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ESE 2018 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test 6 : Renewable Sources of Energy + Industrial and Maintenance Engineering, Production Engineering and Material Science - 1, Strength of Material and Mechanics - 2

Name : ATK

Roll No : M E 1 8 P U M T F 0 0 1

Test Centres					Student's Signature
Delhi ☐	Bhopal ☐	Noida ☐	Jaipur ☐	Indore ☐	
Lucknow ☐	Pune ☑	Kolkata ☐	Bhubaneswar ☐	Patna ☐	
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Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. Answer must be written in English only.
3. Use only black/blue pen.
4. 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.
5. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
6. Last two pages of this booklet are provided for rough work. Strike off these two pages after completion of the examination.

Important

FOR OFFICE USE	
Question No.	Marks Obtained
Section-A	
Q.1	41
Q.2	40
Q.3	42
Q.4	
Section-B	
Q.5	28
Q.6	
Q.7	57
Q.8	
Total Marks Obtained	208

Signature of Evaluator ANKIT

Cross Checked by Ajeet

- Always Be specific in Theory questions.
- Question selection is brilliant

Section A : Renewable Source of Energy, Industrial and Maintenance Engineering

Q.1 (a) Find out solar altitude angle on a horizontal surface at 2 hours, after local noon on June 16 for a city located at 40°N (latitude). Also, find out the solar time (or local apparent time) at sunrise and at sunset and day length. Use following relation:

$\cos\theta_i = \cos\phi \cos\delta \cos\omega + \sin\delta \sin\phi$

where, θ_i - angle of incidence; ϕ - latitude angle; δ - declination angle

ω - hour angle; α - solar altitude angle

[12 marks]

Date given — 16 June

$\therefore n = 31 + 28 + 31 + 30 + 31 + 16$

$= 167$

$\therefore \delta = 23.45 \sin\left(360 \times \frac{(284+n)}{365}\right)$

(11) $\phi = 40^\circ$ $\therefore \delta = 23.354^\circ$

$\omega = 2 \times 15 = 30^\circ$

we have

$\cos\theta_z = \sin\delta \sin\phi + \cos\delta \cos\phi \cos\omega$

$\cos\theta_z = \sin(23.354^\circ) \sin 40^\circ + \cos(23.354^\circ) \cos(40^\circ) \cos(30^\circ)$

$= 0.863872$

$\therefore \theta_z = 30.2488^\circ$

we know that

$\alpha + \theta_z = 90$ $\therefore \alpha = 59.754^\circ$

This is the solar altitude angle.

$\alpha = 59.754^\circ = 59^\circ 45'$

to find the sunrise time & sunset time

$$\omega_s = \cos^{-1}(\tan\phi \tan\delta)$$

$$\therefore \omega_s = \cos^{-1}(-\tan 4^\circ \tan 23.354^\circ)$$

$$\therefore \omega_s = 111.2422^\circ$$

Thus for this ω_s

$$\text{local sunrise time} = 12:00 - \frac{111.2422}{15}$$

$$= 12:00 - 7\text{hr } 24\text{ minut}$$

$$= 04^h:36^m$$

$$\text{local sunset time} = 12:00 + 7\text{hr } 24\text{ mn.}$$

$$= 19^h:24^m$$

$$\text{Day length} = \frac{2\omega_s}{15} = \frac{2\times 111.2422}{15}$$

$$= 14 \text{ hours } 49 \text{ min } 56 \text{ sec}$$

Q.1 (b) A biomass gasifier is used to run a CI engine in a dual fuel model with 80% diesel replacement. The gasifier engine system produces 200 kW of power at 800 rpm. Calculate the biomass feeding rate of the gasifer if the efficiency of the engine is 35% and the calorific value of the producer gas is 17000 kJ/kg, assuming the efficiency of gasifier to be 75%.

[12 marks]

power produced = 200 kW

Thus heat required to supplied.

$$Q_s = \frac{200}{\eta} = \frac{200}{0.35} = 571.42857 \text{ kW}$$

now total producer gas require

$$\dot{m}_f = \frac{Q_s}{C.V.} = \frac{571.42857}{17000}$$

$$\therefore \dot{m}_f = 0.0336134 \text{ kg/s}$$

(11)

out of total 80% diesel is replaced by biomass gasifier.

∴ The biomass burnt

$$= \dot{m}_f \times 0.8 = 0.02689 \text{ kg/s}$$

Now Biomass feeding rate

$$= \frac{\text{biomass burnt}}{\eta_{gasifier}} = \frac{0.02689}{0.75}$$

$$\dot{m}_b = 0.035854 \text{ kg/s}$$

also $\dot{m}_b = 2.659 \times 10^{-5}$ kg/cycle

Q.1 (c) What is *ABC* analysis? Explain with the help of Pareto chart.

[12 marks]

In the any inventory control system there are various kind of products (or) parts which have having various prises.

There are some products

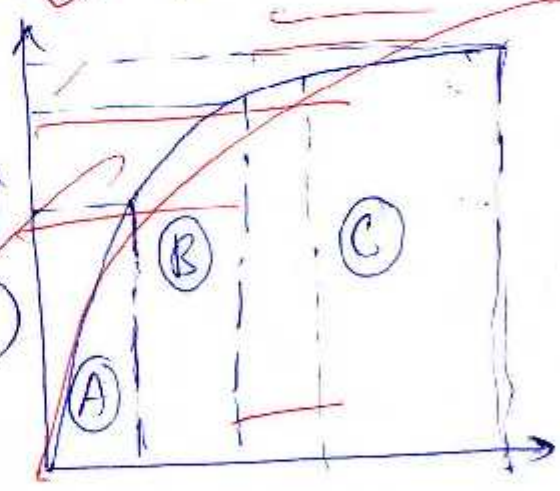
A – Very high price (70% of total price)

B – moderate price (20% of total price)

C – very less price (10% of total price.

Due to very high cost

→ A type of products are in stocks are very less in stock (10% of total) even then they cover 60% of the cost of total.



which can be easily explained by pareto chart given.

