ROHINI
COLLEGE OF ENGINEERING & TECHNOLOGY
Approved by AICTE and Affiliated to Anna University, (An ISO Certified Institution)

ME8651 DESIGN OF TRANSMISSION SYSTEMS

DEPARTMENT OF
MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING
SIXTH SEMESTER / III YEAR

ME8651 DESIGN OF TRANSMISSION SYSTEMS L T P C
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OBJECTIVES:

- To gain knowledge on the principles and procedure for the design of Mechanical power Transmission components.
- To understand the standard procedure available for Design of Transmission of Mechanical elements
- To learn to use standard data and catalogues (Use of P S G Design Data Book permitted)

UNIT I DESIGN OF FLEXIBLE ELEMENTS 9

Design of Flat belts and pulleys - Selection of V belts and pulleys – Selection of hoisting wire ropes and pulleys – Design of Transmission chains and Sprockets.

UNIT II SPUR GEARS AND PARALLEL AXIS HELICAL GEARS 9

Speed ratios and number of teeth-Force analysis -Tooth stresses - Dynamic effects – Fatigue strength- Factor of safety - Gear materials – Design of straight tooth spur & helical gears based on strength and wear considerations – Pressure angle in the normal and transverse plane- Equivalent number of teeth-forces for helical gears.

UNIT III BEVEL, WORM AND CROSS HELICAL GEARS 9

Straight bevel gear: Tooth terminology, tooth forces and stresses, equivalent number of teeth. Estimating the dimensions of pair of straight bevel gears. Worm Gear: Merits and demerits terminology. Thermal capacity, materials-forces and stresses, efficiency, estimating the size of the worm gear pair. Cross helical: Terminology-helix angles-Estimating the size of the pair of cross helical gears.

UNIT IV GEAR BOXES 9

Geometric progression - Standard step ratio - Ray diagram, kinematics layout -Design of sliding mesh gear box - Design of multi speed gear box for machine tool applications - Constant mesh gear box - Speed reducer unit. – Variable speed gear box, Fluid Couplings, Torque Converters for automotive applications.

UNIT V CAMS, CLUTCHES AND BRAKES 9

Cam Design: Types-pressure angle and under cutting base circle determination-forces and surface stresses. Design of plate clutches –axial clutches-cone clutches-internal expanding rim clutches- Electromagnetic clutches. Band and Block brakes - external shoe brakes – Internal expanding shoe brake.

TOTAL : 45 PERIODS

OUTCOMES:

- Upon completion of this course, the students can able to successfully design transmission components used in Engine and machines

TEXT BOOKS:

1. Bhandari V, “Design of Machine Elements”, 3rd Edition, Tata McGraw-Hill Book Co, 2010.
2. Joseph Shigley, Charles Mischke, Richard Budynas and Keith Nisbett “Mechanical Engineering Design”, 8th Edition, Tata McGraw-Hill, 2008.

REFERENCES:

1. Sundararajamoorthy T. V, Shanmugam .N, “Machine Design”, Anuradha Publications, Chennai, 2003.
2. Gitin Maitra, L. Prasad “Hand book of Mechanical Design”, 2nd Edition, Tata McGraw-Hill, 2001.
3. Prabhu. T.J., “Design of Transmission Elements”, Mani Offset, Chennai, 2000.
4. C.S.Sharma, Kamlesh Purohit, “Design of Machine Elements”, Prentice Hall of India, Pvt. Ltd., 2003.
5. Bernard Hamrock, Steven Schmid, Bo Jacobson, “Fundamentals of Machine Elements”, 2nd Edition, Tata McGraw-Hill Book Co., 2006.
6. Robert C. Juvinall and Kurt M. Marshek, “Fundamentals of Machine Design”, 4th Edition, Wiley, 2005
7. Alfred Hall, Halowenko, A and Laughlin, H., “Machine Design”, Tata McGraw-Hill BookCo.(Schaum’s Outline), 2010
8. Orthwein W, “Machine Component Design”, Jaico Publishing Co, 2003.
9. Ansel Ugural, “Mechanical Design – An Integral Approach", 1st Edition, Tata McGraw-Hill Book Co, 2003.
10. Merhyle F. Spotts, Terry E. Shoup and Lee E. Hornberger, “Design of Machine Elements” 8th Edition, Printice Hall, 2003.
11. U.C.Jindal : Machine Design, "Design of Transmission System", Dorling Kindersley, 2010

