UNIVERSITY OF MALTA
FACULTY OF ENGINEERING
B.ENG.(HONS.) IN MECHANICAL ENGINEERING
YEAR III – SEMESTER I
JANUARY/FEBRUARY 2014 SESSION OF EXAMINATIONS

MEC 2307 – Thermodynamics II **27th January, 2014**

0915 -1215 hours

This paper contains **SIX** *questions. You are to attempt* **FIVE**.

Stationery: Use of calculators is allowed
Steam Tables

1. (a) Show that for a nozzle, the critical pressure ratio is given by

$$\frac{p_c}{p_1} = \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$$

(10 marks)

(b) Calculate the throat and exit areas of a nozzle to expand air at the rate of 4.5kg/s from 8.3 bar, 327°C into a space at 1.38 bar. Neglect the inlet velocity and assume isentropic flow.

If a thermometer was placed at the exit plane, assuming that the air around the thermometer is brought to rest adiabatically, what is the temperature measured by the thermometer and comment on this value?

(10 marks)

2. The analysis by mass of a sample of petrol was 84% C, 14 % H and 2% O. Combustion under rich conditions of this petrol resulted in products with dry analysis 13% CO_2, some CO and the remainder N_2.

Calculate
(a) the stoichiometric AFR.
(b) the actual AFR.
(c) the percentage of CO in the exhaust on a dry basis.
(d) the mass of H_20 vapour in the exhaust per kg of total exhaust gases.
(e) the partial pressure of N_2 in the exhaust when the temperature and pressure of the exhaust gases are 350°C and 1bar.

(20 marks)

3. (a) Show that for the Otto cycle, the air standard efficiency is

$$\eta = 1 - \frac{1}{r_v^{\gamma-1}}$$

where r_v is the compression ratio

(8 marks)

(b) A three cylinder engine based on the Otto cycle has a swept volume of 1.4 litres. The compression ratio is 10.2. The intake conditions are 101 kPa and 20 ^{o}C. The maximum cycle temperature is 1400 ^{o}C. Calculate the cycle efficiency, work ratio and the mean effective pressure.

(12 marks)

4. (a) A three stage, single-acting compressor is required to compress 135m^3 of free air per hour from 1 bar, 15^{o}C to 64 bar. All three stages have equal pressure ratios, intercooling is complete, and n =1.3 for each stage.

(i) What are the temperatures at the inlet and outlet of each stage?
(ii) What is the mass flow of air in kg/s?
(iii) What is the amount of energy rejected in each intercooler?
(iv) Calculate the power needed.

(b) If the mean piston speed is to be 140m/min, and all the stages have the same stroke, calculate the piston areas, neglecting clearance.

Sketch the *pv* diagram.

(20 marks)

5. A gas turbine unit has two centrifugal compressors in series with intercooling between stages and an overall pressure ratio of 6/1. The compressors have equal pressure ratios and intercooling is complete between stages. The expansion is in two turbine stages, the first stage driving the compressors and the second stage driving an electrical generator through gearing. The HP turbine inlet temperature is 800 ^{o}C and the air inlet temperature to the unit is 15 ^{o}C. The isentropic efficiency of each compressor is 0.8 and that of each turbine is 0.85. The mechanical efficiency of each shaft is 98 %. Neglect pressure losses and changes in kinetic energy.

For the compression of air γ=1.4 and c_p= 1.005 kJ/kgK while for the combustion and expansion processes γ=1.3 and c_p= 1.15 kJ/kgK.

Calculate
(a) the heat input per kg of air
(b) the power available at the generator input shaft for 0.7kg/s of mass air flow
(c) the overall cycle efficiency
(d) the specific fuel consumption when the calorific value of the fuel used is 42600 kJ/kg and the combustion efficiency is 97%.

(20 marks)

6. (a) A vapour compression refrigerator using R12 works with an evaporator pressure of 2.191 bar and a condenser pressure of 8.477 bar. The compressor receives the refrigerant with 5K of superheat and there is 5K of subcooling in the condenser.

    (i) If the compression process has an isentropic efficiency of 0.9, what is the exit temperature of the refrigerant from the compressor.

    (ii) Calculate the work input, refrigeration effect and coefficient of performance.

(10 marks)

   (b) In a regenerative steam cycle employing one closed feed heater the steam is supplied to the turbine at 50 bar and 500 ^{o}C and is exhausted to the condenser at 0.03 bar. The bleed steam for feed heating is taken at a pressure of 4 bar.

   Sketch the *Ts* diagram.

   Assuming ideal processes and neglecting feed pump work, calculate:

   (i) the fraction of the boiler steam bled for feed heating
   (ii) the power output of the plant per unit mass flow rate of boiler steam
   (iii) the cycle efficiency

(10 marks)

Additional information

$$\frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{n-1} \quad \text{and} \quad \frac{T_1}{T_2} = \left(\frac{p_1}{p_2}\right)^{(n-1)/n}$$

$$W = \frac{(p_2 v_2 - p_1 v_1)}{n-1} = \frac{R(T_2 - T_1)}{n-1}$$

where W is specific work, p is pressure and v specific volume, n is the polytropic index, R is the specific gas constant and T is the temperature. Subscripts 1 and 2 refer to the states

For a reciprocating air compressor, $W_i = \frac{n}{n-1} \dot{m} R T_1 \left\{ \left(\frac{p_2}{p_1}\right)^{(n-1)/n} - 1 \right\}$

$$s_2 - s_1 = c_p \ln\left[\frac{T_2}{T_1}\right] + R \ln\left[\frac{p_1}{p_2}\right]$$

$$\frac{p_c}{p_1} = \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma}{\gamma - 1}}$$

Where p_c is the critical pressure for a nozzle, p_1 is the upstream pressure, and γ is the ratio of specific heats i.e. c_p / c_v

$$C_c = \sqrt{\gamma R T_c}$$

$$Nozzle\, Efficiency = \frac{C_2^2 - C_1^2}{C_{2s}^2 - C_1^2}$$

$$Velocity\ Coefficien\,t = \frac{C_2}{C_{2S}}$$