higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

T1400**(E)**(A12)T

NATIONAL CERTIFICATE

POWER MACHINES N6

(8190046)

12 April 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.

Copyright reserved

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 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. Answer questions in blue or black ink only.
9. Write neatly and legibly.

Copyright reserved

QUESTION 1

Steam is expanded in a convergent-divergent nozzle to an exit pressure of 600 kPa with an isentropic dryness factor of 0,945 which is 99,265% of the actual dryness factor.

At entry to the nozzle, the steam is superheated with a specific heat capacity of 2,76 kJ/kg.K at a temperature of 276 °C and a pressure of 2 600 kPa.

At the throat, the temperature and pressure of the steam are 205 °C and 1400 kPa respectively. The index (n) for the superheated steam is 1,3, while the velocity is 500 m/s.

Assume the velocity at entry to the nozzle to be negligible.

Calculate the following quantities using steam tables only:

1.1 The specific enthalpy of the steam at the nozzle inlet (3)

1.2 At the throat of the nozzle:

1.2.1 The specific enthalpy of the steam (3)

1.2.2 The specific heat capacity of the steam (2)

1.2.3 The specific volume of the steam (2)

1.3 At the exit of the nozzle:

1.3.1 The isentropic specific enthalpy of the steam (3)

1.3.2 The actual dryness factor of the steam (1)

1.3.3 The actual specific enthalpy of the steam (2)

1.3.4 The specific volume of the steam correct to FOUR decimal places (1)

1.4 The efficiency of the divergent part of the nozzle (3)

[20]

Copyright reserved

QUESTION 2

The blades of a two-stage velocity-compounded impulse turbine has an average diameter of 976 mm while rotating at 3 131 r/min.

The velocity of flow at the inlet to the second stage is 100 m/s, while the velocity of flow at the inlet to the first stage is 225 m/s.

The outlet angle of the second row of moving blades is 28°, while the outlet angle of the first row of moving blades is 25°.

There is a 4% loss of velocity across ALL blades due to friction.

The gas exits the turbine at an angle of 80°.

2.1 Construct velocity diagrams for the turbine in the ANSWER BOOK by using a scale of 1 mm = 5 m/s.

Indicate the lengths of ALL lines as well as the magnitude of ALL angles on the diagrams. (10)

2.2 Determine the magnitude of the following quantities from the velocity diagrams:

2.2.1 The relative velocity of the gas at the inlet to the first stage in m/s

2.2.2 The velocity of the gas leaving the turbine in m/s

2.2.3 The velocity of the gas leaving the fixed blades in m/s

2.2.4 The velocity of the gas leaving the first stage in m/s

2.2.5 The nozzle velocity in m/s

2.2.6 The inlet angle to the first row of moving blades

2.2.7 The inlet angle to the second row of moving blades

2.2.8 The outlet angle from the fixed blades

2.2.9 The inlet angle to the fixed blades

2.2.10 The nozzle angle

(10 × 1) (10)

[20]

Copyright reserved

QUESTION 3

An open-circuit, continuous-combustion, constant-pressure gas turbine receives air from the atmosphere at 15 °C and compresses it to five times the intake pressure in a rotary compressor which has an isentropic efficiency of 80%.

The compressed air thereafter passes through a heat exchanger in which the air temperature is increased to 397 °C.

From the heat exchanger, the air passes through a combustion chamber in which 1 018,575 kJ/s of heat is added at constant pressure.

From the combustion chamber, the air expands through a gas turbine to atmospheric pressure. At this pressure, the air travels through the heat exchanger to the exhaust where the temperature is 231,6 °C.

The isentropic efficiency of the turbine is 82%, while the air flows through the plant at a rate of 2,5 kg/s.

Assume gamma as 1,4 and C_p as 1,006 kJ/kg.K. Neglect the mass of fuel.

