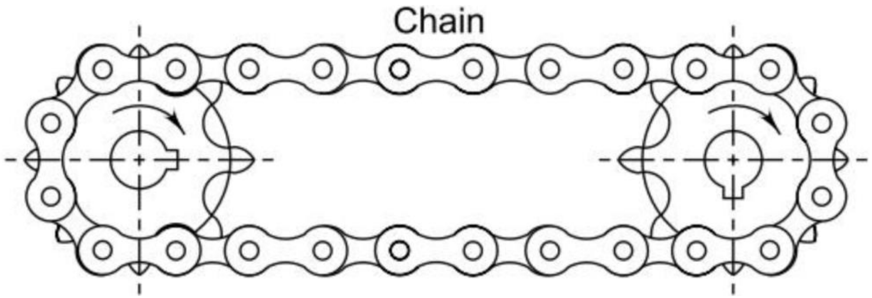
Chain drives

Introduction

- Chain: series of links connected by pin joints
- Sprocket: toothed wheel with a special profile
- Advantages over belt/gear drives
  - Multiple shafts can be driven
  - Smaller in construction
  - Does not slip
- Disadvantages
  - Wear
  - Unsuitable when precise motion is needed (polygonal effect)
  - Slack adjustment
  - Proper maintenance



Roller chain

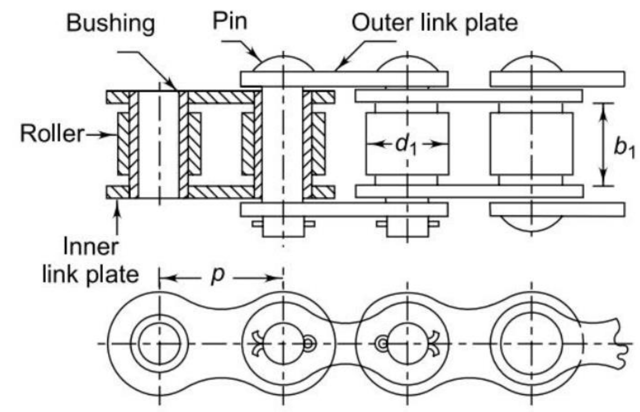


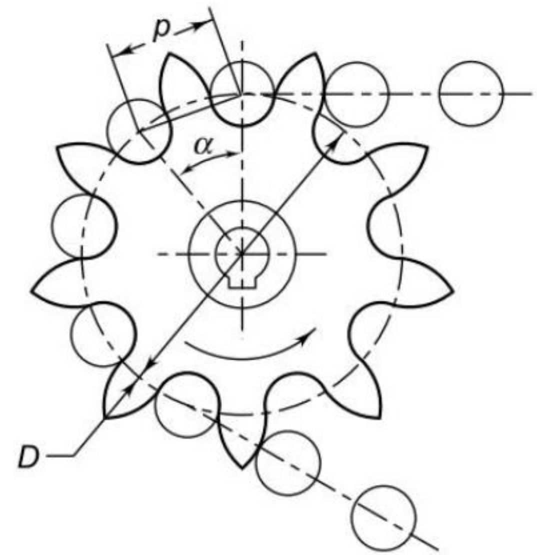
Fig. 14.5 *Construction of Roller Chain*

- Designation
  - 08B or 16A
- The number denotes the pitch in sixteenth of an inch
- A: American National Standards Institute (ANSI)
- B: British Standards Series
- 08B represents a pitch of (08/16)X25.4 mm=12.7 mm
- 08B-2 is a double strand or ‘duplex’ chain
- Breaking load: maximum tensile load, if applied can cause chain failure

