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Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

T1500(E)(N21)T
NOVEMBER 2012

NATIONAL CERTIFICATE

POWER MACHINES N6

(8190046)

21 November (X-Paper)
09:00 – 12:00

REQUIREMENTS: **Steam tables**

Candidates will require drawing instruments, pens and a ruler.

Calculators may be used.

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

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 FIVE questions, only the first five 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 correctly 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

Air flows through the throat of a convergent-divergent nozzle at a pressure 325 kPa and a temperature of 487 °C.
The velocity at the inlet is negligible.
There is a temperature drop of 321,6 °C throughout the nozzle.
Up to the throat the flow is frictionless and the efficiency of the divergent part is 90,7%.
The area of the nozzle at the exit is 2 613,806 mm².
Take R for air as 0,287 kJ/kg.K and Cv as 0,718 kJ/kg.K.

Calculate the following:

1.1 The value of gamma, the pressure in kPa and the absolute temperature at the nozzle inlet (5)

1.2 The velocity in m/s, the actual absolute temperatures, the adiabatic absolute temperature, the pressure in kPa, the specific volume at the exit of the nozzle and the mass flow rate of the air in kg/min (11)

1.3 The velocity in m/s and the specific volume at the throat of the nozzle (4)
[20]

QUESTION 2

During a trial on a four-cylinder petrol engine a Morse test was carried out.
When running at full load, all cylinders operating, the brake power was 25 kW. The measured brake power when each cylinder was cut out and the load reduced to bring the engine back to its original speed, were as follows:

Cylinder number	1	2	3	4
Brake power (kW)	16,3	16,7	17	16,6

The following information was also noted:

Calorific value of fuel	= 45 MJ.kg
Fuel used per brake kilowatt hour	= 0,3 kg
Air fuel ratio	= 20:1
Temperature rise of exhaust gases	= 560 °C
Mass of cooling water	= 9 kg/mm
Temperature rise of cooling water	= 40 °C
Specific heat capacity of exhaust gases	= 1,05 kJ/kg.K
Specific heat capacity of cooling water	= 4,2 kJ/kg.K

Calculate the following:

2.1 The indicated power in kW and the mechanical efficiency (5)

2.2 The mass of fuel used in kg/min (2)

2.3 The heat available in the fuel in kJ/min (2)

2.4 The heat lost to the exhaust gases in kJ/min (2)

2.5 The heat lost to the cooling water in kJ/min (2)

2.6 2.6.1 The brake thermal efficiency

2.6.2 The indicated thermal efficiency (3)

2.7 Draw up a heat balance in kJ/min and as percentage to determine the percentage heat lost to radiation. Assume that the heat lost to friction is absorbed by the cooling water. (4)

[20]

QUESTION 3

The pressure in the intercooler of a two-stage, double-acting, reciprocating air compressor is 380 kPa.
The clearance volume of the low-pressure cylinder is 5% of its stroke volume.
The stroke length of the low-pressure cylinder is equal to the piston diameter which is 450,9 mm.
The index for compression and expansion for both stages is 1,307.
Intercooling is complete for maximum efficiency.
The pressure ratio is 3,8:1.

Calculate the following:

3.1 The inlet pressure and the delivery pressure of the compressor in kPa (3)

3.2 The swept volume, the clearance volume, the cylinder volume and the effective swept volume for the low pressure cylinder in m^3/stroke (6)

3.3 The volumetric efficiency of the low pressure cylinder (2)

3.4 The work done on the compressor in kJ/cycle (4)

3.5 The isothermal efficiency of the compressor (5)

[20]

QUESTION 4

The initial pressure and temperature for a gas-turbine engine working on the Joule cycle principle are 102 kPa and 20 °C respectively.
After compression the gas has a pressure of 816 kPa and a temperature of 303,04 °C.
The heat received during combustion is 530,6 kJ/kg of air.
The temperature of the exhaust gases is 425,47 °C.
Gamma for the air is 1,4 and Cp is 1,005 kJ/kg.K.
The air flows at a rate of 50 kg/s.
The calorific value of the fuel is 44,24 MJ/kg.

