City& Guilds

9210-222
Reference booklet
Sample Paper

The following information is provided in support of the design analysis.

i. Refer to the information in the following tables to select a three phase induction motor.

2 POLES, 3000 *RPM* SYNCHRONOUS AT 50 *Hz*

OUTPUT *KW*	FRAME NO.	FULL LOAD EFFICIENCY (%) FL	¾ L	½ L	FULL LOAD POWER FACTOR (%) FL	¾ L	½ L	SPEED (*RPM*)
0.75	D80	74.0	72.5	70.0	96	82	72	2830
1.1	D80	74.0	73.0	70.7	86	83	74	2820
1.5	D90S	77.8	77.0	75.5	96	83	76	2860
2.2	D90L	80.0	78.5	76.5	87	84	77	2870

4 POLES, 1500 *RPM* SYNCHRONOUS AT 50 *Hz*

OUTPUT *KW*	FRAME NO.	FULL LOAD EFFICIENCY (%) FL	¾ L	½ L	FULL LOAD POWER FACTOR (%) FL	¾ L	½ L	SPEED (*RPM*)
0.75	D80	71.0	69.5	66.5	75	69	55	1420
1.1	D90S	74.0	73.0	69.0	77	71	58.5	1410
1.5	D90L	75.5	74.0	71.0	79	73	60	1425
2.2	D100L	81.5	80.8	78.5	81	75	63	1425

6 POLES, 1000 *RPM* SYNCHRONOUS AT 50 *Hz*

OUTPUT *KW*	FRAME NO.	FULL LOAD EFFICIENCY (%) FL	¾ L	½ L	FULL LOAD POWER FACTOR (%) FL	¾ L	½ L	SPEED (*RPM*)
0.75	D90S	73.0	71.0	67.0	69	62	47	920
1.1	D90L	74.0	73.0	68.0	69	62	47.5	925
1.5	D100L	75.5	74.0	71.0	72	66	54	925
2.2	D112M	80.8	80.0	78.0	74	67	55	950

8 POLES, 750 *RPM* SYNCHRONOUS AT 50 *Hz*

OUTPUT *KW*	FRAME NO.	FULL LOAD EFFICIENCY (%) FL	¾ L	½ L	FULL LOAD POWER FACTOR (%) FL	¾ L	½ L	SPEED (*RPM*)
0.75	D100L	67.0	66.0	63.0	66	58.5	42	690
1.5	D112M	74.0	72.5	70.5	68	61	45	700
2.2	D132S	80.8	80.0	78.0	69	62	48	710

ii. Efficiencies are:

Electric Motor	85%
Gear Drive	96%
Belt drive	90%

iii. Density of steel: 7.8 x 10^3 kg/m^3.

iv. For shafts design: shear stress = 0.3 x yield stress in tension, or
= 0.18 x ultimate stress in tension
(whichever is smaller)

Design value of the normal stress = 0.36 x yield stress in tension, or
= 0.6 x ultimate stress in tension
(whichever is smaller)

v. Select one of the following steels for the shaft material appropriately.

AISI No.	Yield strength (MN/m^2)	Ultimate tensile strength (MN/m^2)
1010	303	366
1018	373	442
1045	532	626
4340	683	766

If key ways are present then above strength values are to be reduced by 25%.

For ductile materials the yield strength in shear = 0.5 x yield strength in tension.

A shaft having a diameter d, when subjected to combined bending and torsion loads the equivalent direct and shear stresses in usual notations are as follows:

$$[\sigma_{eq}] = \frac{16}{\pi d^3}\left[K_b\ M + \sqrt{(K_b\ M)^2 + (K_t\ T)^2}\right]$$

$$[\tau_{eq}] = \frac{16}{\pi d^3}\left[\sqrt{(K_b\ M)^2 + (K_t\ T)^2}\right]$$

The K_b and K_t can be selected from following table,

	K_b	K_t
For stationary shafts		
For gradually applied loads	1.0	1.0
For Suddenly applied loads	1.5 to 2.0	1.5 to 2.0
For rotating shafts		
For gradually applied loads	1.5	1.0
For Suddenly applied loads (minor shock)	1.5 to 2.0	1.0 to 1.5
For Suddenly applied loads (heavy shock)	2.0 to 3.0	1.5 to 3.0

vi. The maximum and minimum direct stress and maximum shear stress of a complex stress system can be calculated using the following equations.

$$\sigma_1 = \left(\frac{\sigma_x + \sigma_y}{2}\right) + \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

$$\sigma_2 = \left(\frac{\sigma_x + \sigma_y}{2}\right) - \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

$$\tau_{(\max)} = \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

Safety factors can be appropriately considered with the equations given above.

vii. Important data and equations to support gear calculations.

