Government College of Engineering and Research, Avasari(Khurd)

Department: Mechanical Engineering

Learning Resource Material (LRM)

Name of the course: Mechanical System Design **Course Code:** 402048

Name of the faculty: J. M. Arackal Class: BE(Mech)

SYLLABUS(6)

Unit 6: Optimum Design
Objectives of optimum design, adequate and optimum design, Johnson's Method of optimum design, primary design equations, subsidiary design equations and limit equations, optimum design with normal specifications of simple machine elements- tension bar, transmission shaft and helical spring, Pressure vessel Introduction to redundant specifications (Theoretical treatment)

Lecture Plan format:

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Unit No	Lecture No.	Topics to be covered	Text/Reference Book/ Web Reference
		UNIT 6	
6	1	Objectives of optimum design, adequate and optimum design	3
6	2	Primary design equations	3
6	3	Subsidiary design equations and limit equations	3
6	4	Optimum design with normal specifications of simple machine elements	3
6	5	tension bar, transmission shaft and helical spring, Pressure vessel Introduction to redundant specifications	3
6	6	General principles of design for manufacture and assembly	3
6	7	Principles of design of castings and forgings	3
6	8	Design for machining, design for safety	3

List of Text Books /Reference Books/ Web Reference

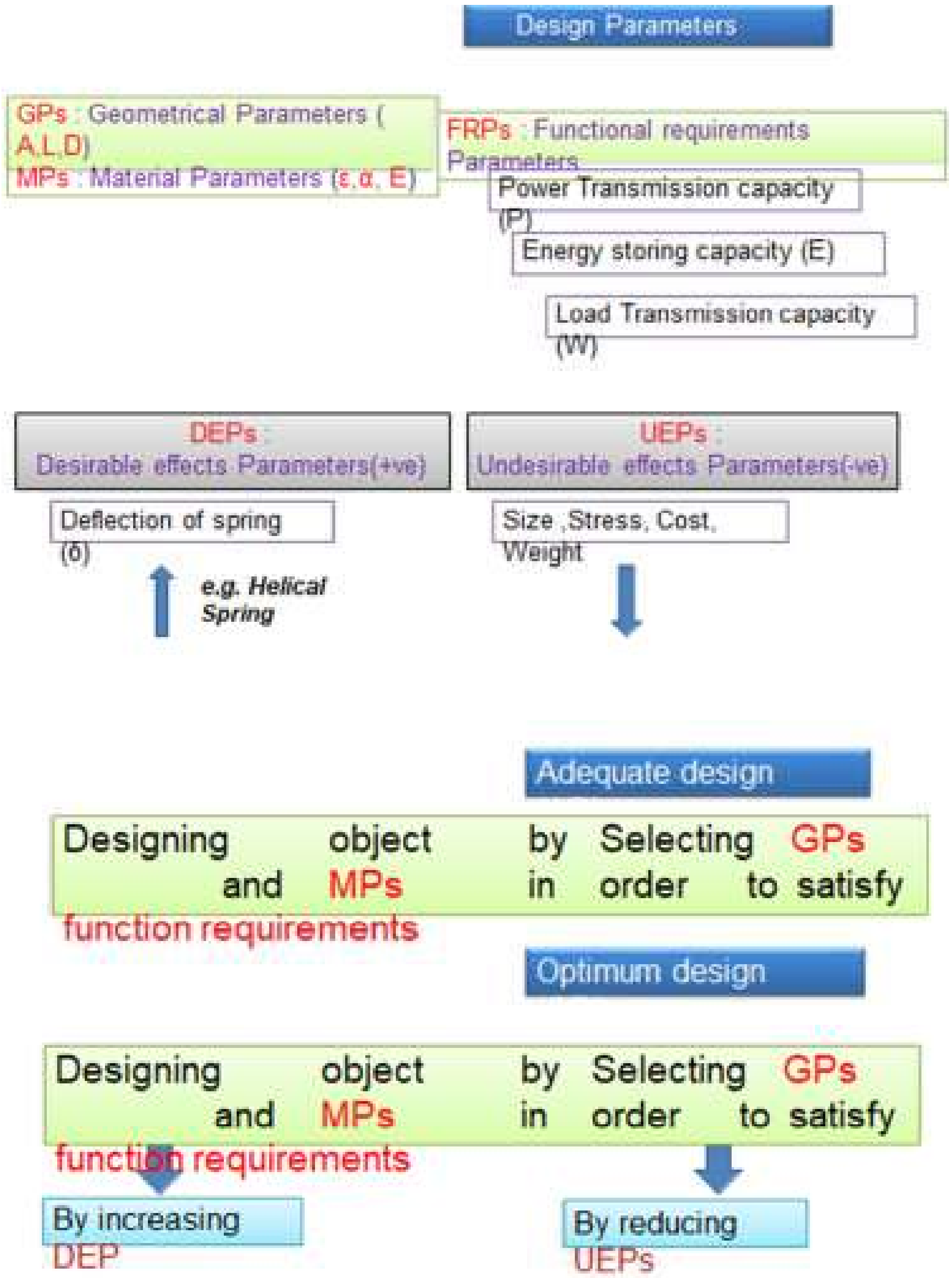
1-Bhandari V.B. ―Design of Machine Elements‖, Tata McGraw Hill Pub. Co. Ltd.

