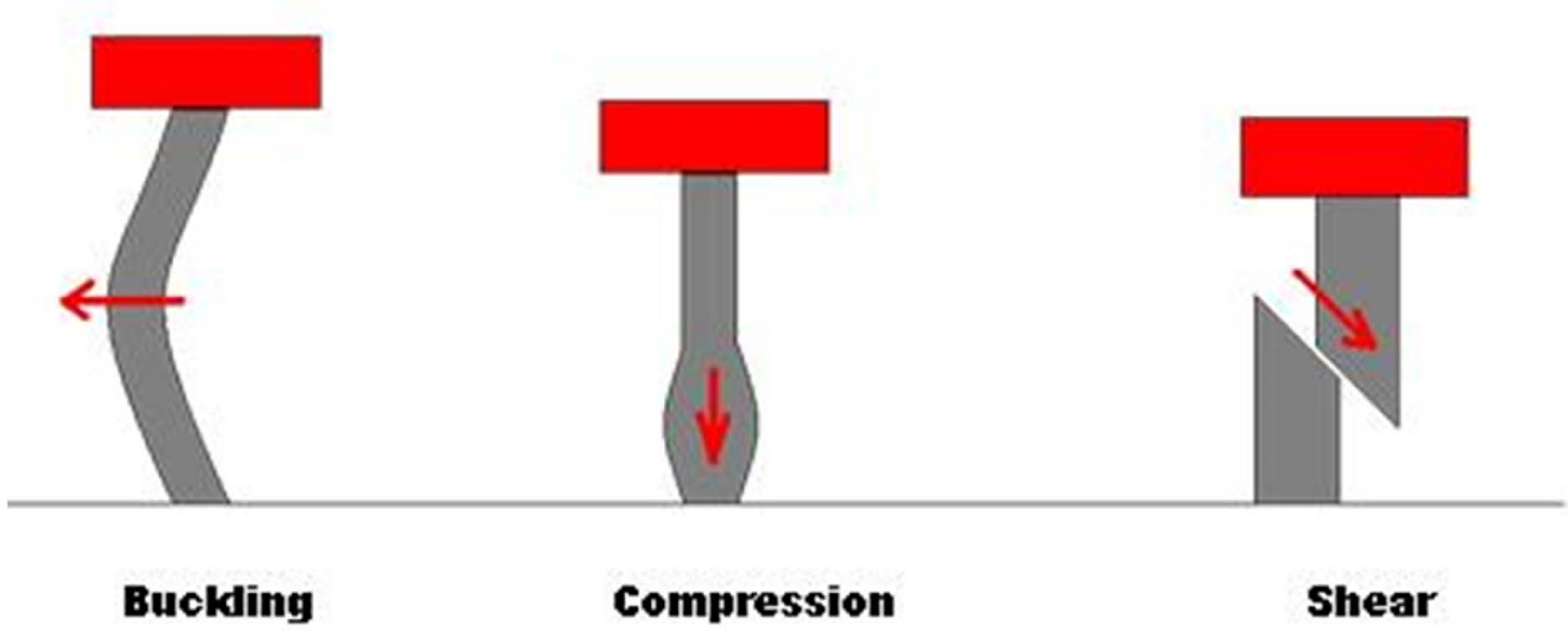
# Mechanical Engineering Design II

Fourteenth & Fifteenth Lectures

## Columns Design

# Columns Design

A column is a long, slender member that carries an axial compressive load and that fails due to buckling rather than due to failure of the material of the column.



# Failure due to buckling

# Analysis of Columns

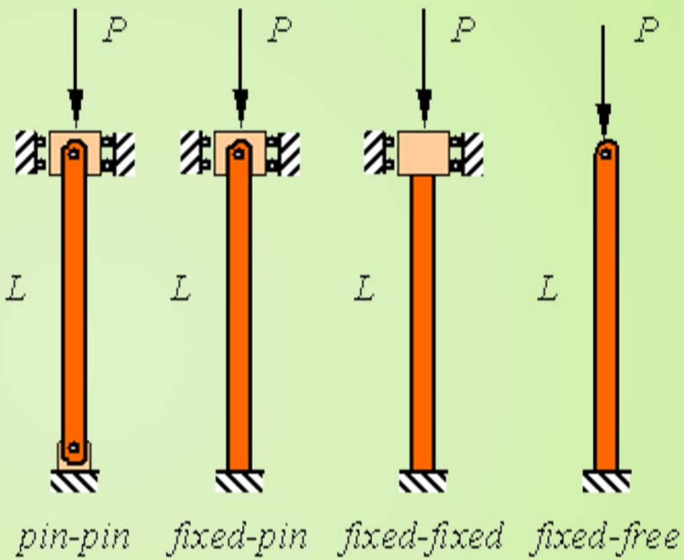
## Properties of C.S

1. Cross Sectional Area (A)
2. Moment of Inertia (I)
3. Radius of gyration $r = \sqrt{\frac{I}{A}}$

## Materials

1. Modulus of elasticity (E)
2. Yield strength ($S_y$)

## Connections




| | pin-pin | fixed-pin | fixed-fixed | fixed-free |
|---|---|---|---|---|
| Theoretical value | K=1 | K=0.7 | K=0.5 | K=2 |
| Practical value | K=1 | K=0.8 | K=0.65 | K=2.1 |

## Column type

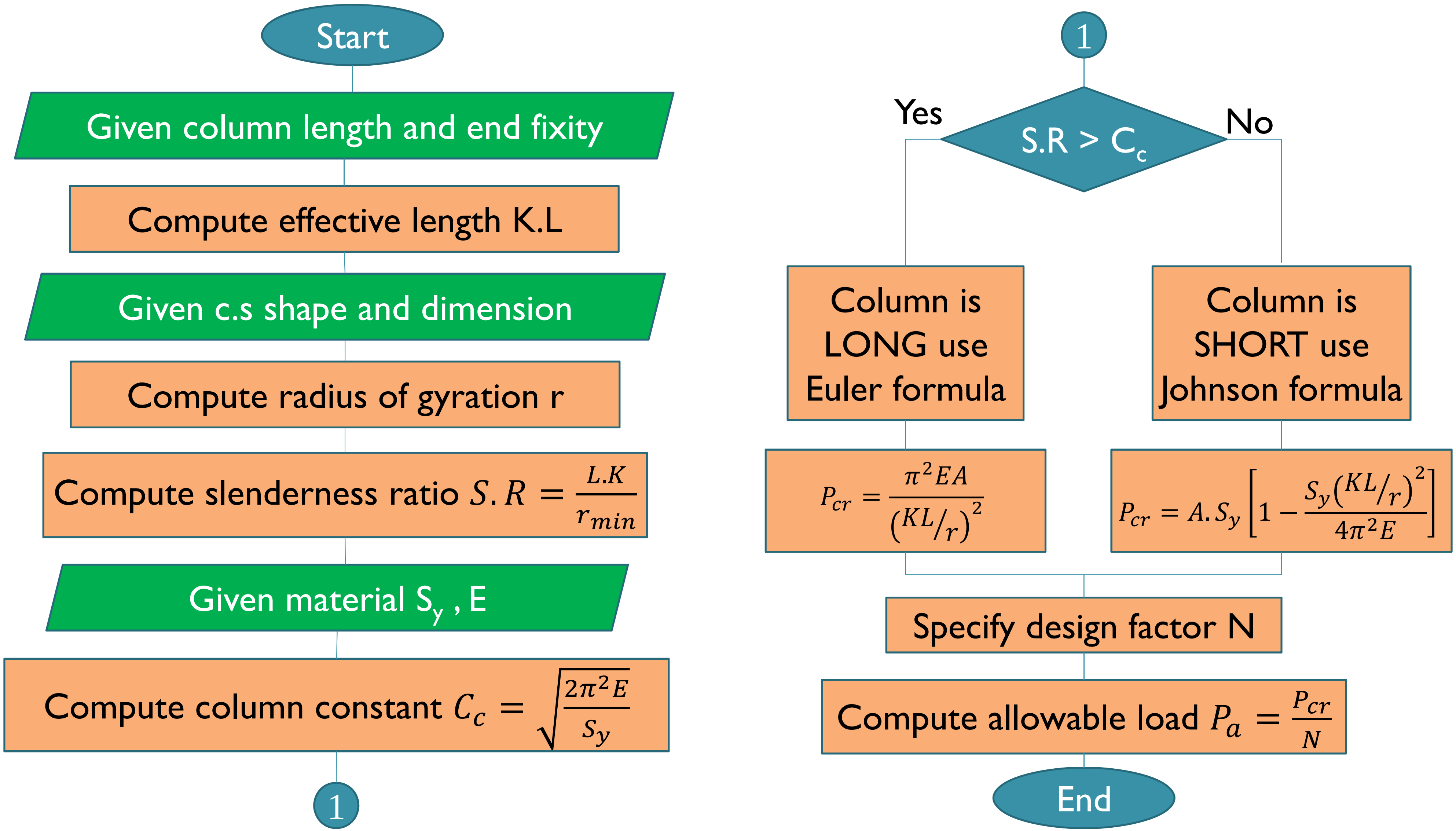
1. Effective length $L_e = K.L$
2. Slenderness ratio $S.R = \frac{L_e}{r_{min}} = \frac{L.K}{r_{min}}$
3. Column constant $C_c = \sqrt{\frac{2\pi^2 E}{S_y}}$

   (Transition slenderness ratio)

If S.R > $C_c$ then column is LONG

If S.R < $C_c$ then column is SHORT

# Flowchart for analyzing of straight centrally loaded column:



Example.1 : A column has a solid circular cross section, 31.75 mm in diameter; it has a length of 1.3716 m and is pinned at both ends. If it is made from AISI 1020 cold-drawn steel, what would be a safe column loading?

Solution: use the flowchart above.

Results :

Step.1: $K = 1 \qquad KL = 1 \times 1.3716 = 1.3716mm$

Step.2: for solid round section $r = \frac{D}{4} = \frac{31.75}{4} = 7.9375mm$

Step.3: compute slenderness ratio $\frac{KL}{r} = \frac{1.3716}{7.9375} = 173$

Step.4: compute the column constant $C_c = \sqrt{\frac{2\pi^2 E}{S_y}} = \sqrt{\frac{2\pi^2(207Gpa)}{350Mpa}} = 108$

For material AISI 1020 cold-drawn steel:
E=207 Gpa
$S_y$=350 Mpa

Step.5: because $\frac{KL}{r} > C_c$ column is long , Eulers formula should be used :

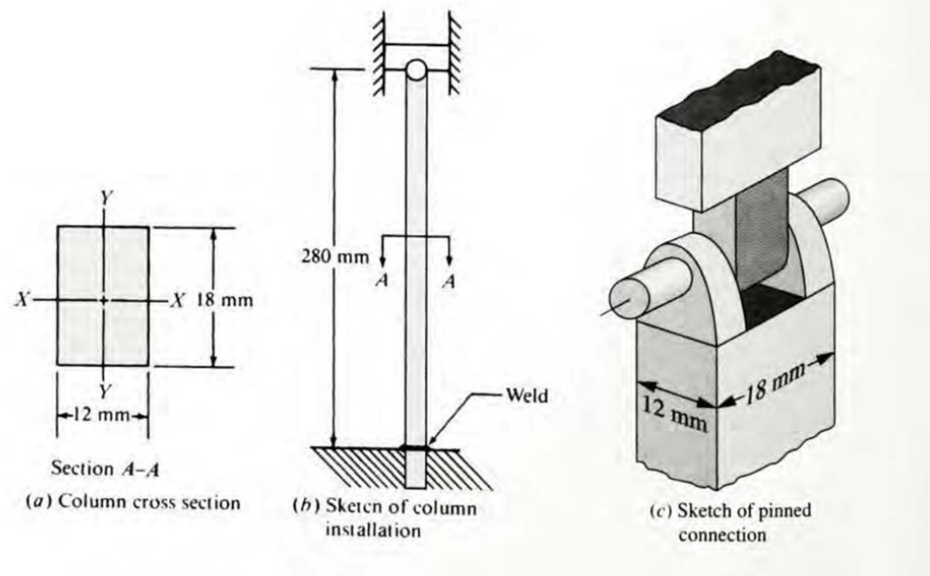
$$A = \frac{\pi D^2}{4} = \frac{\pi(31.75)^2}{4} = 793.596\ mm^2$$

The critical load is $P_{cr} = \frac{\pi^2 EA}{\left(KL/_r\right)^2} = \frac{\pi^2(207Gpa)(793.596\ mm^2)}{(173)^2} = 54265.6\ N$

At this load the column just begin to buckle, now let N=3

Allowable load $P_a = \frac{P_{cr}}{N} = \frac{54265.6}{3} = 18090.016\ N\ \ (the\ safe\ load\ on\ the\ column)$

Example .2: Determine the critical load for:
Mat. AISI 1040 hot rolled steel
lower end is welded and upper was pinned




For material AISI 1040 hot rolled steel:
E=207 Gpa
$S_y$=290 Mpa

Solution: use the flowchart above.

