DESIGN DATA HANDBOOK

S. Md. JALALUDEEN

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In SI UNITS

For MECHANICAL ENGINEERS

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CHAPTER – 1

DESIGN FUNDAMENTALS

Table 1.1

S.I. Basic Quantities and Their Units

	Quantity	Unit	Symbol
	Base units :		
1.	Length	metre	m
2.	Mass	kilogram	kg
3.	Time	second	s
4.	Electric current	ampere	A
5.	Thermodynamic temperature	kelvin	K
6.	Amount of substance	mole	mol
7.	Luminus intensity	candela	Cd
	Supplementary units :		
1.	Plane angle	radian	rad
2.	Solid angle	steradian	sr

Table 1.2

S.I.Derived Quantities and Their Units

Quantity	Unit	S.I. symbol	Formula
Acceleration	metre per second squared		m/s^2
Angular acceleration	radian per second squared		rad/s^2
Angular displacement	radian		rad
Angular momentum	kilogram-metre squared per second		$kg - m^2/s$
Angular velocity	radian per second	ω	rad/s
Area	square metre		m^2
Calorific value	joule per kilogram		J/kg
Density	kilogram per cubic metre		kg/m^3
Discharge	cubic metre per second		m^3/s
Energy, Enthalpy	joule	J	N-m
Entropy	joule per kilogram kelvin		J/kg-K
Force	newton	N	$kg - m/s^2$
Force, couple, moment	newton metre		N-m
Frequency	hertz	Hz	cycles/s
Heat	joule	J	N–m.
Modulus of elasticity	newton per square metre		N/m^2
Momentum	kilogram metre per second		kg-m/s
Moment of inertia	kilogram-metre squared		$kg - m^2$
Power	watt	W	J/s
Pressure	pascal	Pa	N/m^2
Specific enthalpy	joule per kilogram		J/kg
Specific volume	kilogram per cubic metre		kg/m^3
Specific heat	joule per kilogram kelvin		J/kg.K
Speed	revolution per second		rev/s

Quantity	Unit	S.I. symbol	Formula
Surface tension	newton per metre		N/m
Stress	pascal	Pa	N/m^2
Torque	newton-metre		N-m
Velocity	metre per second		m/s
Viscosity (dynamic)	newton second per metre squared		Ns/m^2
Viscosity (kinematic)	metre square per second		m^2/s
Volume	cubic metre		m^3
Work	joule	J	N-m

Table 1.3: Standard Prefixes of SI Units :

Name	Symbol	Multiplying factor
exa	E	$1\ 000\ 000\ 000\ 000\ 000\ 000 = 10^{18}$
peta	P	$1\ 000\ 000\ 000\ 000\ 000 = 10^{15}$
tera	T	$1\ 000\ 000\ 000\ 000 = 10^{12}$
giga	G	$1\ 000\ 000\ 000 = 10^{9}$
mega	M	$1\ 000\ 000 = 10^{6}$
kilo	K, k	$1\ 000 = 10^{3}$
hecto	h	$100 = 10^{2}$
deca	da	$10 = 10^{1}$
deci	d	$0.1 = 10^{-1}$
centi	c	$0.01 = 10^{-2}$
milli	m	$0.001 = 10^{-3}$
micro	μ	$0.000\ 001 = 10^{-6}$
nano	n	$0.000\ 000\ 001 = 10^{-9}$
pico	p	$0.000\ 000\ 000\ 001 = 10^{-12}$
femto	f	$0.000\ 000\ 000\ 000\ 001 = 10^{-15}$
atto	a	$0.000\ 000\ 000\ 000\ 000\ 001 = 10^{-18}$

Note : - 1 Aungstron $= 10^{-10}$ metre

Table 1.4: Some Standard Quantities in SI/MKS/CGS Units and their Relations

Quantities	SI Units	MKS Units	CGS Units	Ratio MKS/SI	Ratio CGS/SI
Length	metre (m)	metre (m)	centimetre (cm)	1.0	10^{-2}
Mass	kilogram (kg)	kilogram (kg)	gram (g)	1.0	10^{-3}
Time	second (s)	second (sec)	second (s)	1.0	1.0
Force	newton (N)	Kilogram force (kgf)	dyne (dyn)	9.81	10^{-5}
Stress	pascal, Pa (N/m^2)	kgf/m^2	dyn/cm^2	9.81	10^{-1}
Pressure	pascal, Pa (N/m^2)	kgf/m^2	dyn/cm^2	9.81	10^{-1}
Work	joule, J (N-m)	kgf-m	dyn-cm (erg)	9.81	10^{-7}
Energy	joule, J (N-m)	kgf-m	dyn-cm (erg)	9.81	10^{-7}
Power	watt, W (N-m/s)	Horse Power (H.P) 1HP = 75 kgf-m/s	dyn-cm/s	735.5	10^{-7}

The Greek Alphabet:

Α	α	Alpha	Ι	ι	Iota	Ρ	ρ	Rho
Β	β	Beta	Κ	κ	Kappa	Σ	σ	Sigma
Γ	γ	Gamma	Λ	λ	Lambda	Τ	τ	Tau
Δ	δ	Delta	Μ	μ	Mu	Υ	υ	Upsilon
Ε	ε	Epsilon	Ν	ν	Nu	Φ	φ	Phi
Ζ	ζ	Zeta	Ξ	ξ	Xi	Χ	χ	Chi
Η	η	Eta	Ο	ο	Omicron	Ψ	ψ	psi
Θ	θ	Theta	Π	π	Pi	Ω	ω	Omega

Table 1.5: General Physical Quantities in Mechanical and Thermal Sciences with SI Units

Sl. No.	Quantity	SI units	Some recommended multiples and submultiples of SI units	Other permissible units	Remarks
(1)	(2)	(3)	(4)	(5)	(6)
1.	Length (wave length)	m (metre)	km, mm, μm, nm	cm (limited use only)	'μm' is sometimes called 'micron'
2.	Mass	kg (kilogram)	Mg, g, mg, μg	tonne (t) = 10^3 kg quintal (q) = 10^2 kg	the metric carat $= 2 \times 10^{-4}$ kg, for precious materials
3.	Time (period)	s (second)	ks, ms, μs, ns	day (d), hour (h), minute (min)	other units like week, month and year are in common use
4.	Plane angle (angular displacement)	rad (radian)	m rad, μ rad	degree = $\pi/180$ rad minute′ = 1°/60 second″ = 1′/60 grade (g) = $\pi/200$ rad	–
5.	Solid angle	sr (steradian)	–	–	–
6.	Area	m^2	km^2, mm^2	hectare (ha =) 10^4 m^2 are (a) = 10^2 m^2	cm^2 for limited use only

(1)	(2)	(3)	(4)	(5)	(6)
7.	Volume	m^3	mm^3	hectolitre (hl) litre (l) = dm^3 millilitre (ml)	litre and its multiples for limited use
8.	Frequency	Hz (hertz)	THz, GHz, MHz, kHz	–	1 Hz = 1 c/s
9.	Rotational frequency	s^{-1}	–	revolution per minute or per second	–
10.	Velocity	m/s	–	km/h = (1/3.6) m/s	–
11.	Acceleration	m/s^2	–	–	–
12.	Angular acceleration	rad/s^2	–	–	–
13.	Density	kg/m^3	Mg/m^3	t/m^3, kg/l, g/l, g/ml	1 g/l = 1 kg/m^3 1 kg/l = 1 kg/dm^3 1 g/ml = 1 g/cm^3
14.	Momentum	kg m/s	–	–	–
15.	Moment of momentum	kg m^2/s	–	–	–
16.	Moment of inertia	kg m^2	–	–	–
17.	Force	N(newton)	MN, kN, mN	–	–
18.	Moment of force	Nm	MNm, kNm, μNm	Nmm	–
19.	Pressure (normal stress)	N/m^2	GN/m^2 = kN/mm^2 MN/m^2, kN/m^2, mN/m^2, $\mu N/m^2$	1 h bar = 10^7 N/m^2 1 bar = 10^5 N/m^2 1 m bar = 10^2 N/m^2 1 μ bar = 10^{-1} N/m^2	the special name 'pascal' for N/m^2 is under consideration.

(1)	(2)	(3)	(4)	(5)	(6)
20.	Dynamic viscosity	Ns/m^2	mNs/m^2	poise (P) $= 10^{-1}\ Ns/m^2$ centipoise (cP) $= 10^{-3}\ Ns/m^2$	poise (P) = $dyn\text{-}s/cm^2$ (cgs unit) poiseuille (Pl) = Ns/m^2 (MKS) (SI)
21.	Kinematic viscosity	m^2/s	–	stokes (St) $= 10^{-4}\ m^2/s$ centistokes (cSt) $= 10^{-6}\ m^2/s$	–
22.	Power	W (watt)	GW, MW, kW, mW, μW	–	$W = J/s = Nm/s$
23.	Impact strength	J/m^2	kJ/m^2	–	–
24.	Temperature	K(kelvin)	–	–	–
25.	Customary temperature	°C	–	–	°C = degree celsius
26.	Temperature interval	K, °C	–	–	1°C = 1K
27.	Linear coefficient of expansion	K^{-1}, $°C^{-1}$	–	–	–
28.	Heat	J	TJ, GJ, MJ, kJ, mJ	–	–
29.	Thermal conductivity	W/mK, W/m°C	–	–	–
30.	Heat capacity	J/K, J/°C	kJ/K, kJ/°C	–	–
31.	Internal energy	J	–	–	–
32.	Entropy	J/K	–	–	–

Table 1.6: Conversion Factors for Various Quantities

(a) Length

1 in	=	25.4 mm
1 ft	=	0.3048 m
1 yard	=	0.9144 m
1 mile	=	1.609 34 km
1 mm	=	0.039 37 in
1 m	=	39.37 in
1 m	=	1.093 61 yards
1 km	=	0.621 37 mile

(b) Area

1 in^2	=	645.16 mm^2
1 ft^2	=	0.092 90 m^2
1 sq. yard	=	0.836 13 m^2
1 sq. mile	=	2.589 99 km^2
1 acre	=	0.404 69 hectare
1 mm^2	=	0.001 55 in^2
1 m^2	=	1550 in^2
1 m^2	=	1.195 99 sq. yard
1 km^2	=	0.386 10 sq. mile
1 hectare	=	2.471 05 acres

(c) Volume and capacity

1 in^3	=	16 387 mm^3
1 ft^3	=	0.028 32 m^3
1 pint	=	0.568 24 litre
1 quart	=	1.136 49 litres
1 gallon (UK)	=	4.545 96 litres
1 gallon (US)	=	3.785 33 litres
1 mm^3	=	0.000 06 in^3
1 m^3	=	61 023 in^3
1 litre	=	1.759 80 pints
1 litre	=	0.879 90 quart
1 litre	=	0.219 98 gallon (UK)
1 litre	=	0.264 18 gallon (US)

(d) Moment of inertia

1 in^4	=	416 231 mm^4
1 ft^4	=	0.008 63 m^4
1 mm^4	=	0.000 002 4 in^4
1 m^4	=	2.402 49 in^4

(e) Force

1 lbf	=	0.453 59 kgf
1 lbf	=	4.448 22 N
1 tonf	=	1 016 kgf
1 tonf	=	9 964.012 N
1 kgf	=	2.205 lbf
1 kgf	=	9.806 65 N
1 tonnef	=	2 205 lbf
1 tonnef	=	1000 kgf
1 tonnef	=	9 806.65 N
1 newton	=	0.102 kgf
1 newton	=	0.224 81 lbf
1 newton	=	100 000 dynes

(f) Force per unit length (Stiffness)

1 lbf/ft	=	1.488 16 kgf/m
1 lbf/ft	=	14.59 N/m
1 tonf/ft	=	3 333.478 kgf/m
1 tonf/ft	=	32690 N/m
1 kgf/m	=	0.671 97 lbf/ft
1 kgf/m	=	9.806 65 N/m
1 tonnef/m	=	671.970 lbf/ft
1 tonnef/m	=	9806.65 N/m
1 N/m	=	0.102 kgf/m
1 N/m	=	0.224 8 lbf/m
1 N/m	=	0.068 5 lbf/ft

(g) Bending moment

1 lbf in	=	11.521 2 kgf mm
1 lbf in	=	112.9 N mm
1 lbf ft	=	0.138 25 kgf m
1 lbf ft	=	1.355 81 N m
1 tonf in	=	25.807 45 kgf m
1 tonf ft	=	3037 N m
1 tonf in	=	253 084 N mm
1 tonf ft	=	309.688 kgf m
1 kgf mm	=	0.007 23 lbf ft
1 kgf mm	=	0.086 81 lbf in
1 kgf mm	=	9.806 65 N mm
1 kgf m	=	7.234 25 lbf ft
1 kgf m	=	86.811 07 lbf in
1 kgf m	=	9.806 65 N m
1 tonnef mm	=	7.234 3 lbf ft
1 tonnef mm	=	86.811 07 lbf in
1 tonnef mm	=	9 806.65 N mm
1 tonnef m	=	7 234.255 8 lbf ft
1 tonnef m	=	86 811.07 lbf in
1 tonnef m	=	9 806.65 N m
1 N m	=	0.109 72 kgf m
1 N m	=	8.850 39 lbf in
1 N m	=	0.737 53 lbf ft

(h) Pressure and stress

1 lbf/in^2	=	0.000 70 kgf/mm^2
1 lbf/in^2	=	0.006 90 N/mm^2
1 tonf/in^2	=	1.575 kgf/mm^2
1 tonf/in^2	=	15.444 N/mm^2
1 tonf/ft^2	=	10936.6 kgf/m^2
1 kgf/mm^2	=	1 422.33 lbf/in^2
1 kgf/mm^2	=	9.806 65 N/mm^2
1 tonnef/m^2	=	204.8 lbf/ft^2
1 tonnef/m^2	=	9 806.65 N/m^2
1 tonf/ft^2	=	107 251 N/m^2
1 N/m^2	=	0.102 kgf/m^2
1 N/m^2	=	0.000 15 lbf/in^2
1 N/m^2	=	0.020 87 lbf/ft^2

(i) Density

1 lb/in^3	=	0.000 028 kg/mm^3
1 lb/ft^3	=	16.018 5 kg/m^3
1 kg/mm^3	=	36 127.30 lb/in^3
1 kg/m^3	=	0.000 036 lb/in^3

(j) Miscellaneous conversion factors

1 atm	=	1.013 3 bar
1 atm	=	1.033 kgf/cm^2
1 atm	=	14.700 lbf/in^2
1 atm	=	760 mm of Hg
1 atm	=	101 330 N/m^2
1 bar	=	0.986 88 atm
1 bar	=	1 000 000 dynes/cm^2
1 bar	=	1.020 kgf/cm^2
1 bar	=	14.500 lbf/in^2
1 bar	=	100 000 N/m^2
1 Btu	=	1 055.100 J
1 Btu	=	0.252 kcal
1 Btu	=	0.000 293 kWh
1 Btu	=	1 055 N m
1 Btu/ft h F	=	1.730 8 J/m sK
1 Btu/ft h F	=	1.488 kcal/m h° C
1 Btu/ft^{2}h	=	0.003 15 kW/m^2
1 Btu/ft^{2}h	=	2.712 kcal/m^{2}h
1 Btu/ft^{2}h F	=	5.678 4 W/m^2 °C
1 Btu/ft^3	=	37 260 J/m^3
1 Btu/hr	=	0.000 29 kW
1 Btu/lb	=	2 326 J/kg
1 Btu/lb F	=	4 186.800 J/kg K
1 Btu/s	=	1.415 hp (FPS)
1 Btu/s	=	1.435 hp (metric)
1 Btu/s	=	1.055 1 kW
1 cal	=	4.186 8 J
1 cal/s	=	0.004 19 kW
1 Chu	=	1.899 1 kJ
1 Chu/ft^3	=	0.067 07 MJ/m^3
1 Chu/hr	=	0.000 53 kW
1 Chu/h ft°C	=	1.730 8 W/m C
1 Chu/h ft^2	=	0.005 68 kW/m^2
1 Chu/lb	=	4.186 8 kJ/kg
1 deg (angle)	=	0.017 45 rad
1 deg/s	=	0.002 78 rev/s
1 dyne	=	0.010 mN
1 dyne/cm^2	=	0.100 N/m^2
1 erg	=	1.000 dyne-cm
1 erg	=	0.000 1 mJ
1 erg/s	=	0.000 000 1 W
1 ft candle	=	10.760 lux
1 ft lbf	=	1.355 8 J

1 ft lbf	=	0.000 32 kcal
1 ft lbf	=	0.138 3 kgf m
1 ft lbf/min	=	0.022 6 W
1 ft lbf/s	=	0.077 17 Btu/min
1 ft lbf/s	=	0.001 84 hp (metric)
1 ft lbf/s	=	0.019 45 kcal/min
1 ft lbf/s	=	1.355 8 W
1 ft/min	=	0.018 29 km/h
1 ft/min	=	0.005 08 m/s
1 ft/s	=	1.097 km/h
1 ft/s	=	18.290 m/min
1 ft/s^2	=	0.304 8 m/s^2
1 ft^2/h	=	25.806 mm^2/s
1 ft^2/s	=	0.092 90 m^2/s
1 ft^3/h	=	0.028 32 m^3/h
1 ft^3/lb	=	0.062 43 m^3/kg
1 ft pdl	=	0.042 14 J
1 ft pdl/s	=	0.042 14 W
1 ft water	=	0.029 5 atm
1 furlong	=	201.200 m
1 hemisphere (solid angle)	=	6.283 Steradians
1 hemisphere (solid angle)	=	4.000 Spherical right angles
1 hp (boiler)	=	55.870 Btu/min
1 hp (boiler)	=	980.400 W

1 hp (FPS)	=	33000 ft lbf/min
1 hp (FPS)	=	1.014 hp (metric)
1 hp (FPS)	=	10.700 kcal/min
1 hp (FPS)	=	0.745 7 kW
1 hp-hr (FPS)	=	2.684 5 MJ
1 hp (metric)	=	75.00 kgf m/s
1 hp (metric)	=	0.735 48 kW
1 hp-hr (metric)	=	2.647 7 MJ
1 hundred weight (cwt)	=	50.800 kg
1 hundred weight/cu. yard	=	66.450 kg/m^3
1 J	=	0.000 24 kcal
1 J	=	0.102 kgf m
1 J	=	0.000 28 W-hr
1 kcal	=	4.186 8 kJ
1 kcal/h	=	0.001 16 kW
1 kcal/h ft °C	=	3.815 6 W/m °C
1 kcal/h ft^2	=	0.012 52 kW/m^2
1 kcal/s	=	4.186 8 kW
1 kgf/m	=	9.806 65 J
1 kgf/ft h	=	0.911 34 cP
1 kg/m h	=	0.277 78 cP
1 kip	=	1000 lb
1 lbf	=	444.822 dynes
1 lb/ft	=	1.488 kg/m

1 lbf/ft^2	=	47.880 N/m^2
1 lb/ft^3	=	16.018 kg/m^3
1 lb/ft^3°F	=	28833 kg/m^3°C
1 lb/ft h	=	0.413 38 cP
1 lb/ft s	=	1.488 2 Ns/m^2
1 lb/in	=	17.860 kg/m
1 lb/in^3	=	27 680 kg/m^3
1 lumen/ft^2	=	1.000 ft-candle
1 lux	=	1.000 lumen/m^2
1 manud	=	37.320 kg
1 maund	=	40.000 seers
1 megaline	=	1 000 000 maxwells
1 micron	=	0.000 001 m
1 mile/h	=	0.447 04 m/s
1 mil	=	0.002 54 cm
1 minute(angle)	=	0.000 29 9 rad
1 nautical mile	=	1.853 km
1 N/m^2	=	0.01 mbar
1 Poise	=	0.0102 kgf-s/m^2
1 Poise	=	0.002 09 lbfs/ft^2
1 Poise	=	0.100 Ns/m^2
1 poundal	=	13.830 dynes
1 poundal	=	14.100 gmf
1 quintal	=	100 kg
1 quire	=	24 sheets
1 rad/s	=	0.159 2 rev/s
1 revolution	=	6.283 rad
1 rod	=	5.029 m
1 stoke	=	100 mm^2/s
1 tola	=	10.660 gm
1 tonne-cal/h	=	1.163 kW
1 ton refrigeration	=	3.516 9 kW
1 torr (mm Hg)	=	133.333 N/m^2

Table 1.7: Conversion Factors between SI and FPS Units

Sl.No.	Quantity	FPS unit	Equivalent SI unit	Reciprocal
1.	Length	1 inch (in)	2.54×10^{-2} m	39.370
		1 foot (ft)	30.48×10^{-2} m	3.281
		1 yard (yd)	91.44×10^{-2} m	1.094
		1 fathom	1.829 m	0.547
		1 chain	20.117 m	0.050
		1 furlong	201.17 m	0.005
		1 mile (mi)	1.609×10^{3} m	6.214×10^{-4}
2.	Area	1 in^2	6.452×10^{-4} m^2	1.55×10^{3}
		1 ft^2	9.290×10^{-2} m^2	10.764
		1 yd^2	0.836 m^2	1.196
		1 mi^2	2.59×10^{6} m^2	3.861×10^{-7}
		1 acre	4.047×10^{3} m^2	2.471×10^{-4}
3.	Volume	1 in^3	1.639×10^{-5} m^3	6.102×10^{4}
		1 ft^3	2.832×10^{-2} m^3	35.315
		1 yd^3	0.765 m^3	1.308
		1 fluid ounce (floz)	2.841×10^{-5} m^3	3.520×10^{4}
		1 pint (pt)	5.683×10^{-4} m^3	1.760×10^{3}
		1 quart (qt)	1.137×10^{-3} m^3	8.799×10^{2}
		1 gallon (gal)	4.546×10^{-3} m^3	2.200×10^{2}
		1 bushal (bu)	0.036 m^3	27.496
		1 gallon (USA)	3.785×10^{-3} m^3	2.642×10^{2}

Sl.No.	Quantity	FPS unit	Equivalent SI unit	Reciprocal
4.	Mass	1 ounce (oz)	2.835×10^{-2} kg	35.274
		1 pound (lb)	0.454 kg	2.205
		1 stone	6.350 kg	0.157
		1 quarter	12.700 kg	7.874×10^{-2}
		1 ton	1.016×10^{3} kg	9.842×10^{-4}
5.	Density	1 lb/in^3	2.768×10^{4} kg/m^3	3.613×10^{-5}
		1 lb/ft^3	16.018 kg/m^3	6.243×10^{-2}
6.	Force	1 poundal (pdl)	0.138 N	7.233
		1 lbf (pound force) (i.e., the wt. of 1 lb mass)	4.448 N	0.225
7.	Pressure, stress	1 pound force/in^2 (psi) (lbf/in^2)	6.895×10^{3} Pa	1.450×10^{-4}
8.	Energy, work	1 ft pdl	4.214×10^{-2} J	23.730
		1 ft lbf	1.356 J	0.738
		1 Btu	1.055×10^{3} J	9.478×10^{-4}
		1 therm	1.055×10^{8} J	9.478×10^{-9}
9.	Power	1 horse power (hp)	7.457×10^{2} W	1.341×10^{-3}
10.	Velocity	1 in/s	2.54×10^{-2} m/s	39.370
		1 ft/s	30.48×10^{-2} m/s	3.281
		1 mile/hour	1.609 km/hr	0.622
11.	Standard atmosphere	14.696 lbf/in^2	1.013×10^{5} Pa	–
12.	Standard acceleration of gravity	32.174 ft/s^2	9.807 m/s^2	–

Table 1.8: Conversion of Thermometric Scales

F = Temperature on the Fahrenheit scale

C = Temperature on the centigrade scale

K = Temperature on the Kelvin scale

$$C = \frac{5}{9}(F - 32)$$

$$C = K - 273.15$$

$$F = \frac{9}{5}C + 32$$

$$F = \frac{9}{5}K - 459.67$$

$$K = C + 273.15$$

$$K = \frac{5}{9}F + 255.37$$

Temperature Difference

$$1°C = \frac{9}{5}°F$$

$$1°C = 1K$$

$$1°F = \frac{5}{9}°C$$

$$1°F = \frac{5}{9}K$$

$$1K = 1°C$$

$$1K = \frac{9}{5}°F$$

Table 1.9: Basic Series of Preferred Numbers

R 5 $\phi = 1.6$	R 10 $\phi = 1.25$	R 20 $\phi = 1.12$	R 40 $\phi = 1.06$
1.00	1.00	1.00	1.00
			1.06
		1.12	1.12
			1.18
	1.25	1.25	1.25
			1.32
		1.40	1.40
			1.50
1.60	1.60	1.60	1.60
			1.70

R 5 $\phi = 1.6$	R 10 $\phi = 1.25$	R 20 $\phi = 1.12$	R 40 $\phi = 1.06$
		1.80	1.80
			1.90
	2.00	2.00	2.00
			2.12
		2.24	2.24
			2.36
2.50	2.50	2.50	2.50
			2.65
		2.80	2.80
			3.00
	3.15	3.15	3.15
			3.35
		3.55	3.55
			3.75
4.00	4.00	4.00	4.00
			4.25
		4.50	4.50
			4.75
	5.00	5.00	5.00
			5.30
		5.60	5.60
			6.00
6.30	6.30	6.30	6.30
			6.70
		7.10	7.10
			7.50
	8.00	8.00	8.00
			8.50
		9.00	9.00
			9.50
10.00	10.00	10.00	10.00

Table 1.10: Sheet and Wire Gauges (Thickness and diameter in inch & mm)

Gauge No. (SWG)	Thickness & diameter in		Gauge No. (SWG)	Thickness & diameter in	
	inch	mm		inch	mm
7/0	0.500	12.700	23	0.024	0.610
6/0	0.464	11.786	24	0.022	0.559
5/0	0.432	10.973	25	0.020	0.508
4/0	0.400	10.160	26	0.018	0.457
3/0	0.372	9.449	27	0.0164	0.4166
2/0	0.348	8.839	28	0.0148	0.3759
0	0.324	8.230	29	0.0136	0.3454
1	0.300	7.620	30	0.0124	0.3150
2	0.276	7.010	31	0.0116	0.2946
3	0.252	6.401	32	0.0108	0.2743
4	0.232	5.893	33	0.0100	0.2540
5	0.212	5.385	34	0.0092	0.2337
6	0.192	4.877	35	0.0084	0.2134
7	0.176	4.470	36	0.0076	0.1930
8	0.160	4.064	37	0.0068	0.1727
9	0.144	3.658	38	0.0060	0.1524
10	0.128	3.251	39	0.0052	0.1321
11	0.116	2.946	40	0.0048	0.1219
12	0.104	2.642	41	0.0044	0.1118
13	0.092	2.337	42	0.0040	0.1016
14	0.080	2.032	43	0.0036	0.0914
15	0.072	1.829	44	0.0032	0.0813
16	0.064	1.626	45	0.0028	0.0711
17	0.056	1.422	46	0.0024	0.0610
18	0.048	1.219	47	0.0020	0.0508
19	0.040	1.016	48	0.0016	0.0406
20	0.036	0.914	49	0.0012	0.0305
21	0.032	0.813	50	0.0010	0.0254
22	0.028	0.711			

Table 1.11: Limits, Fits and Tolerances

Diameter steps in mm	Value of tolerance in microns (1 micron = 0.001 mm)																	
	Tolerance grades IT																	
	01	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14*	15*	16*
Upto 3	0.3	0.5	0.8	1.2	2	3	4	6	10	14	25	40	60	100	140	250	400	600
Over 3 Upto 6	0.4	0.6	1	1.5	2.5	4	5	8	12	18	30	48	75	120	180	300	480	750
Over 6 Upto 10	0.4	0.6	1	1.5	2.5	4	6	9	15	22	36	58	90	150	220	360	580	900
Over 10 Upto 18	0.5	0.8	1.2	2	3	5	8	11	18	27	43	70	110	180	270	430	700	1100
Over 18 Upto 30	0.6	1	1.5	2.5	4	6	9	13	21	33	52	84	130	210	330	520	840	1300
Over 30 Upto 50	0.6	1	1.5	2.5	4	7	11	16	25	39	62	100	160	250	390	620	1000	1600
Over 50 Upto 80	0.8	1.2	2	3	5	8	13	19	30	46	74	120	190	300	460	740	1200	1900
Over 80 Upto 120	1	1.5	2.5	4	6	10	15	22	35	54	87	140	220	350	540	870	1400	2200
Over 120 Upto 180	1.2	2	3.5	5	8	12	18	25	40	63	100	160	250	400	630	1000	1600	2500
Over 180 Upto 250	2	3	4.5	7	10	14	20	29	46	72	115	185	290	460	720	1150	1850	2900
Over 250 Upto 315	2.5	4	6	8	12	16	23	32	52	81	130	210	320	520	810	1300	2100	3200
Over 315 Upto 400	3	5	7	9	13	18	25	36	57	89	140	230	360	570	890	1400	2300	3600
Over 400 Upto 500	4	6	8	10	15	20	27	40	63	97	155	250	400	630	970	1550	2500	4000

*Upto 1 mm, Grades 14 to 16 are not provided.