Table 14.1 *Dimensions and breaking loads of roller chains*

ISO chain number	Pitch p (mm)	Roller diameter d_1 (mm) (max.)	Width b_1 (mm) (min.)	Transverse pitch p_t (mm)	Breaking load (min) N		
					Simple	Duplex	Triplex
05B	8.00	5.00	3.00	5.64	4 400	7 800	11 100
06B	9.525	6.35	5.72	10.24	8 900	16 900	24 900
08A (ANSI-40)	12.70	7.95	7.85	14.38	13 800	27 600	41 400
08B	12.70	8.51	7.75	13.92	17 800	31 100	44 500
10A (ANSI-50)	15.875	10.16	9.4	18.11	21 800	43 600	65 400
10B	15.875	10.16	9.65	16.59	22 200	44 500	66 700
12A (ANSI-60)	19.05	11.91	12.57	22.78	31 100	62 300	93 400
12B	19.05	12.07	11.68	19.46	28 900	57 800	86 700
16A (ANSI-80)	25.40	15.88	15.75	29.29	55 600	111 200	166 800
16B	25.40	15.88	17.02	31.88	42 300	84 500	126 800
20A(ANSI-100)	31.75	19.05	18.90	35.76	86 700	173 500	260 200
20B	31.75	19.05	19.56	36.45	64 500	129 000	193 500
24A (ANSI-120)	38.10	22.23	25.22	45.44	124 600	249 100	373 700
24B	38.10	25.40	25.40	48.36	97 900	195 700	293 600
28A(ANSI-140)	44.45	25.40	25.22	48.87	169 000	338 100	507 100
28B	44.45	27.94	30.99	59.56	129 000	258 000	387 000
32A(ANSI-160)	50.80	28.58	31.55	58.55	222 400	444 800	667 200
32B	50.80	29.21	30.99	58.55	169 000	338 100	507 100
40A(ANSI-200)	63.50	39.68	37.85	71.55	347 000	693 900	1040 900
40B	63.50	39.37	38.10	72.29	262 400	524 900	787 300
48A	76.20	47.63	47.35	87.83	500 400	1000 800	1501 300
48B	76.20	48.26	45.72	91.21	400 300	800 700	1201 000
64B	101.60	63.50	60.96	119.89	711 700	1423 400	—

Geometric relationships



- z: Number of teeth on sprocket
- Angle, $\alpha = 2\pi/z$
- $D = \dfrac{p}{\sin\left(\frac{\pi}{z}\right)} = pz/\pi$
- Velocity ratio, $i = \dfrac{n_1}{n_2} = \dfrac{z_2}{z_1}$
- $v = \dfrac{\pi D n}{60 \times 10^3} = \dfrac{zpn}{60 \times 10^3}$
- $L = L_n \times p$

where

L = length of the chain (mm)

L_n = number of links in the chain

Geometric relationships

$$L_n = 2\left(\frac{a}{p}\right) + \left(\frac{z_1 + z_2}{2}\right) + \left(\frac{z_2 - z_1}{2\pi}\right)^2 \times \left(\frac{p}{a}\right)$$

where,

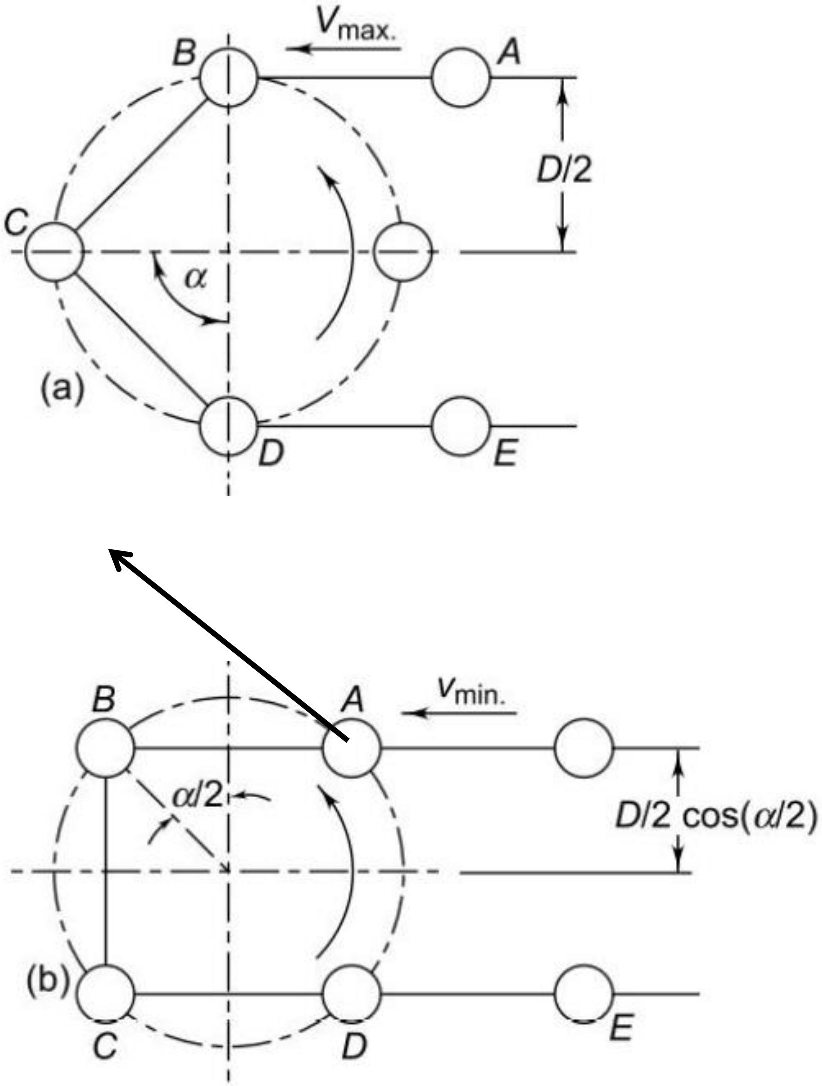
a = centre distance between axes of driving and driven sprockets (mm)

