AIKTC, New Panvel

TE-ME

Module No. 1

MACHINE DESIGN – 1

Machine Design

- Machine Design is the creation of new and better machines and improving the existing ones.

- Machine Design is defined as the use of scientific principles, technical information and imagination in the description of a machine or mechanical system to perform specific functions with maximum economy and efficiency.

Classification of Machine Design

- Adaptive Design
- Development Design
- New Design

Classification of Machine Design

- Based on the method used -
- Rational Design
- Empirical Design
- Industrial Design
- Optimum Design
- System Design
- Element Design
- Computer Aided Design

General Considerations in Machine Design

- Type of Load & Stresses caused by the load
- Motion of the Parts/ Kinematics of machine
- Selection of Materials
- Form & Size of the Parts
- Frictional Resistance & Lubrication
- Convenient & Economical Features
- Use of Standard Parts

General Considerations in Machine Design

- Safety of Operation
- Workshop Facilities
- Number of Machines to be Manufactured
- Cost of Construction
- Assembly

General procedure in Machine Design

Need / Aim

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Synthesis (Mechanism)

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Analysis of Forces

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Selection of Material

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Design of Elements (Size & Stress)

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Modification

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Detailed Drawing

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Production

Standardization

- ADVANTAGES:
- Reduction in Types & Dimensions of identical components.
- Reduction in manufacturing facilities required.
- Interchangeability
- Ease in service & maintenance of machines.
- Less time & Effort in designing new machine.
- Standards of specifications & testing procedures of machine elements improves quality & reliability of the m/c.

Limits, Fits & Tolerance

- **Limits:** Extreme possible sizes
  - Upper Limit & Lower Limit
- **Fits:** Degree of Tightness or looseness between two mating parts.
  - Clearance, Interference & Transition Fit
- **Tolerance:** Difference between Upper & Lower limit of dimension
  - Unilateral & Bilateral

Selection of Material

- Availability of the materials
- Suitability of the Materials for the working conditions in service
- The Cost of the materials

Classification of Engineering Materials

- Metals & their Alloys such as Cast Iron, Steel, Copper, Aluminium
- Metals - Ferrous & Non-ferrous
- Non-metals - glass, rubber, plastics

Physical Properties of Metals

- Luster
- Colour
- Size
- Shape
- Density
- Electric & Thermal Conductivity
- Melting Point

Mechanical Properties of Metals

- **Strength:**

  Resistance to Ext. applied force

- **Stiffness:**

  Resistance to deformation

- **Elasticity:**

  Regain original shape

- **Plasticity:**

  Retain original shape

Mechanical Properties of Metals

- **Ductility:**

  Drawn into thin wire
- **Brittleness:**

  No local deformation
- **Malleability:**

  Material can be rolled or hammered into thin sheets
- **Toughness:**

  Resistance to fracture due to impact load

Mechanical Properties of Metals

Contd...

- **Machinability:**

  Ease in machining

- **Resilience:**

  Absorb energy & resist shocks

- **Hardness:**

  Resistance to wear, scratch, abrasion, deformation & machining. Ability to cut another material

Mechanical Properties of Metals

- **Creep:**

  Material subjected to a constant stress at high temp. for long period of time causing material to undergo slow & permanent deformation

- **Fatigue:**

  Repetitive stress causes material to fail at stress below yield point stress.

Cast Iron

- Carbon: 3-4 %
- Silicon: 1-3 %
- Manganese: 0.5-1 %
- Sulphur: Up to 0.1 %
- Phosphorus: Up to 0.1 %
- Iron: Remainder

Cast Iron..... Advantages

- Availability
- Produced in mass scale
- Tooling required for casting process is simple & inexpensive
- Can be given any complex shape
- High compressive strength (3-5 times steel)
- Ability to damp vibration- Excellent

  (Machine tool guides & frames)
- Resistance to wear
- Do not change mechanical properties (up to 350^{0}C)
- Low notch sensitivity