In order to avoid interference in a spur gear drive, the minimum number of teeth on the pinion T_1 is given by:

$$T_1 \geq \frac{2}{\sqrt{G^2 + \sin^2(\psi)(1+2G)} - G}$$

where G (> 1) is the speed ratio and ψ is the pressure angle.

- Standard modules;

  Preferred modules: 1, 1.25, 1.5, 2, 2.5, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 32, 40, 50
  Second choice: 1.125, 1.375, 1.75, 2.25, 2.75, 3.5, 4.5, 5.5, 7, 9, 11, 14, 18, 22, 28, 36, 45

- Lewis form factor (y) can be calculated from the equation, or extracted from tables

  $$y = 0.154 - \frac{0.912}{(no.\ of\ teeth)}$$ for 20-deg pressure angle and full depth tooth system

  $$y = 0.175 - \frac{0.841}{(no.\ of\ teeth)}$$ for 20-deg pressure angle and stub tooth system

  $$y = 0.124 - \frac{0.684}{(no.\ of\ teeth)}$$ for tooth systems with 14.5-deg pressure angle

  Velocity factors,

  For ordinary spur gears operating at velocities up to 12.5 *m*/*s* - $C_v = 3/(3 + v)$

  For carefully cut gears operating at velocities up to 12.5 *m*/*s* – $C_v = 4.5 / (4.5 + v)$

  For very carefully cut and ground metallic gears operating at velocities

  up to 20 *m/s* - $C_v = 6 / (6 + v)$ where v – pitch line velocity (*m*/*s*)

  For helical gears with pitch line velocities up to 5.0 *m/s* – $C_v = 4.58 / (4.58 + v)$

- For gears, basic Lewis Equation $F_t = \sigma_o C_v\, b\, P_c\, y$, where σ_o is the allowable static stress, C_v is the velocity factor, b is the face width, P_c is the circular pitch and y is the Lewis form factor.

- Dynamic load on the gear tooth can be estimated from,

$$F_d = \frac{21V\,(bC + F_t)}{21V + \sqrt{bC + F_t}} + F_t$$

where, F_d - dynamic load, N , F_t - tangential tooth load, N
V - pitch line velocity, m/s b - face width, m

$$F_t = \frac{\text{Gear Torque}}{\text{Pitch radius}} = \frac{2\,M_t}{D}$$

C- a constant, in *N*/*m* depending on the tooth form, material and the accuracy with which the tooth is cut.

Static Tooth Load = $F_s = \sigma_e \, b \, P_c \, y$; where σ_e is the flexural endurance limit, b is the face width, P_c is the circular pitch and y is the Lewis form factor.

For safety against tooth breakage, the static tooth load F_s should be greater than the dynamic load F_d.

Use the following relationships to ensure that tooth breakage is avoided.

For steady loads; $F_s \geq 1.25 \ F_d$

For pulsating loads; $F_s \geq 1.35 \ F_d$

Wear tooth load F_w may be determined using,

$$F_w = D_p \, b \, Q \, K$$

where D_p = pitch circle diameter of pinion in m

b = face width in m

Q = Ratio factor = $2Z_w / (Z_p + Z_w)$ (for external gears)

Z_w and Z_p are the numbers of teeth on wheel and pinion respectively.

K- Stress factor for surface fatigue and can be calculated from

$$K = \frac{\sigma_{es}^2 (\mathrm{Sin}\,\psi)(1/E_p + 1/E_g)}{1.4}$$

or its values can be extracted from the tables.