Table 1.12: Tolerances for Shafts

(Tolerances in microns)

System Basic hole		Symbol and grade	Diameter limit												
			Over 1	3	6	10	18	30	50	80	120	180	250	315	400
			Upto 3	6	10	18	30	50	80	120	180	250	315	400	500
Running fit-shafts	With large min. clearance	d11	–20 –80	–30 –105	–40 –130	–50 –160	–65 –195	–80 –240	–100 –290	–120 –340	–145 –395	–170 –460	–190 –510	–210 –570	–230 –630
	With medium min. clearance	e7	–14 –24	–20 –32	–25 –40	–32 –50	–40 –61	–50 –75	–60 –90	–72 –107	–85 –125	–100 –146	–110 –162	–125 –182	–135 –198
		e8	–14 –28	–20 –38	–25 –47	–32 –59	–40 –73	–50 –89	–60 –106	–72 –126	–85 –148	–100 –172	–110 –191	–125 –214	–135 –232
	With small minimum clearance	f7	–6 –16	–10 –22	–13 –28	–16 –34	–20 –41	–25 –50	–30 –60	–36 –71	–43 –83	–50 –96	–56 –108	–62 –119	–68 –131
		f8	–6 –20	–10 –28	–13 –35	–16 –43	–20 –53	–25 –64	–30 –76	–36 –90	–43 –106	–50 –122	–56 –137	–62 –151	–68 –165
	With smallest minimum clearance	g5	–2 –6	–4 –9	–5 –11	–6 –14	–7 –16	–9 –20	–10 –23	–12 –27	–14 –32	–15 –35	–17 –40	–18 –43	–20 –47
		g6	–2 –8	–4 –12	–5 –14	–6 –17	–7 –20	–9 –25	–10 –29	–12 –34	–14 –39	–15 –44	–17 –49	–18 –54	–20 –60
Transition fit-shafts	Slide fit	h5	0 –4	0 –5	0 –6	0 –8	0 –9	0 –11	0 –13	0 –15	0 –18	0 –20	0 –23	0 –25	0 –27
		h6	0 –6	0 –8	0 –9	0 –11	0 –13	0 –16	0 –19	0 –22	0 –25	0 –29	0 –32	0 –36	0 –40
		h8	0 –14	0 –18	0 –22	0 –27	0 –33	0 –39	0 –46	0 –54	0 –63	0 –72	0 –81	0 –89	0 –97
		h9	0 –25	0 –30	0 –36	0 –43	0 –52	0 –62	0 –74	0 –87	0 –100	0 –115	0 –130	0 –140	0 –155
		h11	0 –60	0 –75	0 –90	0 –110	0 –130	0 –160	0 –190	0 –220	0 –250	0 –290	0 –320	0 –360	0 –400

System Basic hole		Symbol and grade	Over 1 Upto 3	3 6	6 10	10 18	18 30	30 50	50 80	80 120	120 180	180 250	250 315	315 400	400 500
Push fit		j5	+2 −2	+3 −2	+4 −2	+5 −3	+5 −4	+6 −5	+6 −7	+6 −9	+7 −11	+7 −13	+7 −16	+7 −18	+7 −20
Push fit		j6	+4 −2	+6 −2	+7 −2	+8 −3	+9 −4	+11 −5	+12 −7	+13 −9	+14 −11	+16 −13	+16 −16	+18 −18	+20 −20
Wring fit	Secure against turning	k5	+4 0	+6 +1	+7 +1	+9 +1	+11 +2	+13 +2	+15 +2	+18 +3	+21 +3	+24 +4	+27 +4	+29 +4	+32 +5
Wring fit	Secure against turning	k6	+6 0	+9 +1	+10 +1	+12 +1	+15 +2	+18 +2	+21 +2	+25 +3	+28 +3	+33 +4	+36 +4	+40 +4	+45 +5
Tight fit	Secure against turning	m5	+6 +2	+9 +4	+12 +6	+15 +7	+17 +8	+20 +9	+24 +11	+28 +13	+33 +15	+37 +17	+43 +20	+46 +21	+50 +23
Tight fit	Secure against turning	m6	+8 +2	+12 +4	+15 +6	+18 +7	+21 +8	+25 +9	+30 +11	+35 +13	+40 +15	+46 +17	+52 +20	+57 +21	+63 +23
Tight fit	Secure against turning	n5	+8 +4	+13 +8	+16 +10	+20 +12	+24 +15	+28 +17	+33 +20	+38 +23	+45 +27	+51 +31	+57 +34	+62 +37	+67 +40
Tight fit	Secure against turning	n6	+10 +4	+16 +8	+19 +10	+23 +12	+28 +15	+33 +17	+39 +20	+45 +23	+52 +27	+60 +31	+66 +34	+73 +37	+80 +40
Interference fit		p6	+12 +6	+20 +12	+24 +15	+29 +18	+35 +22	+42 +26	+51 +32	+59 +37	+68 +43	+79 +50	+88 +56	+98 +62	+108 +68
Interference fit		r6	+16 +10	+23 +15	+28 +19	+34 +23	+41 +28	+50 +34	–	–	–	–	–	–	–
Interference fit		s6	+20 +14	+27 +19	+32 +23	+39 +28	+48 +35	+59 +43	–	–	–	–	–	–	–

Table 1.13: Tolerances for Holes (Tolerances in microns)

Table 1.13: Tolerances for Holes (Tolerances in microns)

System Basic shaft		Symbol and grade	Over 1 / Upto 3	3 / 6	6 / 10	10 / 18	18 / 30	30 / 50	50 / 80	80 / 120	120 / 180	180 / 250	250 / 315	315 / 400	400 / 500
Running fit-holes	With large min. clearance	D10	+60 +20	+78 +30	+98 +40	+120 +50	+149 +65	+180 +80	+220 +100	+260 +120	+305 +145	+355 +170	+400 +190	+440 +210	+480 +230
	With medium minimum clearance	E7	+24 +14	+32 +20	+40 +25	+50 +32	+61 +40	+75 +50	+90 +60	+107 +72	+125 +85	+146 +100	+162 +110	+182 +125	+198 +135
		E8	+28 +14	+38 +20	+47 +25	+59 +32	+73 +40	+89 +50	+106 +60	+126 +72	+148 +85	+172 +100	+191 +110	+214 +125	+232 +135
	With small minimum clearance	F7	+16 +6	+22 +10	+28 +13	+34 +16	+41 +20	+50 +25	+60 +30	+71 +36	+83 +43	+96 +50	+108 +56	+119 +62	+131 +68
		F8	+20 +6	+28 +10	+35 +13	+43 +16	+53 +20	+64 +25	+73 +30	+90 +36	+106 +43	+122 +50	+137 +56	+151 +62	+165 +68
	With smallest min. clearance	G7	+12 +2	+16 +4	+20 +5	+24 +6	+28 +7	+34 +9	+40 +10	+47 +12	+54 +14	+61 +15	+69 +17	+75 +18	+83 +20
Transition fit-holes	Slide fit	H6	+6 0	+8 0	+9 0	+11 0	+13 0	+16 0	+19 0	+22 0	+25 0	+29 0	+32 0	+36 0	+40 0
		H7	+10 0	+12 0	+15 0	+18 0	+21 0	+25 0	+30 0	+35 0	+40 0	+46 0	+52 0	+57 0	+63 0
		H8	+14 0	+18 0	+22 0	+27 0	+33 0	+39 0	+46 0	+54 0	+63 0	+72 0	+81 0	+89 0	+97 0
		H9	+25 0	+30 0	+36 0	+43 0	+52 0	+62 0	+74 0	+87 0	+100 0	+115 0	+130 0	+140 0	+155 0
		H11	+60 0	+75 0	+90 0	+110 0	+130 0	+160 0	+190 0	+220 0	+250 0	+290 0	+320 0	+360 0	+400 0

System Basic shaft		Symbol and grade	Diameter limit Over 1 Upto 3	3 6	6 10	10 18	18 30	30 50	50 80	80 120	120 180	180 250	250 315	315 400	400 500
Push fit		J6	+2 −4	+5 −3	+5 −4	+6 −5	+8 −5	+10 −6	+13 −6	+16 −6	+18 −7	+22 −7	+25 −7	+29 −7	+33 −7
		J7	+4 −6	+6 −6	+8 −7	+10 −8	+12 −9	+14 −11	+18 −12	+22 −13	+26 −14	+30 −16	+36 −16	+39 −18	+43 −20
Wring fit	Secure against turning	K6	0 −6	+2 −6	+2 −7	+2 −9	+2 −11	+3 −13	+4 −15	+4 −18	+4 −21	+5 −24	+5 −27	+7 −29	+8 −32
		K7	0 −10	+3 −9	+5 −10	+6 −12	+6 −15	+7 −18	+9 −21	+10 −25	+12 −28	+13 −33	+16 −36	+17 −40	+18 −45
Tight fit		M6	−2 −8	−1 −9	−3 −12	−4 −15	−4 −17	−4 −20	−5 −24	−6 −28	−8 −33	−8 −37	−9 −41	−10 −46	−10 −50
		M7	−2 −12	0 −12	0 −15	0 −18	0 −21	0 −25	0 −30	0 −35	0 −40	0 −46	0 −52	0 −57	0 −63
		N6	−4 −10	−5 −13	−7 −16	−9 −20	−11 −24	−12 −28	−14 −33	−16 −38	−20 −45	−22 −51	−25 −57	−26 −62	−27 −67
		N7	−4 −14	−4 −16	−4 −19	−5 −23	−7 −28	−8 −33	−9 −39	−10 −45	−12 −52	−14 −60	−14 −66	−16 −73	−17 −80
Interference fit-holes		P7	−6 −16	−8 −20	−9 −24	−11 −29	−14 −35	−17 −42	−21 −51	−24 −59	−28 −68	−33 −79	−36 −88	−41 −98	−45 −108
		P9	−6 −31	−12 −42	−15 −51	−18 −61	−22 −74	−26 −88	−32 −108	−37 −124	−43 −143	−50 −165	−56 −186	−62 −202	−68 −223

Table 1.14: Mean Fit and Variation about the Mean Fit

Table 1.14: Mean Fit and Variation about the Mean Fit (Hole Basis)

Tolerances in microns

			Basic size, mm											
		Columns	1	2	3	4	5	6	7	8	9	10	11	12
		Over (mm)	1	3	6	10	18	24	30	40	50	65	80	100
		To & Including (mm)	3	6	10	18	24	30	40	50	65	80	100	120
Running and Sliding Fits	(a)	Precision H7 g6	+ 11 ± 8	+ 14 ± 10	+ 17 ± 12	+ 20.5 ± 14.5	+ 24 ± 17		+ 29.5 ± 20.5		+ 34.5 ± 24.5		+ 40.5 ± 28.5	
	(b)	Close Running H7 f7	+ 16 ± 9	+ 22 ± 12	+ 28 ± 15	+ 34 ± 18	+ 41 ± 21		+ 50 ± 25		+ 60 ± 30		+ 71 ± 35	
	(c)	Normal Running H8 e8	+ 28 ± 14	+ 38 ± 18	+ 47 ± 22	+ 59 ± 27	+ 73 ± 33		+ 89 ± 39		+ 106 ± 46		+ 126 ± 54	
	(d)	Loose Running H8 d9	+ 39.5 ± 19.5	+ 54 ± 24	+ 69 ± 29	+ 85 ± 35	+ 107.5 ± 42.5		+ 130.5 ± 50.5		+ 160 ± 60		+ 190.5 ± 70.5	
	(e)	Positional fits or Slack Running H9 c9	+ 85 ± 25	+ 100 ± 30	+ 116 ± 36	+ 138 ± 43	+ 162 ± 52		+ 182 ± 62	+ 192 ± 62	+ 214 ± 74	+ 224 ± 74	+ 257 ± 87	+ 267 ± 87
	(f)	Positional fits or Slock Running H11 c11	+ 120 ± 60	+ 145 ± 75	+ 170 ± 90	+ 205 ± 110	+ 240 ± 130		+ 280 ± 160	+ 290 ± 160	+ 330 ± 190	+ 340 ± 190	+ 390 ± 220	+ 400 ± 220
	(g)	Precision Location H6 h6	+ 7 ± 7	+ 8 ± 8	+ 9 ± 9	+ 11 ± 11	+ 13 ± 13		+ 16 ± 16		+ 19 ± 19		+ 22 ± 22	
	(h)	Close Location H7 h7	+ 9 ± 9	+ 12 ± 12	+ 15 ± 15	+ 18 ± 18	+ 21 ± 21		+ 25 ± 25		+ 30 ± 30		+ 35 ± 35	

		Columns	1	2	3	4	5	6	7	8	9	10	11	12
Locational and Assembly Fits	(i)	Normal Location H8 h8	+ 14 ± 14	+ 18 ± 18	+ 22 ± 22	+ 27 ± 27	+ 33 ± 33		+ 39 ± 39		+ 46 ± 46		+ 54 ± 54	
	(j)	Loose Location H9 h9	+ 25 ± 25	+ 30 ± 30	+ 36 ± 36	+ 43 ± 43	+ 52 ± 52		+ 62 ± 62		+ 74 ± 74		+ 87 ± 87	
	(k)	Slack Assembly H11 h9	+ 42.5 ± 42.5	+ 52.5 ± 52.5	+ 63 ± 63	+ 76.5 ± 76.5	+ 91 ± 91		+ 111 ± 111		+ 132 ± 132		+ 153.5 ± 153.5	
	(l)	Slack Assembly H11 h11	+ 60 ± 60	+ 75 ± 75	+ 90 ± 90	+ 110 ± 110	+ 130 ± 130		± 160 + 160		+ 190 ± 190		+ 220 ± 220	
	(m)	Positional fits H8 b9	+ 159.5 ± 19.5	+ 164 ± 24	+ 179 ± 29	+ 185 ± 35	+ 202.5 ± 42.5		+ 220.5 ± 50.5	+ 230.5 ± 50.5	+ 250 ± 60	+ 260 ± 60	+ 290.5 ± 70.5	+ 310.5 ± 70.5
	(n)	Positional fits H8 a9	+ 289.5 ± 19.5	+ 294 ± 24	+ 309 ± 29	+ 325 ± 35	+ 342.5 ± 42.5		+ 360.5 ± 50.5	+ 370.5 ± 50.5	+ 400 ± 60	+ 420 ± 60	+ 450.5 ± 70.5	+ 480.5 ± 70.5
Transtion Fits	(o)	Clearance Transition H7 j6	+ 2 ± 8	+ 3 ± 10	+ 5 ± 12	+ 6.5 ± 14.5	+ 8 ± 17		+ 9.5 ± 20.5		+ 12.5 ± 24.5		+ 15.5 ± 28.5	
	(p)	True Transition H7·k6	–	–	+ 2 ± 12	+ 2.5 ± 14.5	+ 2 ± 17		+ 2.5 ± 20.5		+ 3.5 ± 24.5		+ 3.5 ± 28.5	
	(q)	Interference Transition H7 m6	– 1 ± 8	– 2 ± 10	– 3 ± 12	– 3.5 ± 14.5	– 4 ± 17		– 4.5 ± 20.5		– 5.5 ± 24.5		– 6.5 ± 28.5	
Interference Fils	(r)	Press H7 p6	– 8 ± 8	– 10 ± 10	– 12 ± 12	– 14.5 ± 14.5	– 18 ± 17		– 21.5 ± 20.5		+ 25.5 ± 24.5		– 30.5 ± 28.5	
	(s)	Drive H7 r6	– 11 ± 8	– 13 ± 10	– 16 ± 12	– 19.5 ± 14.5	– 24 ± 17		– 29.5 ± 20.5		– 35.5 ± 24.5	– 37.5 ± 24.5	– 44.5 + 28.5	– 47.5 ± 28.5
	(t)	Drive H7 s6	– 12 ± 8	– 17 ± 10	– 20 ± 12	– 24.5 ± 14.5	– 31 ± 17		– 38.5 ± 20.5		– 47.5 ± 24.5	– 53.5 ± 24.5	– 64.5 + 28.5	– 72.5 ± 28.5
	(u)	Force H7 u6	– 17 ± 8	– 21 ± 10	– 25 ± 12	– 29.5 ± 14.5	– 37 ± 17	– 44 ± 17	– 55.8 ± 20.5	– 65.5 ± 20.5	– 81.5 ± 24.5	– 96.5 ± 24.5	– 117.5 ± 28.5	– 137.5 ± 28.5

Columns	13	14	15	16	17	18	19	20	21	22	23	24
Over (mm)	120	140	160	180	200	225	250	280	315	355	400	450
To & Including (mm)	140	160	180	200	225	250	280	315	355	400	450	500
(a)	+ 46.5 ± 32.5			+ 52.5 ± 37.5			+ 59 ± 42		+ 64.5 ± 46.5		+ 71.5 ± 51.5	
(b)	+ 83 ± 40			+ 96 ± 46			+ 108 ± 52		+ 119 ± 57		+ 131 ± 63	
(c)	+ 148 ± 63			+ 172 ± 72			+ 191 ± 81		+ 214 ± 89		+ 232 ± 97	
(d)	+ 226.5 ± 81.5			+ 263.5 ± 93.5			+ 295.5 ± 105.5		+ 324.5 ± 114.5		+ 356 ± 126	
(e)	+ 300 ± 100	+ 310 ± 100	+ 330 ± 100	+ 355 ± 115	+ 375 ± 115	+ 395 ± 115	+ 430 ± 130	+ 460 ± 130	+ 500 + 140	+ 540 + 140	+ 595 ± 155	+ 635 ± 155
(f)	+ 450 ± 250	+ 460 ± 250	+ 480 ± 250	+ 530 ± 290	+ 550 ± 290	+ 570 ± 290	+ 620 ± 320	+ 650 ± 320	+ 720 + 360	+ 760 + 360	+ 840 ± 400	+ 880 ± 400
(g)	+ 25 ± 25			+ 29 ± 29			+ 32 ± 32		+ 36 ± 36		+ 40 ± 40	
(h)	+ 40 ± 40			+ 46 ± 46			+ 52 ± 52		+ 57 ± 57		+ 63 ± 63	
(i)	+ 63 ± 63			+ 72 ± 72			+ 81 ± 81		+ 89 ± 89		+ 97 ± 97	
(j)	+ 100 ± 100			+ 115 ± 115			+ 130 ± 130		+ 140 ± 140		+ 155 ± 155	

Columns	13	14	15	16	17	18	19	20	21	22	23	24
(k)	+ 175 ± 175			+ 202.5 ± 202.5			+ 225 ± 225		+ 250 ± 250		+ 277.5 ± 277.5	
(l)	+ 250 ± 250			+ 290 ± 290			+ 320 ± 320		+ 360 ± 360		+ 400 ± 400	
(m)	+ 341.5 ± 81.5	+ 361.5 ± 81.5	+ 391.5 ± 81.5	+ 433.5 ± 93.5	+ 473.5 ± 93.5	+ 513.5 ± 93.5	+ 585.5 ± 105.5	+ 645.5 ± 105.5	+ 714.5 ± 114.5	+ 794.5 ± 114.5	+ 886 ± 126	+ 966 ± 126
(n)	+ 541.5 ± 81.5	+ 601.5 ± 81.5	+ 661.5 ± 81.5	+ 753.5 ± 93.5	+ 833.5 ± 93.5	+ 913.5 ± 93.5	+ 1025.5 ± 105.5	+ 1155.5 ± 105.5	+ 1314.5 ± 114.5	+ 1484.5 ± 114.5	+ 1626 ± 125	+ 1726 ± 126
(o)	+ 18.5 ± 32.5			+ 21.5 ± 37.5			+ 26 ± 42		+ 28.5 ± 46.5		+ 31.5 ± 51.5	
(p)	+ 4.5 ± 32.5			+ 4.5 ± 37.5			+ 6 ± 42		+ 16.5 ± 46.5		+ 6.5 ± 51.5	
(q)	− 7.5 ± 32.5			− 8.5 ± 37.5			− 10 ± 42		− 10.5 ± 46.5		− 11.5 ± 51.5	
(r)	− 35.5 ± 32.5			− 41.5 ± 37.5			− 46 ± 42		− 51.5 ± 46.5		− 56.5 ± 51.5	
(s)	− 55.5 ± 32.5	− 57.5 ± 32.5	− 60.5 ± 32.5	− 68.5 ± 37.5	− 71.5 ± 37.5	− 75.5 ± 37.5	− 84 ± 42	− 88 ± 42	− 97.5 ± 46.5	− 103.5 ± 46.5	− 114.5 ± 51.5	− 120.5 ± 51.5
(t)	− 84.5 ± 32.5	− 92.5 ± 32.5	− 100.5 ± 32.5	− 113.5 ± 37.5	− 121.5 ± 37.5	− 131.5 ± 37.5	− 148 ± 42	− 160 ± 42	− 179.5 ± 46.5	− 197.5 ± 46.5	− 220.5 ± 51.5	− 240.5 ± 51.5
(u)	− 162.5 ± 32.5	− 182.5 ± 32.5	− 202.5 ± 32.5	− 227.5 ± 37.5	− 249.5 ± 37.5	− 275.5 ± 37.5	− 305 ± 42	− 340 ± 42	− 379.5 ± 46.5	− 424.5 ± 46.5	− 478.5 ± 51.5	− 528.5 ± 51.5

CHAPTER – 2

MATERIALS AND THEIR PROPERTIES

Table 2.1: Properties of Elements

Abbreviations

bcc	–	body-centred cubic
cubic (diam)	–	diamond structure
fcc	–	face-centred cubic
hcp	–	hexagonal close-packed
hex	–	hexagonal
mon	–	monoclinic
ortho	–	orthorhombic
tetr	–	tetragonal

Where a change in structure occurs, the transition temperature is indicated (in K) under the crystal structures.

Name	Symbol	Atomic number	Atomic weight g mol^{-1}	Crystal structure in solid state	Atomic radii (pm)	Density (kg m^{-3})	Melting point (K)	Boiling point (K)
Actinium	Ac	89	227	fcc	188	10100	1320	3470
Aluminium	Al	13	26.98	fcc	142	2700	933-2	2740
Antimony	Sb	51	121.75	rhombic	145	6700	903.7	1650
Argon	Ar	18	39.95	fcc	174	1.66	83.7	87.4
Arsenic	As	33	74.92	rhombic	125	5730	1090 (28 atm)	886 (sub)
Astatine	At	85	210	–	–	–	520	623
Barium	Ba	56	137.34	bcc	217	3600	1000	1910
Beryllium	Be	4	9.01	hcp/cubic 1527	112	1800	1550	3243
Bismuth	Bi	83	208.98	rhombic	155	9800	544.4	1830
Boron	B	5	10.81	ortho (7)	88	2500	2600	2820 (sub)
Bromine	Br	35	79.90	ortho	114	3100 (298 K)	265.9	331.9
Cadmium	Cd	48	112.40	hcp	148	8650	594.2	1038
Caesium	Cs	55	132.90	bcc	262	1870	301.6	960
Calcium	Ca	20	40.08	fcc/bcc 737	196	1540	1120	1760
Carbon	C	6	12.01	hex/cubic	71/77	2300	> 3800	5100
Cerium	Ce	58	140.12	fcc/hex/fcc/bcc 95 263 998	183	6800	1070	3740
Chlorine	Cl	17	35.45	tetr	91	3.21 (273 K)	172.1	238.5

Name	Symbol	Atomic number	Atomic weight g mol^{-1}	Crystal structure in solid state	Atomic radii (pm)	Density (kg m^{-3})	Melting point (K)	Boiling point (K)
Chromium	Cr	24	52.00	bcc	125	7200	2160	2755
Cobalt	Co	27	58.93	hcp/fcc 690	125	8900	1765	3170
Copper	Cu	29	63.55	fcc	128	8930	1356	2868
Dysprosium	Dy	66	162.50	rhombic/hcp 86	175	8500	1680	2900
Erbium	Er	68	167.26	hcp	173	9000	1770	3200
Europium	Eu	63	151.96	bcc	198	5200	1100	1712
Fluorine	F	9	19.00	–	60	1.7 (273 K)	53.5	85.01
Francium	Fr	87	223	–	–	–	303	920
Gadolinium	Gd	64	157.25	hcp/bcc 1537	178	7900	1585	3000
Gallium	Ga	31	69.72	fcc or ortho	121	5950	302.9	2676
Germanium	Ge	32	72.59	cubic (diam)	122	5400	1210.5	3100
Gold	Au	79	196.97	fcc	144	19300	1336.1	3239
Hafnium	Hf	72	178.49	hcp/bcc 2050	158	13300	2423	5700
Helium	He	2	4.003	hcp/cubic	176	0.166	0.95 (26 atm)	4.21
Holmium	Ho	67	164.93	hcp	176	8800	1734	2900
Hydrogen	H	1	1.00797	hcp/cubic	46	0.08987 (273 K)	14.01	20.4
Indium	In	49	114.82	tetr	162	7310	429.8	2300
Iodine	I	53	126.90	ortho	135	4940	386.6	457.4
Iridium	Ir	77	192.2	fcc	135	22420	2716	4800

Name	Symbol	Atomic number	Atomic weight g mol^{-1}	Crystal structure in solid state	Atomic radii (pm)	Density (kg m^{-3})	Melting point (K)	Boiling point (K)
Iron	Fe	26	55.85	bcc/fcc/bcc 1180 1670	123	7870	1808	3300
Krypton	Kr	36	83.80	fcc	201	3.49	116.5	120.8
Lanthanum	La	57	138.91	hcp/fcc/bcc 583 1137	187	6150	1190	3742
Lead	Pb	82	207.19	fcc	174	11340	600.4	2017
Lithium	Li	3	6.94	hcp/fcc/bcc 74 140	152	534	452	1590
Lutetium	Lu	71	174.97	hcp	173	9800	1925	3600
Magnesium	Mg	12	24.31	hcp	160	1741	924	1380
Manganese	Mn	25	54.94	cubic	112	7440	1517	2370
Mercury	Hg	80	200.59	rhombic	156	13590 (273 K)	234.3	629.7
Molybdenum	Mo	42	95.94	bcc	136	10200	2880	5830
Neodymium	Nd	60	144.24	hcp/bcc 1135	181	6960	1297	3300
Neon	Ne	10	20.18	fcc	160	0.839	24.5	27.2
Nickel	Ni	28	58.71	fcc	124	8900	1726	3005
Niobium	Nb	41	92.91	bcc	143	8.570	2741	5200
Nitrogen	N	7	14.01	cubic/hcp 35.4	71	1.165	63.3	77.3
Osmium	Os	76	190.2	hcp	135	22480	3300	4900
Oxygen	O	8	16.00	rhombic	60	1.33	54.7	90.2
Palladium	Pd	46	106.4	fcc	137	12000	1825	3200

Name	Symbol	Atomic number	Atomic weight g mol^{-1}	Crystal structure in solid state	Atomic radii (pm)	Density (kg m^{-3})	Melting point (K)	Boiling point (K)
Phosphorus	P	15	30.97	cubic	–	2200(r) 1800 (y)	317.2	552
Platinum	Pt	78	195.09	fcc	138	21450	2042	4100
Polonium	Po	84	209	monoclinic	168	9400	527	1235
Potassium	K	19	39.10	bcc	231	860	336.8	1047
Praseodymium	Pr	59	140.91	hcp/bcc 1065	182	6800	1208	3400
Promethium	Pm	61	145	–	–	–	1308	3000
Protoactinium	Pa	91	231	tetra	160	15400	1500	4300
Radium	Ra	88	226	–	–	5000	970	1410
Radon	Rn	86	222	–	–	9.73 (273 K)	202	211.3
Rhenium	Re	75	186.2	hcp	137	20500	3450	5900
Rhodium	Rh	45	102.91	fcc	134	12440	2230	4000
Rubidium	Rb	37	85.47	bcc	246	1530	312.0	961
Ruthenium	Ru	44	101.07	hcp	133	12400	2520	4200
Samarium	Sm	62	150.35	Rhomb/bcc 1190	179	7500	1345	2200
Scandium	Sc	21	44.96	hcp/fcc 1223	160	3000	1812	3000
Selenium	Se	34	78.96	hcp	116	4810	490	958
Silicon	Si	14	28.09	cubic	118	2300	1680	2628
Silver	Ag	47	107.87	fcc/hcp 5	144	10500	1234	2485
Sodium	Na	11	22.99	bcc	185	970	371	1165
Strontium	Sr	38	87.62	fcc/hcp/bcc 506 813	215	2600	1042	1657

Name	Symbol	Atomic number	Atomic weight g mol^{-1}	Crystal structure in solid state	Atomic radii (pm)	Density (kg m^{-3})	Melting point (K)	Boiling point (K)
Sulphur	S	16	32.06	ortho	106	2070	386	717.7
Tantalum	Ta	73	180.95	bcc	143	16600	3269	5698
Technetium	Tc	43	98.91	hcp	135	11400	2500	4900
Tellurium	Te	52	127.60	hcp	143	6240	722.6	1260
Terbium	Tb	65	158.92	hcp/rhomb 1590	177	8300	1629	3100
Thallium	Tl	81	204.37	hcp/fcc 503	171	11860	576.6	1730
Thorium	Th	90	232.04	fcc/bcc 1673	180	11500	2000	4500
Thulium	Tm	69	168.93	hcp/bcc 1158	174	9300	1818	2000
Tin	Sn	50	118.69	cub(diam)/bcc	140	7300	505.1	2540
Titanium	Ti	22	47.90	hcp/bcc 1158	146	4540	1948	3530
Tungsten	W	74	183.85	bcc	137	19320	3650	6200
Uranium	U	92	238.03	rhomb/tetr 941	138	19050	1405.4	4091
Vanadium	V	23	50.94	bcc	131	6100	2160	3300
Xenon	Xe	54	131.30	fcc	221	5.50	161.2	166.0
Ytterbium	Yb	70	173.04	fcc/bcc 1071	193	7000	1097	1700
Yttrium	Y	39	88.91	hcp/bcc 1763	181	4600	1768	3200
Zinc	Zn	30	65.37	hcp	133	7140	692.6	1180
Zirconium	Zr	40	91.22	hcp/bcc 1100	160	6500	2125	3851

Table 2.2 : Properties of Metallic Solids (at 293 K)

Table 2.2 : Properties of Metallic Solids (at 293 K)

Name	Density (kg m^{-3})	Melting point (K)	Specific latent heat of fusion (J kg^{-1})	Specific heat capacity (J kg^{-1} K^{-1})	Linear expansivity (K^{-1})	Thermal Conductivity ($Wm^{-1}K^{-1}$)	Electrical resistivity (Ωm)	Temperature coefficient of resistance (dp/dT)/K^{-1}	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Youngs modulus (GPa)	Poisson's ratio
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
			$\times 10^{4}$		$\times 10^{-6}$		$\times 10^{-8}$	$\times 10^{-4}$					
1. Aluminium	2710	932	38	913	23	201	2.65	40	80	50	43	71	0.34
2. Aluminium strong alloy	2800	800	39	880	23	180	5	16	600	550	10	–	–
3. Antimony	6680	904	16	205	10	18	40	50	–	–	–	78	–
4. Bismuth	9800	544	5	126	13	8	115	45	–	–	–	32	0.33
5. Brass (70 Cu/30 Zn)	8500	1300	–	370	18	110	8	15	550	450	8	100	0.35
6. Bronze (90 Cu/10 Sn)	8800	1300	–	360	17	180	30	–	260	140	10	–	–
7. Cobalt	8900	1765	25	420	12	69	6	66	500	–	–	–	–
8. Consrantan	8880	1360	–	420	17	23	47	± 0.4	–	–	–	170	0.33
9. Copper	8930	1356	21	385	17	385	1.7	39	150	75	45	117	0.35
10. German silver (60 Cu/25 Zn/15 Ni)	8700	1300	–	400	18	29	33	4	450	–	–	130	0.33
11. Gold	19300	1340	7	132	14	296	2.4	34	120	–	40	71	0.44
12. Invar (64 Fe/36 Ni)	8000	1800	–	503	0.9	16	81	20	480	280	40	145	0.26

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
13. Iron, pure	7870	1810	27	106	12	80	10	65	300	165	45	206	0.29
14. Iron, cast grey	7150	1500	10	500	11	75	10	–	100	–	–	110	0.27
15. Iron, cast white	7700	1420	14	–	11	75	10	–	230	–	–	–	–
16. Iron, cast wrought	7850	1810	14	480	12	60	14	60	370	150	45	197	0.28
17. Lead	11340	600	2.6	126	29	35	21	43	15	12	50	18	0.44
18. Magnesium	1740	924	38	246	25	150	4	43	190	95	5	44	0.29
19. Manganin	8500	–	41	400	18	22	45	± 0.1	–	–	–	120	0.33
20. Monel (70 Ni/30 Cu)	8800	1600	–	–	14	210	42	20	520	240	40	–	–
21. Nickel	8900	1726	31	460	13	59	59	60	300	60	30	207	0.36
22. Nickel, strong alloy	8950	1320	–	380	–	–	–	–	1300	1200	10	110	0.38
23. Phosphor bronze	–	–	–	–	17	–	7	60	560	420	–	120	0.38
24. Platinum	21450	2042	11	136	9	69	11	38	350	–	–	150	0.38
25. Silver	10500	1230	10	235	19	419	1.6	40	150	180	45	70	0.37
26. Sodium	970	371	12	1240	71	134	4.5	44	–	–	–	–	–
27. Solder, soft (50 Pb/50 Sn)	9000	490	190	176	–	–	–	–	45	–	50	–	–
28. Stainless Steel (18 Cr/8 Ni)	7930	1800	–	510	16	150	96	6	600	230	60	–	–
29. Steel, mild	7860	1700	–	420	15	63	15	50	460	300	35	210	0.29
30. Steel, plano wire	7800	1700	–	–	–	50	–	–	3000	–	–	210	0.29
31. Tin	7300	505	6.0	226	23	65	11	50	30	–	–	40	0.36
32. Titanium	4540	1950	–	523	9	23	53	38	620	480	20	–	0.36
33. Zinc	7140	693	10	385	31	111	5.9	40	150	–	50	110	0.25

Table 2.3: Properties of Non-Metallic Solids (at 293 K)

Table 2.3: Properties of Non-Metallic Solids (at 293 K)

	Name	Density ($kg\ m^{-3}$)	Melting point (K)	Specific heat capacity ($J\ kg^{-1}\ K^{-1}$)	Linear expansivity ($K^{-1} \times 10^{-4}$)	Thermal conductivity ($Wm^{-1}\ K^{-1}$)	Tensile strength (MPa)	Elonga-tion (%)	Young's modulus (GPa)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1.	Alumina, ceramic	3800	2300	800	9	29	150	–	345
2.	Bone	1850	–	–	–	–	140	–	28
3.	Brick, building	2300	–	–	9	0.6	5	–	–
4.	Brick, fireclay	2100	–	–	4.5	0.8	–	–	–
5.	Brick paving	2500	–	–	4.0	–	–	–	–
6.	Brick, silica	1750	–	–	–	0.8	–	–	–
7.	Carbon, graphite	2300	3800	710	7.9	5.0	–	–	207
8.	Carbon, diamond	3300	–	525	0	900	–	–	1200
9.	Concrete	2400	–	3350	12	0.1	4	–	14
10.	Cork	240	–	2050	–	0.05	–	–	–
11.	Cotton	1500	–	1400	–	–	400	–	–
12.	Epoxy resin	1120	–	1400	39	–	50	2-6	4.5
13.	Fluon (PTFE)	2200	–	1050	55	0.25	22	50-75	0.34
14.	Glass (crown)	2600	1400	670	9	1.0	100	–	71
15.	Glass (flint)	4200	1500	500	8	0.8	–	–	80
16.	Glass wool	50	1400	670	–	0.04	–	–	–
17.	Ice	920	273	2100	51	2.0	–	–	–
18.	Kapok	50	–	–	–	0.03	–	–	–
19.	Magnesium oxide	3600	3200	960	12	–	–	–	207

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
20.	Marble	2600	–	880	10	2.9	–	–	–
21.	Melamine formaldehyde	1500	–	1700	40	0.3	70	–	9
22.	Naphthalene	1150	350	1310	107	0.4	–	–	–
23.	Nylon	1150	470	1700	100	0.25	70	60-300	–
24.	Paraffin wax	900	330	2900	110	0.25	–	–	–
25.	Perspex	1190	350	1500	85	0.2	50	2-7	3
26.	Phenol formaldehyde	1300	–	1700	40	0.2	50	0.4-0.8	6.9
27.	Polyethylene (low den)	920	410	2300	250	–	13	400-800	0.18
28.	Polyethylene (high den)	955	410	2300	250	–	26	100-300	0.43
29.	Polypropylene	900	450	2100	62	–	35	> 220	1.2
30.	Polystyrene	1050	510	1300	70	0.08	50	1-3	3.1
31.	Polyvinyl chloride (non-rigid)	1250	485	1800	150	–	15	200-400	0.01
32.	Polyvinyl chloride (rigid)	1700	485	1000	55	–	60	5-25	2.8
33.	Polyvinylidine chloride	–	470	–	190	–	30	160-240	–
34.	Quartz fibre	2660	2020	788	0.4	9.2	–	–	73
35.	Rubber (polyisoprene)	910	300	1600	220	0.15	17	480-510	0.02
36.	Silicon carbide	3170	–	–	4.5	–	–	–	–
37.	Sulphur	2070	386	730	64	0.26	–	–	–
38.	Titanium carbide	4500	–	–	7	28	–	–	345
39.	Wood, oak (with grain)	650	–	–	–	0.15	–	–	12
40.	Wood, Spruce (with grain)	600	–	–	–	–	–	–	14
41.	Wood, Spruce (across grain)	–	–	–	–	–	–	–	0.5

Table 2.4: Properties of Inorganic Compounds (at 293 K)

Abbreviations :

bl.	block	effl.	efflorescent	s.	sublimes
col.	colourless	ex.	explodes	tetr.	tetragonal
crys.	crystals	gn.	green	trig.	trigonal
cub.	cubic	hex.	hexagonal	visc.	viscous
d.	dissociates	mono.	monoclinic	w.	white
delq.	deliquescent	rh.	rhomble	yel.	yellow

Enthalpies of Formation refer to the substance in the crystalline (c), liquid (lq), or gaseous (g) states at 293 K. A negative value indicate that heat is evolved in the formation of the compound, while a positive value indicates absorption of heat.

