



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)

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

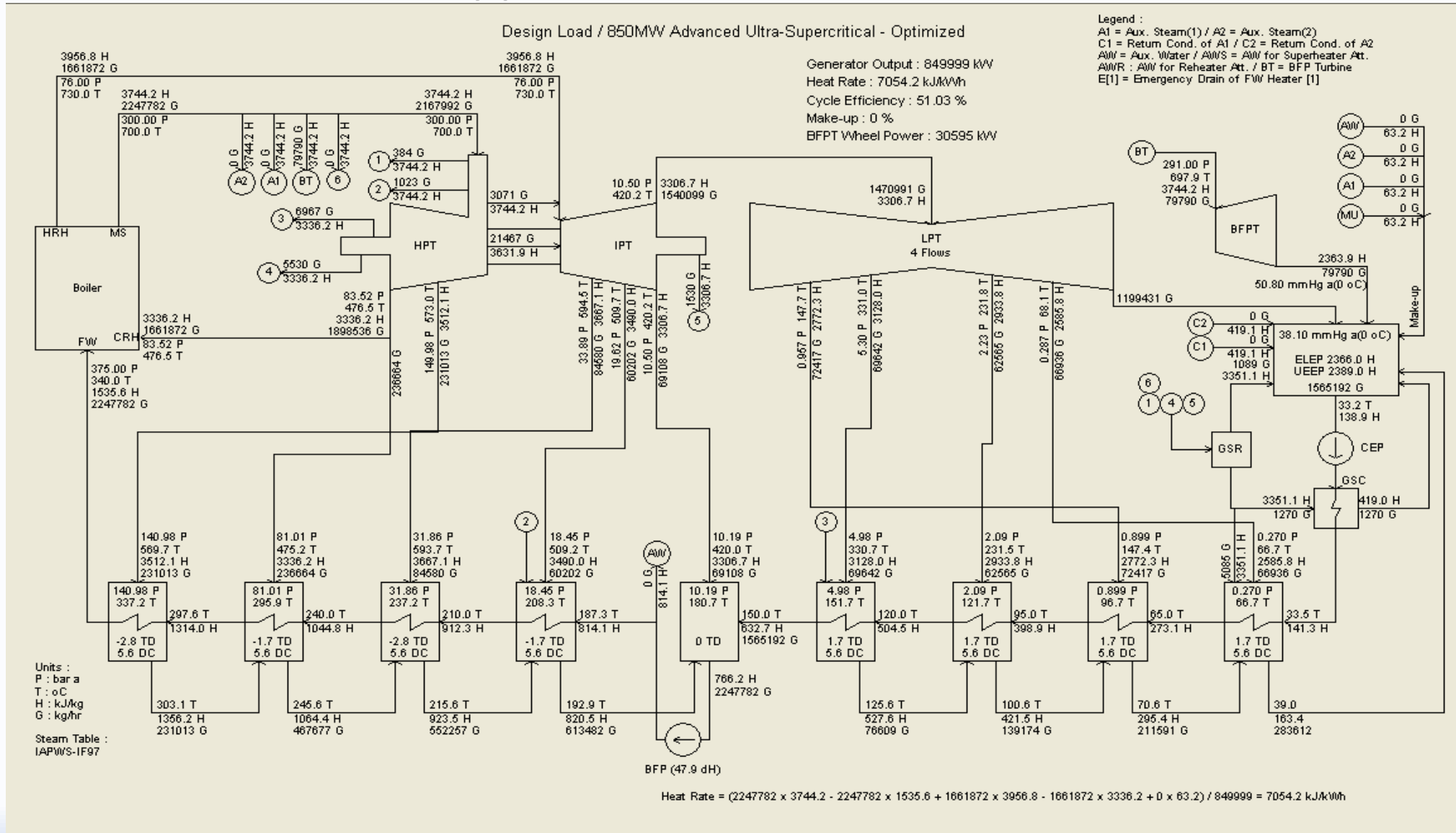
Feature Awareness Webinars

- 1- Assemblies in Thermoflex
- 2- Scripts in Thermostat programs
- 3- Multi Point Design
- 4- Reciprocating Engines
- 5- Simplified Annual & TIME
- 6- Matching ST Performance**

Some Thoughts on ST's

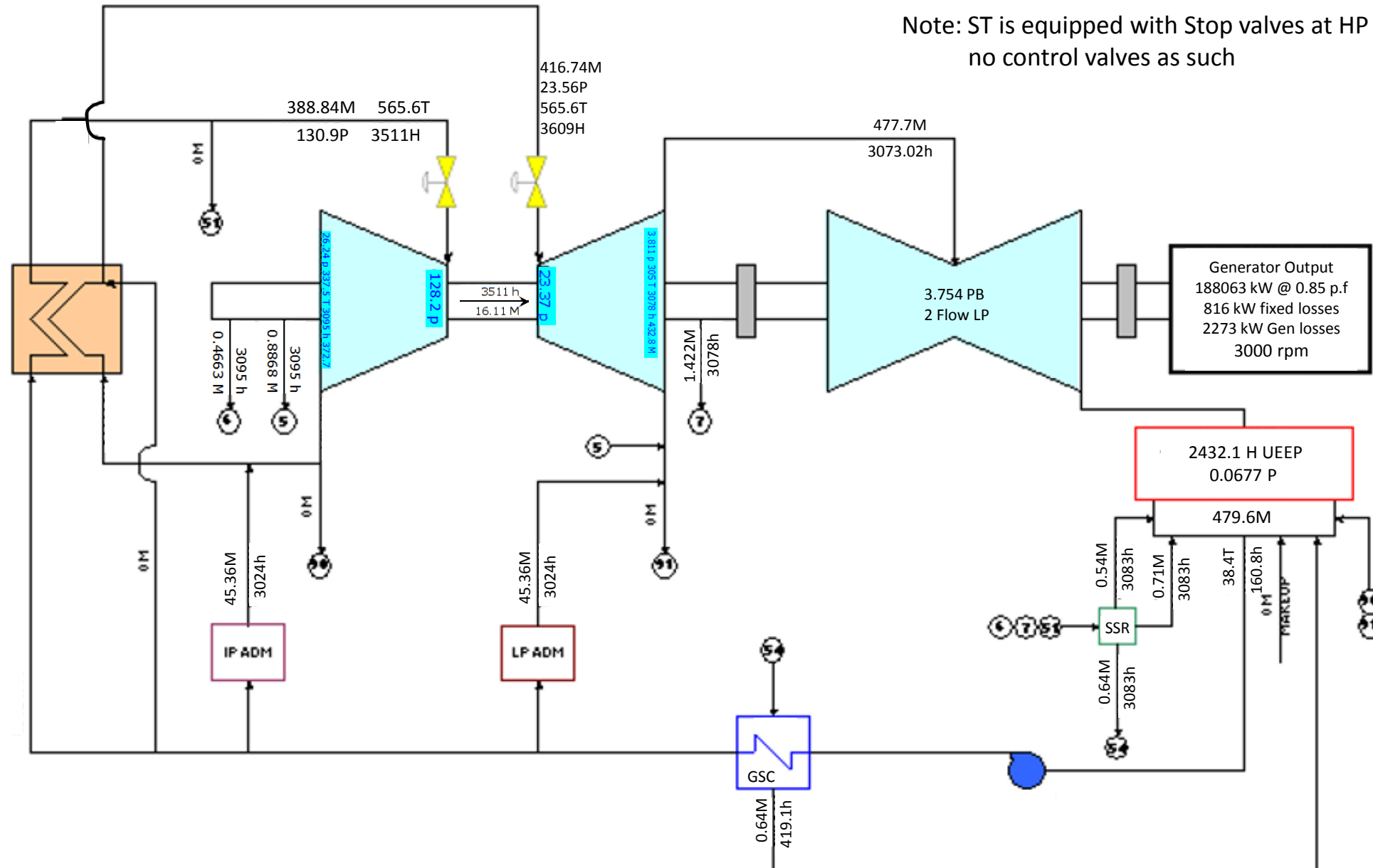
- For a given flow, a fixed flow passing area will generate a corresponding pressure.
- Hence pressure at the HP, IP, LP modules will be dictated by the fixed flow area at the inlet.
- Designing in GTP, STP, TFX (design mode) etc is in reverse to the above ie. Pressures & flows are defined, and flow 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 ...



