higher education
& training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

T1390(**E**)(A9)T
APRIL EXAMINATION

NATIONAL CERTIFICATE

POWER MACHINES N6

(8190046)

9 April 2013 (X-Paper)
09:00–12:00

REQUIREMENTS: Steam tables

Calculators may be used.

Candidates will require drawing instruments, pens and a ruler.

This question paper consists of 7 pages and a 6-page formula sheet.

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 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 the intermediate steps.
7. Questions must be answered in BLUE or BLACK ink.
8. ALL the sketches and diagrams must be done in pencil in the ANSWER BOOK.
9. Write neatly and legibly.

QUESTION 1

A single-acting, three-stage, reciprocating compressor sucks air in at 100 kPa and delivers it at a rate of 900 kg/h at a temperature of 105,002 °C.
The low pressure cylinder has a diameter of 345 mm and its stroke length is 1,24 times the diameter of the piston.
The power required to drive the compressor is 87,05 kW.
The ratio of pressure for all cylinders is 3,4 : 1.
The compression and expansion index is 1,3.
The rotational frequency of the compressor is 324 r/min.
Take *Cp* for air as 1,008 kJ/kg/K.

Calculate the following:

1.1 The effective swept volume of the low pressure cylinder in $\frac{m^3}{cycle}$ (4)

1.2 The swept volume in $\frac{m^3}{cycle}$ and the volumetric efficiency of the low pressure cylinder (4)

1.3 The absolute temperature at the compressor inlet and the value of the characteristic gas constant (5)

1.4 The clearance volume and the cylinder volume for the low-pressure cylinder in $\frac{m^3}{cycle}$ (4)

1.5 The heat extracted by the intercoolers in kW (3)
[20]

QUESTION 2

A boiler plant operating at a pressure of 2,55 MPa produces 8 385 kg of superheated steam, with a specific enthalpy of 3 010 kJ/kg, per hour from coal burned at 975 kg/h.
The specific heat capacity of the superheated steam is 2,75 kJ/kg.K.
The economiser consumed 2 476,8 kJ of heat per kg of coal burned.
The temperature of the feed water in the economiser is increased by 68,6 °C.

The following is an incomplete heat balance of the plant:

Q in $\left(\frac{kJ}{kg}\right)$	Q out $\left(\frac{kJ}{kg}\right)$	%
	Economiser =	8,256
	Evaporator =	65,684
	Superheater =	8,62
	Moisture =	5,25
	Dry flues =	6,35
	Unaccounted =	
Total		

2.1 Complete the heat balance above. (7)

2.2 Calculate the following by using steam tables only:

2.2.1 The thermal efficiency of the plant, the specific enthalpy of the feed water entering the economiser and its temperature and the specific enthalpy of the feed water entering the evaporator (6)

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

2.2.3 The normal temperature of the steam produced (3)

[20]

QUESTION 3

A single-cylinder, four-stroke petrol engine working on the Otto cycle principle has a volume compression ratio of 8,5 : 1.
The polytropic index for compression and expansion is 1,31.
The brake power of the engine at 2 000 r/min is 11,9 kW.
The mechanical efficiency is 85%.
The length of the stroke is 1,25 times the diameter of the piston.
The indicated mean effective pressure is 1 000 kPa.
The initial pressure of the cycle is 100 kPa.
The temperature after expansion is 2,8 times the initial temperature.
Take gamma as 1,4.

Calculate the following:

3.1 The indicated power in kW (2)

3.2 The indicated work done in J/cycle (2)

3.3 The swept volume in m^2, the diameter of the piston in mm and the length of the stroke in mm (6)

3.4 The volumes in cm^2at the principle points (3)

3.5 The missing pressures at the principle points in kPa (5)

3.6 The air standard efficiency (2)
[20]

QUESTION 4

An engine working on the dual cycle principle has a volumetric compression ratio of 16 : 1.
The pressure and temperature at the beginning of the compression stroke are 101 kPa and 32°C respectively.
The compression index is 1,35.
The pressure at the beginning of the expansion stroke is 1,4 times the pressure after polytropic compression.
The pressure at the beginning of the exhaust stroke is 262,424 kPa.
The heat taken in at constant pressure continues for one thirtieth of the stroke.
Take gamma as 1,4.

