EXPERIMENT No. 6

(To be performed by group of 4-5 students)

1.0 Title :

Design and prepare the drawing on drawing sheet of transmission systemby observing transm...
of power through shaft, keys, coupling, pulley and belt drive etc.

2.0 Prior concepts:

Transmission system.

Mechanical properties of materials

Theories of failure

3.0 New concepts :

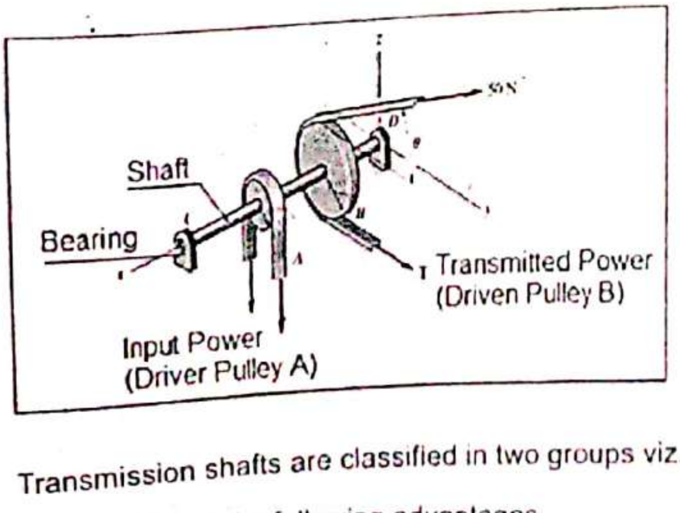
Proposition 1:Transmission Shaft

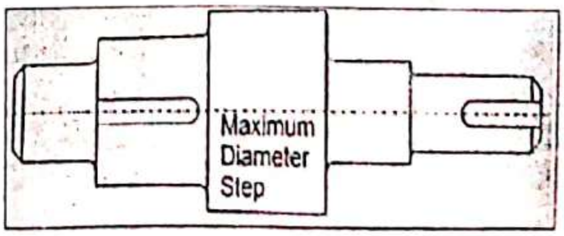
Itisarotating machine element circular in cross section, which supports transmission elements like gears, pulleys, and sprockets and transmits power.

Shaft is always stepped (for positioning gears, pulleys and bearings) with maximum diameter in the middle portion and minimum diameter at the two ends where bearings are mounted.

Fillet radius is provided to produce the effect of stress concentration due to abrupt change in the cross section.

Concept structure:



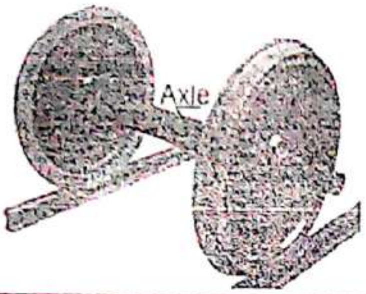


Transmission shafts are classified in two groups viz. solid shafts and hollow shafts.

Hollow shafts offer following advantages.

- Lighter than solid shafts i.e. they have more strength per kilogram of material ... shafts.
- They allow internal support or permit other shafts to operate through the interior.

Some specific categories of shaft are as follows

Specific Name	Description and Function	Applications
Axle 	Supports rotating elements like wheel, hoisting drum or rope sheave Subjected to bending moments. Does not transmit useful torque.	Rear axle of railway wagon, wire rope drum axle of cranes
Spindle 	Threaded short rotating shaft.	All machine tools. e.g. spindle of lathe or drilling machine.
Countershaft 	Secondary shaft which is driven by main shaft. Rotates in counter or opposite to direction of main shaft	Multistage gearboxes. e.g. transmission gear box of automobiles
Jackshaft 	Auxiliary or intermediate shaft between two main power transmitting shafts	Multistage gearboxes.
Line shaft 	Consist number of shafts which are connected in axial direction by means of coupling.	Group drive construction using a single electric motor drive. **Note:** Obsolete system

Proposition 2: Design of Shaft:

It is a determination of shaft dimensions to sustain and to transmit the given power

Shaft may be solid or hollow.

Design of shaft is done using following theories of failure depending on the nature of material used for manufacturing.

Ductile material	Maximum shear stress theory
Brittle material	Maximum normal stress theory (Rankine's Theory)

Design Consideration

Most of the shafts are manufactured by ductile materials and subjected to combined bending and torsional loads.The design of transmission shaft consists of determining the correct shaft diameter from strength and rigidity considerations.

Design Procedure for shafts

Step 1: Select the suitable equation for determining the diameter of shaft.