Sample Heat Balance

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

(=371.4 + 43.6 + 16.1 t/hr)

Exit Conditions

- 3.811 Bar, 3078 kJ/kg

Leaks

1.422 t/hr from IP exit to SSR

Generator

188063 kWe, 816 kW fixed losses,
2273 kW gen. losses, 0.85 pf, H2
cooled, 60Hz

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

Dual flow exhaust

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

The Drill – Key Steps

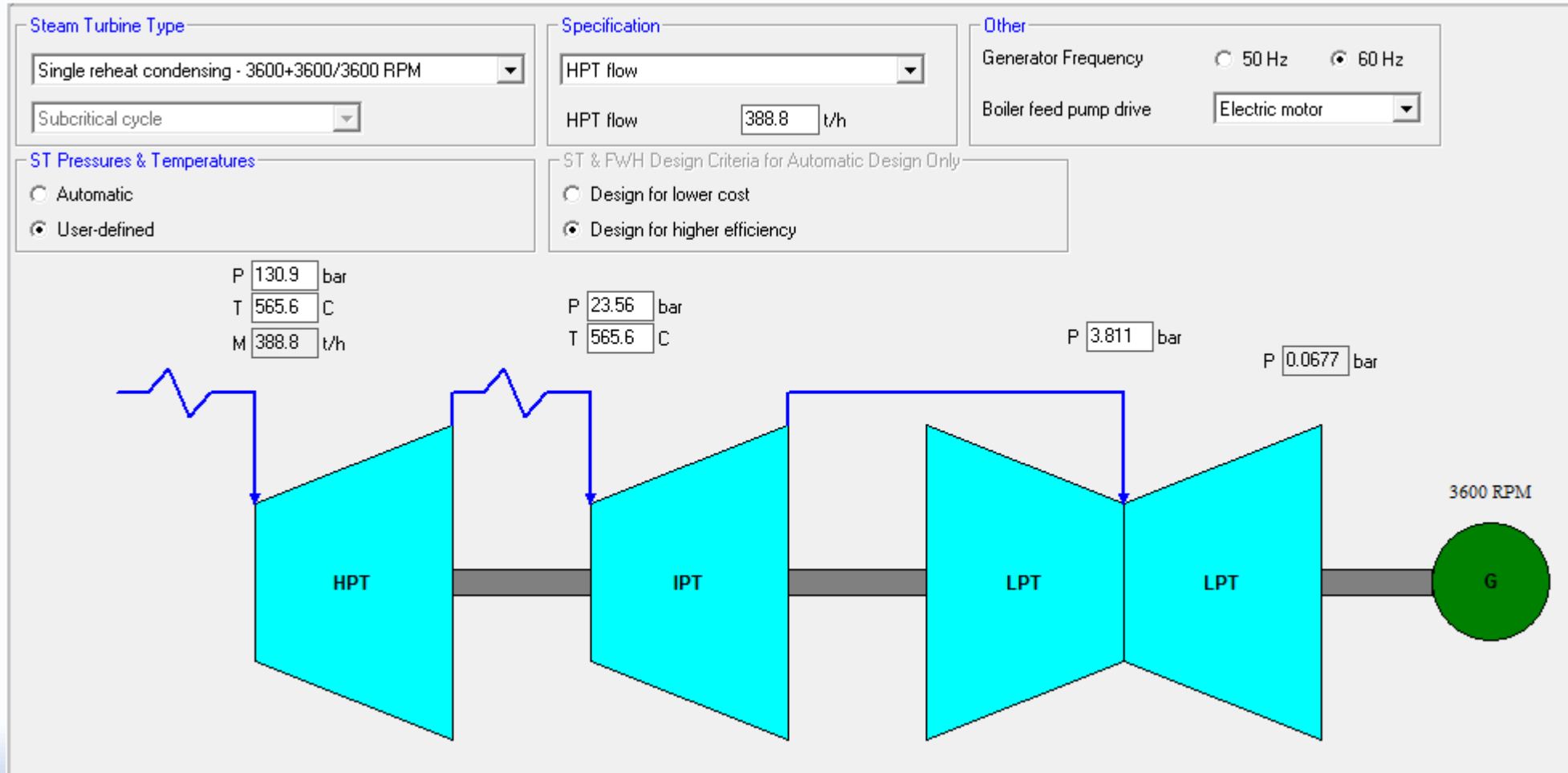
- If possible, determine ST OEM (possibly from internet sources for existing plants)
Determine the key parameters to be matched ie. type of cycle, line frequency, mass flows, pressures, temperatures, condensing conditions, generator & type, p.f etc
- Set up the cooling system (condenser pressure) per 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).

Step 1 – Basic Steam Cycle & Flows

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:



Step 1 Continued...

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.

Feedwater Heater Train Configuration

User-defined Number of feedwater heaters

Boiler feed pump after FWH

HPT Paths

No. of paths

IPT Paths

No. of paths

Distinct paths

LPT Paths

User-defined No. of paths

Distinct paths

Port Pressures

Port 1 bar

Number of ports

The diagram illustrates a feedwater heater train configuration. It consists of three main components in series: HPT (High Pressure Heater), IPT1 (Intermediate Pressure Heater), and LPT1x2 (Low Pressure Heater). The flow path is indicated by a blue line starting from the left. The pressure values at various points are as follows:

- Inlet to HPT: 130.9 p
- Outlet of HPT: 135.5 p
- Inlet to IPT1: 26.24 p
- Outlet of IPT1: 23.56 p
- Inlet to LPT1x2: 3.753 p
- Outlet of LPT1x2: 3.753 p

