Welcome!

Webinar #6: MATCHING STEAM TURBINE PERFORMANCE
19 JULY 2017

**Agenda:**

* Introduction
* ST basics
* Sample HB’s
* The Drill – Performance Matching Procedure
* ST Performance Matching Exercise
* Reference Material- ST LSB’s, Pressures & Flow Areas, ST steam sealing
* Q & A Session (pls. send Q’s anytime during the presentation to both the presenter & host)

Presenter: STAN. KAVALE (CZECH REP.)
Support: Meritt Elmasri (U.S. HQ)
Thermoflow Training and Support

- Standard Training
- On site training course
- Advanced Workshop
- Webinars when new version is released
- Help, Tutorials, PPT, Videos
- Technical Support

→ Feature Awareness Webinars
Feature Awareness Webinars

1- Assemblies in Thermoflex
2- Scripts in Thermoflow programs
3- Multi Point Design
4- Reciprocating Engines
5- Simplified Annual & TIME
6- Matching ST Performance
Some Thoughts on ST’s

- For a given flow, a fixed flow passing area will generate a corresponding pressure.
- Hence pressure at the HP, IP, LP modules will be dictated by the fixed flow area at the inlet.
- Designing in GTP, STP, TFX (design mode) etc is in reverse to the above ie. Pressures & flows are defined, and flow areas are calculated.
- To accurately match ST performance against a given heat balance need to account for:
  - OEM fixed hardware (nozzles, SV & CV dP, LSB geometries & exhaust loss curves)
  - ST section efficiencies
  - Leakage & sealing flows
  - Generator losses & efficiencies
...a typical as received HB ....
Note: ST is equipped with Stop valves at HP & IP admission, no control valves as such.
## Key HB Data

### HPT Module
Steam Conditions Prior to HP SV
- 130.9 Bar, 565.6 degC, 388.8 t/hr

Inlet Conditions (Bowl) – after SV
- 128.2 Bar, 564.6 degC, 372.7 t/hr

Exit Conditions
- 26.24 Bar, 3095 kJ/kg, 371.4 t/hr

Leaks
- 16.11 t/hr from HP inlet to IP inlet
- 0.8868 t/hr from HP exit to X-O
- 0.4663 t/hr from HP exit to SSR

### IPT Module
Steam Conditions Prior to IP Stop Valve
- 23.56 Bar, 565.6 degC, 416.69 t/hr

Inlet Conditions (Bowl)
- 23.27 Bar, 563.8 degC, 431.4 t/hr

Exit Conditions
- 3.811 Bar, 3078 kJ/kg

Dual flow exhaust

### LPT Module
Inlet Conditions
- 3.754 Bar, 302.5 degC, 477.7 t/hr

Exit Conditions (after LL)
- 0.0677 Bar, 2417.9 kJ/kg

### Steam Seal System
Excess SSR flow -> Condenser
Excess SS Packing Exhaust -> GSC
GSC Pressure – 0.8274 Bar
SSR Pressure – 1.241 Bar
SS Flow to Condenser per LPT Path - 0.3545 t/hr
SS Flow to Packing Exhaust per LPT Path – 0.3175 t/hr

### Generator
188063 kWe, 816 kW fixed losses, 2273 kW gen. losses, 0.85 pf, H2 cooled, 60Hz
- If possible, determine ST OEM (possibly from internet sources for existing plants)
  Determine the key parameters to be matched ie. type of cycle, line frequency, mass flows, pressures,
temperatures, condensing conditions, generator & type, p.f etc
- Set up the cooling system (condenser pressure) per HB info provided
- Set up the model so that mass flows and pressures match the HB
- Set up the ST groups > Group Efficiency on basis of exit enthalpy values provided per the HB
- Set up the ST leakages from HB info provided
- Set up the Steam Sealing System
- Set up the IP and LP admission flows via the “Process > Steam Additions “ tabs
- Run the model & check the results
- Return to Inputs & adjust the HP & IP group SV pressure drops to achieve the required ST bowl pressures.
- Run the model and check results, iterate as required on the pressures, also check the LSB geometry, enter OEM
  LSB geometry if available
- Run the model, check results. For final trimming to match generator output, adjust “ST Inputs > Design
  Assumptions > ST mechanical loss as a % of ST expansion power “ (item 17).
New Session - Black box steam generator, 120 – 200 MW plant output, ST Config = Single Reheat, Condensing