z_1 = number of teeth on the smaller sprocket

z_2 = number of teeth on the larger sprocket

$$a = \frac{p}{4}\left\{\left[L_n - \left(\frac{z_1 + z_2}{2}\right)\right] + \sqrt{\left[L_n - \left(\frac{z_1 + z_2}{2}\right)\right]^2 - 8\left[\frac{z_2 - z_1}{2\pi}\right]^2}\right\}$$

Polygonal effect



$$v_{max.} = \frac{\pi D n}{60 \times 10^3} \text{ m/s}$$

$$v_{min.} = \frac{\pi D n \cos\left(\frac{\alpha}{2}\right)}{60 \times 10^3} \text{ m/s}$$

Speed variation is 4% for a sprocket with 11 teeth, 1.6% for a sprocket with 17 teeth, and less than 1% for a sprocket with 24 teeth

Power rating

$$\text{kW} = \frac{P_1 v}{1000}$$

where

P_1 = allowable tension in the chain (N)

v = average velocity of chain (m/s)

Table 14.2 *Power rating of simple roller chain*

Pinion speed (rpm)	*Power (kW)*								
	06 B	*08A*	*08 B*	*10A*	*10 B*	*12A*	*12 B*	*16A*	*16 B*
50	0.14	0.28	0.34	0.53	0.64	0.94	1.07	2.06	2.59
100	0.25	0.53	0.64	0.98	1.18	1.74	2.01	4.03	4.83
200	0.47	0.98	1.18	1.83	2.19	3.40	3.75	7.34	8.94
300	0.61	1.34	1.70	2.68	3.15	4.56	5.43	11.63	13.06
500	1.09	2.24	2.72	4.34	5.01	7.69	8.53	16.99	20.57
700	1.48	2.95	3.66	5.91	6.71	10.73	11.63	23.26	27.73
1000	2.03	3.94	5.09	8.05	8.97	14.32	15.65	28.63	34.89
1400	2.73	5.28	6.81	11.18	11.67	14.32	18.15	18.49	38.47
1800	3.44	6.98	8.10	8.05	13.03	10.44	19.85	—	—
2000	3.80	6.26	8.67	7.16	13.49	8.50	20.57	—	—

kW rating of chain

$$= \frac{(\text{kW to be transmitted}) \times K_s}{K_1 \times K_2}$$

where

K_s = service factor

K_1 = multiple strand factor

K_2 = tooth correction factor

Properties of sprocket wheel

Table 14.6 *Proportions of the sprocket wheel (Figs 14.10 and 14.11)*

Dimension	*Notation*	*Equation*
1. Chain pitch	p	(Table 14.1)
2. Pitch circle diameter	D	$D = \dfrac{p}{\sin\left(\dfrac{180}{z}\right)}$
3. Roller diameter	d_1	(Table 14.1)
4. Width between inner plates	b_1	(Table 14.1)
5. Transverse pitch	p_t	(Table 14.1)
6. Top diameter	D_a	$(D_a)_{max.} = D + 1.25p - d_1$ $(D_a)_{min.} = D + p\left(1 - \dfrac{1.6}{z}\right) - d_1$
7. Root diameter	D_f	$D_f = D - 2r_i$
8. Roller seating radius	r_i	$(r_i)_{max.} = (0.505d_1 + 0.069\sqrt[3]{d_1})$ $(r_i)_{min.} = 0.505d_1$
9. Tooth flank radius	r_e	$(r_e)_{max.} = 0.008d_1\,(z^2 + 180)$ $(r_e)_{min.} = 0.12d_1\,(z + 2)$
10. Roller seating angle	α	$\alpha_{max.} = \left[120 - \dfrac{90}{z}\right]$ $\alpha_{min.} = \left[140 - \dfrac{90}{z}\right]$
11. Tooth height above the pitch polygon	h_a	$(h_a)_{max.} = 0.625p - 0.5d_1 + \dfrac{0.8p}{z}$ $(h_a)_{min.} = 0.5(p - d_1)$
12. Tooth side radius	r_x	$(r_x)_{min.} = p$
13. Tooth width	b_{f1}	$b_{f1} = 0.93b_1$ if $p \le 12.7$ mm $b_{f1} = 0.95b_1$ if $p > 12.7$ mm
14. Tooth side relief	b_a	$b_a = 0.1p$ to $0.15p$