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%

Group Parameters

5. Specify exit enthalpy

User-defined exit enthalpy kJ/kg

Group Parameters

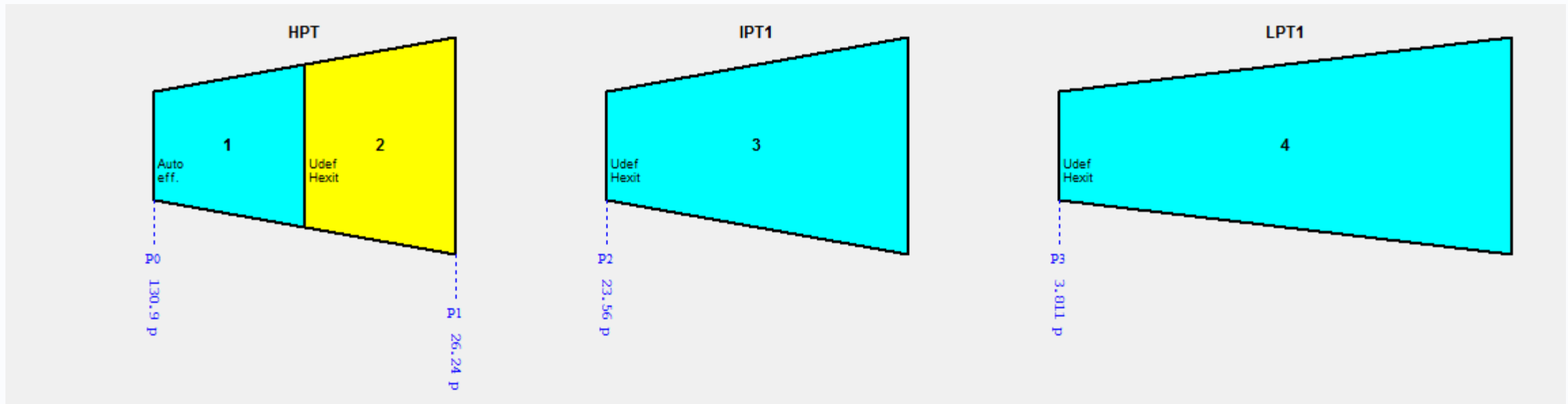
5. Specify exit enthalpy

User-defined exit enthalpy kJ/kg

Group Parameters

5. Specify exit enthalpy

User-defined exit enthalpy kJ/kg



Generator Efficiency Inputs

| Group Design | Design Assumptions | Generator |
|--------------|--------------------|---|
| | | 1. Generator efficiency (0=automatic estimate) <input type="text" value="98.38"/> % |
| | | 2. C.F. for automatic estimate of generator loss <input type="text" value="1"/> |
| | | 3. Generator rated power / nominal output <input type="text" value="1.05"/> |
| | | 4. Generator power factor <input type="text" value="0.85"/> |
| | | 5. Generator cooling; 0=Open ventilated, 1=H2, 2=TEWAC <input type="text" value="1"/> |
| | | 6. Oil-cooler heat recovery (ST+Gen mech. losses) to feedwater <input type="text" value="0"/> % |
| | | 7. Generator coolant heat recovery (elec. & windage losses) to feedwater <input type="text" value="0"/> % |
| | | 8. Generator mechanical loss as percent of generator total loss @ rating <input type="text" value="26.42"/> % |

Step 1 Continued...

ST Inputs– Exhaust End Design > take the defaults
 - ST Leaks > as shown below

The screenshot displays the 'ST Leaks' configuration window. At the top, there are tabs for 'Group Design', 'Design Assumptions', 'Generator', 'Exhaust End Design', 'ST Leaks', 'Steam Seal System', and 'Moisture'. Below the tabs, under 'Automatic Procedure Options', the 'Thermoflow-modified SCC method' is selected. The main area shows a schematic of the steam turbine components: HPT (High Pressure Turbine), IPT (Intermediate Pressure Turbine), and LPT (Low Pressure Turbine). Several leak configuration dialog boxes are open, showing settings for different leak types:

- HPT HP leak 1:** Leak destination is 'IPT inlet', Leak flow modeled by 'User-defined leak flow', Leak Flow is 16.11 t/h.
- HPT LP leak 1:** Leak destination is 'LPT Crossover', Leak flow modeled by 'User-defined leak flow', Leak Flow is 0.8863 t/h.
- HPT LP leak 2:** Leak destination is 'SSR', Leak flow modeled by 'User-defined leak flow', Leak Flow is 0.4663 t/h.
- IPT LP leak:** Leak destination is 'SSR', Leak flow modeled by 'User-defined leak flow', Leak Flow is 1.422 t/h.

Checklists for 'Valve Stem Leaks', 'HPT HP End Leaks', 'HPT LP End Leaks', and 'IPT LP End Leak' are also visible, with various options checked or unchecked.