Study the problem and determine the type of load on shafts and select the equation from the following table.(Table providesshaft design equations based on strength)

Type of load	Type of Equation to be used	
	Solid Shaft	Hollow Shaft $\left(C = \frac{d_i}{d_o}\right)$
Torsional loads	$\tau = \frac{16K_tM_t}{\pi d^3}$	$\tau = \frac{16K_tM_t}{\pi d^3(1-C^4)}$
Bending loads	$\sigma_b = \frac{32K_bM_b}{\pi d^3}$	$\sigma_b = \frac{32K_bM_b}{\pi d_0^3(1-C^4)}$
Combined bending and torsional loads	As per maximum shear stress theory $\tau_{max} = \frac{16}{\pi d^3}\sqrt{(K_bM_b)^2+(K_tM_t)^2}$	As per maximum shear stress theory $\tau_{max} = \frac{16}{\pi d_0^3(1-C^4)}\sqrt{(K_bM_b)^2+(K_tM_t)^2}$
	As principal stress theory $\sigma_1 = \frac{16}{\pi d^3}\left[M_b+\sqrt{(M_b)^2+(M_t)^2}\right]$	As principal stress theory $\sigma_1 = \frac{16}{\pi d_0^3(1-C^4)}\left[M_b+\sqrt{(M_b)^2+(M_t)^2}\right]$

K_b = combined shock and fatigue factor applied to bending moment, and

K_t = combined shock and fatigue factor applied to torsional moment

Step 2: Calculation of torque M_t and bending Moment M_b

Step 3: Calculation of loads on pulley and gears.

Calculation of above loads shall be done considering direction of belt /gears and forces acting on belt/gears.

Step 4: Bending Moment Diagrams

Draw the free body diagrams showing all forces draw bending diagram.

Locate point of maximum bending moment

Step 5: Selection of shock factor and endurance factors

A.S.M.E. code for shaft design

According to the code permissible shear stress τ_{max} for theshaft **without keyways** is taken as 30% of the yield strength in tension or 18% of the ultimate tensile strength of the material, whichever is minimum. Therefore,

$\tau_{max} = 0.30\ S_{yt}$ or $\tau_{max} = 0.18\ S_{ut}$ (whichever is minimum)

If the keyways are present, these values are to be reduced by 25 percent. According to A.S.M.F code, the bending and torsional moments are to be multiplied by factors K_b and K_t respectively, to account for shock and fatigue in operating condition. Equations in above table consider the effect of these factors.

Selection of K_b and K_t can be done from the following table.

	K_b	K_t
i) Load gradually applied	1.5	1.0
ii) Load suddenly applied (minor shock)	1.5-2.0	1.0-1.5
iii) Load suddenly applied (heavy shock)	2.0-3.0	1.5-3.0

Step 6: Selection of material for the shaft

Selection of the material can be done from the following table.

Shaft strength	Description of Material	Material Designation
Ordinary Transmission Shaft (low or medium strength)	Machinery steels Medium carbon steels with carbon percentage of0.15 to 0.40	30 C8 or 40C 8
High Strength shafts	High Carbon steels with carbon percentage of 0.45 to 0.60	45 C8 or 50 C 8
High strength/ hardness/ toughness shafts	Alloy steels including nickel, nickel chromium and molybdenum steels.	16 Ni3 Cr2,35 Ni5 Cr2 40 Ni6 Cr4 Mo2 40 Ni10 Cr3 Mo6

Step 7: Calculation of size of shaft.

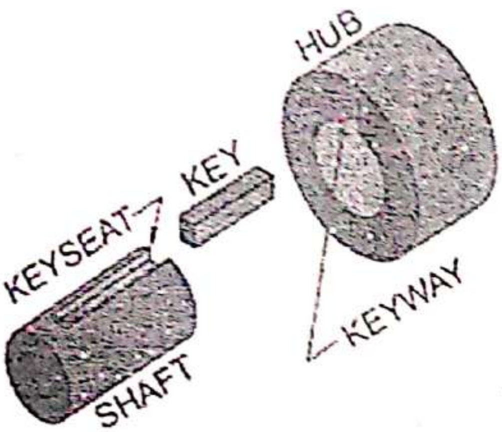
Proposition 3: Key

It is a machine element used to connect the transmission shaft to rotating machine elements like pulley, gear, sprocket or flywheel.

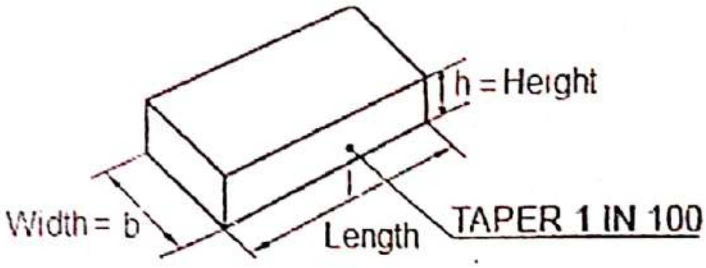
Functions of the key –

- To transmit torque from the shaft to the hub of mating element and vice versa.
- To prevent relative rotational motion between shaft and the joined machine element like gear or pulley (Exception- feather key, splined key)

Concept structure:



A keyed joint consist of shaft, hub and key.
Keys are made of plain carbon steels like 40C8 or 50C8.



Proposition 4: Design of Key

It is a determination of dimensions of key to sustain and to transmit the given power.

Design Consideration

Design criterion for key is shear failure or crushing failure under the action of tangential force.

Material of shaft, key and gear or coupling is normally same but key is deliberately kept weaker (dimensions are kept slightly less than it shall be) for the economy of maintenance of transmission system.

Dimensions of the key are shown in the figure above.

Design Procedure for key

Step 1: Select the type of key.(e.g. sunk key square or rectangular)

Step 2: Select the material for the key.

