50 MW_e and 450 MW_e sCO_2 Turbine concepts for Fossil-based Power Generation

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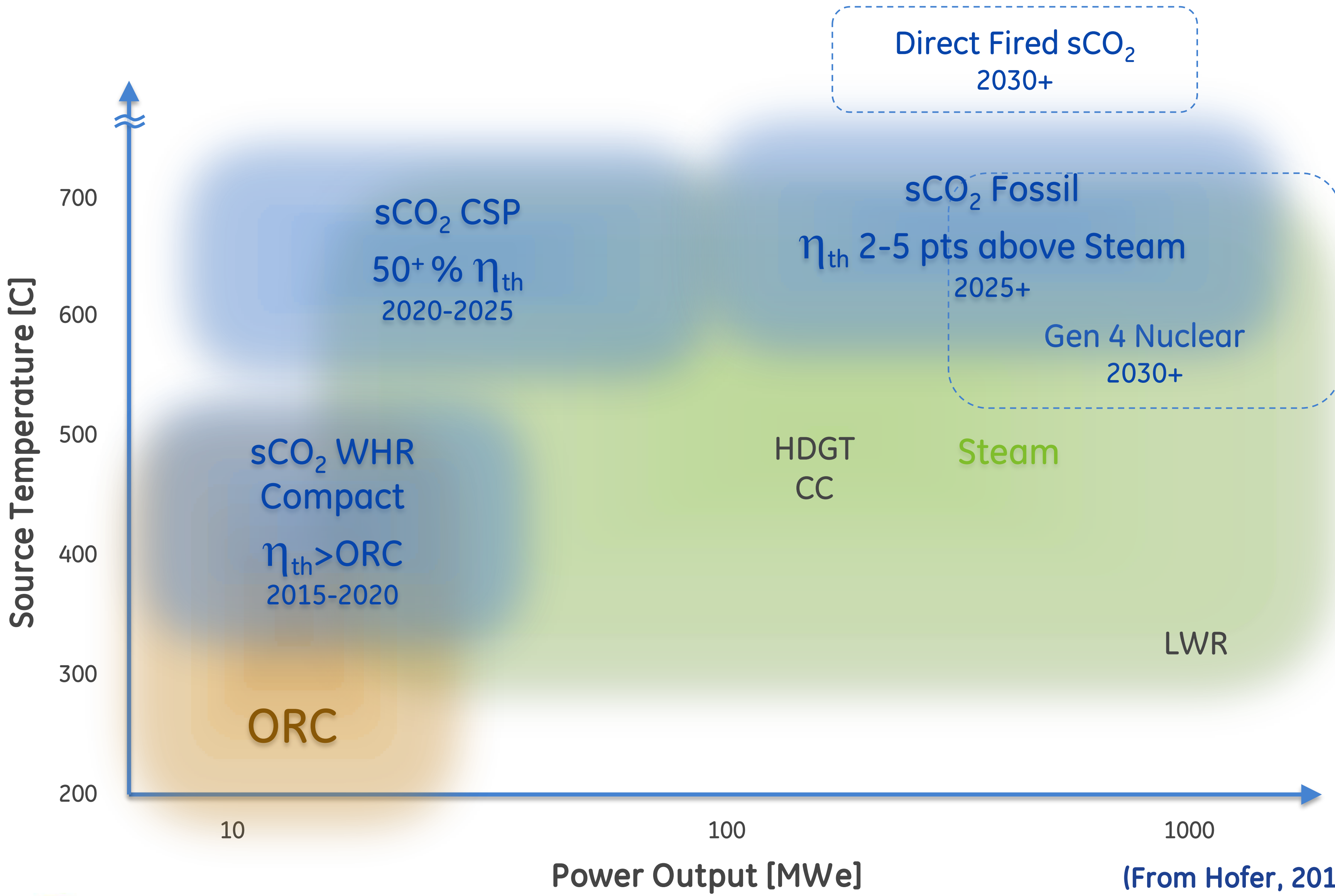
sCO_2 Application Space