Calculate the following:

4.1 The adiabatic temperature after compression and the compression adiabatic efficiency (4)

4.2 The temperature after combustion, the adiabatic temperature after expansion and the expansion adiabatic efficiency (6)

4.3 The heat rejected by the exhaust in kJ/kg of air, the thermal efficiency of the turbine, the power developed by the turbine in kW and the mass of fuel used in kg per second (7)

4.4 The air-fuel ratio if Cp for the exhaust gases is 1,045 kJ/kg.K (3)
[20]

QUESTION 5

The blades of a two-stage, velocity compounded impulse gas turbine has an average diameter of 976 mm and rotates at 3 131 r/min.
The velocity of flow at the inlet to the first stage is 225 m/s.
The velocity of flow at the inlet to the second stage is 100 m/s.
The outlet angle of the first row of moving blades is 25°.
The outlet angle of the second row of moving blades is 28°.
The gas leaves the turbine at an angle of 80°.
There is a 4 % loss of velocity across all blades due to friction.

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

5.2 Determine the following from the velocity diagrams:

5.2.1 The nozzle angle

5.2.2 The inlet angle to the fixed blades

5.2.3 The outlet angle from the fixed blades

5.2.4 The inlet angle to the second row of moving blades

5.2.5 The inlet angle to the first row of moving blades

5.2.6 The nozzle velocity in m/s

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

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

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

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

5.2.11 The blading efficiency (10)

[20]

QUESTION 6

During a test on a coal-fired boiler plant the following observations were made:

Steam pressure	=	3 MPa
Temperature of superheated steam	=	400 °C
Temperature of feed water at economiser inlet	=	54 °C
Temperature of feed water at evaporator inlet	=	130 °C
Steam generated per kg of coal	=	9,5 kg
Pressure of flues at chimney base	=	150 kPa
Temperature of flues at chimney base	=	200 °C
Mass of combustibles in a kg of fuel	=	0,98 kg/kg coal
Boiler room temperature	=	25 °C
Percentage of heat absorbed by plant	=	72,125%
Percentage of heat lost through wet flues	=	3,642%
Percentage of heat lost through dry flues	=	10,78%
Specific heat capacity of flue gases	=	1,045 kJ/kg.K
Specific heat capacity of water	=	4,2 kJ/kg.K

Calculate the following by using steam tables only:

6.1 The calorific value of the coal in MJ/kg and the equivalent evaporation from and at 100 °C of the boiler (5)

6.2 The mass of the moisture in kg/kg fuel in the flues (4)

6.3 The air fuel ratio for the plant (7)

6.4 The temperature of the flue gases at the inlet to the economiser (4)

[20]

QUESTION 7

A vapour-compression refrigeration plant using ammonia as a refrigerant operates between pressure limits of 236 kPa and 915 kPa.
The refrigerant enters the compressor as a wet vapour with a dryness factor of 0,98 and it enters the condenser at a temperature of 58 °C.
The refrigerant is condensed to a saturated liquid but not undercooled.
The specific heat capacity of the superheated ammonia is 4,134 kJ/kg.K.
The motor driving the compressor has a rating of 18 kW and the mechanical efficiency is 88,79%.
The plant must produce ice at 0 °C from water at a temperature of 18 °C.
Take the specific heat capacity of water as 4,2 kJ/kg.K and the latent heat of ice as 336 kJ/kg.

The following are extracts from ammonia tables:

Pressure (kPa)	Saturation temperature (°C)	Specific enthalpy		Specific entropy	
		Liquid (hf)	Vapour (hg)	Liquid (sf)	Vapour (sg)
915	22	284,7	1 464	---------	---------
236	-15	112,3	1 426	0,457	5,549

Calculate the following:

7.1 The specific enthalpy of the refrigerant at the compressor inlet, the specific enthalpy at the condenser outlet, the work done by the compressor in kJ/kg, the refrigeration effect in kJ/kg and the actual coefficient of performance (9)

7.2 The dryness factor and the specific entropy of the refrigerant after throttling (5)

7.3 The mass flow rate of the refrigerant in kg/min (3)

7.4 The mass of ice produced by the plant in kg/h (3)
[20]

TOTAL: 100

POWER MACHINES N6

FORMULA SHEET

Any applicable formula may also be used.

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

ENGLISH	*GENERAL*	*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)

$$= P \times \Delta V$$

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

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

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

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

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

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

ENGLISH	*GENERAL*	*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, η_{vol}

Verskillende volumetriese rendemente, η_{vol}

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

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

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

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

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

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

ENGLISH *GENERAL* *AFRIKAANS*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$h = u + pV$$

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

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

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

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