Cast Iron..... Drawbacks

- Poor tensile strength compare to steel
- Section sensitive - Tensile strength decreases as thickness of the section increases
- Brittle & poor impact resistance.
- Poor Machinability as compared to steel

Grey C.I. as per IS: 210 - 1993

IS Designation	MIN. tensile Strength, MPa	BHN
FG 150	150	130 to 180
FG 200	200	160 to 220
FG 220	220	180 to 220
FG 260	260	180 to 230
FG 300	300	180 to 230
FG 350	350	207 to 241
FG 400	400	207 to 270

Spheroidal graphite C.I.

as per IS: 1865 - 1991

IS Designation	Min. tensile Strength, MPa	Min. % Elongation	BHN	Predominant constituent of matrix
SG 900/2	900	2	280 to 360	Bainite or tempered martensite
SG 800/2	800	2	245 to 335	Pearlite or tempered structure
SG 700/2	700	2	225 to 305	Pearlite
SG 600/3	600	3	190 to 270	Ferrite + Pearlite
SG 500/7	500	7	160 to 240	Ferrite + Pearlite

Effect of impurities on Cast Iron

Silicon:

- It may present up to 4 % in C.I.
- It provides formation of graphite which makes the iron soft & easily machinable.
- It also produces sound casting free from blow holes, because of its high affinity for oxygen.

Effect of impurities on Cast Iron

- Sulphur:
- It makes the C.I. hard & brittle.
- Since too much sulphur gives unsound casting, therefore, it should be kept below 0.1 % for most foundry purposes.

Effect of impurities on Cast Iron

- Manganese:
- It makes the C.I. white & hard.
- It is often kept below 0.75 %
- It controls harmful effect of sulphur.

Effect of impurities on Cast Iron

- Phosphorus:
- It aids fusibility & fluidity in C.I. but induces brittleness.
- It is rarely allowed to exceed 1 %.
- Phosphoric irons are useful for casting of intricate design & for many light engineering castings when cheapness is essential.

Steel

- Alloy of Iron & Carbon
- Carbon: Up to 1.5 % in the form of iron carbide (Hardness & strength)
- Silicon, Manganese, Sulphur, Phosphorus
- Plain Carbon steel- 0.06 to 1.5% C

Indian Standard Designation of Steel

IS:1570 (Part I) – 1978 (Reaffirmed 1993)

IS Designation	Min. Tensile Strength N/mm²	Min. Yield Stress, N/mm²	Min. % Elongation	Uses
Fe 290 Fe E 220	290 290	170 220	27 27	Cycle, Motor cycle & Automobile Tubes
Fe310 Fe E 230 Fe 330 Fe E 250	310 310 330 330	180 230 200 250	26 26 26 26	Locomotive carriages & car structures and other general engineering purposes
Fe 360 Fe E 270	360 360	220 270	25 25	Chemical pressure Vessels & other general engineering purposes

Fe 290 means a steel having min tensile strength of 290 N/mm^2
Fe E 220 means a steel having min yield strength of 220 N/mm^2

Steel designated on the basis of Chemical Composition

- According to IS: 1570 (Part II/ Sec I)- 1979 (Reaffirmed 1991), the carbon steels are designated in the following order:
- 1) FIGURE INDICATES 100 TIMES AVG. % C
- 2) LETTER 'C'
- 3) FIGURE INDICATING 10 TIMES AVG. % Mn
- For Example: "20C8" means carbon steel containing 0.15 to 0.25 %C (avg. 0.2 % C as) and 0.6 to 0.9% (avg. 0.75%) Mn
- 4C2, 5C4, 10C4, 10C4, 14C6, 15C4, 15C8, 20C8, 25C4, 25C8, 30C8, 35C4, 35C8, 40C8, 45C8 & ....