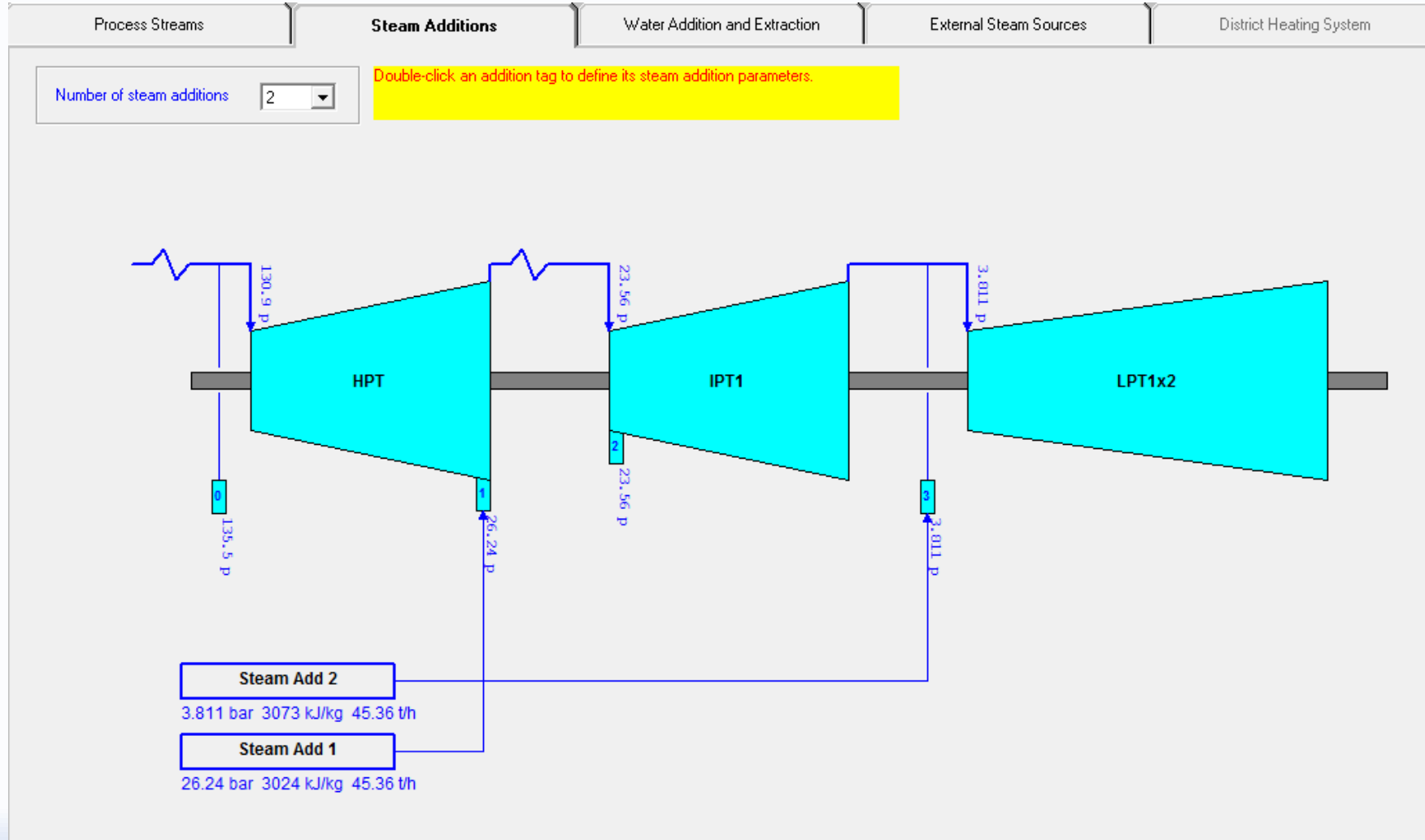
Step 1 Continued

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

| Group Design | Design Assumptions | Generator | Ex |
|---|--------------------|---|-----|
| Destination of excess flow from SSR <input type="text" value="Condenser"/> | | Destination of SS packing exhaust <input type="text" value="Gland steam condenser"/> | |
| 1. 2. Gland steam condenser pressure | | <input type="text" value="0.8274"/> | bar |
| 2. 1. Seal steam regulator pressure | | <input type="text" value="1.241"/> | bar |
| 3. 3. SS flow to condenser per LPT path (0:default cal.) | | <input type="text" value="0.27"/> | t/h |
| 4. 4. SS flow to packing exhaust per LPT path (0:default cal.) | | <input type="text" value="0.32"/> | t/h |

Step 1 Continued

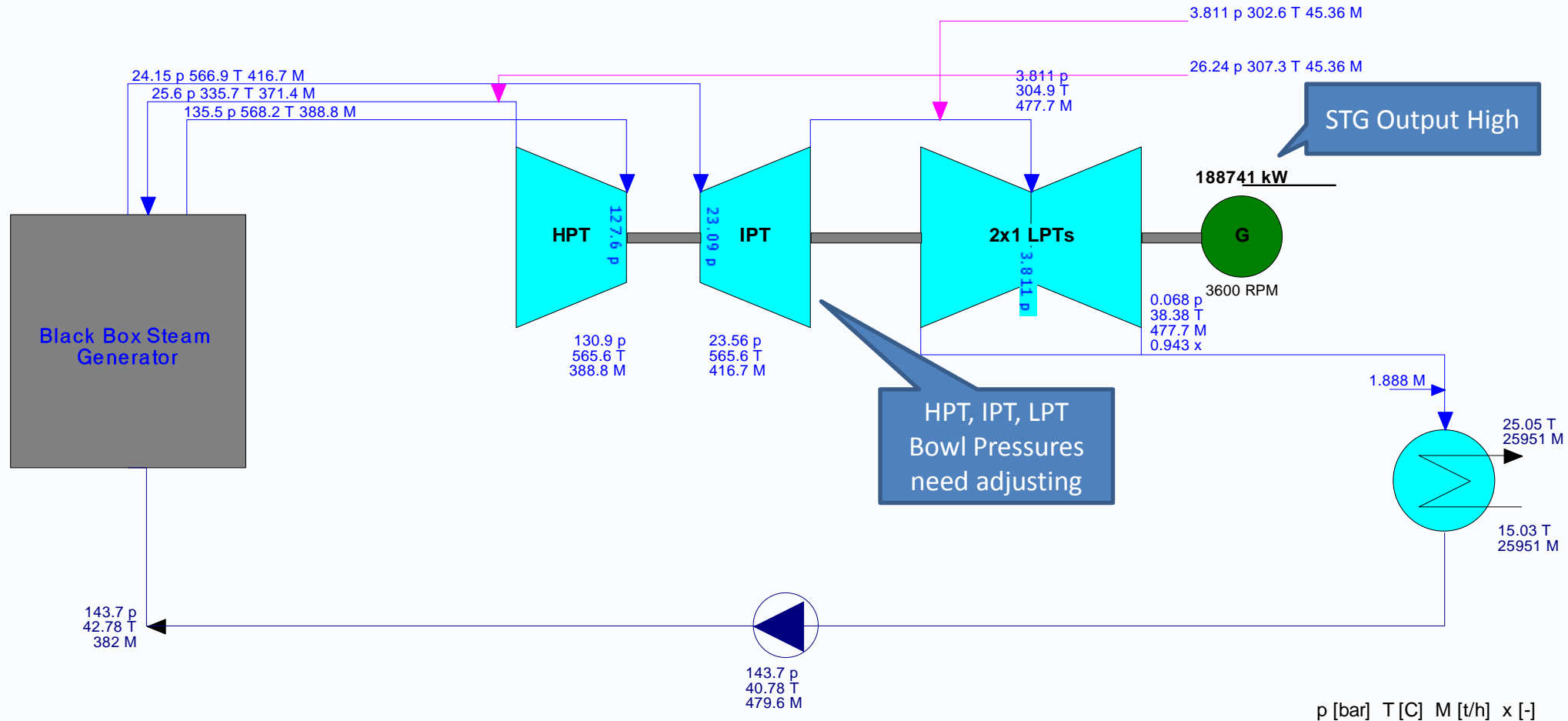
Process > Steam Additions > Define the IP and LP Flows (ref. the Heat Balance per Slide 6)



Step 2 – Run the Model & Check Results

| | |
|------------------------|-------------|
| Plant net power | 188741 kW |
| Aux. & losses | 180475 kW |
| Turbine heat rate | 8266 kW |
| Steam cycle heat rate | 7977 kJ/kWh |
| Steam cycle efficiency | 8016 kJ/kWh |
| | 44.91 % |

Ambient
1.013 p
15 T
60% RH
10.82 T wet bulb



...areas requiring attention...