Calculate:

3.1	The absolute isentropic temperature after compression	(2)
3.2	The absolute actual temperature after compression	(2)
3.3	The absolute temperature before expansion	(2)
3.4	The absolute isentropic temperature after expansion	(2)
3.5	The absolute actual temperature after expansion	(3)
3.6	The power developed by the plant in kW	(3)
3.7	The thermal efficiency of the plant	(3)
3.8	The efficiency of the heat exchanger	(3)

[20]

Copyright reserved

QUESTION 4

A three-stage, single-acting, reciprocating air compressor delivers 900 kg/h of air to an aftercooler at a pressure of 4 116 kPa.

The cylinder volume of the intermediate cylinder is 26 times its clearance volume.

The temperature at the entrance to the low-pressure cylinder is 27 °C and the pressure in the first intercooler is 336 kPa.

The compressor rotates at 290 r/min.

Intercooling is complete and the stage pressures are in geometric progression.

Assume the index for compression for all stages as 1,331 and R for air as 0,288 kJ/kg.K.

Calculate:

4.1 The pressure ratio (1)

4.2 The pressure in the second intercooler in kPa (1)

4.3 The pressure at the inlet to the low-pressure cylinder in kPa (2)

4.4 The absolute temperature after compression in each cylinder (2)

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

4.6 From the intermediate cylinder:

4.6.1 The effective swept volume in m^3/cycle correct to FOUR decimal places (3)

4.6.2 The volumetric efficiency (3)

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

4.6.4 The clearance volume in m^3/cycle correct to SIX decimal places (1)

4.6.5 The cylinder volume in m^3/cycle (2)

[20]

Copyright reserved

QUESTION 5

An engine operating on the ideal constant-volume cycle, using air as the working fluid, has an initial temperature of 77 °C and pressure of 105 kPa.

The network transfer during one cycle is 551,424 kJ/kg of air, while the volumetric compression ratio is 7,179 : 1.

Assume C_v for air as 0,718 kJ/kg.K and gamma as 1,4.

Calculate:

5.1 The unknown pressures in kPa, as well as the unknown absolute temperatures at ALL principal points of the cycle (14)

5.2 The heat received in kJ/kg of air (2)

5.3 The heat rejected in kJ/kg of air (2)

5.4 The air standard efficiency (2)
[20]

QUESTION 6

The overall thermal efficiency of a steam boiler plant consisting of an economiser, evaporator and a superheater is 82,56%.

The economiser absorbs 8,256% of the heat supplied by the fuel, while the superheater absorbs 2 856,02 kJ of heat per kg of fuel burned.

The plant produces 8 170 kg of steam per hour at a pressure of 2 550 kPa and a temperature of 301 °C from 950 kg of fuel burned every hour.

The specific heat capacity of the superheated steam is 2,75 kJ/kg.K while the fuel has a calorific value of 30 MJ/kg.

The moisture in the flue gases carries 1 575 kJ of heat per kg of fuel away through the chimney, while the heat carried away by the dry flue gases is 1 905 kJ/kg of fuel.

6.1 Use steam tables only to calculate the following quantities:

6.1.1 The specific enthalpy of the steam produced (5)

6.1.2 The specific enthalpy of the feed water entering the economiser (2)

6.1.3 The specific enthalpy of the feed water entering the evaporator (2)

6.1.4 The dryness factor of the steam entering the superheater (3)

6.1.5 The heat absorbed by the evaporator in kJ/kg fuel (3)

Copyright reserved

6.2 Draw a heat balance in kJ/kg and as a percentage for each component of the plant, as well as the heat losses through the flue gases, to determine the percentage heat loss unaccounted for. (5)

[20]

QUESTION 7

A vapour-compression refrigeration plant uses 0,5 kg/s of ammonia as a refrigerant.

The plant operates between pressure limits of 2 983 kPa and 6 539 kPa.

The stroke length of the compressor is 1,2 times the piston diameter.

The refrigerant is a dry, saturated vapour at the entrance to the compressor and at the condenser inlet the vapour has a temperature of 65 °C.

