MADE EASY

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ESE 2023 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test-5 : Section A : Production Engineering & Material Science [All Topics]

Section B : *Theory of Machines-1 [Part Syllabus]*

Fluid Mechanics & Turbo Machinery-2 [Part Syllabus]

Name : ....

Roll No :

Test Centres	**Student's Signature**
Delhi ☑ Bhopal ☐ Jaipur ☐ Pune ☐ Kolkata ☐ Bhubaneswar ☐ Hyderabad ☐	

Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	38
Q.2	41
Q.3	—
Q.4	—
Section-B	
Q.5	38
Q.6	50
Q.7	—
Q.8	22
Total Marks Obtained	189

Signature of Evaluator .... Cross Checked by ....

IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

DONT'S

1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

COMMENTS:

1. The attempt was quite good but still there are some gray areas which need to be eliminated.
2. Avoid minor/silly calculation mistakes.
3. Read question carefully for what is being asked.
4. Go through detailed solution to clear the things in which some lack is there.
5. overall just avoid and improve the above written things, you can do much better.

Section : A

Q.1 (a) What do you understand by linear and planar densities?
Zinc has an atomic radius of 0.135 nm with an HCP crystal structure, and atomic weight of 65.39 g/mol. Considering $\frac{c}{a}$ ratio to be 1.856 for zinc, calculate the density for the same in g/cc.

[12 marks]

Linear Density
↳ It is ratio of no of atoms situated on a line vector to the length of vector

Planar Density
↳ It is ratio of no. of atoms suscribed by a plane to the area of the plane.

Zn → HCP

$r = 0.135$ nm

$A = 65.39$ g/mol

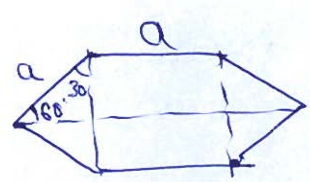
$\frac{c}{a} = 1.856$

N = Avagadro No.

$N = 6.023 \times 10^{23}$

V_c = Volume of shell.

$$\rho = \frac{nA}{V_c \times N}$$



↳ A_c

$V_c = (A_c) \times c$

$A_c = \left(2 \times \frac{1}{2} a \sin 60 \cos 60 \times 2 + 2a \times a \sin 60\right)$

$A_c = 2.598\, a^2$

$V_c = 2.598\, a^2 \times 1.856 a = 4.822 a^3$.

$a = 2r$.

$V_c = 38.576\, r^3$.

(12)

For HCP $n = 6$

$r = 0.135 \times 10^{-9}$ m

Put all the values in ρ ⇒ $\rho = 6863.23$ kg/m³

$\rho = 6.863$ g/cc

Q.1 (b) During an electric discharge drilling of a 12 mm square hole in a low carbon steel plate of 6 mm thickness, brass tool and kerosene are used. The resistance and the capacitance in the relaxation circuit are 60 Ω and 12 μF respectively. The supply voltage is 220 Volts and the gap is maintained at such a value that the discharge (sparking) takes place at 150 Volts. In case of machining steels, the removal rate can be approximately expressed as $Q \simeq 27.4\ W^{1.54}$, where Q is the removal rate of steel in mm^3/min and W is the power input in kW. Estimate the time required to accomplish the drilling operation.

[12 marks]

Square Hole

$a = 12\ mm$ $\quad R = 60\ \Omega$

$L = 6\ mm$ $\quad C = 12\ \mu F$

$V_0 = 220\ V$ $\quad Q = 27.4\ W^{1.54}$

$V_d = 150\ V$

Energy required $E = \frac{1}{2} C V_d^2$

Power $= \frac{E}{t} = \frac{1}{2t} C V_d^2$

$Q = \frac{\text{Volume}\ (V)}{T} =$

$N = \ln\left(\frac{V_0}{V_0 - V_d}\right)$

$N = \left(\frac{t}{RC}\right) = \ln\left(\frac{V_0}{V_0 - V_d}\right)$

$t = 8.244 \times 10^{-4}$ Sec → time of charging

Power $(W) = \frac{1}{2t} C V_d^2$

$W = 163.736$ W $= 0.163736$ kW

$Q = 1.6889 \frac{mm^3}{min}$

$Q = \left(\frac{Vol}{T}\right)$

Time required for drilling (T)

$T = \left(\frac{\text{Vol of Drill}}{Q}\right)$

Volume of Drill $= (a^2) \times L = 864$ mm³.

$T = 511.575$ min

(12)

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Q.1 (c) A hole 150 mm diameter is to be punched in a steel plate of 8 mm thickness. The material is cold rolled C40 steel for which the maximum shear strength can be taken as 560 MPa. With normal clearance on the tools, cutting is complete at 40% penetration of the punch. Estimate suitable diameters for the punch and die, and shear angle on the punch (assuming balanced shear) in order to bring the work within the capacity of a 250 kN press available.

