard Rotor Balance

API 612
- 4-hour uninterrupted mechanical test
- Rotor Dynamics Testing
  - Amplitude vs. Frequency
  - Amplitude vs. Speed
  - Phase Angle vs. Speed
  - Prove Lateral Critical (N/A for stiff shaft rotors)
- Measure Oil Temperature (IN / OUT)
- Measure Oil Pressure (IN / OUT)
- Measure Oil Flow
- Measure Steam Pressure
  - Inlet and Exhaust
- Measure Steam Temperature
  - Inlet and Exhaust
- Check rotor unbalance response (if coupling is furnished by Elliott)
- Incremental Rotor Balance
Standard Documentation

API 611
- Willans Line (Performance Curve)
- API-611 Data Sheets

API 612
- Willans Line (Performance Curve)
- API-612 Data Sheets
- Rotor Response Analysis (Lateral)
- Campbell / Goodman Diagrams
Steam Turbine Selection
Steam Turbine Selection

Data Required

• Musts
  – Inlet pressure
  – Inlet temperature
  – Exhaust pressure
  – Power required (sometimes flow available)
  – Speed of driven equipment
Steam Turbine Selection
Data Required - Additional

- Driven equipment
- Control required (NEMA)
- Operational considerations
- Steam consumption information
#_api611_data_sheet

## General-Purpose Steam Turbine

**Data Sheet**  
**U.S. Customary Units**

<table>
<thead>
<tr>
<th>Job No.</th>
<th>Item No.</th>
<th>Purchase Order No.</th>
<th>Specification No.</th>
<th>Revision No.</th>
<th>Date</th>
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<tbody>
<tr>
<td></td>
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</tbody>
</table>

### Operating Conditions

<table>
<thead>
<tr>
<th>Operating Point</th>
<th>Power, BHP</th>
<th>Speed, RPM</th>
<th>Operating Point/Steam Condition</th>
<th>No. Hand Valves</th>
<th>Steam Rate, LBS/HP-HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td></td>
<td></td>
<td>Normal/Normal (Certified SR)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated</td>
<td></td>
<td></td>
<td>Rated/Normal</td>
<td></td>
<td></td>
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<tr>
<td>Other (4.1.4)</td>
<td></td>
<td></td>
<td>(1) Min. Inlet -</td>
<td></td>
<td>Max Exhaust</td>
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</table>