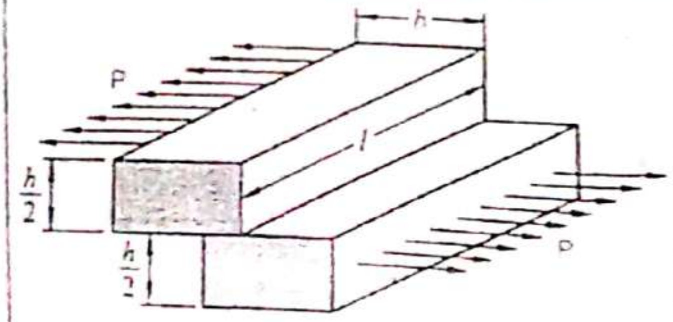
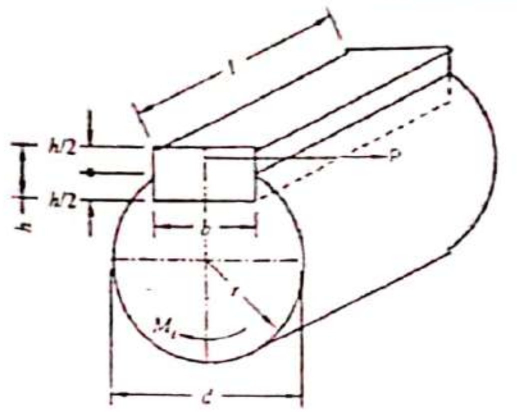
Step 3: Calculate the permissible/ allowable stresses $\left(\tau = \frac{0.5S_{y_t}}{f.s}, \sigma_c = \frac{S_{y_t} = S_{y_c}}{f.s}\right)$

Step 3: Determine the dimensions of key from the two strength equations.

Strength equations are given in the following table.

Select the larger dimensions of key obtained out of two strength equations.

Note: Select the standard key dimensions from the I.S.code IS 2292: 1963 Taper keys and Keyways by comparing the calculated dimensions

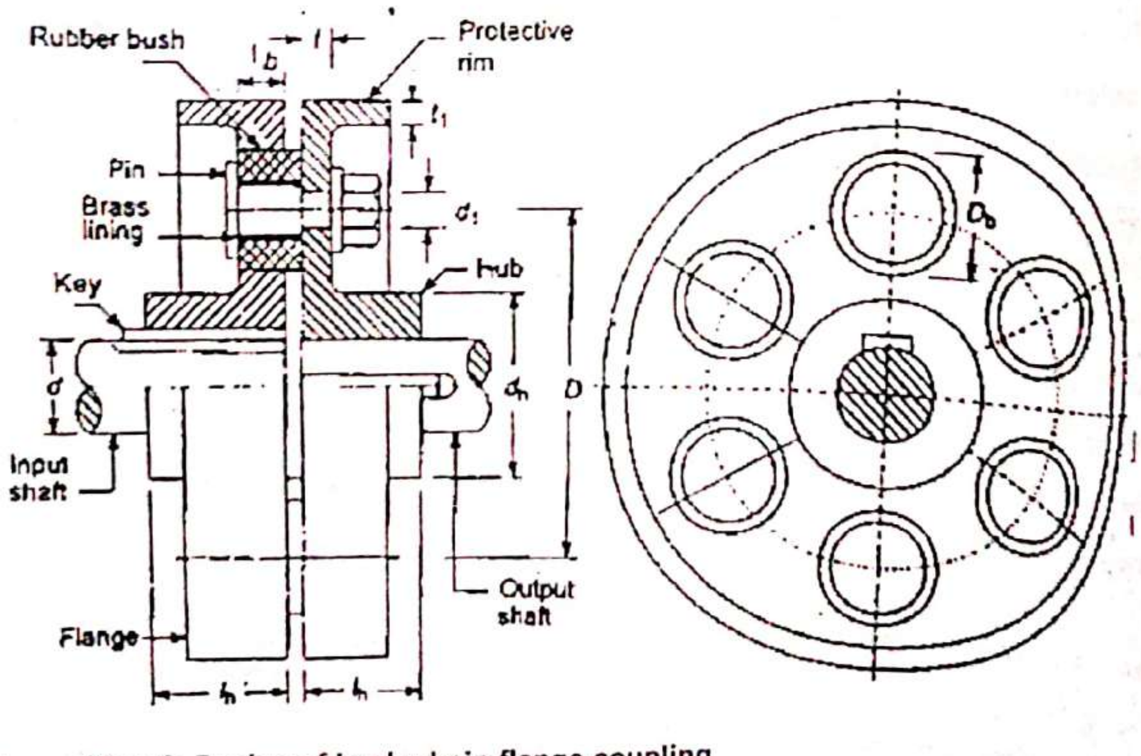
Type of failure	Diagram showing failure	Equation
Shear failure		$\tau = \frac{P}{Area} = \frac{P}{bl}$ As..... $M_t = P \times \frac{d}{2}$ $\tau = \frac{2M_t}{dbl}$
Crushing failure		$\sigma_c = \frac{P}{Area} = \frac{P}{bl}$ As..... $M_t = P \times \frac{d}{2}$ $\sigma_c = \frac{4M_t}{dhl}$

Proposition 5: Bushed pin flange coupling

It is a mechanical device which connects two shafts which are slightly misaligned axially.