[12 marks]

$D = 150 mm$

$t = 8 mm$

$\tau_{max} = 560 MPa$

0

Q.1 (d) Determine the dimensions and tolerances of shaft and hole with 25 H_7/h_8 fit. Also determine the allowance and maximum clearance.
[25 mm falls in the diameter range of 18 mm and 30 mm. Tolerance value for IT7 and IT8 are 16i and 25i respectively]

[12 marks]

$D_1 = 18$ mm

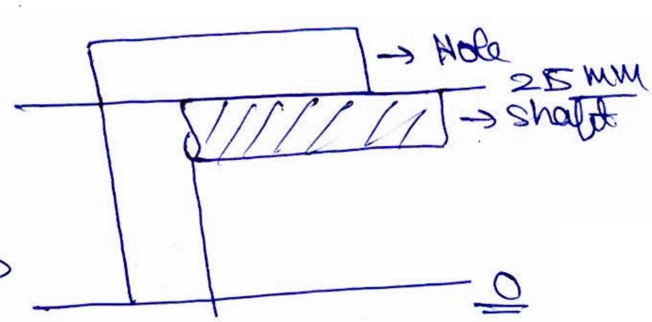
$D_2 = 30$ mm

$D = \sqrt{D_1 D_2}$

$D = 23.238$ mm

$i = 0.45\sqrt[3]{D} + 0.001D$

$i = 1.3073$ μm



Hole tolerance (IT_7) = T_H = $16i$ = 20.918 μm

Shaft tolerance (IT_8) = T_S = $25i$ = 32.683 μm

Hole → $25^{0.0209}_{+0.000}$ mm

UL = BS + T_H = 25.029 mm

LL = BS = 25 mm

~~Shaft~~

BS → Basic size = 25 mm

Shaft:

UL = BS = 25 mm

LL = BS − T_s = 24.996 mm

10

Allowance = Max / or Min. Clearance

Min clearance = Min Hole − Max Shaft = 0

Max clearance = Max Hole − Min shaft

= 53.001 μm

Q.1 (e) For a 79.60 wt%Fe - 0.40 wt%C alloy, determine the following:

(i) The mass fractions of total ferrite and cementite phases.

(ii) The mass fractions of the proeutectoid ferrite and pearlite.

(iii) The mass fraction of eutectoid ferrite.

[12 marks]

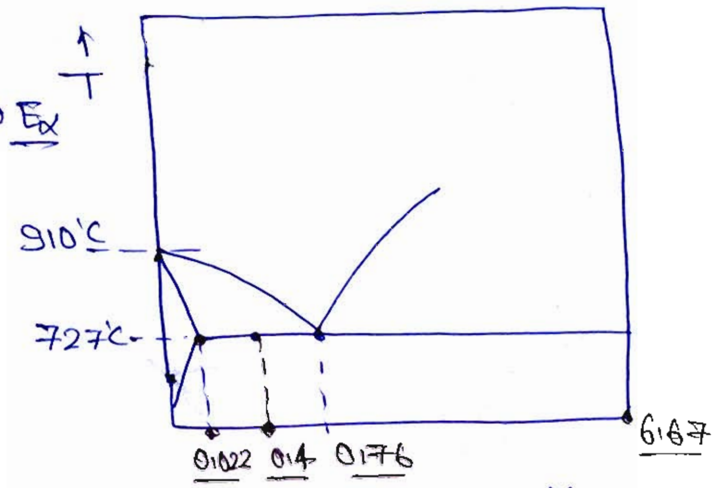
Total ferrite → α

Cementite → Fe_3C

Proeutectoid ferrite → P_α

Pearlite → P

Eutectoid ferrite → E_α



(i) $W_{Fe_3C} = \frac{(0.4 - 0.022)}{(6.67 - 0.022)}$

$W_{Fe_3C} = 0.0568$

$W_\alpha = 1 - W_{Fe_3C}$

$W_\alpha = 0.943$

(ii) $W_{P_\alpha} = \frac{(0.76 - 0.4)}{(0.76 - 0.022)} = 0.4878$

$W_P = \left(\frac{0.4 - 0.022}{0.76 - 0.022}\right) = 0.5122$

Refer solution.

(iii) $W_{E_\alpha} = W_\alpha - W_{P_\alpha}$

$W_{E_\alpha} = 0.4553$

Refer solution

04

Q.2 (a) Mild steel is being machined at a cutting speed of 240 m/min with a tool of rake angle 12°. The width of cut and the uncut thickness are 2 mm and 0.2 mm, respectively. If the average value of the coefficients of friction between the tool and the chip is 0.5 and the shear stress τ_s of the work material is 420 N/mm^2, then using Merchant's second analysis and assuming the machining constant to be 75° for the work material. Determine (i) the shear angle (ii) the cutting and thrust components of the machining force.
Also, find out the results using Lee and Shaffer theory and compare the results.

[20 marks]

$V = 240$ m/min $\qquad \mu = 0.5$

$\alpha = 12°$ $\qquad \tau_s = 420$ MPa

$b = 2$ mm

$t = 0.2$ mm $\qquad \tan\beta = \mu$

$\beta = 26.565°$

$\tan\phi = \left(\dfrac{r\cos\alpha}{1 - r\sin\alpha}\right)$

① Merchant analysis

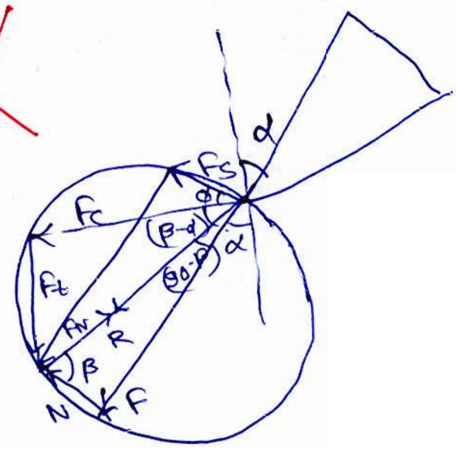
$2\phi + \beta - \alpha = \pi/2$

$\phi = 37.717'$

$F_s = C\tau_s\left(\frac{bt}{\sin\phi}\right)$

C → machining constant. $C = 0.75$

$F_s = 205.96\ N$



$\frac{F_c}{F_s} = \frac{R\cos(\beta-\alpha)}{R\cos(\phi+\beta-\alpha)}$

$F_c = \frac{F_s\cos(\beta-\alpha)}{\cos(\phi+\beta-\alpha)}$

$F_c = 325.84\ N$

$\frac{F_t}{F_s} = \frac{R\sin(\beta-\alpha)}{R\cos(\phi+\beta-\alpha)}$

$F_t = 84.66\ N$

Using Lee & Shaffer theory.

