higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

NATIONAL CERTIFICATE

POWER MACHINES N6

(8190046)

13 August 2021 (X-paper)
09:00–12:00

REQUIREMENTS: Properties of water and steam (BOE 173)
Superheated steam tables (appendix to BOE 173)

Drawing instruments and nonprogrammable 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
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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. Questions may be answered in any order, but 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 correctly to THREE decimals unless stated otherwise.
10. Write neatly and legibly.

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QUESTION 1

Gas at 190 °C expands adiabatically at a rate of 5 kg/s through a convergent-divergent nozzle to a pressure of 103 kPa and a temperature of 252,5 K. The temperature of the gas in the throat is 386 K. Assume R for the gas as 0,298 kJ/kg.K and ignore the gas velocity at the nozzle inlet.

Take the Mach number as 1,653 and calculate the following:

1.1 The gamma

1.2 The specific heat capacity at constant pressure for the gas

1.3 The inlet pressure

1.4 The throat pressure

1.5 The velocity of the gas at the nozzle outlet

1.6 The velocity of the gas at the throat of the nozzle

(6 × 3) (18)

1.7 The power in MW of the gas at the nozzle outlet

HINT: $EK = \frac{1}{2} \times \dot{m} \times C^2$

(2)
[20]

QUESTION 2

A four-stroke, single-cylinder, internal combustion engine has a cylinder diameter of 180 mm and a stroke of 340 mm. During a trial, 4,5 kg/min of cooling water, with a specific heat capacity of 4,187 kJ/kg.K, was circulated through the water jacket, the inlet and outlet temperatures of which being 17,5 °C and 59 °C, respectively.

The indicated mean effective pressure was 555 kPa at a speed of 390 r/min, while the nett brake load was 510 N measured at an effective radius of 0,57 m. The engine consumed fuel of calorific value 43 MJ/kg at a rate of 0,06 kg/min. The amount of energy carried away in the exhaust gasses represented 34,8% of the energy of the fuel.

2.1 Calculate the following:

2.1.1 The brake power in kW

2.1.2 The indicated power in kW

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2.1.3 The mechanical efficiency

2.1.4 The fuel power in kW

2.1.5 The brake thermal efficiency

(5 × 3) (15)

2.2 Draw up an energy balance in kJ/s as well as a percentage to determine the percentage heat lost to radiation. (5)

[20]

QUESTION 3

An open-circuit, continuous-combustion, constant-pressure gas turbine takes in air at 101 kPa and 15 °C. The air is compressed in a rotary compressor through a pressure ratio of 6:1. The air then passes at constant pressure through a heat exchanger, the effectiveness of which is 65%.

From the heat exchanger, the air passes at constant pressure through a combustion chamber in which its temperature is raised to 870 °C. From the combustion chamber, the air passes through a gas turbine in which it is expanded to 101 kPa. Finally, the air passes through the heat exchanger to the exhaust.

The isentropic efficiency of the compressor is 85%, while that of the turbine is 80%. Neglect the mass of fuel and assume air mass flow rate as 4 kg/s. Take gamma as 1,4, and C_p as 1,005 kJ/kg.K.

Calculate the following:

3.1 The nett power output of the plant (10)

3.2 The exhaust temperature from the heat exchanger and the temperature before combustion (4)

3.3 The thermal efficiency of the plant (3)

3.4 The thermal efficiency of the plant if the heat exchanger was removed (3)

[20]

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QUESTION 4

The average diameter of the moving blades of a two-stage, velocity-compounded, impulse gas turbine rotating at 2 546,5 r/min is 1,35 m. The inlet and outlet angles for the first row of moving blades are 27°. The relative inlet and outlet velocities for the first row of moving blades are 570 m/s and 513 m/s, respectively. The outlet angle for the second row of moving blades is 30°. The velocity of flow at entry to the second stage is 120 m/s. There is a constant friction coefficient across all blades.

4.1 Construct velocity diagrams for the turbine in the ANSWER BOOK, using a scale of 1 mm = 5 m/s. Indicate the lengths of ALL line segments, as well as the magnitude of ALL angles on the diagrams. (10)

4.2 Determine the following from the velocity diagrams:

4.2.1 The entry angle to the fixed blades (1)

4.2.2 The exit angle from the fixed blades (1)

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

4.2.4 The velocity of the gas leaving the turbine (1)

4.2.5 The power developed in the turbine in MW, assuming a mass flow rate of steam of 21 kg/s (3)

4.2.6 The diagram efficiency (3)
[20]

QUESTION 5

A vapour compression refrigeration plant, using carbon dioxide as a refrigerant, operates between temperature limits of -6 °C and 28 °C. At entry to the compressor, the refrigerant is a dry saturated vapour, and at entry to the condenser, it has a temperature of 65 °C.