It employees a flexible element like rubber bush between the driving and driven flanges.

Concept structure:



Proposition 6: Design of bushed pin flange coupling

Itis the process of determining dimensions of bushed pin flange coupling to sustain and transmit the given power from one shaft to another.

Design considerations

It is assumed that the power is transmitted by the shear resistance of the pins. Hence design of pins is very critical. Shear failure and bending failure are criterion for failure of the pins.

Design procedure for the bushed pin type flexible couplings.

Step 1: Selection of material for different components

Name of component	Material	Factor of safety
Shaft	Plain carbon steel 40C8 (S_{yt} = 380 MPa)	2
Keys and pins	Plain carbon steel 30 C8 (S_{yt} = 400 MPa) (S_{yc} = 1.5 S_{yt})	2
Flanges	FG 200 (S_{ut} =200 MPa) Ultimate Shear strength S_{su} = 0.5 S_{ut}	6

Step 2: Calculation of permissible/ allowable stresses for different components.

Step 3: Determine the diameter of shaft.(d)

Use equation of power to find the torque.

Using shear strength equation of shaft and determine diameter of shaft .

Step 4: Determine dimensions of flanges as follows.

d_h = outside diameter of hub = 2 d

l_h = length of hub or effective length of the key = 1.5 d

D = pitch circle diameter of pins = 3d or 4d

t = thickness of output flange = 0.5d

t_1 = thickness of protective rim = 0.25d

Check the dimensions of hub for the shear stress developed. Shear stress developed must be within allowable shear stress of flange material.

Note: Hub is treated as hollow shaft subjected to torsional moment.

Step 5: Determine diameter of pins (d_1)

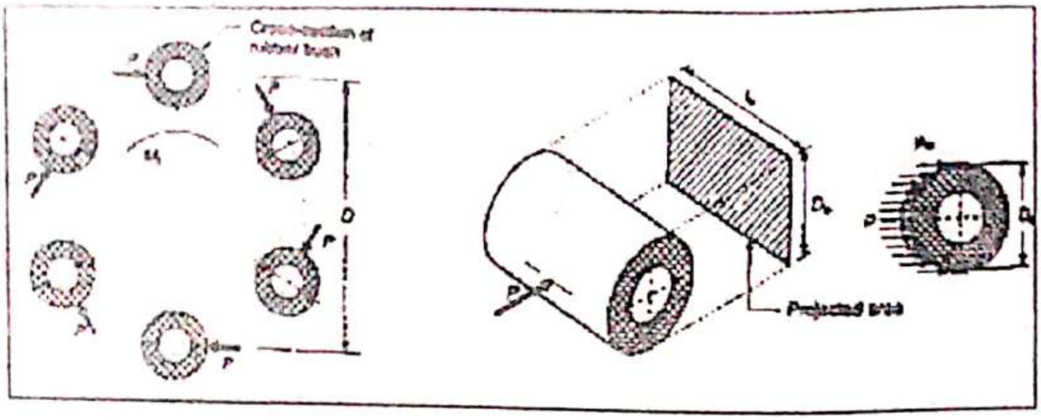
d_1= diameter of pin = $\frac{0.5d}{\sqrt{N}}$ where N is number of pins(usually 4 or 6)

Check the diameter of pin for shear stress developed. Shear stress developed must be within allowable shear stress of pin material.

The bending stress will be determined at a later stages after deciding the dimensions of the rubber bushes.

Step 6: Determine dimension of bushes

Considering the pressure intensity between the rubber bush and cast iron flange as 1 N/mm^2, determine the dimensions of the bushes



$$D_b^2 = \frac{2M_c}{DN}$$

Where D_b = outer diameter of bush, and $D_b = l_b$ = length of bush

Step 7: Bending stress in pins

Force acting on the pin depends upon the torque and the relationship is given by,

$$M_t = P \times \frac{D}{2} \times N \text{ therefore, } P = \frac{2M_t}{DN}$$

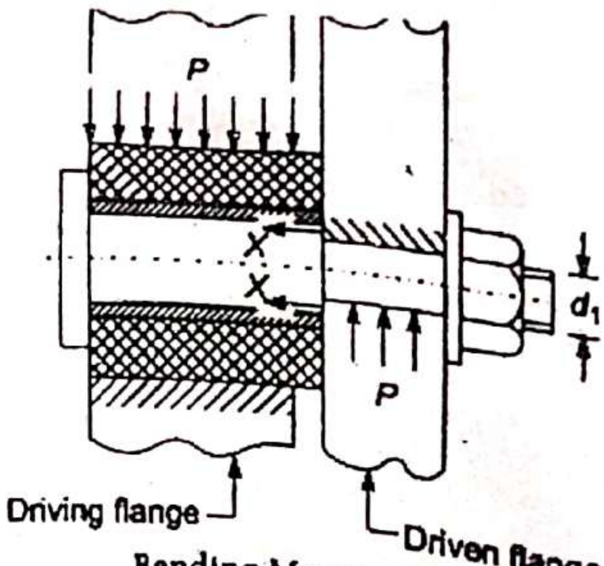
It is assumed that the force P is uniformly distributed over effective length (l_b) of bush as shown in figure.