	Formula	Molecular weight ($g\ mol^{-1}$)	Melting point (K)	Boiling point (K)	Density ($kg\ m^{-3}$)	Refractive index	Enthalpy of formation ($kJ\ mol^{-1}$)		Description
Al	Al_2O_3	101.96	2290	3250	3965	1.768	– 1670	c	Corundum. w. trig.
Ag	AgBr	187.78	705	1600(d)	6473	2.252	– 99.5	c	pale yet. cub
	AgCl	143.32	728	1820	5560	2.071	– 127	c	w. cub
	$AgNO_3$	169.87	485	717(d)	4352	1.744	– 123	c	col. rh.
As	$AsBr_3$	314.65	306	494	3540	–	– 195.0	c	col. prisms
	$AsCl_3$	181.28	265	403	2163	–	– 335	lq	Oily liquid
	As_2O_3	197.84	588	–	3738	1.755	– 1310	c	col. cub. (As_4O_6)
Au	$AuCl_3$	303.33	527 (d)	–	3900	–	– 118	c	red delq.
Ba	$BaCl_2$	208.25	1240	1820	3856	1.736	– 860.1	c	col. mono.
	BaO	153.34	2196	2300	5720	1.98	– 558.1	c	col. cub.

	Formula	Molecular weight (g mol^{-1})	Melting point (K)	Boiling point (K)	Density (kg m^{-3})	Refractive index	Enthalpy of formation (kJ mol^{-1})		Description
Be	$BeCl_2$	79.92	678	790	1899	1.719	−511.7	c	w.delq. needles
	BeO	25.01	2800	4170	3010	1.719	−6109.9	c	w.hex.
C	CO	28.01	74	84	1.25	–	−110.5	g	col. gas
	CO_2	44.01	162	195	1.98	–	−393.5	g	col. gas
Ca	$CaCO_3$	100.09	1612	d	2930	1.6809	−1206.9	c	Aragonite. col. rh.
	$CaCl_2$	110.99	1045	1900	2150	1.52	−795.0	c	w.delq. cub.
	CaO	56.08	2850	3120	3300	1.837	−635.5	c	col. cub.
Cd	$CdBr_2$	272.22	840	1136	5192	–	−314.4	c	w.eff. needles
	$CdCl_2$	183.32	841	1233	4047	–	−389.1	c	w.cub.
	CdO	128.40	1200(d)	–	8150	–	−254.6	c	brown cub.
Co	$CoCl_2$	129.84	997*	1322	2940	–	−326	c	blue crys. *in HCl gas
	CoO	74.93	2208	–	6450	–	−239	c	brown cub.
	$Co(OH)_2$	92.95	d	–	3597	–	−548.9	c	rose-red rh.
Cs	CsCl	168.36	919	1560	3988	1.534	−433.0	c	col. delq.cub.
Cu	CuO	79.54	1599	–	6400	–	−155.2	c	bl. cub. or trig.
	$CuSO_4$	223.14	–	–	3605	1.733	−769.9	c	gn/w.rh.
	$CuSO_4$, $5H_2O$	249.68	–	–	2284	1.537	−2278	c	blue trig.
	Cu_2O	143.08	1508	–	6000	2.705	−166.7	c	red cub.

	Formula	Molecular weight (g mol^{-1})	Melting point (K)	Boiling point (K)	Density (kg m^{-3})	Refractive index	Enthalpy of formation (kJ mol^{-1})		Description
Fe	FeS	87.91	1470	d	4740	–	– 95.1	c	blue hex.
	Fe_2O_3	159.69	1838	–	5240	3.042	– 822.2	c	red or bl. trig
	Fe_3O_4	231.54	1810(d)	–	5180	2.42	– 1117	c	bl.cub.
H	HBr	80.92	185	206	3.5	–	– 36.2	g	col. gas
	HCl	36.46	158	188	1.0	–	– 93.3	g	col. gas
	HF	20.01	190	293	0.99	–	– 268.6	g	col. gas
	HI	127.91	222	238	5.66	–	+ 25.9	g	col. gas
	HNO_3	63.01	231	356	1503	–	– 173.2	lq	col. liquid
	H_2O	18.02	273	373	1000	1.333	– 285.9	lq	col. liquid
	H_2SO_4	98.08	284	610	1841	–	– 814.0	lq	col. visc. liquid
Hg	$HgCl$	236.05	670(s)	–	7150	1.973	– 265*	c	w. tetr. (*Hg_2Cl_2)
	$HgCl_2$	271.50	549	575	5440	1.859	– 230	c	w.rh.
	HgO	216.59	800 (d)	–	11100	2.5	– 90.4	c	yel. or red rh.
K	KCl	74.56	1049	1770(s)	1984	1.490	– 435.9	c	col. cub
	$KHCO_3$	100.12	400(d)	–	2170	1.482	– 959.4	c	mono
	K_2CO_3	138.21	1164	d	2428	1.531	– 1146.1	c	w.delq.
	K_2O	94.20	620(d)	–	2320	–	– 361.5	c	w.cub.
Li	$LiCl$	42.39	887	1600	2068	1.662	– 408.8	c	w.delq.cub.
Mg	$MgBr_2$	184.13	970	–	3720	–	– 517.6	c	w.delq.
	$MgCO_3$	84.32	620	1200	2958	1.700	– 1112	c	w.trig.

	Formula	Molecular weight (g mol^{-1})	Melting point (K)	Boiling point (K)	Density (kg m^{-3})	Refractive index	Enthalpy of formation (kJ mol^{-1})		Description
	$MgCl_2$	95.22	981	1685	2320	1.675	−641.8	c	col. hex.
	MgF_2	62.31	1539	2512	–	1.378	−1102	c	col. tetr.
	MgH_2	26.33	550(d)	–	–	–	–		w.tetr.
	MgI	278.12	1000(d)	–	4430	–	−359	c	w.delq.
	MgO	40.31	3100	3900	3580	1.736	−601.8	c	col.cub.
	$Mg(OH)_2$	58.33	620	–	2360	1.562	−924.7	c	w.trig.
	$MgSO_4$	120.37	1397	–	2660	1.56	−1278	c	col. rh.
Mn	MnO	70.94	–	–	5440	2.16	−385	c	gray/gn cub.
	MnO_2	86.94	808(d)	–	5026	–	−520.9	c	bl.rh
	MnO_3	102.94	–	–	–	–	–		red delq.
	Mn_2O_3	157.87	1350(d)	–	4500	–	−971.1	c	brown/bl.cub.
	Mn_2O_7	221.87	279	328(d)	2396	–	–		red oil
	Mn_3O_4	228.81	1978	–	4856	2.46	−1386	c	brown/bl.tetr.
N	NH_3	17.03	195	240	0.77	–	−46.2	g	col.gas
	NH_4Cl	53.49	613(s)	–	1527	1.64	−315.4	c	w.cub.
	NO	30.01	110	121	1.34	–	+90.4	g	col.gas
	NO_2	44.01	182	185	1.98	–	+33.8	g	red/brown gas (N_2O_4)
	N_2O_3	76.01	171	277(d)	1447	–	+83.8	g	red/brown gas

N_2O_3	76.01	171	277(d)	1447	–	+ 83.8 g	red/brown gas

	Formula	Molecular weight (g mol^{-1})	Melting point (K)	Boiling point (K)	Density (kg m^{-3})	Refractive index	Enthalpy of formation (kJ mol^{-1})	Description
Na	NaBr	102.90	1028	1660	3203	1.641	− 359.9 c	col.cub.
	NaCl	58.44	1074	1686	2165	1.544	− 411.0 c	col.cub.
	NaF	41.99	1261	1968	2558	1.326	− 569 c	col.tetr.
	NaH	24.00	1100(d)	–	920	1.470	− 57.3 c	silver needles
	$NaHCO_3$	84.00	540(d)	–	2159	1.500	− 947.7 c	w.mono.powder
	$NaHSO_4$	120.06	590	d	2435	–	− 1126 c	col.trig.
	NaI	149.89	924	1577	3667	1.774	− 288.0 c	col.cub.
	NaOH	40.00	592	1660	2130	–	− 426.7 c	w.delq.
	Na_2CO_3	105.99	1124	d	2532	1.535	− 1131 c	w.powder
	Na_2O	61.98	1548(s)	–	2270	–	− 416 c	w/gray delq.
	Na_2SO_4	142.04	–	–	2680	1.477	− 1384 c	mono (→hex at 510K)
Ni	$NiCl_2$	129.62	1274	–	3550	–	− 316 c	yel. delq.
	NiO	74.71	2260	–	6670	2.37	− 244 c	gn/bl. cub.
P	PCl_3	137.33	161	349	1574	1.503	− 320 c	col. fuming liquid
	PCl_5	208.24	–	435(s)	4.65	–	− 463.2 g	delq. tetr.
	PH_3	34.00	140	185	–	–	+ 5.2 g	col. gas
	P_2O_3	109.95	297	447*	2135	–	− 820 lq	w. delq. mono *in N_2
	P_2O_4	129.95	370	450*	2540	–	–	w.delq. rh. *in vacuo
	P_2O_5	141.94	850	875	2390	–	− 3012* c	w. delq. amor. *P_4O_{10}

	Formula	Molecular weight (g mol^{-1})	Melting point (K)	Boiling point (K)	Density (kg m^{-3})	Refractive index	Enthalpy of formation (kJ mol^{-1})	Description
Pb	$PbCl_2$	278.10	774	1220	5850	2.217	−359.2 c	w. rh
	$PbCl_4$	349.00	258	378(ex)	3180	–	–	yel. liquid
	PbO	223.19	1161	–	9530	–	−219.2 c	red amor.
	PbO_2	239.19	560(d)	–	9375	2.229	−276.6 c	brown tetr.
	PbS	239.25	1387	–	7500	3.912	−100.4 c	lead gray cub.
	Pb_3O_4	685.57	770(d)	–	9100	–	−718.4 c	red amor.
Rb	$RbCl$	120.92	988	1660	2800	1.494	−430.5 c	cub.
S	SO_2	64 06	200	263	2.93	–	−296.9 g	col. gas
	SO_3	80.06	306	318	1927*	–	−395.2 g	col. gas (*liquid)
Sb	$SbBr_3$	361.48	370	550	4148	1.74	−260 c	col. rh.
	$SbCl_3$	228.11	347	556	3140	–	−382 c	col. rh. delq.
	$SbCl_5$	299.02	276	352	2336	–	−438 lq	pale yel. liquid
Si	SiC	40.10	3000	–	3217	2.654	−111.7 c	blue/bl. trig.
	$SiCl_4$	169.90	203	331	1483	1.412	−640.2 lq	col. fuming liquid
	SiH_4	32.12	88	161	1.44	–	+34 g	col. gas
	SiO	44.09	1975	2150	2130	–	–	w.cub.
	SiO_2	60.08	1880	2500	1.544	–	−911 c	Quartz. hex.

	Formula	Molecular weight (g mol^{-1})	Melting point (K)	Boiling point (K)	Density (kg m^{-3})	Refractive index	Enthalpy of formation (kJ mol^{-1})		Description
Sn	$SnCl_4$	260.50	240	387	2226	–	–511.3	lq	col. fuming liquid
	SnO	134.69	1350(d)	–	6446	–	–286	c	bl.cub.
	SnO_2	150.69	1400	2100(s)	6950	1.997	–581	c	w.tetr.
Sr	$SrCl_2$	158.53	1146	1520	3052	1.536	–828	c	w.rh.
	SrO	103.62	2700	3300	4700	1.870	–590	c	col. cub.
Ti	$TiCl_4$	189.71	248	409	1726	–	–750	lq	col. liquid
	TiO_2	79.90	2098	–	4170	2.586	–912	c	bl.rh.
U	UC_2	262.05	2650	4640	11280	–	–176	c	metallic crystals
	UO_2	270.03	2800	–	10960	–	–1130	c	bl.rh.
W	WC	195.86	3140	6300	15630	–	–38.0	c	gray. cub. powder
	WO_3	231.85	1746	–	7160	–	–840	c	yel.rh.
Zn	$ZnCO_3$	125.39	570(d)	–	4398	1.818	–813	c	w. trig.
	$ZnCl_2$	136.28	556	1005	2910	1.687	–416	c	w.delq.
	ZnO	81.37	2100	–	5606	2.004	–348	c	w.hex.

Table 2.5: Properties of Organic Compounds (at 293 K)

Enthalpies of Formation refer to the substance in the crystalline (c), liquid (lq), or gaseous (g) states at 293 K. A negative value indicates evolution of heat during formation of the compound, while a positive value indicates absorption of heat. Enthalpy changes on combustion refer to combustion at a pressure of 1 atmosphere and temperature 293 K, the final products being liquid water, and gaseous carbon dioxide and nitrogen.

Name and Formula	Mole-cular weight	Melting point (K)	Boiling point (K)	Density ($kg\ m^{-3}$)	Refrac-tive index	Enthalpy of formation ($kJ\ mol^{-1}$)	Heat of combustion ($kJ\ mol^{-1}$)	Alternative name
Hydrocarbons								
Methane CH_4	16.04	91	109	–	–	– 74.85 g	890.4 g	
Ethane C_2H_6	30.07	90	185	–	–	– 84.7 g	1560 g	
Propane C_3H_8	44.11	83	231	–	–	– 103.8 g	2220 g	
n-Butane n-C_4H_{10}	58.13	135	273	579	1.3543	– 146.2 lq	2877 g	
2-Methyl propane iso-C_4H_{10}	58.13	114	261	557	–	– 134.6 g	2869 g	Isobutane
n-Pentane n-C_5H_{12}	72.15	143	309	626	1.3575	– 173 lq	3909 lq	
n-Hexane n-C_6H_{14}	86.18	178	342	660	1.3751	– 198.8 lq	4195 lq	
n-Heptane n-C_7H_{16}	100.21	183	372	638	1.3878	– 224.4 lq	4853 lq	
n-Octane n-C_8H_{18}	114.23	216	399	702	1.3974	– 250 lq	5512 lq	
Ethene n-C_2H_4	28.05	104	169	1.26	–	+ 52.3 g	1411 g	Ethylene
Propene C_3H_6	42.08	88	226	519	1.3567	+ 20.4 g	2059 g	Propylene
Ethyne C_2H_2	26.04	192	189	618	–	+ 229.4 g	1300 g	Acetylene
Benzene C_6H_6	78.12	279	353	879	1.5011	+ 48.7 lq	3273 lq	
Cyclohexane C_6H_{12}	84.16	280	354	779	1.4266	– 156.2 lq	3924 lq	
Halogen derivatives of hydrocarbons								
Monochloromethane CH_3Cl	50.49	175	249	916	–	– 81.9 g	687 g	Methyl chloride

hydrocarbons								
Monochloromethane CH_3Cl	50.49	175	249	916	–	– 81.9 g	687 g	Methyl chloride

Name and Formula	Mole-cular weight	Melting point (K)	Boiling point (K)	Density ($kg\ m^{-3}$)	Refrac-tive index	Enthalpy of formation ($kJ\ mol^{-1}$)	Heat of combustion ($kJ\ mol^{-1}$)	Alternative name
Dichloromethane CH_2Cl_2	84.93	178	313	1327	1.4242	– 117 lq	447 g	Methylene dichloride
Trichloromethane $CHCl_3$	119.38	210	335	1483	1.4459	– 132 lq	373 lq	Chloroform
Tetrachloroethane CCl_4	153.82	250	350	1594	1.4601	– 139.5 lq	156 lq	Carbon tetrachloride
Bromomethane CH_3Br	94.94	180	277	1676	1.4218	– 35.6 g	770 g	Methyl bromide
Iodomethane CH_3I	141.94	207	316	2279	1.5380	– 8.4 lq	815 lq	Methyl iodide
Alcohols								
Methanol CH_3OH	32.04	179	338	791	1.3288	– 238.7 lq	715 lq	
Ethanol C_2H_5OH	46.07	156	352	789	1.3611	– 277.7 lq	1371 lq	
n-propanol n-C_3H_7OH	60.11	147	371	803	1.3850	– 300 lq	2017 lq	
Propane-1,2,3-triol $C_3H_8O_3$	92.11	293	d	1261	1.4746	– 103.9 lq	1661 lq	Glycerol
Acids								
Ethanoic acid CH_3COOH	60.05	290	391	1049	1.3716	– 488.3 lq	876 lq	Acetic acid
Propanole acid C_2H_5COOH	74.08	252	414	993	1.3869	– 509 lq	1574 lq	Propionic acid
n-Butanoic acid n-C_3H_7COOH	88.12	269	437	958	1.3980	– 538.9 lq	2194 lq	
Benzoic acid C_6H_5COOH	122.13	396	522	1266	1.504	– 390 c	3227 c	
Miscellaneous								
Ethanal CH_3CHO	44.05	152	294	783	1.3316	– 166.4 g	1167 lq	Acetaldehyde
2-Propanone $CH_3CO - CH_3$	58.08	178	329	790	1.3588	– 216.7 lq	1821 lq	Acetone
Methoxymethane $CH_3O - CH_3$	46.07	135	250	–	–	– 185 g	1454 g	Dimethylether
Ethoxyethane $C_2H_5 \cdot O - C_2H_5$	74.12	157	308	714	1.3526	– 279.6 lq	2761 lq	Diethylether
Urea $CO(NH_2)_2$	60.06	408	d	1323	1.484	– 333.2 c	634 c	
Glycine $NH_2 - CH_2 - COOH$	75.07	d	–	828	–	– 528.6 c	981 c	

Table 2.6. Properties of Liquids (at 293 K)

Name	Density (kgm^{-3})	Melting point (K)	Boiling point (K)	Specific latent heat of vaporization ($J\ kg^{-1}$)	Specific heat capacity ($Jkg^{-1}\ K^{-1}$)	Cubic expansivity (K^{-1})	Thermal conductivity ($Wm^{-1}\ K^{-1}$)	Surface tension (Nm^{-1})	Viscosity (Nsm^{-2})	Refractive index	Bulk modulus (GPa)
				$\times 10^4$		$\times 10^{-4}$		$\times 10^{-3}$	$\times 10^{-3}$		
1. Acetic acid ($C_2H_4O_2$)	1049	290	391	39	1960	10.7	0.180	27.6	1.219	1.3718	2.49
2. Acetone (C_3H_6O)	780	178	330	52	2210	14.3	0.161	23.7	0.324	1.3620 (288 K)	~ 0.8
3. Benzene (C_6H_6)	879	279	353	40	1700	12.2	0.140	28.9	0.647	1.5011	1.10
4. Bromine (Br)	3100	266	332	18.3	460	11.3	–	41.5	0.993	1.66	1.58
5. Carbon disulphide (CS_2)	1293	162	319	36	1000	11.9	0.144	32.3	0.375	1.6276	1.16
6. Carbon tetrachloride (CCl_4)	1632	250	350	19	840	12.2	0.103	26.8	0.972	1.4607	1.12
7. Chloroform ($CHCl_3$)	1490	210	334	25	960	12.7	0.121	27.1	0.569	1.4467	1.1
8. Ether, diethyl ($C_4H_{10}O$)	714	157	308	35	2300	16.3	0.127	17	0.242	1.3538	0.69
9. Ethyl alcohol (C_2H_6O)	789	156	352	85	2500	10.8	0.177	22.3	1.197	1.3610	1.32

Name	Density (kgm^{-3})	Melting point (K)	Boiling point (K)	Specific latent heat of vaporization ($J\ kg^{-1}$)	Specific heat capacity ($Jkg^{-1}\ K^{-1}$)	Cubic expansivity (K^{-1})	Thermal conductivity ($Wm^{-1}\ K^{-1}$)	Surface tension (Nm^{-1})	Viscosity (Nsm^{-2})	Refractive index	Bulk modulus (GPa)
				$\times 10^4$		$\times 10^{-4}$		$\times 10^{-3}$	$\times 10^{-3}$		
10. Glycerol ($C_3H_8O_3$)	1262	293	563	83	2400	4.7	0.270	63	1495	1.4730	4.03
11. Mercury (Hg)	13546	234	630	29	140	1.82	7.96	472	1.552	1.73	26.2
12. Methyl alcohol (CH_4O)	791	179	337	112	2500	11.9	0.201	22.6	0.594	1.3276	0.97
13. Nitrobenzene ($C_6H_5NO_2$)	1175	279	484	33	1400	8.6	0.160	43.9	2.03	1.5530	2.2
14. Olive oil	920	–	570	–	1970	7.0	0.170	32	84	1.48	1.60
15. Parafin oil	800	–	–	–	2130	900	0.150	26	1000	1.43	1.62
16. Phenol (C_6H_6O)	1073	314	455	53	2350	7.9	–	40.9	12.74	1.5425 (313 K)	–
17. Toluene (C_7H_8)	867	178	384	35	1670	10.7	0.134	28.4	0.585	1.4969	1.09
18. Turpentine	870	263	429	29	1760	9.7	0.136	27	1.49	1.48	1.28
19. Water (H_2O)	998	273	373	226	4190	2.1	0.591	72.7	1.000	1.333	2.05
20. Water, sea	1025	264	377	–	3900	–	–	–	–	1.343	–

Table 2.7. Properties of Gases at S.T.P.

Substance	Density (kgm^{-3})	Boiling point (K)	Specific latent heat of vaporization (Jkg^{-1})	Specific heat capacity ($Jkg^{-1} K^{-1}$)	Ratio of specific heats (c_p/c_v)	Thermal conductivity ($Wm^{-1} K^{-1}$)	Viscosity (Nsm^{-2})	Refractivity	Critical temperature (K)	Critical pressure (MPa)	Critical volume ($m^3 mol^{-1}$)
			$\times 10^4$			$\times 10^{-4}$	$\times 10^{-6}$	$\times 10^{-6}$			$\times 10^{-6}$
1. Acetylene (C_2H_2)	1.173	189	–	1590	1.26	184	9.35	606	309	6.14	113*
2. Air	1.293	83	21.4	993	1.402	241	18.325 (300 K)	292	132	3.77	–
3. Ammonia (NH_4)	0.771	240	137.1	2190	1.310	218	9.18	376	405	11.3	72.5
4. Argon (Ar)	1.784	87	15.8	524	1.667	162	21	281	151	4.86	75.2
5. Carbon dioxide (CO_2)	1.977	195	36.4	834	1.304	145	14	451	304	7.38	94.0
6. Carbon monoxide (CO)	1.250	81	21.1	1050	1.404	232	16.6	338	134	3.50	93.1
7. Chlorine (Cl_2)	3.214	238	28.1	478	1.36	72	12.9	773	417	7.71	124
8. Cyanogen (C_2N_2)	2.337	252	43.2	1720	1.26	–	9.28	835	401	6.0	–
9. Ethylene (C_2H_4)	1.260	170	48.4	1500	1.26	164	9.7	696	283	5.12	127.4
10. Helium (He)	0.179	4.25	2.5	5240	1.66	1415	18.6	36	5.3	0.23	58

Substance	Density (kgm^{-3})	Boiling point (K)	Specific latent heat of vaporization (Jkg^{-1})	Specific heat capacity ($Jkg^{-1} K^{-1}$)	Ratio of specific heats (c_p/c_v)	Thermal conductivity ($Wm^{-1} K^{-1}$)	Viscosity (Nsm^{-2})	Refractivity	Critical temperature (K)	Critical pressure (MPa)	Critical volume ($m^3 mol^{-1}$)
			$\times 10^4$			$\times 10^{-4}$	$\times 10^{-6}$	$\times 10^{-6}$			$\times 10^{-6}$
11. Hydrogen (H_2)	0.090	20.35	45.3	14300	1.41	1684	8.35	132	33.3	12.94	65.5
12. Hydrogen chloride (HCl)	1.640	189	41.4	796	1.40	–	13.8	447	325	8.26	87
13. Hydrogen sulphide (H_2S)	1.538	211	55.3	1020	1.32	120	11.7	634	374	9.01	97.9
14. Methane (CH_4)	0.717	109	51.1	2200	1.313	302	10.3	444	191	4.62	98.7
15. Nitric oxide (NO)	1.340	121	46.2	972	1.394	238	17.8	297	179	6.5	–
16. Nitrogen (N_2)	1.250	77	20.9	1040	1.404	243	16.7	297	126	3.39	90.1
17. Nitrous oxide (N_2O)	1.978	183	37.6	892	1.303	151	13.5	516	310	7.24	96.7
18. Oxygen (O_2)	1.429	90	24.3	913	1.40	244	19.2	272	154	5.08	78
19. Sulphur dioxide (SO_2)	2.927	263	40.3	645	1.26	77	11.7	686	430	7.88	122
20. Water vapour (273 K) (H_2O)	0.800	–	226.1	2020 (373 K)	–	158	8.7	254	647	22.12	56.8

• The critical volume is here defined as the volume of one mole of the gas at its critical temperature and pressure.

Properties of Engineering Materials

Table 2.8: Mechanical Properties of Carbon Steel Castings for General Engg. Purposes

*Grade Designation	Yield stress Min. (MN/m^2)	Tensile strength Min. (MN/m^2)	Elongation% Min. Gauge length $5.65\sqrt{S_0}$	Reduction of area percent Min.	Impact strength Min. J/cm^2	Angle of bend Min.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
20 – 40	200	400	25	40	30	90°
23 – 45	230	450	22	31	25	90°
26 – 52	260	520	18	25	22	60°
27 – 54	270	540	16	23	20	60°
30 – 57	300	570	15	21	18	60°

*On the basis of minimum yield stress and tensile strength values respectively expressed in 10 MN/m^2.

Table 2.9: Mechanical Properties of Iron Castings with Spheroidal or Nodular Graphite

Grade Designation	Tensile strength Min. N/mm^2	Elongation percent Min.	Brinell hardness (HB)	Predominant structural constituent and applications
(1)	(2)	(3)	(4)	(5)
SG 800/2	800	2	248-352	Pearlite or tempered structure-High tensile strength and less ductility.
SG 700/2	700	2	229-302	Pearlite-High tensile strength and less ductility
SG 600/3	600	3	192-269	Pearlite and ferrite-High tensile strength and less ductility.
SG 500/7	500	7	170-241	Ferrite and pearlite-Medium strength with reasonable ductility
SG 400/12	400	12	201, Max.	Ferrite-Medium tensile strength with substantial ductility and toughness
SG 370/17	370	17	179, Max.	Ferrite-High resistance to impact.

Table 2.10: Mechanical Properties of Grey Cast Iron

Properties	Unit	Grade						
		FG 150	FG 200	FG 220	FG 260	FG 300	FG 350	FG 400
Tensile strength	(N/mm^2)	150	200	220	260	300	350	400
0.01 percent proof stress	(N/mm^2)	42	56	62	73	84	98	112
0.1 percent proof stress	(N/mm^2)	98	130	143	169	195	228	260
Total strain at failure	Percent	0.60-0.75*	0.48-0.67*	0.39-0.63*	0.57	0.50	0.50	0.50
Elastic strain at failure	Percent	0.15	0.17	0.18	0.20	0.22	0.25	0.28
Compressive strength	(N/mm^2)	600	720	768	864	960	1080	1200
0.01 percent proof stress	(N/mm^2)	84	112	123	146	168	196	224
0.1 percent proof stress	(N/mm^2)	195	260	286	338	390	455	520
Shear strength	(N/mm^2)	173	230	253	299	345	403	460
Torsional strength	(N/mm^2)	173	230	253	299	345	403	460
Shear strain at failure	Percent	> 4	> 4	> 4	> 4	Up to 4	Up to 4	Up to 4
Modulus of elasticity (Tension)	GN/mm^2	100	114	120	128	135	140	145
(Compression)	GN/mm^2	100	114	120	128	135	140	145
Modulus of rigidity	GN/mm^2	40	46	48	51	54	56	58
Poisson's ratio	–	–	–	0.26	–	–	–	–
Fatigue limit	(N/mm^2)	68	90	99	117	135	149	152
Brinell hardness	HB	130-180	160-220	180-220	180-230	180-230	207-241	207-270

Table 2.11: Mechanical Properties of High Tensile Steel Castings

Grade	Designation	Tensile strength, Min (MN/m^2)	Yield stress (0.5 percent) (Proof stress), Min. (MN/m^2)	Reduction in area, Min. Percent	Elongation of gauge length $5.65\sqrt{S_0}$ Min. Percent	Brinell hardness, Min. HB	Izod impact strength, Min. J/cm^2
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	CS 640	640	390	35	15	190	30
2	CS 700	700	560	30	14	207	30
3	CS 840	840	700	28	12	248	28
4	CS 1030	1030	850	20	8	305	20
5	CS 1230	1230	1000	12	5	355	–

Table 2.12: Mechanical Properties of Carbon Steel Forgings for General Engg. Purposes

Class	Designation	Tensile strength Min. N/mm^2	Yield strength Min. N/mm2	Elongation percent, Min. Gauge length $5.65\sqrt{S_0}$	Hardness Min BHN	Normalizing temperature °C
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1 A	15 C 8	410	220	25	110	880-910
2	20 C 8	430	230	24	120	880-910
2 A	25 C 8	460	250	22	130	880-910
3	30 C 8	490	270	21	140	860-890
3 A	35 C 8	540	280	20	155	850-880
4	45 C 8	620	320	15	175	830-860
5	55 C 8	710	350	13	200	810-840
6	65 C 8	740	370	10	210	800-830

Note: The properties given in the table refer to 100 mm ruling section in the forged and normalized condition and are applicable to test samples taken along the direction of grain flow.