Free cutting Steels

- According to IS: 1570 (Part III)- 1979 (Reaffirmed 1993), carbon and carbon manganese free cutting steels are designated in the following order:

1) FIGURE INDICATES 100 TIMES AVG. % C
2) LETTER 'C'
3) FIGURE INDICATING 10 TIMES AVG. % Mn

- Symbol 'S' followed by the figure indicating the 100 times the avg. content of sulphur / Symbol 'Pb' if lead is used instead of 'S'
- For Example: "10C8S10" means carbon steel containing avg. 0.1 % C, avg. 0.8% Mn & 0.1% S
- Examples: 14C14S14, 25C12S14, 40C10S18, 11C10S25,40C15S12

Alloy Steel (Alloying elements)

- Nickel: Increases strength & Toughness
- Chromium: Hardness with high strength & high elastic limit. Corrosion resistance. Motor car crank shafts, axles & Gears
- Tungsten: Used in conjunction with the other elements. Cutting tool, dies, Valves, taps.
- Vanadium: Small addition increases tensile strength & elastic limit in low CS.

Alloy Steel (Alloying elements)

- **Manganese:** Improves strength of the steel in both hot rolled & heat treated condition.
- **Silicon:** High elastic limit as compared to ordinary CS
- **Cobalt:** Red Hardness by retention of hard carbides at high temperature.
- **Molybdenum:** It is used with Chromium & manganese, Possess extra tensile strength.

IS: 1762 (Part I)- 1974 (reaffirmed 1993), low & medium carbon steels - designated in the following order:

- First figure indicating 100 times the avg. % C
- Chemical symbol for following elements followed by its avg. % content multiplied by a factor as given below:

Element	Multiplying Factor
Cr, Co, Ni, Mn, Si & W	4
Al, Be, V, Pb, Cu, Nb, Ti, Ta, Zr & Mo	10
P, S and N	100

- Example: 40Cr4Mo2 means alloy steel having avg. 4% C, 1% Cr and 0.25% Mo.
- 11Mn2, 50Cr1, 35Mn2Mo28, 15Cr3Mo55 ....

Manufacturing Processes

- Primary Shaping Processes-
- Casting
- Forging
- Extruding
- Rolling
- Drawing
- Bending
- Shearing
- Spinning
- Powder Metal forming
- Squeezing, etc...

Manufacturing Processes Contd….

- Machining Processes:
- Turning
- Planning
- Shaping
- Drilling
- Reaming
- Sawing
- Broaching
- Milling
- Grinding
- Hobbing, etc

Manufacturing Processes Contd....

- **Surface Finishing processes:**
- Polishing
- Buffing
- Honing
- Lapping
- Abrasive Belt Grinding
- Electroplating
- Super finishing

Manufacturing Processes Contd….

Joining processes:

- Welding
- Riveting
- Soldering
- Brazing
- Screw Fastening
- Pressing
- Sintering, etc

Manufacturing Processes Contd....

- **Processes affecting change in properties:**
- Heat Treatment
- Hard working
- Cold working
- Shot pinning, etc

Casting

- Pouring Molten Metal into Moulds, filling cavity & getting a casting after solidification.
- Sand Mould Casting
- Permanent Mould Casting
- Slush Casting
- Die Casting
- Centrifugal Casting

Casting Design

- Rules for designing Casting-
- As simple as possible, good appearance
- Avoid Sharp Corners to avoid stress concentration
- Preferably all sections should be uniform, if unavoidable then gradual
- Avoid Abrupt change from extremely thick to thin section
- Avoid large flat surfaces, as it is difficult to obtain it.
- Provide different Pattern Allowances
- Provide curved shapes to get improved design of casting

Casting Design

- Use minimum stiffening members (Web, Ribs) as they give rise to hot tears & shrinkage etc.
- Casting should be designed in such a way that it will require a simpler pattern & its molding is easier.
- Provide adequate support in the mould while designing core.
- Avoid deep & narrow pockets in the casting to reduce cleaning Cost.
- Use of metal inserts should be kept minimum.
- Avoid marking names, numbers on vertical surfaces, it provide a hindrance in withdrawal of the pattern.