Then,

$$M_b = P\left(5 + \frac{l_b}{2}\right)N - mm$$

$$\sigma_b = \frac{32M_b}{\pi d_1^3}$$

This diameter of pin is to be selected, because the pin diameter determined by shear failure criterion may not withstand bending stresses.



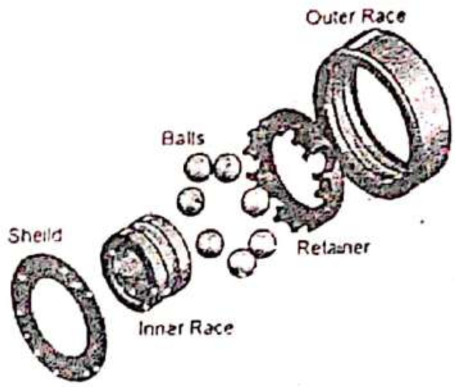
Bending Moment at Section XX

Diameter of pin need to be enlarged by 6mm to fit in the driving flange as shown in figure. Brass lining of 2 mm thickness is also added. Minimum thickness of rubber bush is 10 mm. Hence the final diameter of enlarged hole of driving flange becomes (d_1+ 6 + 4 + 20) mm.

Step 8: Dimensions of key

Proposition 7: Selection of bearing

Nomenclatureof ball and roller bearings

Nomenclature	
F_a - axial load,	L - required life of the bearing in million revolutions
F_r - radial load,	mr - million revolutions
C - basic dynamic capacity,N	L_{10} - life of the bearing for 90% survival at 1 mr
C_o - basic static capacity, N	p - probability of survial
P - equivalent load ,N	p_{10} - probability of survival for 90% or 0.9
S - service factor	L_{50} - median life based on 50% survival
X - radial factor	
Y - thrust factor	
F_m - cubic mean load (axial or radial), N	
n - revolutions	
t - time	

(i) Calculate the radial and axial forces acting on the bearing and determine the diameter of the shaft where the bearing is to be fitted.

(ii) Select the type of bearing for the given application.

(iii) Determine the values of **X** and **Y**, the radial and thrust factors, from the catalogue. The values of **X** and **Y** for single row deep groove ball bearings are given intable*of design data book. The values depend upon two ratios $\left(\frac{F_a}{F_r}\right)$ and $\left(\frac{F_a}{C_o}\right)$.

The Selection of bearing is therefore done by trial and error. The static and dynamic capacities of single row deep groove ball bearings of different series are given in table* of design data book. To begin with, a bearing of light series, such as 60, is selected for the given diameter of the shaft, is selected for the given diameter of the shaft and the value of is found from table*showing dimensions and static and dynamic life.

Knowing the ratios $\left(\frac{F_a}{F_r}\right)$ and $\left(\frac{F_a}{C_o}\right)$ the values of **X** and **Y**are foundfrom table* showing X and Y factors single- row deep groove ball bearing.

Calculate the equivalent dynamic load from the equation,

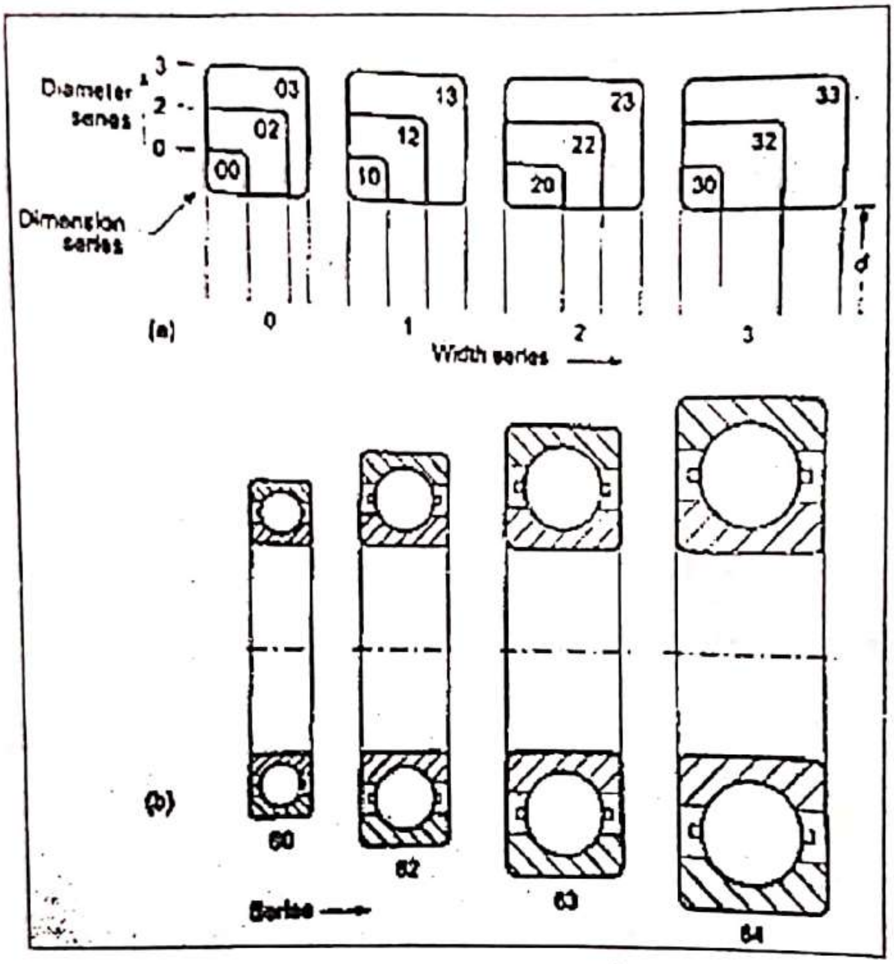
Note:* refers to the table provided in the design data book of PSG Coimbatore

(iv) Make the decision about the expected bearing life and express the life L in million revolutions.