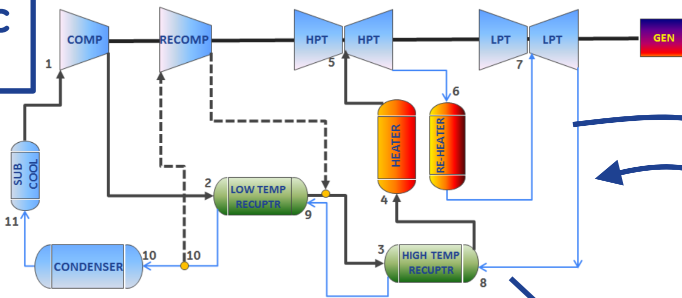
(From Hofer, 2014)

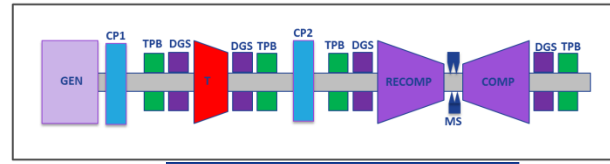
Outline

- Overview – sCO_2 power cycles
- Overview of the Turbine Design process
- Thermodynamic Cycle Modeling
- Layout considerations
- Turbine designs
  - Aero design
  - Mechanical Design
  - Rotordynamic considerations
- Turbine Technology Gaps