Plant Criteria – take defaults

Cooling System> Main Inputs> Condenser Design Method > User defined Pressure Only> 0.0677 Bar

Steam Cycle – ST P’s & T’s as shown:
ST – FWH – Feed Water Heater Train Configuration = User defined, Number of FWH= 0, also define no. of ports for HPT, IPT, LPT groups as zero & LPT Paths = User Defined, No. of Paths = 2, Distinct Paths =1 ....as shown below.
Step 1 Continued...

ST Inputs – Group Design > As shown below
- Generator > Enter gen. eff. of 98.384% and change PF from 0.9 to 0.85, also define gen. mech. Loss as a % of total loss as 26.42%
## Generator Efficiency Inputs

<table>
<thead>
<tr>
<th>Group Design</th>
<th>Design Assumptions</th>
<th>Generator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Generator efficiency (G=automatic estimate)</td>
<td>98.38 %</td>
<td></td>
</tr>
<tr>
<td>2. C.F. for automatic estimate of generator loss</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3. Generator rated power / nominal output</td>
<td>1.05</td>
<td></td>
</tr>
<tr>
<td>4. Generator power factor</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>5. Generator cooling: 0=unventilated, 1=H2, 2=TEWAC</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>6. Oil cooler heat recovery (ST+Gen mech. losses) to feedwater</td>
<td>0 %</td>
<td></td>
</tr>
<tr>
<td>7. Generator coolant heat recovery (elec. &amp; windage losses) to feedwater</td>
<td>0 %</td>
<td></td>
</tr>
<tr>
<td>8. Generator mechanical loss as percent of generator total loss @ rating</td>
<td>26.42 %</td>
<td></td>
</tr>
</tbody>
</table>
Step 1 Continued...

ST Inputs– Exhaust End Design > take the defaults
- ST Leaks > as shown below
**Step 1 Continued**

ST Inputs Continued > Steam Seal System > enter the data as shown

<table>
<thead>
<tr>
<th>Group Design</th>
<th>Design Assumptions</th>
<th>Generator</th>
<th>Ex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destination of excess flow from SSR</td>
<td>Destination of SS packing exhaust</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condenser</td>
<td>Gland steam condenser</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Gland steam condenser pressure: 0.8274 bar
2. Seal steam regulator pressure: 1.241 bar
3. SS flow to condenser per LPT path (0 default cal): 0.27 t/h
4. SS flow to packing exhaust per LPT path (0 default cal): 0.32 t/h
Step 1 Continued

Process > Steam Additions > Define the IP and LP Flows (ref. the Heat Balance per Slide 6)
Step 2 – Run the Model & Check Results

Black Box Steam Generator

HPT, IPT, LPT
Bowl Pressures need adjusting

Black Box Steam Generator

HPT

IPT

2x1 LPTs

G

3600 RPM

188741 kW

143.7 p
42.78 T
362 M

130.9 p
565.6 T
388.8 M

135.5 p
568.2 T
388.8 M

24.15 p
586.9 T
416.7 M

24.6 p
332.7 T
371.4 M

3.811 p
302.6 T
45.36 M

26.24 p
307.3 T
45.36 M

3.815 p
304.9 T
477.7 M

0.943 x

188741 kW

143.7 p
42.78 T
362 M

15.03 T
25951 M

25.05 T
25951 M

135.5 p
568.2 T
388.8 M

24.15 p
566.9 T
416.7 M

25.6 p
335.7 T
371.4 M

335.7 T
371.4 M

25.6 p
335.7 T
371.4 M

24.15 p
566.9 T
416.7 M

25.6 p
335.7 T
371.4 M

135.5 p
568.2 T
388.8 M

24.15 p
566.9 T
416.7 M

25.6 p
335.7 T
371.4 M

135.5 p
568.2 T
388.8 M

24.15 p
566.9 T
416.7 M

25.6 p
335.7 T
371.4 M

3.811 p
302.6 T
45.36 M

26.24 p
307.3 T
45.36 M

3.815 p
304.9 T
477.7 M
...areas requiring attention....