(v) Calculate the dynamic load capacity using the equation, $L = \left(\frac{C}{P}\right)^{P}$

(vi) Check whether the selected bearing of series 60 has the required dynamic capacity. If not, select the bearing of the next series and go back to the step (iii) and continue.

Note: ISO plan for the dimension series of the bearing is illustrated in figure(a) given below.



It consists of two digit numbers.

a. The first number indicates the width series 8,0,1,2,3,4,5 and 6 in order of increasing width.

b. The second number indicates the diameter series 7,8,9,0,1,2,3 and 4 in order of ascending outer diameter of the bearing

Figure (b) shows the proportionate dimensions of SKF bearing to different series with a 50 mm above bore diameter (Bearing No. 6010, 6210, 6310 and 6410)

4.0 LearningObjectives:

Intellectual Skills:

- Understand various modes of failure in machine components.
- Apply the basic knowledge of the earlier subject like Strength of Materials, Engineering Mechanics.
- Analyse and evaluate the loads, moments, torque and stresses involved in machine components.

Motor Skills:

- Ability to draw the area subjected to failure for given stress condition.
- Ability to determine the area subjected to failure for given stress condition.
- Ability to calculate various dimensions of machine component under given load condition using appropriate criterion for failure.

5.0 Learning Aids:

- Working Model of Components.
- Machines available in Workshop like Lathe machine, Milling machine etc.
- Equipment available in different laboratories used for practicals of mechanical engineering like Applied Mechanics/ Strength of Materials/ Power Engineering/ Theory of machines and mechanisms, etc.

6.0 Stepwise Procedure :

Teacher activity:

1. Introduce the students to new concepts of shafts, types of shafts , keys, flexible couplings, pulleys and bearings with suitable examples of mechanisms/ available models or actual machine setup.
2. Introduce the students about design procedure of shaft, key, coupling and selection of bearing in detail.
3. Introduce students about the different factors used for design procedures..

Teacher shall use models of or assemblies like components of toys, models or machine tool or other laboratory equipment set up.

Student activity:

4. Observe different mechanical elements introduced by teacher.
5. Observe the different applications of the different shafts, keys, couplings and bearings and pulleys.
6. Observe the system where transmission of power takes place through shaft, keys, coupling, pulley and belt drive.
7. Get the required information regarding power transmitted (power output by motor or engine etc.) and note under the observations.
8. By selecting suitable materials, design the shaft, key and coupling and pulley and note under the observations.
9. Also select suitable Ball Bearing from Manufacturer's catalogue.
10. Prepare design report, details and assembly drawing indicating overall dimensions, tolerances, fits and surface finish.
11. Also prepare bill of materials on drawing sheet.

7.0 Observations :

A sample power transmission system shall include the components like shaft, key, pulley, bearings and couplings as shown in figure.