Table 2.13: Mechanical Properties of Standard Wrought Steels.

Designation	Tensile strength (N/mm^2)	Yield stress Min. (N/mm^2)	Elongation percent, Min. (Gauge length $5.65 \sqrt{A}$)
(1)	(2)	(3)	(4)
Fe 290	290	170	27
FeE 220	290	220	27
Fe 310	310	180	26
FeE 230	310	230	26
Fe 330	330	200	26
FeE 250	330	250	26
Fe 360	360	220	25
FeE 270	360	270	25
Fe 410	410	250	23
Fe E 310	410	310	23
Fe 490	490	290	21
FeE 370	490	370	21
Fe 540	540	320	20
FeE 400	540	400	20
Fe 620	620	380	15
FeE 460	620	460	15
Fe 690	690	410	12
FeE 520	690	520	12
Fe 770	770	460	10
FeE 580	770	580	10
Fe 870	870	520	8
FeE 650	870	650	8

2.14 : Mechanical Properties and Applications of Cast Irons and Cast Steels

IS Designation	Tensile strength N/mm^2	Stress N/mm^2	Elongation per cent (Gauge length $5.65\sqrt{A}$) [A = Area of cross section]	Hardness BHN	Typical applications	Other important properties
Grey C.I Castings		Transverse Rupture Stress			Machine tool beds and frames, flywheels, pulleys, low speed gears etc.	Endurance Limit : 40 to 130 N/mm^2
Grade – 15	130 to 190	285 to 417	–	149 to 197		$E = 0.7$ to 1.4×10^5 N/mm^2
20	170 to 240	335 to 464	–	179 to 223		
25	220 to 280	386 to 510	–	197 to 241		$G = 0.3$ to 0.56×10^5 N/mm^2
30	270 to 310	436 to 525	–	207 to 241		
35	320 to 350	553 to 573	–	207 to 241		
40	370 to 400	627 to 637	–	241 to 320		
Malleable cast iron	350 to 490	Ultimate compression stress – 800	–	120 to 190	Used for parts of complex shape involving considerable machining such as pipe fittings, valves, flanges, chains etc.	Endurance Limit: 160 to 210 N/mm^2 $E = 1.7$ to 1.9×10^5 N/mm^2 $G = 0.7$ to 0.77×10^5 N/mm^2
Spheroidal or Nodular Graphite Cast Iron		Minimum Proof Stress (0.2 per cent)			Intricate castings, frames for machines, dies for press formings, low speed gears, shafts etc.	Endurance Limit : 200 to 300 N/mm^2 $E = 1.75 \times 10^5$ N/mm^2
IS Grade – SG 80/2	800	480	2	260 to 330		

IS Designation	Tensile strength N/mm^2	Stress N/mm^2	Elongation per cent (Gauge length $5.65\sqrt{A}$) [A = Area of cross section]	Hardness BHN	Typical applications	Other important properties
SG 60/2	600	400	2	210 to 280		
SG 47/12	420	280	12	187 max.		
SG 38/17	380	240	17	171 max.		
Mechanite	About 300	Ultimate compressive stress 1100 to 1400 N/mm^2	–	195–230	Four common types of mechanite are used for general engineering, wear, heat, and corrosion resistance.	Endurance Limit 130 to 180 N/mm^2 $E = 1.2$ to 1.8×10^5 N/mm^2
Cast Steels		Yield Strength (0.5 per cent proof stress)			Complicated castings, cast parts can be welded	
IS – CS 65	650	400	17	190		
CS 85	850	710	12	248		
CS 125	1250	1020	5	363		
Alloy Cast Iron		Yield Strength			Castings where toughness, strength, wear-resistance are required as in crank shafts of automobile engines.	
Nickel C.I.	250	120	–	180 min.		
Ni-Mn C.I.	300	180	–	220 min.		
Nitro alloy	420	230	–	1050 min.		

Table 2.15: Properties and Uses of Carbon Steels

Designation (ISI Grade)	%C	%Mn	Tensile strength N/mm^2	Yield stress N/mm^2	Minimum elongation percentage (gauge length $5.65\sqrt{A}^*$ round test piece)	Brinell hardness (HB) No.	Suggested uses
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
C 07	0.12 max	0.50 max	314-392	196	27	–	Cold forming and deep drawing. Rimming quality used for automobile bodies and rivets, killed quality used for forgings.
C 10	0.15 max	0.30-0.60	333-412	206	26	–	-do-
C 14	0.10-0.18	0.40-0.70	363-441	216	26	137	Cam shafts, cams, light duty gears, worms, gudgeon pins, spindles, ratchets, chain wheels, tappets, etc.
C 15	0.20 max	0.30-0.60	363-481	235	25	137	Cold worked-rivets
C 15 Mn <u>75</u>	0.10-0.20	0.60-0.90	412-490	245	25	163	General purpose-low stressed components.
C 20	0.15-0.25	0.60-0.90	432-510	245	24	156	-do-
C 25	0.20-0.30	0.30-0.60	432-520	275	27	170	-do-
C 25 Mn <u>75</u>	0.20-0.30	0.60-0.90	461-560	275	22	207	-do-
C 30	0.25-0.35	0.60-0.90	490-588	294	21	179	Cold formed levers, hardened and tempered tie rods, cables, sprockets, hubs and bushes, steel tubes etc.
C 35	0.30-0.40	0.30-0.60	510-608	304	20	187	Low stressed components, automobile tubes and fasteners.

Designation (ISI Grade)	%C	%Mn	Tensile strength N/mm^2	Yield stress N/mm^2	Minimum elongation percentage (gauge length $5.65\sqrt{A}$* round test piece)	Brinell hardness (HB) No.	Suggested uses
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
C 35 Mn 75	0.30-0.40	0.60-0.90	540-637	314	20	223	Low stressed parts, cycle and motor cycle frame tubes, fish plates for rails and fasteners.
C 40	0.35-0.45	0.60-0.90	570-667	324	18	217	Crank shafts, shafts, spindles, axle beams, push rods, connecting rods, studs, bolts, gears, etc.
C 45	0.40-0.50	0.60-0.90	618-696	353	15	229	Shafts, bolts, gears and spindles of machine tools.
C 50	0.45-0.55	0.60-0.90	647-765	373	13	241	Shafts, keys, cylinders, hardened stock for worms and worm gears.
C 50 Mn 1	0.45-0.55	1.00-1.10	706 (min)	392	11	255	Rail steel, bolts, gear shafts, rocking levers and cylinder liners.
C 55 Mn 75	0.50-0.60	0.60-0.90	706 (min)	392	13	265	Keys, crank shafts, cylinders, cams, gears, sprockets, parts requiring moderate wear resistance.
C 60	0.55-0.65	0.50-0.80	736 (min)	412	11	255	Hardened screws and nuts, Crank shafts, axles, couplings, gears and spindles for machine tools.
C 65	0.60-0.70	0.50-0.80	736 (min)	422	10	255	Locomotive carriage and wagon tyres, engine valve springs, washers and thin stamped parts.

*A, area of cross section.

Table 2.16: Properties and Uses of Alloys Steels (Other than Stainless and Heat Resisting Steels)

Designation (ISI Grade)	Tensile strength MN/m^2	Yield strength MN/m^2	Minimum elongation $(e = 6.55 \sqrt{a^*})$	Minimum Izod impact value, Nm	Brinell hardness No.HB	Suggested uses
(1)	(2)	(3)	(4)	(5)	(6)	(7)
20 Mn 2	588-736	432	18	47.07	170-217	Welded structures, crank shafts, steering, shafting and spindles.
	687-834	490	16	47.07	201-248	
27 Mn 2	588-736	432	18	47.07	170-217	Welded structures, crank shafts, shafts, spindles and steering.
	687-834	490	16	47.07	201-248	
37 Mn 2	588-736	432	18	47.07	170-217	Crank shafts, shafts, axles and connecting rods.
	687-834	530	18	47.07	201-248	
	785-932	588	16	47.07	229-277	
	882-1030	687	15	40.21	255-311	
35 Mn 2 Mo 28	687-834	530	18	54.00	201-248	Crank shafts, levers, bolts and connecting rods
	785-932	588	16	54.00	229-277	
	882-1030	687	15	54.00	255-311	
	981-1128	785	13	47.07	285-341	
35 Mn 2 Mo 45	785-932	588	16	54.00	229-277	Crank shafts, connecting rods, bolts, and levers.
	882-1030	687	15	54.00	225-311	
	981-1128	785	13	47.07	285-341	
40 Cr 1 Mo 28	687-834	530	18	54.00	201-248	Connecting rods, gears, wear resisting plates, shafts, bolts etc.
	785-932	588	16	54.00	229-277	
	882-1030	687	15	54.00	255-311	
	981-1128	785	13	47.07	255-341	

Designation (ISI Grade)	Tensile strength MN/m^2	Yield strength MN/m^2	Minimum Elongation ($e = 6.55 \sqrt{a^*}$)	Minimum Izod Impact value, Nm	Brinell Hardness No.HB	Suggested uses
(1)	(2)	(3)	(4)	(5)	(6)	(7)
15 Cr 3 Mo 55 and 25 Cr 3 Mo 55	687-834	530	18	54.00	201-248	Parts requiring high surface hardness and wear resistance.
	785-932	588	16	54.00	229-277	
	882-1030	687	15	54.00	255-311	
	981-1128	785	13	47.07	285-341	
	1080-1226	863	12	40.21	311-363	
	1520 min	1275	8	13.73	444 Min	
40 Cr 3 Mo 1 V 20	1324 min	1098	8	20.60	363 Min	Components requiring high tensile strength.
	1520 Min	1275	8	13.73	448 Min	
40 Cr 2 Al 1 Mo 18	687-834	530	18	54.00	201-248	Components requiring high surface hardness and core strength.
	785-932	588	16	54.00	229-277	
	822-1030	687	15	37.27	255-311	
40 Ni 3	785-932	588	16	54.00	229-277	Heavy forgings, turbine blades, high stressed screws, bolts and nuts, cold though steel-used at low temperature (refrigerators and compressors).
	822-1030	687	15	54.00	255-311	
35 Ni 1 Cr 60	687-834	530	18	54.00	201-248	Aircrafts and heavy vehicle components
	785-932	588	16	54.00	229-277	
	882-1030	687	15	54.00	255-311	
30 Ni 4 Cr 1	1520 Min	1275	8	13.73	444 min	Highly stressed gears.
40 Ni 2 Cr 1 Mo 15	785-932	588	16	54.00	229-277	Gears, bolts, etc.
	882-1030	687	15	54.00	225-311	

Designation (ISI Grade)	Tensile strength MN/m^2	Yield strength MN/m^2	Minimum Elongation ($e = 6.55\sqrt{a^*}$)	Minimum Izod Impact value, Nm	Brinell Hardness No.HB	Suggested uses
(1)	(2)	(3)	(4)	(5)	(6)	(7)
40 Ni 2 Cr 1 Mo 28	981-1128	785	13	47.07	285-431	High strength machines' parts like gears, bolts, spindles, etc.
	1080-1226	863	11	40.21	311-363	
	785-932	588	16	54.00	229-277	
	882-1030	687	15	54.00	255-311	
	1080-1128	785	13	47.07	255-341	
	1080-1226	863	11	40.21	311-363	
	1180-1324	981	10	29.42	341-401	
	1520 min	1275	6	10.79	444 min	
40 Ni 2 Cr 65 Mo 55	981-1128	785	12	47.07	285-341	Highly stressed bolts, gears, shafts, mandrels, etc.
	1080-1226	863	11	40.21	311-363	
	1180-1324	981	10	34.32	341-401	
	1520 min	1275	8	13.73	444 min	

*a, area of cross-section.

Table 2.17: Mechanical Properties of Austenitic Stainless Steel Bars, Flats, Plates, Sheets and Strips in the Softened Condition

Steel designation	HB Max	0.2% Proof-stress Min	Tensile strength	Percentage elongation		Percentage elongation plates, sheets and strips	
				Bars from 5 to 100	Flats from 3 to 30	From 0.5 to 3	From 3 to 30
		MN/m^2	MN/m^2	mm	mm	mm	mm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
02Cr18Ni11	192	180	440 to 650	40	40	38	40
04Cr18Ni10	192	200	490 to 690	40	40	38	40
07Cr18Ni9	192	210	490 to 690	40	40	38	40
10Cr17Ni7	212	220	590 to 780	–	40	38	40
04Cr18Ni10Ti20	192	210	490 to 690	35	35	33	35
04Cr18Ni10Nb40	192	210	490 to 690	35	35	33	35
04Cr17Ni12Mo20	192	210	490 to 690	40	40	38	40
02Cr17Ni12Mo2	192	200	440 to 640	40	40	38	40
04Cr17Ni12Mo2Ti20	192	220	490 to 690	35	35	33	35
10Cr17Mn6Ni14	217	300	640 to 830	40	40	38	40
15Cr24Ni13	–	210	490 to 590	40	40	–	–
20Cr25Ni20	–	210	490 to 690	40	40	–	–

Table 2.18: Mechanical Properties of Stainless Steel Bars and Flats in the Hardened and Tempered Condition

Steel designation	Annealed HB Max	0.2% proof stress Min N/mm^2	Tensile strength N/mm^2	Percentage elongation Min		KCU* Min. J/cm^2
				Bars from 5 to 100 mm	Flats from 3 to 30 mm	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
12Cr13	212	410	590 to 780	16	16	6
20Cr13	229	490	690 to 880	14	14	4
30Cr13	235	590	780 to 980	11	11	–
15Cr16Ni2	262	640	830 to 1030	10	10	3

*Values applicable on bars from 15 to 63 mm diameter.

Table 2.19: Tensile Strength of Structural Steels

Grade	Tensile strength (N/mm^2)	Grade	Tensile strength (N/mm^2)
St 30	300 to 380	St 47	470 to 570
St 32	320 to 440	St 50	500 to 600
St 34	340 to 460	St 52	520 to 620
St 37	370 to 490	St 55	550 to 650
St 39	390 to 510	St 58	580 to 680
St 42	420 to 540	St 63	630 to 710
St 44	440 to 540	St 88	880 to 1000

Table 2.20: Properties of Brasses of Different Chemical Compositions

Chemical Composition			Tensile strength, MN/m^2	%Elongation*	Brinell hardness
%Cu	%Pb	%Zn			
54-47	upto 2.5	Rest	441	10	110
57-59.5	1.0-3.0	Rest	363-667	2 to 25	90-170
59.5-62	upto 0.3	Rest	333-580	3 to 30	80-170
62-65	upto 0.2	Rest	294-687	5 to 45	70-160
66-69	upto 0.1	Rest	284-530	5 to 45	70-160
69.5-73	upto 0.07	Rest	275-520	5 to 44	70-155

*Gauge Length; 5.8 $\sqrt{a}$ Round test piece; a, Area of cross-section

Table 2.21: Chemical Composition and Properties of Tin Bronze

Chemical composition					Mechanical properties		
%Cu	%Sn	%Zn	%Pb	%P	Tensile strength, MN/m^2	% Elongation gauge length 5.8 $\sqrt{a}$*	Brinell hardness HB
96	4	–	–	less than 0.4	314-440	10-55	65-120
94	6	–	–	0.4	343-490	12-60	70-130
92	8	–	–	0.4	392-540	20-60	80-150
91	8.5	–	–	0.3	540	5	150
90	10	–	–	–	216	15	60
88	12	–	–	–	235-275	8	80-95
86	14	–	–	–	196	3	85
85	5	7	3	–	147-245	10-12	60-75
86	10	4	–	–	196	10	65

*a area of cross-section, round

Table 2.22: Properties of Plastics

Material	Type	Condi- -tion	Tensile strength N/mm^2	Compressive strength N/mm^2	Flexure strength N/mm^2	Rock well hardness	E $\times 10^{-2}$ N/mm^2	Specific gravity	Trade names
Phenolformaldehyde	TS	L Sheet	98	245	162	M 100	28 – 140	1.35	Bakelite, durez, Formica, textolite, Micarta, Synthane durite.
Urea formaldehyde	TS	M	63	175	70	M 118	105	1.45	Beetle, sylplast, plaskon
Poly vinyl Chloride	TP	M	56	70	–	R 65	21	1.2	Geon, Vinylite, Marvinol
Poly Vinyl Chloride (Unplasticized)	TP	M	56	91	–	M 70	56	1.41	Exon, pliovic, ultron.
Poly methyl methacrylate	TP	M	56	98	63	M 100	28	1.16	Lucite, plexiglass, perspex
Polystyrene	TP	M	35	80	42	M 85	3.5	1.06	Lustrex, Styron, styrene, pliolite
Polyamide	TP	M	82	35	95	R 118	24	1.14	Nylon, Zetol
Cellulose Acetate	TP	M	32	140	–	R 100	14	1.27	Plastacele, Celanese, Kodapak.
Polyethylene	TP	M	12	2.8	12	R 11	1	0.92	Dylon, Alathon, Orizon
Polytetrafluoroethylene	TP	M	26	12	14	R 20	4	2.2	Teflon, (PTFE)
Polyvenylidene Chloride	TP	M	35	14	–	M 55	5	1.7	Saron
Polychlorotrifluoroethylene	TP	M	42	35	–	R 110	17	2.1	Kel-f fluorothene

Note: TS – Thermosetting

TP – Thermoplastic

L – Laminated

M – Moulded

Table 2.23: Materials for Gears

Material	IS Specification	Tensile strength N/mm^2	Brinell hardness number
Grey Cast Iron	Grade 25	250	197
Phosphor Bronze	Sand Cast Chill Cast Centrifugally Cast	160 240 270	60 70 90
Cast steel	Grade I	550	145
Constructional Steel	St 58	580 – 680	160 – 190
Plain Carbon Steel	C 60	600 – 700	180 – 200
Caron steel for surface hardening	C 45 C 55	700 720	145 Core 460 Case 200 Core 520 Case
Carbon steel for case hardening	C 14	500 – 750	650 Case
Direct hardening Alloy steels	40 Ni 2 Cr 1 Mo. 28 30 Ni 4 Cr 1 35 Ni 1 Cr 60 40 Ni 3	1550 1000 – 1150 1150 750 – 1050	444 400 – 500 400 – 500 400 – 500
Alloy Steels for case hardening	17 Mn 1 Cr 95 15 Ni 2 Cr 1 Mo 15 13 Ni 3 Cr 80 15 Ni 4 Cr 1 15 Cr 65	800 – 1100 1040 900 – 1200 1200 – 1500 600 – 850	650 Case 630 Case 600 – 620 Case 600 – 650 Case 650 Case
Nitriding Alloy steel	40 Cr 2 Al 1 Mo 18	> 660	750 – 800 Case

Table 2.24: Recommended Values of Factor of Safety

Material	For steady load	For varying load	For shock load

Table 2.24: Recommended Values of Factor of Safety

Material	For steady load	For varying load	For shock load
Cast Iron	5 to 6	8 to 12	16 to 20
Wrought Iron	4	7	10 to 50
Steel	4	8	12 to 60
Soft Metals and Alloys	6	9	15
Leather	9	12	15
Timber	7	10 to 15	20

Table 2.25: Conversion of Hardness Number and Their Correlation with Tensile Strength

Brinell Hardness Number		Rock well Hardness Number			Diamond pyramid hardness number	Shore Scleroscope hardness number	Tensile strength N/mm^2		
Impression dia, mm	Hardness number	Scale					Carbon steel	Chromium steel	Nickel and Chrome nickel steel
		C	A	B					
2.2	780	72	89	–	1224	–	–	–	–
2.25	745	70	87	–	1116	–	–	–	–
2.30	712	68	86	–	1022	–	–	–	–
2.35	682	66	85	–	941	90	–	–	–
2.40	653	64	84	–	868	86	–	–	–
2.45	627	62	83	–	804	84	–	–	–
2.50	601	60	82	–	746	81	–	–	–
2.55	578	58	81	–	694	78	–	–	–
2.60	555	56	79	–	649	75	–	–	–
2.65	534	54	78	–	606	71	–	–	–
2.70	514	52	77	–	587	69	–	–	–
2.75	495	50	76	–	551	66	1780	1730	1680
2.80	477	49	76	–	534	65	1720	1670	1610
2.85	461	48	75	–	502	64	1650	–	–

Brinell Hardness Number		Rock well Hardness Number			Diamond pyramid hardness number	Shore Scleroscope hardness number	Tensile strength N/mm^2		
		Scale							
Impression dia, mm	Hardness number	C	A	B			Carbon steel	Chromium steel	Nickel and Chrome nickel steel
2.90	444	46	74	–	473	61	1600	1560	–
2.95	429	45	73	–	460	59	1550	1500	1460
3.00	415	44	72	–	435	58	1490	1450	1410
3.02	409	43	72	–	423	57	1470	1430	1390
3.05	401	42	71	–	412	56	1440	1395	1365
3.10	388	41	71	–	401	55	1395	1360	1320
3.15	375	40	70	–	390	53	1350	1315	1275
3.20	363	39	70	–	380	52	1305	1270	1235
3.25	352	38	69	–	361	51	1265	1230	1195
3.30	341	37	68	–	344	50	1225	1190	1160
3.35	331	36	68	–	335	49	1195	1165	1130
3.40	321	35	67	–	320	48	1155	1120	1090
3.45	311	34	67	–	312	47	1115	1085	1055
3.50	302	33	67	–	305	46	1085	1055	1025
3.55	293	31	66	–	291	43	1055	1025	1000
3.60	286	30	66	–	285	42	1030	1005	975
3.65	277	29	65	–	278	41	995	970	940
3.70	269	28	65	–	272	40	970	940	915
3.75	262	27	64	–	261	39	945	920	895
3.80	255	26	64	–	255	38	920	890	865
3.85	248	25	63	–	250	37	895	870	845
3.90	241	24	63	100	240	36	870	845	820
3.95	235	23	62	99	235	35	845	825	805
4.00	228	22	62	98	226	34	825	800	775

Brinell Hardness Number		Rock well Hardness Number			Diamond pyramid hardness number	Shore Scleroscope hardness number	Tensile strength N/mm^2		
Impression dia, mm	Hardness number	Scale C	Scale A	Scale B			Carbon steel	Chromium steel	Nickel and Chrome nickel steel
4.05	223	21	61	97	221	33	800	775	765
4.10	217	20	61	97	217	33	780	760	740
4.15	212	19	60	96	213	32	760	740	720
4.20	207	18	60	95	209	32	745	725	705
4.25	202	16	59	94	201	31	720	710	685
4.30	196	15	58	93	197	31	705	685	665
4.35	192	15	58	92	190	30	690	670	650
4.40	187	–	57	91	186	–	675	655	635
4.45	183	–	56	89	183	–	660	640	625
4.50	179	–	56	88	177	–	640	625	605
4.55	174	–	55	87	174	–	625	610	590
4.60	170	–	–	86	171	–	610	595	580
4.65	166	–	–	85	165	–	600	585	570
4.70	163	–	–	84	162	–	585	570	555
4.75	159	–	–	83	159	–	575	555	545
4.80	156	–	–	82	154	–	560	545	530
4.85	153	–	–	81	152	–	550	535	520
4.90	149	–	–	80	149	–	535	520	505
4.95	146	–	–	78	147	–	525	510	500
5.00	143	–	–	76	144	–	510	495	485
5.05	140	–	–	76	–	–	500	490	475
5.10	137	–	–	75	–	–	495	480	465
5.15	134	–	–	74	–	–	486	470	455
5.20	131	–	–	72	–	–	470	455	445

Brinell Hardness Number		Rock well Hardness Number			Diamond pyramid hardness number	Shore Scleroscope hardness number	Tensile strength N/mm^2		
		Scale							
Impression dia, mm	Hardness number	C	A	B			Carbon steel	Chromium steel	Nickel and Chrome nickel steel
5.25	128	–	–	71	–	–	462	447	435
5.30	126	–	–	69	–	–	450	435	425
5.35	124	–	–	69	–	–	440	430	420
5.40	121	–	–	67	–	–	435	425	410
5.45	118	–	–	66	–	–	425	415	400
5.50	116	–	–	65	–	–	417	407	393
5.55	114	–	–	64	–	–	412	402	387
5.60	112	–	–	62	–	–	405	395	385
5.65	109	–	–	61	–	–	390	–	–
5.70	107	–	–	59	–	–	385	–	–
5.75	105	–	–	58	–	–	380	–	–
5.80	103	–	–	57	–	–	370	–	–
5.85	101	–	–	56	–	–	365	–	–
5.90	99	–	–	54	–	–	355	–	–
5.95	97	–	–	53	–	–	350	–	–
6.00	96	–	–	52	–	–	345	–	–
6.10	92	–	–	49.5	–	–	330	–	–
6.20	88	–	–	47	–	–	320	–	–
6.36	84	–	–	43.5	–	–	300	–	–
6.48	80	–	–	40.5	–	–	290	–	–
6.56	78	–	–	38.5	–	–	280	–	–

CHAPTER – 3

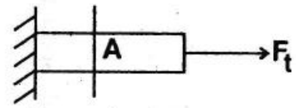
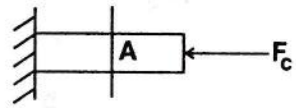
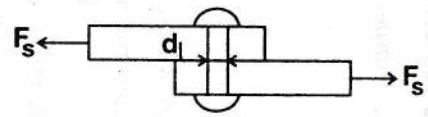
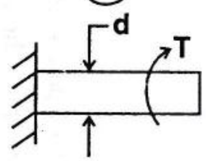
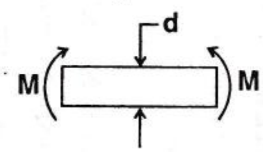
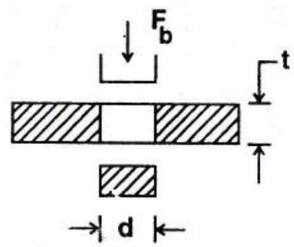
STRESSES AND STRAINS

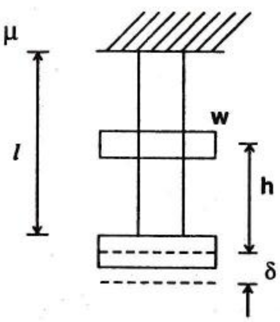
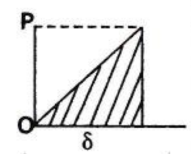
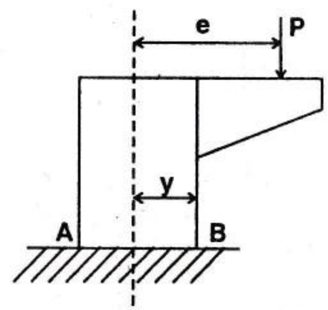
Symbols : (with S.I. units)

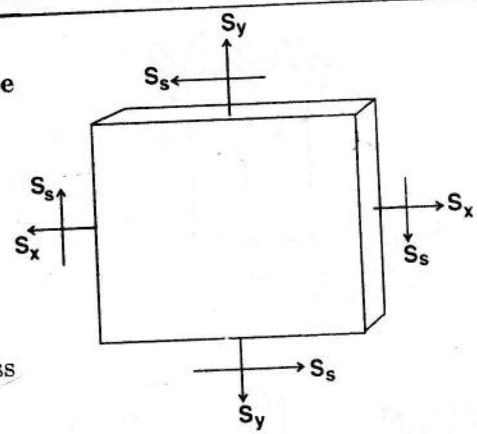
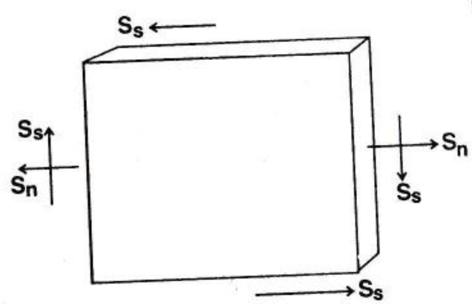
A	–	Area of cross-section, mm^2
b	–	Section width, mm
C	–	Spring index, Centre distance
D	–	Diameter of rod or shaft or any circular section, mm
d	–	Diameter of rod or shaft or any circular section, mm; Damage ratio
E	–	Modulus of elasticity or Youngs modulus, N/mm^2
e	–	Eccentricity, mm; Linear strain.
$\varepsilon_x, \varepsilon_y, \varepsilon_z$	–	Resultant strain in x, y, z directions due to stresses S_x, S_y, S_z acting combinedly
e_x, e_y, e_z	–	Strain in x, y, z directions due to stresses S_x, S_y, S_z acting individually.
F	–	Force or load, N
F_b	–	Bending force, Blanking force
F_c	–	Compression force, Crushing force
F_n	–	Normal force
F_s	–	Shear force
F_t	–	Tensile force
f_s	–	Factor of safety
G	–	Modulus of rigidity or shear modulus, N/mm^2

g	–	Acceleration due to gravity
I	–	Area moment of inertia, mm^4
J	–	Polar moment of inertia, mm^4
K	–	Bulk modulus, Stress concentration factor
k	–	Ratio of inner diameter to outer diameter $\left(\text{i.e., } k = \frac{d_i}{d_0}\right)$
K_a	–	Load correction factor for reversed axial load.
K_b	–	Load correction factor for reversed bending load.
K_s	–	Load correction factor for reversed shear (i.e., torsional) load.
K_{sr}	–	Surface finish factor
K_{sz}	–	Size factor
K_t	–	Theoretical or static stress concentration factor for normal stress.
K_{ts}	–	Theoretical or static stress concentration factor for shear stress.
K_t'	–	Theoretical combined factor which takes account of both stress concentration and strength theory (Mises criterion).
K_f	–	Fatigue stress concentration factor for normal stress
K_{fs}	–	Fatigue stress concentration factor for shear stress.
L	–	Length of rod or shaft or any beam, mm
l	–	Length of rod or shaft or any beam, mm
M	–	Bending moment, N-mm; Metric symbol.
$\frac{1}{m}$ or μ	–	Poisson's ratio
N	–	Speed in rpm, Unit of force in newtons, Number of cycles
n	–	Number of cycles, Factor of safety, Speed
P	–	Power, W; Load, N
p	–	Pressure, N/mm^2
p_b	–	Bearing pressure
q	–	Notch sensitivity factor.
R	–	Radius of curvature, mm
r	–	Radius of rod or shaft or any circular object, mm
S	–	Stress, N/mm^2
S_b	–	Bending stress, Blanking stress

S_c – Compressive stress, Crushing stress
S_e – Endurance stress
S_m – Mean stress
S_n – Normal stress
S_{p1} – Maximum principal stress
S_{p2} – Minimum principal stress
S_s – Shear stress
S_{sm} – Maximum shear stress
S_t – Tensile stress
S_u – Ultimate stress
S_v – Variable stress amplitude.
S_y – Yield normal stress
S_{ys} – Yield shear stress
S_x, S_y, S_z – Normal stresses in x, y, z directions respectively
T – Twisting moment or torque, N-mm; Temperature, °C.
t – Time, s; Thickness, mm
u – Modulus of resilience
V – Volume, mm^3
v – Velocity, m/s
W – Weight or load, N; Unit of power in watts.
y – Distance of extreme fibre from the neutral axis of any section, mm.
Z – Section modulus, mm^3
δ – Deformation or elongation, mm; deflection, mm.
η – Efficiency
Θ – Angle of twist in radians
μ – Poisson's ratio, coefficient of friction, micro (metre)
ρ – Density, kg/m^3
σ – Normal stress, N/mm^2
τ – Shear stress, N/mm^2.
ϕ – Shear strain.
ω – Angular velocity, rad/s.