Refer solution

03

$\phi = \frac{\pi}{4} - \beta + \alpha$

$\phi = 30.435$

$F_s = C\tau_s\left(\frac{bt}{\sin\phi}\right)$

$F_s = 248.73\ N$

$\frac{F_c}{F_s} = \frac{\cos(\beta-\alpha)}{\cos(\phi+\beta-\alpha)}$

$F_c = 340.457\ N$

$F_t = F_c\tan(\beta-\alpha)$

$F_t = 88.46\ N$

Comparision

- In Lee shaffer theory shear angle increases due to which shear force decreases & there is corresponding decrease in the cutting & thrust forces in compare to merchant analysis

0 Refer solution

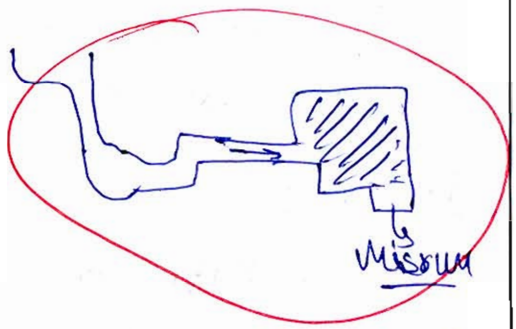
Q.2 (b) (i) Describe any five casting defects with neat sketch.

(ii) A casting of size 1200 mm × 1200 mm × 260 mm was filled by top and bottom gates with manometric height in pouring basin to be 260 mm. Compare the time to fill casting by different gates. The area of gate is 600 mm^2.

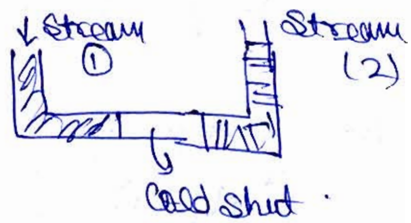
[10 + 10 marks]

Casting Defect.

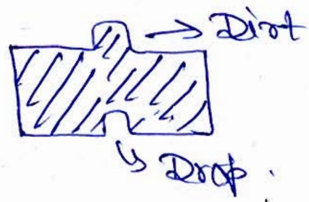
1. Misrun
↳ Defect arises due to freezing of molten metal before reaching each corner of the pattern.



2. Cold Shut
↳ When the two stream of the molten metal freezes before meeting this defect occurs.



3. Dirt & Drop.
↳ When the moulding sand from cope & drag fallen over pattern.

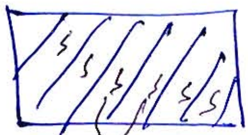


4. Hot tears.
↳ Due to non uniform cooling at minimum cross-section
↳ Residual stress generated

5. Pin Hole Porosity

↳ Due to escape of hydrogen molecule cavity generated inside mould.

↳ As H_2 mass less it is evaporated.



Porosity

(II) Casting

$V_c = 1200 \times 1200 \times 260 = 374.4 \times 10^6 \ mm^3$

$h_t = 260 \ mm$

$A_g = 600 \ mm^2$

$A_m = 1200 \times 1200$

$h_m = 260 \ mm$

$A_m = 1440000 \ mm^2$

Top Gate

$t_f \times A_g \times V_g = V_c$

$V_g = \sqrt{2 g h_t} = 2258.583 \ mm/s$

$t_f = 276.279 \ sec$

19

Bottom Gate

$\int_0^{t_f} dt_f \cdot A_g V_g = V_c = \int_0^{h_t} A \, dh$

$t_f = \frac{A_m}{A_g} \int_0^{h_t} \frac{dh}{\sqrt{2g(h_t - h)}}$

$V_g = \sqrt{2g(h_t - h)}$

$t_f = \frac{A_m}{A_g \cdot \sqrt{2g}} \left(\sqrt{h_t} - \sqrt{h_t - h_m} \right)$

$t_f = 552.56 \ sec$

Q.2 (c) Name the various forms of corrosion, which can occur in a system. Briefly explain pitting corrosion, stress corrosion and galvanic corrosion along with their respective remedies.

[20 marks]

Corrosion types:

1. Uniform corrosion
2. Galvanic corrosion
3. Erosion corrosion.
4. Intergranular corrosion.
5. Pitting corrosion.
6. Crevice corrosion.
7. ~~Erosion~~ Stress corrosion.
8.

Pitting Corrosion

↳ It is ~~indigen~~ localised form of the corrosion in a metal which occurs due to concentration difference between two regions of the metal

↳ It initiated at surfaces & moves down due to gravity.

Remedies:

(i) Polishing the surface

(ii) Add Mn at 6% to steel to avoid pitting corrosion.

Stress Corrosion

↳ It occurs when both corrosive atmosphere and the tensile stresses present inside the material.

↳ The stress need not to be external, it may be internal

Remedies:

↳ Recrystallises the metal by heating so that residual stresses can be minimised.

↳ Reduced the external loading.

↳ Increased the surface area of metal.

Galvanic Corrosion

↳ It is electrochemical reaction between the two metal when their cell potential is different

↳ The metal at anode will loose electron & gets corroded

$$M_1 \longrightarrow M_1^{n+} + ne^- \qquad -V_1^o$$

↳ Anode

$$M_2^{n+} + ne^- \longrightarrow M_2 \qquad V_2^o$$

↳ Cathode

$M_1 + M_2^{n+} \longrightarrow M_1^{n+} + M_2$

Remedies

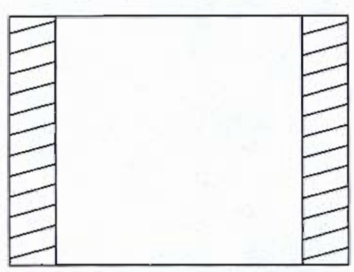
(I) Insulate the ~~two~~ electrode by 3rd metal

(II) Choose ~~two~~ metals that are closed in galvanic series

(III) Increasing the Anode Area.