Results :

Step.1: $K = 0.8 \quad KL = 1 \times 1.3716 = 1.3716mm$

Step.2: for solid rectangular section $r = \frac{B}{\sqrt{12}}$

$$r = \frac{12}{\sqrt{12}} = 3.46\ mm$$

Step.3: compute slenderness ratio $\frac{KL}{r} = \frac{0.8 \times 280}{3.46} = 64.7$

Step.4: compute the column constant $C_c = \sqrt{\frac{2\pi^2 E}{S_y}} = \sqrt{\frac{2\pi^2 (207Gpa)}{290Mpa}} = 119$

Step.5: because $\frac{KL}{r} < C_c$ column is short, J.B.Johnson formula should be used :

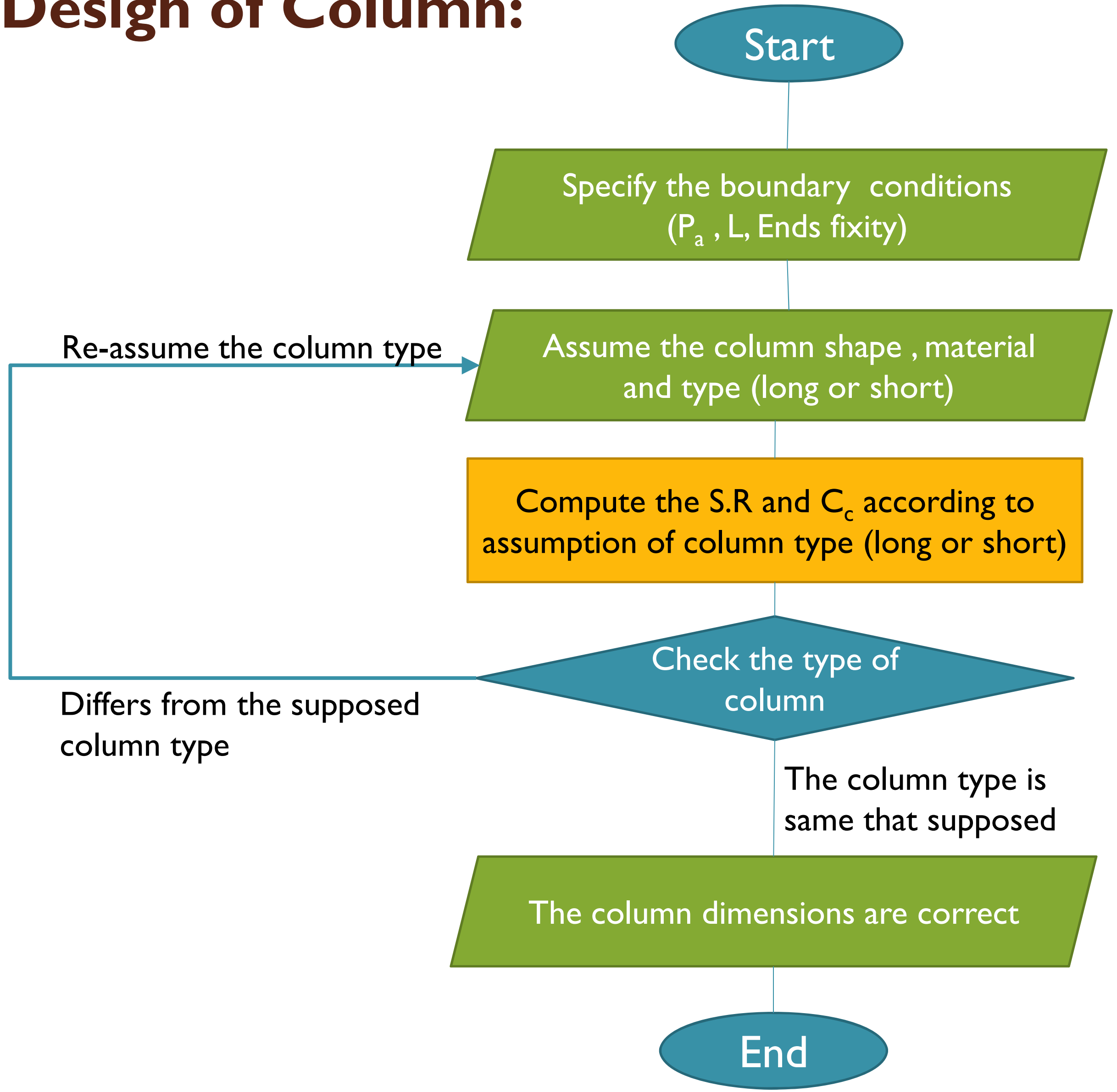
$A = 12 \times 18 = 216\ mm^2$

The critical load is $P_{cr} = A.S_y\left[1 - \frac{S_y(KL/r)^2}{4\pi^2 E}\right] = 53.3\ kN$

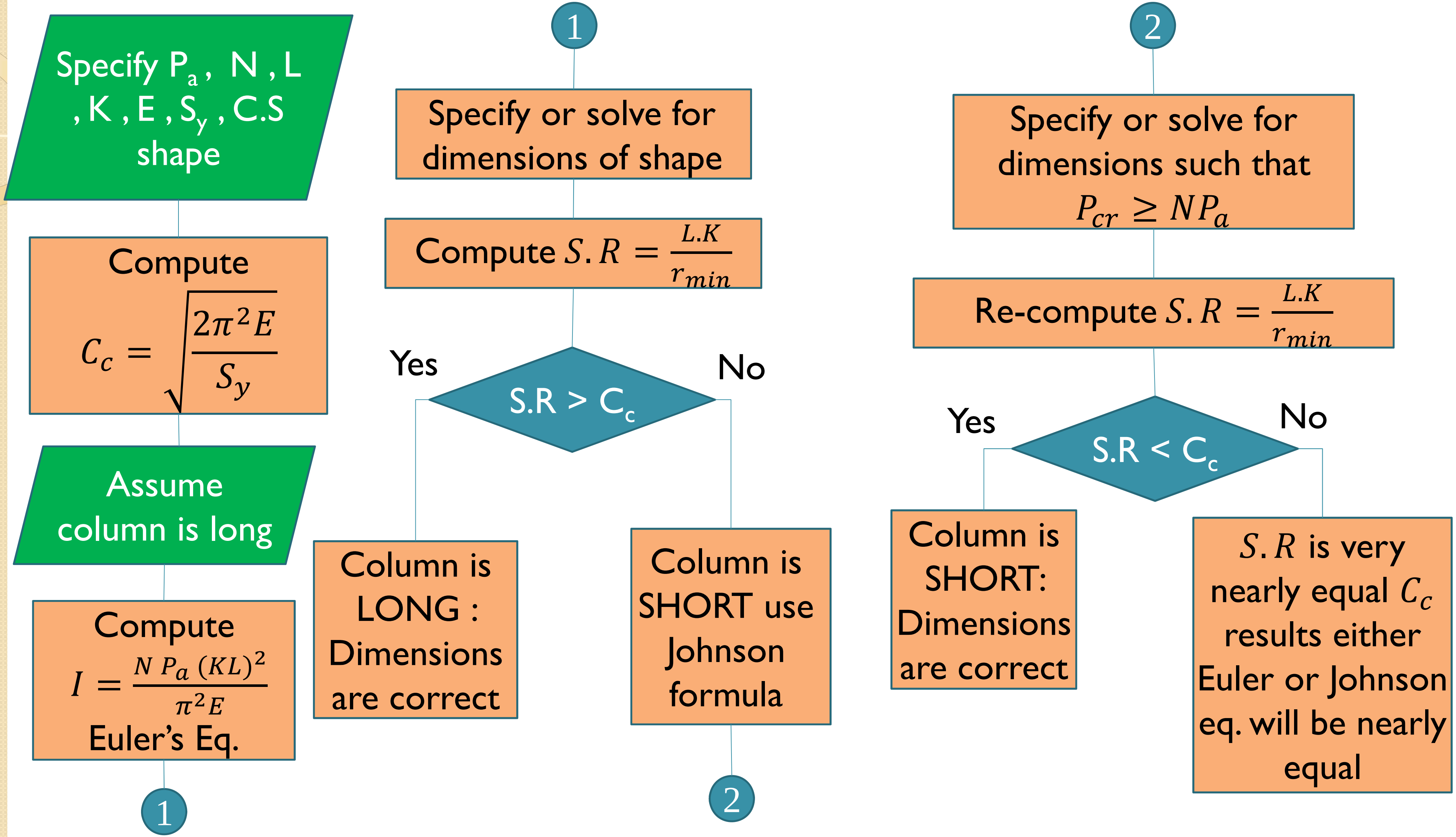
At this load the column just begin to buckle, now let N=3

Allowable load $P_a = \frac{P_{cr}}{N} = \frac{53.3}{3} = 17.8\ kN$ $(the\ safe\ load\ on\ the\ column)$

# The Design of Column:



# Flowchart for designing of straight centrally loaded column:



## Design assuming a long column (Euler's Eq.)

$$I = \frac{P_{cr}\,(KL)^2}{\pi^2 E} = \frac{N\,P_a\,(KL)^2}{\pi^2 E}$$

For solid circular section $I = \frac{\pi D^4}{64}$

$$\therefore D = \left[\frac{64\,N\,P_a (KL)^2}{\pi^2 E}\right]^{1/4}$$

## Design assuming a short column (Johnson's Eq.)

$$P_{cr} = A.S_y\left[1 - \frac{S_y\left({KL}/{r}\right)^2}{4\pi^2 E}\right]$$

For solid circular section $A = \frac{\pi D^2}{4}$ , $r = \frac{D}{4}$

$$\therefore D = \left[\frac{4NP_a}{\pi S_y} + \frac{4\,S_y (KL)^2}{\pi^2 E}\right]^{1/2}$$

Example.3 : specify a suitable dia. of solid, round cross section for a machine link if it carry 43590.4 N of axial compressive load. L=635mm , ends will be pinned, N=3 , Mat. AISI 1020 hot-rolled steel.

Analysis: * use the flowchart shown before.

* Assume the column is LONG.

Results: $D = \left[\frac{64\ N\ P_a (KL)^2}{\pi^2 E}\right]^{1/4} = \left[\frac{64 \times 3 \times 43590.4\ (635mm)^2}{\pi^2 (207 \times 10^9)}\right]^{1/4} = 26.924mm$

$\therefore r = \frac{D}{4} = 6.731mm\ ,\ S.R = \frac{L.K}{r_{min}} = \frac{635 \times 1}{6.731} = 94.3$ and $C_s$=138 $\therefore S.R < C_s$

Column is redesign as short column by using Johnson's eq.:

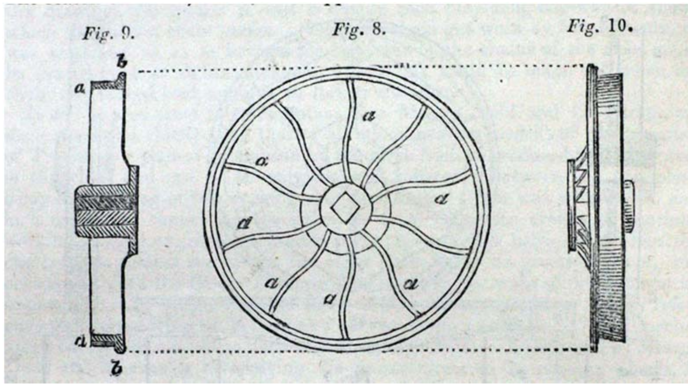
$$D = \left[\frac{4NP_a}{\pi S_y} + \frac{4\ S_y (KL)^2}{\pi^2 E}\right]^{1/2} = \left[\frac{4(3)(43590.4)}{\pi(206.85MPa)} + \frac{4\ (206.85MPa)(635mm)^2}{\pi^2 (207 \times 10^9)}\right]^{1/2} = 31.242mm$$

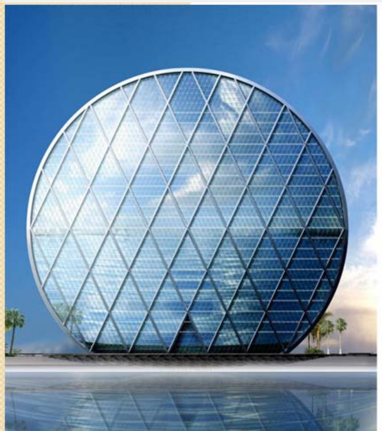
Checking the S.R again, we have : $S.R = \frac{L.K}{r_{min}} = \frac{635 \times 1}{31.242/4} = 81.3$

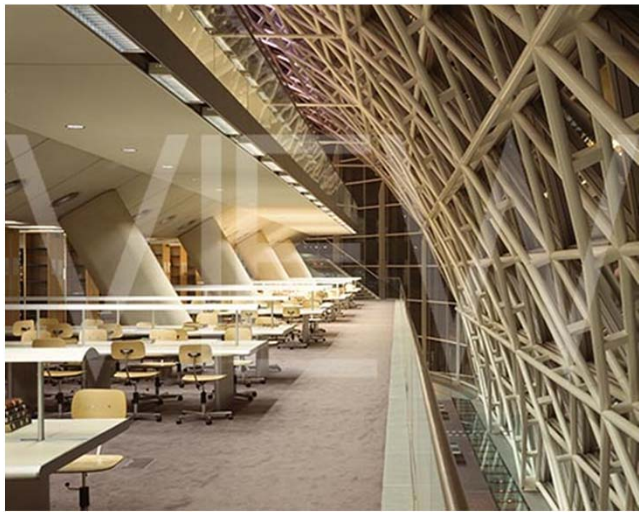
Comments: this is still lass than $C_s$ , then our analyzing is acceptable .

## Crooked Column:

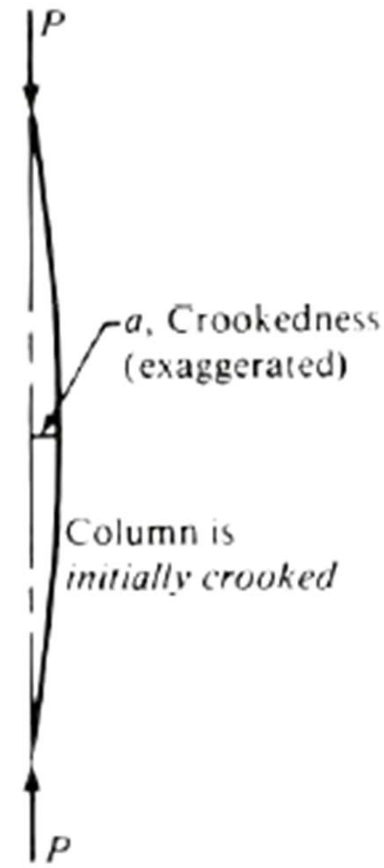
The columns shown in figures below are crooked, bending occurs in addition to the column action.





The Euler and Johnson formulas assume that the column is straight and that the load acts in line with the centroid of the cross section of the column. So the crooked column has special formula:




$$P_a{}^2 - \frac{1}{N}\left[S_y A + \left(1 + \frac{ac}{r^2}\right) P_{cr}\right] P_a + \frac{S_y . A . P_{cr}}{N^2} = 0$$

Where a = initial crookedness.
c = distance from the neutral axis of C.S about which bending occurs to its outer edge.

The equation can be written as :

$$P_a{}^2 + C_1 P_a + C_2 = 0 \quad and \quad P_a = 0.5\left[-C_1 - \sqrt{C_1{}^2 - 4C_2}\right]$$

The smaller of the two possible solutions is selected.

Example.4 : A column has both ends pinned and has a length of 812.8mm. It has a circular cross section with a diameter of 19.05mm and an initial crookedness of 3.175mm. The material is AISI 1040 hot-rolled steel. Compute the allowable load for a design factor of 3.

