

16.682: Technology in Transportation

Problem Set #4

Issued: 4/21/2011

Due: 4/28/2011

1. Brayton Cycle:

For gas turbines used in applications where weight is not critical, there are a few ways to re-use the heat of the exhaust gases in order to increase overall system efficiency. (Problem is adapted from material created by Professor Alexander Mitsos, used with permission).

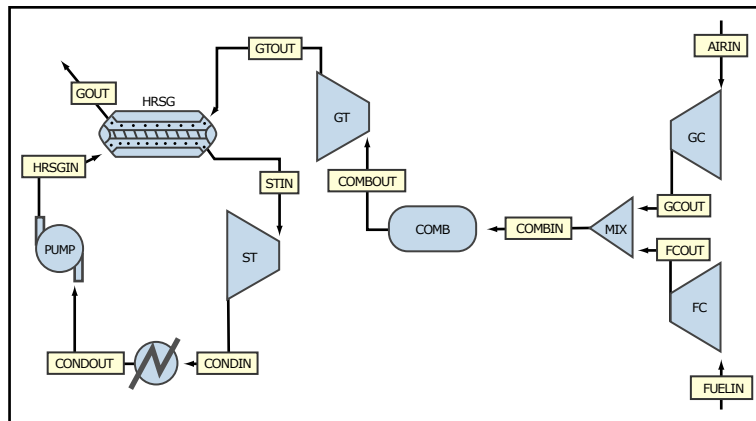


Image by MIT OpenCourseWare.

The system schematic above is for a cogenerating power plant, which runs a Rankine (steam) cycle off of the Brayton (gas turbine) cycle's exhaust gases. In addition to the electrical generator on the gas turbine engine's shaft, there is also a generator on the steam turbine's shaft. Estimate the shaft power output of this combined-cycle plant (hint: you only need the first law of thermodynamics), if you were provided the following minimal information.

Methane flowrate into the turbine:	9.46 kg/sec
Air-fuel ratio for this turbine (by mass):	40:1
Ratio of exhaust gas species (molar ratio):	(CO ₂ : H ₂ O : O ₂ : N ₂) = (1 : 2.3 : 3.1 : 19)
Gas turbine outlet temperature (GTOUT):	1000 K

- 1) What is the mass flow rate of the exhaust gases coming out of the gas turbine?
- 2) What is the mass of one mole of exhaust gases?
- 3) What is the molar flow rate of each exhaust gas molecule (CO₂, H₂O, O₂, N₂), in mol/sec?
- 4) What is the heat capacity of the exhaust gases coming out of the gas turbine?
 - a. Use [source](#) to look up the heat capacity of each molecule at different temperatures. Assume water vapor at 300K is 32.0J/mol*K.

5) How much “power” is lost to the hot exhaust gases? I.E. if you were to heat up these exhaust gases from 300 K to 1,000 K, how much power would that take? Interpolate the average heat capacity of these gases from 1,000 K to 300 K for a rough estimate (note that the heat capacity of the gases change with temperature).

6) What is the mechanical power output of the gas turbine shaft?

7) If an ideal heat engine could cool down the exhaust gases to slightly above ambient temperature (400K), what is the maximum work output that this engine could provide?

8) Suppose you know that a simple single-stage Rankine cycle typically has thermal efficiencies of about 35%. How much power can you expect this “bottoming” cycle to put out?

2) Propeller Mechanics

A survey vessel has a B 5-90 propeller with a diameter (d) of 10 ft and a pitch (p) of 10 ft. The propeller speed is 200 rpm and the boat speed (V_s) is 20 knots. The thrust reduction factor (t) is 0.12, the wake fraction (w) is 0.18, and the relative rotational efficiency is 1.0. Ensure that you make SI unit conversions as necessary. If certain terms are unfamiliar, look them up in the notes or online for quick clarification.

Using a B 5-90 prop curve, you determine that the constants K_T and K_Q for this propeller are:

$$K_T = 0.12 \quad K_Q = 0.023$$

The following equations hold:

$$\text{Thrust} = K_T \cdot \rho \cdot n^2 \cdot d^4 \quad \text{Torque} = K_Q \cdot \rho \cdot n^2 \cdot d^5$$

Where d = prop diameter, ρ = density of water, and n = speed of propeller in rev/s

Determine:

- (a) Propeller Advance Ratio (you should be using V_s , w , n , and d)
- (b) Propeller Thrust (in pounds of force)
- (c) Shaft torque (in foot-pounds)
- (d) Effective Horsepower P_E (EHP) of the Boat (*power required to overcome the vessel's resistance at the given speed*)
- (e) Delivered Propeller Shaft horsepower (P_D) (*power actually transmitted along propeller shaft to the propeller at a particular RPM*)

- (f) The Propeller Quasi Efficiency (*think about the how much we're getting out versus how much we put in*)

3) Signal Processing

Download the file 'modsignal.mat' from the course website and open it in Matlab. Your goal is to take this modulated signal and reconstruct the original base band waveform.

(a) Perform a Fourier analysis to identify the carrier frequency. (*hint: look up how to use the `fft()` function in Matlab*)

(b) Based on the presentation of modulation/demodulation in lecture, reconstruct the base band signal using the determined carrier frequency. Plot the original signal in Matlab. Turn in your Matlab code and plot.

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