higher education
& training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

T1460**(E)**(A11)T

NATIONAL CERTIFICATE

POWER MACHINES N6

(8190046)

11 April 2017 (X-Paper)
09:00–12:00

REQUIREMENTS: Steam tables (BOE 173)

Calculators may be used.

This question paper consists of 6 pages and a formula sheet of 5 pages.

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DEPARTMENT OF HIGHER EDUCATION AND TRAINING
REPUBLIC OF SOUTH AFRICA

NATIONAL CERTIFICATE
POWER MACHINES N6
TIME: 3 HOURS
MARKS: 100

NOTE: If you answer more than the required number of questions only the required number of questions will be marked. All work you do not want to be marked must be clearly crossed out.

INSTRUCTIONS AND INFORMATION

1. Answer any FIVE questions.
2. Read ALL the questions carefully.
3. Number the answers according to the numbering system used in this question paper.
4. Questions may be answered in any order but subsections of questions must be kept together.
5. ALL formulae used must be written down.
6. Show ALL intermediate steps.
7. Questions must be answered in blue or black ink.
8. ALL sketches and diagrams must be done in pencil in the ANSWER BOOK.
9. Write neatly and legibly.

QUESTION 1

An intercooled three-stage reciprocating air compressor is rated at 1,42 m^3/s measured at 32°C and 86 kPa absolute and delivery pressure of 1 155 kPa absolute. The mass flow rate per second is 1,3951 kg. Assume that the stage pressures are in geometric progression and that there is perfect intercooling between stages but no aftercooler. Assume that $n = 1{,}3$ for both compression and expansion. Assume Cp as 1,005 kJ/kg.K, Cv as 0,718 kJ/kg.K and $\gamma = 1{,}4$.

Calculate the following:

1.1 The heat removed from the two intercoolers in kJ/s (6)

1.2 The heat removed by the water jackets in kJ/s (5)

1.3 The actual work done in kJ/s (5)

1.4 The isothermal efficiency (4)

[20]

QUESTION 2

During the planning stage of a steam plant it was determined that 21 650 kg steam per hour at a pressure of 0,5 MPa and a temperature of 200 °C were required. The heating areas of the evaporator are planned to absorb 80% of the available heat, the super heater 5% and the economiser 15%. The available feed-water temperature is 34,6 °C. The planned efficiency of the plant is 70%. The temperature of the gases is 760 °C while the atmospheric temperature is 15 °C. Waste gases will be used for the heating of the plant. Assume Cp for waste gases as 1,1 kJ/kg.K.

Calculate by using steam tables:

2.1 The mass of waste gas required in kg/h (7)

2.2 The temperature of the gas leaving the evaporator in °C (5)

2.3 The temperature of the gas leaving the super heater in °C (4)

2.4 The temperature of the gas leaving the economiser in °C (4)

[20]

QUESTION 3

A four-cylinder petrol engine operates on the four-stroke Otto cycle principle and is required to deliver a brake power of 83,6 kW at 3 100 r/min with a mechanical efficiency of 80% while the indicated mean effective pressure is 600 kPa. The stroke length is 1,43 times the piston diameter. Assume that the free volume is 12,5% of the stroke volume. The relative efficiency based on the brake power circumstances is 53%. Assume R = 0,287 kJ/kg.K, Cp = 1,005 kJ/kg.K and $\gamma = 1,4$.

Calculate the following:

3.1 The piston diameter and stroke length in mm (6)

3.2 The swept volume, clearance volume and cylinder volume in m^3 (6)

3.3 The volumetric compression ratio to one decimal (2)

3.4 The air standard efficiency (3)

3.5 The brake thermal efficiency (3)

[20]

QUESTION 4

Steam enters a group of convergent-divergent nozzles at a pressure of 2,2 MPa and a temperature of 260 °C. The rate of steam flow through the nozzle is 11 kg/s. The Cp value for the superheated steam at the entry to the nozzle is 3,294 kJ/kg.K. At the throat the steam is still superheated at 190 °C with a pressure of 1 200 kPa and a Cp value of 5 kJ/kg.K. Expansion through the nozzle takes place to an exit pressure of 0,4 MPa. From the throat to the exit there is an expansion efficiency of 85%. At the exit the steam is wet at an isentropic dryness fraction of 0,93. Up to the throat the flow can be considered to be frictionless.