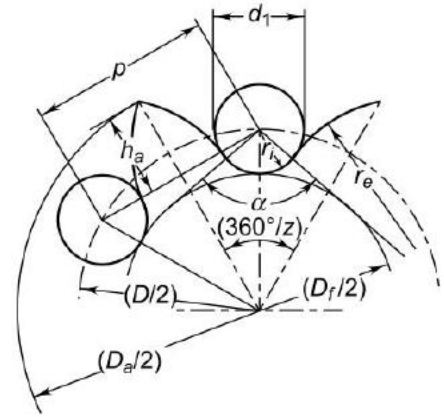


Fig. 14.10 *Tooth Profile of Sprocket*

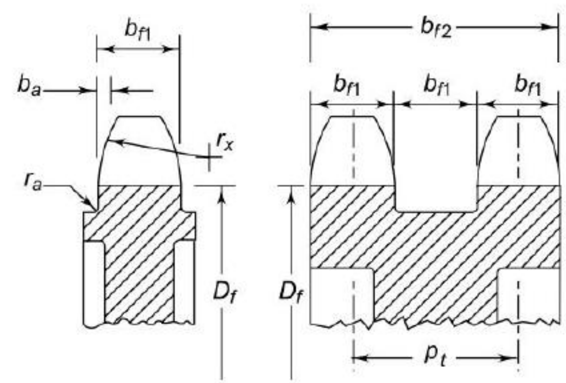
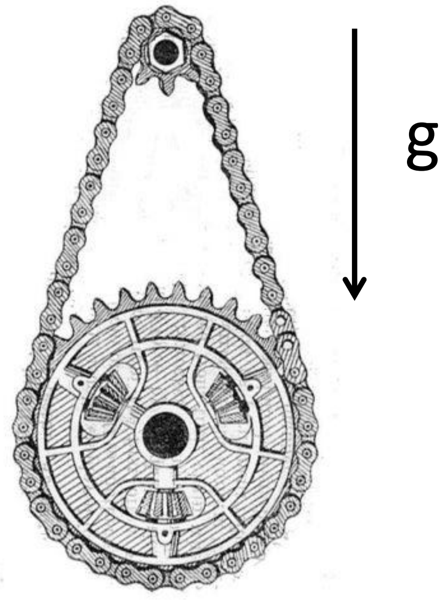


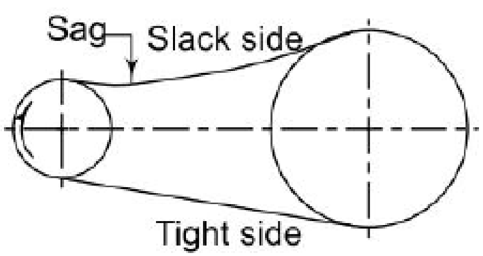
Fig. 14.11 *Rim Profile of Sprocket*

Rules and considerations for design

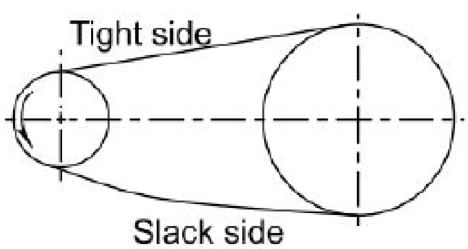
- Rule 1: The number of pitches or links of the chain should be always ‘even’.
- Rule 2: The number of teeth on the driving sprocket should be always ‘odd’, such as 17, 19 or 21.
- Avoid vertical chain drives
- Tight side up or down?