→ Product C are having very less price thus even for large stocking their cost is (10% of total so they are stored in large number

→ In case of product B they are having moderate stock and moderat cost (30% of total.)

Q.1 (d) Name the different techniques used for condition monitoring and list its main objective. **[12 marks]**

Condition monitoring

→ Monitoring the condition of the machine using the information of the parameters which influence the condition of it is called as condition based monitoring.

→ It is based on the predictive maintainance a type of preventive maintainance.

→ Techniques useds

1) wear Debris analysis
2) more.
3) ?
4) ?

(6)

Main objectives

1) To reduce (or) eleminate the break down of machine and cost related to it.
2) To reduce unwanted cost of maintainance due to regular check up.
3) To reduce the cost of the maintainance using advance and easy to operate technique
4) Eleminate break down of machine.

Q.1 (e) Differentiate between zero wear and measurable wear. Name all the types of possible common wear mechanisms.

[12 marks]

→ When the wear of the machine part is measurable length is instruments ie. can be detected by the equipments using some techniques and sensors then it is called measurable wear.

→ Zero wears can not be detected by the instruments so called zero wear.

Types of wearing mechanisms

1) Pitting wear
2) Corrosive wear
3) erosive wear
4) scuffing wear
5) Abrasive wear
6) Electrolytic wear
7) Diffusive wear.
8) Shearing wear.

9. Adhesion wear.

6

Q.2 (a) Derive the relationship between the maximum power developed by the turbine in comparison to the total available power in wind?

If the inlet wind velocity (upstream) is 18 m/s and drop to 60% of wind velocity over blade and drop to 33% at downstream wind velocity, then determine the ratio maximum thrust on turbine rotor at maximum power condition to at maximum torque condition. Atmospheric condition are $T_1 = 27°C$ and $P_1 = 1.012$ bar.

[20 marks]

Assumption

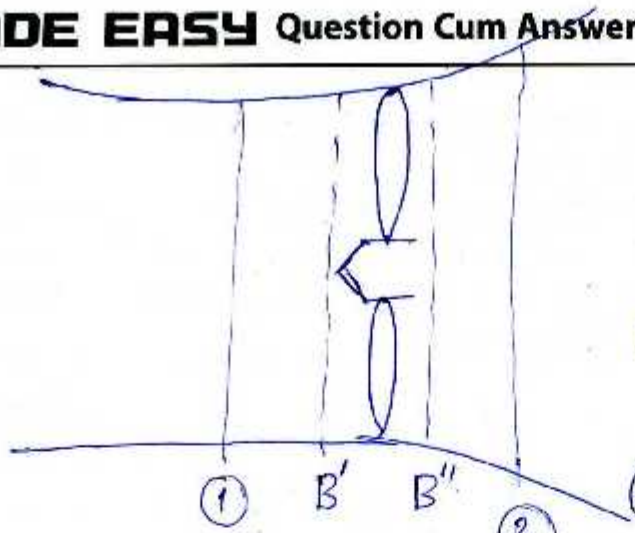
1) wind velocity is constant V_∞
2) There is no friction loss over the turbine blade or other losses due to friction neglected.
3) Flow of velocity is normal to the plane of rotation. & ρ is constant.

When air flows through the area A with V_∞ velocity the energy posses by it

$$P = \frac{1}{2} \dot{m} V_\infty^2 \quad W$$

$$\boxed{P = \frac{1}{2} \rho A V_\infty^3} \quad \text{---} (1)$$

Now considering the wind turbine of some radius such that flow area is A as shown in figure



① - inlet
B' - close to the blade just before
B'' - close to the blade just after
② - outlet.

now applying the bernullje beth ① & B' & B'' & ②

$$P_1 + \frac{1}{2}\rho V_1^2 = P_{B'} + \frac{1}{2}\rho V_{B'}^2 \quad \text{——} (2)$$

$$P_{B''} + \frac{1}{2}\rho V_{B''}^2 = P_2 + \frac{1}{2}\rho V_2^2 \quad \text{——} (3)$$

by ~~subtracting~~ adding (3) & (2)

$$P_{B''} + P_1 + \frac{1}{2}\rho V_1^2 + \frac{1}{2}\rho V_{B''}^2 = P_2 + P_{B'} + \frac{1}{2}\rho V_{B'}^2 + \frac{1}{2}\rho V_2^2$$

as A remains same for B' & B''

$V_{B'} = V_{B''}$ also $P_1 = P_2 = P_{atm}$.

$$\therefore P_{B''} + \frac{1}{2}\rho V_1^2 = P_{B'} + \frac{1}{2}\rho V_2^2$$

$$\therefore P_{B'} - P_{B''} = \frac{1}{2}\rho(V_1^2 - V_2^2)$$

from mass flow rate $\dot{m} = \rho A \times V_B$

$$F_{drag} = A(P_{B'} - P_{B''}) = \rho A\left(\frac{V_1^2 - V_2^2}{2}\right) \quad \text{——} (4)$$

also $F_{drag} = \rho A V_B (V_1 - V_2)$ —— (5) (by change of momentum eqn)

Thus $\boxed{V_B = \frac{V_1 + V_2}{2}}$ —— (using (4) & (5))

Finally

$$P_{actual} = \frac{1}{2}\rho A v_B (V_1^2 - V_2^2) = \frac{1}{2}\rho A \left(\frac{V_1+V_2}{2}\right) \times 2\left(\frac{V_1^2-V_2^2}{2}\right)$$

$$\frac{dP}{dV_2} = \frac{1}{4}\rho A \left[(V_1^2 - V_2^2) \times 1 - 2V_2 \times (V_1 + V_2) \right]$$

for P_{max} $dP/dV_2 = 0$

$$\therefore V_1^2 - V_2^2 = 2V_2(V_1+V_2) \Rightarrow V_2 = \frac{V_1}{3}$$

(10) $$P_{max} = \frac{1}{4}\rho A \left(1+\frac{1}{3}\right) \times \left(1-\frac{1}{9}\right) V_1^3 = \frac{8}{27}\rho A V_1^3$$

But $V_1 = V_\infty$

$$\therefore P_{max} = \frac{8}{27}\rho A V_1^3 = \frac{16}{27} P_{available}$$

We have

$V_\infty = 18$ m/s

Numerical ?