<table>
<thead>
<tr>
<th>P</th>
<th>Preq</th>
</tr>
</thead>
<tbody>
<tr>
<td>bar</td>
<td>bar</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HPT GROUP IN</th>
<th>127.591</th>
<th>128.2</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>IPT GROUP IN</th>
<th>23.09</th>
<th>23.27</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>LPT GROUP IN</th>
<th>3.811</th>
<th>3.753</th>
</tr>
</thead>
</table>

Pressure discrepancy at HP Inlet – fix by adjusting the stop valve pressure losses (2%)

Pressure discrepancy at IP Inlet – fix by adjusting the stop valve pressure losses (0.8%)

Pressure discrepancy at LP Inlet – fix by adjusting the LP Intercept Valve dP

LSB Detail – change to OEM LSB if available

Exhaust Loss Curve

Make the required changes & re-run the model
Changes Made to Correct HP, IP, LP inlet Pressures,

(OEM “.exl “ also loaded)

Required to correctly simulate the LP bowl pressure
Corrected Run Results

Black Box Steam Generator

STG Output Still
High - Adjust ST
Mechanical Losses
## Final Adjustment

<table>
<thead>
<tr>
<th>Group Design</th>
<th>Design Assumptions</th>
<th>Generator</th>
<th>Exch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Apply ST miscellaneous auxiliary load defined in item 1</td>
<td>1.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G. Apply ST miscellaneous auxiliary load defined by item 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Reference pressure ratio for steam turbine expansion step</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Condensation quality (Wilson Line)</td>
<td>0.37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Moisture efficiency penalty (Baumann coefficient)</td>
<td>0.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. HPT stop valve and throttle pressure drop (D/P)</td>
<td>2.05</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>7. PHT/APT stop and control valve pressure drop (D/P)</td>
<td>0.8</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>8. LPT intercept valve pressure drop (D/P)</td>
<td>1.5</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>9. Number of HPT governing stage rows (0, 1, or 2)</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Throttle pressure / First stage set pressure</td>
<td>1.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Governing stage pitch diameter method, 0-user defined, 1-auto</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Governing stage pitch diameter</td>
<td>35.6 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. Apply modified method for governing stage eff. adjustment, 0=yes, 1=no</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. HPT inlet leakage after governing stage, 1=yes, 0=no</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. Throttle pressure / HPT inlet leakage pressure</td>
<td>1.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16. Throttle enthalpy - HPT inlet leakage enthalpy</td>
<td>0</td>
<td>kg/kWh</td>
<td></td>
</tr>
<tr>
<td>17. Steam turbine mechanical loss as % of ST expansion power</td>
<td>0.264</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>18. Steam turbine mechanical efficiency</td>
<td>58.72</td>
<td>%</td>
<td></td>
</tr>
</tbody>
</table>

Adjust to give 188063kW at generator.
Final Result....

Generator Output @ 188063 kW as required
Check through other parameters to verify results,
AeN from STM etc
OEM Exhaust End – Losses Data

<table>
<thead>
<tr>
<th>Description</th>
<th>Value 1</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annulus velocity</td>
<td>214.1</td>
<td>m/s</td>
</tr>
<tr>
<td>Dry exhaust loss</td>
<td>22.04</td>
<td>kJ/kg</td>
</tr>
<tr>
<td>Corrected exhaust loss</td>
<td>17.18</td>
<td>kJ/kg</td>
</tr>
</tbody>
</table>
Reference Material – Last Stage Blade Lengths
(Condensing ST)

Exhaust Loss EL (ETU/lb)

"Indicates blade length [inches]
Points represent data of Spencer Cotton & Cannon
Curves generated with ThermoFlo model
All at 3600 RPM except 43" blades at 1800 RPM

From TF Help Menu, GTPro, Ch. 12.5.1
Reference Material – Pressures & Flow Areas

AeN Modules $\dot{m}$ vs P

- AeN 6.5
- AeN 11.8
- AeN 19.6
Reference Material - Typical Sealing System for ST Configuration Being Considered
Q & A Time....