UNIT I

DESIGN OF FLEXIBLE ELEMENTS

Characteristics of Belt Drives

S.No	Characteristics	Flat belts	V- belts	Toothed or timing belts
1.	Maximum velocity ratio	16	12	11
2.	Maximum belt speed (m/s)	35 to 110	25	80
3.	Slip	1 to 5%	1 to 5%	Nil
4.	Tension	High	Less	Very less
5.	Shock resistance	Good	Good	Fair
6.	Resistance to wear	Good	Fair	Good
7.	Dressing	Required	Not Required	Not Required
8.	Initial cost	Less	Less	Moderate

SELECTION OF A BELT DRIVE

Selection of a belt drive depends upon:

- Power to be transmitted
- Speed of driver and driven shafts
- Shaft relationship
- Service conditions
- Speed reduction ratio
- Centre distance
- Positive drive requirement
- Space available

VELOCITY RATIO OF BELT DRIVE

The ratio between the speeds of the driver and the follower or driven is known as velocity ratio.

D and d = Diameters of the driver and driven respectively,

N_1 and N_2 = Speeds of the driver and driven respectively, and

ω_1 and ω_2 = Angular velocities of the driver and driven respectively.

$$\text{Velocity ratio, } \frac{N2}{N1} = \frac{\omega 2}{\omega 1} = \frac{D}{d}$$

Effect of Belt Thickness on Velocity Ratio

When the thickness of belt *(t)* is considered, then velocity ratio is given by

$$\frac{N2}{N1} = \frac{D+t}{d+t}$$

Effect of Slip on Velocity Ratio

Let S1 = Percentage slip between the driver and the belt,

S2 = Percentage slip between the belt and the driven pulley, and

S = Total percentage slip = S1 + S2

$$\textbf{Velocity ratio, } \frac{N2}{N1} = \frac{D}{d}\left[1 - \frac{S1+S2}{100}\right] = \frac{D}{d}\left[1 - \frac{S}{100}\right]$$

If thickness of the belt *(t)* is considered, then

$$\textbf{Velocity ratio, } \frac{N2}{N1} = \frac{D+t}{d+t}\left[1 - \frac{S}{100}\right]$$

Effect of Creep of Belt

Let σ_1 and σ_2 = Stresses in the belt on the tight side and slack side respectively, and
E = Young's modulus of the belt material.

$$\textbf{Velocity ratio, } \frac{N2}{N1} = \frac{D}{d} \times \frac{E+\sqrt{\sigma 1}}{E+\sqrt{\sigma 2}}$$

GEOMETRICAL RELATIONSHIPS

For open belt drive: An open belt drive is shown in Fig.

Let D and *d* = Diameters of the larger and smaller pulleys respectively in meters,

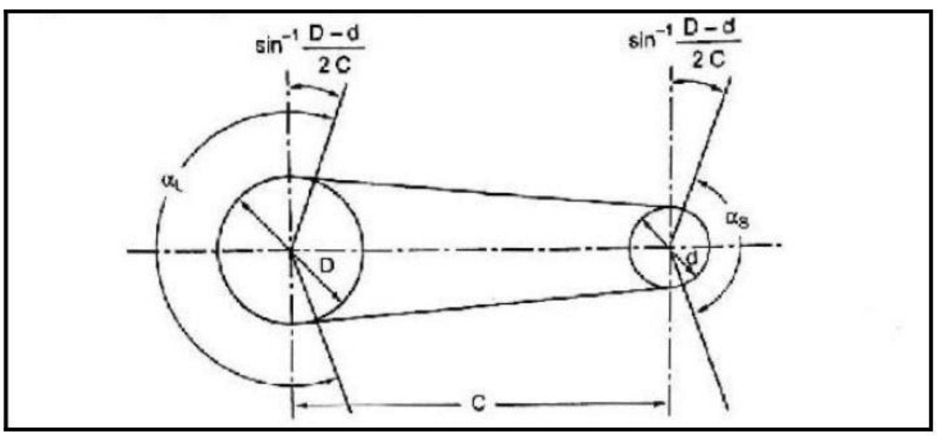
C = Centre distance between the two pulleys in meters,