Config. 1



Config. 2



Selection of chain drives

Example 14.4 *It is required to design a chain drive to connect a 12 kW, 1400 rpm electric motor to a centrifugal pump running at 700 rpm. The service conditions involve moderate shocks.*

(i) Select a proper roller chain and give a list of its dimensions.

(ii) Determine the pitch circle diameters of driving and driven sprockets.

(iii) Determine the number of chain links.

(iv) Specify the correct centre distance between the axes of sprockets.

Solution

Given kW = 12 $n_1 = 1400$ rpm $n_2 = 700$ rpm

Step I *kW rating of chain*

In order to reduce the polygonal effect, the number of teeth on the driving sprocket is selected as 17 (K_2 = 1). It is further assumed that the chain is simple roller chain with only one strand (K_1 = 1). The service factor from Table 14.3 is 1.3. From Eq. (14.8),

$$\text{kW rating of chain} = \frac{(\text{kW to be transmitted}) \times K_s}{K_1 \times K_2}$$

$$= \frac{12 \times 1.3}{1 \times 1} = 15.6 \text{ kW}$$

Table 14.3 *Service factor (K_s)*

Type of driven load	*Type of input power*		
	IC engine with hydraulic drive	*Electric motor*	*IC engine with mechanical drive*
(i) *Smooth:* agitator, fan, light conveyor	1.0	1.0	1.2
(ii) *Moderate shock:* machine tools, crane, heavy conveyor, food mixer, grinder	1.2	1.3	1.4
(iii) *Heavy shock:* punch press, hammer mill, reciprocating conveyor, rolling mill drive	1.4	1.4	1.7

Table 14.5 *Tooth correction factor (K_2)*

Number of teeth on the driving sprocket	K_2
15	0.85
16	0.92
17	1.00
18	1.05
19	1.11
20	1.18
21	1.26
22	1.29
23	1.35
24	1.41
25	1.46
30	1.73

Selection of chain drives

Step II *Selection of chain*

Referring to Table 14.2, the power rating of the chain 12B at 1400 rpm is 18.15 kW. Therefore the chain number 12B is selected.

The dimensions of this chain (Table 14.1) are as follows:

$$p = 19.05 \text{ mm} \quad d_1 = 12.07 \text{ mm} \quad b_1 = 11.68 \text{ mm} \qquad \text{(i)}$$

Step III *Pitch circle diameter of driving and driven pulleys*

From Eq. 14.2,

$$D = \frac{p}{\sin\left(\frac{180}{z}\right)} = \frac{19.05}{\sin\left(\frac{180}{17}\right)} = 103.67 \text{ mm} \qquad \text{(iia)}$$

For the driven sprocket,

$$z_2 = z_1\left(\frac{n_1}{n_2}\right) = 17\left(\frac{1400}{700}\right) = 34$$

$$D_2 = \frac{p}{\sin\left(\frac{180}{z}\right)} = \frac{19.05}{\sin\left(\frac{180}{34}\right)} = 206.46 \text{ mm} \qquad \text{(iib)}$$

Table 14.2 *Power rating of simple roller chain*

Pinion speed (rpm)	*Power (kW)*								
	06 B	*08A*	*08 B*	*10A*	*10 B*	*12A*	*12 B*	*16A*	*16 B*
50	0.14	0.28	0.34	0.53	0.64	0.94	1.07	2.06	2.59
100	0.25	0.53	0.64	0.98	1.18	1.74	2.01	4.03	4.83
200	0.47	0.98	1.18	1.83	2.19	3.40	3.75	7.34	8.94
300	0.61	1.34	1.70	2.68	3.15	4.56	5.43	11.63	13.06
500	1.09	2.24	2.72	4.34	5.01	7.69	8.53	16.99	20.57
700	1.48	2.95	3.66	5.91	6.71	10.73	11.63	23.26	27.73
1000	2.03	3.94	5.09	8.05	8.97	14.32	15.65	28.63	34.89
1400	2.73	5.28	6.81	11.18	11.67	14.32	18.15	18.49	38.47
1800	3.44	6.98	8.10	8.05	13.03	10.44	19.85	—	—
2000	3.80	6.26	8.67	7.16	13.49	8.50	20.57	—	—