19

Q.3 (a) As an engineer, you are supplied with a parallel bore as shown in figure whose internal diameter is to be measured using steel balls, dial indicator and slip gauge.



Describe three methods with steps to determine the internal diameter along with mathematical derivation.

[20 marks]

Q.3 (b) A round rod of annealed brass is being drawn from 8 mm to 6 mm at a speed of 0.5 m/s. Assume that frictional and redundant work together constitutes 30% of the ideal work of deformation. If the strength coefficient (k) is 900 MPa and strain hardening exponent (n) is 0.5, then calculate

(i) the power required in this operation.

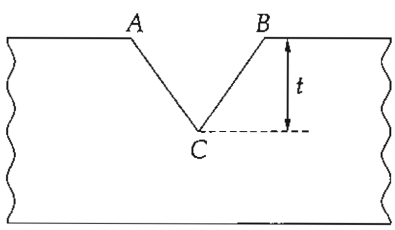
(ii) the die pressure at the exit of the die.

[20 marks]

Q.3 (c) **(i)** Enlist the various ingredients of electrode coatings.

(ii) 200 amperes of current is required for welding of C40 steel plate (as shown in figure) of 15 mm thickness while the requirement of current becomes 420 amperes when thickness of plate is increased by 50%. Estimate the welding current for 10 mm thickness of same material.

[Except current all other parameters are assumed to be constant]



[8 + 12 marks]

Q.4 (a) (i) Explain flank wear and crater wear along with a schematic diagram showing the corresponding regions of occurring.

(ii) The relationship for HSS tools is $VT^{1/8} = C_1$ and for tungsten carbide tools, it is $VT^{1/5} = C_2$. Assuming that at a speed of 30 m/min, the tool life was 150 min, in each case. Compare their cutting lives at 40 m/min.

(iii) What are the various factors which affect the tool life?

[10 + 5 + 5 marks]

Q.4 (b) What are the various methods involved in the production of metal powders in powder metallurgy? Discuss any four in brief. Also write some of the applications of powder metallurgy products.

[20 marks]

Q.4 (c) The orthogonal cutting of steel is done with 12° rake tool with a depth of cut of 2 mm and feed rate of 0.2 mm/rev. The cutting speed is 240 m/min. The chip thickness ratio is 0.36. The vertical cutting force is 1300 N and horizontal cutting force is 700 N. From the Merchant's theory, calculate

(i) Shear work percentage out of the total work done.

(ii) Friction work percentage out of the total work done.

(iii) Shear stress and shear strain.

(iv) Rate of shear strain (s^{-1})

[Assume the thickness of primary shear zone to be 20 microns]

[20 marks]

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Section : B

Q.5 (a) The disc of a torsional pendulum has a moment of inertia of 500 kg-cm^2 and is immersed in a viscous fluid. The brass shaft attached to it is of 20 cm diameter and 50 cm long. When the pendulum is vibrating, the observed amplitude on the same side of the rest position for successive cycles are 6.75°, 4.5° and 3°. Determine

(i) Logarithmic decrement

(ii) Damping torque at unit velocity, and

(iii) the periodic time of vibration

Assume for the brass shaft, $G = 4.5 \times 10^{10}$ N/m^2

[12 marks]

$I = 500$ kgcm^2 Disc

$D = 20$ cm, $L = 50$ cm } shaft

$X_0 = 6.75'$

$X_1 = 4.5'$

$X_2 = 3'$

(i) Logerthamic decrement (δ)

$\delta = \ln\left(\frac{X_0}{X_1}\right)$

$\delta = 0.405$

(ii) $\frac{TL}{GJ} = \theta$

$S_\theta = \left(\frac{T}{\theta}\right) = \left(\frac{GJ}{L}\right)$

$J = \left(\frac{\pi}{32} D^4\right)$

$S_\theta = 14137166.94$

$\sqrt{\frac{S_\theta}{I}} = \omega_n$

$\omega_n = 16814.97$ rad/s

$\delta = \frac{2\pi \xi}{\sqrt{1-\xi^2}}$

$\xi = 0.0643$

$2\xi\omega_n = \frac{c}{I}$

$C = 108.12$

$\omega_d = \sqrt{1-\xi^2}\,\omega_n = 16780.147$ rad/s

$T_d = \left(\frac{2\pi}{\omega_d}\right)$

$T_d = 3.744 \times 10^{-4}$ sec

10

Damping ~~torque~~ $= F_d \times L$

Q.5 (b) Oil of kinematic viscosity 3.684 stokes and density 950 kg/m^3 is pumped through a 120 mm diameter pipe and 600 m long at a rate of 0.003 m^3/s. Determine

(i) Reynolds number of the flow.

(ii) Pressure required at the pump.

If the outlet end, which is free is at 25 m above the pump level.

(iii) Power input, if the overall efficiency of the pump set is 70 percent.