L = Total length of the belt in meters,

2α = The angle subtended between the straight portions of the belt in degrees,

α_s = Wrap angle (or angle of contact/lap) for small pulley in degrees, and

α_L = Wrap angle for large pulley in degrees.



OPEN BELT DRIVE

$$\sin \alpha = \frac{D-d}{2C}$$

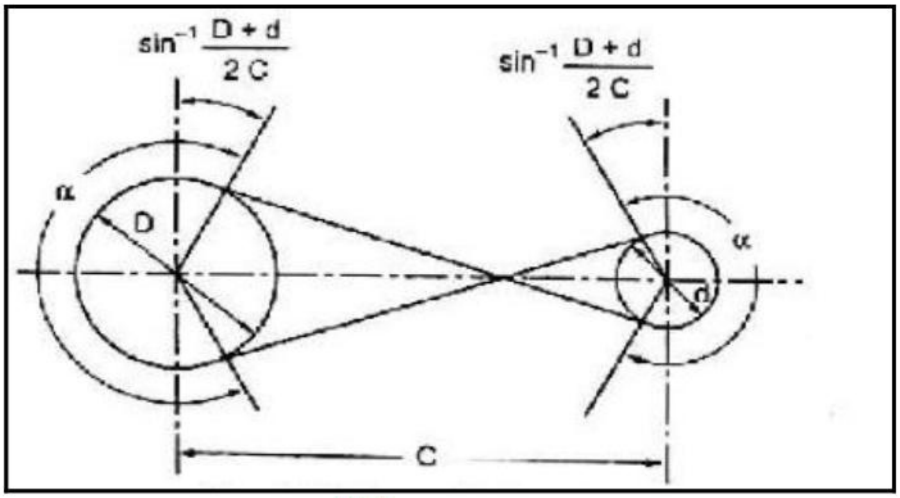
also $\alpha_s = (180 - 2\alpha)$ and $\alpha_L = (180 + 2\alpha)$

Wrap angle for smaller pulley, $\alpha_s = 180 - 2\ \mathrm{Sin}^{-1}\left(\frac{D-d}{2C}\right)$

Wrap angle for larger pulley, $\alpha_L = 180 + 2\ \mathrm{Sin}^{-1}\left(\frac{D-d}{2C}\right)$

and Length of the belt, $L = 2C + \left(\frac{\pi}{2}\right)(D + d) + \frac{(D-d)^2}{4C}$

For Crossed Belt Drive:



$\sin \alpha = \left(\frac{D+d}{2C}\right)$

also $\alpha_s = \alpha_L = (180 + 2\alpha)$

Therefore, wrap angels for smaller and larger pulleys are same and is given by

$\alpha_s = \alpha_L = 180 + 2\ \mathrm{Sin}^{-1}\left(\frac{D+d}{2C}\right)$

and Length of the belt, $L = 2C + \left(\frac{\pi}{2}\right)(D + d) + \frac{(D+d)^2}{4C}$

STRESSES IN THE BELT

The various stresses acting at various portions of the belt are.

1. Stress due to maximum working tension, TI (σ_t):

$$\sigma_t = \frac{Tightsidetension}{Cross-sectionalareaofthebelt} = \frac{T_1}{b.t}$$

Where b = width of the belt, and

t = Thickness of the belt.