σ_{es} = surface endurance limit of a gear pair, *N/m*^{2}

E_p = modulus of elasticity of the pinion material, *N/m*^{2}

Eg = modulus of elasticity of the gear material, *N/m*^{2}

ψ = pressure angle.

The surface endurance limit may be estimated from,

$$\sigma_{es} = (2.75\ (\mathrm{BHN})\text{-}70)\ MN/m^2$$

where BHN may be approximated by the average Brinell hardness number of the gear and pinion up to a BHN of about 350 for steels.

The wear load F_w is the allowable load and must be greater than the dynamic load F_d.

Values of Deformation Factor *C* in *kN*/*m* – for dynamic load check

,

Materials		**Involute tooth form**	**Tooth Error - *mm***				
Pinion	Gear		0.01	0.02	0.04	0.06	0.08
Cast iron	Cast iron	$14\frac{1}{2}^{o}$	55	110	220	330	440
Steel	Cast iron	$14\frac{1}{2}^{o}$	76	152	304	456	608
Steel	Steel	$14\frac{1}{2}^{o}$	110	220	440	660	880
Cast iron	Cast iron	20^{o} full depth	57	114	228	342	456
Steel	Cast iron	20^{o} full depth	79	158	316	474	632
Steel	Steel	20^{o} full depth	114	228	456	684	912
Cast iron	Cast iron	20^{o} stub	59	118	236	354	472
Steel	Cast iron	20^{o} stub	81	162	324	486	648
Steel	Steel	20^{o} stub	119	238	476	714	952

Values of Flexural Endurance Limit (σ_e)

Material of pinion and wheel	Brinell hardness number (BHN)	Flexural endurance limit (σ_e) in MPa
Grey cast iron	160	84
Semi-steel	200	126
Phosphor bronze	100	168
Steel	150	252
	200	350
	240	420
	280	490
	300	525
	320	560
	350	595
	360	630
	400 and above	700

Values for σ_{es} as used in the wear load equation depend upon a combination of the gear and pinion materials. Some values for various materials for both $ó_{es}$ and *K* are tabulated below.

Average Brinell Hardness Number of steel pinion and steel gear		Surface Endurance Limit σ_{es} (*MN/m²*)	Stress Fatigue Factor K (*kN/m²*)	
			14 ½ °	20°
150		342	206	282
200		480	405	555
250		618	673	919
300		755	1004	1372
400		1030	1869	2553
Brinnel Hardness Number BHN				
Steel Pinion	Gear			
150	C.I.	342	303	414
200	C.I.	480	600	820
250	C.I.	618	1000	1310
150	Phosphor Bronze	342	317	427
200	Phosphor Bronze	445	503	689
C.I. Pinion	**C.I. Gear**	549	1050	1420
C.I. Pinion	**C.I. Gear**	618	1330	1960

Form Factors y – for use in Lewis Strength Equation (transformed), $F = s^2 kym^2$ are given in the following table;

Number of Teeth	14 ½ ° Full-Depth Involute or Composite	20 ° Full-Depth Involute	20 ° Stub Involute
12	0.067	0.078	0.099
13	0.071	0.083	0.103
14	0.075	0.088	0.108
15	0.078	0.092	0.111
16	0.081	0.094	0.115
17	0.084	0.096	0.117
18	0.086	0.098	0.120
19	0.088	0.100	0.123
20	0.090	0.102	0.125
21	0.092	0.104	0.127
23	0.094	0.106	0.130
25	0.097	0.108	0.133
27	0.099	0.111	0.136
30	0.101	0.114	0.139
34	0.104	0.118	0.142
38	0.106	0.122	0.145
43	0.108	0.126	0.147
50	0.110	0.130	0.151
60	0.113	0.134	0.154
75	0.115	0.138	0.158
100	0.117	0.142	0.161
150	0.119	0.146	0.165
300	0.122	0.150	0.170
Rack	0.124	0.154	0.175

