Project GA1: Advanced-cycle Power Generation Demonstrator Notes

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Abstract

These notes are intended to assist demonstrators for the Advanced-cycle Power Generation project with the most common student questions. Comments on selected tasks are given in handout order, including both thermodynamic insight and practical analysis hints. Some things to look for when debugging the code are also suggested.

1 Gas turbines

- The design conflict is that the pressure ratio for maximum specific work is much lower than the pressure ratio for maximum efficiency. But, the efficiency curves are relatively flat so a compromise is possible.

- The cooling flow rate $\dot{m}_c$ required for a given turbine entry temperature T_3 can be estimated as,

$$\dot{m}_c = K \frac{T_3 - T_\mathrm{m}}{T_\mathrm{m} - T_2}$$

  where T_m is the allowable metal temperature, T_2 is the cooling air temperature i.e. the compressor exit temperature, and the constant $K = 0.18$. This is suggested by Horlock in *Advanced Cycle Gas Turbines*.

2 Steam plant

- The temperature difference between the stack and feed water, requested as input data, is determined from heat transfer considerations. A small difference implies low heat flux, large area and large cost. A large difference implies irreversibility.

- It is much easier to vary the number of feedheaters by performing one-off calculations. The code limits the number of feedheaters per turbine to eight. To loop over the number of feedheaters, first get the saturation temperatures at the condenser and boiler pressures using `TSAT`. Then, split the temperature rise equally, assuming that the specific heat capacity does not change very much, and call `PSAT` to get the extraction pressures at each temperature.

- When changing steam temperature and pressure, the effect of changing wetness fraction on the isentropic efficiency of the turbine is not modelled.

- The evaporator comes first due to the need to cool combustion gases as quickly as possible to control material life. The evaporator has large temperature difference and a high heat transfer coefficient. The plant layout diagram is helpful for visualising this.

- The flue gas leaving the boiler must be hotter than the feed water. So, the larger the feedheating train, the more air preheat must be applied to keep the stack temperature low. The stack temperature must be above the exhaust dew point to prevent corrosion, setting an upper limit on boiler efficiency.

- A supercritical plant requires a different boiler design, a 'once-through' system rather than a separate evaporator, economiser and superheater as with a subcritical plant. There is no actual boiling because water immediately becomes steam. The boiler pressure and hence material stresses are higher, requiring more expensive materials.

- The constant A is really a conversion factor which can be deduced from dimensional arguments.

3 Combined cycles

- It is good research practice to change one thing at a time. So, find the optimal pressure ratio for the gas turbine and don't change it for the rest of the optimisation. It could be interesting to perform the optimisation again at the end and assess the change.

- The equation,

  $$\eta_{\mathrm{cc}} = \eta_{\mathrm{gt}} + \eta_{\mathrm{st}} - \eta_{\mathrm{gt}}\eta_{\mathrm{st}},$$

  is based on a simple control volume analysis. It is a useful check that the more complicated analysis in the code yields the correct result as the control volume analysis. What is required is to simply write out η_{gt} and η_{st} using the code and plug in to the above equation.

- When installed in simple cycle configuration, gas turbines usually produce much less power than steam turbines. In the combined case, the gas turbine produces more power than the steam turbine. This is because in the combined case the mass flow rate of steam is only about 20% of the gas mass flow rate, and also there is no exhaust exergy penalty on the gas turbine.
- The gas turbine exhaust is not as hot as the boiler outlet in a simple cycle steam plant, so the HRSG design is more straightforward. The sections of the boiler can be placed optimally to reduce the heat transfer temperature difference.
- Feedheating has no effect on the combined cycle efficiency because it is an internal heat transfer, i.e. does not change the average temperature of external heat addition. Feedheating is not used to prevent flue gas corrosion in a combined cycle as in a steam cycle; instead a preheating drum is used.
- When looping, if supplementary firing will not work in a particular case then it will be turned off for the rest of the loop. Setting `SPFIRE = .TRUE.` before each calculation corrects this.

4 Humid cycles

- The maximum amount of water injection is determined by the saturation temperature at the local pressure. Water can be injected until the temperature is reduced to the saturation temperature and the two-phase region is entered.

5 Debugging

Things to check for if the code does not compile or gives unrealistic results, in approximate frequency order:

1. Input data not physically possible.
2. Long line truncated by the compiler, add line continuation with `&` in column 6.
3. Input data is corrupted.
4. Looping variable set in wrong part of loop.
5. Accidental typing somewhere in the source code.
6. Using a variable before it is initialised.
7. Indexing out of bounds of an array.

8. Looping variable is not part of the input data set.

9. Integer division when calculating a float.

If the problem is not obvious, use print statements such as,

```
WRITE (*,*) "test"
```

to see if the code reaches a given point, or,

```
WRITE (*,*) "The␣efficiency␣is␣", EFFCYC
```

to print out the value of a variable. To enable array bounds checking add the following option into the first line of the Makefile:

```
FC = gfortran -fcheck-bounds
```