Overview - Turbine Design Process

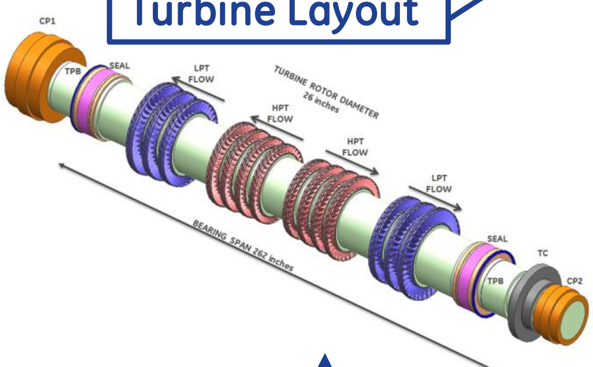
Thermodynamic cycle modeling





Layout considerations

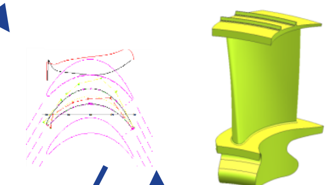
Turbine Layout



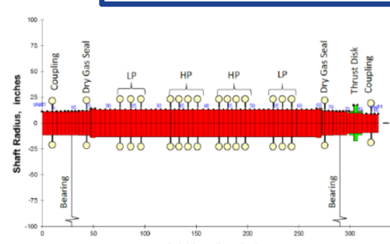
Turbine Specifications

- Pressure, temperatures
- Speed
- Target efficiency

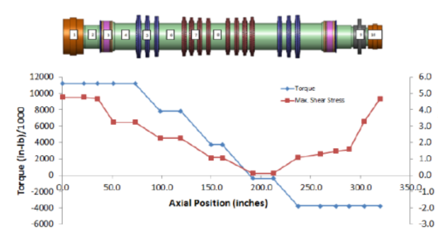
Turbine Aero



Turbine Rotordynamics



Turbine Mechanical Design



Highly iterative and coupled process

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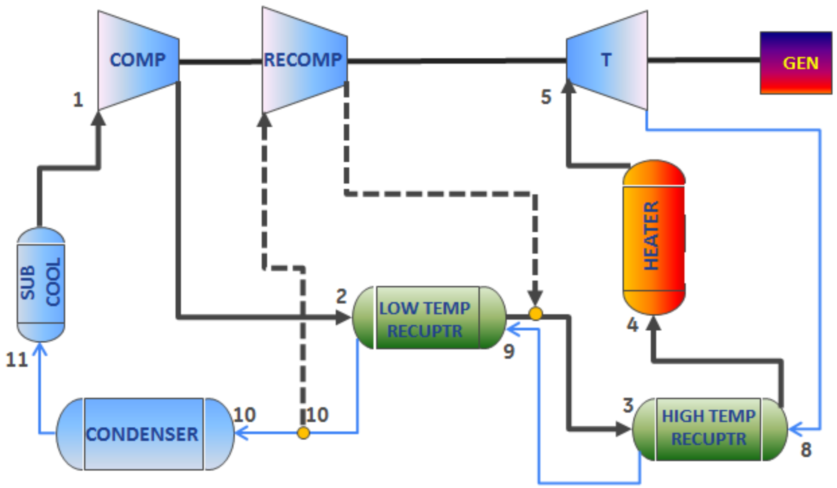
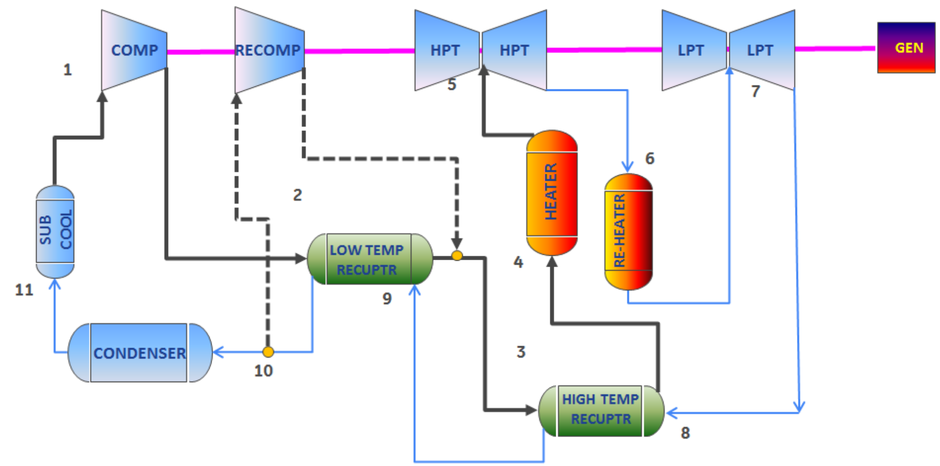
Thermodynamic cycle modeling

50 MW_e cycle - 49.6% efficient cycle



450 MW_e cycle – 51.9% efficient cycle



- Starting point – Recompression 10 MW_e Sunshot cycle
- 700°C, 251 bar turbine inlet
- Water-cooled condenser at ISO ambient -- liquid at compressor inlet
- Reheat assumed for the 450 MW_e cycle
- No restrictions assumed on heater, reheater
- Designed HPT, LPT, compressor and re-compressor
- Assumed compact heat exchangers
- Loss models for turbine diffusors, re-heater & piping
- Seal leakage penalty modeled separately

Layout constraints

50 MW_e design

- Scale-up of the 10 MW_e GE-SwRI design
- Gearbox between high-speed turbine & generator
- Turbine rotor – single forging
- Integral blades
- Speed 9500 rpm

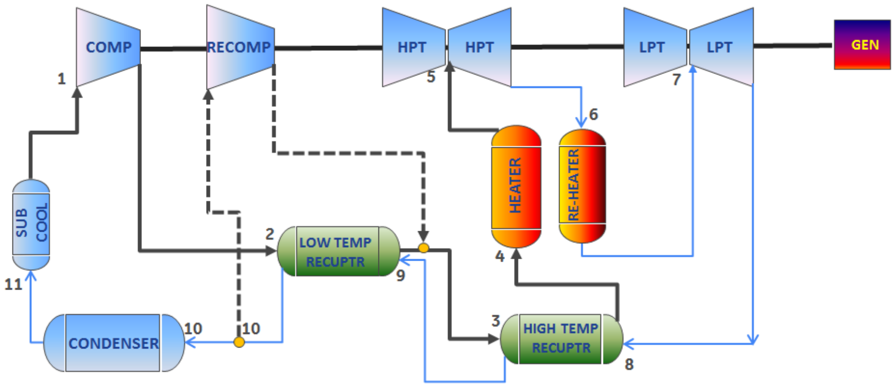
450 MW_e design

- Clean sheet design
- No gearboxes, generator and turbine are directly coupled
- Coupled stages, large forgings
- Blades attached with dovetail joints
- Speed 3600 rpm