The saturated liquid refrigerant exits the condenser at a temperature of 22 °C.

The specific heat capacity of the superheated refrigerant is 2,18 kJ/kg.K, while the specific heat capacity of the liquid refrigerant is 4,12 kJ/kg.K.

The specific volume of the saturated refrigerant at the compressor inlet is 0,012 m³/kg.

The volumetric efficiency of the compressor is 92,1%, whilst rotating at 240 r/min.

The following are extracts from ammonia tables:

Saturation temperature (°C)	Pressure (kPa)	Specific enthalpy [kJ/kg]	
		Liquid (h_f)	Vapour (h_g)
-4	2 983	74,3	320
27	6 539	172,3	269,2

Use the data provided above to calculate the following quantities:

7.1 The specific enthalpy of the refrigerant after isentropic compression (3)

7.2 The power required to drive the compressor in kW (2)

7.3 The mass of the refrigerant in kg/cycle (1)

7.4 The volume of the refrigerant in m³/cycle correct to FOUR decimal places (1)

7.5 The swept volume of the compressor in m³/cycle correct to SIX decimal places (3)

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

Copyright reserved

7.7 The specific enthalpy of the refrigerant at the condenser outlet (3)

7.8 The refrigerating effect in kJ/s (2)

7.9 The actual coefficient of performance (2)
[20]

TOTAL : 100

Copyright reserved

FORMULA SHEET

NOTE: This formula sheet may not necessarily be complete.

Any formulae utilised by candidates that do not appear on this list, must be written in full in the ANSWER BOOK.

ENGLISH GENERAL AFRIKAANS

$$P_a V_a = mRT_a$$

$$R = C_p - C_v$$

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

$PV = c$ $PV = k$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Copyright reserved

ENGLISH GENERAL AFRIKAANS

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

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

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

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

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

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

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

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

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

Different formulae for work done (Wd)

verskillende formules vir arbeid verrig (Av)

$$= P \times \Delta V$$

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

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

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

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

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

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

Copyright reserved

ENGLISH GENERAL AFRIKAANS

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}

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

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

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

Copyright reserved

ENGLISH

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

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

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

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

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

GENERAL

AFRIKAANS

Verskillende termiese rendemente, $\eta_{therm.}$

$$= \frac{\text{Av}}{\text{warmte toegevoeg}}$$

$$\eta_{rem\ term.} = \frac{RD}{m_{b/s} \times WW}$$

$$\eta_{ind.\ term.} = \frac{ID}{m_{b/s} \times WW}$$

$$\eta_{term.} = \frac{m_s (h_s - h_w)}{m_b \times WW}$$

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

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

$$\eta_k = \frac{T_2' - T_1}{T_2 - T_1}$$

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

$$\eta_{meg.} = \frac{RD}{ID}$$

Indicated efficiency ratio

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

Brake efficiency ratio

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

Indikateurrendementverhouding

$$= \frac{\eta_{ind.\ term.}}{LSR}$$

Remrendementverhouding

$$= \frac{\eta_{rem.\ term.}}{LSR}$$

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

$$BP = P_{brake\ mean}\ L \times A \times N \times E$$

$$IP = P_{ind.\ mean}\ L \times A \times N \times E$$

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

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

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

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

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

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

$$T = F \times r$$

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

$$RD = P_{rem\ gem.}\ L \times A \times N \times E$$

$$ID = P_{ind.\ gem.}\ L \times A \times N \times E$$

$$ISBV = \frac{M_{b/h}}{ID}$$

$$RSBV = \frac{M_{b/h}}{RD}$$

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

$$KVW = \frac{VE}{Av}$$

$$D = m\ .\ U\ .\ \Delta Vw$$

$$F_{aks.} = m\ .\ \Delta V_f$$

Copyright reserved

ENGLISH GENERAL AFRIKAANS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$h = u + pV$$

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

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

Copyright reserved