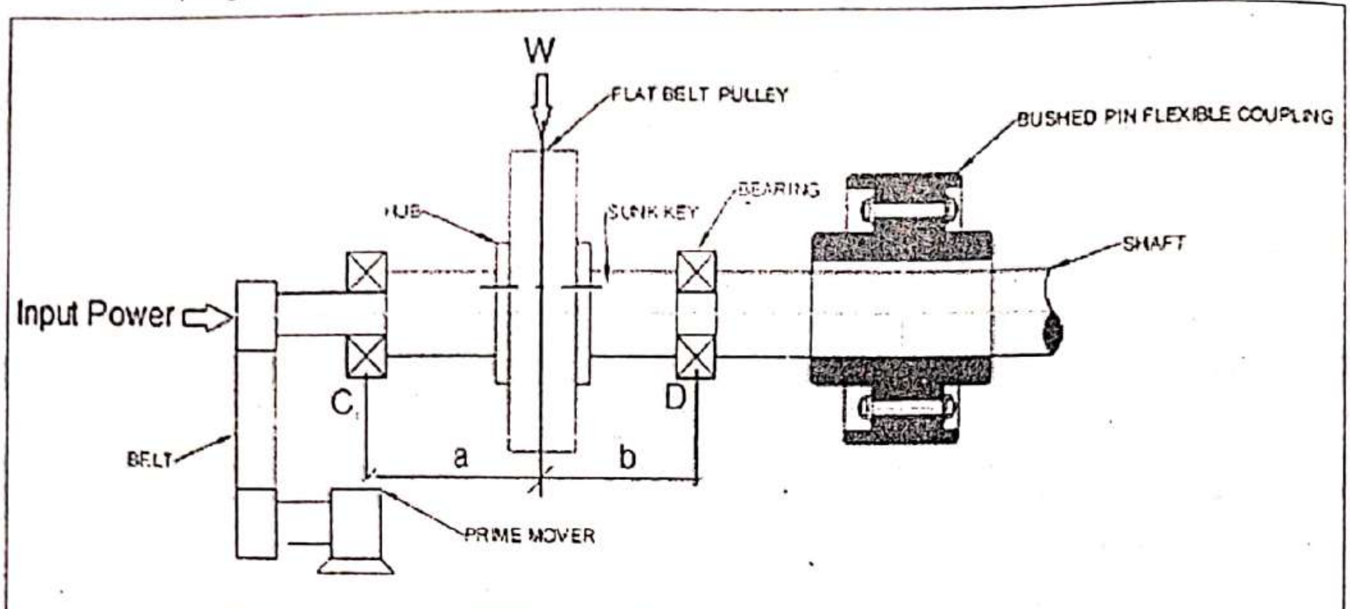


FIG.: SAMPLE POWER TRANSMISSION SYSTEM

Teacher shall provide the values of the following (Values will be different group of students)

- Power input to the shaft P = ... kW at ....rpm

- Ratio of belt tensions acting vertically downwards on tight and loose sides of pulley is

  T_1/T_2 = ...

- Distanceof pulley from bearing C, a = ...mm,

- Distance of pulley from bearing D, b= ....mm,

- Service factor for bushed pin flexible coupling if any = ...

Design the shaft, key, pulley, bushed pin flexible coupling and select the rolling contact bearings at C and D.

Assumptions

Selected Material for the shaft is ....(S_{ut} = ...MPa, S_{yt}=.............)

A.S.M.E. code is to be used for shaft design.

Select combined shock and fatigue factors applied to bendingmoment K_b= ....and in torsional moment K_t =......................

Bearing life of selected deep groove ball bearing at C and D is assumes as 15000 hr at 90% reliability. The load factor is taken as 3.

(Teacher shall guide each the group of students for design of every component.)

Design of shaft on strength basis

Calculate the forces acting on the shaft and calculate the reactions at the bearing supports.

Draw the free body diagram showing the forces and reactions on shaft

(Space for force diagram)

Draw the bending moment diagram showing the point of maximum bending moment.

(Space for bending moment diagram)

Maximum bending moment acting on shaft is M_b= ....N-mm

Torque transmitted by shaft M_t = ...N-mm

Permissible values of shaft material as per A.S.M.E. code

$0.30\ S_{ut}$ = ...=....................N/mm^2,

$0.18\ S_{yt}$= ....=....................N/mm^2

Select the lower value as permissible shear stress τ_{max} = ...N/mm^2

Select appropriate equation for the calculation of diameter of shaft,

Hint : Shaft is subjected to combined bending and torsional loads

Calculated diameter of shaft d =................ mm.

Select the standard shaft diameter by comparing the calculated diameter

then modified shaft diameter d = ...mm.

Shaft diameter will be reduced at the ends to fit the bearings and = ...mm.

Selection of bearings

There is no axial load acting on the bearings.

Calculate the resultant radial forces acting on the bearings at C and D

Rc = ...

Rd =...

Follow the procedure of selection of bearings from manufacturer's catalogue as explained earlier in proposition 7.

(Space for the calculations)

From equation $L = \left(\frac{60_n L_h}{10^6}\right)$

for ball bearings, $C = PL^3$

considering load factor, $C_1 = P_1 L^3 \times$ Load factor

for bearing at C, $C_1 = P_1 L^3$ =.............................. =...........................N

for bearing at D, $C_2 = P_2 L^3$ =.............................=...........................N

Referring to table* showing dimensions and static and dynamic life, and express the life L in million revolutions

Note:* refers to the table provided in the design data book of PSG Coimbatore

Selected bearing designation and their dimensions are as follows.

	Designation	Inner diameter d (mm)	Outer diameter D(mm)	Width B (mm)
Bearing at C	....	....	....	....
Bearing at D	....	....	....	....

Design of the Key

Standard cross section of selected flat sunk key for designed shaft diameter..........mm(diameter of shaft designed earlier shall be considered) is .....× ....mm from the table* showing dimensions of key for the given shaft diameter.

Calculate permissible stresses for the key material

It is assumed that keys and shaft are made of same material and the factor of safety is 4.

Torque transmitted keys is same as that of transmitted by shaft

M_t =............................mm

$S_{yc} = S_{yt}$ = ...N/mm²

$\sigma_c = \frac{S_{yc}}{(f.s)}$ = ...=............N/mm²

$\tau = \frac{S_{yc}}{(f.s)} = \frac{0.5 S_{yt}}{(f.s)}$ =................=...........N/mm²

Determine the dimensions of the key i.e. length l by shear strength and crushing strength equation.

Shear strength equation, $\tau = \frac{2M_t}{dbl}, l = \frac{2M_t}{db\tau}$ ....=..............mm

Crushing strength equation, $\sigma_c = \frac{4M_t}{dhl}, l = \frac{2M_t}{db\sigma_c}$ = ...=..............mm

Select the larger length of the key for safety.

