



higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

NATIONAL CERTIFICATE

POWER MACHINES N6

(8190046)

1 December 2022 (X-paper)
09:00–12:00

REQUIREMENTS: Steam table (BOE 173)
Superheated steam tables (Appendix to BOE 173)

Nonprogrammable calculators and drawing instruments may be used

This question paper consists of 5 pages and a 6-page formula sheet.

310Q1E2201

DEPARTMENT OF HIGHER EDUCATION AND TRAINING
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POWER MACHINES N6
TIME: 3 HOURS
MARKS: 100

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. Use only a blue or black pen.
 5. Write neatly and legibly.
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QUESTION 1

1.1 In multistage compression, explain what is meant by *perfect intercooling*. (2)

1.2 In a single-acting, two-stage reciprocating compressor, the delivery pressure is nine times the initial pressure while the pressure ratio is equal in both stages. The index of compression of the mass of 4,5 kg a minute is 1,3. Initial conditions are 101,3 kPa and 15 °C. The compressor speed is 300 revolutions a minute and, in both stages, the clearance volume is 5% of the swept volume.



Given ideal cooling conditions, calculate the following:

1.2.1 The absolute temperature before cooling and the absolute delivery temperature (4)

1.2.2 The total power output in kilowatt (3)

1.2.3 The swept volume of the low-pressure cylinder in m³ (6)

1.2.4 The volumetric efficiency, induced volume, and the swept volume of the high-pressure cylinder in m³ (5)

[20]

**QUESTION 2**

2.1 Explain the difference between *actual dryness fraction* and *isentropic dryness fraction*. (3)

2.2 Steam enters a convergent-divergent nozzle, dry saturated, at a pressure of 900 kPa. At the throat, the steam has a dryness factor of 0,96 at a pressure of 0,5 MPa. At the exit, the pressure is 0,35 MPa while the steam has the actual and isentropic dryness factor of 0,945 and 0,929 respectively. A mass of 0,645 kilogram steam passes through the nozzle at a time.



Use steam tables and calculate the following:

2.2.1 The specific enthalpy, the velocity in m/s and the specific volume of steam at the nozzle throat (8)

2.2.2 The total actual exit enthalpy, total exit isentropic enthalpy, and overall efficiency of the nozzle (9)

[20]



QUESTION 3

- 3.1 In a velocity-compound impulse turbine, explain the purpose of *the fixed row of blades*. (3)
- 3.2 A two-row velocity-compound impulse turbine receives steam through a set of nozzles at a velocity of 700 m/s and 18° . The turbine shaft rotates at 3 000 rev/min and has a mean diameter of 750 mm. The exit angles of the first row of moving blades and fixed blades, and second row of moving blades are 21° , 27° and 35° respectively. The velocity coefficient of all blades is 0,9 and the steam mass flow rate is 2,1 kg/s. 
- Use a scale of 1 cm = 40 m/s and construct the velocity diagrams for the turbine in the ANSWER BOOK. Indicate all lengths (in cm) and all angles on the diagrams.
- Use the diagrams and determine the following: (10)
- 3.2.1 The fixed blades' inlet angle (1)
- 3.2.2 The first-stage axial thrust in Newton (3)
- 3.2.3 The turbine diagram efficiency (3)
- [20]**

**QUESTION 4**

- 4.1 State the *first law of thermodynamics* in words. (3)
- 4.2 A steam plant operating at a pressure of 3,5 MPa produces superheated steam at a temperature of 305°C with a specific heat capacity of 3,1125 kJ/kg.K. The plant burns fuel with a calorific value of 32 MJ/kg. The economiser increases feedwater temperature from $24,1^\circ\text{C}$ to $83,7^\circ\text{C}$ while absorbing 2 100 kJ/kg of supplied energy. At the entrance to the superheater, steam has a wetness of 2,13%. The pre-heater heats the air from 25°C to 119°C . The air-fuel ratio is 18:1 while the temperature at the chimney base is $177,09^\circ\text{C}$. The specific heat capacity of air and flue gases is 1,005 kJ/kg.K and 1,07 kJ/kg.K respectively. 
- Use steam tables and calculate the following. Give all final answers correct to TWO decimal places:
- 4.2.1 The mass of steam generated in kilogram per kilogram of fuel burnt (4)
- 4.2.2 The thermal efficiency of the whole plant (4)
- 4.2.3 The energy absorbed by the evaporator, superheater and the air pre-heater in kJ/kg of fuel (6)
- 4.2.4 The percentage heat carried away with the flue gases at the chimney (3)
- [20]**