Analysis: use equation above to evaluate $C_1$ and $C_2$ then find $P_a$

Results: $S_y = 289590\ KPa$

$$A = \frac{\pi D^2}{4} = 285.1784mm^2$$

$$r = \frac{D}{4} = 4.7752mm \quad \text{and} \quad c = \frac{D}{2} = 9.525mm$$

$$\frac{KL}{r} = 171 \quad \text{and} \quad P_{cr} = \frac{\pi^2 EA}{\left({}^{KL}/_{r}\right)^2} = \frac{\pi^2 (207Gpa)(285.1784\ mm^2)}{(171)^2} = 19909.25N$$

$$C_1 = -\frac{1}{N}\left[S_y A + \left(1 + \frac{ac}{r^2}\right) P_{cr}\right] = -42969 \qquad C_2 = \frac{S_y.A.P_{cr}}{N^2} = 182.7 \times 10^6$$

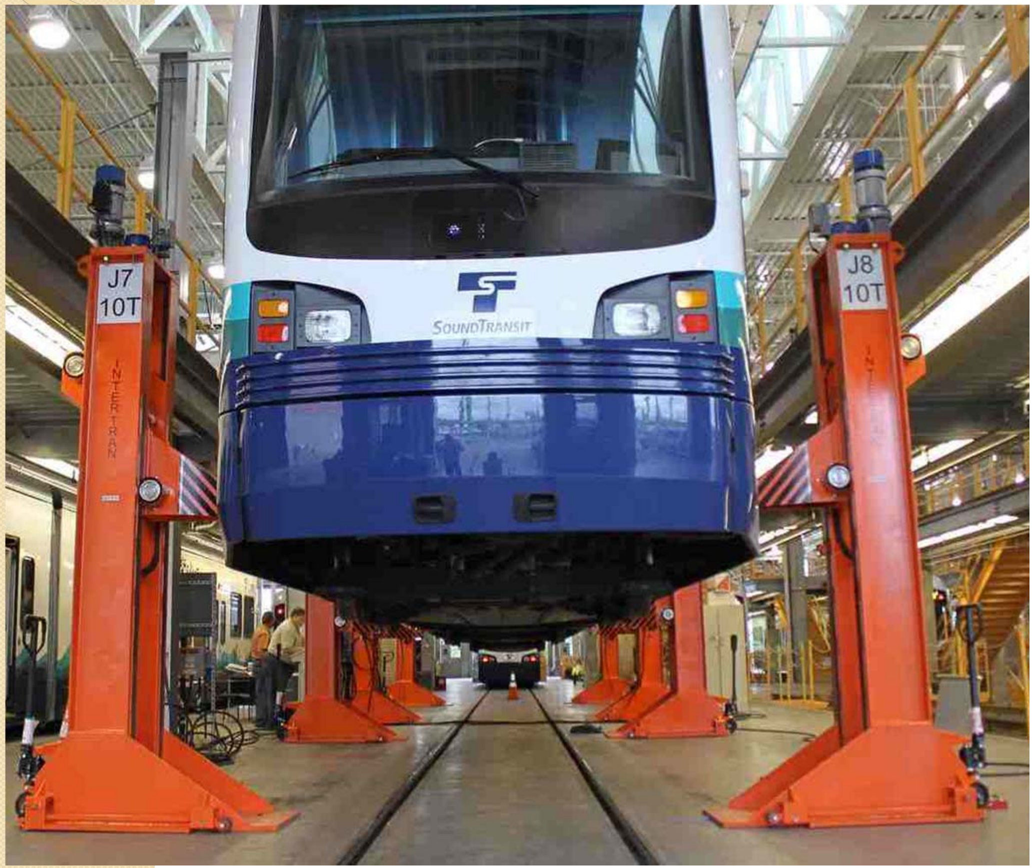
$$\therefore The\ eq.\ is: \quad {P_a}^2 - 42969P_a + 182.7 \times 10^6 = 0$$

$$\therefore P_a = 4784.7\ N \ \ is\ the\ allowable\ load.$$

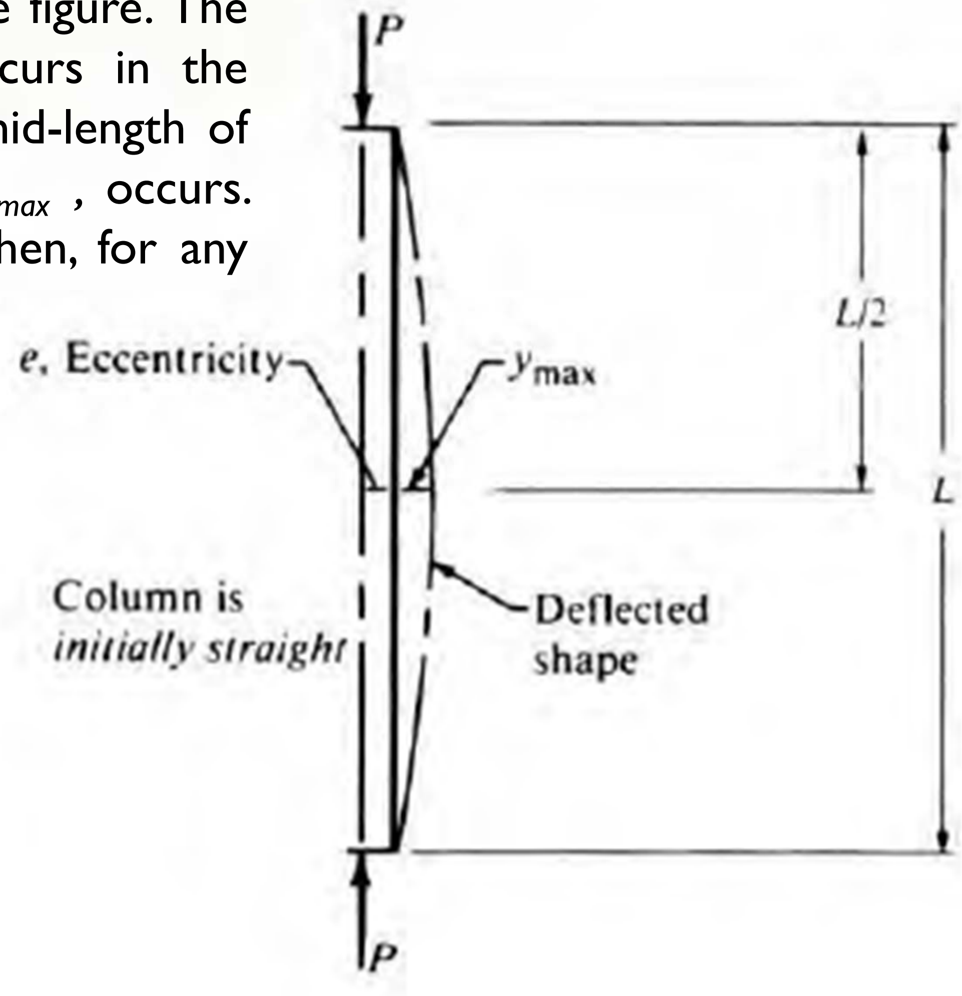
**Note: This solution process is most accurate for long column.**

# Eccentrically Loaded Columns:

An eccentric load is one that applied away from the centroidal axis of the c.s of column as shown in the following figures.




Such a load exerts bending in addition to the column action that results in the deflected shape shown in the figure. The maximum stress in the deflected column occurs in the outermost fibers of the cross section at the mid-length of the column where the maximum deflection, $y_{max}$ , occurs. Let's denote the stress at this point as $\sigma_{L/2}$Then, for any applied load, *P*,




$$\sigma_{L/2} = \frac{P}{A}\left[1 + \frac{ec}{r^2}.\sec\left(\frac{KL}{2r}\sqrt{\frac{P}{AE}}\right)\right]$$

When max. stress is equal yield stress $S_y$

$$\therefore\ S_y = \frac{P_y}{A}\left[1 + \frac{ec}{r^2}.\sec\left(\frac{KL}{2r}\sqrt{\frac{P_y}{AE}}\right)\right]$$

But $P_a = \frac{P_y}{N}$

$$\therefore Required\ \ S_y = \frac{NP_a}{A}\left[1 + \frac{ec}{r^2} . \sec\left(\frac{KL}{2r}\sqrt{\frac{NP_a}{AE}}\right)\right]$$

* The above eq. cannot be solved for either A or $P_a$ , therefore an iterative solution is required as will be demonstrated in the example.6 .

* Another critical factor may be amount of deflection of the axis of the column due to the eccentric load.

$$y_{max} = e\left[\sec\left(\frac{KL}{2r}\sqrt{\frac{P}{AE}}\right) - 1\right]$$

Example.5 : For the column of Example.4, compute the maximum stress and deflection if a load of 4781.6N is applied with an eccentricity of 19.05mm. The column is initially straight.

Given: e=19.05mm , D=19.05mm , L=812.8mm , both ends pinned, KL=812.8mm
r= 4.7752mm , c=D/2=9.525mm , Mat. AISI 1040 hot-rolled steel

Results: $\sigma_{L/2} = \frac{4781.6}{272.25}\left[1 + \frac{19.05\times 9.525}{(4.7752)^2}.\sec\left(\frac{812.8}{2(4.7752)}\sqrt{\frac{4781.6}{285.1784\times 206.85\times 10^9}}\right)\right]$

=202023.5 Kpa

$$y_{max} = 19.05\left[\sec\left(\frac{812.8}{2(4.7752)}\sqrt{\frac{4781.6}{285.1784\times 206.85\times 10^6}}\right) - 1\right]$$

=7.4022mm

Example.6 : The stress in the column found in Example.5 seems high for the AISI 1040 hot-rolled .steel. Redesign the column to achieve a design factor of at least 3.

Results: * $S_y$ for AISI 1040 HR to be 289590 Kpa

* If we choose to retain same material. The c.s of the column must increased to decrease stress.

* The objective is to find suitable value for A , c , and r such that $P_a$=4781.6N N=3 & $L_e$=8128mm & e=19.05mm and $S < S_y$ .

* The original design D=19.05mm, Let us try D=25.4mm then:

$$A = \frac{\pi D^2}{4} = 506.482mm^2 \, , r = \frac{D}{4} = 6.35mm \, , r^2 = 40.325mm^2 \; \& \; c = \frac{D}{2} = 12.7mm$$

$$S = \frac{3 \times 4781.6}{506.45}\left[1 + \frac{19.05 \times 12.7}{40.325} . \sec\left(\frac{812.8}{2(6.35)}\sqrt{\frac{3 \times 4781.6}{506.482 \times 207 \times 10^9}}\right)\right]$$

= 260217.3 Kpa < Required value for $S_y$ then we have satisfactory results

$$y_{max} = 19.05\left[\sec\left(\frac{812.8}{2(6.35)}\sqrt{\frac{4781.6}{506.482 \times 207 \times 10^9}}\right) - 1\right] = 1.9304 \, mm$$

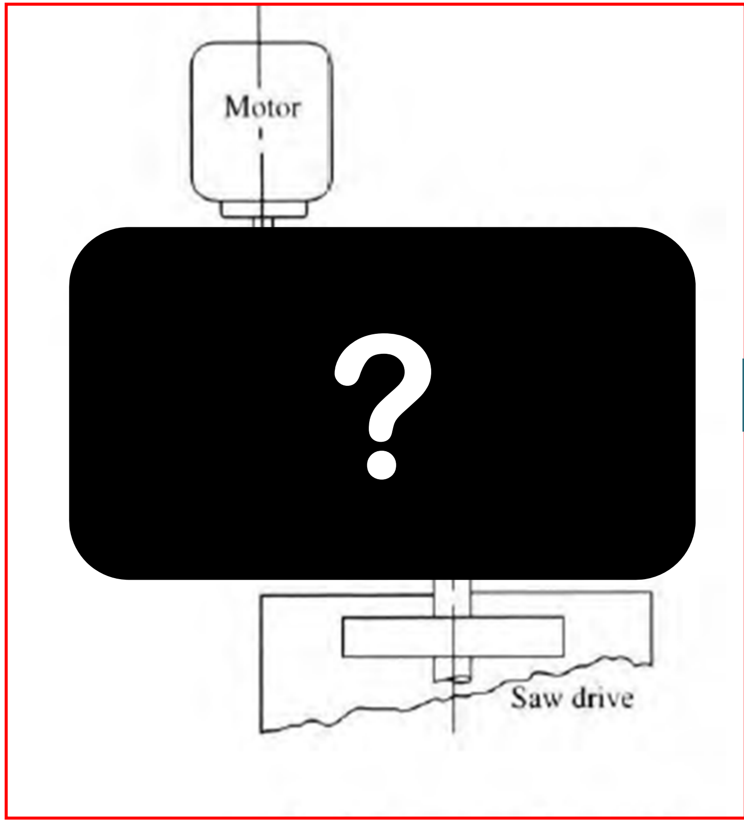
$\therefore$ *dia assumed is satisfactory*

# Mechanical Engineering Design II

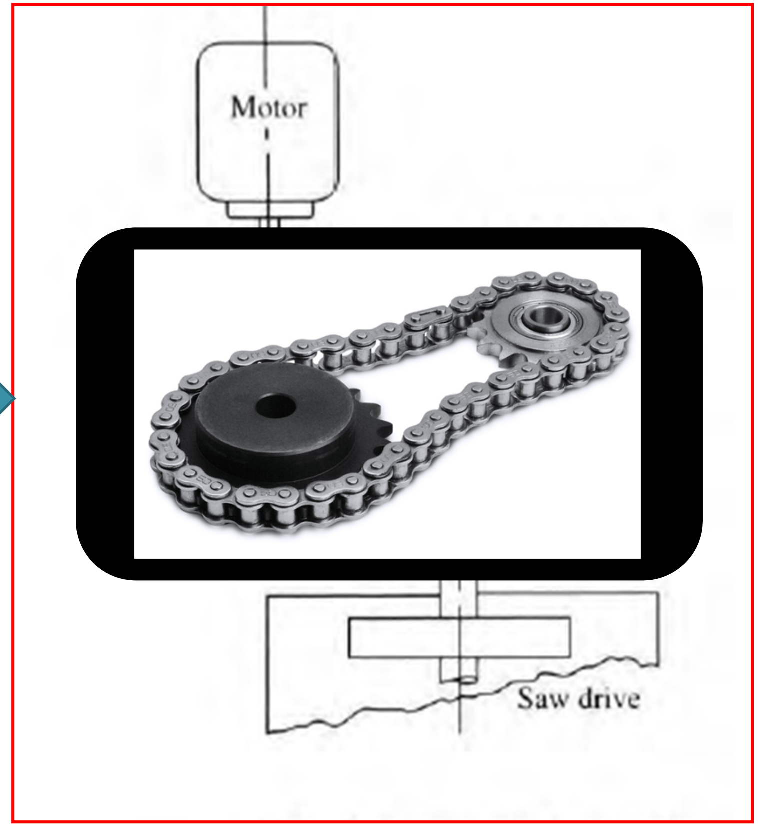
Sixteenth Lecture

# Design of Chain Drive

## Power Transmission Problem




## Proposed solution (Chain Drive)




**Transmitted Power is Known**

**Input and output range speed is Known**

# Flowchart for designing a chain drive:

**Transmitted Power , Input and Output range speed**

**Specify a service factor from Table 7-8 page.290 (306Pdf)**

**TABLE 7–8** Service factors for chain drives

| Load type | Type of driver: Hydraulic drive | Type of driver: Electric motor or turbine | Type of driver: Internal combustion engine with mechanical drive |
|---|---|---|---|
| Smooth (agitators; fans; light, uniformly loaded conveyors) | 1.0 | 1.0 | 1.2 |
| Moderate shock (machine tools, cranes, heavy conveyors, food mixers and grinders) | 1.2 | 1.3 | 1.4 |
| Heavy shock (punch presses, hammer mills, reciprocating conveyors, rolling mill drive) | 1.4 | 1.5 | 1.7 |