Forging

- Smith Forging or hand forging
- Power Forging
- Machine Forging or Upset Forging
- Drop Forging Or Stamping

Advantages

- Refines structure of the metal
- Stronger metal by setting the direction of grains
- Considerable saving in Time, Labour & Material as compare to the production of similar item by cutting
- Reasonable degree of accuracy.

Forging Design Considerations

- Should be able to achieve Radial flow of grains.
- Parting line should divide forging into two equal halves.
- Parting line should lie in one plane.
- Sufficient draft for easy removal of forgings from die.
- Avoid sharp corners to prevent stress concentration
- Minimum pockets & recess to avoid increased die wear.
- Ribs should not be high & thin.
- Avoid too thin sections to facilitate easy flow of metal.

Modes of failure of machine components

- Mechanical component fails mean material is unable to perform its function satisfactorily
- **Failure by elastic deformation:**

- Elastic deflection results in unstable condition like buckling of column , vibration

- **Failure by Yielding:**

- Yield point is the criteria for failure of ductile material in static loading

- **Failure by fracture:**

- Brittle materials are considered to have failed by fracture with a very little permanent deformation.

Various strengths of material

- **Yield Strength:** Max. stress at which a marked increase in elongation occurs without increase in load.
- **Ultimate Tensile Strength:** Max. stress that can be reached in a tensile test.
- **Breaking Strength:** Stress at the time of fracture.
- **Static Strength:** Ability to resist stress without failure, when subjected to static loading.
- **Fatigue Strength:** Ability to resist stress without failure, when subjected to fatigue loading.

Why Structural beams are made up of I- section

- Bending stress = M x Y / I
- Equal amount of material throughout is a wastage of material. Hence for optimum utilization of strength of material a c/s should have more material at extreme section & less material at the middle section.
- So, I-section is generally used for beams.

Preferred series numbers

- To reduce unnecessary variations in the sizes, powers etc
- It is concluded by the experience that a certain range can be covered efficiently when it follows geometrical progression with a constant ratio.
- Preferred numbers are conventionally rounded off values derived from geometric series

Preferred series numbers

- There are 5 basic series
- Series factors are as follows:
- R5 Series: $\sqrt[5]{10} = 1.58$
- R10 Series: $\sqrt[10]{10} = 1.26$
- R20 Series: $\sqrt[20]{10} = 1.12$
- R40 Series: $\sqrt[40]{10} = 1.06$
- R80 Series: $\sqrt[80]{10} = 1.03$
- Increases in steps of 58%, 26%, 12%, 6%, 3%

Series Factors

- R5 Basic series from 1 to 10
- R5 Series: $\sqrt[5]{10} = 1.5849$
- 1st Number = 1
- 2nd Number = 1x 1.5849 = 1.6
- 3rd Number = 1.5849 x 1.5849 = $(1.5849)^2$ = 2.5
- 4th Number = $(1.5849)^2$ x 1.5849 = $(1.5849)^3$=4
- 5th Number = $(1.5849)^3$ x 1.5849 = $(1.5849)^4$=6.3
- 6th Number = $(1.5849)^4$ x 1.5849 = $(1.5849)^5$=10

Derived Series

- Derived series may be obtained by multiplying the preferred number in the series by 10, 100 .. etc.
- For 10 to 100 (Multiplying the series by 10)
- 10, 16, 25, 40, 63, 100
- For 100 to 1000 (Multiplying the series by 100)
- 100, 160, 250, 400, 630, 1000
- Example: If 5 tractors are to be produced with different power using R5 series, the power will be 10, 16, 25, 40 & 63 H.P.

Aesthetic & Ergonomic Considerations

- **Aesthetic consideration:**

-Set of principles of appreciation of beauty

-It deals with the appearance of the product

-Product should be aesthetically appealing.

- **Ergonomic Consideration:**

ergon: Work, *nomos:* Natural Laws

-Scientific study of the man- machine- working environment relationship and application of anatomical, Physiological & psychological principles to solve the problem arising from this relationship.