[12 marks]

$\nu = 3.684 \times 10^{-4}$

$\rho = 950$ kg/m^3 $\quad Q = 0.003$ m^3/s

$D = 120$ mm $\quad A = \left(\frac{\pi}{4}D^2\right) = 0.01131$ m^2

$L = 600$ m

(i) $Re = \frac{\bar{U}D}{\nu} = \frac{Q\,D}{A\,\nu}$

$Re = 86.403$ (I)

(ii) $h_f = \frac{f L \bar{V}^2}{2gD}$ $\quad \bar{V} = \frac{Q}{A} = 0.2652$ m/s

$h_f = 17.93 f.$

Re < 2000 (∵ Laminar flow)

$f = \left(\frac{64}{Re}\right)$

$h_f = 13.281$ m

Pressure (P) = $\rho g(h_f + H)$

H = 25 m.

$P = 356.759$ kPa —(1)

12

Power input

$\eta_o = \frac{P_{ideal}}{(P_{in})}$

$P_{ideal} = PQ = 1.0702$ kW

$P_{in} = 1.528$ kW —(1)

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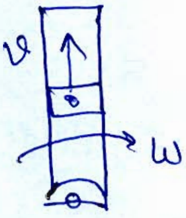
Q.5 (c) What is coriolis acceleration component? Derive the expression for it.

[12 marks]

- When a slider sliding under a revolving component the corolis acceleration generated

- <u>Sense of acc^n</u>

↳ Rotate the slider velocity in the sense of rotation of component (ω)



$$a_c = 2 v \omega$$

- Both the effect is necessary to generate corolis component.

04

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Q.5 (d) A reservoir whose water surface elevation is 180 m above datum, is being discharged through a pipeline 700 mm in diameter. The pipe is 6000 m long and is laid completely at the datum level. In the last 1600 m of the pipe, water is withdrawn by a series of pipes at a uniform rate of 0.098 m^3/s per 350 m. Find the pressure head at the end of pipeline. Assume f = 0.03 and the pipe to have a dead end.

[12 marks]

$H = 180\,m$

$D = 700\,mm$

$L = 6000\,m$

For the first ($L_1 = L - 1600$)

$L_1 = 4400\,m$

$h_f = \frac{f L_1 V_1^2}{2 g D_1}$

0

Q.5 (e) A centrifugal compressor with an isentropic efficiency of 85 percent, running at 18000 rpm has pressure ratio of 6 : 1 and inducing air at 288 K. Curved vane at inlet gives the air a prewhirl 28° to the axial direction at all radii and the mean diameter of eye is 28 cm. The absolute air velocity at inlet is 180 m/s. Impeller tip diameter is 65 cm. Calculate the slip factor.

[12 marks]

Centrifugal compressor

$\eta_{ic} = 0.85$

$N = 18000$ rpm

$r_p = 6$

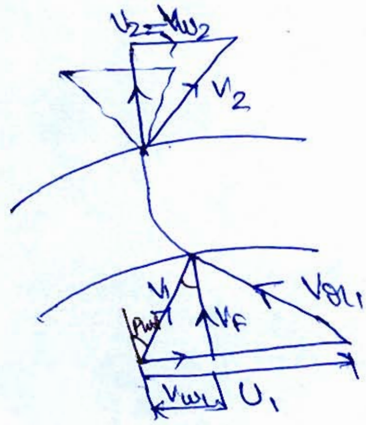
$T_1 = 288K$

$V_1 = 180$ m/s.

$D_2 = 65$ cm.

$\phi_s = ??$

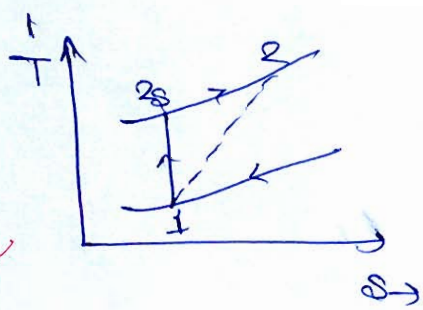
$D_1 = 28$ cm.



PWA = 28°

$(r_p)^{\frac{\gamma-1}{\gamma}} = \left(\frac{T_{2s}}{T_1}\right)$

$T_{2s} = 480.518$ K



$\eta_{ic} = \frac{(T_{2s}-T_1)}{(T_2-T_1)}$

$(T_2 - T_1) = 226.492$ K

$W_{in} = C_p(T_2 - T_1) = 227.625 \frac{kJ}{kg}$ — (1)

$W_{in} = (V_{w_2}U_2 - V_{w_1}U_1)$

$\phi_s = \left(\frac{V_{w_2}}{U_2}\right)$

$U_1 = \left(\frac{\pi D_1 N}{60}\right) = 263.894$ m/s

$U_2 = \left(\frac{\pi D_2 N}{60}\right) = 612.61$ m/s

$V_{w_1} = V_1 \sin(PWA) = 84.50$ m/s.

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$W_{in} = (\phi_s U_2^2 - V_{w_1} U_1) = C_p(T_2 - T_1)$

$\boxed{\phi_s = 0.666}$

(12)

Do not write in this margin

Q.6 (a) A Hooke's joint connects two shafts whose axes intersect at 25°. The driving shaft rotates at a uniform speed of 240 rpm. The driven shaft with attached masses has a mass of 72 kg and radius of gyration is 150 mm. Determine the

(i) Maximum and minimum speeds of the driven shaft.

(ii) Angle turned by the driving shaft when the velocity ratio is unity.

(iii) Torque required at the driving shaft if a steady torque of 320 Nm resists rotation of the driven shaft and the angle of rotation is 45°.

(iv) Angle between the shafts at which the total fluctuation of speed of the driven shaft is limited to 24 rpm.