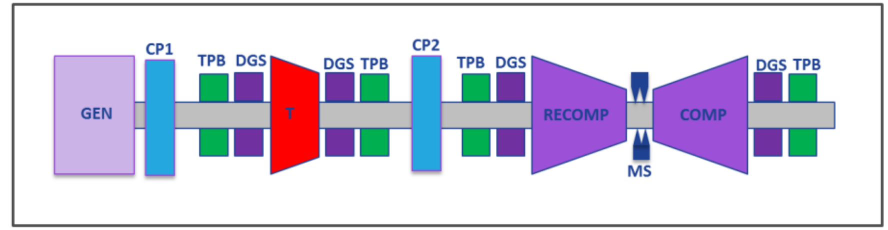
- 50 MW_e size is the upper limit for scaling the Sunshot architecture
- 450 MW_e was a clean sheet design

450 MW_e – Layout Conceptual design & Cycle design

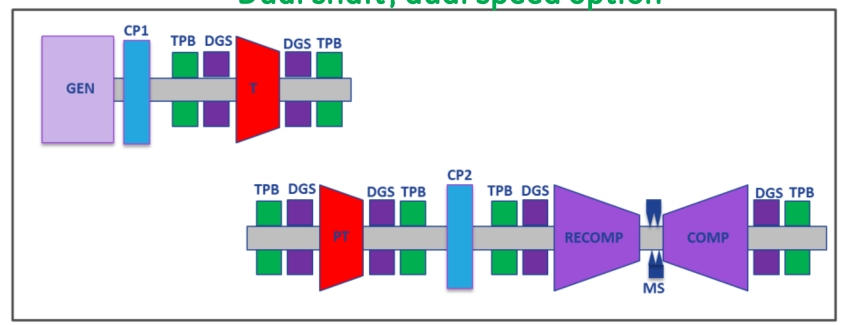
450 MW_e Thermodynamic cycle



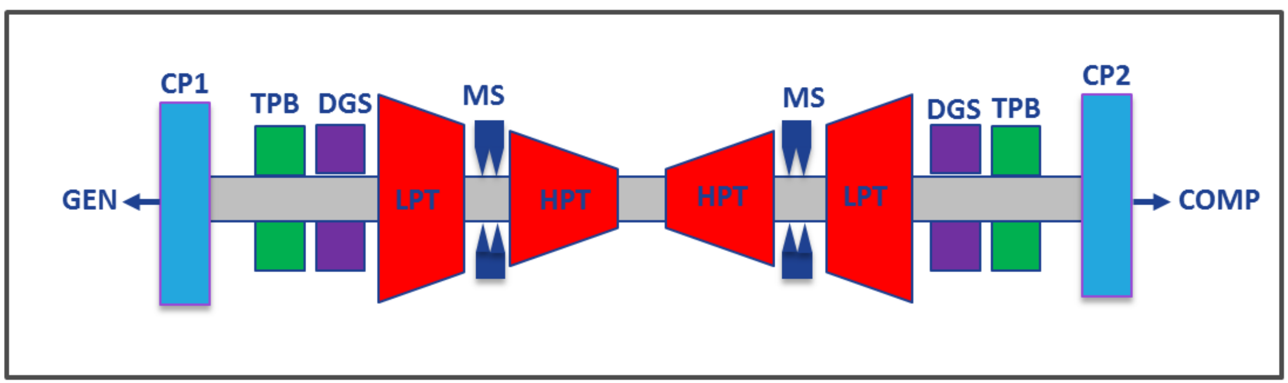
Single shaft, single speed option



Dual shaft, dual speed option



Final turbine layout – single shaft, single speed, dual flow, single casing