Q.2 (b) What is a fuel cell and what are its main advantages? Classify fuel cells based on

1. Type of electrolyte
2. Types of the fuel and oxidant
3. Operating temperature
4. Application
5. Chemical nature of electrolyte **[20 marks]**

Fuel cell - It is the device which uses fuels to combine in presence of electrolyte to convert it chemical energy into heat energy and electrical energy.

Advantages

1) No moving part so no vibration, low maintance
2) very high efficiency
3) By product water (generally) is useful in space
4) Can produce heat aswell as electricity which can be used in powerplant applications.

Classification

1) Type of electrolyte
   (i) Alkaline fuel cell (KOH)
   (ii) Phosporic acid fuel cell (H_3PO_4)
   (iii) Molten Carbonate fuel cell (H_2CO_3)
   (iv) Polymer electrolyte membrane fuel cell
   (v) proton ion exchange fuel cell. (H^+)
   (vi) Solid oxide fuel cell (O^{-2})

2) Type of fuel cell -

There are various types of fuel cell which use different fuels

(1) H_2 and O_2 fuel cell
(2) Carbon and oxygen fuel cell
(3) H_2 and air fuel cell
(4) methand and O_2 fuel cell
(5) methanol & O_2 fuel cell etc.

Same

3) Operating temperature

(i) Low temperature fuel cell (80°-100°C)
(ex) polymer membrane fuel cell.
(ii) medium temperature fuel cell (100°-300°C)
(ex) Alkaline fuel cell, phosperic acid fuel cell
(iii) High temperature fuel cell (500°-1000°C)
ex molten Carbonate fuel cell, solid oxide fuel cell.

(4) Application

(i) Domastic application fuel cell
→ to produce small amount of electricity
→ these are basic fuel cells
(ii) Comurtial fuel cells.
→ They generate moderate amount of electric power generally used in buses & vehicals.

(iii) Industrial fuel cells

They produce large amount of power these are used in power generating industries to run electrical applications.

5) Chemical nature of electrolyte

1) +ve ion electrolyte ex — H^+

2) -ve ion electrolyte ex — OH^-, O^{-2}, CO_3^{-2}

14 more?

Q.2 (c) Discuss the relative merits and limitations of tidal power. What are the difficulties in tidal power developments? For a typical tidal power plant shown below, the basin area is 25×10^6 m^2. The tide has a range of 10 m. However, turbine stops working when the head on it falls below 2 m. Assume that density of seawater is 1025 kg/m^3, acceleration due to gravity is 9.81 m/s^2, combined efficiency of turbine and generator is 75% and period of energy generation is 6h and 12.5 min.

Determine:

1. Work done in filling or emptying the basin
2. Average power
3. The energy generated in one filling process (in kWh)

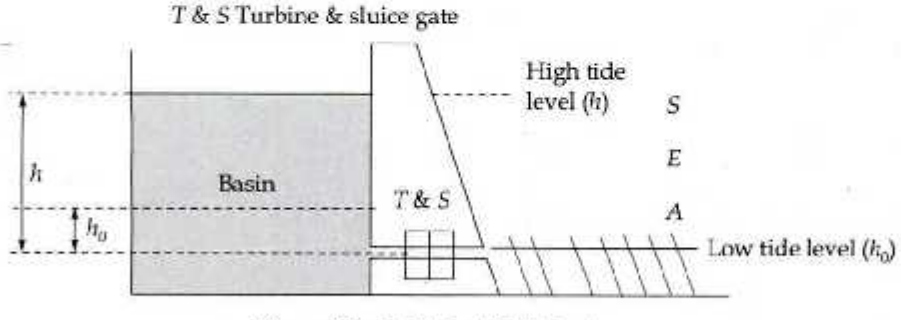


Figure: Single Basin tidal plant

[20 marks]

Merits

1) It is renuable form of energy thus there is no harm to the environment.
2) At costal are lands neat sea are totaly can be utilized.
3) With very low investmet charge amount of energy can be capture with no polution.

Demerits

1) Direction of tides and the head available is always varing with time so very complex power generation procss
2) Due to Reduction in tidal height due to disturbane it affect the ecosystem at costal region.
3) It is not continuous and reliable source of energy.

Difficulties in developing tidal power plant

1) Tidal height and the velocity is is always time dependant and vary continuously so difficulty in designing the turbine generator
2) Seag water contain huge amount of salt thus very high danger of corrosion.
3) Due to the high impact of wave erroion of the turbine takes place.

Given

$A_b = 25 \times 10^6 \, m^2$

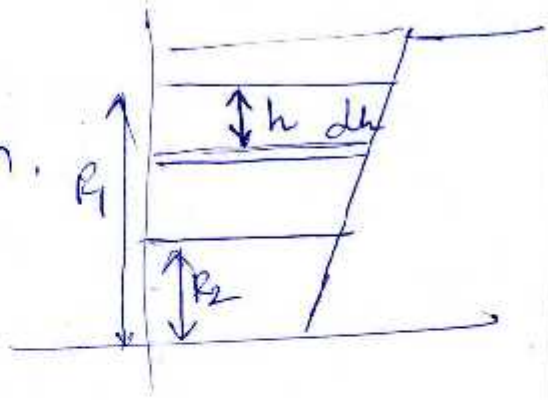
$R_1 = 10m, \; R_2 = 2m.$

$\rho = 1025 \, kg/m^3$

$g = 9.81 \, m/s^2$

$\eta_0 = 0.75$

Period = 6 h 12.5 min = 22350 sec



(i) work done on ~~filling~~ emptying the basin

$$W = -\int_{R_1}^{R_2} \rho A_b g h \, dh = \int_{R_2}^{R_1} \rho A_b g h \, dh$$