| | | |
|--|-----|------|
| | P | Preq |
| | bar | bar |

| | | |
|--------------|---------|-------|
| HPT GROUP IN | 127.591 | 128.2 |
|--------------|---------|-------|

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

| | | |
|--------------|-------|-------|
| IPT GROUP IN | 23.09 | 23.27 |
|--------------|-------|-------|

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

| | | |
|--------------|-------|-------|
| LPT GROUP IN | 3.811 | 3.753 |
|--------------|-------|-------|

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

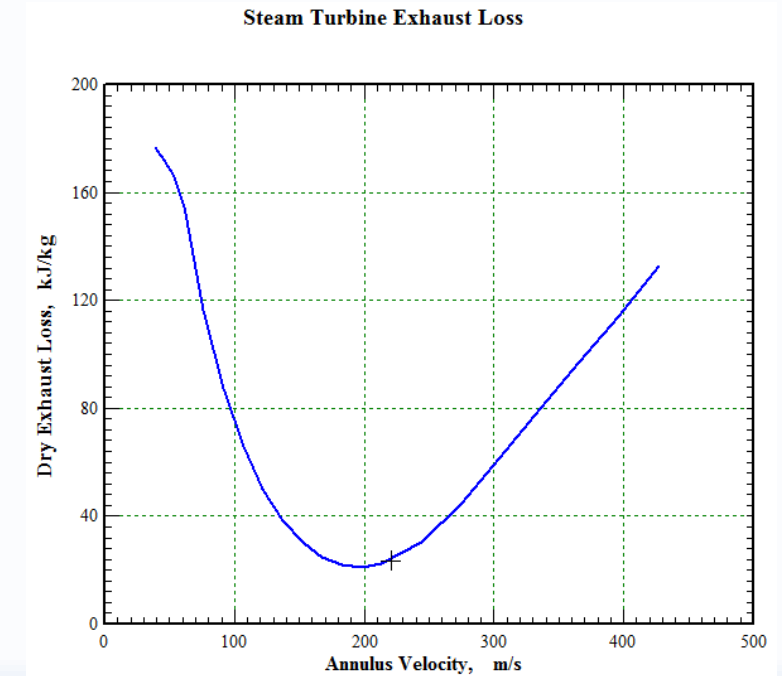
| Blading Exit | |
|-------------------------|--------------------------|
| Pressure | 0.0677 bar |
| Temperature | 38.38 C |
| Enthalpy | 2413.9 kJ/kg |
| Volume flow (per path) | 1313.8 m ³ /s |
| Annulus area (per path) | 5.963 m ² |
| Annulus velocity | 220.3 m/s |
| Pitch Diameter | 2320.3 mm |
| Bucket Length | 818 mm |
| Pitch Speed | 437.4 m/s |
| Tip Speed | 591.6 m/s |

| | | |
|------------------------|-------|-------|
| Annulus velocity | 220.3 | m/s |
| Dry exhaust loss | 23.41 | kJ/kg |
| Corrected exhaust loss | 18.24 | kJ/kg |

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)

Group Design | **Design Assumptions** | Generator

Apply ST miscellaneous auxiliary load defined in item 1
 Apply ST miscellaneous auxiliary load defined by item 2

- Miscellaneous steam turbine auxiliary load: 0 kW
- Miscellaneous ST auxiliary load (% of steam turbine generator rated power): 0.05 %
- Reference pressure ratio for steam turbine expansion step: 1.35
- Condensation quality (Wilson Line): 0.97
- Moisture efficiency penalty (Baumann coefficient): 0.72
- HPT stop valve and throttle pressure drop (DP/P): 2.05 %
- PIPT/IPT stop and control valve pressure drop (DP/P): 0.8 %
- LPT intercept valve pressure drop (DP/P): 1.5 %

Required to correctly simulate the LP bowl pressure

Group Design | Design Assumptions | Generator

LPT Speed

Synchronous
 Gear drive LPT
 Desired LPT last stage rotation speed: 3600 RPM

LPT Exhaust End Selection

STEAM PRO automatic exhaust sizing procedure
 User-defined exhaust characteristics

LPT exhaust loss correction factor: 1

Edit User-defined Steam Turbine Exhaust End

Exhaust End Selection

Exhaust end database: C:\TFLOW26\MYFILES\ND\QHLTH.DAT
User type: 3

Selected Exhaust End:
C:\TFLOW26\MYFILES\Exhst_ST\No_Name_33.5in_60Hz.exl

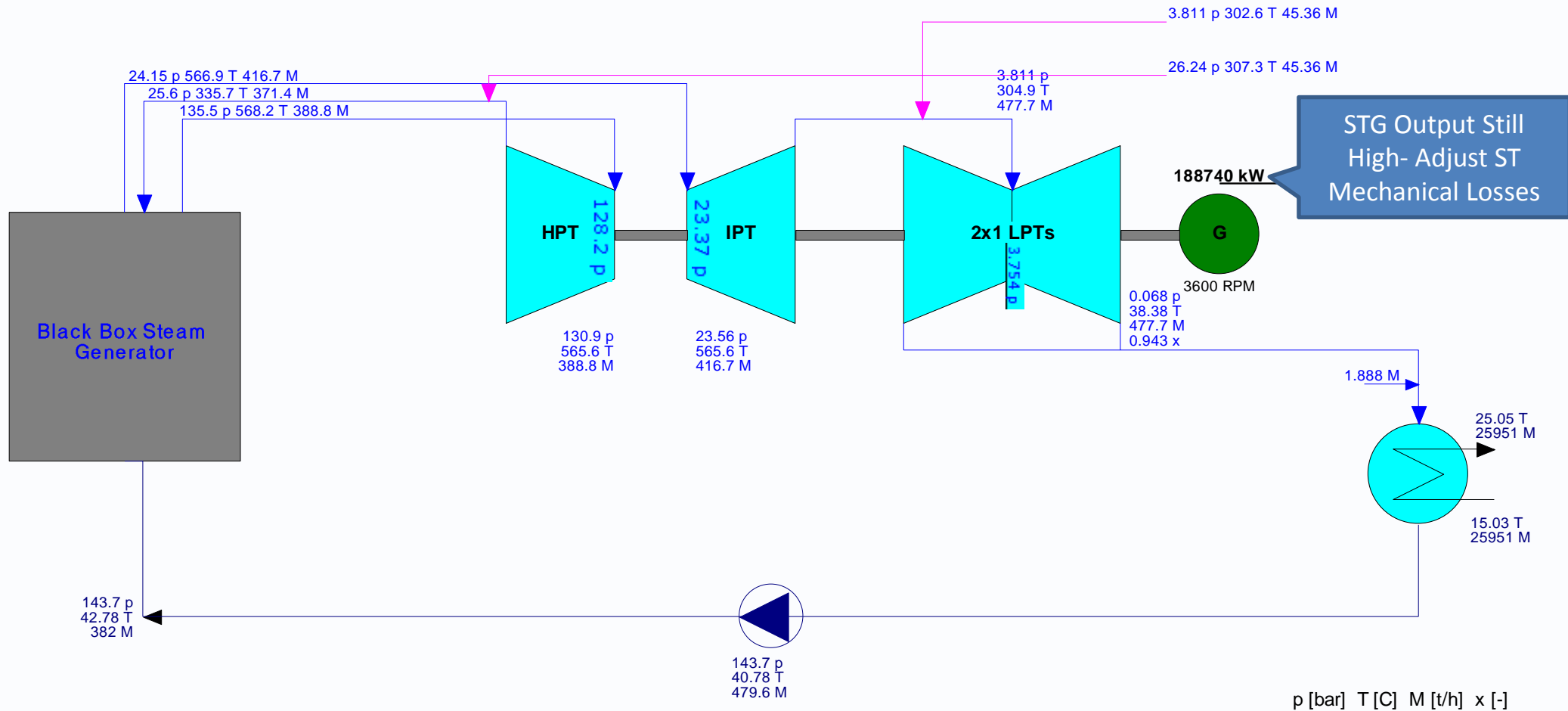
Load an Exhaust End file (*.exl)