DESIGN PARTICULARS		EQUATIONS	
Simple Stresses (Uni-Axial Stresses)			
Tensile stress		$S_t = \frac{F_t}{A}$	.... (3.1)
Compressive stress		$S_c = \frac{F_c}{A}$	.... (3.2)
Transverse shear stress		$S_s = \frac{4\,F_s}{\pi\,d^2}$	.... (3.3)
Torsional shear stress		$S_s = \frac{16\,T}{\pi\,d^3}$	.... (3.4)
Bending stress		$S_b = \frac{32\,M}{\pi\,d^3}$	.... (3.5)
Blanking stress		$S_b = \frac{F_b}{\pi\,d\,t}$	.... (3.6)
Bending equation		$\frac{M}{I} = \frac{S_b}{y} = \frac{E}{R}$	.... (3.7)
Torsion equation		$\frac{T}{J} = \frac{S_s}{r} = \frac{G\,\theta}{l}$	.... (3.8)

DESIGN PARTICULARS	EQUATIONS
Uni-axial Deformations:	
Linear strain	$e = \frac{S_n}{E} = \frac{F}{AE} = \frac{\delta}{l}$ .... (3.9)
Linear elongation or deformation	$\delta = \frac{Fl}{AE}$ .... (3.10)
Shear strain	$\phi = \frac{S_s}{G}$ .... (3.11)
Relation between E, G, K, μ	$E = 3K(1 - 2\mu) = 2G(1 + \mu)$ .... (3.12)
Modulus of resilience  	$u = \frac{S^2}{2E}$, ... (3.13) S–Normal stress at elastic limit
Impact loading equation	$W(h + \delta) = \frac{1}{2} P \delta$ .... (3.14) W = Impact load, P = Gradual load.
Eccentric loading 	Resultant stress at $A = S_b \sim S_n$ Resultant stress at $B = S_b + S_n$ $S_b = \frac{P.e.y}{I}$, $S_n = \frac{P}{A}$ .... (3.15)

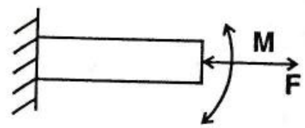
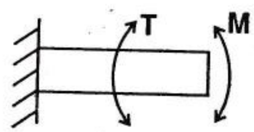
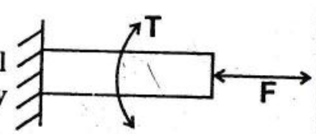
DESIGN PARTICULARS	EQUATIONS
Bi-axial Stresses:	
At any strained particle inside the body	
For condition (1) (Two normal stresses and one shear stress)  ($S_x > S_y$) & unit thickness	
Maximum principal stress	$S_{p1} = \frac{1}{2}\left[(S_x + S_y) + \sqrt{(S_x - S_y)^2 + 4\,S_s^2} \right]$ 3.16
Minimum principal stress	$S_{p2} = \frac{1}{2}\left[(S_x + S_y) - \sqrt{(S_x - S_y)^2 + 4S_s^2} \right]$ .... (3.17)
Maximum shear stress	$S_{sm} = \frac{1}{2} \sqrt{(S_x - S_y)^2 + 4S_s^2}$ .... (3.18)
For condition (2) (One normal stress and one shear stress) 	
Maximum principal stress	$S_{p1} = \frac{1}{2}\left[S_n + \sqrt{S_n^2 + 4\,S_s^2} \right]$ .... (3.19)
Minimum principal stress	$S_{p2} = \frac{1}{2}\left[S_n - \sqrt{S_n^2 + 4S_s^2} \right]$ .... (3.20)
Maximum shear stress	$S_{sm} = \frac{1}{2} \sqrt{S_n^2 + 4S_s^2}$ .... (3.21)

Maximum shear stress	S_s	$S_{sm} = \frac{1}{2}\sqrt{S_n^2 + 4S_s^2}$ .... (3.21)

DESIGN PARTICULARS	EQUATIONS
Bi-Axial Deformations:	
Poisson's ratio	$\mu = \frac{-e_y}{e_x} = \frac{-e_z}{e_x}$ .... (3.22)
Resultant unit deformations or strain in the x-direction	$\varepsilon_x = \frac{S_x}{E} - \mu \frac{S_y}{E}$ .... (3.23)
Resultant unit deformation or strain in the y-direction	$\varepsilon_y = \frac{S_y}{E} - \mu \frac{S_x}{E}$ .... (3.24)
Tri-Axial Deformations:	
Resultant unit deformation or strain in the x-direction	$\varepsilon_x = \frac{1}{E}\left[S_x - \mu\,(S_y + S_z) \right]$ .... (3.25)
Resultant unit deformation or strain in the y-directions	$\varepsilon_y = \frac{1}{E}\left[S_y - \mu\,(S_z + S_x) \right]$ .... (3.26)
Resultant strain in the z-direction	$\varepsilon_z = \frac{1}{E}\left[S_z - \mu\,(S_x + S_y) \right]$ .... (3.27)
Failure Theories:	
Maximum principal stress theory (or) Rankine's theory	$\frac{1}{2}\left[S_n + \sqrt{S_n^2 + 4S_s^2} \right] = \frac{S_y}{f_s}$ .... (3.28)
Maximum shear stress theory (or) Guest's theory	$\frac{1}{2}\sqrt{S_n^2 + 4S_s^2} = \frac{S_{ys}}{f_s}$ .... (3.29)
Maximum principal strain theory (or) Saint venant's theory	$S_{p1} - \mu\, S_{p2} = \frac{S_y}{f_s}$ .... (3.30)
Maximum strain energy theory (or) Haigh's theory	$S_{p1}^2 + S_{p2}^2 - 2\,\mu\, S_{p1}\, S_{p2} = \left(\frac{S_y}{f_s}\right)^2$ .... (3.31)
Maximum distortion energy theory (or) Hencky and Mises theory	$S_{p1}^2 + S_{p2}^2 - S_{p1}\, S_{p2} = \left(\frac{S_y}{f_s}\right)^2$ .... (3.32)

DESIGN PARTICULARS	EQUATIONS	
Variable simple stresses:		
Gerber's equation	$\frac{K_f S_v}{S_e'} + \left(\frac{S_m}{S_u}\right)^2 = \frac{1}{f_s}$	.... (3.33)
Goodman's equation	$\frac{K_f S_v}{S_e'} + \frac{S_m}{S_u} = \frac{1}{f_s}$	.... (3.34)
Soderberg's equation	$\frac{K_f S_v}{S_e'} + \frac{S_m}{S_y} = \frac{1}{f_s}$	.... (3.35)
Mean stress	$S_m = \frac{S_{max} + S_{min}}{2}$	.... (3.36)
Variable stress amplitude	$S_v = \frac{S_{max} - S_{min}}{2}$	.... (3.37)
Fatigue stress concentration factor	$K_f = 1 + q\,(K_t - 1)$	.... (3.38)
	$K_{fs} = 1 + q\,(K_{ts} - 1)$	.... (3.39)
Corrected endurance limit for variable bending load	$S_e' = S_e \cdot K_b \cdot K_{sr} \cdot K_{sz}$	.... (3.40)
Corrected endurance limit for variable axial load	$S_e' = S_e \cdot K_a \cdot K_{sr} \cdot K_{sz}$	.... (3.41)
Corrected endurance limit for variable torsional load	$S_e' = S_e \cdot K_s \cdot K_{sr} \cdot K_{sz}$	.... (3.42)
Relation between S_e, S_u, S_y	$\left.\begin{array}{l} S_e \simeq 0.5\,S_u \\ \quad \simeq 0.85\,S_y \end{array}\right\}$ For steel	

Relation between S_e, S_u, S_y	$\left.\begin{aligned} S_e &\simeq 0.5\,S_u \\ &\simeq 0.85\,S_y \end{aligned}\right\}$ For steel

DESIGN PARTICULARS	EQUATIONS
Values of K_b, K_a, K_s, K_{sr}, K_{sz}	$S_e \simeq 0.35\,S_u$ For cast iron $\simeq 0.3\,S_u$ For nonferrous metal $K_b = 1, \quad K_a = 0.8, \quad K_s = 0.55$ $K_{sr} = 1$ For mirror-polished specimen < 1 For rough specimen $= 1$ For non ferrous metal. $K_{sz} = 1$ For standard specimen.
Variable Combined Stresses: For combined bending and axial variable loads, the resultant normal stress 	$S_{rba} = S_{rb} + S_{ra} = \dfrac{S_y}{f_s}$ .... (3.43)
For combined bending and shear variable loads the resultant normal stress according to Rankine's theory 	$S_{rbst} = \dfrac{1}{2}\left[S_{rb} + \sqrt{S_{rb}^2 + 4\,S_{rs}^2}\right] = \dfrac{S_y}{f_s}$ .... (3.44)
For the above conditions, the resultant shear stress according to Guest's theory	$S_{rbss} = \dfrac{1}{2}\sqrt{S_{rb}^2 + 4\,S_{rs}^2} = \dfrac{S_{ys}}{f_s}$ .... (3.45)
For combined axial and shear variable loads, the resultant normal stress according to Rankine's theory 	$S_{rast} = \dfrac{1}{2}\left[S_{ra} + \sqrt{S_{ra}^2 + 4S_{rs}^2}\right] = \dfrac{S_y}{f_s}$ .... (3.46)

DESIGN PARTICULARS	EQUATIONS
For the above conditions, the resultant shear stress according to Guest's theory	$S_{rass} = \frac{1}{2}\sqrt{S_{ra}^2 + 4\,S_{rs}^2} = \frac{S_{ys}}{f_s}$ .... (3.47)
Values of S_{rb}, S_{ra}, S_{rs} and S_{ys}	$S_{rb} = \frac{K_{fb} \cdot S_{vb} \cdot S_y}{S_e \cdot K_b \cdot K_{sr} \cdot K_{sz}} + S_{mb}$ .... (3.48)
	$S_{ra} = \frac{K_{fa} \cdot S_{va} \cdot S_y}{S_e \cdot K_a \cdot K_{sr} \cdot K_{sz}} + S_{ma}$ .... (3.49)
	$S_{rs} = \frac{K_{fs} \cdot S_{vs} \cdot S_{ys}}{S_e \cdot K_s \cdot K_{sr} \cdot K_{sz}} + S_{ms}$ .... (3.50)
	$S_{ys} \simeq 0.5\,S_y$
Life of fatigue loaded machine parts	$\frac{S_v}{S_u} = \left\{1 - \frac{S_m}{S_u}\right\}\left\{A_0 + \alpha\,(1 - A_0)\right\}$ .... (3.51)
	$A_0 = \frac{1 + 0.0038\,n^4}{1 + 0.008\,n^4}$ .... (3.52)
	$\alpha = \frac{S_m}{3\,S_u}\left(2 + \frac{S_m}{S_u}\right)$ .... (3.53)
	$n = \log_{10} N$ (or) $N = 10^n$
	N = Number of cycles for failure (or) Life of specimen.

N = Number of cycles for failure
(or) Life of specimen.

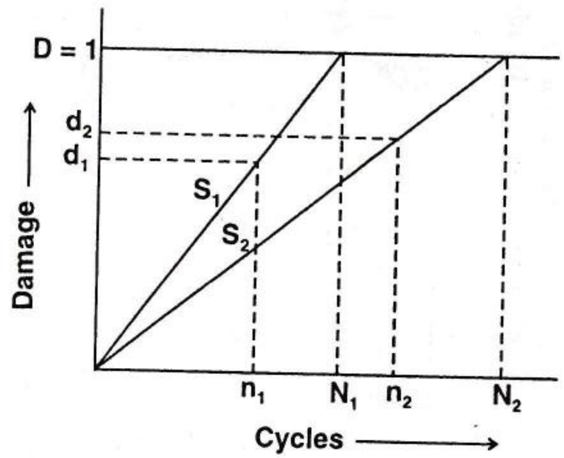
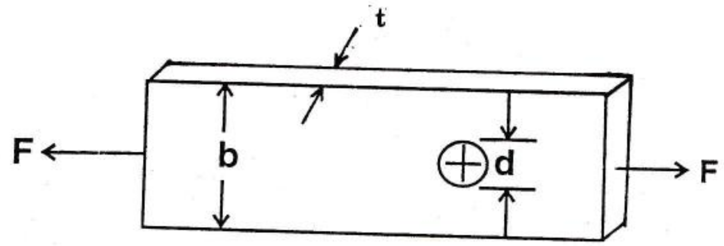
DESIGN PARTICULARS	EQUATIONS
Miner's rule for cumulative fatigue damage (i.e., the condition for failure of machine part)  	$$\frac{n_1}{N_1} + \frac{n_2}{N_2} + \ldots = 1 \qquad \ldots (3.54)$$ $n_1, n_2 \ldots$ = No. of operated cycles at stresses $S_1, S_2 \ldots$ respectively. $N_1, N_2 \ldots$ = No. of cycles for failure at stresses $S_1, S_2 \ldots$ respectively.

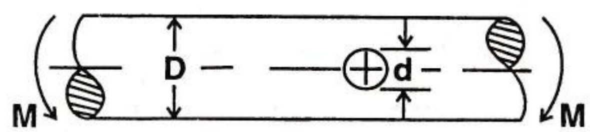
Table 3.1: Theoretical Stress Concentration Factor (K_t) for a Plate with Hole (of Diameter d) in Tension.



$$A = (b - d)\,t$$

$\frac{d}{b}$	0.05	0.1	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55
K_t	2.83	2.69	2.59	2.50	2.43	2.37	2.32	2.26	2.22	2.17	2.13

Table 3.2: Theoretical Stress Concentration Factor (K_t) for a Shaft with Transverse Hole (of Diameter d) in Bending.

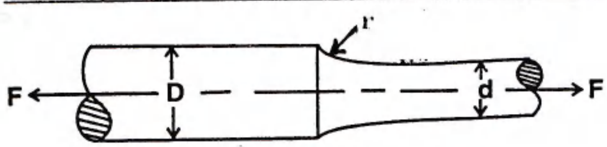


$$Z = \frac{\pi}{32} \times D^3$$

$\frac{d}{D}$	0.02	0.04	0.08	0.10	0.12	0.16	0.20	0.24	0.28	0.30
K_t	2.70	2.52	2.33	2.26	2.20	2.11	2.03	1.96	1.92	1.90

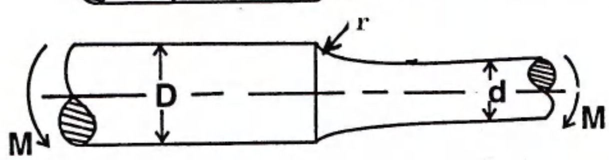
Table 3.3: Theoretical Stress Concentration Factor (K_t) for Stepped Shaft with a Shoulder Fillet (of radius r) in Tension

$\frac{D}{d}$	Theoretical stress concentration factor (K_t)									
	r/d									
	0.08	0.10	0.12	0.16	0.18	0.20	0.22	0.24	0.28	0.30
1.01	1.27	1.24	1.21	1.17	1.16	1.15	1.15	1.14	1.13	1.13
1.02	1.38	1.34	1.30	1.26	1.24	1.23	1.22	1.21	1.19	1.19
1.05	1.53	1.46	1.42	1.36	1.34	1.32	1.30	1.28	1.26	1.25
1.10	1.65	1.56	1.50	1.43	1.39	1.37	1.34	1.33	1.30	1.28
1.15	1.73	1.63	1.56	1.46	1.43	1.40	1.37	1.35	1.32	1.31
1.20	1.82	1.68	1.62	1.51	1.47	1.44	1.41	1.38	1.35	1.34
1.50	2.03	1.84	1.80	1.66	1.60	1.56	1.53	1.50	1.46	1.44
2.00	2.14	1.94	1.89	1.74	1.68	1.64	1.59	1.56	1.50	1.47



$$A = \frac{\pi}{4} \times d^2$$

Fig. for Table 3.3



$$Z = \frac{\pi}{32} \times d^3$$

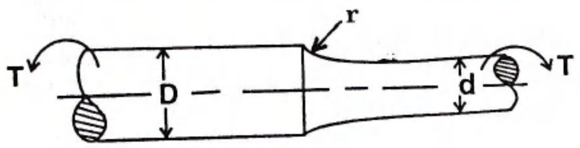
Fig. for Table 3.4

Table 3.4: Theoretical Stress Concentration Factor (K_t) for a Stepped Shaft with a Shoulder Fillet (of radius r) in Bending.

$\frac{D}{d}$	Theoretical stress concentration factor (K_t)									
	r/d									
	0.02	0.04	0.08	0.10	0.12	0.16	0.20	0.24	0.28	0.30
1.01	1.85	1.61	1.42	1.36	1.32	1.24	1.20	1.17	1.15	1.14
1.02	1.97	1.72	1.50	1.44	1.40	1.32	1.27	1.23	1.21	1.20
1.05	2.20	1.88	1.60	1.53	1.48	1.40	1.34	1.30	1.27	1.25
1.10	2.36	1.99	1.66	1.58	1.53	1.44	1.38	1.33	1.28	1.27
1.20	2.52	2.10	1.72	1.62	1.56	1.46	1.39	1.34	1.29	1.28
1.50	2.75	2.20	1.78	1.68	1.60	1.50	1.42	1.36	1.31	1.29
2.00	2.86	2.32	1.87	1.74	1.64	1.53	1.43	1.37	1.32	1.30
3.00	3.00	2.45	1.95	1.80	1.69	1.56	1.46	1.38	1.34	1.32
6.00	3.04	2.58	2.04	1.87	1.76	1.60	1.49	1.41	1.35	1.33

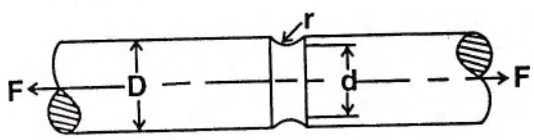
Table 3.5: Theoretical Stress Concentration Factor (K_t) for a Stepped Shaft with a Shoulder Fillet (or radius r) in Torsion.

$\frac{D}{d}$	Theoretical stress concentration factor (K_{ts})									
	r/d									
	0.02	0.04	0.08	0.10	0.12	0.16	0.20	0.24	0.28	0.30
1.09	1.54	1.32	1.19	1.16	1.15	1.12	1.11	1.10	1.09	1.09
1.20	1.98	1.67	1.40	1.33	1.28	1.22	1.18	1.15	1.13	1.13
1.33	2.14	1.79	1.48	1.41	1.35	1.28	1.22	1.19	1.17	1.16
2.00	2.27	1.84	1.53	1.46	1.40	1.32	1.26	1.22	1.19	1.18



$$\frac{J}{d/2} = \frac{\pi\, d^3}{16}$$

Fig. for Table 3.5



$$A = \frac{\pi}{4} \times d^2$$

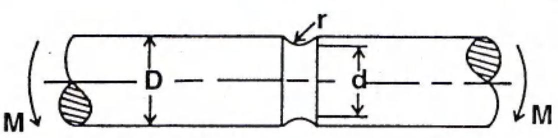
Fig. for Table 3.6

Table 3.6: Theoretical Stress Concentration Factor (K_t) for a Grooved Shaft in Tension.

$\frac{D}{d}$	Theoretical stress concentration factor (K_t)									
	r/d									
	0.02	0.04	0.08	0.10	0.12	0.16	0.20	0.24	0.28	0.30
1.01	1.98	1.71	1.47	1.42	1.38	1.33	1.28	1.25	1.23	1.22
1.02	2.30	1.94	1.66	1.59	1.54	1.45	1.40	1.36	1.33	1.31
1.03	2.60	2.14	1.77	1.69	1.63	1.53	1.46	1.41	1.37	1.36
1.05	2.85	2.36	1.94	1.81	1.73	1.61	1.54	1.47	1.43	1.41
1.10	2.85	2.70	2.16	2.01	1.90	1.75	1.70	1.57	1.50	1.47
1.20	2.85	2.90	2.36	2.17	2.04	1.86	1.74	1.64	1.56	1.54
1.30	2.85	2.90	2.46	2.26	2.11	1.91	1.77	1.67	1.59	1.56
1.50	2.85	2.90	2.54	2.33	2.16	1.94	1.79	1.69	1.61	1.57
2.00	2.85	2.90	2.61	2.38	2.22	1.98	1.83	1.72	1.63	1.59
∞	2.85	2.90	2.69	2.44	2.26	2.03	1.86	1.74	1.65	1.61

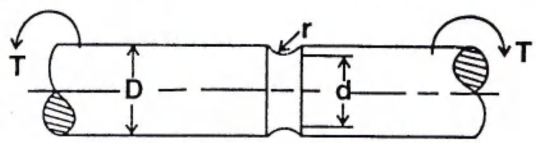
Table 3.7: Theoretical Stress Concentration Factor (K_t) for a Grooved Shaft in Bending

$\frac{D}{d}$	Theoretical stress concentration factor (K_t)									
	r/d									
	0.02	0.04	0.08	0.10	0.12	0.16	0.20	0.24	0.28	0.30
1.01	1.74	1.68	1.47	1.41	1.38	1.32	1.27	1.23	1.22	1.20
1.02	2.28	1.89	1.64	1.53	1.48	1.40	1.34	1.30	1.26	1.25
1.03	2.46	2.04	1.68	1.61	1.55	1.47	1.40	1.35	1.31	1.28
1.05	2.75	2.22	1.80	1.70	1.63	1.53	1.46	1.40	1.35	1.33
1.12	3.20	2.50	1.97	1.83	1.75	1.62	1.52	1.45	1.38	1.34
1.30	3.40	2.70	2.04	1.91	1.82	1.67	1.57	1.48	1.42	1.38
1.50	3.48	2.74	2.11	1.95	1.84	1.69	1.58	1.49	1.43	1.40
2.00	3.55	2.78	2.14	1.97	1.86	1.71	1.59	1.55	1.44	1.41
∞	3.60	2.85	2.17	1.98	1.88	1.71	1.60	1.56	1.45	1.42



$$Z = \frac{\pi}{32} \times d^3$$

Fig. for Table 3.7



$$\frac{J}{d/2} = \frac{\pi\, d^3}{16}$$

Fig. for Table 3.8

Table 3.8: Theoretical Stress Concentration Factor (K_t) for a Grooved Shaft in Torsion

$\frac{D}{d}$	Theoretical stress concentration factor (K_{ts})									
	r/d									
	0.02	0.04	0.08	0.10	0.12	0.16	0.20	0.24	0.28	0.30
1.01	1.50	1.30	1.22	1.20	1.18	1.16	1.13	1.12	1.12	1.12
1.02	1.62	1.45	1.31	1.27	1.23	1.20	1.18	1.16	1.15	1.16
1.05	1.88	1.61	1.40	1.35	1.32	1.26	1.22	1.20	1.18	1.17
1.10	2.05	1.73	1.47	1.41	1.37	1.31	1.26	1.24	1.21	1.20
1.20	2.26	1.83	1.53	1.46	1.41	1.34	1.27	1.25	1.22	1.21
1.30	2.32	1.89	1.55	1.48	1.43	1.35	1.30	1.26	–	–
2.00	2.40	1.93	1.58	1.50	1.45	1.36	1.31	1.26	–	–
∞	2.50	1.96	1.60	1.51	1.46	1.38	1.32	1.27	1.24	1.23

Table 3.9: Properties of Commonly Used Metals

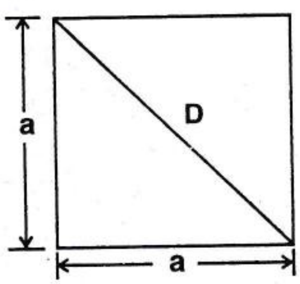
Material	Elastic limit: Tension N/mm^2	Elastic limit: Compression N/mm^2	Elastic limit: Direct shear N/mm^2	Modulus of elasticity (E) N/mm^2	Modulus of rigidity (G) N/mm^2	Poisson's ratio (μ) approx
Aluminium	220	220	140	0.68×10^5	0.26×10^5	0.34
Brass	175	175	105	0.97×10^5	0.35×10^5	0.36
Copper	280	280	160	1.23×10^5	0.39×10^5	0.32
Cast iron	42	175	42	1.00×10^5	0.35×10^5	0.25
Mild steel	245	245	147	2.10×10^5	0.84×10^5	0.30
Wrought iron	210	210	126	1.75×10^5	0.85×10^5	0.29

Table 3.10: Circumference, Area, Volume (For different objects)

Notations:

Circumference – C	Surface area for solid – A_s
Area – A	Base area for solid – A_b
Height – h	Circumference of base for solid – C_b
Diagonal – D	
Solid diagonal – D_s	
Volume – V	
Diameter – d	

Square

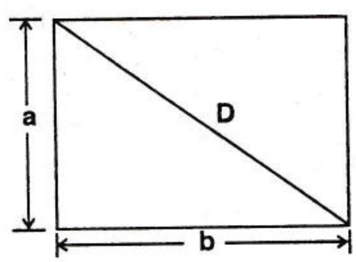


$C = 4a$

$A = a^2$

$D = \sqrt{2} \cdot a = 1.414\ a$

Rectangle

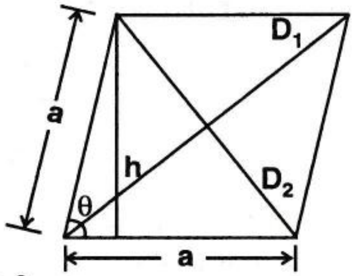


$C = 2\,(a + b)$

$A = ab$

$D = \sqrt{a^2 + b^2}$

Rhombus



$C = 4a$

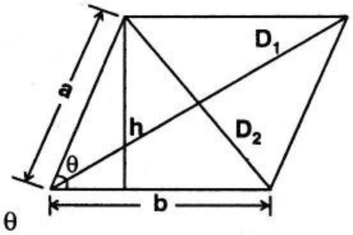
$A = ah = a^2 \sin\theta$

$h = a \sin\theta$

$D_1 = a\sqrt{2\,(1 + \cos\theta)}$

$D_2 = a\sqrt{2\,(1 - \cos\theta)}$

Parallelogram



$C = 2\,(a + b)$

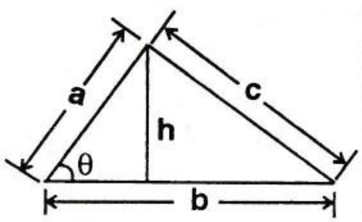
$A = bh = ab \sin\theta$

$h = a \sin\theta$

$D_1 = \sqrt{a^2 + b^2 + 2ab\cos\theta}$

$D_2 = \sqrt{a^2 + b^2 - 2ab\cos\theta}$

Triangle

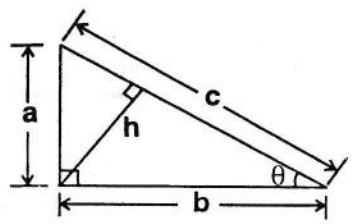


$C = (a + b + c)$

$A = \dfrac{bh}{2} = \dfrac{1}{2} \cdot ab \sin\theta$

$h = a \sin\theta$

Right Angled Triangle



$C = (a + b + c)$

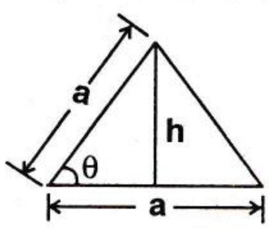
$A = \dfrac{ab}{2} = \dfrac{ch}{2}$

$h = b \sin\theta = a \sin(90 - \theta)$

$c^2 = a^2 + b^2$

$\sin\theta = \dfrac{a}{c}$, $\cos\theta = \dfrac{b}{c}$, $\tan\theta = \dfrac{a}{b}$

Equilateral Triangle

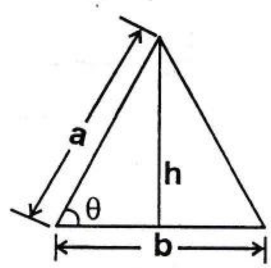


$C = 3a$

$A = \dfrac{\sqrt{3}}{4}\, a^2 = \dfrac{ah}{2}$

$h = a \sin\theta = a \sin 60 = \dfrac{\sqrt{3}}{2} \cdot a$

Isosceles Triangle

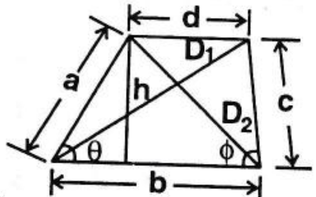


$C = 2a + b$

$A = \dfrac{bh}{2} = \dfrac{1}{2}\, ab \sin\theta$

$h = a \sin\theta = \sqrt{a^2 - (b/2)^2}$

Trapezium



$C = (a + b + c + d)$

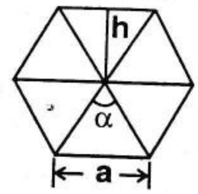
$A = \dfrac{(b + d)\,h}{2}$

$h = a \sin\theta = c \sin\phi$

$D_1 = \sqrt{a^2 + b^2 + 2ab\cos\theta}$

$D_2 = \sqrt{b^2 + c^2 + 2bc\cos\phi}$

Regular Polygon



n = Number of sides

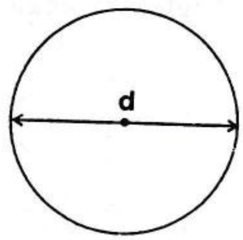
α = Central angle

$C = na$

$\alpha = 360°/n$

$A = \dfrac{n\,a\,h}{2}$

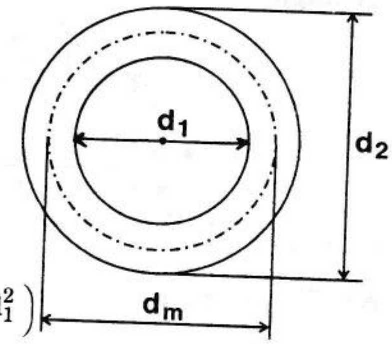
Circle



$C = \pi\,d$

$A = \dfrac{\pi\,d^2}{4}$

Annulus

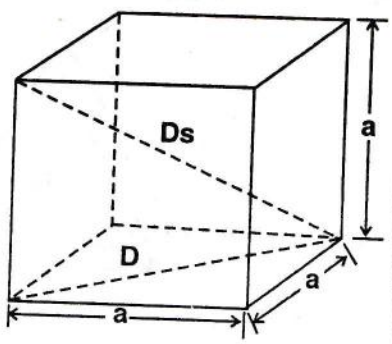


$A = \dfrac{\pi}{4}\left(d_2^2 - d_1^2\right)$

$= \pi\,d_m\,t$

$t = \dfrac{d_2 - d_1}{2}$

Cube



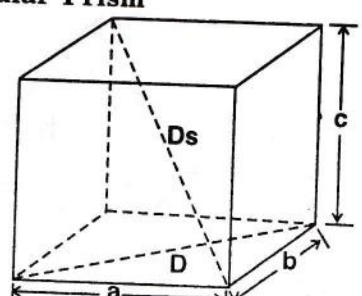
$A_s = 6a^2$

$V = a^3$

$D = \sqrt{2}\cdot a$

$D_s = \sqrt{3}\cdot a$

Rectangular Prism



$A_s = 2\,(ab + bc + ca)$

$V = abc$

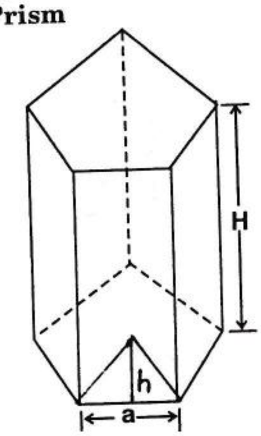
$D_s = \sqrt{a^2 + b^2 + c^2}$

Right Polygonal Prism

n = Number of sides of base

$C_b = na$

$A_b = \dfrac{nah}{2}$



$A_s = 2A_b + C_b H$

$V = A_b \cdot H$

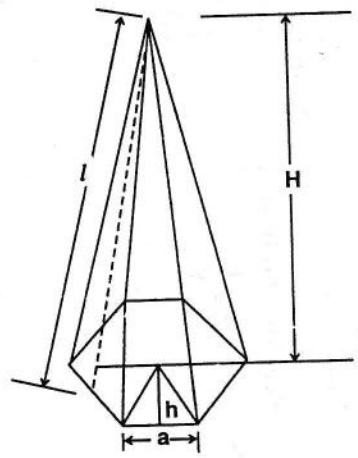
Regular Pyramid

$C_b = n \cdot a$

$A_b = \dfrac{nah}{2}$

$A_s = \dfrac{C_b}{2}(h + l)$

l = Height of slant face $= \sqrt{H^2 + h^2}$

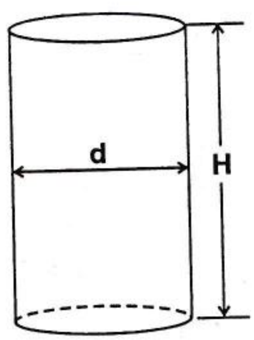


Cylinder

$A_b = \dfrac{\pi d^2}{4}$

$A_s = \dfrac{\pi d^2}{2} + \pi d H$

$V = \dfrac{\pi d^2}{4} \cdot H$



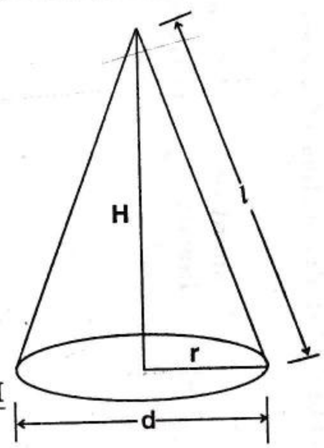
Cone

$A_b = \dfrac{\pi d^2}{4}$

$A_s = \dfrac{\pi d^2}{4} + \dfrac{\pi d l}{2}$

$V = \dfrac{\pi d^2}{4} \cdot \dfrac{H}{3} = \dfrac{\pi d^2 H}{12}$

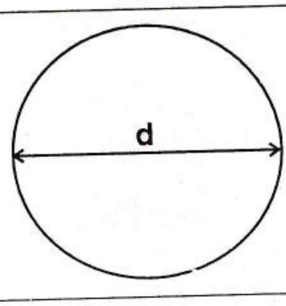
$l = \sqrt{r^2 + H^2}$



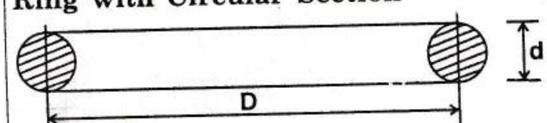
Sphere

$A_s = \pi d^2$

$V = \dfrac{\pi d^3}{6}$



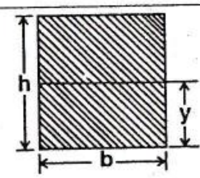
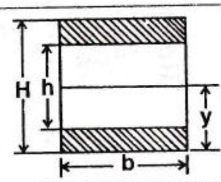
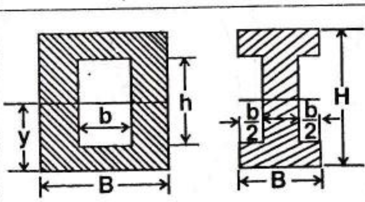
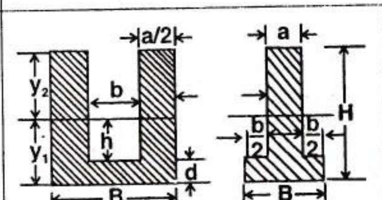
Ring with Circular Section

