higher education & training

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REPUBLIC OF SOUTH AFRICA

NATIONAL CERTIFICATE

POWER MACHINES N6

(8190046)

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This question paper consists of 7 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

INSTRUCTIONS AND INFORMATION

1. Answer all the questions.
2. Read all the questions carefully.
3. Number the answers according to the numbering system used in this question paper.
4. Keep subsections of questions together.
5. All sketches and diagrams must be neat, fully labelled and drawn in pencil in the ANSWER BOOK.
6. Write down all formulae used.
7. Show all intermediate steps for calculations.
8. Use only a black or blue pen.
9. Approximate final answers to THREE decimals unless stated otherwise.
10. Write neatly and legibly.

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QUESTION 1

A velocity-compounded, two-stage impulse gas turbine has two rows of moving blades separated by a row of fixed blades. The inlet and outlet angles for the fixed blades are 36° and 17° respectively. The inlet and outlet angles for the first row of moving blades are equal. The velocity of the gas at the inlet to the second stage is 2,2 times the average blade velocity. The mass flow rate of the gas is 62 kg/s. The inlet and outlet angles for the second row of moving blades are equal. There is a 4% loss of velocity across all blades due to friction.

1.1 Use a length of 40 mm for the average blade velocity and construct velocity diagrams for the turbine. Indicate the lengths of all lines in mm, as well as the magnitude of all angles, on the diagrams. (10)

1.2 Calculate the scale if the relative velocity of the gas at the inlet to the first stage is 526 m/s. (1)

1.3 From the diagrams determine:

1.3.1 The magnitude of the angle at which the gas leaves the turbine (1)

1.3.2 The nozzle velocity of the gas in m/s (1)

1.3.3 The velocity of the gas leaving the first stage in m/s (1)

1.3.4 The axial thrust developed in the turbine in N (3)

1.3.5 The power developed by the turbine in MW (3)

[20]

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QUESTION 2

Air at a pressure of 653 kPa and a temperature of 747 °C is expanded in a convergent-divergent nozzle to an isentropic temperature of 477 °C at a rate of 240 kg/min. The velocity of the air at the throat is 584,55 m/s. The isentropic efficiency of the nozzle is 90%. Take the C_p for air as 1,005 kJ/kg.°C and R as 0,287 kJ/kg.°C. Ignore the velocity of the air at the inlet.

Calculate:

2.1 The absolute temperature of the air at the throat (2)

2.2 The value of gamma (2)

2.3 The pressure at the throat in kPa (2)

2.4 At the exit:

2.4.1 The pressure in kPa

2.4.2 The absolute actual air temperature

2.4.3 The velocity of the air in m/s

2.4.4 The specific volume of the air

2.4.5 The area in mm^2

2.4.6 The diameter in mm

(6 × 2) (12)

2.5 The volume of air passing the throat in m^3/s (2)

[20]

QUESTION 3

A test was performed on a steam plant which consisted of an economiser, evaporator and a superheater. The following data was recorded:

Mean boiler pressure	2 MPa
Dryness factor of steam at superheater inlet	0,92
Final steam temperature	250 °C
Feedwater temperature to economiser	59 °C
Feedwater temperature to evaporator	104,8 °C
Mass of steam generated per hour	28 000 kg
Fuel consumption per hour	2 940 kg
Calorific value of fuel	31 MJ/kg
Moisture formation per kg of fuel	0,55 kg
Dry flue gas formation per kg of fuel	16 kg
Temperature of flue gas at economiser outlet	200 °C
Atmospheric temperature	20 °C
Atmospheric pressure	100 kPa
Specific heat capacity of dry flue gas	1,05 kJ/kg.K
Specific heat capacity of water	4,2 kJ/kg.K

3.1 Use only steam tables to calculate:

3.1.1 The heat transfer in the economiser in kJ/kg steam (2)

3.1.2 The heat transfer in the evaporator in kJ/kg steam (2)

3.1.3 The heat transfer in the superheater in kJ/kg steam (3)

3.1.4 The heat lost with the superheated combustion moisture leaving the plant with the flue gases in kJ/min (3)

3.1.5 The heat lost with the dry flue gases in kJ/min (3)

3.2 Draw up a heat balance, in kJ/min and as a percentage of the heat supplied, to determine the percentage heat lost to radiation. Include all components of the plant as well as the wet and dry flue gases. Assume a 3% energy loss due to ash and unburnt fuel. (7)