The refrigerant is undercooled to a saturated liquid with a temperature of 22 °C and a specific enthalpy of 100,5 kJ/kg. The mass flow rate of the refrigerant is 88 kg/h.

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The specific heat capacity of the superheated refrigerant is 1,62 kJ/kg.K. The compressor rotates at 310 r/min and has a swept volume of 1 150 cm³. The specific volume of the saturated vapour at -6 °C is 0,2 m³/kg.

The following are extracts from carbon dioxide tables:

Saturation temperature [°C]	Specific enthalpy [kJ/kg]		Specific entropy [kJ/kg.K]	
	Liquid (h_f)	Vapour (h_g)	Liquid (s_f)	Vapour (s_g)
-6	48,5	461,7	0,195	1,754
28		478,7		

Calculate the following:

5.1 The specific enthalpy of the refrigerant after compression (2)

5.2 The dryness fraction of the refrigerant at the evaporator inlet (2)

5.3 The specific entropy of the refrigerant at the evaporator inlet (2)

5.4 The effective swept volume of the compressor in m³/h (2)

5.5 The volumetric efficiency of the compressor (4)

5.6 The power required to drive the compressor in kW (3)

5.7 The refrigerating effect in kJ/s (3)

5.8 The actual coefficient of performance (2)

[20]

TOTAL: 100

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FORMULA SHEET

This formula sheet may NOT necessarily be complete. Any formulae used by candidates that do NOT appear on this list must be written in full in the ANSWER BOOK.

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$$P_a V_a = mRT_a$$

$$R = C_p - C_v$$

$$\gamma = \frac{C_p}{C_v}$$

$PV = c$ $PV = k$

$PV^n = c$ $PV^n = k$

$PV^\gamma = c$ $PV^\gamma = k$

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

$$\Delta U = m.C_v.\Delta T$$

$Q = \Delta U + Wd$ $Q = \Delta U + Av$

$$\Delta s = m\left[C_v \,.\, \ln\left(\frac{P_2}{P_1}\right) + C_p \,.\, \ln\left(\frac{V_2}{V_1}\right)\right]$$

$$\Delta s = m \,.\, C_v \,.\, \ln\left(\frac{P_2}{P_1}\right)$$

$$\Delta s = m.C_p.\ln\left(\frac{V_2}{V_1}\right)$$

$$\Delta s = m \,.\, R \,.\, \left(\frac{P_1}{P_2}\right)$$

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

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

$$S_{su} = S_g + C_p.\ln\left(\frac{T_{su}}{T_s}\right)$$

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

$$S = S_f + x \,.\, S_{fg}$$

$$h_{su} = h_g + C_p \,.\, \left(t_{su} - t_s\right)$$

$$T_a\left(s_a - s_b\right) = h_a - h_b$$

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ENGLISH

$$h_{ws} = h_f + x.h_{fg}$$

$$V_{ws} = x.V_g$$

GENERAL

$$V_{su} = \frac{\frac{n-1}{n}\left(h_{su} - 1\,941\right)}{P_{su}}$$

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

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

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

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

AFRIKAANS

$$h_{ns} = h_f + x.h_{fg}$$

$$V_{ns} = x.V_g$$

Different formulae for work done (Wd)

verskillende formules vir arbeid verrig (Av)

$$= P \times \Delta V$$

$$= P_1 V_1 . \ln\left(\frac{V_2}{V_1}\right)$$

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

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

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

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

$$= \frac{xn}{n-1} \times mRtT_1 \left[\left(r_{ps}\right)^{\left(\frac{n-1}{n}\right)} - 1\right]$$

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Different formulae for work done (Wd)

= area of PV - diagram

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

$Wd_{nett} = Wd_t - Wd_c$

$Wd_{nett} = Q_{nett}$

Verskillende formules vir arbeid verrig (Av)

= area van PV - diagram

= arbeid verrig eerste stadium + arbeid verrig tweede stadium +...