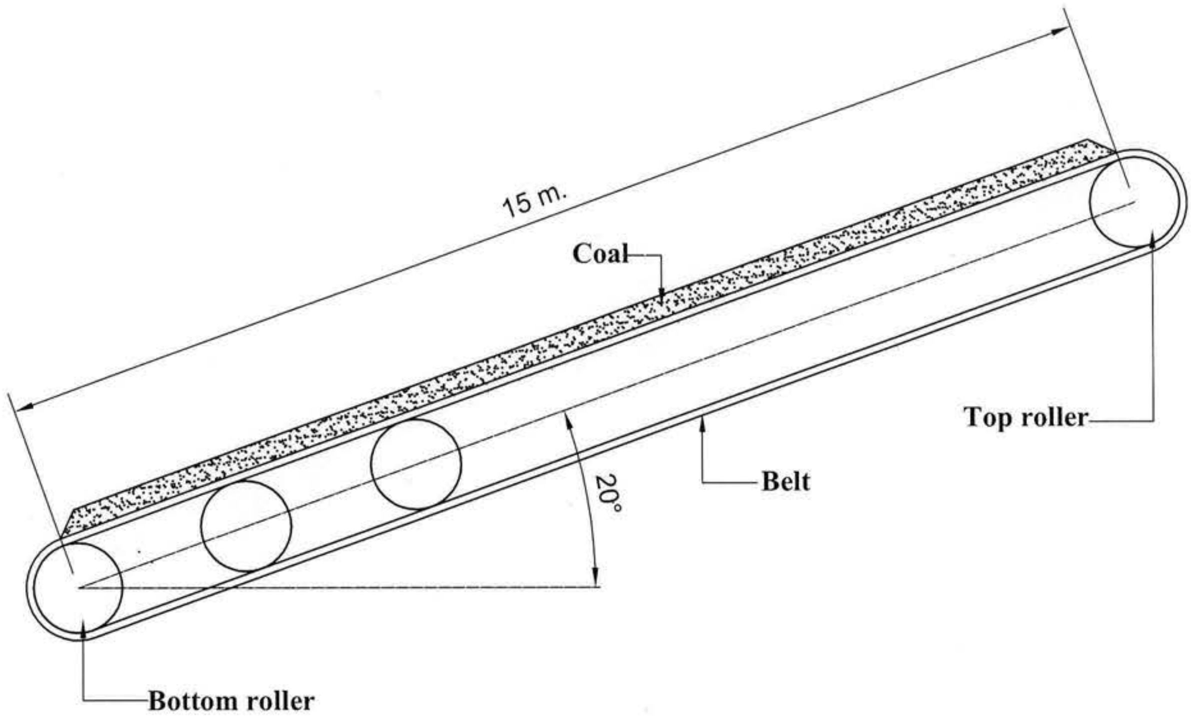


Figure Q1a : Schematic Diagram of the Belt Conveyor

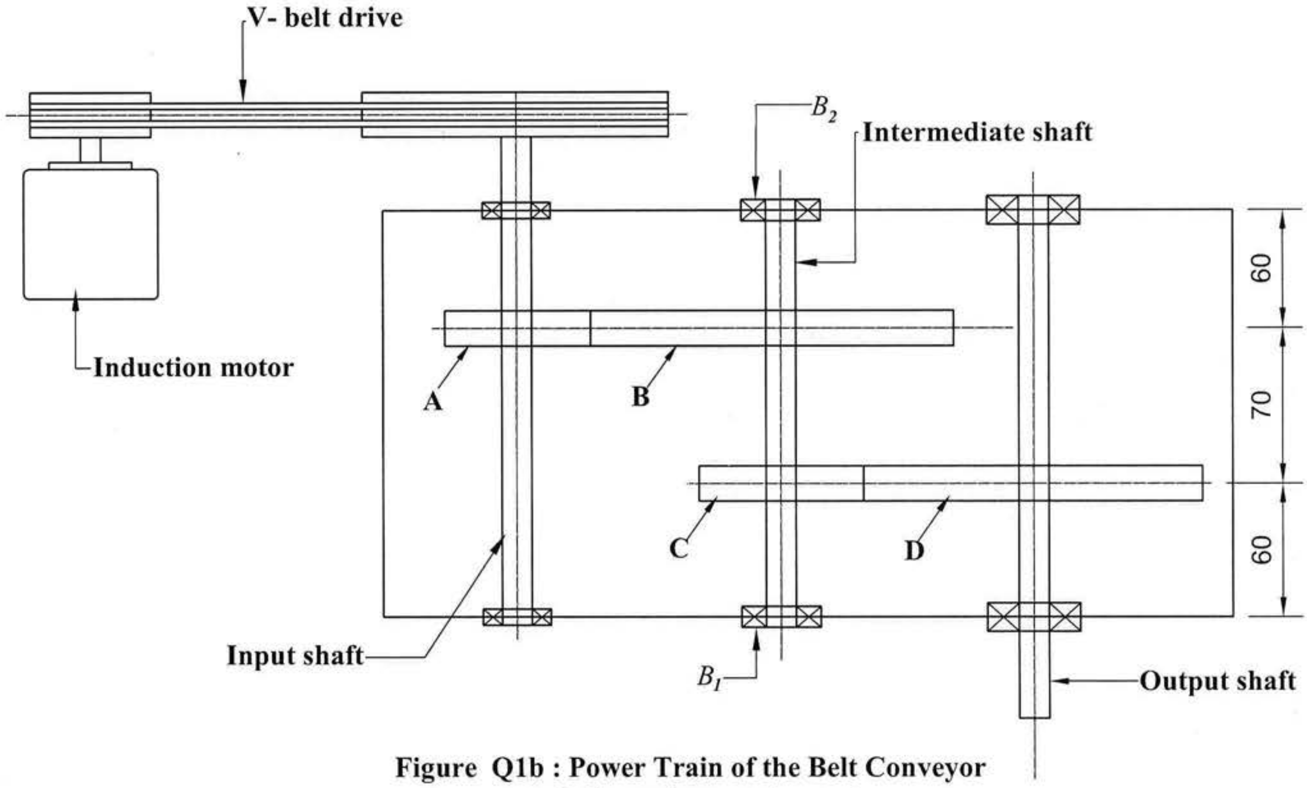


Figure Q1b : Power Train of the Belt Conveyor

(All dimensions are in mm.)