-To make machine fit for the user

Aesthetic Considerations in Design

- Shape
- Symmetry & Balance
- Colour
- Continuity
- Variety
- Proportion
- Contrast
- Impression & Purpose
- Style
- Material & Surface Finish
- Tolerance
- Noise

Ergonomic Considerations in Design

- Anatomical factors in the design of a drivers' seat
- Layout of instrument dials & display panels for accurate perception by the operator
- Design of hand levers & hand wheels
- Energy expenditure in hand & foot operations.
- Lighting, noise & climatic conditions in machine environment.

Factor of Safety

- Ratio of Maximum or failure stress to Working Stress.
- For Ductile material
- Ratio of Yield stress to Working Stress.
- For Brittle material
- Ratio of Ultimate stress to Working Stress.

Factors affecting Selection of F.O.S.

- Kind of Load
- Material
- Stress Concentration
- Danger to life or Property
- Service Condition
- Degree of Accuracy in force analysis
- Cost of Component
- Quality of manufacture
- Reliability of Component
- Testing of Machine Element

Guidelines for selection of FOS

- C.I. –

UTS &

FOS =3

- Steel –

Static Forces- YS &

FOS = 1.5-2

- Steel-

External Fluctuating Forces

Endurance Limit &

FOS=1.3-1.5

Guidelines for selection of FOS

Contd…

- Design of Cams & Followers, Gears, Rolling Contact Bearing, Rail & Wheel is based on the calculation of contact stresses by the Hertz's Theory.
- Failure of such components are by PITTING.
- Pitting is a Surface fatigue failure, occurs when contact stress exceeds surface endurance limit.
- Surface endurance limit can be improved by increasing the surface hardness
- FOS = 1.8-2.5

Guidelines for selection of FOS

Contd…

- Piston rods, Power screws or Studs are designed on the basis of buckling consideration
- Buckling is elastic instability, which results in sudden large lateral deflection.
- Buckling depends upon YS, E, end condition & radius of gyration
- FOS = 3-6

When to select Higher FOS ?

- No precise estimation of mag. & nature of Ext. Forces .
- Material of non homogenous structure.
- Impact force in service condition.
- Possibility of residual stresses in component.
- Corrosive atmosphere
- High temperature during operation
- Failure may hazard the lives of people (Hoist, lifting machinery & boilers) & substantial loss of property

When to select Higher FOS ? Contd...

- Not possible to test machine component under actual conditions of service and there is variation in actual conditions & standard test conditions.
- Higher reliability is demanded in applications like aircraft components
- Possibility of abnormal variation in external load on some occasions
- Quality of manufacture is poor.
- Exact mode of failure of component is unpredictable.
- Stress concentration in machine component.

Theories of Failure

- Maximum Principal or Normal Stress Theory (Rankine's Theory)

$\sigma_t = \sigma_u / FS$

- Maximum Shear Stress Theory (Guest's/ Tresca's Theory)

$\tau_{max} = 0.5\ \sigma_y / FS$

- Maximum Distortion Energy Theory

Theories of Failure (Contd….)

- Maximum Principal Strain Theory (Saint Venant’s Theory)
- Maximum Strain Energy Theory (Haigh’s Theory)
- Maximum Distortion Energy Theory
- (Hencky and Von Mises Theory)

Important Formulae

- Stress
- M.I.
- Section Modulus
- Torsion Equation
- Bending Equation

Working Stress/ Design Stress/ Safe /Allowable Stress

- While designing it is desirable to keep the stress lower than maximum or Ultimate Stress at which failure of the material take place. This stress is known as Working Stress/ Design Stress/ Safe /Allowable Stress

Types of Stresses

- Tensile Stress
- Compressive Stress
- Bending Stress
- Direct Transverse Shear Stress
- Torsional Shear Stress
- Bearing Pressure/ Stress
- Crushing Stress

Solve Problems…………..