Organize | New folder

| Name | Date modified | Typ |
|-------------------------|------------------|-----|
| 1.5in_50Hz.exl | 16/11/2016 14:28 | EXL |
| 0.6in_50Hz.exl | 28/04/2017 17:28 | EXL |
| 2.5in_50Hz.exl | 31/01/2017 21:30 | EXL |
| 9in_50Hz.EXL | 16/09/2016 12:02 | EXL |
| 0Hz.exl | 27/11/2014 14:32 | EXL |
| 0Hz.exl | 10/11/2015 15:36 | EXL |
| _50Hz.exl | 28/11/2013 16:50 | EXL |
| _60Hz.exl | 8/07/2017 09:42 | EXL |
| 0Hz.exl | 2/11/2015 11:32 | EXL |
| 0Hz.exl | 9/11/2015 14:12 | EXL |
| 2.exl | 24/11/2013 11:10 | EXL |
| No_Name_33.5in_60Hz.exl | 15/07/2017 19:35 | EXL |

File name: No_Name_33.5in_60Hz
Exhaust End files (*.exl)

Corrected Run Results



Final Adjustment

| Group Design | Design Assumptions | Generator | Exh |
|--------------|---|-----------|-----|
| | <input type="radio"/> Apply ST miscellaneous auxiliary load defined in item 1 <input checked="" type="radio"/> Apply ST miscellaneous auxiliary load defined by item 2 | | |
| | 3. Reference pressure ratio for steam turbine expansion step | 1.35 | |
| | 4. Condensation quality (Wilson Line) | 0.97 | |
| | 5. Moisture efficiency penalty (Baumann coefficient) | 0.72 | |
| | 6. HPT stop valve and throttle pressure drop (DP/P) | 2.05 % | |
| | 7. PIPT/IPT stop and control valve pressure drop (DP/P) | 0.8 % | |
| | 8. LPT intercept valve pressure drop (DP/P) | 1.5 % | |
| | 9. Number of HPT governing stage rows (0, 1, or 2) | 1 | |
| | 10. Throttle pressure / First stage exit pressure | 1.3 | |
| | 11. Governing stage pitch diameter method, 0=user-defined, 1=auto | 1 | |
| | 12. Governing stage pitch diameter | 958.6 mm | |
| | 13. Apply modified method for governing stage eff. adjustment; 0=yes, 1=no | 0 | |
| | 14. HPT inlet leakage after governing stage; 1=yes, 0=no | 0 | |
| | 15. Throttle pressure / HPT inlet leakage pressure | 1.3 | |
| | 16. Throttle enthalpy - HPT inlet leakage enthalpy | 0 kJ/kg | |
| | 17. Steam turbine mechanical loss as % of ST expansion power | 0.284 % | |
| | 18. Steam turbine mechanical efficiency | 99.72 % | |

Adjust to give
188063kW at
generator

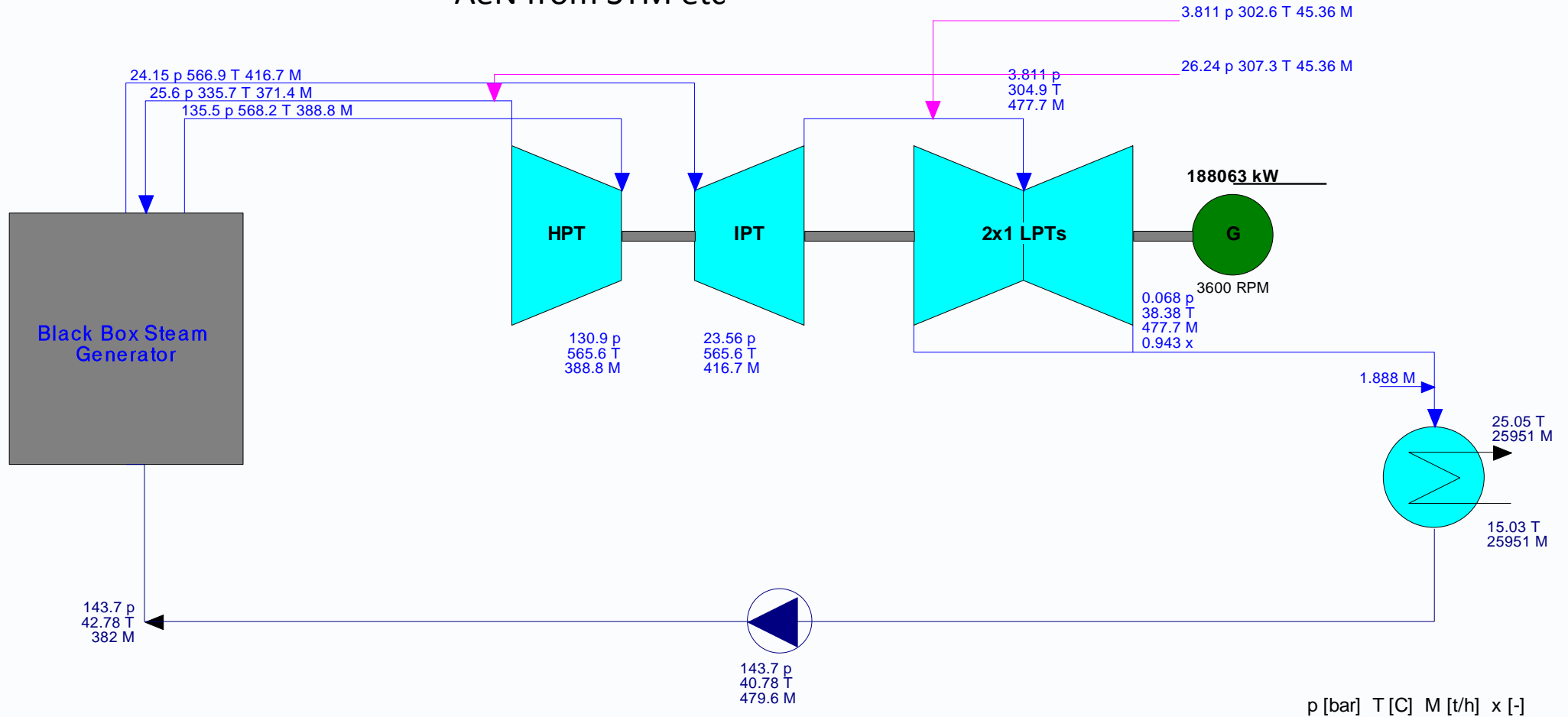
Final Result....