[20 marks]

$\alpha = 25^\circ$ $\quad$ $m_2 = 72$ kg

$N_1 = 240$ rpm $\quad$ $k_2 = 150$ mm

$I_2 = 1.62$ kg m²

$\omega_1 = \left(\frac{2\pi N_1}{60}\right)$

$\omega_1 = 25.132$ rad/s

1 → Driver
2 → Driven

(i) $(N_2)_{max} = \left(\frac{N_1}{\cos\alpha}\right) = 264.81$ rpm

$(N_2)_{min} = (N_1)\cos\alpha = 217.513$ rpm

(ii) $\omega_2 = \frac{\omega_1 \cos\alpha}{1 - \sin^2\alpha \cos^2\theta}$

When $\omega_2 = \omega_1$

~~$1 - \sin^2\alpha \cos^2\theta = \cos\alpha$~~

~~$\sin^2\alpha + \cos^2\alpha + (1 - \cos\alpha) = (1 - \cos^2\alpha)\cos^2\theta$~~

$\tan\theta = \pm\sqrt{\cos\alpha}$

$\theta_1 = 43.58$

$\theta_2 = 316.408$

Angle turned $(\theta) = (\theta_2 - \theta_1) = 272.818^\circ$

Two more angles ?? Refer solution

(iii) If $\theta = 45^\circ$

$(T_{mean})_2 = 820$ Nm

$$\alpha_2 = -\frac{\omega^2 \cos\alpha \sin^2\alpha \sin 2\theta}{(1-\sin^2\alpha \cos^2\theta)^2}$$

$\alpha_2 = -123.276$ rad/s

$T_2 = (T_{mean})_2 + (I\alpha)_2$

18

$T_2 = 1201.292$ Nm

$$\omega_2 = \frac{\omega_1 \cos\alpha}{(1-\sin^2\alpha \cos^2\theta)} = 25.0108$$

Power Input = Power output (Assume $\eta = 100\%$)

$T_2\omega_2 = T_1\omega_1$

$\boxed{T_1 = 1191.712 \text{ Nm}}$ — Ans.

(iv) $(N_{max} - N_{min}) = \left(\frac{N_1}{\cos\alpha} - N_1\cos\alpha\right) = 24$

$$\left(\frac{1}{\cos\alpha} - \cos\alpha\right) = \left(\frac{24}{N_1}\right)$$

$$\left(\frac{1-\cos^2\alpha}{\cos\alpha}\right) = 0.1$$

$$\frac{\sin^2\alpha}{\cos\alpha} = 0.1$$

$\cos\alpha = 0.951$

$\boxed{\alpha = 17.964^\circ}$

Q.6 (b) The nozzle angle of a simple impulse turbine is 22°, and velocity of steam at entrance is 1200 m/s. The mean peripheral velocity of blade is 350 m/s and the blades are symmetrical. If the steam is to enter the blades without shock, what will be the blade angles?

(i) Determine the tangential force on the blades and the diagram power for a mass flow rate of 0.85 kg/s. Also, estimate the axial thrust and diagram efficiency, assume friction effects on the blades are negligible.

(ii) Estimate the axial thrust, diagram power and diagram efficiency if the relative velocity at exit is reduced by friction to 88% of that at inlet.

[20 marks]

Simple impulse turbine

$\alpha = 22'$

$V_1 = 1200$ m/s

$U = 350$ m/s

$\theta = \phi$ (symmetrical blade)

$V_{f_1} = V_{f_2}$ (without shock)

↳ Axial thrust ↳ 0

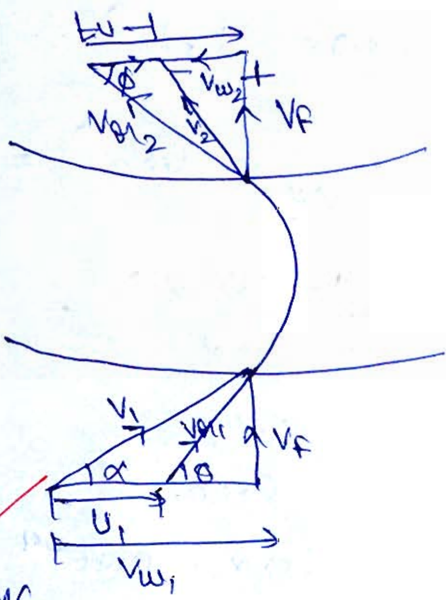
$V_{w_1} = V_1 \cos\alpha = 1112.62$ m/s

$V_{f_1} = V_1 \sin\alpha = 449.53$ m/s

$\tan\theta = \frac{(V_f)}{(V_{w_1} - U)}$

$\boxed{\theta = 80.517'}$

↳ entry blade angle.



$V_{r_1} = \sqrt{V_f^2 + (V_{w_1} - U)^2}$

$V_{r_1} = 885.249$ m/s

Assume No friction.

$V_{r_1} = V_{r_2} = 885.249$ m/s

$V_{r_2} \sin\phi = V_f$

$\boxed{\phi = 80.517'}$

$U + V_{w_2} = V_{r_2} \cos\phi = 762.619$ m/s

$V_{w_2} = 412.619$ m/s

(i) Tangential force

$F_T = \dot{m}(V_{w_1} + V_{w_2}) = 1296.458$ N

Power $= (F_T \cdot U) = 453.758$ kW

$\eta_b = \frac{\text{Power}}{\frac{1}{2}\dot{m}V_1^2} \times 100$

$\eta_b = 74.148$

As shock less $V_{f_1} = V_{f_2}$

Axial thrust $= F_a = \dot{m}(V_{f_1} - V_{f_2}) = 0$

20

(ii) If $V_{r_2} = 0.88\, V_{r_1}$

$V_{r_2} = 779.019$ m/s.

$V_{f_2} = V_{r_2}\sin\phi = 395.581$ m/s

$V_{r_2}\cos\phi = U + V_{w_2}$

$V_{w_2} = 321.108$ m/s.