2-R.K. Jain- Machine Design, Khanna Publishers

3-Johnson R.C., ―Mechanical Design Synthesis with Optimization Applications‖, Von Nostrand Reynold Pub

<u>**UNIT6- OPTIMUM DESIGN**</u>

Optimum design is th selection of material & the values for independent geometrical parameters with the explicit objective of either minimizing most significant undesirable effects or maximizing most significant functional requirement while making certain that the mechanical element satisfies function requirement & other undesirable effects are kept within tolerable limits. For example if one wants to design a shaft for a machine with "Minimum weight criteria for that particular application" then there will be a single solution out of various options available. Such design is called optimum design.



Optimization

Ex 1

SPRING

Design object to increase load carrying capacity

Functional requirement: To carry Load(W)

$$\delta = \frac{8 W D^3 n}{G d^4} \qquad W = \frac{\delta d^4 G}{8 D^3 n}$$

Equation in the form of FRPs, MPs, GPs

FRP	DP	GP	MP
$W =$	$\frac{\delta}{8}$	$\frac{d^4}{D^3 n}$	G

Design object for Cost reduction

Ex2

Cost

Unit Cost c = Rs per Kg
Total Cm = Cost in Rs

$$Cm = c * W$$

$$Cm = c \rho V$$

$$Cm = c \rho (A L)$$

Equation in the form of FRPs, MPs, GPs

FRP	UEP	GP	MP
$Cm =$	c	A , L	ρ

Eliminate U/U parameter

Developed PDE

3) Combining SDE with PDE	
PDE: cm= C (ρ A L g)	Cm= C (ρ (P/ σ) L g)
SDE: σ= P/A ….. A = P/ σ	

Eliminated U/U Parameter: A

4) Combining LE with PDE	
PDE: Cm= C (ρ (P/ σ) L g)	Cm= C (ρ (Fos*P/ Syt) L g)
LE: σ ≤ [Syt/FoS]	

LE effect can be directly included in Developed PDE

NORMAL CASE

Developed

Cm= C (ρ (Fos*P/ Syt) L g)

Separate Material parameters

Cm= [C ρ / Syt] * [g P L] * (FoS.)

Final design

Cm= [MSF]* [g P L]* (FoS.)

MSF=[C δ/ Syt]

Material	δ Kg/m^3	C Material Cost Rs/Weight(N)	Yield Strength MPa	MSF=[C δ/Syt]
Steel	**7500**	**16**	**130**	**923.077**
Aluminum alloy	3000	32	50	**1920**
Titanium Alloy	4800	480	90	**25600**
Magnesium Alloy	2100	32	20	**3360**

Eliminated U/U Parameter: **A**

$\sigma = P/A$.

σ = Syt/ FoS=130/2=60

A= P/ σ =5000/60=76.923 mm^2

Cm= [MSF]* [g P L]* (FoS.)