$Av_{nett} = Av_t - Av_k$

$Av_{nett} = Q_{nett}$

Different formulae for air standard efficiencies (ASE)

Verskillende formules vir lugstandaardrendemente (LSR)

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

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

$= \dfrac{heat\ added - heat\ \ rejected}{heat\ added}$ $= 1 - \dfrac{\beta^{\gamma} - 1}{r^{(\gamma-1)} \times \gamma\left(\beta - 1\right)}$ $= \dfrac{warmte\ toegevoeg - warmte\ afgestaan}{warmte\ toegevoeg}$

Different volumetric efficiencies, η_{vol}

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

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

Verskilllende volumetriese rendemente, η_{vol}

$= \dfrac{Volume\ lug\ ingeneem}{Slagvolume}$

$= \dfrac{Volume\ vrylug}{Slagvolume}$

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

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ENGLISH	GENERAL	AFRIKAANS
Different thermal efficiencies, $\eta_{therm.}$		Verskillende termiese rendemente, $\eta_{therm.}$
$= \frac{\text{Wd}}{\text{heat supplied}}$		$= \frac{\text{Av}}{\text{warmte toegevoeg}}$
$\eta_{brake\ therm.} = \frac{BP}{m_{f/s} \times CV}$		$\eta_{rem\ term.} = \frac{RD}{m_{b/s} \times WW}$
$\eta_{ind.\ therm.} = \frac{IP}{m_{f/s} \times CV}$		$\eta_{ind.\ term.} = \frac{ID}{m_{b/s} \times WW}$
$\eta_{therm.} = \frac{m_s (h_s - h_w)}{m_f \times CV}$		$\eta_{term.} = \frac{m_s (h_s - h_w)}{m_b \times WW}$

$\eta_c = \frac{T_2' - T_1}{T_2 - T_1}$	$\eta_t = \frac{T_3 - T_4}{T_3 - T_4'}$	$\eta_k = \frac{T_2' - T_1}{T_2 - T_1}$
$\eta_{mech.} = \frac{BP}{IP}$		$\eta_{meg.} = \frac{RD}{ID}$
Indicated efficiency ratio		Indikateurrendementverhouding
$= \frac{\eta_{ind.\ therm.}}{ASE}$		$= \frac{\eta_{ind.\ term.}}{LSR}$
Brake efficiency ratio		Remrendementverhouding
$= \frac{\eta_{brake\ therm.}}{ASE}$		$= \frac{\eta_{rem.\ term.}}{LSR}$

$BP = 2\pi \frac{TN}{60}$	$T = F \times r$	$RD = 2\pi \frac{TN}{60}$
$BP = P_{brake\ mean}\ L \times A \times N \times E$		$RD = P_{rem\ gem.}\ L \times A \times N \times E$
$IP = P_{ind.\ mean}\ L \times A \times N \times E$		$ID = P_{ind.\ gem.}\ L \times A \times N \times E$
$ISFC = \frac{M_{f/h}}{IP}$		$ISBV = \frac{M_{b/h}}{ID}$
$BSFC = \frac{M_{f/h}}{BP}$		$RSBV = \frac{M_{b/h}}{RD}$
$COP = \frac{T_1}{T_2 - T_1}$		$KVW = \frac{T_1}{T_2 - T_1}$
$COP = \frac{RE}{Wd}$		$KVW = \frac{VE}{Av}$
$P = m\ .\ U\ .\ \Delta Vw$		$D = m\ .\ U\ .\ \Delta Vw$
$F_{ax.} = m\ .\ \Delta V_f$		$F_{aks.} = m\ .\ \Delta V_f$

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$$\eta_{dia.} = \frac{2 \,.\, U \,.\, \Delta V_w}{(V_1)^2}$$

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

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

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

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

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

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

$$A_c = \frac{m \,.\, V_c}{C_c} \qquad A_2 = \frac{m \,.\, V_2}{C_2}$$

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

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

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

$$EE = \frac{m_s \left(h_s - h_w \right)}{m_f \times 2\ 257} \qquad EV = \frac{m_s \left(h_s - h_w \right)}{m_b \times 2\ 257}$$

$$\eta_{iso.} = \frac{Wd_{iso.}}{Wd_{poly.}} \qquad \eta_{iso.} = \frac{Av_{iso.}}{Av_{poli.}}$$

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

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

$$h = u + pV$$

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

$$gZ_2 + U_2 + P_2V_2 + \frac{(C_2)^2}{2} + Wd \qquad gZ_2 + U_2 + P_2V_2 + \frac{(C_2)^2}{2} + Av$$

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