2. Stress due to bending of the belt over the pulley(σ_b):

$$(\sigma_b) = \frac{E.t}{d}$$

Where E = young's modulus of the belt over the pulley (σ_b)

d = diameter of the smaller pulley

3. Stress due to the effect of centrifugal force (σ_c)

$$(\sigma_c) = \frac{\text{centrifugal force}}{\text{cross sectional area of the belt}} = \frac{mv^2}{b.t} = \rho v^2$$

Where ρ = *density of the belt material in Kg/m³*

It is noted that the stress will be maximum when the belt moves over the smaller pulley. Therefore the maximum stress in the tight side of the smaller pulley is given by

$$\sigma_{max} = \sigma_t + \sigma_b + \sigma_c$$

Permissible stresses

Leather belt = 2 to 3.45 M Pa

Rubber belt = 1 to 1.7 M Pa

Fabric belt = Less that 1.5 M Pa

DESIGN OF FLAT BELT PULLEYS

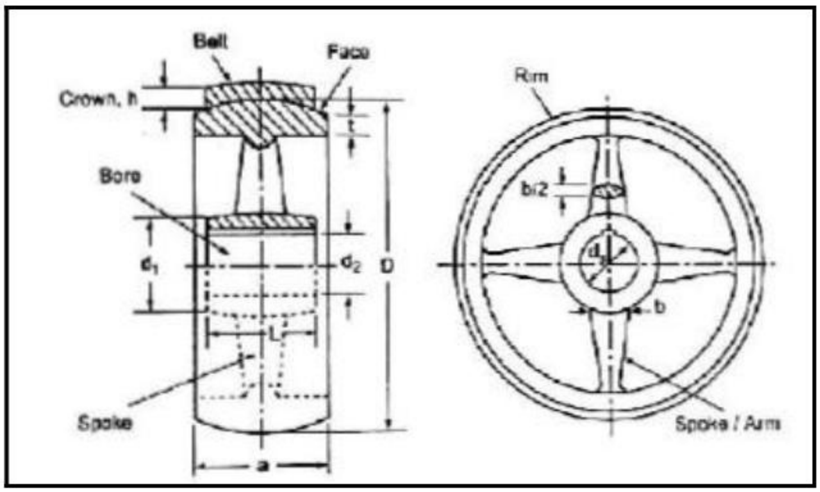
Materials Used for Pulleys

The commonly used pulley materials are: Cast iron

- Fabricated steel
- Wood or fiber.
- Compressed paper
- Cast Iron pulleys are most widely used in actual practice.

Design Procedure for Cast Iron Pulleys

The cross-section of a cast iron pulley is shown in Fig.1.13. (**Refer PSG data book, page no. 7.56).**



D = Diameter of the pulley,

a = Width of the pulley,

b = Thickness of the arm,

d_1 = Diameter of the hub,

d_2= Diameter of the shaft, and

l = Length of the hub,

t = Thickness of the rim,

1. Dimension of pulley:

(i) Diameter of the pulley (D): Obtain the diameter of the pulley either from velocity ration consideration or centrifugal stress consideration. We know that the centrifugal stress induced in the rim of the pulley,

$$\sigma_c = \rho v^2$$

Where ρ = Density of the rim material.

= 7200 kg/m^3 for cast iron, and

v = Velocity of the rim = $\frac{\pi DN}{60}$ D being the diameter of pulley and N the speed of the pulley.

(ii)Width of the pulley (a): If the width of the belt is known, then select the width of the pulley referring to tables **[from data book, page no. 7.54]**

2. Dimension of arms :

(i) Number of arms (n):

Number of arms $\begin{cases} 4 \; for \; diameters \; upto \; 450mm \\ 6 \; for \; diameters \; over \; 450mm \end{cases}$ ....**[from data book, page no. 7.56]**

(ii)Cross-section of arms (b and b/2):

Major axis of elliptical section near the boss, **b = 2.94**$\sqrt[3]{\frac{aD}{4n}}$for single belt, and

$$= \mathbf{2.94}\sqrt[3]{\frac{aD}{2n}} \text{for double belt.}$$

Minor axis of elliptical section near the boss = $\frac{b}{2}$

(iii) Arms raper : The arms are tapered from hub to rim.