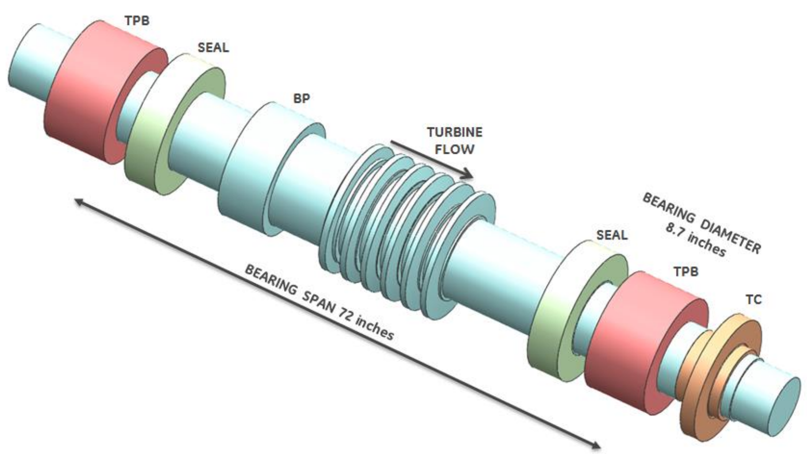


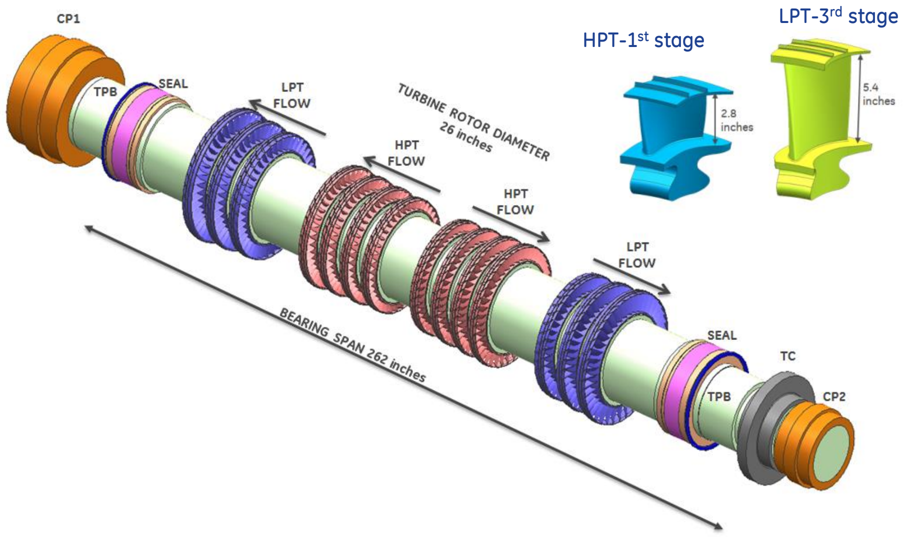
Reheat cycle with single-shaft, single speed layout and dual flow turbines to maximize efficiency

Aero design & layouts for 50 MW_e and 450 MW_e scales

50 MW_e design

450 MW_e design





- 6-stage single flow
- 9500 rpm
- 72-inch bearing span, 8.7-inch bearing diameter

- 4-stage HPT, 3-stage LPT, both dual flow
- 3600 rpm
- 262-inch bearing span, 26-inch bearing diameter

