higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

T1400**(E)**(A7)T

NATIONAL CERTIFICATE

POWER MACHINES N6

(8190046)

7 August 2018 (X-Paper)
09:00–12:00

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

Nonprogrammable calculators and drawing instruments may be used.

This question paper consists of 9 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

NOTE: If you answer more than the required number of questions only the required number will be marked. Clearly cross out ALL work you do NOT want to be marked.

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. Answer questions in any order, but do NOT separate subsections of questions.
5. ALL sketches and diagrams must be neat, fully labelled and be drawn in pencil in the ANSWER BOOK.
6. Write down ALL formulae used.
7. Show ALL intermediate steps for calculations.
8. Answer questions in blue or black ink only.
9. Approximate final answers correctly to THREE decimal places unless stated otherwise.
10. Write neatly and legibly.

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QUESTION 1

A two-stage, single-acting, reciprocating air compressor rotates at 500 r/min and compresses 18 kg of air per minute. The pressure ratio for the low-pressure cylinder is 4:1 and for the high-pressure cylinder 4,5:1. The index for expansion and compression is 1,32 for both stages. The volumetric efficiency for the low-pressure cylinder is 95%. The length of the stroke for the low-pressure cylinder is 1,25 times the piston diameter. The initial temperature and pressure for the low-pressure cylinder are 25 °C and 102 kPa respectively. The polytropic temperature after compression in the high-pressure cylinder is 200 °C. There is an intercooler between the stages. Assume R for air as 287,6 J/kg.K and C_p as 1 kJ/kg.K.

Calculate the following quantities:

1.1 The polytropic temperature after compression in the low-pressure cylinder (2)

1.2 The temperature at the entrance to the high-pressure cylinder (2)

1.3 The heat extracted by the intercooler in kJ/s (1)

1.4 For the low-pressure cylinder:

1.4.1 The effective swept volume in m^3/s and in m^3/cycle (3)

1.4.2 The swept volume in m^3/cycle correct to SIX decimal places (2)

1.4.3 The diameter and stroke length of the piston in mm (3)

1.4.4 The clearance volume in m^3/cycle correct to SEVEN decimal places (3)

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

[20]

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QUESTION 2

The nozzle velocity of a velocity-compounded, two-stage, impulse turbine consisting of two rows of moving blades separated by a row of fixed blades is 640 m/s. The nozzles are inclined at an angle of 19° to the plane of the moving blades. The average diameter of the moving blades is 955 mm and it rotates at 3 000 r/min. The inlet and outlet angles of the first row of moving blades are equal. There is a 5% loss of velocity across all blades due to friction. The relative velocity at exit from the first row of moving blades is 475 m/s. The inlet angle of the second row of moving blades is 30°. NO axial thrust is developed in the second stage. The mass flow rate of the steam is 50 kg/s.

2.1 Use a scale of 1 mm = 5 m/s and construct velocity diagrams for the turbine in the ANSWER BOOK. Indicate the lengths of ALL lines as well as the magnitude of ALL angles on the diagrams. (10)

2.2 Determine from the velocity diagrams:

2.2.1 The velocity at exit from the first stage in m/s (1)

2.2.2 The velocity at the inlet to the second stage in m/s (1)

2.2.3 The inlet and outlet angles for the first row of moving blades (1)

2.2.4 The inlet angle of the fixed blades (1)

2.2.5 The axial thrust developed in the turbine in kN (2)

2.2.6 The power developed by the turbine in MW (2)

2.2.7 The blading efficiency of the turbine (2)

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QUESTION 3

A three-litre, six-cylinder, four-stroke petrol engine was tested on a rope brake and the following data was recorded:

Duration of test	20 minutes
Rotational frequency of the engine	3 000 r/min
Mean diameter of the brake	1,35 m
Net load on the rope	41 kg
Indicated power developed	105 kW
Diameter of each piston	95 mm
Brake thermal efficiency	35%
Calorific value of fuel	45 MJ/kg
Air-fuel ratio	22:1

Use gravitational acceleration as 9,81 m/s² and calculate the following quantities:

3.1 The brake power in kW (3)

3.2 The mean effective pressure of the brakes in kPa (3)

3.3 The mechanical efficiency (2)

3.4 The indicated mean effective pressure in kPa (2)

3.5 The stroke length of each piston in mm (3)

3.6 The mass of fuel used during the test in kg (3)

3.7 The indicated specific fuel consumption in kg/kW.h (2)

3.8 The mass flow rate of the exhaust gases in kg/min (2)

[20]

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QUESTION 4

A convergent-divergent nozzle expands air from a pressure of 800 kPa and a temperature of 600 °C to a pressure of 175 kPa. The overall efficiency and the Mach number for the nozzle are 89% and 1,3 respectively. The area at the exit of the nozzle is 745 mm². Take gamma for air as 1,4 and R as 0,287 kJ/kg.K. Ignore the inlet velocity of the air.