Calculate the following:

4.1 The missing absolute temperatures and pressures in kPa at the principle points (12)

4.2 The expansion index (4)

4.3 The ideal thermal efficiency of the cycle (4)
[20]

QUESTION 5

Superheated steam enters a convergent-divergent nozzle at a pressure of 3 MPa, with a temperature of 300 °C and no velocity and is expanded to a pressure of 860 kPa with an actual dryness factor of 98%.
At the throat the pressure is 1,6 MPa, the specific heat capacity is 2,825 kJ/kg.K and the index for superheated steam is 1,3.
At the exit the isentropic dryness factor is 99,286% of the actual dryness factor.
The steam flows at a rate of 5,2 kg/s.
The specific enthalpy drop in the convergent part is 135,2 kJ/kg.

Calculate the following by using steam tables only:

5.1 The velocity of the steam in m/s, the specific enthalpy of the steam, the temperature of the steam, the specific volume of the steam, the area in mm^2 and the diameter in mm at the throat of the nozzle (12)

5.2 The actual specific enthalpy and the isentropic specific enthalpy at the nozzle exit, the actual enthalpy drop and the isentropic enthalpy drop through the nozzle and the nozzle efficiency (8)

[20]

QUESTION 6

Steam discharges axially from a velocity compounded, two-stage, impulse turbine with a velocity of 80 m/s.
The inlet and exit angle of the first row of moving blades as well as the inlet angle of the second row of moving blades are equal.
The exit angle of the second row of moving blades is 26°.
No axial thrust is developed in the second stage.
The velocity coefficient for all the blades is 0,96.
The steam flow rate is 45 kg/s.

6.1 Use a scale of 1 mm = 4 m/s and construct velocity diagrams for the turbine in the ANSWER BOOK.
Indicate the lengths of ALL the lines as well as the magnitude of the angles on the diagrams. (10)

6.2 Determine the following from the velocity diagrams:

6.2.1 The nozzle angle

6.2.2 The exit angle of the fixed blades

6.2.3 The inlet and exit angles of the first row of moving blades as well as the inlet angle of the second row of moving blades

6.2.4 The inlet angle of the fixed blades

6.2.5 The average blade velocity in m/s

6.2.6 The nozzle velocity in m/s

6.2.7 The velocity of the steam leaving the first stage in m/s

6.2.8 The blade efficiency

6.2.9 The power developed by the turbine in MW (10)

[20]

QUESTION 7

A vapour compression refrigeration plant uses carbon dioxide as a refrigerant and operates between temperature limits of –8 °C and 34 °C .
The compressor has a piston with a diameter of 120 mm, a stroke of 141,5 mm and it rotates at 360 r/min.
The volumetric efficiency of the compressor is 90%.
The refrigerant enters the compressor as a dry saturated vapour and it enters the condenser at a temperature of 64 °C.
The refrigerant leaves the condenser as a saturated liquid with no undercooling.

At: –8 °C

The specific volume of the dry saturated vapour	$= 0{,}072\ \frac{m^3}{kg}$
The specific enthalpy of the dry saturated vapour	= 184,1 kJ/kg
The specific entropy of the dry saturated vapour	= 0,700 8 kJ/kg.K

At: 34 °C

The specific enthalpy of the saturated liquid	= 68,5 kJ/kg
The specific enthalpy of the dry saturated vapour	= 201,1 kJ/kg
The specific entropy of the dry saturated vapour	= 0,684 2 kJ/kg.K

Calculate the following:

7.1 The specific heat capacity of the superheated vapour and the specific enthalpy of the superheated vapour at the compressor outlet (6)

7.2 The swept volume of the compressor in $\frac{m^3}{s}$, the volume flow of the refrigerant in $\frac{m^3}{s}$ and the mass flow rate of the refrigerant in kg/s (6)

7.3 The power required to drive the compressor in kW, the power required to produce ice in kW and the actual coefficient of performance (6)

7.4 The energy required to condense the refrigerant in kJ/min

HINT: *s at 64 °C = s_g at 34 °C + C_p ln [T at 64 °C ÷ T at 34 °C]* (2)
[20]

TOTAL: 100

FORMULA SHEET

Any applicable formula may also be used.