$F_a = \dot{m}(V_{f_1} - V_{f_2})$ → Axial thrust

$F_a = 45.856$ N

Power $= (F_T\, U) = \dot{m}(V_{w_1} + V_{w_2})U$

Power $= 426.534$ kW

$\eta_b = \frac{\text{Power}}{\frac{1}{2}\dot{m}V_1^2} \times 100$

$\eta_b = 69.69\%$

Q.6 (c) A punching machine punches 10 holes of 20 mm diameter in 30 mm thick plates per minute. The actual punching operation is done in $\frac{1}{10^{th}}$ of a revolution of the crankshaft. Ultimate shear strength of the steel plates is 250 N/mm^2. The coefficient of fluctuation of speed is 0.2. The flywheel with a maximum diameter of 1.5 m rotates at 15 times the speed of the crankshaft. Determine the

(i) Power of the motor assuming the mechanical efficiency to be 90%.

(ii) Dimensions of the flywheel rim if width is twice the thickness.

The flywheel is of cast iron with a working tensile stress of 6 N/mm^2 and a density of 7500 kg/m^3. The hub and the spokes of the flywheel may be assumed to deliver 10% of the rotational inertia of the wheel.

[20 marks]

- Holes per min = 10
- Hole
  - $D = 20$ mm
  - $t = 30$ mm
- $\tau_s = 250$ MPa
- $C_s = 0.2$

Flywheel

$D = 1.5$ m

1 Hole → 6 Sec

1 rev of crankshaft → 6 Sec.

~~W_{crank}~~ $= \left(\frac{1}{6}\right)$

~~W_{crank}~~ $= N_{crank} = 10$ rpm.

$N_{Flywheel} = (10 \times 15) = 150$ rpm

Energy required by each hole (E_{hole})

$= \tau_S \times \left(\frac{\pi D t}{2}\right) \times \left(\frac{t}{2}\right) = 7068.583$ J

Power of motor (P) $= \left(\begin{matrix}\text{Energy required}\\ \text{by each hole}\end{matrix}\right) \times \left(\frac{\text{No of hole}}{\text{Sec}}\right)$

Power (P) = 1178.09 W

Actual Power (P_a) $= \left(\frac{P}{\eta_m}\right)$

$P_a = 1.309$ kW — (1)

(12)

Actual punching (t_{act}) $= \left(\frac{1}{10}\right) \times 6 = 0.6$ Sec

Energy provided by Motor in 0.6 Sec

$E_m = 785.4$ J

Extra energy required (Provided by flywheel) (ΔE_{max})

ΔE_{max} = Energy required by each hole (E_{hole}) − ~~Each~~ Energy provided by motor

$\Delta E_{max} = 6283.183$ J

$\Delta E_{max} = E_{flywheel} = (0.9)\, E_{wheel}$.

$\Delta E_{max} = (I \omega^2 C_s)_{max} = 6283.183$ J
↳ (E_{wheel})

~~$\omega = \left(\frac{150\times 2\pi}{60}\right)$~~ $\omega = \left(\frac{2\pi N}{60}\right) = 1.047$ rad/s

$(0.9) I \omega^2 C_s =$

$I = 81842.99$ kgm^2

$I = mk^2 = m\left(\frac{D}{2}\right)^2 = I$

$m = 56609.76$ kg

$\rho \times V = m$

$V = 7.5479$ m^3

$V = (\pi D) bt = (\pi D)(2t^2)$

$t = 89.49$ cm

$b = 178.98$ cm

X Refer Solution

Q.7 (a) In laminar boundary layer over a flat plate, the velocity distribution is assumed as $u = a\sin(by) + c$; where a, b and c are constants.

Determine the velocity distribution law by applying appropriate boundary conditions. Also develop an expression for boundary layer thickness, wall shear stress and skin friction coefficient, drag force on one side of plate and the drag coefficient in terms of Reynolds number. Use momentum integral equation.

[20 marks]

Q.7 (b) In a spring loaded Hartnell type of governor, the mass of each ball is 5 kg and the lift of the sleeve is 50 mm. The governor begins to float at 240 rpm when the radius of the ball is 100 mm. The mean working speed of the governor is 15 times the range of speed when friction is neglected. The lengths of the ball and roller arms of the bell-crank lever are 100 mm and 80 mm respectively. The pivot centre and the axis of the governor are 120 mm apart. Determine the initial compression of the spring, taking into account the obliquity of arms.

Assume the friction at the sleeve to be equivalent to a force of 130 N, determine the total alteration in speed before the sleeve begins to move from the mid-position.

[20 marks]

Q.7 (c) (i) Briefly discuss the working of the ramjet engine. Also, write down it's advantages, disadvantages and characteristics.

(ii) Air at 290 K and 1 bar enters a turbojet engine at a rate of 35 kg/s and is compressed adiabatically to 190°C and four times the pressure. Products of combustion enter the turbine at 920°C and leave at 715°C to enter the nozzle. Determine

(a) Isentropic efficiency of compressor.

(b) Power required to drive the compressor.

(c) The exit speed of gases and thrust developed when flying at 275 m/s.

Assume the isentropic efficiency of turbine is same as that of the compressor and the nozzle efficiency 92 percent. Take $\gamma_{air} = 1.4$ and $\gamma_{gas} = 1.33$, $(c_p)_{air} = 1.005$ kJ/kgK; $(c_p)_{gas} = 1.147$ kJ/kgK

[10 + 10 marks]

Q.8 (a) A disc of mass 5 kg is mounted midway between bearing which may be assumed to be simple supported. The bearing span is 100 cm. The steel shaft is of 20 mm diameter and is horizontal. The centre of gravity of the disc is displaced 2.5 mm from the geometric centre. The equivalent viscous damping at the centre of the disc shaft may be assumed to be 50 N-sec/m. If the shaft rotates at 320 rpm, determine the maximum stress in the shaft.