Not to Scale

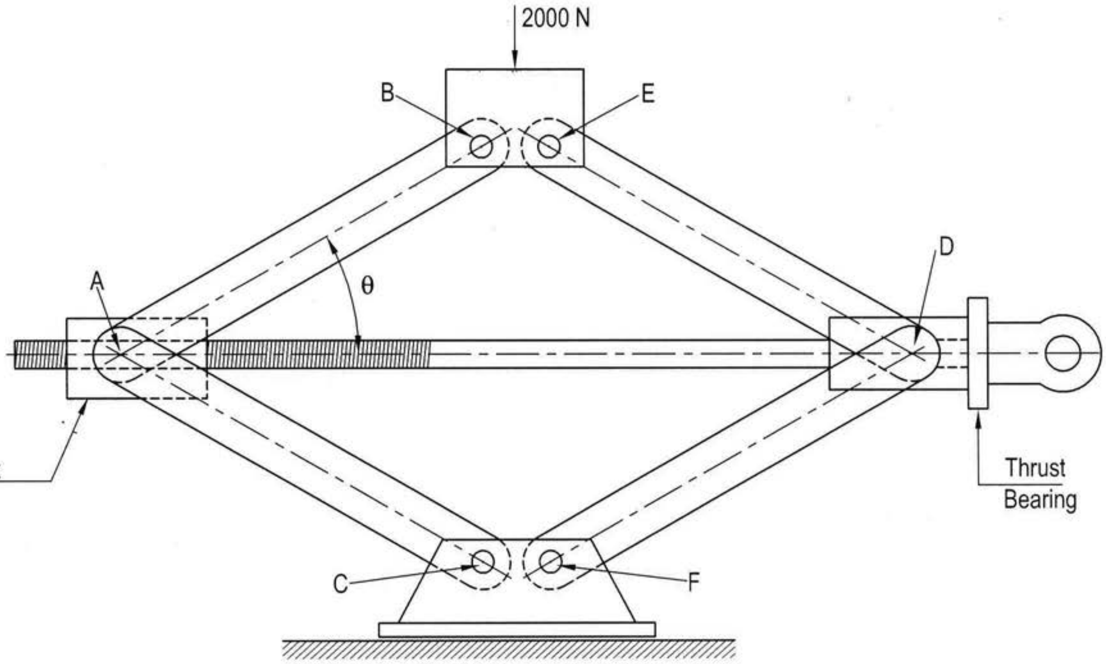


Figure Q2a

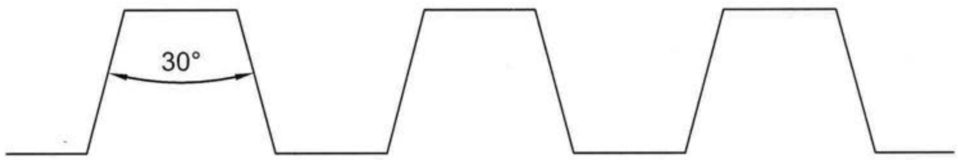


Figure Q2b

Friction torque at a thrust bearing $= \mu W R_m$