Note : But the length of the key must not be smaller than 1.5 times shaft diameter. If it is so select the length of the key $l = 1.5d$

Then dimensions of the key are = length × width × height

.... × .... × ....mm

Design of the bushed pin flexible coupling

Select the material for components of coupling

Material for bolt =............................(same as that of key)

Material for Flanges = FG200 (S_{yc} = 200 N / mm²)

and ultimate Shear strength $S_{su} = 0.5\ S_{ut}$

factor of safety = 6

Calculation of permissible / allowable stresses for different components.

(Space for calculations)

Bolts: τ = ...=...............N/mm²

Crushing strength σ_c = ...=...............N/mm²

Flanges: τ = ...=...............N/mm²

Determine the diameter of shaft. (d)

Diameter of shaft is already calculated, hence d =........... .mm.

Determine dimensions of flanges as follows:

d_h = outside diameter of hub = 2d =...........mm

l_h = length of hub or effective length of the key = 1.5 d =........mm

D = pitch circle diameter of pins = 3d or 4d =..........=............mm

t = thickness of output flange = 0.5d =...........= .... mm

t_1 = thickness of protective rim = 0.25d = ... =.........mm

Check the dimensions of hub for the shear stress developed at the junction of flange. Shear stress developed must be within allowable shear stress of flange material.

Note: Hub is treated as hollow shaft subjected to torsional moment.

$$M_t = \frac{1}{2}\pi d_h^2 t\tau = ...$$

τ = ...=...............N/mm².

Determine diameter of pins (d_1):

d_1= diameter of pin = $\frac{0.5d}{\sqrt{N}}$ where N is number of pins (usually 4 or 6)

Check the diameter of pin for shear stress developed. Shear stress developed must be within allowable shear stress of pin material.

$$\tau = \frac{8M_t}{\pi d_1^2 \, DN} = ...$$

τ = ...=...............N/mm².

The bending stress will be determined at later stages after deciding the dimensions of the rubber bushes.

Determine dimension of bushes:

Considering the pressure intensity between the rubber bush and cast iron flange as 1 N/mm², determine the dimensions of the bushes

$$D_b{}^2 = \frac{2M_t}{DN} = \text{..}$$

Where D_b = outer diameter of bush,

and $D_b = l_b$ = length of bush=.........mm

Bending stress in pins

Force acting on the pin depends upon the torque and the relationship is given by,

$$M_t = P \times \frac{D}{2} N \text{ therefore, } P = \frac{2M_t}{DN} = \text{....................N}$$

It is assumed that the force P is uniformly distributed over effective length (l_b) of bush as shown in figure.

Then,

$$M_b = P\left(5 + \frac{l_b}{2}\right) \text{...=..................N.mm}$$

$$\sigma_b = \frac{32M_b}{\pi d_1^3} = \text{...} d_1 = \text{...}$$

Enlarged diameter of pin = (d_1 + 6) mm = ...mm

Hole diameter in driving flange where enlarged portion diameter of pin will fit

= (d_1 + 6) + (2 mm thick brass×2) + (10 mm thick rubber bush ×2)

= (..... + 6) + (2 × 2) + (10 × 2) =.............................mm.

8.0 Questions for confirmation of learning:

(Students shall write answers to the questions at the time of practical independently before completing the experiment to have **self-feedback**. He/ She may refer to the notes, etc. Teacher shall supervise.)

1. State the reason for use of mild steel for manufacturing of shaft.

....

....

2. State the type of stress developed in key.

....

....

3. State the reason for mounting the coupling near the bearing .

....

....

9.0 Conclusion:

1. As per A.S.M.E. code of shaft design, the strength of the shaft get reduced by ....(50/25/45) percent.
2. For a square key, the permissible crushing stress is...............(same/thrice/twice) the permissible shear stress.
3. Stress developed at the junction of flange and hub is .... (Crushing / circumferential shear/ bearing /bending) stress.
4. When a small misalignment between two shafts is to be permitted while transmitting the torque, then..(rigid/bushed pin flexible/universal) coupling is used .

10.0 Student Activity:(May be done by arranging laboratory/field visits)

(Teacher shall form a group of 4-5 students each. Each group shall perform only one allotted activity from the following. Teacher shall supervise these activities.)

Determine the dimensions of the flat belt pulley in the above design project.

Refer the design data book or pages numbers 272, 273,274 from the book ' Introduction to machine design' by V.B.Bhandari for the guidance of design of pulley.

(Space for answer)

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11.0 Questions:

Write answers to Q....Q....Q....Q.... (Teacher shall allot the question)

1. State the reasons for using hollow shaft rather than solid shaft for larger power transmission.
2. Write design procedure of shaft on rigidity basis.
3. State the reason for keeping the key, deliberately weaker than the shaft and other component.
4. Compare mathematically,the weight of hollow shaft and solid shaft for the same diameter.
5. Compare mathematically, the strength of hollow shaft and solid shaft for the same diameter.
6. Compare mathematically, the stiffness of hollow shaft and solid shaft for the same diameter.
7. Classify different types of keys and state applications of each.
8. Derive the relation between shaft diameter and length of the key.
9. Derive the relation between the crushing strength and shear strength of the key.
10. Distinguish between rigid and flexible coupling on the basis of

    (i) Alignment (ii) vibration (iii) deflection (iv) Cost

(Space for Answers)