Calculate the following quantities:

4.1 The value of C_p for the air in kJ/kg.K correct to THREE decimal places (3)

4.2 At the exit of the nozzle:

4.2.1 The absolute adiabatic temperature of the air (2)

4.2.2 The absolute actual temperature of the air (2)

4.2.3 The velocity of the air in m/s (2)

4.3 At the throat of the nozzle:

4.3.1 The velocity of the air in m/s (1)

4.3.2 The absolute actual temperature of the air (2)

4.3.3 The absolute adiabatic temperature of the air (2)

4.3.4 The pressure of the air in kPa (2)

4.4 The specific volume of the air at the exit in m³/kg (2)

4.5 The air flow rate through the nozzle in kg/s (2)

[20]

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QUESTION 5

The following data was recorded during a test on a steam-boiler plant:

Rate of evaporation	14 400 kg/h
Pressure of the generated superheated steam	2 000 kPa
Temperature of the generated superheated steam	300 °C
Temperature of the feed water at the economiser inlet	59 °C
Mass of fuel burned	1 650 kg/h
Calorific value of the fuel	34 000 MJ/kg
Heat absorbed by the superheater per kg of fuel burned	2 326 kJ/kg
Heat carried away by the dry flue gases per kg of fuel burned	3 112 kJ/kg
Air supplied per kg of fuel burned	16,5 kg/kg
Temperature at the chimney base	200 °C
Boiler room temperature	25 °C
Pressure at the chimney base	300 kPa
Specific heat capacity of the flue gases	1,05 kJ/kg.K
Specific heat capacity of the water	4,2 kJ/kg.K

Use the information presented in the table to calculate the following quantities:

5.1 The thermal efficiency of the plant (3)

5.2 The mass of moisture formed in the flue gases per kg of fuel burned (4)

5.3 The heat carried away by the moisture in the flue gases per kg of fuel burned (3)

5.4 The dryness factor of the steam entering the superheater (4)

5.5 The heat absorbed by the evaporator in kJ/kg of fuel burned if the temperature of the water entering the evaporator is 88 °C (3)

5.6 The temperature of the flue gases entering the economiser if the economiser absorbs 1 225 kJ/kg of fuel burned (3)

[20]

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QUESTION 6

A single-cylinder, four-stroke petrol engine operating on the Otto-cycle principle has a volumetric compression ratio of 6,5:1. The temperature after compression is 1,82 times the initial temperature, while the pressure before expansion is 11,397 times the pressure after expansion. The heat transferred during a compression stroke is 88 J. The temperature rise during compression is 226 K and the temperature drop during expansion is 791,07 K. Assume R as 0,287 kJ/kg.K and C_v as 0,718 kJ/kg.K for the gas.

Calculate the following quantities:

6.1 The compression index n_c (3)

6.2 The expansion index n_e (3)

6.3 The mass of the gas in kg/cycle (3)

6.4 The work done in kJ/cycle (2)

6.5 The absolute temperatures at ALL principal points (7)

6.6 The heat lost through the exhaust in kJ/s assuming that the rotational frequency of the engine is 625 r/min (2)

[20]

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QUESTION 7

Ammonia is used as a refrigerant in a vapour-compression refrigerating plant which operates between temperature limits of -10 °C and 30 °C. The refrigerant is a wet vapour before compression and after compression it is a dry saturated vapour. The refrigerant leaves the condenser as a saturated liquid at a temperature of 22 °C. The plant is required to produce 1 200 kg of ice every 12 hours at a temperature of -2 °C from water at 15 °C. The specific heat capacity for ice at -2 °C is 1,91 kJ/kg.K, while the specific heat capacity for the saturated liquid refrigerant is 1,6 kJ/kg.K.