Table 14.1 *Dimensions and breaking loads of roller chains*

ISO chain number	*Pitch p (mm)*	*Roller diameter d_1 (mm) (max.)*	*Width b_1 (mm) (min.)*	*Transverse pitch p_t (mm)*	*Breaking load (min) N*		
					Simple	*Duplex*	*Triplex*
05B	8.00	5.00	3.00	5.64	4 400	7 800	11 100
06B	9.525	6.35	5.72	10.24	8 900	16 900	24 900
08A (ANSI-40)	12.70	7.95	7.85	14.38	13 800	27 600	41 400
08B	12.70	8.51	7.75	13.92	17 800	31 100	44 500
10A (ANSI-50)	15.875	10.16	9.4	18.11	21 800	43 600	65 400
10B	15.875	10.16	9.65	16.59	22 200	44 500	66 700
12A (ANSI-60)	19.05	11.91	12.57	22.78	31 100	62 300	93 400
12B	19.05	12.07	11.68	19.46	28 900	57 800	86 700
16A (ANSI-80)	25.40	15.88	15.75	29.29	55 600	111 200	166 800
16B	25.40	15.88	17.02	31.88	42 300	84 500	126 800
20A(ANSI-100)	31.75	19.05	18.90	35.76	86 700	173 500	260 200
20B	31.75	19.05	19.56	36.45	64 500	129 000	193 500
24A (ANSI-120)	38.10	22.23	25.22	45.44	124 600	249 100	373 700
24B	38.10	25.40	25.40	48.36	97 900	195 700	293 600
28A(ANSI-140)	44.45	25.40	25.22	48.87	169 000	338 100	507 100
28B	44.45	27.94	30.99	59.56	129 000	258 000	387 000
32A(ANSI-160)	50.80	28.58	31.55	58.55	222 400	444 800	667 200
32B	50.80	29.21	30.99	58.55	169 000	338 100	507 100
40A(ANSI-200)	63.50	39.68	37.85	71.55	347 000	693 900	1040 900
40B	63.50	39.37	38.10	72.29	262 400	524 900	787 300
48A	76.20	47.63	47.35	87.83	500 400	1000 800	1501 300
48B	76.20	48.26	45.72	91.21	400 300	800 700	1201 000
64B	101.60	63.50	60.96	119.89	711 700	1423 400	—

Selection of chain drives

Step IV *Number of chain links*

The centre distance between the sprocket wheels should be between ($30p$) to ($50p$). Taking a mean value of ($40p$), the approximate centre distance is calculated.

$$a = 40\,p = 40(19.05) = 762 \text{ mm} \quad \text{(assume)}$$

From Eq. (14.6),

$$L_n = 2\left(\frac{a}{p}\right) + \left(\frac{z_1 + z_2}{2}\right) + \left(\frac{z_2 - z_1}{2\pi}\right)^2 \times \left(\frac{p}{a}\right)$$

$$= 2\left(\frac{762}{19.05}\right) + \left(\frac{17+34}{2}\right) + \left(\frac{34-17}{2\pi}\right)^2 \times \left(\frac{19.05}{762}\right)$$

$$= 105.68 \text{ or } 106 \text{ links} \qquad \text{(iii)}$$

Step V *Correct centre distance*

$$\left[L_n - \left(\frac{z_1 + z_2}{2}\right)\right] = \left[106 - \left(\frac{17+34}{2}\right)\right] = 80.5$$

From Eq. (14.7),

$$a = \frac{p}{4}\left\{\left[L_n - \left(\frac{z_1+z_2}{2}\right)\right] + \sqrt{\left[L_n - \left(\frac{z_1+z_2}{2}\right)\right]^2 - 8\left[\frac{z_2 - z_1}{2\pi}\right]^2}\right\}$$

$$= \frac{19.05}{4}\left\{80.5 + \sqrt{(80.5)^2 - 8\left[\frac{34-17}{2\pi}\right]^2}\right\}$$

$$= 765.03 \text{ mm}$$

For satisfactory performance, the centre to centre distance should provide a wrap angle of 120 degs. It is recommended that $30p < a < 50p$

To provide small sag, for allowing the chain links to take the best position on the sprocket teeth, the centre distance is reduced by ($0.002a$). Therefore, the correct centre distance is given by,

$$a = 0.998 \times 765.03 = 763.5 \text{ mm} \qquad \text{(iv)}$$

Reference

- “Design of Machine Elements” by V. B. Bhandari

Numerical problems on chain drives

(1) A single-strand chain No. 12A is used in a mechanical drive. The driving sprocket has 17 teeth and rotates at 1000 rpm. What is the factor of safety used for standard power rating? Neglect centrifugal force acting on the chain.