where, μ = coefficient of friction

W = thrust load at the bearing

R_m = mean radius of the bearing

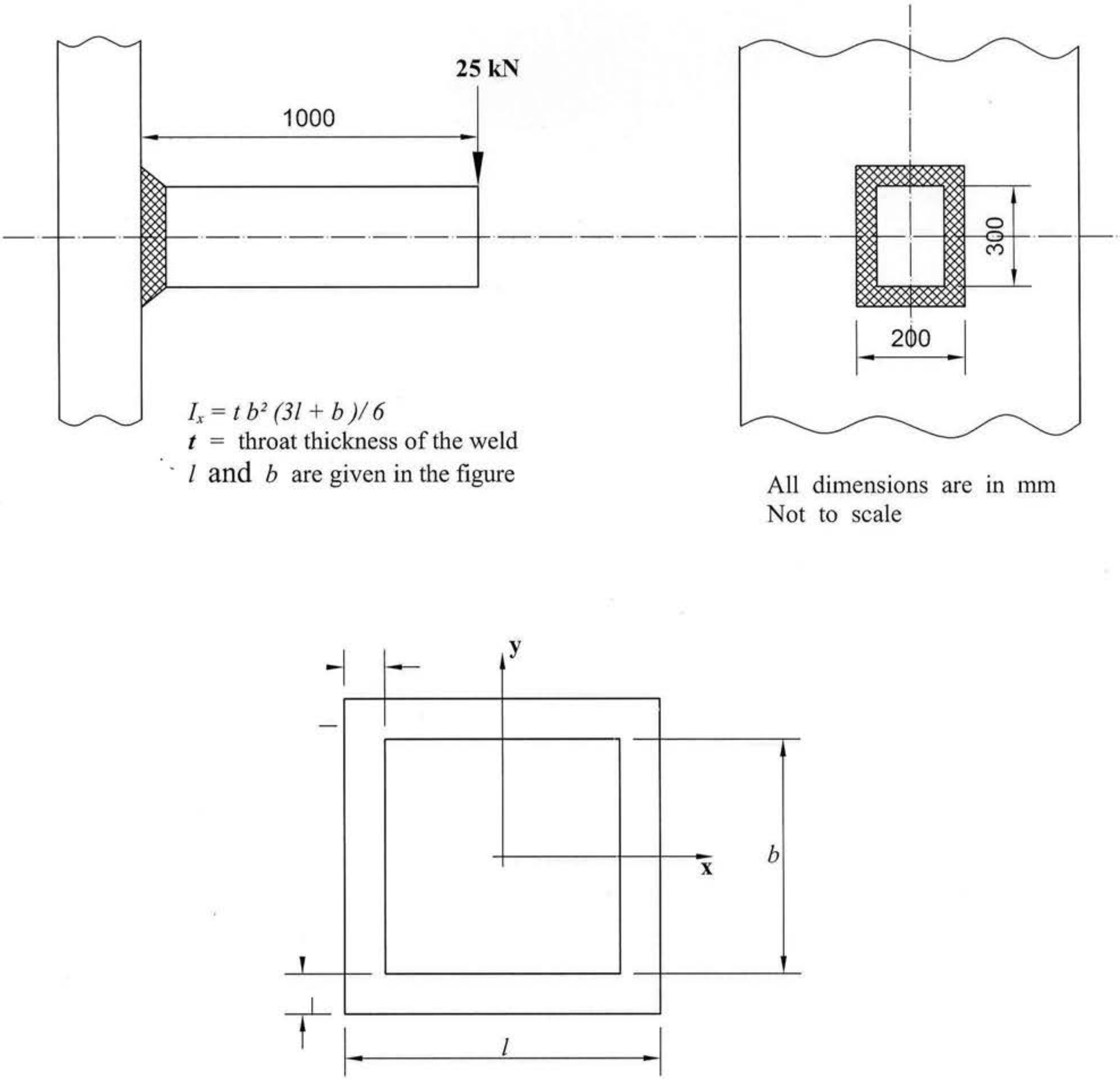
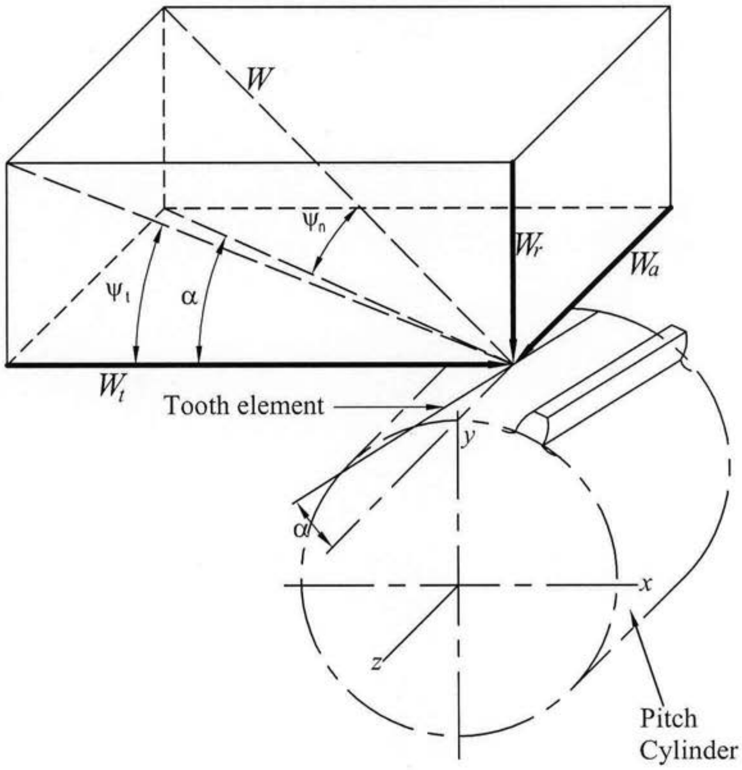