ENGELS	*ALGEMEEN*	*AFRIKAANS*
	$P_a V_a = mRT_a$	
	$R = Cp - Cv$	
	$\gamma = \frac{Cp}{Cv}$	
$PV = c$		$PV = k$
$PV^n = c$		$PV^n = k$
$PV^\gamma = c$		$PV^\gamma = k$
	$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{n-1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$	
	$\Delta U = m \,.\, Cv \,.\, \Delta T$	
$Q = \Delta U + Wd$		$Q = \Delta U + Av$
	$\Delta s = m\left(Cv \,.\, \ln\frac{P_2}{P_1} + Cp \,.\, \ln\frac{V_2}{V_1}\right)$	
	$\Delta s = m \,.\, Cv \,.\, \ln\frac{P_2}{P_1}$	
	$\Delta s = m \,.\, Cp \,.\, \ln\frac{V_2}{V_1}$	
	$\Delta s = m \,.\, R \,.\, \ln\frac{P_1}{P_2}$	
	$Q = m \,.\, Cp \,.\, \Delta T$	
	$Q = m \,.\, Cv \,.\, \Delta T$	
	$S_{su} = S_g + Cp \,.\, \ln\frac{T_{su}}{T_s}$	
	$S_{fg} = S_g - S_f$	
	$S = S_f + xS_{fg}$	
	$h_{su} = h_g + Cp\,(t_{su} - t_s)$	

ENGELS	***ALGEMEEN***	***AFRIKAANS***
$h_{ws} = h_f + xh_{fg}$	$V_{su} = \dfrac{\frac{n-1}{n}(h_{su} - 1941)}{P_{su}}$	$h_{ns} = h_f + xh_{fg}$
$V_{ws} = xV_g$	$r = \dfrac{V_s + V_c}{V_c}$	$V_{ns} = xV_g$
	$V_s = \dfrac{\pi}{4} d^2 \times L$	
	$P_2 = \sqrt{P_1 \times P_3}$	
	$r_{ps} = \sqrt[x]{\dfrac{P_{x+1}}{P_1}}$	

Different formulae for work done (Wd)		*Verskillende formules vir arbeid verrig (Av)*

$$= P \times \Delta V$$

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

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

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

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

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

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

ENGELS	ALGEMEEN	AFRIKAANS
Different formulae for work done (Wd)		*Verskillende formules vir arbeid verrig (Av)*
= area of PV-diagram		*= area van PV-diagram*
= work done first stage + work done second stage + ...	...	*= arbeid verrig eerste stadium + arbeid verrig tweede stadium +*
$Wd_{nett} = Wd_t - Wd_c$	$Av_{nett} = Av_t - Av_k$	
$Wd_{nett} = Q_{nett}$	$Av_{nett} = Q_{nett}$	

Different formulae for air standard efficiencies (ASE)

Verskillende formules vir lugstandaardrendemente (LSR)

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

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

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

Different volumetric efficiencies, 0_{vol}

Verskillende volumetriese rendemente, 0_{vol}

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

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

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

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

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

ENGELS | *ALGEMEEN* | *AFRIKAANS*

Different thermal efficiencies, $0_{therm.}$

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

Verskillende termiese rendemente, $0_{term.}$

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

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

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

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

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

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

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

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

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

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

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

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

Indicated efficiency ratio

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

Indikateurrendementverhouding

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

Brake efficiency ratio

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

Remrendementverhouding

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

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

$$T = F \times r$$

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

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

$$RD = P_{rem\ gem.}\ LANE$$

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

$$ID = P_{ind.\ gem.}\ LANE$$

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

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

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

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

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

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

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

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

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

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

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

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

ENGELS ***ALGEMEEN*** ***AFRIKAANS***

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

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

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

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

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

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

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

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

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

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

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

ENGELS

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

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

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

AFRIKAANS

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

$$\eta_{iso.} = \frac{Av_{iso.}}{Av_{poli.}}$$

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

ALGEMEEN

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

$$h = u + pV$$

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

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

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

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