Problem (2):

Design a shaft for minimum weight. It transmits a torque 900 N-m. Required torsional stiffness (rigidity) is 90 N-m/degree. Using Maximums Shear stress theory of failure. Use FoS =1.5

Material	δ, Mass Density Kg/m^3	G Modulus of rigidity GPa	Yield Strength MPa	Material Cost (Rs/ N weight)
M1	8500	80	130	16
M2	3000	26.5	50	32
M3	4800	40	90	480
M4	2100	16	20	32

Aim: Design: To find L and d [minimize weight]

Significant Undesirable effect: **To minimize weight (W)**

Problem (3):

Design a thin walled spherical vessel for maximizing gas storing capacity under pressure, pi=4 Mpa. t<<D, t=wall thickness, D= Mean diameter of the vessel. FoS = 3; Mass of vessel ≤ 125 Kg. Design the pressure vessel with the objective of maximizing the gas storage capacity,

Material	ρ: Mass Density Kg/m^3	Ultimate Strength Sult MPa
M1	7800	500
M2	2800	250
M3	8400	420

Mass of vessel $M=\rho \pi D^2 t$

Stress induced $\sigma t = (p D)/4t$

Aim: Design: To find D and t [For maximizing storage capacity, V]

PDE: Gas storage capacity to be maximized $V = \frac{1}{3}\pi D^3$

SDE: $\sigma t = [(p\,D)/4t]$ --- $D = (p\,\sigma t)/4t$

$M = \rho\,\pi\,D^2\,t$ --- $t = M/\rho\,\pi\,D^2$

U/U

LE: $M \le Mmax$ & $\sigma t \le Sult/FoS$

Combining SDE with PDE

PDE: $V = \frac{1}{3}\pi D^3$	Developed PDE
SDE: $D = (p\,\sigma t)/4t$ U/U $t = M/\delta\,\pi\,D^2$	$V = \frac{M\,\sigma t}{3\,pi\,\rho}$

Combining LE with PDE

PDE: $V = \frac{M\,\sigma t}{3\,pi\,\rho}$	FoS=3 Mmax=125
LE: $M \le Mmax$ & $\sigma t \le Sult/FoS$ **For maximization of V** $M = Mmax$ & $\sigma t = Sult/FoS$	Final PDE $V = 6.944 * 10^{-6} * \frac{Sult}{\rho}$

Both SDE and LE are directly included so this is Normal specification

Final PDE

$V = 6.944 * 10^{-6} * \frac{Sult}{\rho}$ MSF= $\frac{Sult}{\rho}$

$V = 6.944 * 10^{-6} * MSF$

Material selection factor

Material	ρ, Mass Density Kg/m^3	Ultimate Strength Sult N/m^2	MSF= $\frac{Sult}{\rho}$
M1	7800	$500*10^6$	64102.564
M2	2800	$250*10^6$	89285.714
M3	8400	$420*10^6$	50000

As to maximize V , MFS should be maximum

M= Mmax & σt = Sult/FoS

Mass of vessel $M = \rho \pi D^2 t$ Stess induced $\sigma t = (p D)/4t$

Mmax= $\rho \pi D^2 t$

Sult/FoS = (p D)/4t

We get

Result

D=1.05796 m =1057.96 mm

t=12.7 mm

$V = 6.944 * 10^{-6} * \frac{Sult}{\rho}$ =0.62 m^3

ASSIGNMENT- DESIGN OF IC ENGINE COMPONENTS

1- Explain the procedure of solving optimum design problems with redundant specifications.

2- A tensile bar of length 400mm is subjected to constant tensile force of 3000N. If the factor of safety is 2, design the bar diameter, using Johnson's method, with the objective of minimizing material weight using optimum material from the list given in Table.

Material	Density(Kg/m^3)	Cost (Rs/ Kg)	Syt(N/mm^2)
Steel	7800	28	400
Aluminium Alloy	2800	132	150
Titanium Alloy	4500	2200	800

3- Explain the design considerations for design of castings
4- What is design for manufacture? Explain the general principles to be followed while designing the parts of manufacture
5- What is design for safety? Explain the general principles to be followed while designing the product for safety?
6- What are the principals of design of castings and forgings?
7- How to identify whether an optimum design problem is based on normal specifications or redundant specifications? What is the difference in the design procedure of problems based on these two specifications?
8- Differentiate between adequate and optimum design. Also explain different types of equations that are used in 'Johnson's method of optimum design'.

9- A tensile bar of length 450mm is subjected to constant tensile force of 4000N. If the factor safety is 1.5, design the bar diameter, using Johnson's method, with the objective of minimizing material weight using optimum material from the list given in Table.

Material	Density(Kg/m^3)	Cost (Rs/ Kg)	Syt(N/mm^2)
Steel	7800	28	400
Aluminium Alloy	2800	132	150
Titanium Alloy	4500	2200	800

10-Write a short note on design for machining