1

1

**COMPUTE THE DESIGN POWER**

**Design Power=service factor x transmitted power**

**COMPUTE THE DESIRED SPEED RATIO**

**Ratio=Input Speed / Middle Output Speed**

**Specify the standard chain size from Table 7-4 page.284 (300 Pdf)**

**TABLE 7–4** Roller chain sizes

| Chain number | Pitch (in) | Roller diameter | Roller width | Link plate thickness | Average tensile strength (lb) |
|---|---|---|---|---|---|
| 25 | 1/4 | None | – | 0.030 | 925 |
| 35 | 3/8 | None | – | 0.050 | 2100 |
| 41 | 1/2 | 0.306 | 0.250 | 0.050 | 2000 |
| 40 | 1/2 | 0.312 | 0.312 | 0.060 | 3700 |
| 50 | 5/8 | 0.400 | 0.375 | 0.080 | 6100 |
| 60 | 3/4 | 0.469 | 0.500 | 0.094 | 8500 |
| 80 | 1 | 0.626 | 0.625 | 0.125 | 14 500 |
| 100 | $1\frac{1}{4}$ | 0.750 | 0.750 | 0.156 | 24 000 |
| 120 | $1\frac{1}{2}$ | 0.875 | 1.000 | 0.187 | 34 000 |
| 140 | $1\frac{3}{4}$ | 1.000 | 1.000 | 0.219 | 46 000 |
| 160 | 2 | 1.125 | 1.250 | 0.250 | 58 000 |
| 180 | $2\frac{1}{4}$ | 1.406 | 1.406 | 0.281 | 80 000 |
| 200 | $2\frac{1}{2}$ | 1.562 | 1.500 | 0.312 | 95 000 |
| 240 | 3 | 1.875 | 1.875 | 0.375 | 130 000 |

2

# Select the chain pitch from Tables 7-5, 7-6, and 7-7 page(287-289) (Pdf 303-305)

**TABLE 7–5** Horsepower ratings—single strand roller chain no. 40

0.500 inch pitch — Rotational speed of small sprocket, rev/min

| No. of teeth | 10 | 25 | 50 | 100 | 180 | 200 | 300 | 500 | 700 | 900 | 1000 | 1200 | 1400 | 1600 | 1800 | 2100 | 2500 | 3000 | 3500 | 4000 | 5000 | 6000 | 7000 | 8000 | 9000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 0.06 | 0.14 | 0.27 | 0.52 | 0.91 | 1.00 | 1.48 | 2.42 | 3.34 | 4.25 | 4.70 | 5.60 | 6.49 | 5.57 | 4.66 | 3.70 | 2.85 | 2.17 | 1.72 | 1.41 | 1.01 | 0.77 | 0.61 | 0.50 | 0.00 |
| 12 | 0.06 | 0.15 | 0.29 | 0.56 | 0.99 | 1.09 | 1.61 | 2.64 | 3.64 | 4.64 | 5.13 | 6.11 | 7.09 | 6.34 | 5.31 | 4.22 | 3.25 | 2.47 | 1.96 | 1.60 | 1.15 | 0.87 | 0.69 | 0.57 | 0.00 |
| 13 | 0.07 | 0.16 | 0.31 | 0.61 | 1.07 | 1.19 | 1.75 | 2.86 | 3.95 | 5.02 | 5.56 | 6.62 | 7.68 | 7.15 | 5.99 | 4.76 | 3.66 | 2.79 | 2.21 | 1.81 | 1.29 | 0.98 | 0.78 | 0.00 | |
| 14 | 0.07 | 0.17 | 0.34 | 0.66 | 1.15 | 1.28 | 1.88 | 3.08 | 4.25 | 5.41 | 5.98 | 7.13 | 8.27 | 7.99 | 6.70 | 5.31 | 4.09 | 3.11 | 2.47 | 2.02 | 1.45 | 1.10 | 0.87 | 0.00 | |
| 15 | 0.08 | 0.19 | 0.36 | 0.70 | 1.24 | 1.37 | 2.02 | 3.30 | 4.55 | 5.80 | 6.41 | 7.64 | 8.86 | 8.86 | 7.43 | 5.89 | 4.54 | 3.45 | 2.74 | 2.24 | 1.60 | 1.22 | 0.97 | 0.00 | |
| 16 | 0.08 | 0.20 | 0.39 | 0.75 | 1.32 | 1.46 | 2.15 | 3.52 | 4.86 | 6.18 | 6.84 | 8.15 | 9.45 | 9.76 | 8.18 | 6.49 | 5.00 | 3.80 | 3.02 | 2.47 | 1.77 | 1.34 | 0.00 | | |
| 17 | 0.09 | 0.21 | 0.41 | 0.80 | 1.40 | 1.55 | 2.29 | 3.74 | 5.16 | 6.57 | 7.27 | 8.66 | 10.04 | 10.69 | 8.96 | 7.11 | 5.48 | 4.17 | 3.31 | 2.71 | 1.94 | 1.47 | 0.00 | | |
| 18 | 0.09 | 0.22 | 0.43 | 0.84 | 1.48 | 1.64 | 2.42 | 3.96 | 5.46 | 6.95 | 7.69 | 9.17 | 10.63 | 11.65 | 9.76 | 7.75 | 5.97 | 4.54 | 3.60 | 2.95 | 2.11 | 1.60 | 0.00 | | |
| 19 | 0.10 | 0.24 | 0.46 | 0.89 | 1.57 | 1.73 | 2.56 | 4.18 | 5.77 | 7.34 | 8.12 | 9.66 | 11.22 | 12.64 | 10.59 | 8.40 | 6.47 | 4.92 | 3.91 | 3.20 | 2.29 | 0.09 | 0.00 | | |
| 20 | 0.10 | 0.25 | 0.48 | 0.94 | 1.65 | 1.82 | 2.69 | 4.39 | 6.07 | 7.73 | 8.55 | 10.18 | 11.81 | 13.42 | 11.44 | 9.07 | 6.99 | 5.31 | 4.22 | 3.45 | 2.47 | 0.00 | | | |
| 21 | 0.11 | 0.26 | 0.51 | 0.98 | 1.73 | 1.91 | 2.83 | 4.61 | 6.37 | 8.11 | 8.98 | 10.69 | 12.40 | 14.10 | 12.30 | 9.76 | 7.52 | 5.72 | 4.54 | 3.71 | 2.65 | 0.00 | | | |
| 22 | 0.11 | 0.27 | 0.53 | 1.03 | 1.81 | 2.01 | 2.96 | 4.83 | 6.68 | 8.50 | 9.40 | 11.20 | 12.99 | 14.77 | 13.19 | 10.47 | 8.06 | 6.13 | 4.87 | 3.98 | 2.85 | 0.00 | | | |
| 23 | 0.12 | 0.28 | 0.56 | 1.08 | 1.90 | 2.10 | 3.10 | 5.05 | 6.98 | 8.89 | 9.83 | 11.71 | 13.58 | 15.44 | 14.10 | 11.19 | 8.62 | 6.55 | 5.20 | 4.26 | 3.05 | 0.00 | | | |
| 24 | 0.12 | 0.30 | 0.58 | 1.12 | 1.98 | 2.19 | 3.23 | 5.27 | 7.28 | 9.27 | 10.26 | 12.22 | 14.17 | 16.11 | 15.03 | 11.93 | 9.18 | 6.99 | 5.54 | 4.54 | 0.87 | 0.00 | | | |
| 25 | 0.13 | 0.31 | 0.60 | 1.17 | 2.06 | 2.28 | 3.36 | 5.49 | 7.59 | 9.66 | 10.69 | 12.73 | 14.76 | 16.78 | 15.98 | 12.68 | 9.76 | 7.43 | 5.89 | 4.82 | 0.00 | | | | |
| 26 | 0.13 | 0.32 | 0.63 | 1.22 | 2.14 | 2.37 | 3.50 | 5.71 | 7.89 | 10.04 | 11.11 | 13.24 | 15.35 | 17.45 | 16.95 | 13.45 | 10.36 | 7.88 | 6.25 | 5.12 | 0.00 | | | | |
| 28 | 0.14 | 0.35 | 0.67 | 1.31 | 2.31 | 2.55 | 3.77 | 6.15 | 8.50 | 10.82 | 11.97 | 14.26 | 16.53 | 18.79 | 18.94 | 15.03 | 11.57 | 8.80 | 6.99 | 5.72 | 0.00 | | | | |
| 30 | 0.15 | 0.37 | 0.72 | 1.41 | 2.47 | 2.74 | 4.04 | 6.59 | 9.11 | 11.59 | 12.82 | 15.28 | 17.71 | 20.14 | 21.01 | 16.67 | 12.84 | 9.76 | 7.75 | 6.34 | 0.00 | | | | |
| 32 | 0.16 | 0.40 | 0.77 | 1.50 | 2.64 | 2.92 | 4.31 | 7.03 | 9.71 | 12.38 | 13.68 | 16.30 | 18.89 | 21.48 | 23.14 | 18.37 | 14.14 | 10.76 | 8.54 | 1.41 | | | | | |
| 35 | 0.18 | 0.43 | 0.84 | 1.64 | 2.88 | 3.19 | 4.71 | 7.69 | 10.62 | 13.52 | 14.96 | 17.82 | 20.67 | 23.49 | 26.30 | 21.01 | 16.17 | 12.30 | 9.76 | 0.00 | | | | | |
| 40 | 0.21 | 0.50 | 0.96 | 1.87 | 3.30 | 3.65 | 5.38 | 8.79 | 12.14 | 15.45 | 17.10 | 20.37 | 23.62 | 26.85 | 30.06 | 25.67 | 19.76 | 15.03 | 0.00 | | | | | | |
| 45 | 0.23 | 0.56 | 1.08 | 2.11 | 3.71 | 4.10 | 6.08 | 9.89 | 13.66 | 17.39 | 19.24 | 22.92 | 26.57 | 30.20 | 33.82 | 30.63 | 23.58 | 5.53 | 0.00 | | | | | | |

Type A Type B Type C

3

**TABLE 7–6** Horsepower ratings—single strand roller chain no. 60

| No. of teeth | 0.750 inch pitch | | | | Rotational speed of small sprocket, rev/min | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 25 | 50 | 100 | 120 | 200 | 300 | 400 | 500 | 600 | 800 | 1000 | 1200 | 1400 | 1600 | 1800 | 2000 | 2500 | 3000 | 3500 | 4000 | 4500 | 5000 | 5500 | 6000 |
| 11 | 0.19 | 0.46 | 0.89 | 1.72 | 2.05 | 3.35 | 4.95 | 6.52 | 8.08 | 9.63 | 12.69 | 15.58 | 11.85 | 9.41 | 7.70 | 6.45 | 5.51 | 3.94 | 3.00 | 2.38 | 1.95 | 1.63 | 1.39 | 1.21 | 0.00 |
| 12 | 0.21 | 0.50 | 0.97 | 1.88 | 2.24 | 3.66 | 5.40 | 7.12 | 8.82 | 10.51 | 13.85 | 17.15 | 13.51 | 10.72 | 8.77 | 7.35 | 6.28 | 4.49 | 3.42 | 2.71 | 2.22 | 1.86 | 1.59 | 1.38 | 0.00 |
| 13 | 0.22 | 0.54 | 1.05 | 2.04 | 2.43 | 3.96 | 5.85 | 7.71 | 9.55 | 11.38 | 15.00 | 18.58 | 15.23 | 12.08 | 9.89 | 8.29 | 7.08 | 5.06 | 3.85 | 3.06 | 2.50 | 2.10 | 1.79 | 0.00 | |
| 14 | 0.24 | 0.58 | 1.13 | 2.19 | 2.61 | 4.27 | 6.30 | 8.30 | 10.29 | 12.26 | 16.15 | 20.01 | 17.02 | 13.51 | 11.05 | 9.26 | 7.91 | 5.66 | 4.31 | 3.42 | 2.80 | 2.34 | 0.41 | 0.00 | |
| 15 | 0.26 | 0.62 | 1.21 | 2.35 | 2.80 | 4.57 | 6.75 | 8.90 | 11.02 | 13.13 | 17.31 | 21.44 | 18.87 | 14.98 | 12.26 | 10.27 | 8.77 | 6.28 | 4.77 | 3.79 | 3.10 | 2.60 | 0.00 | | |
| 16 | 0.27 | 0.66 | 1.29 | 2.51 | 2.99 | 4.88 | 7.20 | 9.49 | 11.76 | 14.01 | 18.46 | 22.87 | 20.79 | 16.50 | 13.51 | 11.32 | 9.66 | 6.91 | 5.26 | 4.17 | 3.42 | 1.78 | 0.00 | | |
| 17 | 0.29 | 0.70 | 1.37 | 2.66 | 3.17 | 5.18 | 7.65 | 10.08 | 12.49 | 14.88 | 19.62 | 24.30 | 22.77 | 18.07 | 14.79 | 12.40 | 10.58 | 7.57 | 5.76 | 4.57 | 3.74 | 0.00 | | | |
| 18 | 0.31 | 0.75 | 1.45 | 2.82 | 3.36 | 5.49 | 8.10 | 10.68 | 13.23 | 15.76 | 20.77 | 25.73 | 24.81 | 19.69 | 16.11 | 13.51 | 11.53 | 8.25 | 6.28 | 4.98 | 4.08 | 0.00 | | | |
| 19 | 0.33 | 0.79 | 1.53 | 2.98 | 3.55 | 5.79 | 8.55 | 11.27 | 13.96 | 16.63 | 21.92 | 27.16 | 26.91 | 21.35 | 17.48 | 14.65 | 12.50 | 8.95 | 6.81 | 5.40 | 0.20 | 0.00 | | | |
| 20 | 0.34 | 0.83 | 1.61 | 3.13 | 3.73 | 6.10 | 9.00 | 11.86 | 14.70 | 17.51 | 23.08 | 28.59 | 29.06 | 23.06 | 18.87 | 15.82 | 13.51 | 9.66 | 7.35 | 5.83 | 0.00 | | | | |
| 21 | 0.36 | 0.87 | 1.69 | 3.29 | 3.92 | 6.40 | 9.45 | 12.46 | 15.43 | 18.38 | 24.23 | 30.02 | 31.26 | 24.81 | 20.31 | 17.02 | 14.53 | 10.40 | 7.91 | 6.28 | 0.00 | | | | |
| 22 | 0.38 | 0.91 | 1.77 | 3.45 | 4.11 | 6.71 | 9.90 | 13.05 | 16.17 | 19.26 | 25.39 | 31.45 | 33.52 | 26.60 | 21.77 | 18.25 | 15.58 | 11.15 | 8.48 | 0.00 | | | | | |
| 23 | 0.40 | 0.95 | 1.85 | 3.61 | 4.29 | 7.01 | 10.35 | 13.64 | 16.90 | 20.13 | 26.54 | 32.88 | 35.84 | 28.44 | 23.28 | 19.51 | 16.66 | 11.92 | 9.07 | 0.00 | | | | | |
| 24 | 0.41 | 0.99 | 1.93 | 3.76 | 4.48 | 7.32 | 10.80 | 14.24 | 17.64 | 21.01 | 27.69 | 34.31 | 38.20 | 30.31 | 24.81 | 20.79 | 17.75 | 12.70 | 9.66 | 0.00 | | | | | |
| 25 | 0.43 | 1.04 | 2.01 | 3.92 | 4.67 | 7.62 | 11.25 | 14.83 | 18.37 | 21.89 | 28.85 | 35.74 | 40.61 | 32.23 | 26.38 | 22.11 | 18.87 | 13.51 | 10.27 | 0.00 | | | | | |
| 26 | 0.45 | 1.08 | 2.09 | 4.08 | 4.85 | 7.93 | 11.70 | 15.42 | 19.11 | 22.76 | 30.00 | 37.17 | 43.07 | 34.18 | 27.98 | 23.44 | 20.02 | 14.32 | 10.90 | 0.00 | | | | | |
| 28 | 0.48 | 1.16 | 2.26 | 4.39 | 5.23 | 8.54 | 12.60 | 16.61 | 20.58 | 24.51 | 32.31 | 40.03 | 47.68 | 38.20 | 31.26 | 26.20 | 22.37 | 16.01 | 0.00 | | | | | | |
| 30 | 0.52 | 1.24 | 2.42 | 4.70 | 5.60 | 9.15 | 13.50 | 17.79 | 22.05 | 26.26 | 34.62 | 42.89 | 51.09 | 42.36 | 34.67 | 29.06 | 24.81 | 17.75 | 0.00 | | | | | | |
| 32 | 0.55 | 1.33 | 2.58 | 5.02 | 5.98 | 9.76 | 14.40 | 18.98 | 23.52 | 28.01 | 36.92 | 45.75 | 54.50 | 46.67 | 38.20 | 32.01 | 27.33 | 19.56 | 0.00 | | | | | | |
| 35 | 0.60 | 1.45 | 2.82 | 5.49 | 6.54 | 10.67 | 15.75 | 20.76 | 25.72 | 30.64 | 40.39 | 50.03 | 59.60 | 53.38 | 43.69 | 36.62 | 31.26 | 1.35 | 0.00 | | | | | | |
| 40 | 0.69 | 1.66 | 3.22 | 6.27 | 7.47 | 12.20 | 18.00 | 23.73 | 29.39 | 35.02 | 46.16 | 57.18 | 68.12 | 65.22 | 53.38 | 44.74 | 38.20 | 0.00 | | | | | | | |
| 45 | 0.77 | 1.86 | 3.63 | 7.05 | 8.40 | 13.72 | 20.25 | 26.69 | 33.07 | 38.39 | 51.92 | 64.33 | 76.63 | 77.83 | 63.70 | 53.38 | 12.45 | 0.00 | | | | | | | |