$$W = \rho A_b g \left[\frac{R_1^2 - R_2^2}{2}\right]$$

$$W = 1025 \times 25 \times 10^6 \times 9.81 \left[\frac{10^2 - 2^2}{2}\right]$$

$$\boxed{W = 12066.3 \times 10^9 \text{ Joule}}$$

Thus work done on filling or emptying the basin

$$\boxed{W = 120.663 \times 10^{12} \text{ Joule}}$$

(ii) Average power

$$P = \frac{W}{T} = \frac{120.663 \times 10^{12}}{22350}$$

$$\therefore P = 0.53988 \times 10^9 \text{ W}$$

$$\therefore P = 539.88 \text{ MW}$$ ×0.75

Thus average power of plant is 539.88 MW

(iii) After the feeding to turbine energy generated

$$E = \eta_0 \frac{\times PW}{3600 \times 1000}$$

$$E = \frac{0.75 \times 120663 \times 10^9}{3600 \times 10^3}$$

$$E = 25138125 \text{ kWh}$$

Energy generated in one filling process is 25138125×10^3 kwh

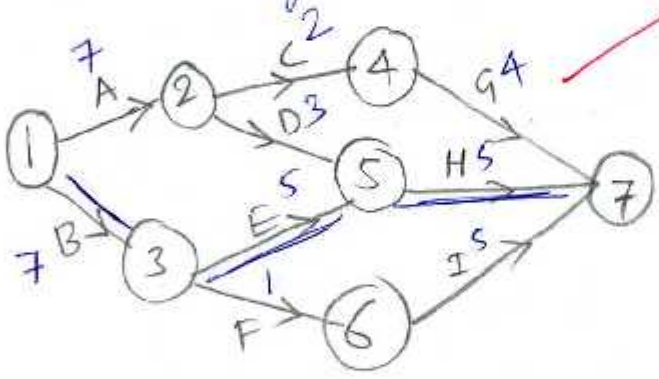
Q.3 (a) The data shown below is for a PERT network.

Predecessor Event	Successor Event	Activity Time		
		t_0	t_m	t_p
1	2	5	6	13
1	3	2	7	12
2	4	1.5	2	2.5
2	5	1	3	5
3	5	4	5	6
3	6	1	1	1
4	7	2	3	10
5	7	4	5	6
6	7	3	5	7

1. Draw the network
2. Each day the project can be shortened is worth ₹ 5000. Should the firm pay ₹12500 to reduce duration of activity 3 – 5 to 2 days?

[20 marks]

(i) Network diagram is ass follow.



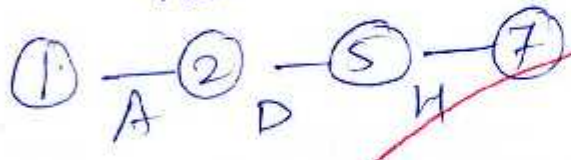
activity	$\frac{(t_0+t_p+4t_m)}{6}$	$(t_p-t_0)_6$
A	7	8/6
B	7	10/6
C	2	1/6
D	3	4/6
E	5	2/6
F	1	0
G	4	8/6
H	5	2/6
I	5	4/6

Critical path is

Duration of Critical path = 7+5+5 = 17 days

when firm reduce the duration of the activity 3-5 to 2 days Critical path will be changed and B new will become

18



7+3+5 = 15 days.

Thus firm should not reduce the duration B to 2 days. Mention Cost Also

Q.3 (b) For a product, the price discount is as follows:

Order quantity	Unit price (₹)
$0 \le Q < 550$	12
$550 \le Q < 700$	11.20
$700 \le Q$	10.70

Determine the *EOQ* considering discount and total inventory cost. The monthly demand for the product is 225 units, carrying cost is 2% of unit cost per month and cost of ordering is ₹ 100. **[20 marks]**

$D = 225 \times 12 = 2700$ units

$C_o = 100$ ₹

$C_h = 12 \times 0.02 C_p$ ₹/unit/year

Let $C_p = 12$ ₹ $\therefore C_h = 2.88$ ₹/unit/year

$\therefore Q^* = \sqrt{2DC_o/C_h} = \sqrt{\frac{2 \times 2700 \times 100}{2.88}}$

$Q^* = 433.01 \approx 433.$

$TIC = \sqrt{2DC_oC_h} = 1247.0765$ ₹

$T.C. = TIC + 12 \times 2700 = 33647.0765$ ₹

Now Assuming
$C_p = 11.2$ ₹ $C_h = 2.688$ ₹/unit/year

$\therefore Q^* = \sqrt{\frac{2 \times 2700 \times 100}{2.688}} = 448.2$

but for $C_p = 11.2$ $550 \le Q \le 700$.

Thus taking $Q = 550$ units/order

$TC = 11.2 \times 2700 + \frac{2700}{550} \times 100 + \frac{550}{2} \times 2.688$ (5 orders)

$TC = 31479.209$ ₹

Now for
$C_p = 10.7$₹, $C_h = 2.568$ ₹/unit/year

18

$\therefore Q^* = \sqrt{\frac{2 \times 2700 \times 100}{2.568}} = 458.5633$ units

Q^* does not belong to ≥ 700

Thus taking $Q = 700$
no of orders $\rightarrow D/Q = 3.857 \simeq 4$

$TC = 10.7 \times 2700 + 4 \times 100 + \frac{700}{2} \times 2.568$

$TC = 30188.8$ ₹

Thus EOQ considering discount is 700 unit/order
and total Cost for inventry is

$TC = 30188.8$ ₹

Q.3 (c) (i) Define production planning and control and identify its objectives.

[10 marks]

Production planning and control

~~It is the.~~

Q.3 (c) **(ii)** Distinguish between CPM and PERT in tabular form. Explain with the help of practical examples.

[10 marks]

PERT	CPM
1) It is project evaluation Review technique	1) It is critical path method.
2) Uses three time estimation system	2) As activity period is known so used only single time estimation
3) It is event oriented	3) It is activity oriented.
4) It is used or performed for new projects	4) It is used for well known project
5) Crashing analysis is not performed	5) Crashing is performed to reduce the cost and time of project.
6) Based on the probability approach and activities have beta distribution.	6) Based on Deterministic model and project time is well known
ex New projects like R&D and huge project having no previous data. Thus there is no absolute idea about the completion of project time	ex Regular Construction projects which are well known and huge data is present to evaluate. Thus there is well known structure of the cost and period of each activity.