Aux. & losses
Turbine heat rate
Steam cycle heat rate
Steam cycle efficiency

188063 kW
179801 kW
8262 kW
8006 kJ/kWh
8045 kJ/kWh
44.75 %

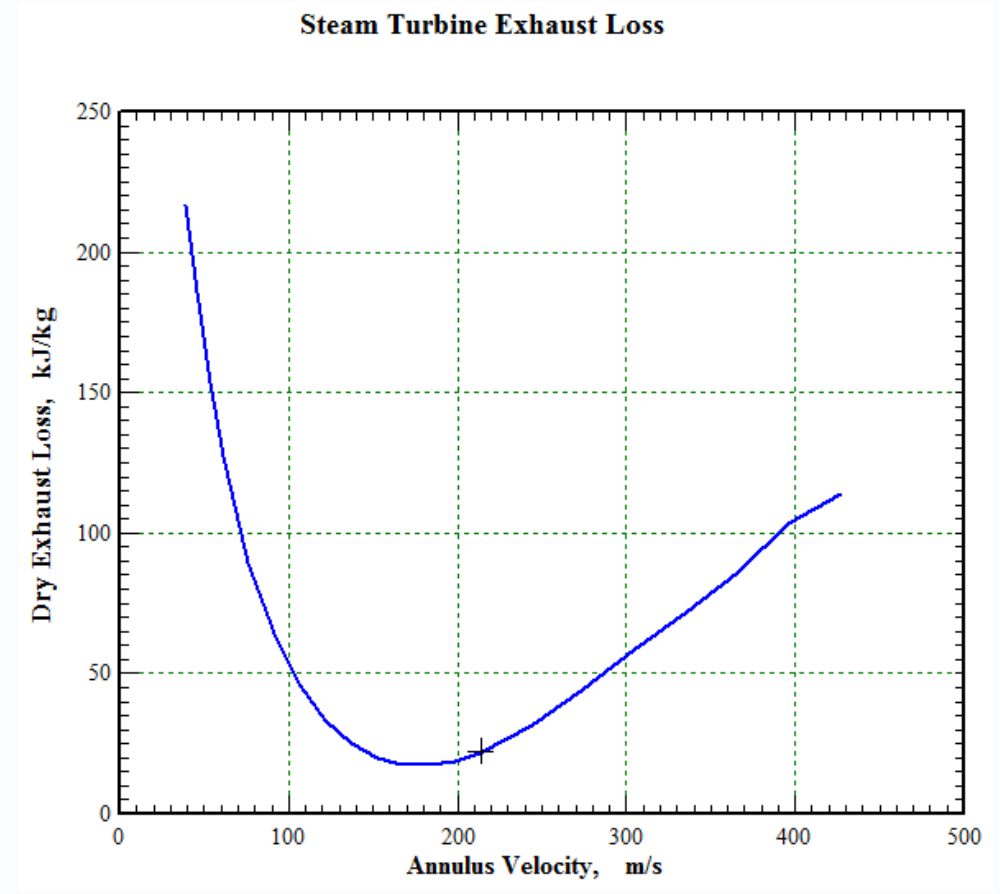
Ambient
1.013 p
15 T
60% RH
10.82 T wet bulb

Generator Output @ 188063 kW as required
Check through other parameters to verify results,
AeN from STM etc

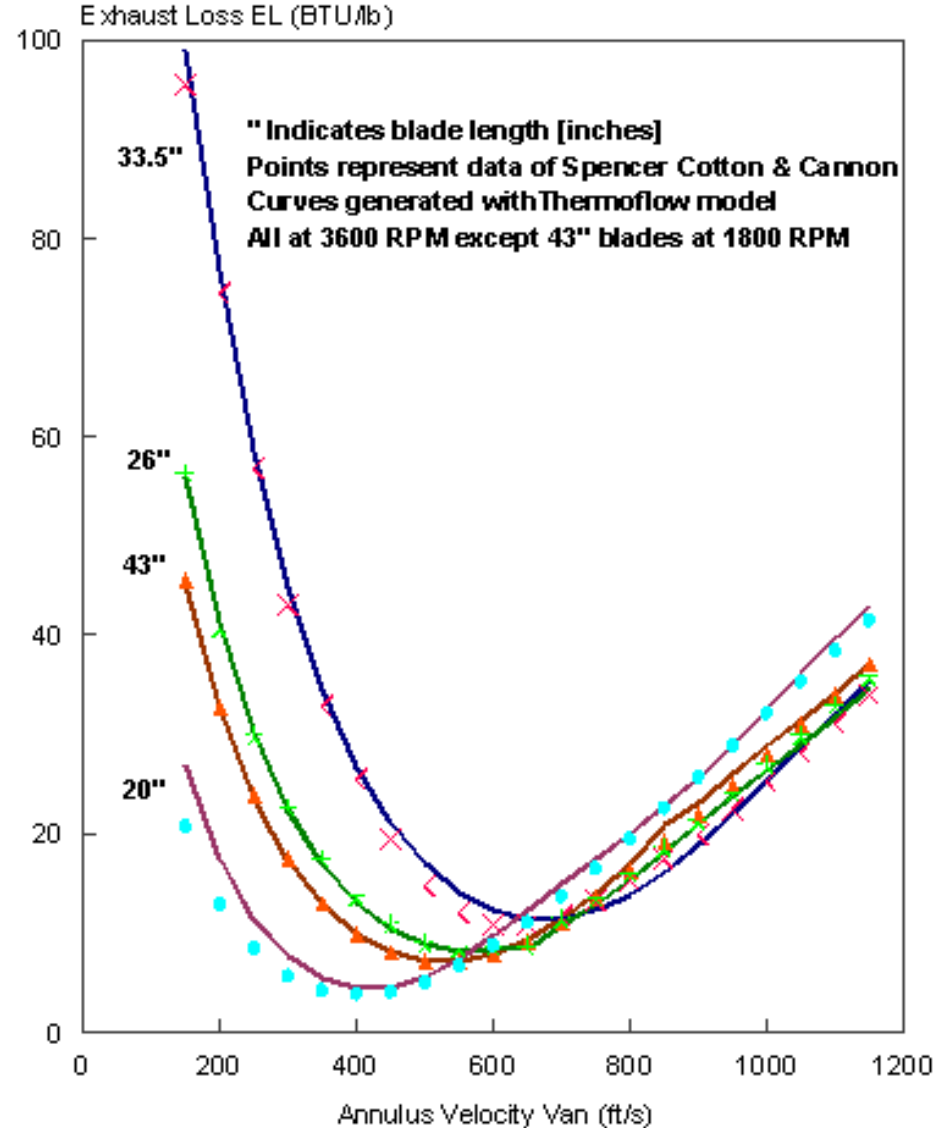


OEM Exhaust End – Losses Data

| | | |
|------------------------|-------|-------|
| Annulus velocity | 214.1 | m/s |
| Dry exhaust loss | 22.04 | kJ/kg |
| Corrected exhaust loss | 17.18 | kJ/kg |