Figure Q5 : Eccentrically loaded welded joint



W_t - tangential tooth load on a transverse plane

W_r - radial tooth load

W_a - axial tooth load

α - Helix angle

ψ_n - Normal pressure angle

ψ_t - Transverse pressure angle

Figure Q6: Forces acting on a helical gear

Equivalent Spur Wheel:

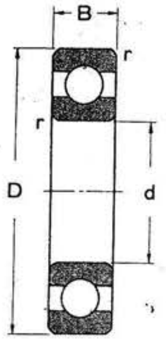
A helical gear with T teeth and helix angle α is equivalent to a spur gear with T_e teeth, where

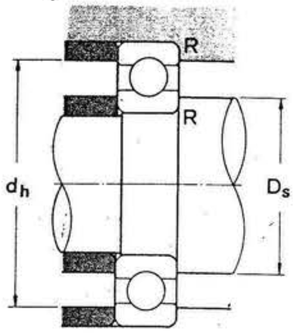
$$T_e = T\,\mathrm{Sec}^3(\alpha)$$

NTN Deep Groove Ball Bearings

Open type

d 28–50 mm





Equivalent bearing load
dynamic
$P_r = XF_r + YF_a$

$\frac{F_a}{C_{or}}$	e	$\frac{F_a}{F_r} \leq e$ X	$\frac{F_a}{F_r} \leq e$ Y	$\frac{F_a}{F_r} > e$ X	$\frac{F_a}{F_r} > e$ Y
0.010	0.18	1	0	0.56	2.46
0.020	0.20				2.14
0.040	0.24				1.83
0.070	0.27				1.61
0.10	0.29				1.48
0.15	0.32				1.35
0.20	0.35				1.25
0.30	0.38				1.13
0.40	0.41				1.05
0.50	0.44				1.00

static
$P_{or} = 0.6 F_r + 0.5 F_a$
When $P_{or} < F_r$ use $P_{or} = F_r$.