6

Section B : Production Engineering & Material Science - 1, SOM & Mechanics - 2

Q.5 (a) Compare sand, die, investment, lost foam and continuous casting techniques.

[12 marks]

Sand Casting

→ It is the casting technique used for the casting of the huge products like machine beds.

→ Due to lack of the availability of the complex patterns, simple casting can be performed

→ low surface finish & Dimensional Accuracy

Die Casting

→ It is the casting process used to cast the small and low melting point products

→ They have well established dies so complex shaped casting can be performed with very high dimensional accuracy and surface finish.

→ They have directional solidification due to die material and cooling provided.

→ ex - Casting Al, Zn, Cu. IC engine casing and Al piston.

6

Investment Casting (wax used as patern)

→ For casting of the high temperature melting point metals like tungstan

→ They have very high surface finish due to ceramic coated surface.

→ There is dimensional accuracy and can be suitable for complex parts also.

→ ex gold ornaments, turbine blades, body implants etc.

→ There is limit of size (20 kg) - !!

Lost foam casting

→ Disposable material like foam is used as patern which gets evaporated when mould is poured.

→ Complex shape and internal parts with small inserts can be easily produced.

→ Once used pator is not used again.

Continuous Casting

→ This type is used to produce the Continuous casting of long length having same cross section area.

→ Mass production of casting blooms and Ingot is performed.

Q.5 (b) What are 'hybrid composites'? State the principal applications of hybrid composites.

[12 marks]

hybrid composite

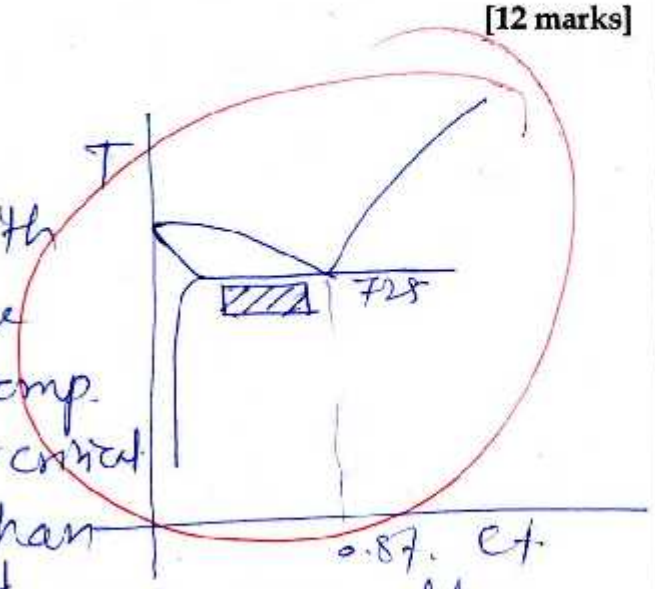
Q.5 (c) Explain the following:

1. Process annealing
2. Normalising
3. Spheroidizing

[12 marks]

1) Process annealing

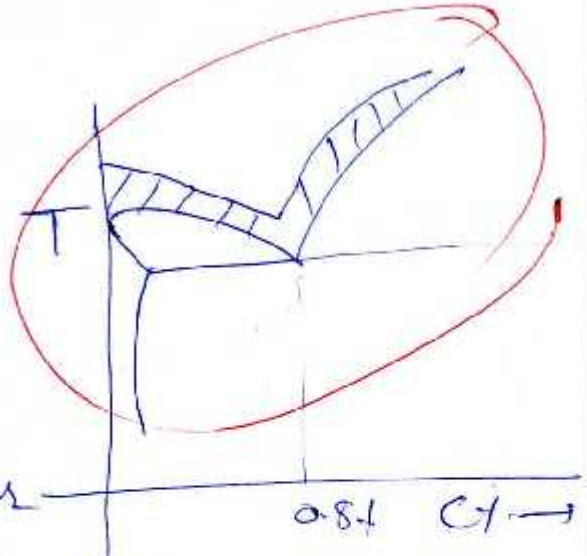
when the iron with low carbon persentage is heated to the temp. lower than the lower critical temp and higher than Rx temperature and cooled in furnace then



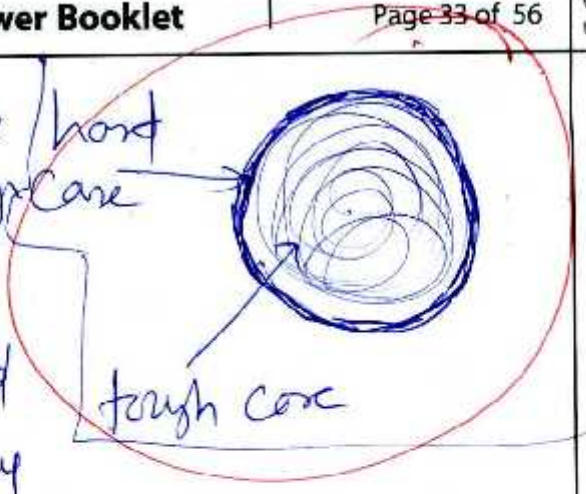
Proces annealing is permoned to improve the grain structure and improve the ductility of low carbon steel.

2) Normalising

when low or medium Carbon containing iron is heated above the upper critical temperatu and cood in the atmosphere air then outer body is Called at very high rate & more than Critical Cooling rate) and Case (or) outer party becomes hard and inner part remains tough.