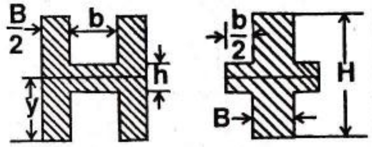
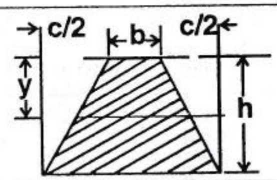
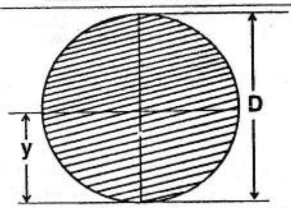
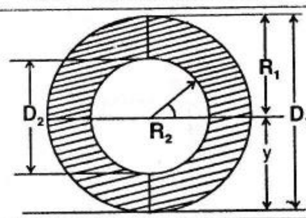
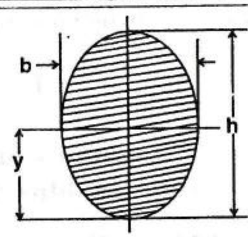


$A_s = \pi^2 d \cdot D$

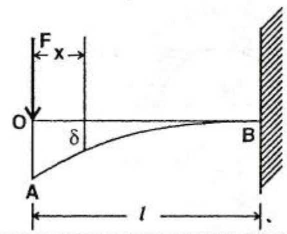
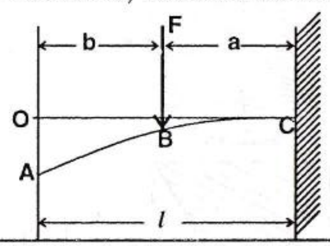
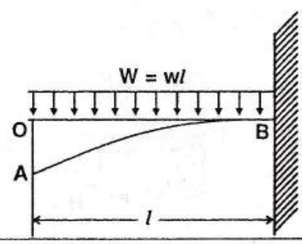
$V = \dfrac{\pi^2}{4} d^2 D$

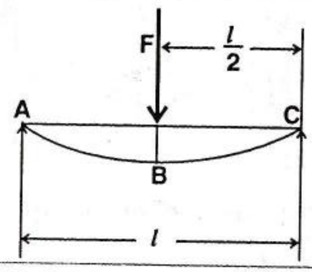
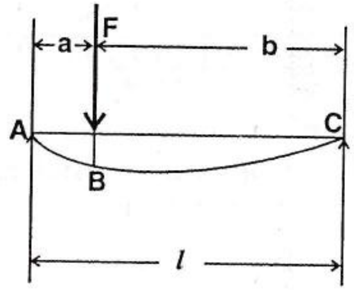
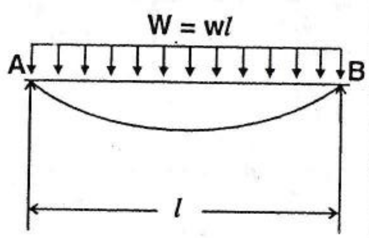
Table 3.11: Properties of Various Cross Sections

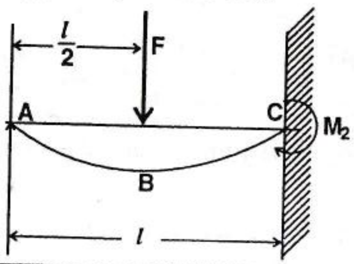
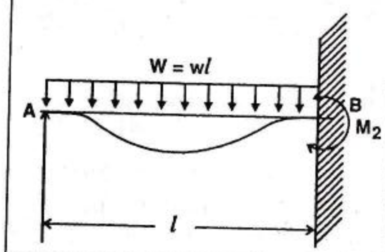
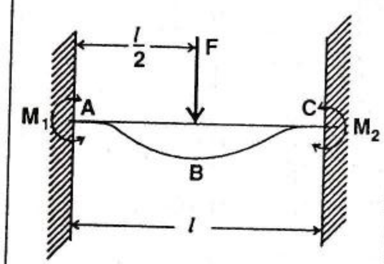
Type	Section	Moment of Inertia I	Distance to Farthest Point y	Section Modulus $Z = \frac{I}{y}$	Radius of Gyration $k = \sqrt{\frac{I}{A}}$
(1)	(2)	(3)	(4)	(5)	(6)
(a)		$\frac{bh^3}{12}$	$\frac{h}{2}$	$\frac{bh^2}{6}$	0.289 h
(b)		$\frac{b}{12}\left(H^3 - h^3\right)$	$\frac{H}{2}$	$\frac{b\,(H^3 - h^3)}{6H}$	$\sqrt{\frac{H^3 - h^3}{12\,(H - h)}}$
(c)		$\frac{BH^3 - bh^3}{12}$	$\frac{H}{2}$	$\frac{BH^3 - bh^3}{6H}$	$\sqrt{\frac{BH^3 - bh^3}{12\,(BH - bh)}}$
(d)		$\frac{By_1^3 - bh^3 + ay_2^3}{3}$ $h = y_1 - d$	$y_1 = \frac{aH^2 + bd^2}{2\,(aH + bd)}$ $y_2 = H - y_1$	$\frac{I}{y_1}$ and $\frac{I}{y_2}$	$\sqrt{\frac{I}{Bd + a\,(H - d)}}$

(1)	(2)	(3)	(4)	(5)	(6)
(e)		$\frac{BH^3 + bh^3}{12}$	$\frac{H}{2}$	$\frac{BH^3 + bh^3}{6H}$	$\sqrt{\frac{BH^3 + bh^3}{12\,(BH + bh)}}$
(f)		$\frac{(6b^2 + 6bc + c^2)\,h^3}{36\,(2b + c)}$	$\frac{(3b + 2c)\,h}{3\,(2b + c)}$	$\frac{(6b^2 + 6bc + c^2)\,h^2}{12\,(3b + c)}$	$\sqrt{\frac{I}{A}}$
(g)		$\frac{\pi D^4}{64} = \frac{\pi R^4}{4}$	$\frac{D}{2} = R$	$\frac{\pi D^3}{32}$	$\frac{D}{4} = \frac{R}{2}$
(h)		$\frac{\pi}{64}(D_1^4 - D_2^4)$ $= \frac{\pi}{4}(R_1^4 - R_2^4)$	$\frac{D_1}{2} = R_1$	$\frac{\pi\,(D_1^4 - D_2^4)}{32\,D_1}$	$\frac{\sqrt{D_1^2 + D_2^2}}{4}$ (or) $\frac{\sqrt{R_1^2 + R_2^2}}{2}$
(i)		$\frac{\pi\,bh^3}{64}$	$\frac{h}{2}$	$\frac{\pi\,bh^2}{32}$	$\frac{h}{4}$

3.12: Shear, Moment and Deflection Formulas for Beams

Loading, support, and reference number	Reactions R_1 and R_2, Vertical shear V	Bending moment M, maximum bending moment	Deflection δ and maximum deflection
I	II	III	IV
1. Cantilever, end load 	$R_2 = +F$ $V = -F$	$M = -Fx$ Max $M = -Fl$ at B	$\delta = \frac{1}{6}\frac{F}{EI}(x^3 - 3l^2 x + 2l^3)$ Max $\delta = \frac{1}{3}\frac{Fl^3}{EI}$ at A
2. Cantilever, intermediate load 	$R_2 = +F$ A to B; $V = 0$ B to C : $V = -F$	A to B; $M = 0$ B to C; $M = -F(x - b)$ Max $M = -Fa$ at C	A to B; $\delta = \frac{1}{6}\frac{F}{EI}(-a^3 + 3a^2 l - 3a^2 x)$ B to C; $\delta = \frac{1}{6}\frac{F}{EI}[(x-b)^3 - 3a^2(x-b) + 2a^3]$ Max $\delta = \frac{1}{6}\frac{F}{EI}(3a^2 l - a^3)$
3. Cantilever, uniform load 	$R_2 = +W$ $V = -\frac{W}{l}x$	$M = -\frac{1}{2}\frac{W}{l}x^2$ Max $M = -\frac{1}{2}Wl$ at B	$\delta = \frac{1}{24}\frac{W}{EIl}(x^4 - 4l^3 x + 3l^4)$ Max $\delta = \frac{1}{8}\frac{Wl^3}{EI}$

I	II	III	IV
4. End supports, center load 	$R_1 = +\frac{1}{2}F, R_2 = +\frac{1}{2}F$ A to B: $V = +\frac{1}{2}F$ B to C: $V = -\frac{1}{2}F$	A to B: $M = +\frac{1}{2}Fx$ B to C: $M = +\frac{1}{2}F(l - x)$ Max $M = +\frac{1}{4}Fl$ at B	A to B: $\delta = \frac{1}{48}\frac{F}{EI}(3l^2x - 4x^3)$ Max $\delta = \frac{1}{48}\frac{Fl^3}{EI}$ at B
5. End supports, intermediate load 	$R_1 = +F\frac{b}{l}$; $R_2 = +F\frac{a}{l}$ A to B: $V = +F\frac{b}{l}$ B to C: $V = -F\frac{a}{l}$	A to B: $M = +F\frac{b}{l}x$ B to C: $M = +F\frac{a}{l}(l - x)$ Max $M = +F\frac{ab}{l}$ at B	A to B: $\delta = \frac{Fbx}{6EIl}\left[2l(l - x) - b^2 - (l - x)^2\right]$ B to C: $\delta = \frac{Fa(l - x)}{6EIl}\left[2lb - b^2 - (l - x)^2\right]$ Max $\delta = \frac{Fab}{27EIl}(a + 2b)\sqrt{3a(a + 2b)}$ at $x = \sqrt{\frac{1}{3}a(a + 2b)}$ when $a > b$
6. End supports, uniform load 	$R_1 = +\frac{1}{2}W$; $R_2 = +\frac{1}{2}W$ $V = \frac{1}{2}W\left(1 - \frac{2x}{l}\right)$	$M = \frac{1}{2}W\left(x - \frac{x^2}{l}\right)$ Max $M = +\frac{1}{8}Wl$ at $x = \frac{1}{2}l$	$\delta = \frac{1}{24}\frac{Wx}{EIl}(l^3 - 2lx^2 + x^3)$ Max $\delta = \frac{5}{384}\frac{Wl^3}{EI}$ at $x = \frac{1}{2}l$

I	II	III	IV
7. One end fixed, one end supported, centre load 	$R_1 = \frac{5}{16} F$; $R_2 = \frac{11}{16} F$ $M_2 = \frac{3}{16} Fl$ A to B; $V = \frac{5}{16} F$ B to C: $V = \frac{11}{16} F$	A to B : $M = \frac{5}{16} Fx$ B to C: $M = F\left(\frac{1}{2} l - \frac{11}{16} x\right)$ Max $+M = \frac{5}{32} Fl$ at B Max $-M = -\frac{3}{16} Fl$ at C	A to B; $\delta = \frac{1}{96} \frac{F}{EI} (5x^3 - 3l^2 x)$ B to C: $\delta = \frac{1}{96} \frac{F}{EI} \left[5x^3 - 16 \left(x - \frac{l}{2} \right)^3 - 3l^2 x \right]$ Max $\delta = 0.00932 \frac{Fl^3}{EI}$ at $x = 0.4472l$
8. One end fixed, one end supported, uniform load 	$R_1 = \frac{3}{8} W$; $R_2 = \frac{5}{8} W$ $M_2 = \frac{1}{8} Wl$ $V = W\left(\frac{3}{8} - \frac{x}{l}\right)$	$M = W\left(\frac{3}{8} x - \frac{1}{2} \frac{x^2}{l}\right)$ Max $+M = \frac{9}{128} Wl$ at $x = \frac{3}{8} l$ Max $-M = -\frac{1}{8} Wl$ at B	$\delta = \frac{1}{48} \frac{W}{EIl} (3l x^3 - 2x^4 - l^3 x)$ Max $\delta = 0.0054 \frac{Wl^3}{EI}$ at $x = 0.4215l$
9. Both ends fixed, centre load 	$R_1 = \frac{1}{2} F$; $R_2 = \frac{1}{2} F$ $M_1 = \frac{1}{8} Fl$; $M_2 = \frac{1}{8} Fl$ A to B: $V = +\frac{1}{2} F$ B to C $V = -\frac{1}{2} F$	A to B: $M = \frac{1}{8} F (4x - l)$ B to C: $M = \frac{1}{8} F (3l - 4x)$ Max $+M = \frac{1}{8} Fl$ at B Max $-M = \frac{1}{8} Fl$ at A and C	A to B: $\delta = \frac{1}{48} \frac{F}{EI} (3lx^2 - 4x^3)$ Max $\delta = \frac{1}{192} \frac{Fl^3}{EI}$ at E

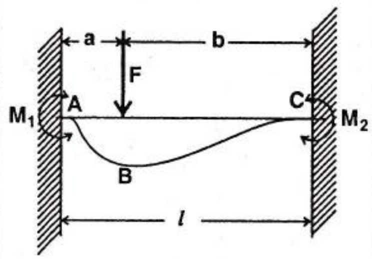
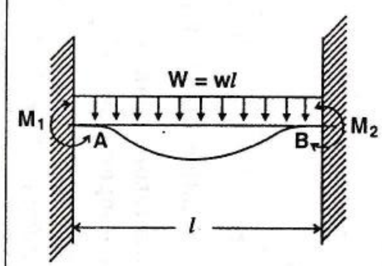
I	II	III	IV
10. Both ends fixed, intermediate load 	$R_1 = \frac{Fb^2}{l^3}(3a+b)$ $R_2 = \frac{Fa^2}{l^3}(3b-a)$ $M_1 = F\frac{ab^2}{l^2}$; $M_2 = F\frac{a^2b}{l^2}$ A to B: $V = R_1$ B to C: $V = R_1 - F$	A to B: $M = -F\frac{ab^2}{l^2} + R_1x$ B to C: $M = -F\frac{ab^2}{l^2} + R_1x - F(x-a)$ Max $+M = -F\frac{ab^2}{l^2} + R_1 a$ at B Max $-M = -M_1$ where $a < b$ Max $-M = -M_2$ when $a > b$	A to B: $\delta = \frac{1}{6}\frac{Fb^2x^2}{EIl^3}(3ax+bx-3al)$ B to C: $\delta = \frac{1}{6}\frac{Fa^2(l-x)^2}{EIl^3}[(3b+a)(l-x)-3bl]$ Max $\delta = \frac{2}{3}\frac{F}{EI}\frac{a^3b^2}{(3a+b)^2}$ at $x = \frac{2al}{3a+b}$ if $a > b$ Max $\delta = \frac{2}{3}\frac{F}{EI}\frac{a^2b^3}{(3b+a)^2}$ at $x = l - \frac{2bl}{3b+a}$ if $a < b$
11. Both ends fixed, uniform load 	$R_1 = \frac{1}{2}W$; $R_2 = \frac{1}{2}W$ $M_1 = \frac{1}{12}Wl$, $M_2 = \frac{1}{12}Wl$ $V = \frac{1}{2}W\left(1 - \frac{2x}{l}\right)$	$M = \frac{1}{2}W\left(x - \frac{x^2}{l} - \frac{1}{6}l\right)$ Max $+M = \frac{1}{24}Wl$ at $x = \frac{1}{2}l$ Max $-M = -\frac{1}{12}Wl$ at A and B	$\delta = \frac{1}{24}\frac{Wx^2}{EIl}(2lx - l^2 - x^2)$ Max $\delta = \frac{1}{384}\frac{Wl^3}{EI}$ at $x = \frac{1}{2}l$

Table 3.13: Values of Factor of Safety

Material	Steady load	Variable load	Shock load
Wrought iron	4	7	10 to 15
Steel	4	8	12 to 16
Cast iron	5 to 6	8 to 12	16 to 20
Soft materials and alloys	6	9	15
Leather	9	12	15
Timber	7	10 to 15	20

Table 3.14: Values of Poisson's ratio for Commonly used Materials

S.No.	Material	Poisson's ratio ($1/m$ or μ)
1.	Aluminium	0.32 to 0.36
2.	Brass	0.32 to 0.42
3.	Copper	0.31 to 0.34
4.	Steel	0.25 to 0.33
5.	Cast-iron	0.23 to 0.27

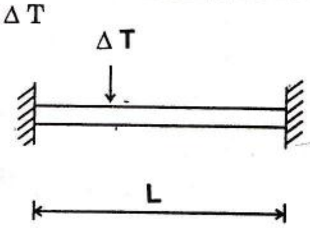
Table 3.15: Coefficient of Thermal Expansion (α)

(Linear mean coefficients for the temperature range 0 – 100°C)

Material	Coefficient of thermal expansion (α)
Aluminium	23.9×10^{-6}
Brass	18.7×10^{-6}
Carbon steel	10.8×10^{-6}
Cast iron	10.6×10^{-6}
Magnesium	25.2×10^{-6}
Nickel steel	13.1×10^{-6}
Stainless steel	17.3×10^{-6}
Tungsten	4.3×10^{-6}

Thermal stress, $S_{th} = \alpha \cdot \Delta T \cdot E$; Thermal strain, $e_{th} = \alpha \cdot \Delta T$

Linear deformation due to temperature, $\delta_{th} = \alpha \cdot \Delta T \cdot L$



ΔT = Temperature change (i.e.,) rise or lowering in temperature, °C

α = Coefficient of linear expansion due to temperature, mm/mm °C or / °C

CHAPTER – 4

SHAFTS

Symbols : (With S.I. Units)

A – Area of cross-section, mm^2

b – Section width, mm

C – Euler's coefficient, Key way weakening factor

D – Diameter of rod or shaft, mm

d – Diameter of rod or shaft, mm

d_i – Inner diameter of hollow shaft, mm

d_0 – Outer diameter of hollow shaft, mm

E – Modulus of elasticity or Youngs modulus, N/mm^2

e – Eccentricity, mm

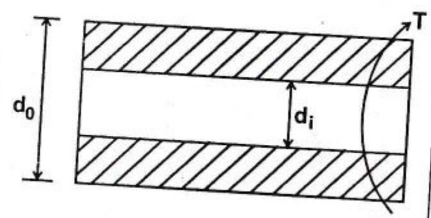
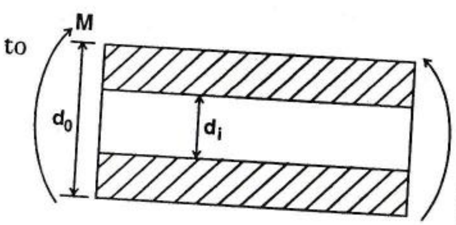
F – Force or load, N

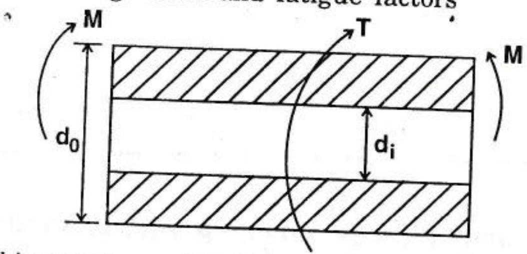
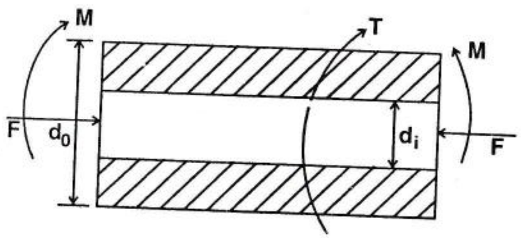
F_a – Axial force, N

F_b – Bending force, N

F_c	–	Compression force, N
F_n	–	Normal force, N
F_s	–	Shear force, N
F_t	–	Tensile force, N
f_s	–	Factor of safety
G	–	Modulus of rigidity or shear modulus, N/mm^2
g	–	Acceleration due to gravity, m/s^2
h	–	Depth of keyway, mm
I	–	Area moment of inertia, mm^4
J	–	Polar moment of inertia, mm^4
K	–	Least radius of gyration
K_m	–	Combined shock and fatigue factor for bending
K_t	–	Combined shock and fatigue factor for torsion
k	–	Ratio of inner diameter to outer diameter (i.e., $k = \frac{d_i}{d_0}$)
L	–	Length of shaft, mm
l	–	Length of shaft, mm
M	–	Bending moment, N-mm
M_e	–	Equivalent bending moment, N-mm
$\frac{1}{m}$ (or) μ	–	Poisson's ratio

N	–	Speed of shaft in rpm, Unit of force in newtons.
P	–	Power, W
r	–	Radius of shaft, mm
S	–	Stress, N/mm^2
S_a	–	Axial stress, N/mm^2
S_b	–	Bending stress, N/mm^2
S_c	–	Compressive stress, N/mm^2
S_n	–	Normal stress, N/mm^2
S_s	–	Shear stress, N/mm^2
S_t	–	Tensile stress, N/mm^2
S_y	–	Yield stress, N/mm^2
T	–	Twisting moment or torque, N-mm.
W	–	Weight, N; Unit of power in watts
w	–	Width of keyway, mm; Load per unit length, N/m (or) N/mm
Z	–	Section modulus, mm^3
δ	–	Deflection, mm
θ	–	Angle of twist in radians or torsional deflection.
μ	–	Poisson's ratio
ω	–	Angular velocity, rad/s
ω_c	–	Critical speed of shaft, rad/s

DESIGN PARTICULARS	EQUATIONS
Power-torque relationship	$P = \dfrac{2\pi N T}{60 \times 1000}$ .... (4.1) P in watts N in rpm T in N-mm (or) $P = \dfrac{2\pi N T}{4500 \times 1000}$ .... (4.2) P in H.P N is rpm T in kgf-mm
Outside diameter (d_0) and inside diameter (d_i) of hollow shaft:	
When subjected to simple torque only 	$d_0 = \left[\dfrac{16\,T}{\pi S_s (1-k^4)}\right]^{1/3}$ and $d_i = k\,d_0$ .... (4.3)
When subjected to simple bending moment only 	$d_0 = \left[\dfrac{32\,M}{\pi S_b (1-k^4)}\right]^{1/3}$ and $d_i = k\,d_0$ .... (4.4)

DESIGN PARTICULARS	EQUATIONS
When subjected to combined torque and bending moment including shock and fatigue factors 	$d_0 = \left[\dfrac{16\,T_e}{\pi\,S_s\,(1-k^4)}\right]^{1/3}$ (or) $d_0 = \left[\dfrac{32\,M_e}{\pi\,S_b\,(1-k^4)}\right]^{1/3}$ .... (4.5) and $d_i = k\,d_0$ where $T_e = \sqrt{(K_m \cdot M)^2 + (K_t \cdot T)^2}$ and, $M_e = \dfrac{1}{2}\left[K_m \cdot M + \sqrt{(K_m \cdot M)^2 + (K_t \cdot T)^2}\right]$
When subjected to combined torque, bending moment and axial compressive load, including shock and fatigue factors. 	$d_0 = \left[\dfrac{16\,T_e}{\pi\,S_s\,(1-k^4)}\right]^{1/3}$ (or) $d_0 = \left[\dfrac{32\,M_e}{\pi\,S_b\,(1-k^4)}\right]^{1/3}$ .... (4.6) and $d_i = k\,d_0$ Where $T_e = \sqrt{\left\{K_m \cdot M + \dfrac{\alpha\,F\,d_0\,(1+k^2)}{8}\right\}^2 + (K_t \cdot T)^2}$ and $M_e = \dfrac{1}{2}\left[\left\{K_m \cdot M + \dfrac{\alpha\,F\,d_0\,(1+k^2)}{8}\right\} + \sqrt{\left\{K_m\,M + \dfrac{\alpha\,F\,d_0\,(1+k^2)}{8}\right\}^2 + (K_t \cdot T)^2}\right]$

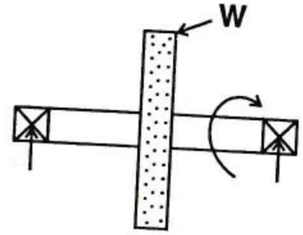
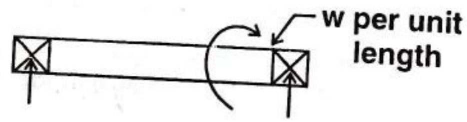
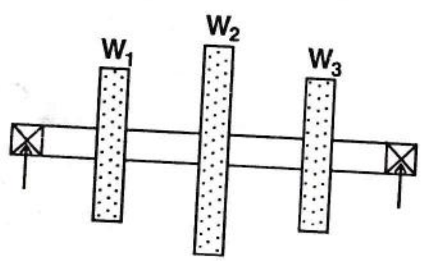
DESIGN PARTICULARS	EQUATIONS
Column factor, α	For tensile load, $\alpha = 1$ For compressive load, $\alpha = \dfrac{1}{1 - 0.0044\left(\dfrac{L}{K}\right)}$ when $\dfrac{L}{K} \le 115$ $= \dfrac{S_y\left(\dfrac{L}{K}\right)^2}{C\pi^2 E}$ when $\dfrac{L}{K} > 115$ C = Euler's coefficient for column = 1 for hinged ends = 2.25 for fixed ends = 1.6 for ends that are partly restrained in bearings.
Modifications for the diameter of solid shaft	Take $d_0 = d$ and $k = 0$ in the above equations for hollow shaft, (4.3 to 4.6)

Table 4.1: Shock and Fatigue Factors

Table 4.1: Shock and Fatigue Factors

Nature of load	K_m	K_t
1. **Stationary shafts:**		
(i) Gradually applied load	1.0	1.0
(ii) Suddenly applied load	1.5 to 2.0	1.5 to 2.0
2. **Rotating shafts:**		
(i) Gradually applied load	1.5	1.0
(ii) Suddenly applied load with minor shock	1.5 to 2.0	1.0 to 1.5
(iii) Suddenly applied load with major shock	2.0 to 3.0	1.5 to 3.0

DESIGN PARTICULARS	EQUATIONS
Weakening factor due to key way on shafts	$C = 1.0 + 0.2\dfrac{w}{d} + 1.1\dfrac{h}{d}$ .... (4.7)
Equation for torsional rigidity	$\dfrac{T}{J} = \dfrac{G\,\theta}{l}$ .... (4.8) $J = \dfrac{\pi}{32} d^4$ for solid shaft $= \dfrac{\pi}{32}(d_0^4 - d_i^4)$ for hollow shaft

DESIGN PARTICULARS	EQUATIONS
Critical or whirling speeds of shafts: (ω_c)	
For a shaft of negligible self-weight with single attached disc 	$\omega_c = \sqrt{\frac{g}{\delta}}$ rad/s .... (4.9) $g = 9.81$ m/s^2 δ = Deflection at the disc location in metres
For a shaft of constant cross-section, simply supported at the ends with no weight involved other than that of the shaft only 	$\omega_c = \sqrt{\frac{5}{4}\left(\frac{g}{\delta_{max}}\right)}$ rad/s .... (4.10)
For a shaft having self-weight and carrying several concentrated weights 	$\frac{1}{\omega_c^2} = \frac{1}{\omega_{c1}^2} + \frac{1}{\omega_{c2}^2} + \dots \frac{1}{\omega_{cn}^2} + \frac{1}{\omega_{cs}^2}$ .... (4.11) (Dunkerley equation) ω_c = Critical speed of shaft when all the loads are acting together. $\omega_{c1}, \omega_{c2} \dots \omega_{cn}$ = Critical speeds of shaft when the loads $W_1, W_2 \dots W_n$ are acting individually ω_{cs} – Critical speed of shaft by its self-weight only.
Critical speed in rpm	$N_c = \frac{30}{\pi}\omega_c$ .... (4.12)

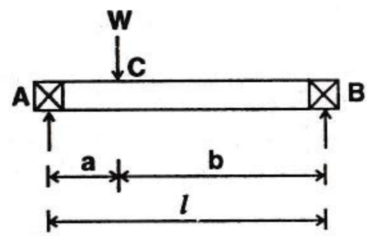
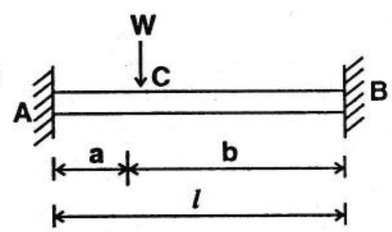
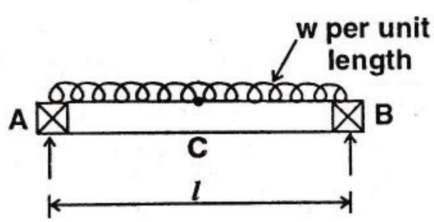
DESIGN PARTICULARS	EQUATIONS
For a shaft of negligible self-weight and two loads only	$N_c = \dfrac{945.8}{\sqrt{\delta_1 + \delta_2}}$ rpm when δ_1 and δ_2 are in mm
Deflections on shafts due to various loading conditions:	
For a shaft of negligible weight with a non-central load in simple supports 	$\delta_c = \dfrac{W\,a^2\,b^2}{3\,EIl}$ .... (4.14) (δ_c – Deflection at C)
For the above conditions with fixed supports 	$\delta_c = \dfrac{W\,a^3\,b^3}{3\,EIl^3}$ .... (4.15)
For a shaft of negligible self-weight with a uniformly distributed load or a shaft with no load except its self-weight only 	$\delta_c = \dfrac{5\,w\,l^4}{384\,EI}$ .... (4.16)

Table 4.2: Properties of Shafting Materials

Material (Steel)	Percentage carbon	Ultimate strength, N/mm^2			Elastic limit, N/mm^2			Percentage Elongation
		Tension	Compression	Shear	Tension	Compression	Shear	
Commercial Cold rolled	0.10-0.25	482.0	482.0	241.0	241.0	241.0	122.5	35
Commercial turned	0.10-0.25	412.0	412.0	206.0	206.0	206.0	103.0	35
Hot rolled or forged	0.15-0.25	451.0	451.0	225.0	245.0	245.0	113.0	26
	0.25-0.35	482.0	482.0	241.0	275.0	275.0	121.0	24
	0.35-0.45	520.0	520.0	260.0	314.0	314.0	130.0	22
	0.45-0.55	553.0	553.0	276.5	345.0	345.0	138.0	20
3 ½ % Nickel	0.15-0.25	588.0	588.0	294.0	382.0	382.0	147.0	26
Chrome Vanadium	0.25-0.35	620.0	620.0	310.0	414.0	414.0	155.0	25

Table 4.3: Meximum Permissible Working Stresses for Shafts, N/mm^2

Grade of shafting	Simple bending	Simple torsion	Combined stress
"Commercial Steel" shafting without allowance for keyways	110	55	55
"Commercial Steel" shafting with allowance for keyways	83	41	41

Table 4.4: (Column factor α)

L/K	0	25	50	75	100	115
α	1.00	1.12	1.28	1.49	1.78	2.02

Standard Diameter of Shafts (mm)

6, 8, 10, 12, 14, 16, 18, 20, 22, 25, 28, 32, 36, 40, 45, 50, 56, 63, 71, 80, 90, 100, 110, 125, 140, 160, 180, 200, 220, 240, 260, 280, 300, 320, 340, 360, 380, 400, 420, 440, 450, 480, 500, 530, 560, 600.