Boundary dimensions mm d	D	B	r	Basic load ratings N dynamic C_r	static C_{or}	Limiting speeds rev/min grease	oil	Bearing number	Abutment and fillet dimensions mm D_s min	d_h max	R max	Mass kg
28	52	12	1	9 600	6 550	14 000	16 000	60/28	33	47	0.6	0.098
	58	16	1.5	13 800	9 050	12 000	14 000	62/28	34	52	1	0.171
	68	18	2	20 600	13 700	11 000	13 000	63/28	35	61	1	0.284
30	42	7	0.5	3 600	2 960	15 000	18 000	6806	32	40	0.3	0.026
	47	9	0.5	5 550	4 200	14 000	17 000	6906	32	45	0.3	0.048
	55	9	0.5	8 650	6 300	13 000	15 000	16006	32.5	52.5	0.3	0.091
	55	13	1.5	10 200	7 250	13 000	15 000	6006	36	49	1	0.116
	62	16	1.5	15 000	10 300	11 000	13 000	6206	36	56	1	0.199
	72	19	2	20 500	14 100	10 000	12 000	6306	37	65	1	0.360
32	58	13	1.5	11 600	8 100	12 000	15 000	60/32	38	52	1	0.129
	65	17	1.5	16 000	10 700	11 000	12 000	62/32	38	59	1	0.226
	75	20	2	23 000	16 000	9 500	11 000	63/32	39	68	1	0.382
35	47	7	0.5	3 750	3 300	13 000	16 000	6807	37	45	0.3	0.029
	55	10	1	8 600	6 350	12 000	15 000	6907	39	51	0.6	0.074
	62	9	0.5	10 100	7 350	12 000	14 000	16007	37.5	59.5	0.3	0.110
	62	14	1.5	12 300	8 950	12 000	14 000	6007	41	56	1	0.155
	72	17	2	19 700	14 000	9 800	11 000	6207	42	65	1	0.288
	80	21	2.5	25 600	18 000	8 800	10 000	6307	43.5	71.5	1.5	0.457
40	52	7	0.5	3 900	3 650	12 000	14 000	6808	42	50	0.3	0.033
	62	12	1	9 350	7 450	11 000	13 000	6908	44	58	0.6	0.110
	68	9	0.5	10 500	8 050	10 000	12 000	16008	42.5	65.5	0.3	0.125
	68	15	1.5	12 900	9 900	10 000	12 000	6008	46	62	1	0.190
	80	18	2	22 400	16 200	8 700	10 000	6208	47	73	1	0.366
	90	23	2.5	31 500	22 600	7 800	9 200	6308	48.5	81.5	1.5	0.630
45	58	7	0.5	4 900	4 700	11 000	12 000	6809	47	56	0.3	0.040
	68	12	1	11 600	9 450	9 800	12 000	6909	49	64	0.6	0.128
	75	10	1	11 500	9 500	9 200	11 000	16009	50	70	0.6	0.171
	75	16	1.5	16 100	13 000	9 200	11 000	6009	51	69	1	0.237
	85	19	2	25 200	18 400	7 800	9 200	6209	52	78	1	0.398
	100	25	2.5	40 500	30 000	7 000	8 200	6309	53.5	91.5	1.5	0.814
50	65	7	0.5	5 050	5 150	9 600	11 000	6810	52	63	0.3	0.052
	72	12	1	12 000	10 200	8 900	11 000	6910	54	68	0.6	0.132
	80	10	1	11 900	10 200	8 400	9 800	16010	55	75	0.6	0.180
	80	16	1.5	16 800	14 100	8 400	9 800	6010	56	74	1	0.261
	90	20	2	27 000	20 700	7 100	8 300	6210	57	83	1	0.454
	110	27	3	47 500	36 000	6 400	7 500	6310	60	100	2	1.07