Taper = **4mm per 100mm**

(iv) Radius of the cross-section of arms : r = $\frac{3}{4}$**b**

3. Dimensions of hub:

(i) Diameter of hub(d_1):

Diameter of the hub(d_1) = (1.7 to 2.0)* Diameter of the shaft (d_2)

(ii)Length of the hub(l):

Minimum length of bore, l = $\frac{2}{3}$**a**

Where, **a = width of pulley.**

4. Crowning of pulley rim:

Selection of crown height (h): Knowing diameter (D) and width (a) of the pulley, select the crown height (h) referring to tables 1.7(a) and (b)

Table 1.7(a). Crown of flat pulleys (40 to 355 mm diameter) **(from data book, page no. 7.55)**

(Crown is unrelated to the width in this diameter range)

Table 1.7(b). Crown of flat pulleys (40 to 2000mm diameter) **(from data book,page no. 7.55)**

(Crown varies with the width in this diameter range)

DESIGN OF FLAT BELT

The two different design procedures used are:

(i) Using the manufacturer's data, and

(ii) Using the basic equations.

DESIGN OF FLAT BELT DRIVE BASED ON MANUFACTURER'S DATA

1. Selection of pulley diameters:

Select the pulley diameters and angle of contact (i.e., wrap angle). By using the given belt speed and assuming number of plies, minimum pulley diameter is chosen. Use Table to choose the diameter of the smaller pulley.**(from data book, page no. 7.52)**

2. Calculation of design power in KW:

Calculate the design KW by using the relationship given below

$$\textbf{Design KW} = \frac{\text{RatedKWxLoadcorrectionfactor}(K_s)}{\text{Arcofcontactfactor}(K_\alpha)\text{xSmallpulleyfactor}(K_d)}$$

i. **Load correction factor (k_s):** This factor is used to account for the nature of application and type of load. The value of K_s can be selected from table 1.9. (**From data book, page no. 7.53)**

ii. **Arc of contact factor(k_α):**

Arc of contact= 180 –$(\frac{D-d}{c})$*60 ……….[from data book pg.no 7.54]

Where D and d are Diameter of larger and smaller pulley resp.

C is the centre distance.

iii. **Small pulley factor (k_d):**

Table. Small pulley factor, K_d (from data book, page no. 7.62)

3. Selection of belting:

Select a belt referring from table below.

Table. Load rating of fabric belts per mm width per ply at 180~arc of contact at 10m/s belt speed **(from data book, page no.7.54)**

4. Load rating correction:

Correct the load rating to the actual speed of the belt by using the relation given below.

Load rating at V m/s = Load rating at 10 m/s x $\frac{V}{10}$ … [From data book, page no. 7.54]

5. Determination of belt width(b):

Determine the belt width by using the following relation:

$$\textbf{Width of belt} = \frac{\text{Designpower}}{\text{LoadratingxNo.ofplies}}$$

Knowing the smaller pulley diameter and velocity of the belt, and consulting table. The number of plies can be found.

The calculated belt width should be rounded off to the standard belt width by consulting Table. Standard widths of transmission belting **(from data book no. 7.52)**

6. Determination of pulley width(B):

Detemine the pulley width, by referring the tables1.6 (a and b)**[From data book, page no. 7.54]**

Table 1.6(a). Pulley width ... **[From data book, page no. 7.54]**

Table1.6(b). Recommended series of width of flat pulley,mm**[From data book, page no. 7.55]**

7. Calculation of belt length (L):

Calculation the length of the belt by using the equation given below.

For open belt drive: $\mathbf{L = 2C + (\frac{\pi}{2})(D+d) + \frac{(D-d)^2}{4C}}$ **[From data book, page no. 7.53]**