### Duty, Site and Utility Data

<table>
<thead>
<tr>
<th>Operating Condition</th>
<th>Performance</th>
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<tr>
<td></td>
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<tr>
<td>No.</td>
<td>Description</td>
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<tr>
<td>17</td>
<td>Slow Roll Req. (4.10.4)</td>
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<tr>
<td>18</td>
<td>Duty</td>
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<tr>
<td>19</td>
<td>Unattended Auto Start (4.1.6)</td>
</tr>
<tr>
<td>20</td>
<td>Location (4.1.14)</td>
</tr>
<tr>
<td>21</td>
<td>Location</td>
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<tr>
<td>22</td>
<td>Ambient Temp., °F: Min.</td>
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<tr>
<td>23</td>
<td>Unusual Conditions (4.1.14)</td>
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<tr>
<td>25</td>
<td>Control Power</td>
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<td>26</td>
<td>Aux. Motors</td>
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<tr>
<td>27</td>
<td>Cooling Water Press, PSIG</td>
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<td>28</td>
<td>Temp Flow, GPM</td>
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<td>29</td>
<td>Allow. Sound Press Level (4.1.12)</td>
</tr>
<tr>
<td>30</td>
<td>Steam Conditions</td>
</tr>
<tr>
<td>31</td>
<td>Inlet Press, PSIG</td>
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<tr>
<td>32</td>
<td>Inlet Temp., °F</td>
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<td>33</td>
<td>Exhaust Press (PSIG)(IN. HGA)</td>
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<td>34</td>
<td>Steam Contaminants (4.11.1.7)</td>
</tr>
<tr>
<td>35</td>
<td>API-611 Other</td>
</tr>
<tr>
<td>36</td>
<td>Construction</td>
</tr>
<tr>
<td>37</td>
<td>Turbine Type</td>
</tr>
<tr>
<td>38</td>
<td>No Stages</td>
</tr>
<tr>
<td>39</td>
<td>Rotor</td>
</tr>
<tr>
<td>40</td>
<td>Blading</td>
</tr>
<tr>
<td>41</td>
<td>Casing Support</td>
</tr>
<tr>
<td>42</td>
<td>Vertical Turbine Flange</td>
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<tr>
<td>43</td>
<td>Type Thrust Bearing (4.9.1)</td>
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<tr>
<td>44</td>
<td>Trip Valve</td>
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<td>45</td>
<td>Interstage Seals</td>
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<td>46</td>
<td>End Seals</td>
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<tr>
<td>47</td>
<td>Type Radial Bearings (4.9.1)</td>
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<tr>
<td>TURBINE DATA</td>
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<tr>
<td>ALLOWSPEEDS, RPM, MAX MIN</td>
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<td>MAX CONT SPEED, RPM (3.1.10)</td>
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<td>TRIP SPEED, RPM BLADE TIP VEL, FPS</td>
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<td>FIRST CRITICAL SPEED, RPM (4.8.2.1)</td>
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<td>EXH. TEM °F NORMAL NO LOAD</td>
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<td>POTENTIAL MAX POWER, BHP (3.1.20)</td>
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<td>MAX. NOZZLE STEAM FLOW, LBS/HR</td>
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<td>ROTATION FACING GOVERNOR END CCW CW</td>
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<tr>
<td>DRIVEN EQUIPMENT THRUST, LBS (4.9.11)</td>
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<tr>
<td>(VERTICAL TURBINE) (4.9.3)</td>
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<tr>
<td>WATER PIPING FURN. BY VENDOR OTHERS</td>
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<tr>
<td>OIL PIPING FURN. BY VENDOR OTHERS</td>
<td></td>
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</tbody>
</table>

| CALCULATED THRUST LOAD PSI (4.9.15) |  |
| BEARING MFGR'S ULTIMATE RATING PSI |  |
| THRUST COLLAR (4.9.10.2) REPLACEABLE INTEGRAL NONE |  |
| LUBE OIL VISCOSITY (4.10.3) ISO GRADE |  |
| LUBRICATION RING OILED PRESSURE GREASE OIL MIST (4.9.19) |  |
| PURGE OIL MIST PURE OIL MIST BEARING HOUSING OILER TYPE |  |

<table>
<thead>
<tr>
<th>CASING DESIGN</th>
<th>INLET</th>
<th>EXHAUST</th>
</tr>
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<tbody>
<tr>
<td>MAX. ALLOW. PRESS, PSIG</td>
<td>MAX ALLOW. TEMP, °F</td>
<td>HYDRO TEST PRESS., PSIG</td>
</tr>
<tr>
<td>WATER PIPING FURN. BY</td>
<td>O O</td>
<td></td>
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<tr>
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<td>O O</td>
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</tbody>
</table>
Factors that affect Turbine Performance

Steam Conditions
More "available energy" means lower steam flow to produce power.

Horsepower & RPM
In general, higher HP & RPM turbines are more efficient.

Frame Size
Number of stages.
Stage pitch diameters.

Inlet & Exhaust Losses
Minimized by keeping velocities within reasonable limits.
Steam Turbine Selection

Steam Rate = Flow/Power or TSR/\eta

TSR – theoretical steam rate = \frac{\Delta h_{is}}{\text{Constant}}
Power = \((\text{Flow}) \times (H_{is}) \times (\eta) / 2545\) - HP losses

In English units:
Power = horsepower
\(H_{is} = \text{Isentropic BTU per pound}\)
\(\eta = \text{efficiency}\)
Flow = Pounds per hour
And $V_j = \text{Steam Jet Velocity} = \sqrt{\frac{2g_c J(\Delta H_{is})}{K}}$