CHAPTER – 5

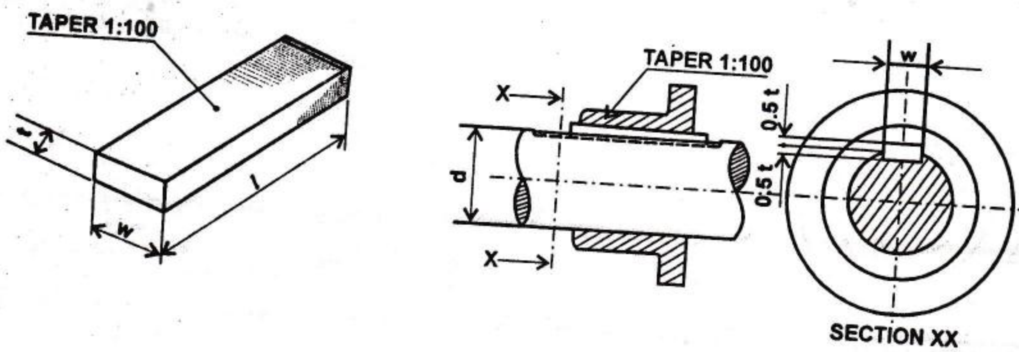
KEYS AND PINS

Symbols : with S.I. Units

T	–	Torque transmitted by the shaft, N-mm.
F	–	Tangential force acting on the shaft, N
d	–	Diameter of the shaft, mm
l	–	Length of sunk key, mm
w	–	Width of sunk key, mm
t	–	Thickness of sunk key, mm
S_s	–	Shear stress for the key material, N/mm^2
S_c	–	Crushing stress for the key material, N/mm^2

DESIGN PARTICULARS	EQUATIONS	
Approximate proportions of sunk key	$w = \frac{d}{4}$	.... (5.1)
	$t = \frac{2}{3} w = \frac{d}{6}$	.... (5.2)
	$l = 1.6\, d$	.... (5.3)
Torque transmitted by the sunk key	$T = l \cdot w \cdot S_s \cdot \frac{d}{2} = l \cdot \frac{t}{2} \cdot S_c \cdot \frac{d}{2}$	.... (5.4)
Relationship between the width and thickness	$\frac{w}{t} = \frac{S_c}{2S_s}$	.... (5.5)

Standard type of keys:

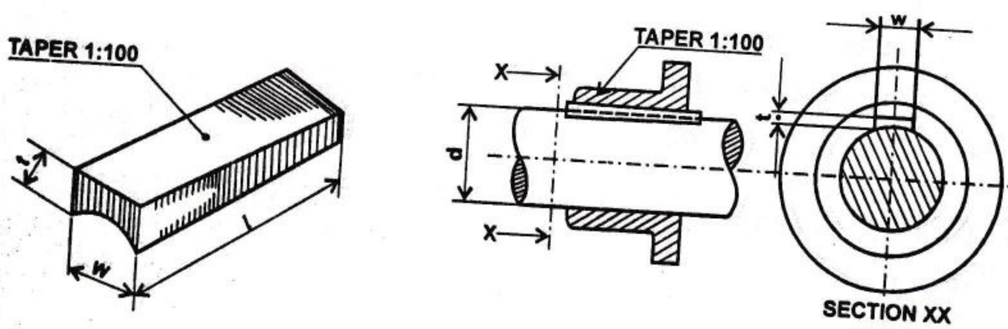


Width of key, w = 0.25 d + 2 mm

Nominal thickness, t = 0.66 w

Standard taper = 1:100

Fig. 5.1: Sunk Taper Key

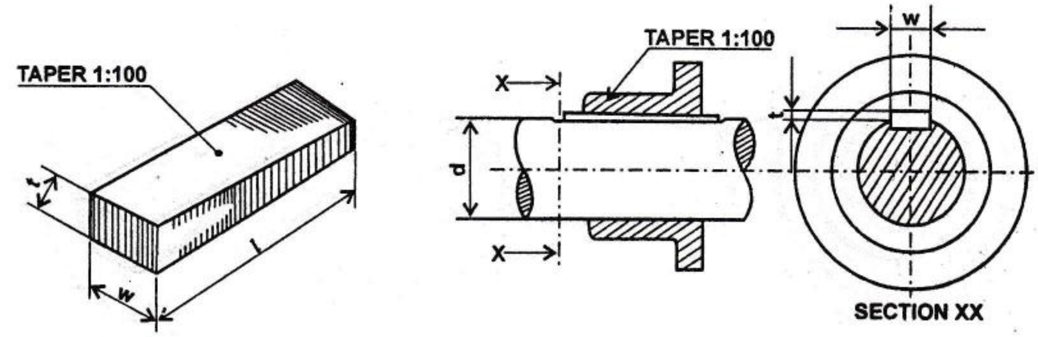


Width of key, w = 0.25 d + 2 mm

Nominal thickness, t = 0.33 w

Standard taper = 1 : 100

Fig. 5.2: Hollow Saddle Key

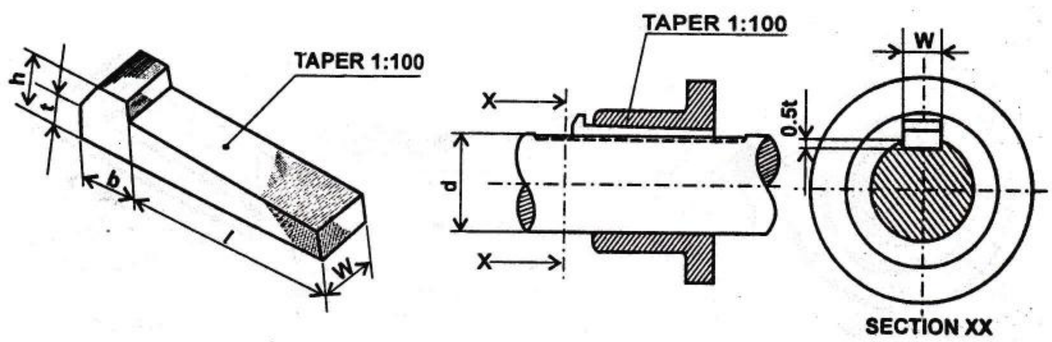


Width of key, w = 0.25 d + 2 mm

Nominal Thickness, t = 0.33 w

Standard Taper = 1 : 100

Fig. 5.3: Flat Saddle Key



Width of key, w = 0.25 d + 2 mm

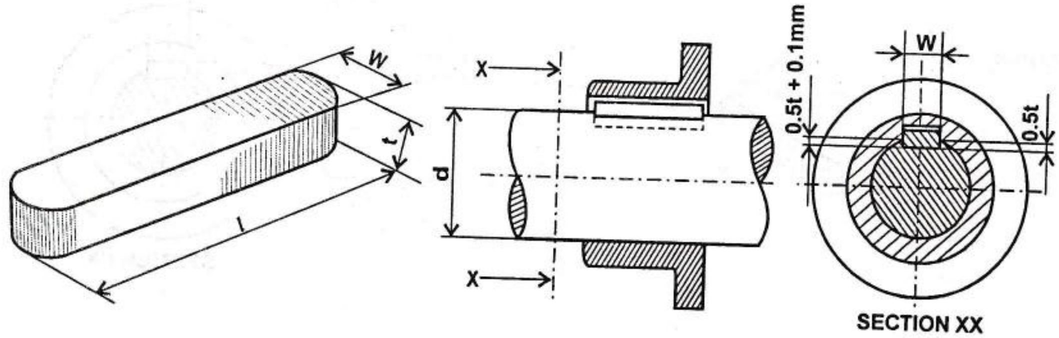
Nominal Thickness, t = 0.66 w

Standard Taper = 1 : 100

Height of Gib-head, h = 1.75 t

Width of Gib-head, b = 1.5 t

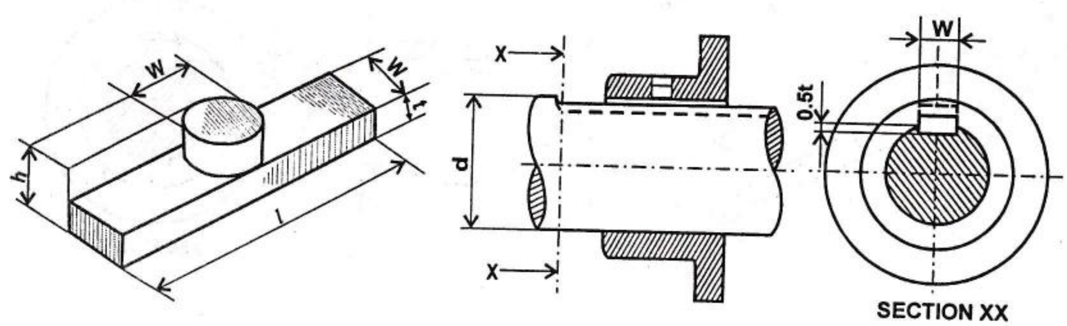
Fig. 5.4: Gib – head key



Width of key, w = 0.25 d + 2 mm

Nominal thickness, t = 0.66 w

Fig. 5.5: Feather or Parallel Key

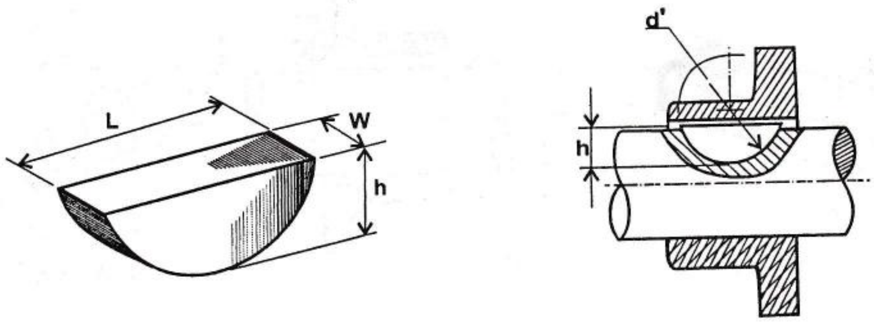


Width of key, w = 0.25 d + 2 mm

Thickness of Peg = 0.5 t

Nominal thickness, t = 0.66 w

Fig. 5.6: Peg Key

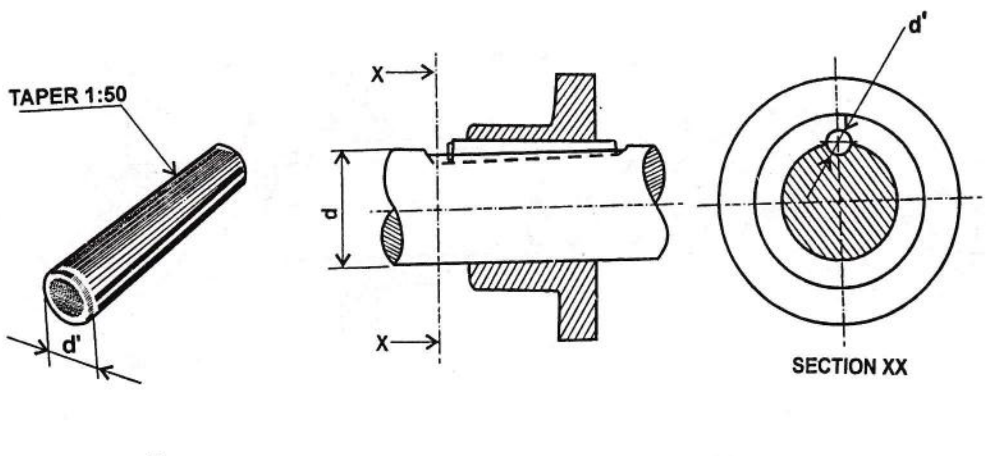


Width of key, w = 0.25 d

Diameter of key, d′ = 4 w

Height of key, h = 1.75 w

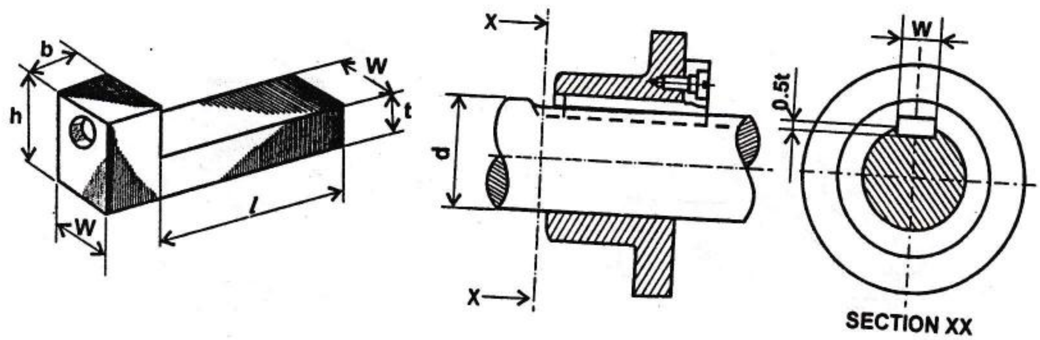
Fig. 5.7: Woodruff Key



Diameter of pin, d′ = 0.2 d

Taper = 1 : 50

Fig. 5.8: Pin Key



Width of key, $w = 0.25\ d + 2\ mm$

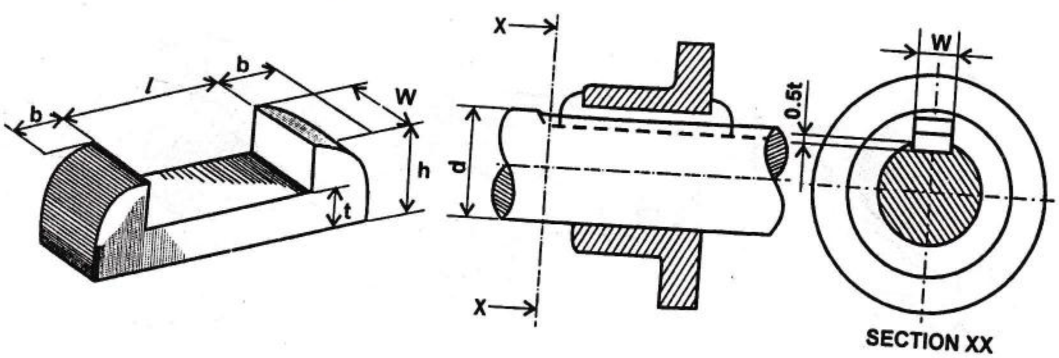
Nominal thickness, $t = 0.66\ w$

Height of the head, $h = 1.75\ t$

Width of the head, $b = 1.5\ t$

Fig. 5.9: Single Head Key

Double Head Key



Width of key, $w = 0.25\ d + 2\ mm$

Nominal thickness, $t = 0.66\ w$

Height of the head, $h = 1.75\ t$

Width of the head, $b = 1.5\ t$

Fig. 5.10: Double Head Key

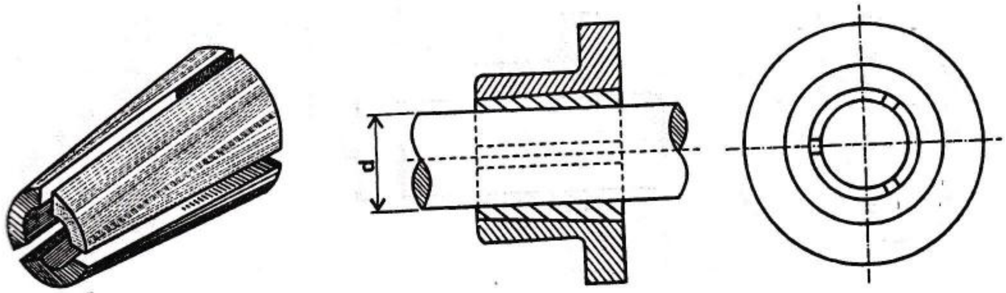
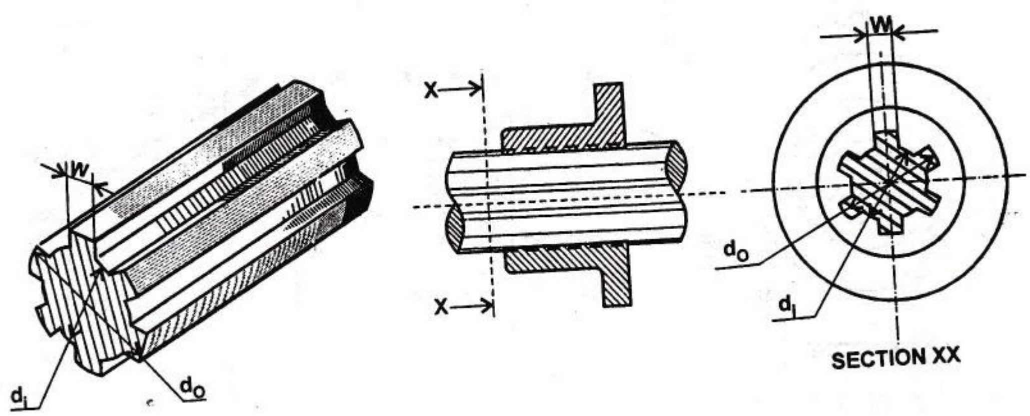


Fig. 5.11: Cone key

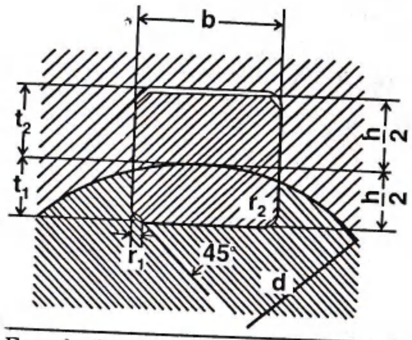


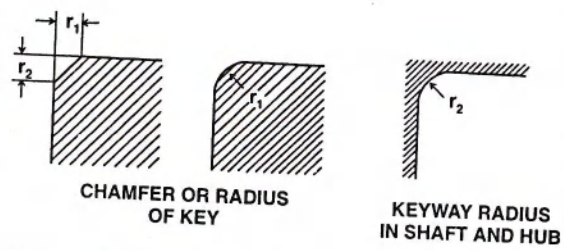
Width of each spline, w = 0.25D
Major diameter of spline key, D = 1.25d

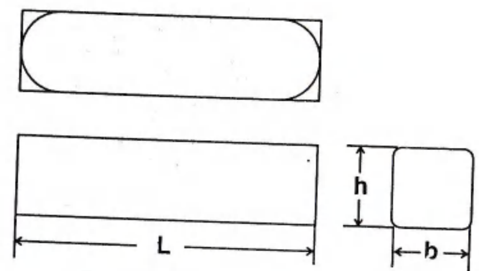
Fig. 5.12: Spline shaft

Table 5.1: Dimensions of Parallel Keys and Keyways

All dimensions in millimetres







For shaft diameters	Above	6	8	10	12	17	22	30	38	44	50	58	65	75	85	95	110	130	150	170	200	230	260	290	330	380	440
	Up to	8	10	12	17	22	30	38	44	50	58	65	75	85	95	110	130	150	170	200	230	260	290	330	380	440	500
Key cross section	Width b	2	3	4	5	6	8	10	12	14	16	18	20	22	25	28	32	36	40	45	50	56	63	70	80	90	100
	Height h	2	3	4	5	6	7	8	8	9	10	11	12	14	14	16	18	20	22	25	28	32	32	36	40	45	50
Keyway depth (nominal)	in Shaft, t_1	1.2	1.8	2.5	3	3.5	4	5	5	5.5	6	7	7.5	8.5	9	10	11	12	13	15	17	19	20	22	25	28	31
	in hub, t_2	1	1.4	1.8	2.3	2.8	3.3	3.3	3.3	3.8	4.3	4.4	4.9	5.9	5.4	6.4	7.4	8.4	9.4	10.4	11.4	13.4	12.4	14.4	15.4	17.4	19.5
Tolerance on keyway depth	t_1	+ 0.1					+ 0.2										+ 0.3										
	t_2	+ 0.1									+ 0.2										+ 0.3						
Chamfer or radius of key	r_1 Max	0.25			0.35			0.55					0.80					1.30				2.00			2.95		
	Min	0.16			0.25			0.40					0.60					1.00				1.60			2.50		
Key way radius	r_2 Max	0.16			0.25			0.40					0.60					1.00				1.60			2.50		
Length of key	L min	6	6	8	10	14	18	22	28	36	45	50	56	63	70	80	90	100	110	125	140	160	180	200	220	250	280
	Max	20	36	45	56	70	90	110	140	160	180	200	220	250	280	320	360	400	400	400	400	400	400	400	400	400	400

Designation: A Parallel Key of width 10 mm height 8 mm and length 50 mm shall be designated as: Parallel Key $10 \times 8 \times 50$ IS: 2048 – 1962

Designation: A Parallel Key of width 10 mm height 8 mm and length 50 mm shall be designated as: Parallel Key $10 \times 8 \times 50$ IS: 2048 – 1962

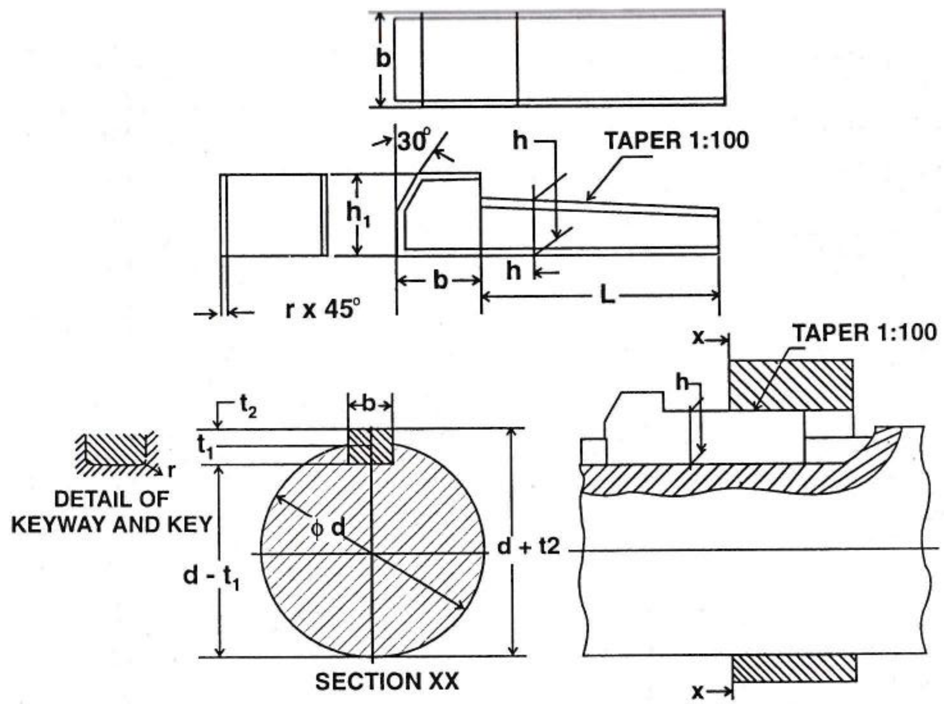
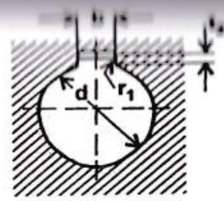


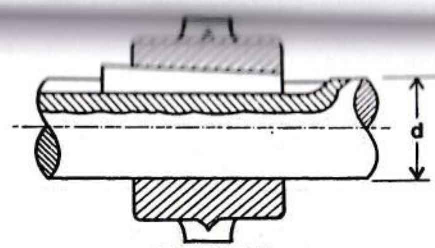
Table 5.2: Gib-Head Keys and Keyways
(All dimensions in millimeters)

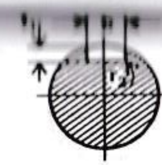
Range of Shaft Dia d		Key		Keyways								Range of Key Length	
		b × h	h_1	b	Tol on b D 10	t_1	Tol on t_1	t_2	Tol on t_2	r			
Above	Upto									min	max	min	max
10	12	4 × 4	7	4		2.5		1.2		0.08	0.16	14	45
12	17	5 × 5	8	5	+ 0.078	3.0	+ 0.1	1.7	+ 0.1	0.16	0.25	14	56
17	22	6 × 6	10	6	+ 0.030	3.5	0	2.2	0	0.16	0.25	16	70

Range of Shaft Dia d		Key		Keyways								Range of Key Length	
Above	Upto	b × h	h_1	b	Tol on b D 10	t_1	Tol on t_1	t_2	Tol on t_2	r min	r max	min	max
22	30	8 × 7	11	8	+ 0.098	4.0		2.4		0.16	0.25	20	90
30	38	10 × 8	12	10	+ 0.040	5.0		2.4		0.25	0.40	25	110
38	44	12 × 8	12	12		5.0		2.4		0.25	0.40	32	140
44	50	14 × 9	14	14	+ 0.120	5.5		2.9		0.25	0.40	40	160
50	58	16 × 10	16	16	+ 0.050	6.0	+ 0.2	3.4	+ 0.2	0.25	0.40	45	180
58	65	18 × 11	18	18		7.0	0	3.4	0	0.25	0.40	50	200
65	75	20 × 12	20	20		7.5		3.9		0.40	0.60	56	220
75	85	22 × 14	22	22	+ 0.149	9.0		4.4		0.40	0.60	63	250
85	95	25 × 14	22	25	+ 0.065	9.0		4.4		0.40	0.60	70	280
95	110	28 × 16	25	28		10.0		5.4		0.40	0.60	80	320
110	130	32 × 18	28	32		11.0		6.4		0.40	0.60	90	360
130	150	36 × 20	32	36	+ 0.180	12.0		7.1		0.70	1.00	100	400
150	170	40 × 22	36	40	+ 0.080	13.0		8.1		0.70	1.00	110	400
170	200	45 × 25	40	45		15.0		9.1		0.70	1.00	125	400
200	230	50 × 28	45	50		17.0		10.1		0.70	1.00	140	400
230	260	56 × 32	50	56		20.0		11.1		1.20	1.60	–	–
260	290	63 × 32	50	63	+ 0.220	20.0	+ 0.3	11.1	+ 0.3	1.20	1.60	–	–
290	330	70 × 36	56	70	+ 0.100	22.0	0	13.1	0	1.20	1.60	–	–
330	380	80 × 40	63	80		25.0		14.1		2.00	2.50	–	–
380	440	90 × 45	70	90	+ 0.260	28.0		16.1		2.00	2.50	–	–
440	500	100 × 50	80	100	+ 0.120	31.0		18.1		2.00	2.50	–	–

IS 2293 – 1974







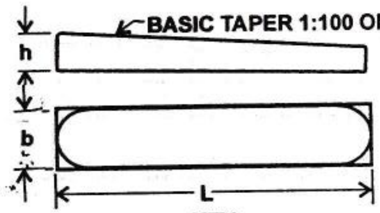


Table 5.3: Taper Keys and Keyways
(All Dimensions in mm)

Shaft Diameter, d		Key			Keyway in Shaft and Hub						Length	
Above	Upto & Including	Cross Section Width, b (h9)	Cross Section Height h	Chamfer or Radius r_1 (Min)	Keyway width b (D 10)	Depth in shaft t_1	Tol. on t_1	Depth in hub t_2	Tol. on t_2	Radius r_2 Max.	Min.	Max.
6	8	2	2	0.16	2	1.2	+ 0.05	0.5		0.16	6	20
8	10	3	3		3	1.8		0.9			8	36
10	12	4	4		4	2.5		1.2			10	45
12	17	5	5	0.25	5	3.0		1.7	+ 0.10	0.25	12	56
17	22	6	6		6	3.5		2.1			16	70
22	30	8	7		8	4.0	+ 0.1	2.5			20	90
30	38	10	8		10	5.0		2.5			25	110

Shaft Diameter, d		Key			Keyway in Shaft and Hub						Length	
Above	Upto & Including	Cross Section Width, b (h9)	Cross Section Height h	Chamfer or Radius r_1 (Min)	Keyway width b (D 10)	Depth in shaft t_1	Tol. on t_1	Depth in hub t_2	Tol. on t_2	Radius r_2 Max.	Min.	Max.
38	44	12	8		12	5.0		2.5			32	140
44	50	14	9	0.40	14	5.5		2.9			40	160
50	58	16	10		16	6.0		3.4			45	180
58	65	18	11		18	7.0		3.4			50	200
65	75	20	12		20	7.5		3.8			56	220
75	85	22	14		22	8.5		3.8			63	250
85	95	25	14	0.60	25	9.0		4.3	+ 0.2	0.60	70	280
95	110	28	16		28	10.0		5.3			80	315
110	130	32	18		32	11.0		6.2			90	355
130	150	36	20		36	12.0		7.2			100	400
150	170	40	22	1.00	40	13.0	+ 0.15	8.2		1.00	110	400
170	200	45	25		45	15.0		9.2			125	400
200	230	50	28		50	17.0		10.1			140	400
230	260	56	32		56	19.0		12.1				
260	290	63	33	1.6	63	20.0		12.1		1.60		
290	330	70	36		70	22.0		13.1	+ 0.3			
330	380	80	40		80	25.0		14.1				
380	440	90	45	2.5	90	28.0		16.1		2.50		
440	500	100	50		100	31.0		18.1				

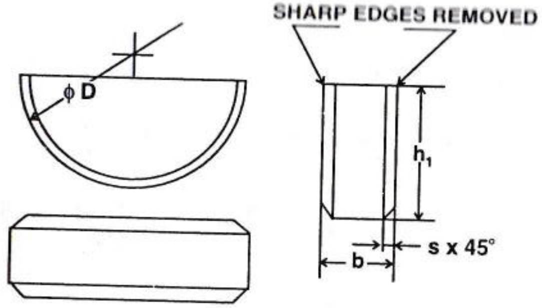
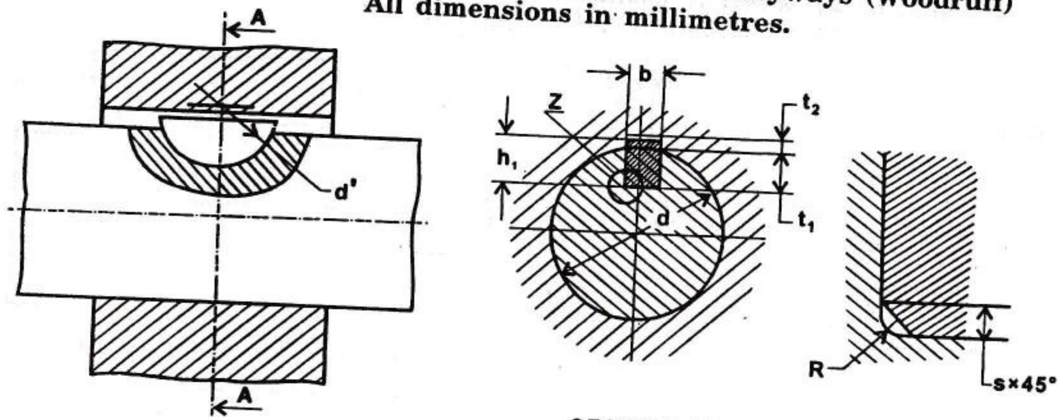


Table 5.4: Dimensions and Tolerances of Keys (Woodruff) (All dimensions in millimetres)

b	Tol on b h_9^*	h_1	Tol on h_1 h11	D	Tol on D h12	s Min	s Max
1.0	0 − 0.025	1.4	0 − 0.060	4.0	0 − 0.120	0.16	0.25
1.5		2.6		7.0	0 − 0.150	0.16	0.25
2.0		2.6		7.0		0.16	0.25
2.0		3.7	0 −0.075	10.0		0.16	0.25
.2.5		3.7		10.0		0.16	0.25
3.0		5.0		13.0		0.15	0.25
3.0		6.5	0 −0.090	16.0	0 −0.180	0.16	0.25
4.0	0 −0.030	6.5		16.0		0.25	0.40
4.0		7.5		19.0	0 −0.210	0.25	0.40
5.0		6.5		16.0	0 −0.180	0.25	0.40
5.0		7.5		19.0	0 −0.210	0.25	0.40
5.0		9.0		22.0		0.25	0.40
6.0		9.0		22.0		0.25	0.40
6.0		10.0		25.0		0.25	0.40
8.0	0 −0.036	11.0	0 −0.110	28.0		0.40	0.60
10.0		13.0		32.0	0 −0.250	0.40	0.60

* A closer tolerance may be adopted subject to agreement between the supplier and the purchaser.