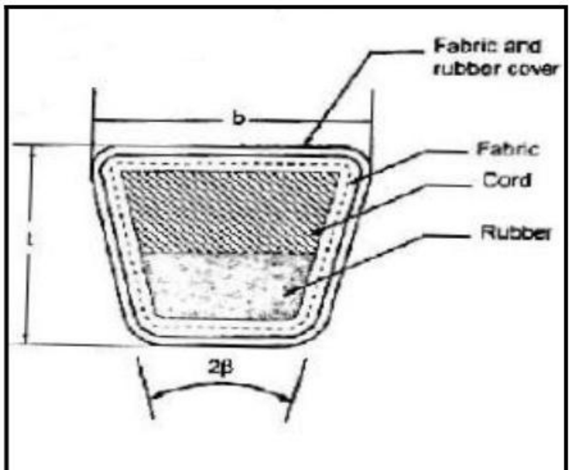
For crossed belt drive: $\mathbf{L = 2C + (\frac{\pi}{2})(D+d) + \frac{(D+d)^2}{4C}}$ **[From data book, page no. 7.53]**

$$\frac{T_1 - mv^2}{T_2 - mv^2} = e^{\frac{\mu\alpha}{\sin\beta}} = e^{\mu\alpha.\mathrm{cosec}\beta}$$

Where T_1, T2, m, v and α have usual meaning, and

2β is the V- groove angle (=180^0 for flat belt)

V -Belts and Pulleys



Cross-section of V-belt

Materials of V-belts

V -belts are made of cotton fabric and cords molded in rubber and covered with fabricand rubber, as shown in Fig

Specification of V-belts

V-belts are designated by its type and nominal inside length. For example, a C2845belt has a cross-section of type C and has a nominal inside length of2845 mm.

RATIO OF DRIVING TENSIONS FOR V-BELT

$$\frac{T_1}{T_2} = e^{\mu\alpha/\sin\beta} = e^{\mu\alpha\,.\mathrm{Cosec}\beta}$$

Where TI and T2 = Tensions in the tight and slack sides respectively,

2β = Angle of the groove, and

μ = Coefficient of friction between the belt and sides of the groove.

Note. **Number of V-belt =** $\frac{TotalPowerTransmitted}{PowerTransmitted}$

DESIGN OF SHEAVES (OR V-GROOVED PULLEYS)

1. Materials of V-grooved pulleys:

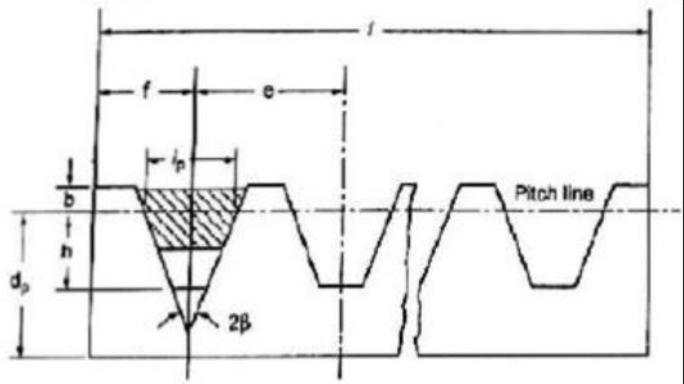
The commonly used sheave materials and their characteristics are summarized In Table 2.1.

Table 2.1

Material of sheaves	Characteristics and /or applications
1. cast iron	It is economical, stable and durable also it has excellent friction characteristics on V-belts.
2.Pressed steel	It is lighter and cheaper but it gives rise to excessive belt slip wear and noise.
3.Formed steel	Primarily used in automotive and agricultural purposes
4.Diecast aluminum	Used for special applications

2. Dimensions of sheaves:

The cross-section of a sheave (i.e., V-grooved pulley) for V-belt drives IS shown In Fig.2.2. **(Refer data book, page no. 7.70).**



Cross -Sectional of a Sheave

where

Ip= Pitch width,

I = Face width,

f = Edge of pulley to first groove centre,

e = centre to centre distance of grooves

d_p = pulley pitch diameter,

b = Minimum distance down to pitch line,

h = Minimum depth below the pitch line.

Table 2.2 The various dimensions of standard V-grooved pulley in mm**(from data book, page no. 7.70)**

Note Face width, I= (n – 1) e + 2f

The two different design procedures used are:

(i) Using the manufacturer's data, and

(ii) Using the basic equations.