Where $V_b = \text{Bucket Velocity} = \pi(\text{Stage Diameter})(\text{Speed}) / K$

And $V_j = \text{Steam Jet Velocity} = \sqrt{\frac{2g_c J(\Delta H_{is})}{K}}$
Steam Turbine Selection

Example

- 770 Horsepower @ 3600 RPM
- 600 psig/700 Deg. F/150 PSIG
- 847 maximum Horsepower
Steam Turbine Selection Design Checks

Inlet and Exhaust velocities

<table>
<thead>
<tr>
<th></th>
<th>Non – Condensing feet/second</th>
<th>Condensing feet per second</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet</td>
<td>175</td>
<td>175</td>
</tr>
<tr>
<td>Exhaust</td>
<td>250</td>
<td>450</td>
</tr>
</tbody>
</table>
Steam Turbine Selection Design Checks

Mechanical Limits

- Shaft end torque
- Blade stresses (Goodman diagram)
- Blade frequencies (Campbell Diagram)
- Speed limits
  - Blades, Shrouds, Disks, Critical speed
Steam Turbine Selection Design Checks

Aerodynamics

Pressure ratio across the stage determines ideal nozzle expansion ratio – ratio of exit area to throat area.
Steam flow divided by critical flow determines nozzle area required.

Nozzle area required divided by the nozzle throat area determines the number of nozzles.

Nozzles are arranged to accommodate the hand valve ports ribs.
Nozzles are arranged to accommodate the hand valve ports, ribs
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Steam Turbine Design - Components

Instrumentation

Following instrumentation available:
- Thermocouples or RTDs
- Radial vibration probes
- Axial position probes
- Keyphasor
- Vibraswitch
- Accelerometer
Leakoffs & Drains (Typical)

Leakoffs to Open Drain

- 2 packing case
- 1 trip valve stem
- 1 governor valve stem

Open Drains with Suitable Valve

- 1 turbine case drain
- 1 below the seat drain (steam chest)
- 1 above the seat drain (steam chest)
Steam Traps

- Spirax Sarco
  - TD-52 or TD-62 (based on temperatures)
- Located on turbine drain lines
Steam Turbine Design - Components

Accessories

Following accessories are available:

- Low oil / air pressure trip
- Solenoid trip arrangement
- Alarm & trip switches
- Tachometers (digital, externally powered or self-powered)
- 2 out of 3 voting overspeed trip arrangement
- Gaugeboards with gauges and tachometer mounted
- Soleplate or baseplate (turbine alone or with gear/generator)
Steam Turbine Design - Components

Accessories

- Valved casing drain connections
- Seal steam piping
  - Manual system
  - Automatic system
- Gland condenser options - standard & TEMA C
- Automatic steam traps
- Couplings
- Optical alignment flats & tooling balls
Steam Turbine Design - Components

Accessories

Material certifications
- BOM
- Material certs on major castings
- Certificate of compliance

Miscellaneous tests
- API 612
- M & E runout check
Steam Turbine Design - Components

Software - Drawings, Lists and Data

Main equipment outline (General Arrangement)
Section drawings - normally contained in IOM
Parts Lists - normally contained in IOM
Lube schematics - furnished when FF lube system supplied
Electrical schematics - supplied when several electrical devices and instrumentation is furnished
Instruction manuals - CD plus 1 hard copy. Hard copy shipped with turbine
Software - Drawings, Lists and Data

Optional drawings and data submittals available at extra cost:

- Combined outline - all major equipment on one drawing
- As-built section drawings
- P & I diagram
- Performance curves
- Campbell & Goodman diagrams
- Critical speed analysis
- Torsional data and or analysis
- Report on balance machine sensitivity - API
- API Appendix requirements
Steam Turbine Selection

Conclusions

• Pump OEMs – don’t over-specify the power
• Contractors – Use realistic min/max conditions
• Users – Use the Hand valves!!!
Summary

- Steam turbines are a reliable and flexible driver for pumps
- Construction allows long term reliability
- Specifying appropriate operating conditions can save significant amounts of money