Type A — Type B — Type C

4

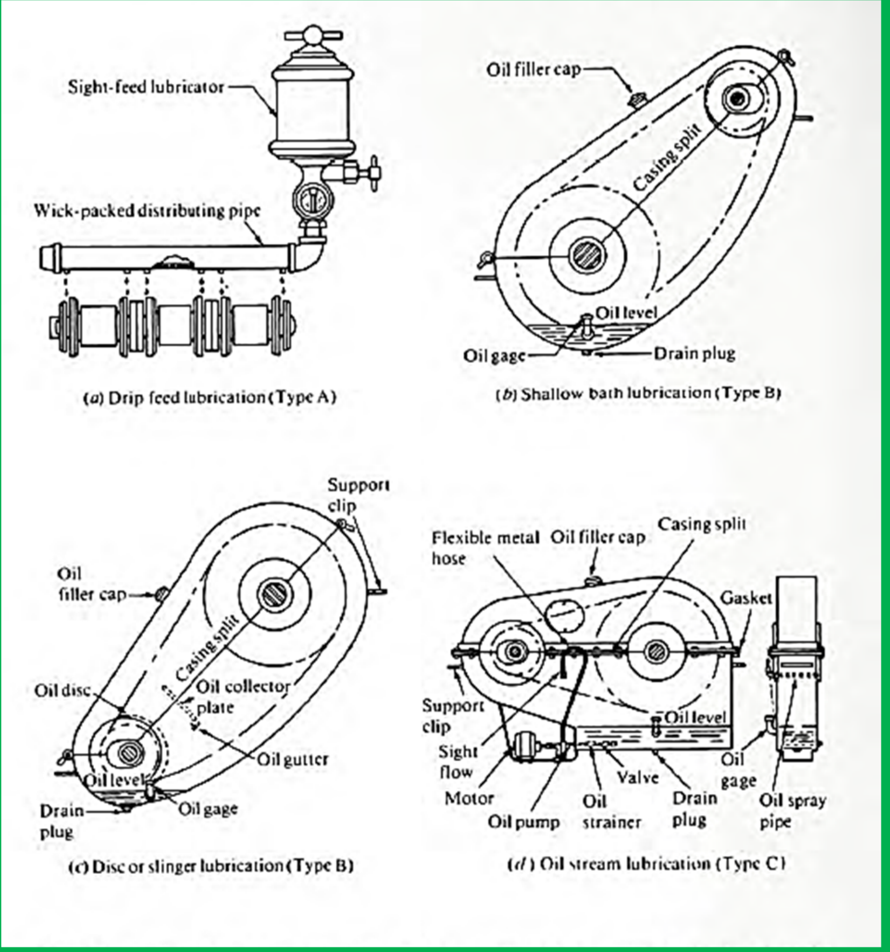
**TABLE 7–7** Horsepower ratings—single strand roller chain no. 80

| No. of teeth | 1.000 inch pitch | | | | | | | | | Rotational speed of small sprocket, rev/min | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 25 | 50 | 75 | 88 | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 | 1200 | 1400 | 1600 | 1800 | 2000 | 2500 | 3000 | 3500 | 4000 | 4500 |
| 11 | 0.44 | 1.06 | 2.07 | 3.05 | 3.56 | 4.03 | 7.83 | 11.56 | 15.23 | 18.87 | 22.48 | 26.07 | 27.41 | 22.97 | 19.61 | 14.92 | 11.84 | 9.69 | 8.12 | 6.83 | 4.96 | 3.77 | 3.00 | 2.45 | 0.00 |
| 12 | 0.48 | 1.16 | 2.26 | 3.33 | 3.88 | 4.39 | 8.54 | 12.61 | 16.82 | 20.59 | 24.53 | 28.44 | 31.23 | 26.17 | 22.35 | 17.00 | 13.49 | 11.04 | 9.25 | 7.90 | 5.65 | 4.30 | 3.41 | 2.79 | 0.00 |
| 13 | 0.52 | 1.26 | 2.45 | 3.61 | 4.21 | 4.76 | 9.26 | 13.66 | 18.00 | 22.31 | 26.57 | 30.81 | 35.02 | 29.51 | 25.20 | 19.17 | 15.21 | 12.45 | 10.43 | 8.91 | 6.37 | 4.85 | 3.85 | 3.15 | |
| 14 | 0.56 | 1.35 | 2.63 | 3.89 | 4.53 | 5.12 | 9.97 | 14.71 | 19.39 | 24.02 | 28.62 | 33.18 | 37.72 | 32.98 | 28.16 | 21.42 | 17.00 | 13.91 | 11.66 | 9.96 | 7.12 | 5.42 | 4.30 | 3.52 | |
| 15 | 0.60 | 1.45 | 2.82 | 4.16 | 4.86 | 5.49 | 10.68 | 15.76 | 20.77 | 25.74 | 30.66 | 35.55 | 40.41 | 36.58 | 31.23 | 23.76 | 18.85 | 15.43 | 12.93 | 11.04 | 7.90 | 6.01 | 4.77 | 0.00 | |
| 16 | 0.64 | 1.55 | 3.01 | 4.44 | 5.18 | 5.86 | 11.39 | 16.81 | 22.16 | 27.45 | 32.70 | 37.92 | 43.11 | 40.30 | 34.41 | 26.17 | 20.77 | 17.00 | 14.25 | 12.16 | 8.70 | 6.62 | 5.25 | 0.00 | |
| 17 | 0.68 | 1.64 | 3.20 | 4.72 | 5.50 | 6.22 | 12.10 | 17.86 | 23.54 | 29.17 | 34.75 | 40.29 | 45.80 | 44.13 | 37.68 | 28.66 | 22.75 | 18.62 | 15.60 | 13.32 | 9.53 | 7.25 | 0.00 | | |
| 18 | 0.72 | 1.74 | 3.39 | 5.00 | 5.83 | 6.59 | 12.81 | 18.91 | 24.93 | 30.88 | 36.79 | 42.66 | 48.49 | 48.08 | 41.05 | 31.23 | 24.78 | 20.29 | 17.00 | 14.51 | 10.39 | 7.90 | 0.00 | | |
| 19 | 0.76 | 1.84 | 3.57 | 5.28 | 6.15 | 6.95 | 13.53 | 19.96 | 26.31 | 32.60 | 38.84 | 45.03 | 51.19 | 52.15 | 44.52 | 33.87 | 26.88 | 22.00 | 18.44 | 15.74 | 11.26 | 0.36 | 0.00 | | |
| 20 | 0.80 | 1.93 | 3.76 | 5.55 | 6.47 | 7.32 | 14.24 | 21.01 | 27.70 | 34.32 | 40.88 | 47.40 | 53.88 | 56.32 | 48.08 | 36.58 | 29.03 | 23.76 | 19.91 | 17.00 | 12.16 | 0.00 | | | |
| 21 | 0.84 | 2.03 | 3.95 | 5.83 | 6.80 | 7.69 | 14.95 | 22.07 | 29.08 | 36.03 | 42.92 | 49.77 | 56.58 | 60.59 | 51.73 | 39.36 | 31.23 | 25.56 | 21.42 | 18.29 | 13.09 | 0.00 | | | |
| 22 | 0.88 | 2.13 | 4.14 | 6.11 | 7.12 | 8.05 | 15.66 | 23.12 | 30.47 | 37.75 | 44.97 | 52.14 | 59.27 | 64.97 | 55.47 | 42.20 | 33.49 | 27.41 | 22.97 | 19.61 | 14.03 | | | | |
| 23 | 0.92 | 2.22 | 4.33 | 6.39 | 7.45 | 8.42 | 16.37 | 24.17 | 31.85 | 39.46 | 47.01 | 54.51 | 61.97 | 69.38 | 59.30 | 45.11 | 35.80 | 29.30 | 24.55 | 20.97 | 15.00 | | | | |
| 24 | 0.96 | 2.32 | 4.52 | 6.66 | 7.77 | 8.78 | 17.09 | 25.22 | 33.24 | 41.18 | 49.06 | 56.88 | 64.66 | 72.40 | 63.21 | 48.08 | 38.16 | 31.23 | 26.17 | 22.35 | 15.99 | | | | |
| 25 | 1.00 | 2.42 | 4.70 | 6.94 | 8.09 | 9.15 | 17.80 | 26.27 | 34.62 | 42.89 | 51.10 | 59.25 | 67.35 | 75.42 | 67.20 | 51.12 | 40.57 | 33.20 | 27.83 | 23.76 | 8.16 | | | | |
| 26 | 1.04 | 2.51 | 4.89 | 7.22 | 8.42 | 9.52 | 18.51 | 27.32 | 36.01 | 44.61 | 53.14 | 61.62 | 70.05 | 78.43 | 71.27 | 54.22 | 43.02 | 36.22 | 29.51 | 25.20 | 0.00 | | | | |
| 28 | 1.12 | 2.71 | 5.27 | 7.77 | 9.06 | 10.25 | 19.93 | 29.42 | 38.78 | 48.04 | 57.23 | 66.36 | 75.44 | 84.47 | 79.65 | 60.59 | 48.08 | 39.36 | 32.98 | 28.16 | 0.00 | | | | |
| 30 | 1.20 | 2.90 | 5.64 | 8.33 | 9.71 | 10.98 | 21.36 | 31.52 | 41.55 | 51.47 | 61.32 | 71.10 | 80.82 | 90.50 | 88.33 | 67.20 | 53.33 | 43.65 | 36.58 | 31.23 | | | | | |
| 32 | 1.28 | 3.09 | 6.02 | 8.89 | 10.36 | 11.71 | 22.78 | 33.62 | 44.32 | 54.91 | 65.41 | 75.84 | 86.21 | 96.53 | 97.31 | 74.03 | 58.75 | 48.08 | 40.30 | 5.65 | | | | | |
| 35 | 1.40 | 3.38 | 6.58 | 9.72 | 11.33 | 12.81 | 24.92 | 36.78 | 48.47 | 60.05 | 71.54 | 82.95 | 94.29 | 105.58 | 111.31 | 84.68 | 67.20 | 55.00 | 28.15 | 0.00 | | | | | |
| 40 | 1.61 | 3.87 | 7.53 | 11.11 | 12.95 | 14.64 | 28.48 | 42.03 | 55.40 | 68.63 | 81.76 | 94.80 | 107.77 | 120.67 | 133.51 | 103.46 | 82.10 | 40.16 | 0.00 | | | | | | |
| 45 | 1.81 | 4.35 | 8.47 | 12.49 | 14.57 | 16.47 | 32.04 | 47.28 | 62.32 | 77.21 | 91.98 | 106.65 | 121.24 | 135.75 | 150.20 | 123.45 | 72.28 | 0.00 | | | | | | | |

Type A | Type B | Type C

5

## Select the lubrication type at the rotational speed of smaller sprocket from Tables 7-5, 7-6, and 7-7 page(287-289) (Pdf 303-305)




6

6

**COMPUTE THE REQUIRED NUMBER OF TEETH ON THE LARGE SPROCKET:**
$N_2 = N_1 \times$ Ratio

**COMPUTE THE ACTUAL EXPECTED OUTPUT SPEED:**
$n_2 = n_2 (N_1/N_2)$

**COMPUTE THE PITCH DIAMETERS OF THE SPROCKETS**

$$D_1 = \frac{P_1}{\sin\left(180/N_1\right)} \quad \text{and} \quad D_2 = \frac{P_2}{\sin\left(180/N_2\right)}$$