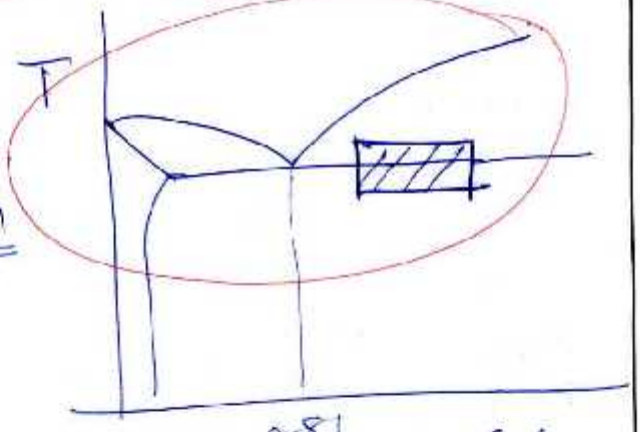
These parts are suitable / used for the direct engineering applications as core is hard so no wear and Due to tough core they can absorb shocks.



Thus normalizing is also called as final heat treatment.

(3) Spheroidizing

When iron having high content of carbon is heated to the temp very close to lower critical temperature and cooled very slowly Carbons combine together to form spheroids and thus medium and high carbon steels becomes ductile.



This heating process is used to improve the ductility of the high & medium carbon steel.

Q.5 (d) What are the laws of Coulomb's friction? Be Before

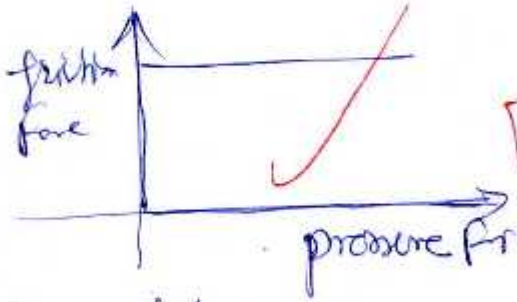
[12 marks]

When there is friction between the solid parts at high temperature then there will be sticking of metals occurs due to welding action. or there will be sliding friction due to presence of normal pressure force

4

In sticking zone

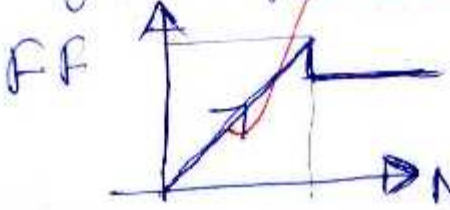
Friction is due to welding of mating parts thus to over come this kind of friction Constant shear stress [K] is require



$$\text{Friction force} = K \times A_s$$

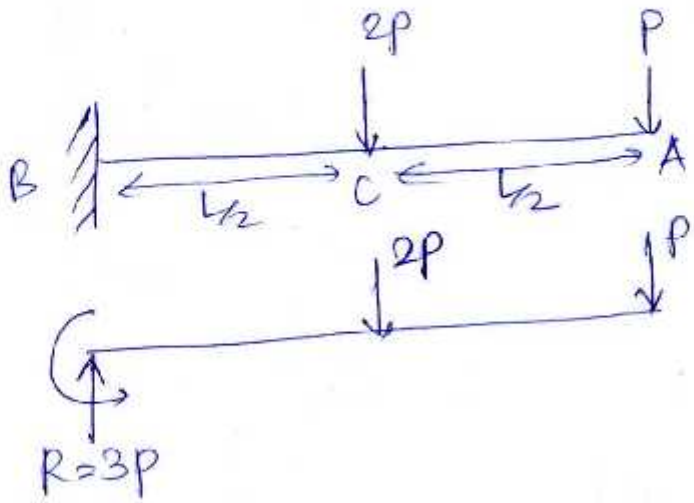
In sliding zone → $F_f = \mu_s \times N$

The friction is due to rough surfaces of mating solids then friction is due to & the coef of friction proportional to normal force applied. once there is relative motion then μ_s becomes μ_k and that friction force becomes Constant. (generally $\mu_s > \mu_k$)



Q.5 (e) A cantilever beam of length L, is subjected to two concentrated loads of $2P$ and P at its mid length and free end respectively. If the deflection at its free end is limited to $\frac{L}{500}$. What should be the value of P? Take flexural rigidity of the beam as EI.

[12 marks]



We have for cantilever beam with concentrated load.

$$\delta = \frac{WL^3}{3EI} \quad \& \quad \text{slope} = \frac{WL^2}{2EI}$$

11

Now Considering load P

$$\delta \text{ at } A = \frac{PL^3}{3EI} \quad \text{---} (1)$$

Now Considering Load 2P

$$\delta \text{ at } A = \delta \text{ at } C + \text{slope at } C \times L/2$$

$$= \frac{(2P)(L/2)^3}{3EI} + \frac{(2P)(L/2)^2 \times (L/2)}{2EI}$$

$$= \frac{PL^3}{EI}\left(\frac{1}{12} + \frac{1}{8}\right) = \frac{5}{24}\frac{PL^3}{EI}$$

Total deflection $\delta_A = \frac{PL^3}{3EI} + \frac{5}{24}\frac{PL^3}{EI} = \frac{L}{500}$

$$\therefore \quad P = \frac{6}{1625}\frac{EI}{L^2}$$

Q.7 (a) A solid shaft is to transmit 310 kW at 117 rpm. If the the shear stress is not to exceed 100 MPa, find the diameter of the shaft. What percent saving in material would be obtained if this shaft is replaced by a hollow one whose internal diameter equals 0.65 of its external diameter? Assume the length, material and maximum allowable shear stress of both the shaft being the same.

[20 marks]

$P = 310\ KW \quad N = 117\ rpm$

$$T = \frac{P}{\omega} = \frac{P \times 60}{2\pi \times N} = 25.3015\ KNm$$

$$T = 25.3015 \times 10^6\ Nmm$$

we have

$$\tau_{max} = \frac{16T}{\pi D^3} \quad \therefore D = \sqrt[3]{\frac{16 \times T}{\pi \tau_{max}}}$$

$$\therefore D = 108.819\ mm \quad \text{---} (1)$$

Now this shaft is to be replaced by shaft (hollow) having $D_i = 0.65 D_o$

For same strength

$$\tau_{max} = \frac{16T}{\pi D_o^3(1-K^4)} \quad \left(K = \frac{D_i}{D_o}\right)$$

$$\therefore D_o^3 = \frac{16 \times 25.3015 \times 10^6}{\pi \times (1-0.65^4) \times 100}$$