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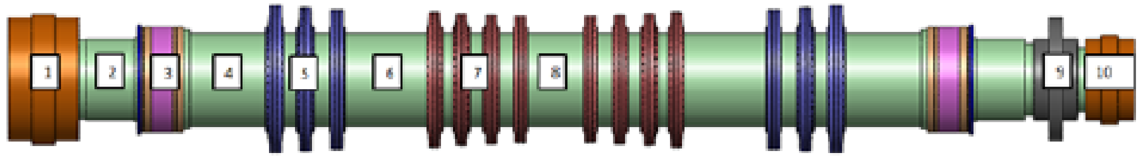
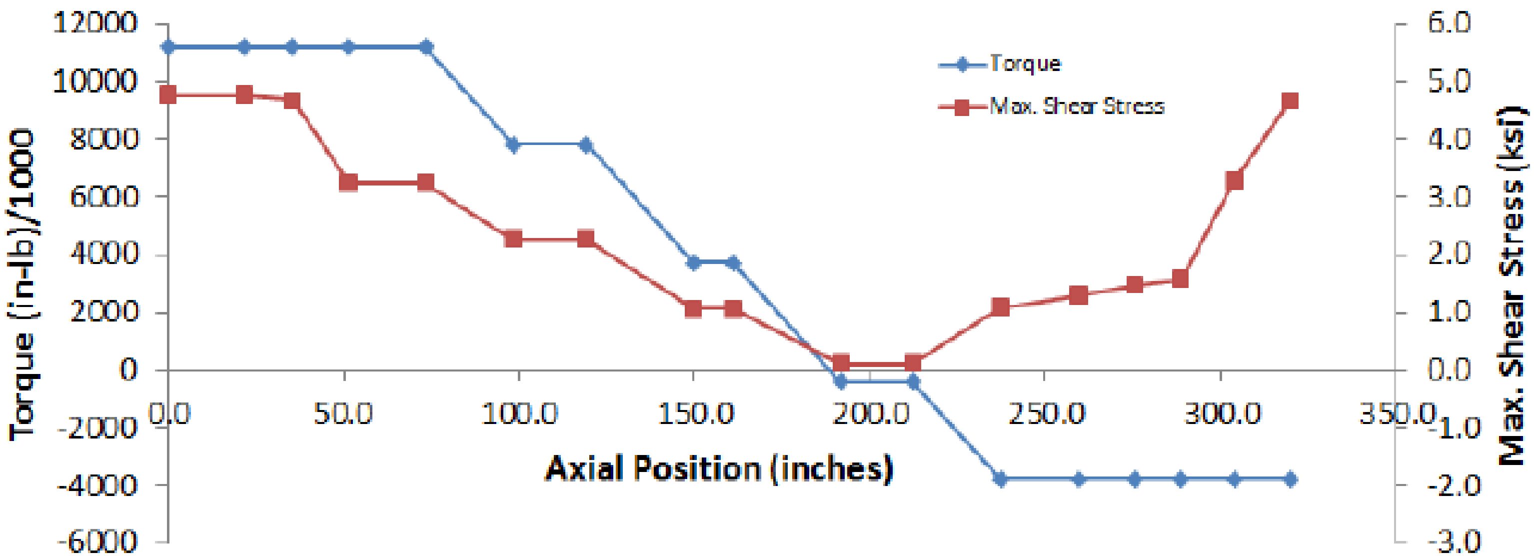
Turbine Axial Sizing & Mechanical Design





- Turbine axial sizing performed based on space needed for bearings, seals, inlet and exit diffusors, thermal management section
- Rotors, blade roots , dovetails analyzed for stress

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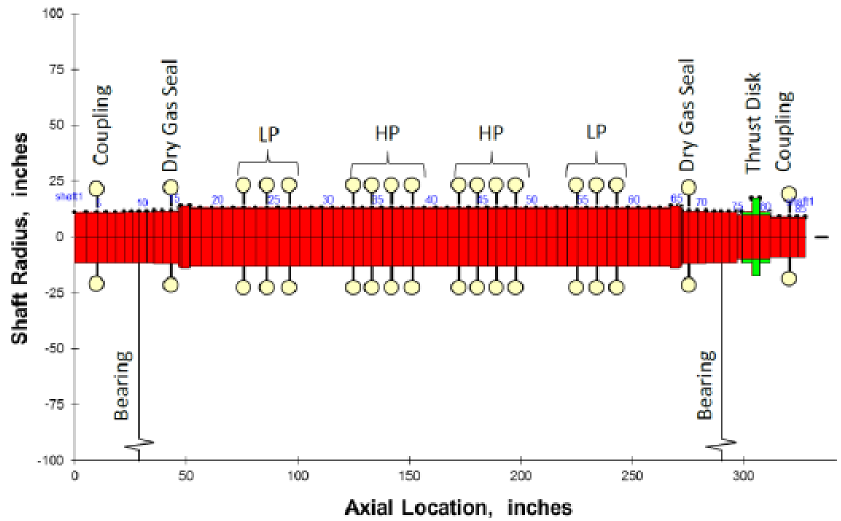
Turbine Rotordynamic Studies



- Analysis performed using XLTRC code on three configurations

- Rigid bearing analysis
  - Separation margin – Second mode operation close to operating speed.
  - Good stability but not enough margin

- Reduced coupling weight led to an acceptable rotordynamic configuration

- Soft-mounted bearings and squeeze film dampers --- an alternate configuration with good stability and required separation margins

Two configurations with acceptable rotordynamic stability

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Summary and Conclusions

- Presented a thermodynamic cycle with 51.9% cycle efficiency
    - Reheat cycle with recompression for 450 MW net electric output
- Presented conceptual design for turbine
    - Dual flow single casing HPT and LPT
    - Mechanical design and rotordynamic studies
- Overall, the 450 MW_e turbine concept is feasible based on preliminary design considerations

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