**ASSUME THE CENTER DISTANCE BETWEEN SPROCKETS**
$C \cong 30 \; to \; 50 \; (pitches)$

**COMPUTE THE REQUIRED CHAIN LENGTH IN PITCHES**

$$L = 2C + \frac{N_2 + N_1}{2} + \frac{(N_2 - N_1)^2}{4\pi^2 C}$$

7

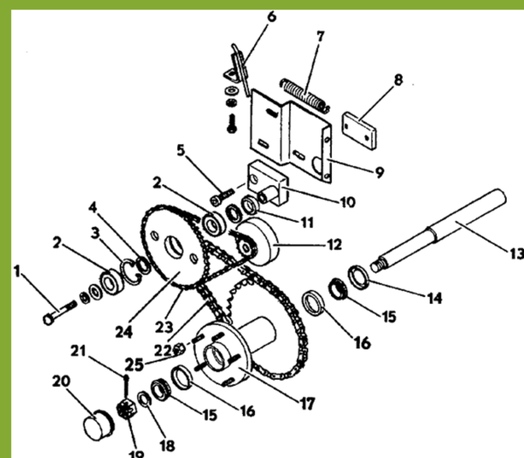
## SPECIFY AN INTEGRAL & EVEN NUMBER OF PITCHES FOR THE CHAIN LENGTH, AND COMPUTE THE ACTUAL THEORETICAL CENTER DISTANCE

$$C = \frac{1}{4}\left[L - \frac{N_2 + N_1}{2} + \sqrt{\left[L - \frac{N_2 + N_1}{2}\right]^2 - \frac{8(N_2 - N_1)^2}{4\pi^2}}\right]$$

## COMPUTE THE ANGLE OF WRAP OF THE CHAIN FOR EACH SPROCKET

$$\theta_1 = 180^o - 2\sin^{-1}\left[\frac{D_2 - D_1}{2C}\right] \ (\textit{must be larger than } 120\ ^o)$$

$$\theta_2 = 180^o + 2\sin^{-1}\left[\frac{D_2 - D_1}{2C}\right]$$

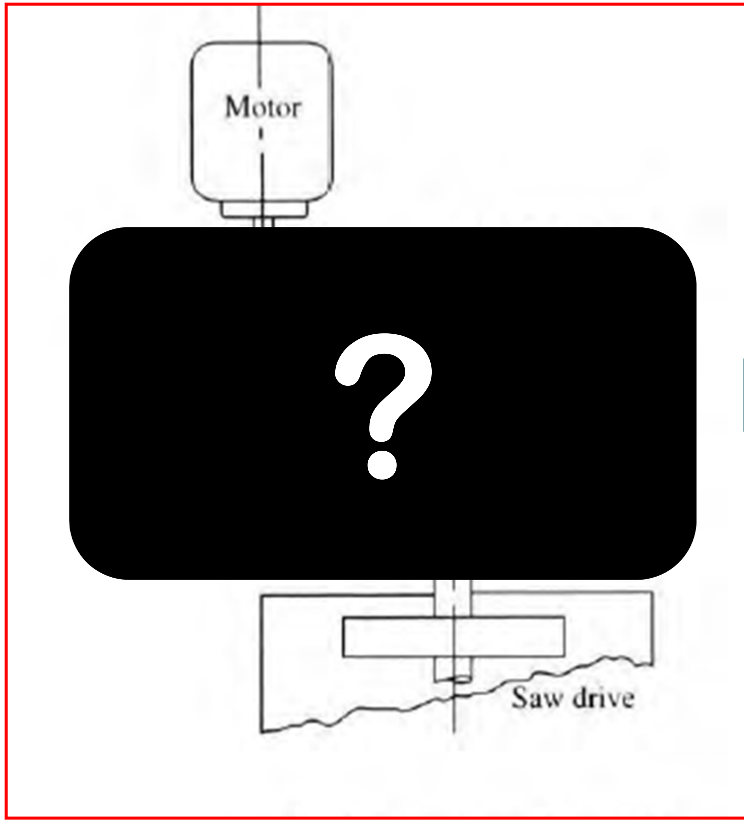


# Mechanical Engineering Design II

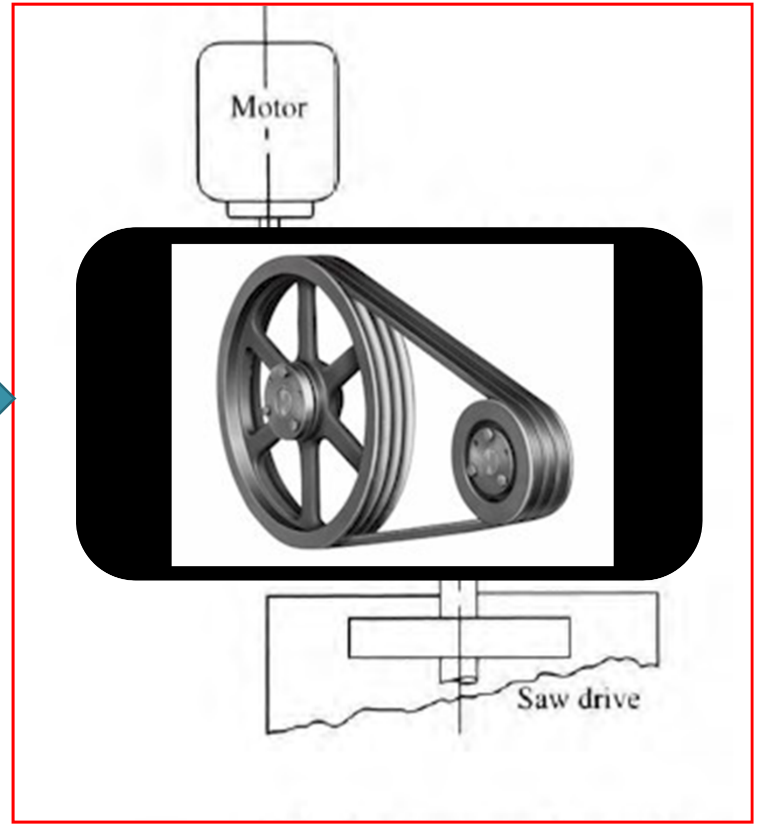
Seventeenth Lecture

## Design of Belt Derive

## Power Transmission Problem




## Proposed solution (Belt Drive)




**Transmitted Power is Known**

**Input and output range speed is Known**

# Types of Belt Drives

(a) Wrapped construction

(b) Die cut, cog type

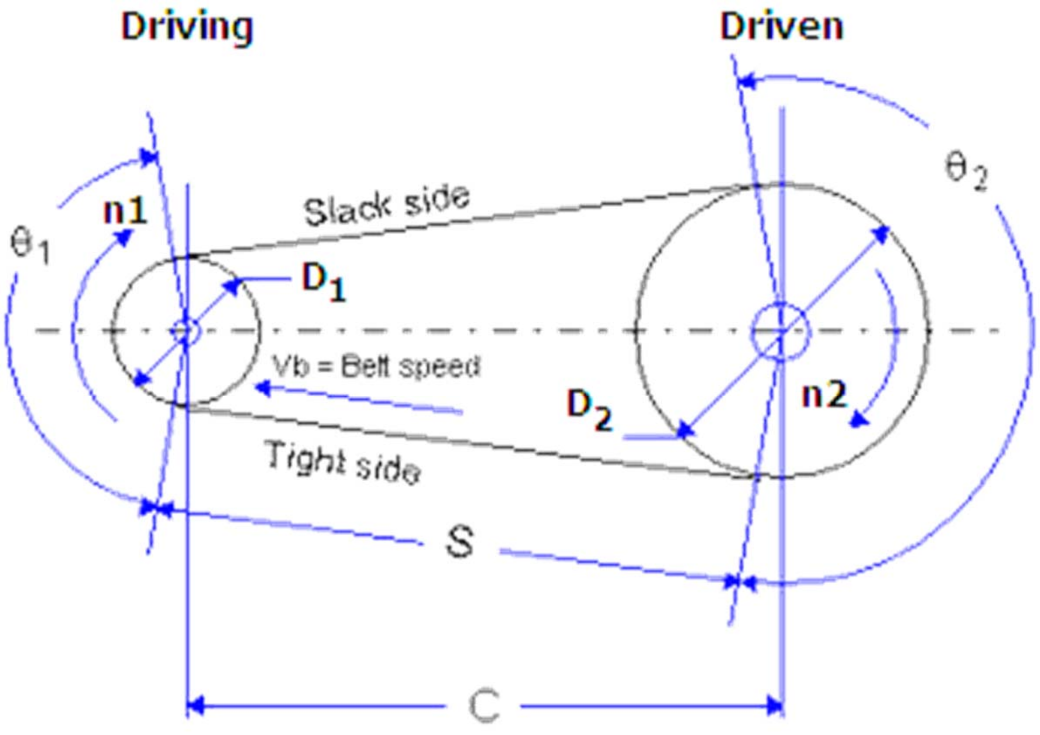
(c) Synchronous belt

(d) Poly-rib belt

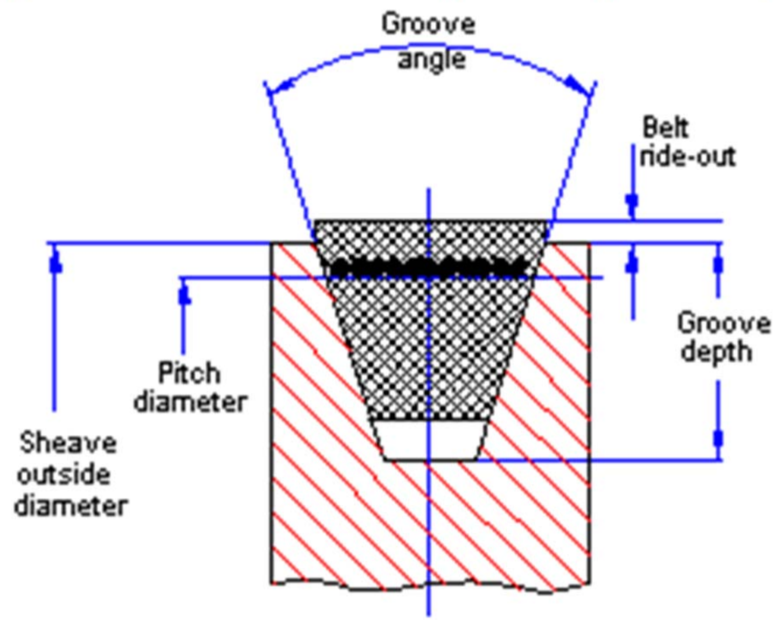
(e) Vee-band

(f) Double angle V-belt

# Basic Belt Drive Geometry




Note: D1 and D2 are pitch diameters



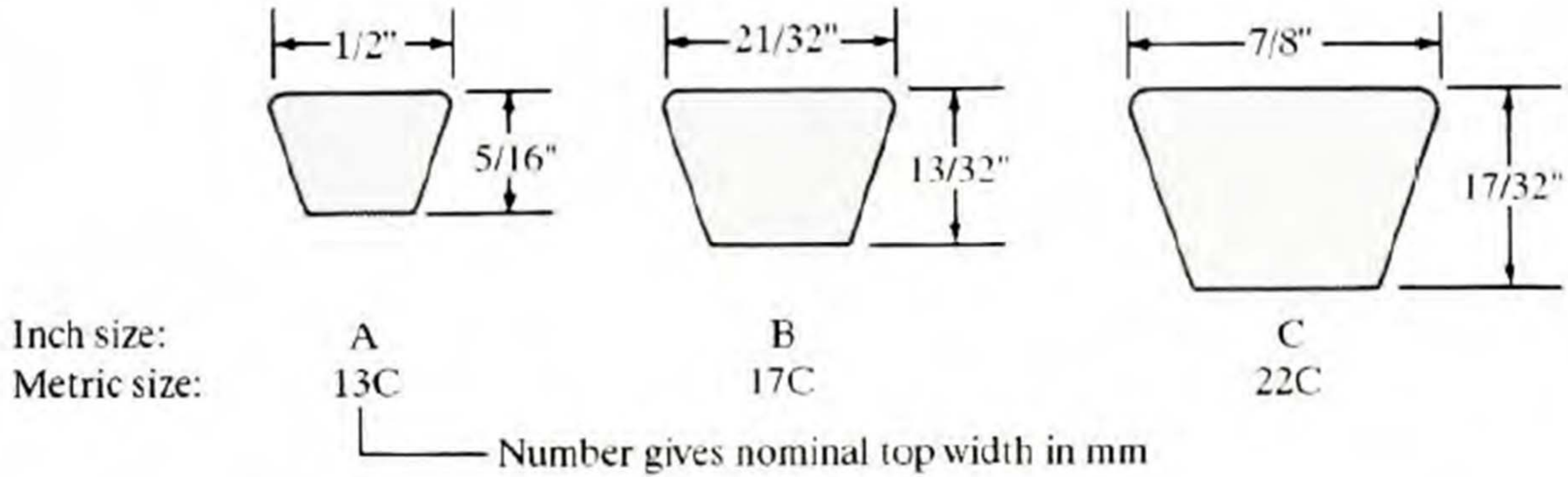

$\theta_1, \theta_2$ are the angles of wrap for small and big sheaves respectively

$n_1, n_2$ are the angular velocity for small and big sheaves respectively

C the center distance

S the span distance

# Standard Belt Cross Sections




SAE Standard J636: V-belts and pulleys

SAE Standard J637: Automotive V-belt drives

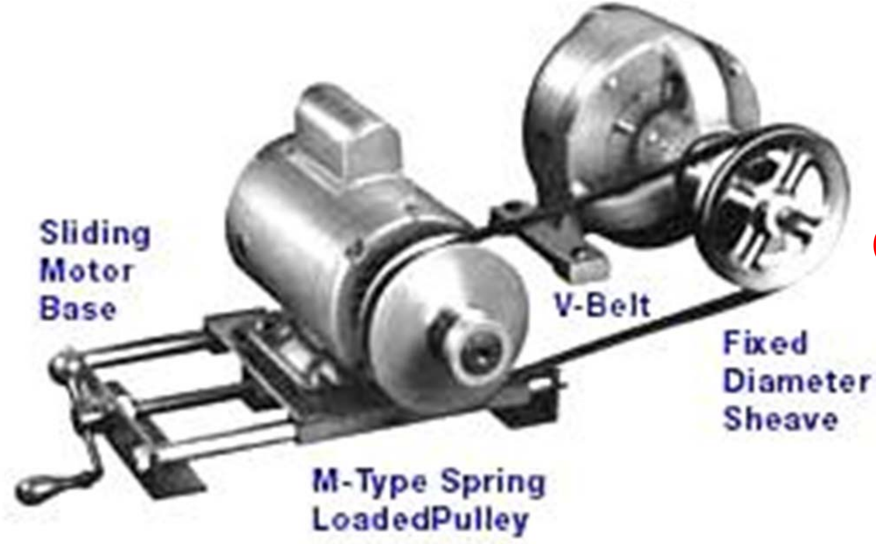
SAE Standard J1278: SI (metric) synchronous belts and pulleys