$$\therefore D_o = 116.1905 \text{ mm}$$

$$\therefore D_i = 75.523839 \text{ mm}.$$

Now

$$\% \text{ Saving in material} = \frac{A_{solid} - A_{hollow}}{A_{solid}} \times 100$$

$$= \frac{D_s^2 - (D_o^2 - D_i^2)}{D_s^2}$$

18

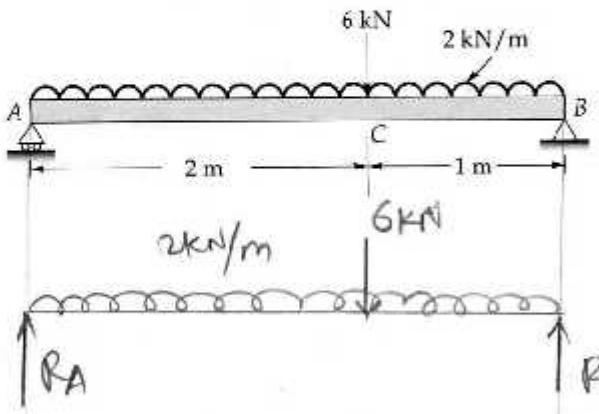
$$= \frac{108.819^2 - (116.1905^2 - 75.524^2)}{108.819^2}$$

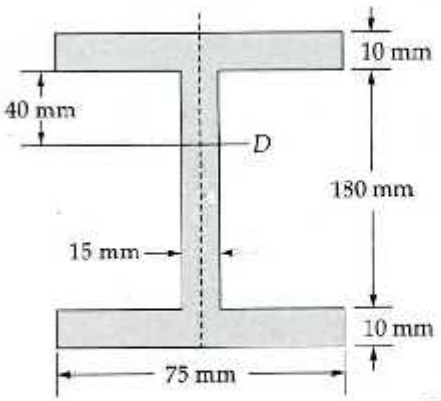
$$= \frac{4045.1928}{11841.57476} \times 100$$

$$= 34.1609$$

Thus 34.1609 % of material is saved.

Q.7 (b) Simply supported beam of 3 m span is subjected to loads as shown below. Determine the principal stresses at point D in the web. The section is located at a distance of 1 m from the right hand support.





[20 marks]

Let us find the bending moment at 1 meter from right hand support

applying moment eqn

$\Sigma M_A = 0$

$\therefore R_B \times 3 = 6 \times 2 + \frac{2 \times 3^2}{2}$

$\therefore R_B = 7$ kN.

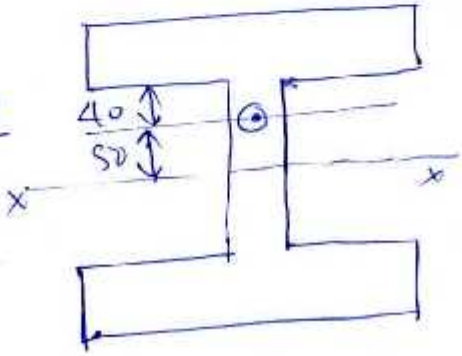
Thus bending moment at C

$BM_C = R_B \times 1 - \frac{2 \times 1}{2} = 7 - 1 = 6$ kNm (Sagging)

& $F_C = R_B - 2 \times 1 = 7 - 2 = 5$ kN.

First we will find the moment of area about natural axis.

$I_{xx} = \frac{200^3 \times 75}{12} - \frac{180^3 \times 60}{12}$



$I_{xx} = 20840000$ mm^4

Thus

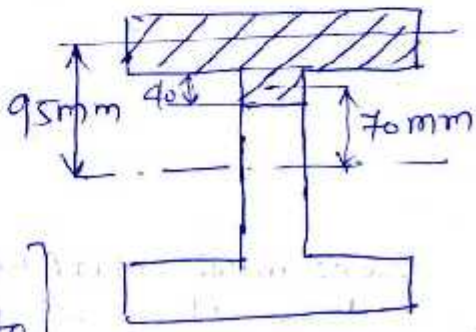
$$\sigma_D = \frac{BM \times y}{I_{xx}} = \frac{6 \times 10^6 \times 50}{2084 \times 10^6} = 14.3954 \text{ MPa}$$

σ_D is compressive in nature

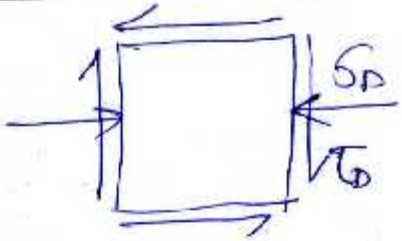
$$\therefore \sigma_D = -14.3954 \text{ MPa}$$

Now for shear stress at D

$$\tau_D = \frac{F_c \times A\bar{y}}{b \times I_{xx}}$$



$$\tau_D = \frac{5000 \times [95 \times 75 \times 10 + 15 \times 40 \times 70]}{15 \times 20.84 \times 10^6}$$



$$\tau_D = 1.81142 \text{ MPa}$$

Now To determine principle stresses

$$\sigma_1/\sigma_2 = \frac{-14.3954}{2} \pm \sqrt{\left(\frac{14.3954}{2}\right)^2 + (1.81142)^2}$$