QUESTION 5

5.1 Explain the difference between *indicated thermal efficiency* and *brake thermal efficiency* of an engine. (3)

5.2 A four-cylinder, four-stroke diesel engine has a bore and stroke length of 212 mm and 292 mm respectively. The engine's brake-specific fuel consumption is 0,226 kg/kW.h while running at a speed of 720 revolutions a minute at a brake mean pressure of 593 kPa. The air-fuel ratio is 25:1, and the diesel has a calorific value of 44,2 MJ/kg. Assume the air has a characteristic gas constant of 0,287 kJ/kg.K. The atmospheric conditions are 101,1 kPa and 15 °C.



Calculate the following:

5.2.1 Engine brake power in kilowatt (4)

5.2.2 Fuel mass flow rate per hour (3)

5.2.3 Brake thermal efficiency of the engine (3)

5.2.4 Volumetric efficiency of the engine (7)

[20]

**QUESTION 6**

A continuous-combustion, constant-pressure gas-turbine unit takes in air at 95 kPa and 20 °C. The rotary compressor, with 83% of isentropic efficiency, compresses air to 550 kPa. After leaving the combustion chamber, the fuel gases have a temperature of 870 °C that are expanded to 95 kPa through the turbine that has an isentropic efficiency of 80%. Assume a uniform working fluid with flow rate, adiabatic index and specific heat capacities of 10 kg/s, 1,4 and 1,03 kJ/kg.K respectively.

Calculate:

6.1 The compressor's output isentropic and actual absolute temperature (4)

6.2 The turbine's output isentropic and actual absolute temperature (4)

6.3 The compressor input power, the turbine output power and the plant net power output in kJ/min (5)

6.4 The plant input thermal energy in kJ/s and the plant thermal efficiency (4)

6.5 The plant work ratio. (3)

[20]

TOTAL:

100



POWER MACHINES N6**FORMULA SHEET**

Any applicable formula may also be used.

ENGLISH**GENERAL****AFRIKAANS**

$$P_a V_a = m R T_a$$

$$R = C_p - C_v$$

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

$$PV = c$$

$$PV^n = c$$

$$PV^\gamma = c$$

$$PV = k$$

$$PV^n = k$$

$$PV^\gamma = k$$

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

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

$$Q = \Delta U + Wd$$

$$Q = \Delta U + Av$$

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

$$\Delta s = m \cdot C_v \cdot \ln \frac{P_2}{P_1}$$

$$\Delta s = m \cdot C_p \cdot \ln \frac{V_2}{V_1}$$

$$\Delta s = m \cdot R \cdot \ln \frac{P_1}{P_2}$$

$$Q = m \cdot C_p \cdot \Delta T$$

$$Q = m \cdot C_v \cdot \Delta T$$

$$S_{su} = S_g + C_p \cdot \ln \frac{T_{su}}{T_s}$$

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

$$S = S_f + x S_{fg}$$

$$h_{su} = h_g + C_p (t_{su} - t_s)$$

ENGLISH**GENERAL****AFRIKAANS**

$$h_{ws} = h_f + xh_{fg}$$

$$V_{su} = \frac{\frac{n-1}{n} (h_{su} - 1941)}{P_{su}}$$

$$h_{ns} = h_f + xh_{fg}$$

$$V_{ws} = xV_g$$

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

$$V_{ns} = xV_g$$

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

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

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

*Different formulae for
work done (Wd)*

*Verskillende formules vir
arbeid verrig (Av)*

$$= P \times \Delta V$$

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

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

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

$$= m \cdot C_p \cdot \Delta T$$

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

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

ENGLISH**GENERAL****AFRIKAANS**

*Different formulae for
work done (Wd)*

= 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 efficien-
cies (ASE)*

*Verskillende formules
vir lugstandaardrende-
mente (LSR)*

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

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

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

*Different volumetric
efficiencies, θ_{vol}*

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

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

*Verskillende volumetriese
rendemente, θ_{vol}*

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

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

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

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

ENGLISH**GENERAL****AFRIKAANS**

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$h = u + pV$$

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

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

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

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