SAE Standard J1313: Automotive synchronous belt drives

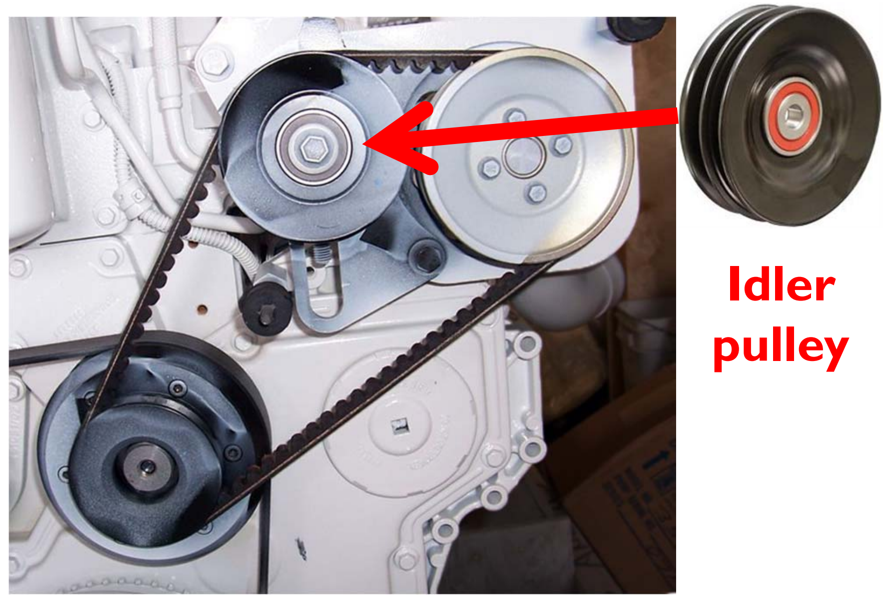
SAE Standard J1459: V-ribbed belts and pulleys

# Design Conditions for V-belt

- The center distance must be adjustable in both directions, or if it was fixed, idler pulleys should be used.




or




- The nominal range of center distance should be: $D_2 < C < 3(D_2 + D_1)$
- The angle of wrap on smaller sheave ($\theta_1$) should be $> 120^o$
- Most commercially available sheaves are cast iron, which should be limited to ***(1981 m/min = 33 m/sec)***
- Consider an alternative type of drive, such as a gear type or chain, ***if the belt speed is less than (304.8 m/min = 5 m/sec)***

# V-Belt Drive Design

- The rated power of the driving motor or other prime mover
- Type of driver and driven load
- The center distance
- The size of the driving and driven sheaves
- Speed of the smaller sheave

Designer

- The service factor
- The power rating for one belt
- The belt length
- The correction factor for belt length
- The correction factor for the angle of wrap on the smaller sheave
- The number of belts
- The initial tension on the belt

# Flowchart for designing a Belt drive:

**Transmitted Power , Input and Output speed, Type of driver and driven load**

**Specify a service factor from Table 7-1 page.274 (290 Pdf)**

**TABLE 7–1** V-belt service factors

| Driven machine type | Driver type: AC motors: Normal torque[a] DC motors: Shunt-wound Engines: Multiple-cylinder | | | AC motors: High torque[b] DC motors: Series-wound, compound-wound Engines: 4-cylinder or less | | |
|---|---|---|---|---|---|---|
| | <6 h per day | 6–15 h per day | >15 h per day | <6 h per day | 6–15 h per day | >15 h per day |
| Agitators, blowers, fans, centrifugal pumps, light conveyors | 1.0 | 1.1 | 1.2 | 1.1 | 1.2 | 1.3 |
| Generators, machine tools, mixers, gravel conveyors | 1.1 | 1.2 | 1.3 | 1.2 | 1.3 | 1.4 |
| Bucket elevators, textile machines, hammer mills, heavy conveyors | 1.2 | 1.3 | 1.4 | 1.4 | 1.5 | 1.6 |
| Crushers, ball mills, hoists, rubber extruders | 1.3 | 1.4 | 1.5 | 1.5 | 1.6 | 1.8 |
| Any machine that can choke | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |

[a]Synchronous, split-phase, three-phase with starting torque or breakdown torque less than 175% of full-load torque.
[b]Single-phase, three-phase with starting torque or breakdown torque greater than 175% of full-load torque.

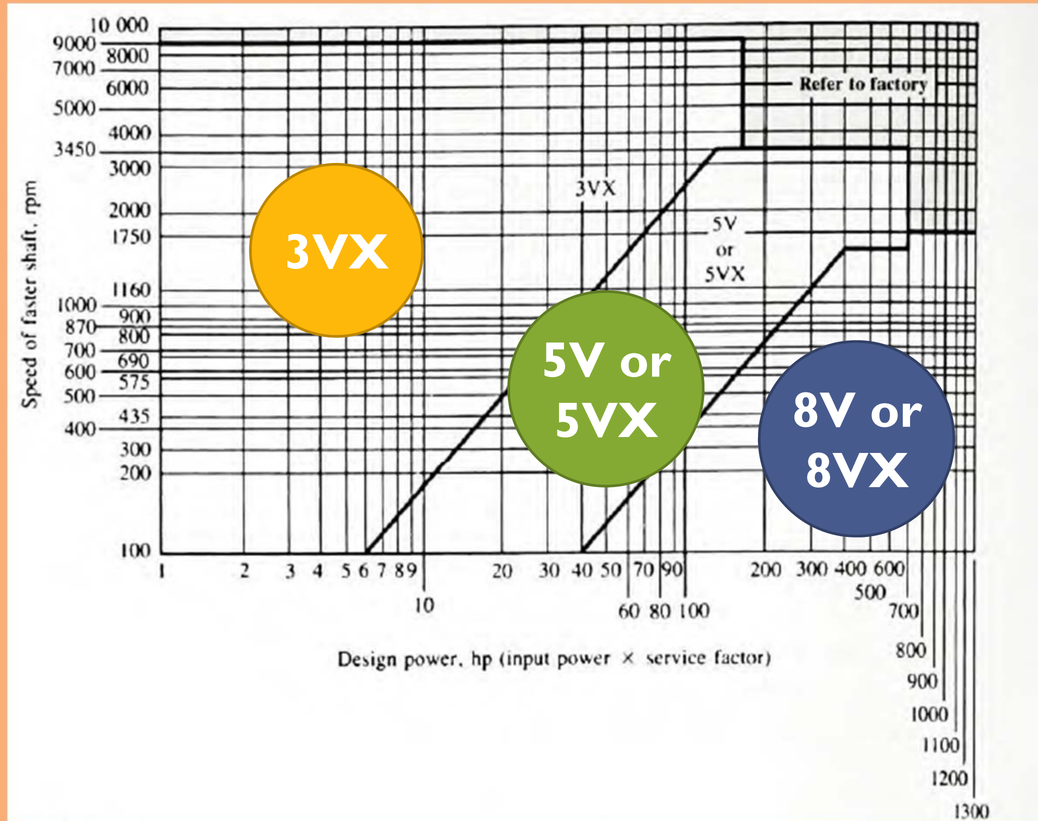
1

1

# COMPUTE THE DESIGN POWER

**Design Power=service factor x transmitted power**

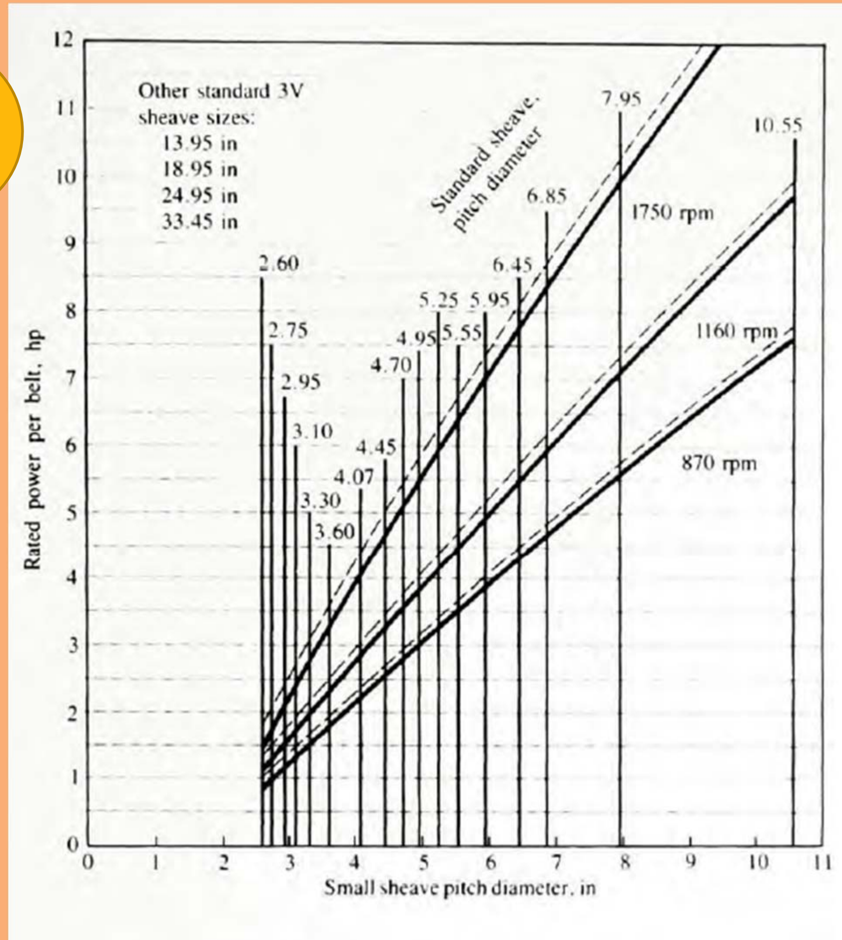
## Specify the standard belt size from Figure 7-9 page.284 (300 Pdf)




2

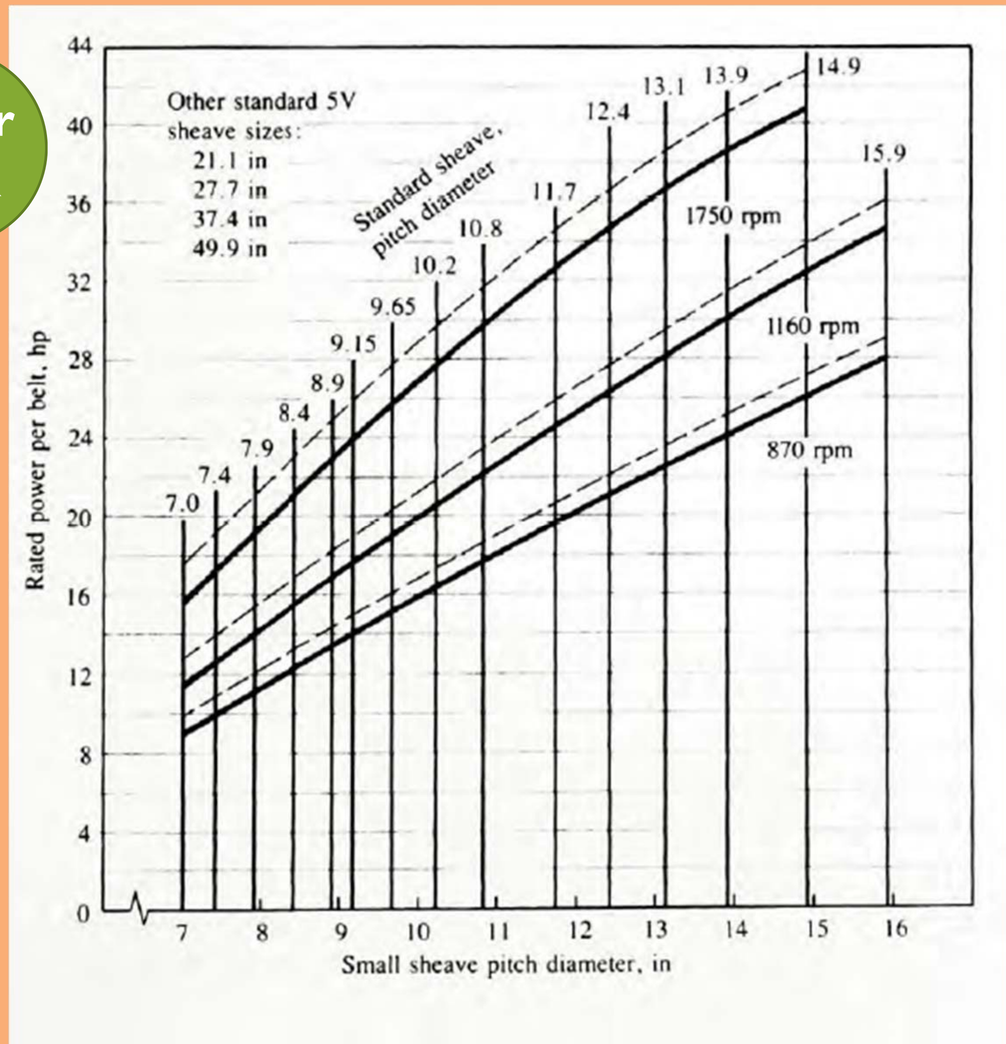
# State the power rating for one belt from Figures (7-10, 7-11, and 7-12) page(275-276) (Pdf 291-292)