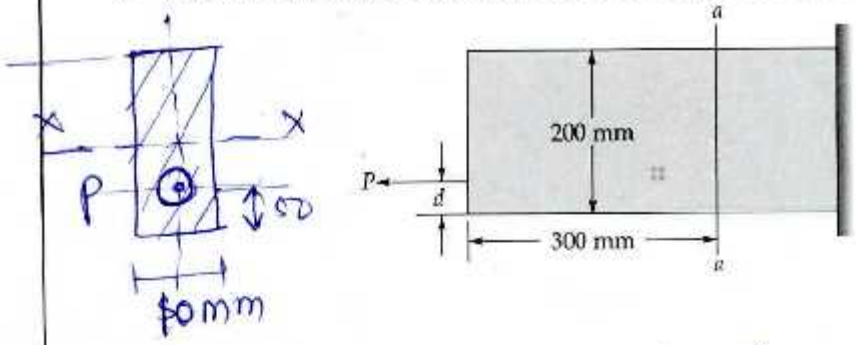
$$\sigma_{1/2} = -7.1977 \pm 7.42214 \text{ MPa}$$

$$\therefore \sigma_1 = -14.61984 \text{ MPa}$$

$$\therefore \sigma_2 = +0.22444 \text{ MPa}$$

$$\therefore \tau_{max} = \pm 7.42214 \text{ MPa}$$

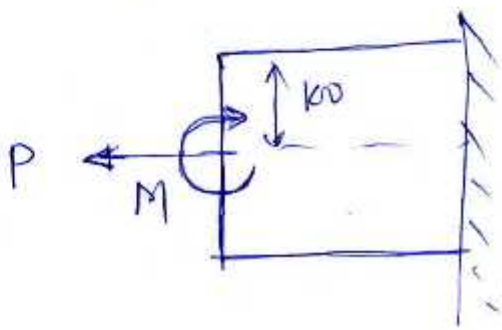
Q.7 (c) (i) The horizontal force of $P = 80$ kN acts at the end of the plate. The plate has a thickness of 10 mm and P acts along the centerline of this thickness such that $d = 50$ mm. Plot the distribution of normal stress acting along section a-a.



[10 marks]

Due to eccentric loading there will be moment due to P on natural axis along with Pull P

The new equivalent diagram for section a–a



$M = P \times (100 - d)$

$M = 80 \times 10^3 \times 50$

$M = 4 \times 10^6$ Nmm

For section x-x

$$I_{xx} = \frac{200^3 \times 10}{12} = 6.667 \times 10^6$$

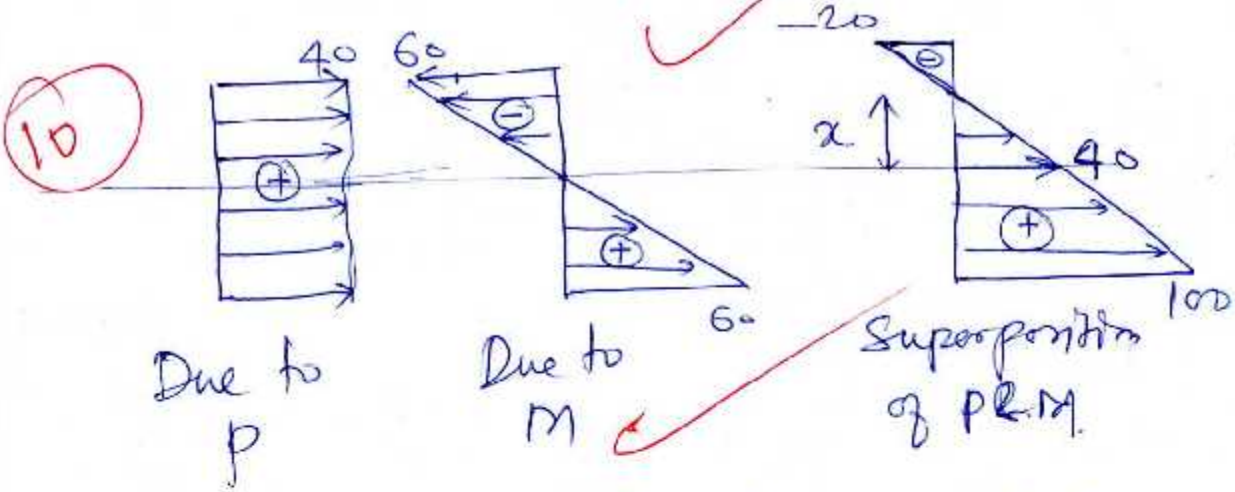
σ_{max} at (a-a) Due to bending

$$\sigma_{max} = \frac{4 \times 10^6 \times y_{max}}{I_{x-x}} = \frac{4 \times 10^6 \times 100}{6.667 \times 10^6}$$

$\boxed{\sigma_{max} = 60 \text{ MPa}}$ [tensile at bottom & compressive at top]

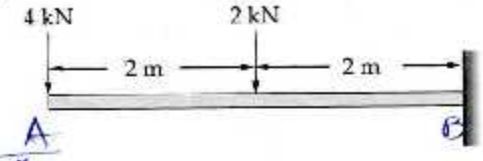
Due to P

$$\sigma_{AA} = \frac{P}{10 \times 200} = \frac{80000}{2000} = 40 \text{ MPa}.$$

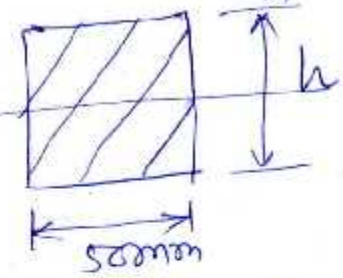


$$x = \frac{40}{60} \times 100 = 66.67 \text{ mm}$$

Q.7 (c) **(ii)** The cantilever beam shown below has a rectangular cross-section of 50 mm width and h mm depth. Find the depth h if the maximum deflection is not to exceed 10 mm. (Use $E = 10$ GPa.)



[10 marks]



Assuming EI as Constant over length.

Due to load 4 kN Diflection at free end

$$\delta_A' = \frac{(4000) \times (4000)^3}{3EI} = \frac{8.5333 \times 10^{13}}{EI}$$

Due to load 2 kN Diflection at free end

$$\delta_A'' = \frac{(2000)(2000)^3}{3EI} + \frac{2000\,(2000)^3}{2EI}$$

$$= \frac{1.3333 \times 10^{13}}{EI}$$

10

$$\therefore \delta_A = \delta_A'' + \delta' = \frac{9.8666}{EI} \times 10^{13}$$

for $\delta_A = 10$ mm

$$EI = 9.8666 \times 10^{12} \quad \therefore I = 9.8666 \times 10^8 \text{ mm}^4$$

$$I = \frac{bh^3}{12} = \frac{50}{12} \times h^3 \quad (E = 10^4 \text{ MPa})$$

$$\therefore h = 61.86707 \text{ mm}$$