[20]

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QUESTION 4

A four-cylinder, four-stroke petrol engine was tested on a Pröny brake whilst rotating at 2 900 r/min. The fuel consumption was 0,3 kg/min for fuel with a calorific value of 43 MJ/kg. The scale on the 1 100 mm long brake arm gave a reading of 17,412 kg nett. The mass of the exhaust gases formed was 290 kg/h and the exhaust gas temperature rise was 530 °C. The ratio of the indicated thermal efficiency to the brake thermal efficiency was 4:3. The cooling water flow rate was 14 kg/min with a temperature rise of 52 °C. The specific heat capacity of the exhaust gas was 1,045 kJ/kg.K and for the water 4,2 kJ/kg.K.

4.1 Calculate:

4.1.1 The brake power in kW (3)

4.1.2 The indicated power in kW (2)

4.1.3 The brake-specific fuel consumption in kg/kW.h (2)

4.1.4 The air-fuel ratio (2)

4.1.5 The energy carried away by the exhaust gases in kJ/min (2)

4.1.6 The indicated thermal efficiency (2)

4.2 Draw up a heat balance, in kJ/min and as a percentage of the heat supplied, to determine the percentage heat lost to radiation. Assume that the heat lost to friction was absorbed by the cooling water. (7)

[20]

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QUESTION 5

A two-stage, single-acting, reciprocating compressor delivers 14,6 kg of air per minute whilst rotating at 310 r/min. The initial pressure and temperature for the low-pressure cylinder are 98 kPa and 24 °C respectively. The air temperature after compression in the low-pressure cylinder is 142 °C. The temperature of the air leaving the intercooler is 59 °C. The pressure ratio for the low-pressure cylinder is 4:1 and for the high-pressure cylinder 3,5:1. The diameter of the low-pressure cylinder is 360 mm with a stroke length of 450 mm.

Calculate:

5.1 The index (n) for compression correct to TWO decimals (4)

5.2 The power required to drive the compressor in kW (4)

5.3 For the low-pressure cylinder:

5.3.1 The effective swept volume in m^3/cycle (3)

5.3.2 The swept volume in m^3/cycle (2)

5.3.3 The volumetric efficiency (2)

5.4 For the high-pressure cylinder (assuming the same volumetric efficiency as the low-pressure cylinder):

5.4.1 The effective swept volume in m^3/cycle correct to FOUR decimals (3)

5.4.2 The swept volume in m^3/cycle correct to FOUR decimals (2)

[20]

TOTAL: 100

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FORMULA SHEET

Any applicable formula may also be used.

$P_a V_a = mRT_a$

$R = Cp - Cv$

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

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

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

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

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

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

$Q = \Delta U + Wd$

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

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

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

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

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

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

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

$S_{fg} = S_g - S_f$

$S = S_f + xS_{fg}$

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

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

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

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$V_{ws} = xV_g$ $\qquad r = \frac{V_s + V_c}{V_c}$

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

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

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

Different formulae for work done (Wd)

$= P \times \Delta V$

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

$= \frac{P_1 V_1 - P_2 V_2}{n-1}$

$= \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$

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

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

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

= *area of PV-diagram*

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

$Wd_{nett} = Wd_t - Wd_c$

$Wd_{nett} = Q_{nett}$

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Different formulae for air-standard efficiencies (ASE)

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

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

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

Different volumetric efficiencies, η_{vol}

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

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

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

Different thermal efficiencies, $\eta_{therm.}$

$$= \frac{Wd}{heat\ supplied}$$

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

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

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

$$\eta_c = \frac{T_2^{'} - T_1}{T_2 - T_1} \qquad \eta_t = \frac{T_3 - T_4}{T_3 - T_4^{'}}$$

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

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Indicated efficiency ratio

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

Brake efficiency ratio

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

$$BP = 2\pi \frac{TN}{60} \qquad T = F \times r$$

$$BP = P_{brake\,mean}\ LANE$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$h = u + pV$$

$$gZ_1 + U_1 + P_1V_1 + \frac{C_1^2}{2} + Q = gZ_2 + U_2 + P_2V_2 + \frac{C_2^2}{2} + Wd$$

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