Calculate the following using steam tables:

4.1 The enthalpy of the steam at the inlet and the isentropic enthalpy at the exit (6)

4.2 The enthalpy of the steam at the throat and the enthalpy at the exit (6)

4.3 The throat and exit velocities in m/s (4)

4.4 The throat and exit areas in mm^2 (4)

[20]

QUESTION 5

The following information refers to a four-stroke, four-cylinder petrol engine rotating at 4 400 r/min:

- Compression ratio = 7,5 : 1
- Cylinder diameter = 75 mm
- Stroke length = 105 mm
- Brake power = 37 kW
- Indicated power = 47 kW
- Air consumption = 21 kg/kg fuel
- Fuel consumption = 13,7 kg/h
- Heat value of fuel = 41,8 MJ/kg
- At STP conditions = 0 °C and 101,325 kPa

Assume that R = 0,287 kJ/kg.K and γ = 1,4 and calculate the following:

5.1 The mechanical efficiency (2)

5.2 The indicated mean pressure in kPa (3)

5.3 The volumetric efficiency at STP (7)

5.4 The brake thermal efficiency (3)

5.5 The efficiency ratio based on brake conditions (5)
[20]

QUESTION 6

The following information is known about a two-stage velocity compounded impulse turbine:

- Average blade circumferential velocity = 200 m/s
- Velocity leaving the nozzle = 900 m/s
- Nozzle angle = 25°
- Velocity of flow at outlet side of first row of moving blades = 250 m/s
- Velocity of flow at inlet side of second row of moving blades = 100 m/s
- Relative coefficient of velocity of first row of moving blades = 0,8
- Velocity entering the second row = 328 m/s
- Ratio between exit relative velocity and inlet relative velocity of second row (no change in velocity of flow for second row) = 1,867
- The mass flow rate = 2 kg/s
- Use a scale of 1 mm = 5 m/s

6.1 Draw velocity diagrams for the turbine in the ANSWER BOOK. Indicate the lengths of ALL the lines as well as the magnitude of the angles. (14)

6.2 Determine the following from the velocity diagrams:

6.2.1 The power developed in kW

6.2.2 The axial thrust in N

(2 × 3) (6)
[20]

QUESTION 7

A simple heat pump circulates Freon-12 and is required for heating. The heat pump cycle consists of a vaporiser, compressor, condenser and a choke control valve. The pressure limits vary between 491 kPa and 1,219 MPa. The heat transfer required from the condenser unit is 102 MJ/hour. Assume that the Freon-12 refrigerating agent is dry-saturated at the beginning of compression and is at 55 ºC after compression. After the condensation effect the refrigerating agent is a liquid (not under-refrigerated). Assume the specific heat capacity of the superheated vapour as a constant.

The following characteristic table refers to the Freon-12:

Pressure	**Saturation temperature**	**Specific enthalpy (kJ/kg)**		**Specific entropy (kJ/kg/K**	
kPa	(°C)	Liquid (hf)	Vapour (hg)	Liquid (sf)	Vapour (sg)
491	15	50,1	193,8	0,1915	0,6902
1 219	50	84,9	206,5	0,3037	0,6797

Calculate the following:

7.1 The specific heat capacity of the superheated vapour (4)

7.2 The mass flow rate of the Freon-12 in kg/s if no loss is observed (7)

7.3 The dryness factor of the Freon-12 at the entrance to the vaporiser (3)

7.4 The power of the motor if only 80% of the power is available for the Freon-12 in kW (6)

[20]

TOTAL: 100

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FORMULA SHEET

Any applicable formula may also be used.

ENGLISH

$$\mathrm{PV} = \mathrm{c}$$

$$\mathrm{PV}^{\mathrm{n}} = \mathrm{c}$$

$$\mathrm{PV}^{\gamma} = \mathrm{c}$$

$$Q = \Delta U + Wd$$

GENERAL

$$P_a V_a = mRT_a$$

$$R = Cp - Cv$$

$$\gamma = \frac{Cp}{Cv}$$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{n-1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$$

$$\Delta U = m \,.\, Cv \,.\, \Delta T$$

$$\Delta s = m\left(Cv \,.\, \ln \frac{P_2}{P_1} + Cp \,.\, \ln \frac{V_2}{V_1}\right)$$

$$\Delta s = m \,.\, Cv \,.\, \ln \frac{P_2}{P_1}$$

$$\Delta s = m \,.\, Cp \,.\, \ln \frac{V_2}{V_1}$$

$$\Delta s = m \,.\, R \,.\, \ln \frac{P_1}{P_2}$$

$$Q = m \,.\, Cp \,.\, \Delta T$$

$$Q = m \,.\, Cv \,.\, \Delta T$$

$$S_{su} = S_g + Cp \,.\, \ln \frac{T_{su}}{T_s}$$

$$S_{fg} = S_g - S_f$$

$$S = S_f + xS_{fg}$$

$$h_{su} = h_g + Cp\,(t_{su - t_s})$$

ENGLISH

$$h_{ws} = h_f + xh_{fg}$$

$$V_{ws} = xV_g$$

GENERAL

$$V_{su} = \frac{\frac{n-1}{n}(h_{su} - 1941)}{P_{su}}$$

$$r = \frac{V_s + V_c}{V_c}$$

$$V_s = \frac{\pi}{4} d^2 \times L$$

$$P_2 = \sqrt{P_1 \times P_3}$$

$$r_{ps} = \sqrt[x]{\frac{P_{x+1}}{P_1}}$$

Different formulae for work done (Wd)

$$= P \times \Delta V$$

$$= P_1 V_1 \ln \frac{V_2}{V_1}$$

$$= \frac{P_1V_1 - P_2V_2}{n-1}$$

$$= \frac{P_1V_1 - P_2V_2}{\gamma - 1}$$

$$= m \,.\, Cp \,.\, \Delta T$$

$$= \frac{xn}{n-1} P_1 V_e \left[\left(\frac{P_{x+1}}{P_1} \right)^{\frac{n-1}{xn}} - 1 \right]$$

$$= \frac{xn}{n-1} mRT_1 \left[(r_{ps})^{\frac{n-1}{n}} - 1 \right]$$

ENGLISH **GENERAL**

Different formulae for work done (Wd)