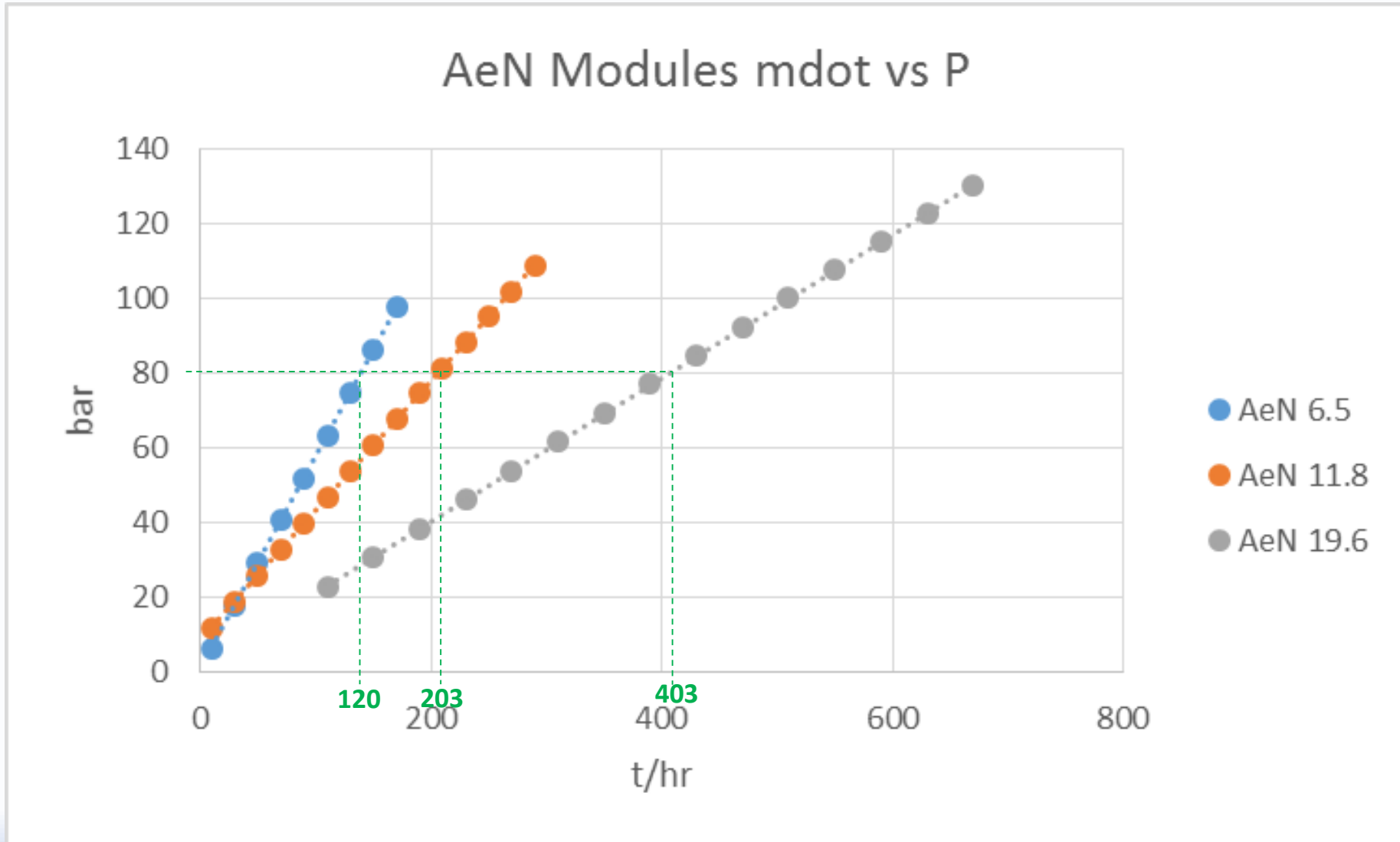


Reference Material – Last Stage Blade Lengths (Condensing ST)

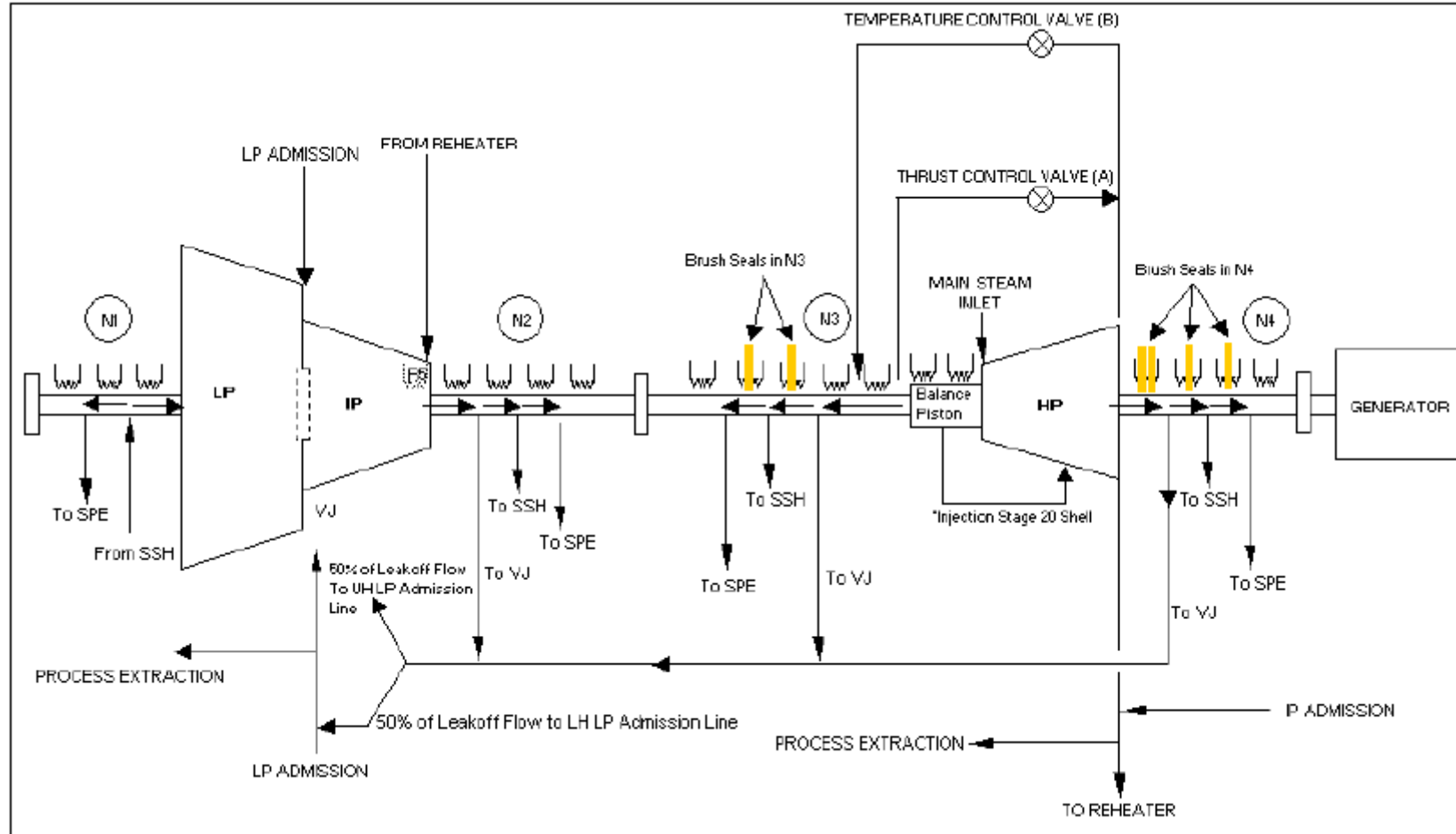


From TF Help
Menu, GTPro, Ch.
12.5.1

Reference Material – Pressures & Flow Areas



Reference Material - Typical Sealing System for ST Configuration Being Considered



Q & A Time....