DESIGN OF V-BELT DRIVE BASED ON MANUFACTURER'S DATA

The design of V-belt is primarily concerned with the selection of belt section, selection of pulley diameters, determination of number of belts and centre distance required for the given transmitted power.

DESIGN PROCEDURE:

1. **Selection of belt section:**

   Consulting Table 2.3, select the cross-section of a belt (i.e., type of belt) depending on thepower to be transmitted. **... [From data book, page no. 7.58]**

2. **Selection of pulley diameters (d and D):**

   Select small pulley diameter (d) from Table 2.3. Then using the speed ratio, calculate the large pulley diameter (D). These pulley diameters should be rounded off to a standard diameter by using Table 1.5. **... [From data book, page no. 7.58]**

3. **Determination of nominal pitch length:**

   Determine the length of the belt L (which is also known as nominal inside length) by using the formula,

   $L = 2C + (\frac{\pi}{2})(D + d) + \frac{(D-d)^2}{4C}$ **... [From data book, page no. 7.53]**

   For the calculated nominal inside length and belt section, consulting Table 2.5, select the next standard pitch length.

   Tile nominal pitch lengthis defined as the circumferential length of the belt at the pitch width (i. e., the width at the neutral axis of the belt). The value of the pitch width remains constant for each type of belt irrespective of the groove angle .

   For pitch length, add with inside length, 36 mm for A belt, 43 mm for B, 56 mm for C. 79 mm for 0 and 92 mm for E belt.

4. **Selection of various modification factors:**In order to calculate the design power the following modification factors have to bedetermined.

(i) Length correction factor (F_C):

Table.Nominal inside length, nominal pitch length and length correction/actor/or standard sizes 0/ JI-belts **(from data book, page no. 7.58, 7.59 and 7.60)** (The values for a few cases only given)

(ii) Correction factor for arc of contact (F_d):

- First determine the angle of contact (or arc of contact) of the smaller pulley.
- **Arc of contact = $180^\circ - (\frac{D-d}{C}) \times 60^\circ$... [From data book, page no 7.68]**
- For the calculated arc of contact, select the correction factor from Table 2.6.
- Arc of contact factor is taken into account because the power transmitted may be limited by slipping of the belt on the smaller pulley.

Table 2.6.Arc 0/ contact/actor, Fd...[From data book, page no. 7.68]

(The values/or a few cases are given below)

(iii) Service factor (F_a):

- Select the service factor (Fa) consulting Table 2.7.

- The service factor takes into account the severity of the load transmitted which depends upon the characteristics of the driving and driven units.

Table 2.7.Service factor for V-Belts, Fa…**[From data book, page no. 7.69]**

Note. The details of driving units and driven machines under different duties are available in the**data book, page no. 7.69.**

6. Calculation of maximum power capacity :

Calculate the maximum power capacity (in kW) of a V-belt using the formulas given in Table 2.8…..**[From data book, page no. 7.62]**

where kW = Maximum power in kW at 180^0 arc of contact for a belt of average length,

S = Belt speed, m/s,

d_e= Equivalent pitch diameter = dpx Fb,

d_p= Pitch diameter of the smaller pulley, mm, and

F_2= Small diameter factor to account for variation of arc of contact, from Table 2.9…..**[From data book, page no. 7.62]**

7. Determination of number of belts (n_b):

Determine number of belts the (n_b) from the relation,

$$n_b = \frac{P * F_a}{KW * F_c * F_d}$$ ….**[From data book, page no. 7.70]**

Where P = Drive power, in kW,

Fa= Service factor for V-belts,

KW = Rated power (i.e., rating of a single V-belt),

Fc = Length correction factor, and

F_d= Correction factor for arc of contact.

8. Calculation of actual centre distance:

Calculate the actual centre distance from the relation,

$$C_{actual} = A + \sqrt{A^2 - B}$$ **… [From data book, page no. 7.61]**

Where $A = \frac{L}{4} - \pi \left[\frac{D+d}{8}\right]$

$B = \frac{(D-d)^2}{8}$, **and**

L = Nominal pitch length of the belt from table 2.5 (refer step 4)