Given:

12 A

$z_1 = 17$

$n = 1000$ rpm

fos = ?

$P = 19.05$ mm

breaking load = 31,100 N

$$V = \frac{zpn}{60\times10^3} = \frac{17\times1000\times19.05}{60\times10^3} = 5.39 \text{ m/s}$$

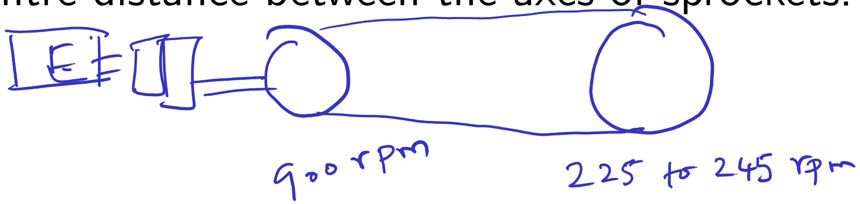
$$\text{Power rating} = \frac{P_1 V}{1000} \Rightarrow \cancel{14}.32 = \frac{P_1\times5.39}{1000}$$

$$P_1 = 2656.77\text{ N}$$

$$\text{fos} = \frac{31,100}{2656} = 11.7$$

Numerical problems on chain drives

(3) It is required to design a chain drive to connect a 10 kW, 900 rpm petrol engine to a conveyor. The driving sprocket is mounted on engine shaft. The driven sprocket is mounted on conveyor shaft. The conveyor shaft should run between 225 to 245 rpm. The service conditions involve moderate shocks. (i) Select a proper roller chain and give a list of its dimensions. (ii) Determine the pitch circle diameters of the driving and driven sprockets. (iii) Determine the number of chain links. (iv) Specify the correct centre distance between the axes of sprockets. Create an alternative design for the above application, which will result in compact construction using multi-strand chain. For this design, (v) Select the roller chain with multi-strand construction, (vi) Determine the number of chain links, (vii) Specify the correct centre distance between the axes of sprockets.



$$\text{Power rating} = \frac{\text{Power to be transmitted} \times K_s}{K_1 \times K_2} = \frac{10 \times 1.4}{1 \times 1.26}$$

$$= 11.11 \text{ kW @ } 900 \text{ rpm}$$

$Z_1 = 21$ teeth

$k_1 = 1$

Numerical problem-3

11.11 kW @ 900 rpm → $y = 13.12$ kW @ 900 rpm

12A ⇒ $P = 19.05$ mm

12A ✓

rpm	kW
700	10.73
1000	14.32

$$D_1 = \frac{P}{\sin\left(\frac{180}{Z_1}\right)} = \frac{19.05}{\sin\left(\frac{180}{21}\right)} = 127.81\text{ mm}$$

$$\frac{y - y_1}{y_2 - y_1} = \frac{x - x_1}{x_2 - x_1}$$

$$D_2 = \frac{P}{\sin\left(\frac{180}{Z_2}\right)} = 503.41\text{ mm}$$

$$\frac{y - 10.73}{14.32 - 10.73} = \frac{900 - 700}{1000 - 700}$$

$$\frac{Z_2}{Z_1} = \frac{n_1}{n_2} \Rightarrow Z_2 = \frac{900 \times 21}{230} = 83$$

Numerical problem-3

$$L_n = \left(\frac{2a}{p}\right) + \left(\frac{z_1+z_2}{2}\right) + \left(\frac{z_2-z_1}{2\pi}\right)^2\left(\frac{p}{a}\right)$$

$30p < a < 50p$

$a = 45p$

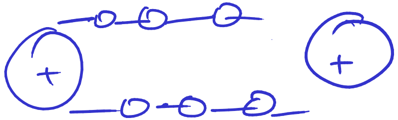
$= 45 \times 19.05$

$= 857.25$ mm

$L_n = 144.16$

$L_n = 145$

$L_n = 146$



$a =$

Numerical problem-4

[4] It is required to design a chain drive with a duplex chain to connect a 15 kW, 1400 rpm electric motor to a transmission shaft running at 350 rpm. The operation involves moderate shocks. (i) Specify the number of teeth on the driving and driven sprockets. (ii) Select a proper roller chain. (iii) Calculate the pitch circle diameters of the driving and driven sprockets. (iv) Determine the number of chain links. (v) Specify the correct centre distance. During preliminary stages, the centre distance can be assumed to be 40 times the pitch of the chain.

Numerical problem-4