The following are extracts from ammonia tables:

Saturation Temperature [°C]	Specific enthalpy		Specific entropy	
	Liquid (h_f)	Vapour (h_g)	Liquid (s_f)	Vapour (s_g)
-10	45,4	460,7	0,183	1,762
30	108,6	478,7	0,406	1,627

Calculate the following:

7.1 The dryness factor at the entrance to the compressor (3)

7.2 The specific enthalpy at the compressor entrance (2)

7.3 The specific work done by the compressor (2)

7.4 The specific enthalpy at the evaporator entrance (3)

7.5 The specific entropy at the evaporator entrance (3)

7.6 The mass flow rate of the refrigerant in kg/min (4)

7.7 The power required to drive the compressor if the mechanical efficiency is 90% (3)

[20]

TOTAL: 100

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FORMULA SHEET

NOTE: This formula sheet may NOT necessarily be complete. Any formulae NOT on this list utilised by candidates 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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$$h_{ws} = h_f + x.h_{fg}$$

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

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

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

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

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

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

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

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

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)

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

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

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

Different volumetric efficiencies, η_{vol}

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

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

Verskilllende volumetriese rendemente, η_{vol}

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

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

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

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Different thermal efficiencies, $\eta_{therm.}$ $= \frac{\text{Wd}}{\text{heat supplied}}$		Verskillende termiese rendemente, $\eta_{therm.}$ $= \frac{\text{Av}}{\text{warmte toegevoeg}}$
$\eta_{brake\ therm.} = \frac{BP}{m_{f/s} \times CV}$		$\eta_{rem\ term.} = \frac{RD}{m_{b/s} \times WW}$
$\eta_{ind.\ therm.} = \frac{IP}{m_{f/s} \times CV}$		$\eta_{ind.\ term.} = \frac{ID}{m_{b/s} \times WW}$
$\eta_{therm.} = \frac{m_s(h_s - h_w)}{m_f \times CV}$		$\eta_{term.} = \frac{m_s(h_s - h_w)}{m_b \times WW}$
$\eta_c = \frac{T_2' - T_1}{T_2 - T_1}$	$\eta_t = \frac{T_3 - T_4}{T_3 - T_4'}$	$\eta_k = \frac{T_2' - T_1}{T_2 - T_1}$
$\eta_{mech.} = \frac{BP}{IP}$		$\eta_{meg.} = \frac{RD}{ID}$
Indicated efficiency ratio $= \frac{\eta_{ind.\ therm.}}{ASE}$		Indikateurrendementverhouding $= \frac{\eta_{ind.\ term.}}{LSR}$
Brake efficiency ratio $= \frac{\eta_{brake\ therm.}}{ASE}$		Remrendementverhouding $= \frac{\eta_{rem.\ term.}}{LSR}$
$BP = 2\pi \frac{TN}{60}$	$T = F \times r$	$RD = 2\pi \frac{TN}{60}$
$BP = P_{brake\ mean}\ L \times A \times N \times E$		$RD = P_{rem\ gem.}\ L \times A \times N \times E$
$IP = P_{ind.\ mean}\ L \times A \times N \times E$		$ID = P_{ind.\ gem.}\ L \times A \times N \times E$
$ISFC = \frac{M_{f/h}}{IP}$		$ISBV = \frac{M_{b/h}}{ID}$
$BSFC = \frac{M_{f/h}}{BP}$		$RSBV = \frac{M_{b/h}}{RD}$
$COP = \frac{T_1}{T_2 - T_1}$		$KVW = \frac{T_1}{T_2 - T_1}$
$COP = \frac{RE}{Wd}$		$KVW = \frac{VE}{Av}$
$P = m\ .\ U\ .\ \Delta Vw$		$D = m\ .\ U\ .\ \Delta Vw$
$F_{ax.} = m\ .\ \Delta V_f$		$F_{aks.} = m\ .\ \Delta V_f$

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

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

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

$$C_c = \sqrt{2\times10^3\left(h_1 - h_c\right) + (C_1)^2}$$

$$C_2 = \sqrt{2\times10^3\left(h_1 - h_2\right) + (C_1)^2}$$

$$C_c = \sqrt{2\times10^3\times C_p\left(T_1 - T_c\right) + (C_1)^2}$$

$$C_2 = \sqrt{2\times10^3\times C_p\left(T_1 - T_2\right) + (C_1)^2}$$

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

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

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

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

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

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

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

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

$$h = u + pV$$

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

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

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