= *area of PV-diagram*

= *work done first stage + work done second + stage + ...*

$$Wd_{nett} = Wd_t - Wd_c$$

$$Wd_{nett} = Q_{nett}$$

Different formulae for air standard efficiencies (ASE)

$$= 1 - \left(\frac{1}{r}\right)^{\gamma - 1}$$

$$= 1 - \frac{r_p r_c^{\gamma - 1}}{r_v^{\gamma - 1}\,[(r_p - 1) + \gamma^{r_p}\,(r_c - 1)]}$$

$$= \frac{heat\ added - heat\ rejected}{heat\ added} = 1 - \frac{\beta^{\gamma} - 1}{r^{\gamma - 1} \times \gamma\,(\beta - 1)}$$

Different volumetric efficiencies, 0_{vol}

$$= \frac{Volume\ of\ air\ taken\ in}{Swept\ volume}$$

$$= \frac{Volume\ of\ free\ air}{Swept\ volume}$$

$$= 1 - \frac{V_c}{V_s}\left[\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} - 1\right]$$

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ENGLISH **GENERAL**

Different thermal efficiencies, 0_{therm}

$$\eta_{braketherm} = \frac{BP}{m_{f/s} \times CV}$$

$$\eta_{ind.\,therm} = \frac{IP}{m_{f/s} \times CV}$$

$$\eta_{therm} = \frac{m_s\,(hs - hw)}{m_f \times CV}$$

$$\eta_c = \frac{T_2^{'} - T_1}{T_2 - T_1}$$

$$\eta_t = \frac{T_3 - T_4}{T_3 - T_4^{'}}$$

$$\eta_{mech.} = \frac{BP}{IP}$$

Indicated efficiency ratio

$$= \frac{\eta_{ind.\,therm}}{ASE}$$

Brake efficiency ratio

$$= \frac{\eta_{braketherm}}{ASE}$$

$$BP = 2\pi\frac{TN}{60}$$

$$T = F \times r$$

$$BP = P_{brakemean}\,LANE$$

$$IP = P_{ind.\,mean}\,LANE$$

$$ISFC = \frac{m_{f/h}}{IP}$$

$$BSFC = \frac{m_{f/h}}{BP}$$

$$COP = \frac{T_1}{T_2 - T_1}$$

$$COP = \frac{RE}{Wd}$$

$$P = m\,.\,U\,.\,\Delta Vw$$

$$F_{ax} = m\,.\,\Delta V_f$$

ENGLISH

GENERAL

$$\eta_{dia.} = \frac{2 \,.\, U \,.\, \Delta Vw}{V_1^2}$$

$$P_c = P_1\left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma}{\gamma - 1}}$$

$$T_c = T_1\left(\frac{2}{\gamma + 1}\right)$$

$$C_c = \sqrt{2 \times 10^3\,(h_1 - h_c) + C_1^2}$$

$$C_2 = \sqrt{2 \times 10^3\,(h_1 - h_2) + C_1^2}$$

$$C_c = \sqrt{2 \times 10^3 \times C_p\,(T_1 - T_c) + C_1^2}$$

$$C_2 = \sqrt{2 \times 10^3 \times C_p\,(T_1 - T_2) + C_1^2}$$

$$A_c = \frac{mV_c}{C_c} \qquad A_2 = \frac{mV_2}{C_2}$$

$$\eta = \frac{h_1 - h_c}{h_1 - h_c'} \qquad \eta = \frac{T_1 - T_c}{T_1 - T_c'}$$

$$\eta = \frac{h_c - h_2}{h_c - h_2'} \qquad \eta = \frac{T_c - T_2}{T_c - T_2'}$$

$$\eta = \frac{h_1 - h_2}{h_1 - h_2'} \qquad \eta = \frac{T_1 - T_2}{T_1 - T_2'}$$

$$EE = \frac{m_s\,(h_s - h_w)}{m_f \times 2\,257}$$

$$\eta_{iso.} = \frac{Wd_{iso.}}{Wd_{poly.}}$$

$$\eta_{rank.} = \frac{Wd}{Q}$$

$$\eta_{carn.} = 1 - \frac{T_2}{T_1}$$

$$h = u + pV$$

$$gZ_1 + U_1 + P_1V_1 + \frac{C_1^2}{2} + Q =$$

$$gZ_2 + U_2 + P_2V_2 + \frac{C_2^2}{2} + Wd$$

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