Also find the power required to drive the shaft, at this speed. Take Young's modulus $E = 1.5 \times 10^{11}$ N/m² for steel shaft.

[20 marks]

Disc

$m = 5\,kg$

Bearing

↳ SSB

↳ $L = 1\,m$

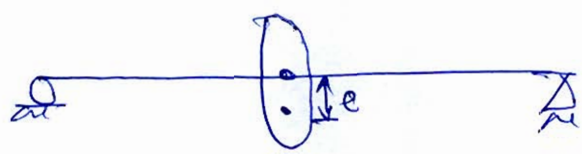
Shaft $D = 20\,mm$

↳ Horizontal

$e = 2.5\,mm$

$C = 50\,\frac{Ns}{m}$

$N = 320\,rpm$



$\omega = \left(\frac{2\pi N}{60}\right) = 33.51\ rad/s$

Deflection of shaft due to load at mid point (Δ)

$\Delta = \frac{PL^3}{48EI}$ $\quad P = (mg)$

$I = \left(\frac{\pi}{64} D^4\right)$

$\Delta = 8.673 \times 10^{-4}\ m$

$\omega_n = \sqrt{g/\Delta} = 106.347\ rad/s$

Amplitude $(A) = \frac{(e)}{\left(\frac{\omega_n}{\omega}\right)^2 - 1}$

$A = 0.275\ mm$

$F_d = (C\omega A) = 0.4617\ N$

↳ Dynamic force acting due to misalignment & rotation of shaft at centre.

$$\frac{M}{I} = \frac{\sigma}{y} \qquad M = \left(F_d \times \frac{L}{4}\right)$$

$$\sigma = \left(\frac{M}{Z}\right) \qquad Z = \left(\frac{\pi}{32} D^3\right)$$

$$\boxed{\sigma_{max} = 0.14697 \text{ MPa}}$$

Refer solution

Power required

$$P = (F_d) \cdot V = (F_d) \cdot (\omega A)$$

$$\boxed{P = 4.246 \times 10^{-3} \text{ W}}$$

13

Q.8 (b) The first stage of an axial compressor with no inlet guide vanes is designed on free vortex principle. The stagnation temperature rise is 20 K and the rotational speed is 5000 rev/min. The work done factor is 0.92, the hub-tip ratio is 0.7 and the isentropic efficiency of the stage is 0.87. Assuming ambient conditions of 1 bar and 290 K and an inlet velocity of 160 m/s. Determine

(i) Tip radius and corresponding rotor air angles β_1 and β_2, if the mach number relative to tip is limited to 0.9.

(ii) the mass flow entering the stage.

(iii) the stage stagnation pressure ratio and power input, and

(iv) the rotor air angles at the root section.

[Assume axial inlet]

[20 marks]

Axial compressor

Axial compressor

1st stage

↳ No GV

↳ Vortex Principle $(V_w r) = C$

$T_{02} - T_{01} = 20K$

$N = 5000$ rpm

$\omega = \left(\frac{2\pi N}{60}\right) = 523.598$ rad/s

$\phi_w = 0.92$

$\frac{D_1}{D_2} = 0.7$ $\left(\begin{matrix} 2 \rightarrow \text{tip} \\ 1 \rightarrow \text{Hub} \end{matrix}\right)$

$\eta_{isen} = 0.87$.

$T_{00} = 1$ bar $V_1 = 160$ m/s.

$P_{00} = 290K$

(I) r_2, β_1, β_2, $M_2 = 0.9$

(II) $\dot{m}_f$ (III) r_{P_0}, P_{in}

Axial inlet

$\eta_{isen} =$

02

Q.8 (c) A gun barrel of mass 500 kg has a recoil spring of stiffness 235 N/mm. If the barrel recoils 1.5 m on firing and the time taken by the gun barrel is one-fourth of the total cycle time, then determine:

(i) the initial recoil velocity of the barrel.

(ii) the critical damping coefficient of the dashpot which is engaged at the end of recoil stroke.

(iii) the time required for the barrel to return to a position 5 cm from the initial position.

Also plot the variation of displacement with time.

[20 marks]

$m = 500$ kg

$S = 235$ N/mm

$\omega_n = \sqrt{S/m} = 21.679$ rad/s

$T_n = \left(\frac{2\pi}{\omega_n}\right) = 0.1047$ s

time taken by barrel $(t) = \left(\frac{T_n}{4}\right)$

$t = 0.0261$ sec

Barrel

$V_f = 0$, $V_i = ?$

$L = 1.5$ $t = 0.0261$

$L = V_i t + \frac{1}{2} a t^2$ — (I)

$V_f^2 = V_i^2 + 2aL$ — (II)

$V_f = V_i + at$ — (III)

from (II)

$-V_i^2 = 2aL$

$a = \frac{-V_i^2}{2L}$

Put it in (III)

$0 = V_i - \frac{V_i^2 t}{2L}$

$V_i = \frac{V_i^2 t}{2L}$ $\Rightarrow$ $\frac{2L}{t} = V_i$

Refer solution

$$N_i = 114.942\ m/s$$

$$\left(\frac{C}{2m}\right)^2 = \frac{S}{m}$$

$$C_c = \sqrt{\frac{S}{m}} \cdot 2m$$

$$C_c = 21679\ \frac{Ns}{m}$$

07

OOOO

Space for Rough Work

1 A B (C) D E

2. A B C →

3. A B C X

4. A B (C)

5. A B (C) D E

6. A B C →

7. A B C

8. A B C →