3VX



3

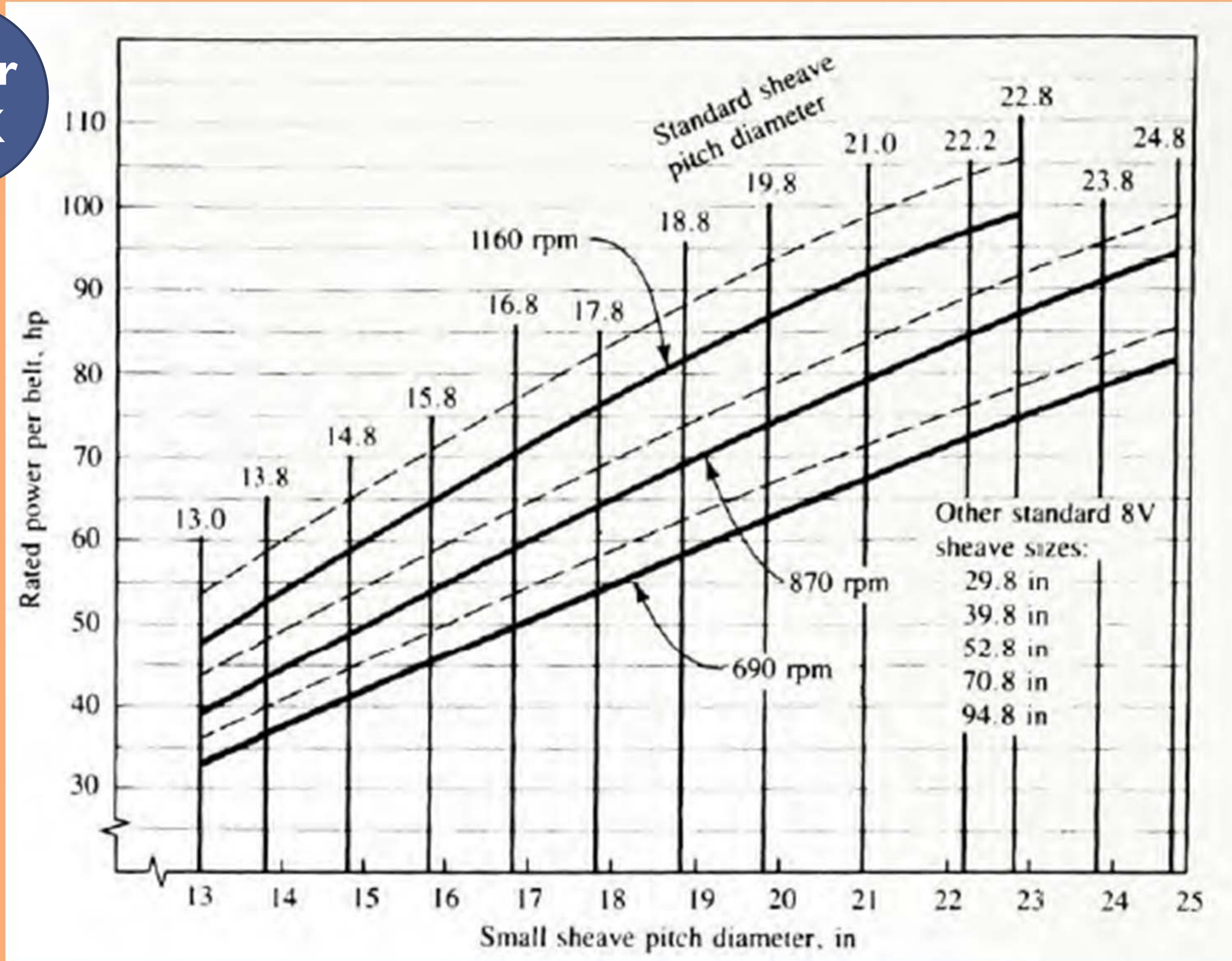
5V or 5VX



Other standard 5V sheave sizes:
21.1 in
27.7 in
37.4 in
49.9 in
Standard sheave, pitch diameter
7.0
7.4
7.9
8.4
8.9
9.15
9.65
10.2
10.8
11.7
12.4
13.1
13.9
14.9
15.9
1750 rpm
1160 rpm
870 rpm
Rated power per belt, hp
0
4
8
12
16
20
24
28
32
36
40
44
7
8
9
10
11
12
13
14
15
16
Small sheave pitch diameter, in


4

**8V or 8VX**



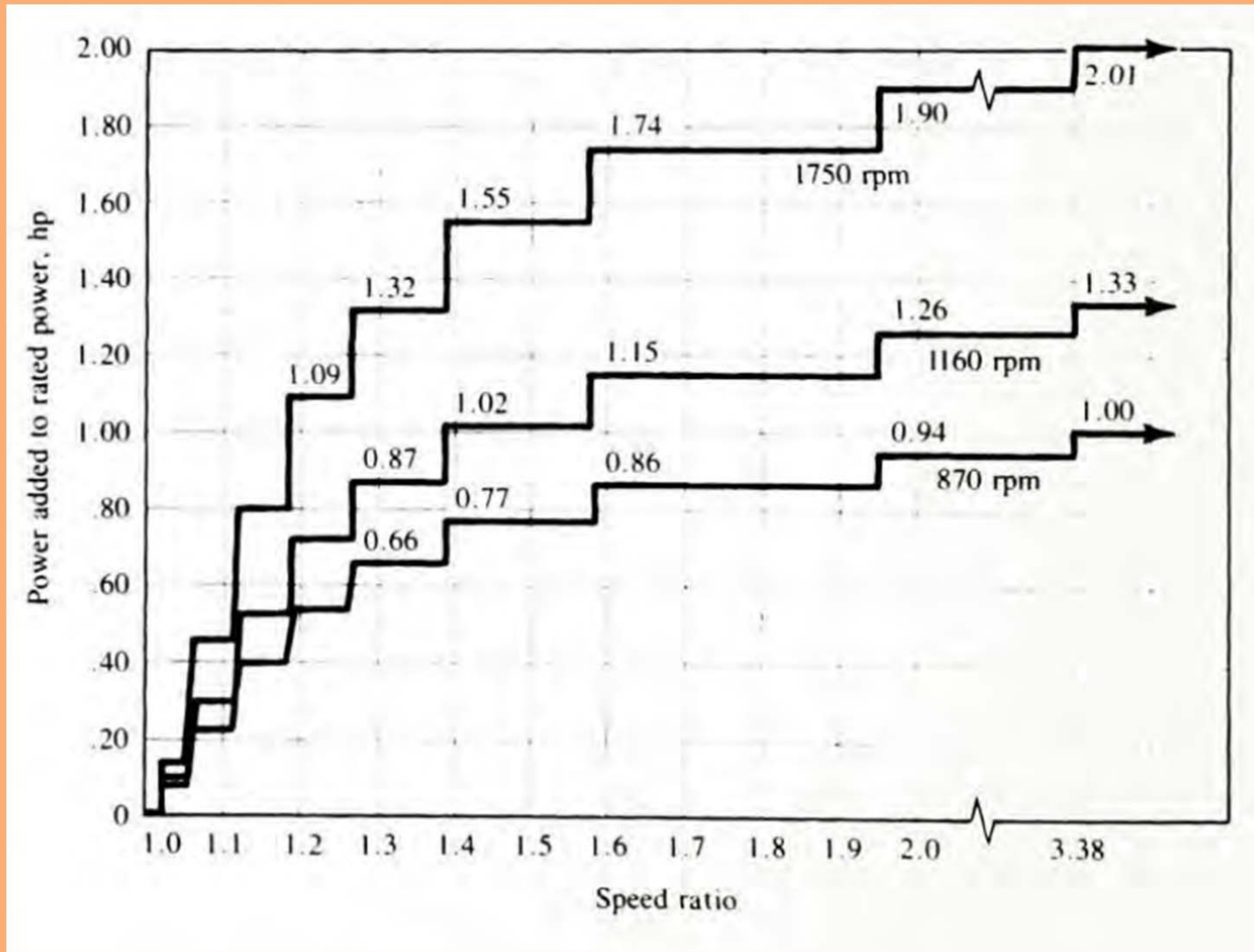
Standard sheave pitch diameter
1160 rpm
870 rpm
690 rpm
13.0
13.8
14.8
15.8
16.8
17.8
18.8
19.8
21.0
22.2
22.8
23.8
24.8
Other standard 8V sheave sizes:
29.8 in
39.8 in
52.8 in
70.8 in
94.8 in
Rated power per belt, hp
30
40
50
60
70
80
90
100
110
13
14
15
16
17
18
19
20
21
22
23
24
25
Small sheave pitch diameter, in


4

5

5

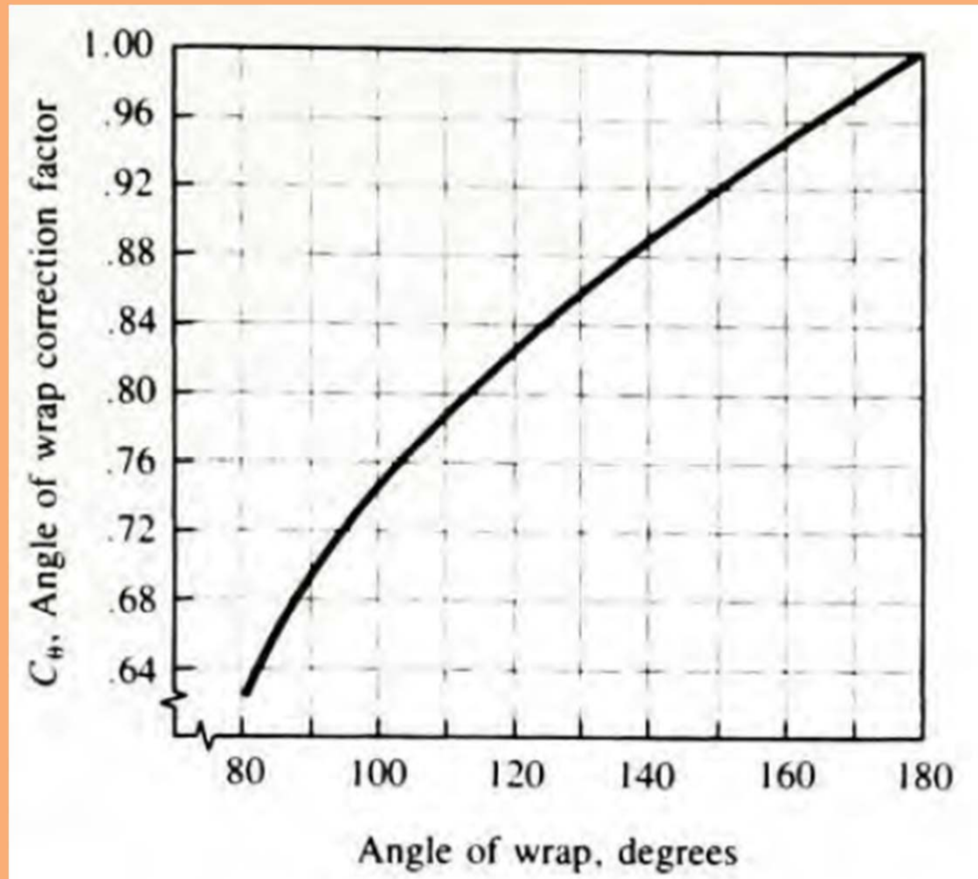
## State the power added to rated power from Figure (7-13) page(276) (Pdf 292)




6

**Compute the angle of wrap:** $\theta_1 = 180^O - 2\sin^{-1}\left[\frac{D_2 - D_1}{2C}\right]$

**State the correction factor of wrap angle $C_\theta$ from figure (7-14) page (277) (293 pdf):**



7

**Specify a trial center distance:** $D_2 < C < 3(D_2 + D_1)$

**Compute the required belt length:** $L = 2C + 1.57(D_2 + D_1) + \frac{(D_2+D_1)^2}{4C}$

**Select the nearest standard belt length from Table (7-2) page (277) (293 pdf)**

**TABLE 7–2** Standard belt lengths for 3V, 5V, and 8V belts (in)

| 3V only | 3V and 5V | 3V, 5V, and 8V | 5V and 8V | 8V only |
|---|---|---|---|---|
| 25 | 50 | 100 | 150 | 375 |
| 26.5 | 53 | 106 | 160 | 400 |
| 28 | 56 | 112 | 170 | 425 |
| 30 | 60 | 118 | 180 | 450 |
| 31.5 | 63 | 125 | 190 | 475 |
| 33.5 | 67 | 132 | 200 | 500 |
| 35.5 | 71 | 140 | 212 | |
| 37.5 | 75 | | 224 | |
| 40 | 80 | | 236 | |
| 42.5 | 85 | | 250 | |
| 45 | 90 | | 265 | |
| 47.5 | 95 | | 280 | |
| | | | 300 | |
| 165 | | | 315 | |
| | | | 335 | |
| | | | 355 | |

8

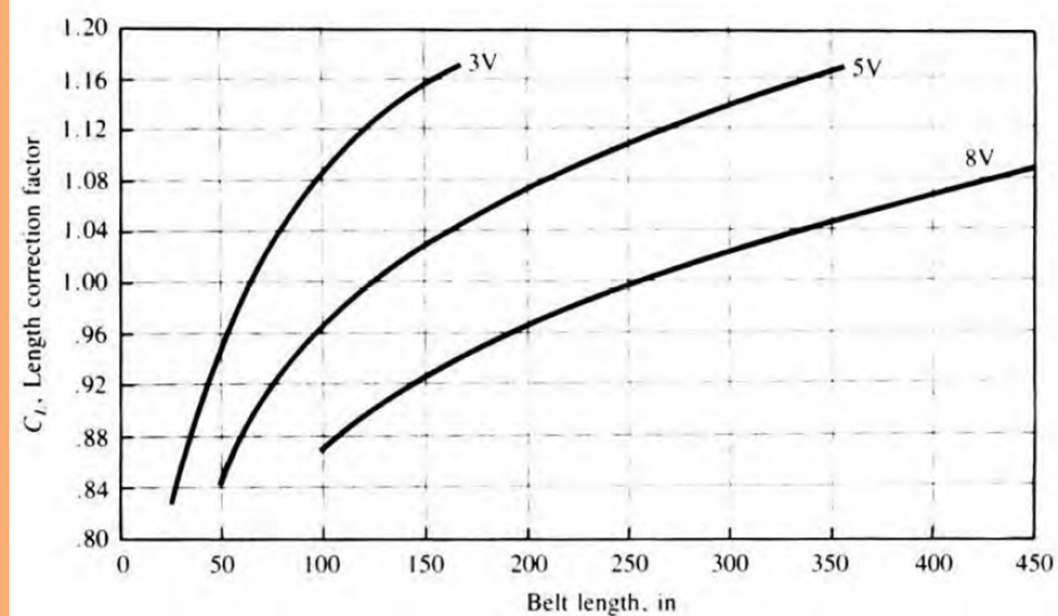
8

**Re-calculate the center distance and angle of wrap:**

$$C = \frac{B + \sqrt{B^2 - 32(D_2 - D_1)^2}}{16} \quad \textit{where } B = 4L - 6.28(D_2 + D_1)$$

$$\theta_1 = 180^o - 2\sin^{-1}\left[\frac{D_2 - D_1}{2C}\right]$$

**State the length correction factor from Figure (7-15) page (277) (293 pdf)**




9

**Compute the corrected rated power per belt and the number of belts required to carry the design power:**

$$Corrected\ rated\ power = C_\theta C_L P$$

**where**

$$P = (actual\ rated\ power) = \boxed{\begin{matrix} rated\ power \\ (fig.\,7-10, 11\ \&12) \end{matrix}} + \boxed{\begin{matrix} added\ power \\ (fig.\,7-13) \end{matrix}}$$

$$Number\ of\ belts = \frac{Design\ Power}{Corrected\ Rated\ Power}$$