Table 5.5: Dimensions and Tolerances of Keyways (Woodruff)
All dimensions in millimetres.



SECTION AA

DETAIL Z

Key $b \times h_1 \times D$	Width				Depth				R	
	b Nom	Tolerance on b			t_1	Tol on t_1	t_2	Tol on t_2	Max	Min
		Normal	Fit	Close Fit						
		Shaft N9	Hub Js9	Shaft & Hub P9						
1.0 × 1.4 × 4.0	1.0				1.0		0.6		0.16	0.08
1.5 × 2.6 × 7.0	1.5				2.0		0.8		0.16	0.08
2.0 × 2.6 × 7.0	2.0				1.8	+ 0.1 0	1.0		0.16	0.08
2.0 × 3.7 × 10.0	2.0	− 0.004 − 0.029	+ 0.012 − 0.012	− 0.006 − 0.031	2.9		1.0	+ 0.1 0	0.16	0.08
2.5 × 3.7 × 10.0	2.5				2.7		1.2		0.16	0.08
3.0 × 5.0 × 13.0	3.0				3.8	+ 0.2 0	1.4		0.16	0.08
3.0 × 6.5 × 16.0	3.0				5.3		1.4		0.16	0.08

Key $b \times h_1 \times D$	Width				Depth				R	
	b Nom	Tolerance on b			t_1	Tol on t_1	t_2	Tol on t_2	Max	Min
		Normal	Fit	Close Fit						
		Shaft N9	Hub Js9	Shaft & Hub P9						
4.0 × 6.5 × 16.0	4.0	0 – 0.030	+ 0.015 – 0.015	– 0.012 – 0.042	5.0		1.8		0.25	0.16
4.0 × 7.5 × 19.0	4.0				6.0		1.8		0.25	0.16
5.0 × 6.5 × 16.0	5.0				4.5		2.3		0.25	0.16
5.0 × 7.5 × 19.0	5.0				5.5		2.3		0.25	0.16
5.0 × 9.0 × 22.0	5.0				7.0	+ 0.3 0	2.3		0.25	0.16
6.0 × 9.0 × 22.0	6.0				6.5		2.8		0.25	0.16
6.0 × 10.0 × 25.0	6.0				7.5		2.8	+ 0.2 0	0.25	0.16
8.0 × 11.0 × 28.0	8.0	0 – 0.036	+ 0.018 – 0.018	– 0.015 – 0.051	8.0		3.3		0.40	0.25
10.0 × 13.0 × 32.0	10.0				10.0		3.3		0.40	0.25

Note: The diameter of the keyways in the shaft shall be equal to nominal diameter 'D' of the key with a tolerance of + 0.5 mm.

Table 5.6: Relationship of Shaft Diameter to Key Size (Woodruff)

All dimensions in millimetres.

Shaft Diameter d				Key Size
Series 1*		Series 2**		
Over	Including	Over	Including	$b \times h_1 \times D$
3	4	3	4	1.0 × 1.4 × 4.0
4	5	4	6	1.5 × 2.6 × 7.0
5	6	6	8	2.0 × 2.6 × 7.0
6	7	8	10	2.0 × 3.7 × 10.0
7	8	10	12	2.5 × 3.7 × 10.0
8	10	12	15	3.0 × 5.0 × 13.0
10	12	15	18	3.0 × 6.5 × 16.0
12	14	18	20	4.0 × 6.5 × 16.0
14	16	20	22	4.0 × 7.5 × 19.0
16	18	22	25	5.0 × 6.5 × 16.0
18	20	25	28	5.0 × 7.5 × 19.0
20	22	28	32	5.0 × 9.0 × 22.0
22	25	32	36	6.0 × 9.0 × 22.0
25	28	36	40	6.0 × 10.0 × 25.0
28	32	40	–	8.0 × 11.0 × 28.0
32	38	–	–	10.0 × 13.0 × 32.0

* Series 1 – For Torque Applications

** Series 2 – For Positional Applications

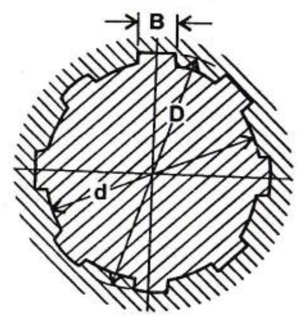
IS 2294 – 1980

* Series 1 – For Torque Applications

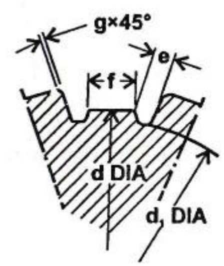
** Series 2 – For Positional Applications

Table 5.7: Straight Sided Splines

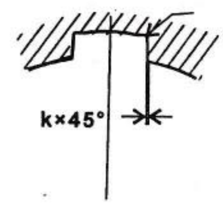
All dimensions in millimetres.



Splined shaft and hub profile



Splined shaft



Splined hub

Nominal Size N × d × D	No. of splines N	Minor Dia d	Major Dia D	Width B	d_1^* Min	e^* Max	f^*	g Max	k max	r Max	Centering On
Light Duty Series											
6 × 23 × 26	6	23	26	6	22.1	1.25	3.54	0.3	0.3	0.2	Inside* diameter
6. × 26 × 30	6	26	30	6	24.6	1.84	3.85	0.3	0.3	0.2	
6 × 28 × 32	6	28	32	7	26.7	1.77	4.03	0.3	0.3	0.2	

Nominal Size $N \times d \times D$	No. of splines N	Minor Dia d	Major Dia D	Width B	d_1^* Min	e^* Max	f^*	g Max	k max	r Max	Centering On
8 × 32 × 38	8	32	38	6	29.4	3.30	0.15	0.4	0.4	0.3	Inside† diameter or flanks
8 × 36 × 42	8	36	42	7	33.5	3.01	1.02	0.4	0.4	0.3	
8 × 42 × 48	8	42	48	8	39.5	2.91	2.57	0.4	0.4	0.3	
8 × 46 × 54	8	46	54	9	42.7	4.10	0.86	0.5	0.5	0.5	
8 × 52 × 60	8	52	60	10	48.7	4.00	2.44	0.5	0.5	0.5	
8 × 56 × 65	8	56	65	10	52.2	4.74	2.50	0.5	0.5	0.5	
8 × 62 × 72	8	62	72	12	57.8	5.00	2.40	0.5	0.5	0.5	
10 × 72 × 82	10	72	82	12	67.4	5.43	–	0.5	0.5	0.5	
10 × 82 × 92	10	82	92	12	77.1	5.40	3.00	0.5	0.5	0.5	
10 × 92 × 102	10	92	102	14	87.3	5.20	4.50	0.5	0.5	0.5	
10 × 102 × 112	10	102	112	16	97.7	4.90	6.30	0.5	0.5	0.5	
10 × 112 × 125	10	112	125	18	106.3	6.40	4.40	0.5	0.5	0.5	

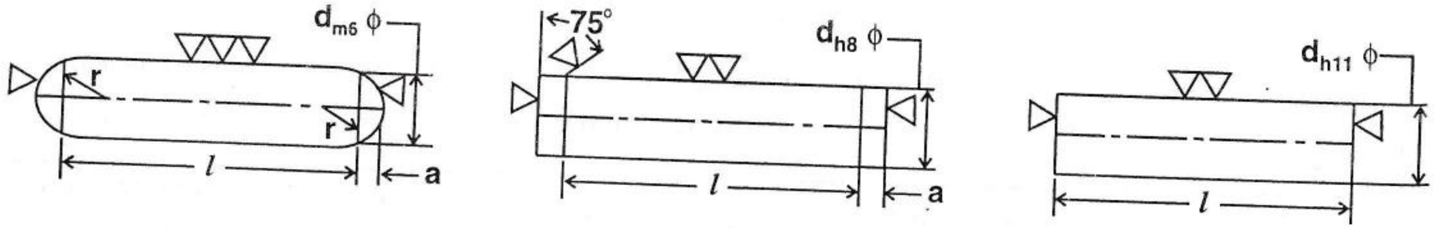
IS 2327 – 1963

* These values are based on the generating process.

† Inside contering is not always possible with generating processes.

Table 5.8: Dimensions for Cylindrical Pins

All dimensions in millimetres.



	d Nom	1.6	2	2.5	3	4	5	6	8	10	12	16	20	25	32	40	50
d_{m6}	Max	1.61	2.01	2.51	3.01	4.01	5.01	6.01	8.02	10.02	12.02	16.02	20.02	25.02	32.02	40.02	50.02
	Min	1.60	2.00	2.50	3.00	4.00	5.00	6.00	8.01	10.01	12.01	16.01	20.01	25.01	32.01	40.01	50.01
d_{h8}	Max	1.60	2.00	2.50	3.00	4.00	5.00	6.00	8.00	10.00	12.00	16.00	20.00	25.00	32.00	40.00	50.00
	Min	1.59	1.99	2.49	2.99	3.98	4.98	5.98	7.98	9.98	11.97	15.97	19.97	24.97	31.96	39.96	49.96
d_{h1L}	Max	1.60	2.00	2.50	3.00	4.00	5.00	6.00	8.00	10.00	12.00	16.00	20.00	25.00	32.00	40.00	50.00
	Min	1.54	1.94	2.44	2.94	3.92	4.92	5.92	7.91	9.91	11.89	15.89	19.87	24.87	31.84	39.84	49.84
	a Max	0.2	0.25	0.3	0.4	0.5	0.63	0.8	1	1.2	1.6	2	2.5	3	4	5	6.3
	r Nom	1.6	2	2.5	3	4	5	6	8	10	12	16	20	25	32	40	50

Designation: A cylinderical pin of nominal diameter 10 mm, tolerance h8 and nominal length 20 mm shall be designated as: Cylindrical Pin 10 h8 × 20 IS: 2393 – 1963.

Table 5.9: Preferred Length Diameter Combinations for Cylindrical Pins

All dimensions in millimetres

Designation: A cylinderical pin of nominal diameter 10 mm, tolerance h8 and nominal length 20 mm shall be designated as: Cylindrical Pin 10 h8 × 20 IS: 2393 – 1963.

Table 5.9: Preferred Length Diameter Combinations for Cylindrical Pins

All dimensions in millimetres

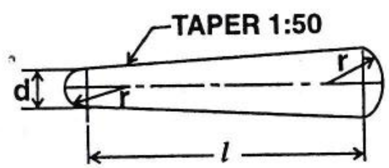
Length, l (j15)			d, Nom.															
Nom	Max	Min	1.6	2	2.5	3	4	5	6	8	10	12	16	20	25	32	40	50
4	4.24	3.76	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
5	5.24	4.76	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
6	6.24	5.76	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–
8	8.29	7.71	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–
10	10.3	9.71	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–
12	12.4	11.6	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–
14	14.4	13.6	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–
16	16.4	15.6	+	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–
20	20.4	19.6	+	+	+	+	+	+	+	+	+	–	–	–	–	–	–	–
25	25.4	24.6	–	+	+	+	+	+	+	+	+	+	–	–	–	–	–	–
30	30.4	29.6	–	–	+	+	+	+	+	+	+	+	+	–	–	–	–	–
35	35.5	34.5	–	–	–	+	+	+	+	+	+	+	+	–	–	–	–	–
40	40.5	39.5	–	–	–	–	+	+	+	+	+	+	+	+	–	–	–	–
45	45.5	44.5	–	–	–	–	+	+	+	+	+	+	+	+	–	–	–	–
50	50.5	49.5	–	–	–	–	–	+	+	+	+	+	+	+	+	–	–	–
55	55.6	54.4	–	–	–	–	–	+	+	+	+	+	+	+	+	–	–	–

Length, l (j15)			d, Nom.															
Nom	Max	Min	1.6	2	2.5	3	4	5	6	8	10	12	16	20	25	32	40	50
60	60.6	59.4	–	–	–	–	–	+	+	+	+	+	+	+	+	–	–	–
65	65.6	64.4	–	–	–	–	–	–	+	+	+	+	+	+	+	+	–	–
70	70.6	69.4	–	–	–	–	–	–	+	+	+	+	+	+	+	+	–	–
75	75.6	74.4	–	–	–	–	–	–	+	+	+	+	+	+	+	+	–	–
80	80.6	79.4	–	–	–	–	–	–	–	+	+	+	+	+	+	+	+	–
90	90.7	89.3	–	–	–	–	–	–	–	+	+	+	+	+	+	+	+	–
100	101	99.3	–	–	–	–	–	–	–	+	+	+	+	+	+	+	+	+
110	111	109	–	–	–	–	–	–	–	–	+	+	+	+	+	+	+	+
120	121	119	–	–	–	–	–	–	–	–	+	+	+	+	+	+	+	+
130	131	129	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+	+
140	141	139	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+	+
150	151	149	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+	+
160	161	159	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+
170	171	169	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+
180	181	179	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+
190	191	189	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+
200	201	199	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+

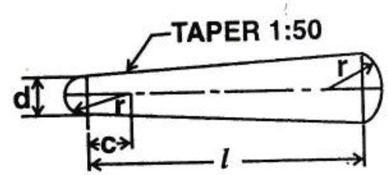
Note : For lengths beyond 200 mm, steps of 20 mm may be used.

Table 5.10: Dimensions for Solid and Split Taper Pins

All dimensions in millimetres



(r = d approx)
Solid Taper Pin



(r = d approx, and split length C = 0.2*l*)
Split Taper Pin

d Nom	1.6	2	2.5	3	4	5	6	8	10	12	16	20	25	32	40	50
d Max (h10)	1.60	2.00	2.50	3.00	4.00	5.00	6.00	8.00	10.00	12.00	16.00	20.00	25.00	32.00	40.00	50.00
d Min	1.54	1.96	2.46	2.94	3.95	4.95	5.95	7.94	9.94	11.93	15.93	19.92	24.92	31.90	39.90	49.90

Preferred Length Diameter Combinations

Length, l (j15)			d, Nom.															
Nom	Max	Min	1.6	2	2.5	3	4	5	6	8	10	12	16	20	25	32	40	50
8	8.29	7.71	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
10	10.3	9.71	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
12	12.4	11.6	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–
14	14.4	13.6	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–
16	16.4	15.6	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–

Length, l (j15)			d, Nom.															
Nom	Max	Min	1.6	2	2.5	3	4	5	6	8	10	12	16	20	25	32	40	50
20	20.4	19.6	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–
25	25.4	24.6	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–
30	30.4	29.6	–	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–
35	35.5	34.5	–	–	+	+	+	+	+	+	+	+	–	–	–	–	–	–
40	40.5	39.5	–	–	–	+	+	+	+	+	+	+	+	–	–	–	–	–
45	45.5	44.5	–	–	–	+	+	+	+	+	+	+	+	–	–	–	–	–
50	50.5	49.5	–	–	–	–	+	+	+	+	+	+	+	–	–	–	–	–
55	55.6	54.4	–	–	–	–	+	+	+	+	+	+	+	+	–	–	–	–
60	60.6	59.4	–	–	–	–	+	+	+	+	+	+	+	+	–	–	–	–
65	65.6	64.4	–	–	–	–	–	+	+	+	+	+	+	+	+	–	–	–
70	70.6	69.4	–	–	–	–	–	+	+	+	+	+	+	+	+	+	–	–
75	75.6	74.4	–	–	–	–	–	+	+	+	+	+	+	+	+	+	+	–
80	80.6	79.4	–	–	–	–	–	–	+	+	+	+	+	+	+	+	+	+
90	90.7	89.3	–	–	–	–	–	–	+	+	+	+	+	+	+	+	+	+
100	101	99.3	–	–	–	–	–	–	–	+	+	+	+	+	+	+	+	+

Length, l (j15)			d, Nom.															
Nom	Max	Min	1.6	2	2.5	3	4	5	6	8	10	12	16	20	25	32	40	50
110	111	109	–	–	–	–	–	–	–	+	+	+	+	+	+	+	+	+
120	121	119	–	–	–	–	–	–	–	+	+	+	+	+	+	+	+	+
130	131	129	–	–	–	–	–	–	–	–	+	+	+	+	+	+	+	+
140	141	139	–	–	–	–	–	–	–	–	+	+	+	+	+	+	+	+
150	151	149	–	–	–	–	–	–	–	–	+	+	+	+	+	+	+	+
160	161	159	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+	+
170	171	169	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+	+
180	181	179	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+	+
190	191	189	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+
200	201	199	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+

Note: For lengths above 200 mm, steps of 20 mm may be used.

Designation: A solid taper pin of 10 mm diameter and 50 mm nominal length shall be designated as : Solid Taper Pin 10 × 50 IS: 2393 – 1963.

Table 5.11: Dimensions for Splines Shaft.

Number of splines	width, w for all fits	A Permanent fit	B To slide when not under load	C To slide under load
		height, h	height, h	height, h
4	0.241 D	0.075 D	0.125 D	–
6	0.250 D	0.05 D	0.075 D	0.100 D
10	0.156 D	0.045 D	0.07 D	0.095 D
16	0.098 D	0.045 D	0.07 D	0.095 D

Table 5.12: Allowable Compressive (Crushing) Stress for Keys (N/mm^2)

Type of joint	Material	Load		
		Steady	Intermittent	Impact
Fixed	Steel	150	100	50
Fixed	Cast iron	80	53	20
Sliding	Steel	50	40	30

CHAPTER – 6

COUPLINGS

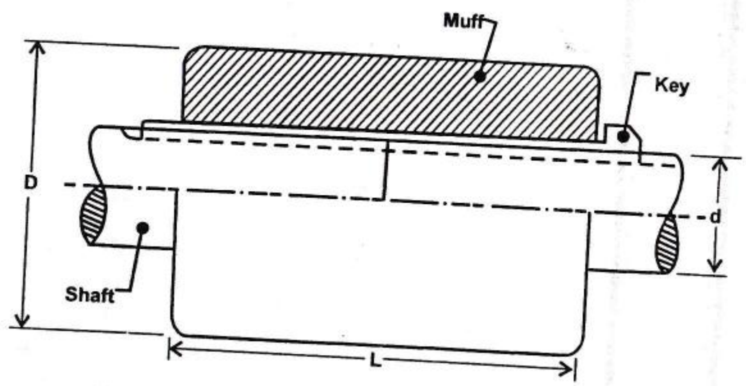
Symbols: (with S.I. Units)

d	–	Diameter of shaft, mm
N	–	Speed of shaft m rpm, Unit of force in newtons
P	–	Power, W
T	–	Torque transmitted, N-mm
S_{s1}	–	Shear stress for shaft, key and bolt material, N/mm^2
S_{s2}	–	Shear stress for coupling material, N/mm^2
S_{c1}	–	Crushing stress for key material, N/mm^2
S_{t1}	–	Tensile strength of bolt material, N/mm^2

DESIGN PARTICULARS	EQUATIONS
Torque transmitted by the shaft	$T = \frac{60 \times 10^3 \times P}{2 \pi N}$ .... (6.1)
Diameter of shaft (d)	$d = \left[\frac{16\,T}{\pi S_{s1}} \right]^{1/3}$ .... (6.2)

Approximate proportions of

(a) Muff coupling:



Sleeve or muff coupling

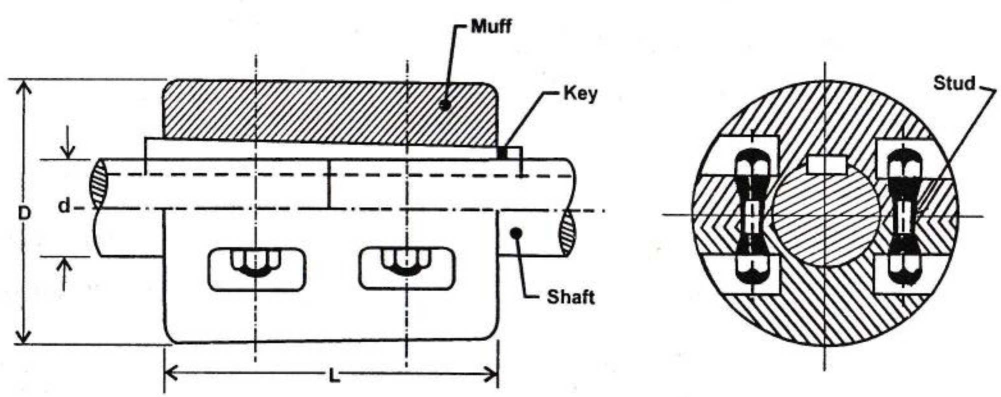
Fig. 6.1

Outer diameter of muff or sleeve (D)	$D \simeq 2d$
Length of muff (L)	$L \simeq 3d$

DESIGN PARTICULARS	EQUATIONS
Length of key (l)	$l = 3d$
Width of key (w)	$w = d/4$

DESIGN PARTICULARS	EQUATIONS
Length of key (l)	$l = 3d$
Width of key (w)	$w = d/4$
Thickness of key (t)	$t = d/6$
Number of keys (n)	$n = 2$
Torque transmitted by the coupling	$T = \frac{\pi}{16} S_{s2} D^3 (1 - k^4)$ .... (6.3) where $k = d/D$
Torque transmitted by the key	$T = l\, w\, S_{s1}\, d/2 = l t\, S_{c1}\, d/4$ .... (6.4)

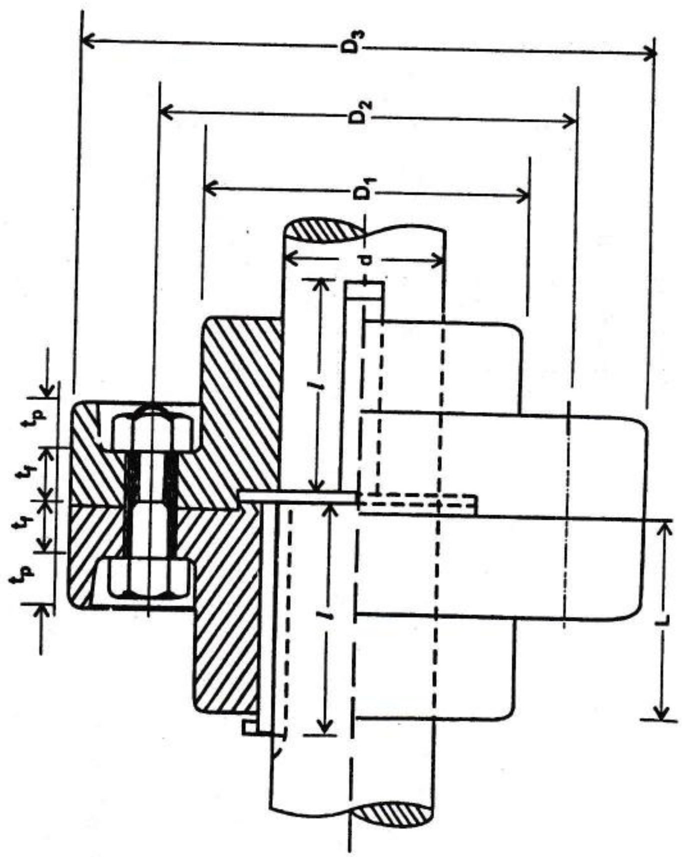
(b) Split muff coupling (or) compression coupling



Clamp or compression coupling

Fig. 6.2

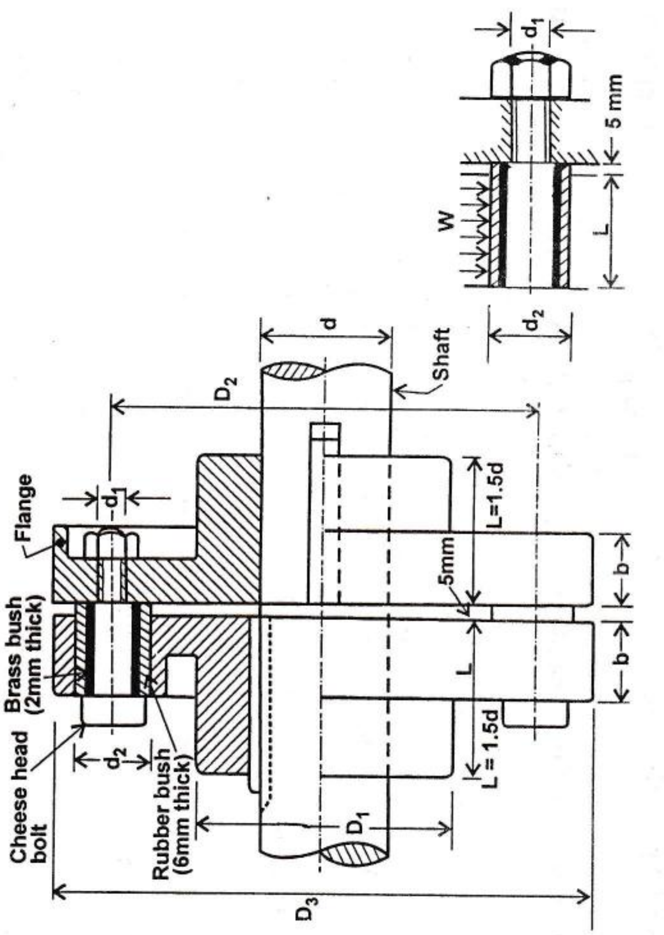
DESIGN PARTICULARS	EQUATIONS
Outer diameter of muff (D)	$D = 2.5\ d$
Length of muff (L)	$L = 3.5\ d$
Length of key (l)	$l = L = 3.5\ d$
Number of bolts (n)	$n = 4, 6$ or 8
Number of keys (n′)	$n' = 1$
Torque transmitted by the coupling due to friction	$T = \frac{\pi^2}{16} \mu\, d_c^2\, S_t\, nd$ .... (6.5) where μ = coefficient of friction between muff and shaft d_c = Core diameter of bolt
(c) Rigid Flange coupling:	
Outer diameter of hub (D_1)	$D_1 = 2d$
Pitch circle diameter of bolts (D_2)	$D_2 = 3d$
Outer diameter of flange (D_3)	$D_3 = 4d$
Length of hub (L)	$L = 1.5d$
Thickness of flange (t_f)	$t_f = 0.5\ d$
Thickness of protecting flange (t_p)	$t_p = 0.25\ d$
Length of key (l)	$l = 1.5\ d$



Protective type rigid flange coupling

Fig. 6.3

DESIGN PARTICULARS	EQUATIONS	
Width of key (w)	$w = d/4$	
Thickness of key (t)	$t = d/6$	
Number of bolts (n)	$n = 3$ for $d \le 40$ mm	
	$= 4$ for $40 < d \le 100$ mm	
	$= 6$ for $100 < d \le 180$ mm	
	$= 8$ for $d > 180$ mm.	
Torque capacity based on shearing strength of coupling hub	$T = \frac{\pi}{16} S_{s2} D_1^3 (1 - k^4)$ where $k = d/D_1$	.... (6.6)
Torque capacity based on shearing strength of flange	$T = \frac{\pi}{2} D_1^2 t_f S_{s2}$	.... (6.7)
Torque transmitted by the bolts	$T = \frac{\pi}{4} d_b^2 S_{s1} \frac{D_2}{2} n$	.... (6.8)
	where d_b = Nominal diameter of bolt.	
(d) Flexible Flange coupling:		
Outer diameter of hub (D_1)	$D_1 = 2d$	
Length of hub (L)	$L = 1.5\ d$	
Thickness of flange (t_f)	$t_f = 0.5\ d$	
Diameter of pin (d_1)	$d_1 = \frac{0.5\ d}{\sqrt{n}}$	



Bushed pin flexible flange coupling

Fig. 6.4

DESIGN PARTICULARS	EQUATIONS	
Pitch circle diameter of bolts (D_2)	$D_2 = D_1 + d_2 + 2c_1$	where n = Number of pins
Outer diameter of flanges (D_3)	$D_3 = D_2 + d_2 + 2c_2$	p_b = Bearing pressure on the bush.
Bearing load on each pin (W)	$W = p_b\, d_2\, l$	c_1, c_2 = clearances
Torque transmitted by all the pins	$T = W.n.\dfrac{D_2}{2}$	l = Length of bush in the flange.

Table 6.1: Dimensions for Forged end type Rigid Coupling (Refer Fig. 6.5) All Dimensions in mm

Coupling Number		For Shaft Dia D		Coupling Dimensions						Bolt* Size d	Bolt Hole Dia d' H8	Number of Bolts
Recessed Flange	Spigot Flange	Max	Min	Flange Outside Dia D_3	Flange Width t'	Locating Dia D'	Recess Depth b_1	Spigot Depth b_2	Pitch Circle Dia D_2			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
R1	S1	35	–	100	17	50	6	4	70	M10	11	4
R2	S2	45	36	120	22	60	6	4	85	M12	13	4
R3	S3	55	46	140	22	75	7	5	100	M14	15	4
R4	S4	70	56	175	27	95	7	5	125	M16	17	6
R5	S5	80	71	195	32	95	7	5	140	M18	19	6
R6	S6	90	81	225	32	125	7	5	160	M20	21	6
R7	S7	110	91	265	36	150	9	7	190	M24	25	6
R8	S8	130	111	300	46	150	9	7	215	M30	32	6
R9	S9	150	131	335	50	195	9	7	240	M33	34	6

R8	S8	130	111	300	46	150	9	7	215	M30	32	6
R9	S9	150	131	335	50	195	9	7	240	M33	34	6

Coupling Number		For Shaft Dia D		Coupling Dimensions						Bolt* Size d	Bolt Hole Dia d' H8	Number of Bolts
Recessed Flange	Spigot Flange	Max	Min	Flange Outside Dia D_3	Flange Width t'	Locating Dia D'	Recess Depth b_1	Spigot Depth b_2	Pitch Circle Dia D_2			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
R10	S10	170	151	375	55	195	10	8	265	M36	38	8
R11	S11	190	171	400	55	240	10	8	290	M36	38	8
R12	S12	210	191	445	65	240	10	8	315	M42	44	8
R13	S13	230	211	475	70	280	10	8	340	M45	46	8
R14	S14	250	231	500	70	280	10	8	370	M45	46	10
R15	S15	270	251	560	80	330	10	8	400	M52	55	10
R16	S16	300	271	600	85	330	10	8	440	M56	60	10
R17	S17	330	301	650	90	400	10	8	480	M60	65	10
R18	S18	360	331	730	100	400	10	8	520	M 68	72	10
R19	S19	390	361	775	105	480	11	9	570	M72	76	10
R20	S20	430	391	875	110	480	11	9	620	M76	80	12
R21	S21	470	431	900	115	560	11	9	670	M80	85	12
R22	S22	520	471	925	120	560	12	10	730	M90	95	12
R23	S23	570	521	1000	125	640	12	10	790	M100	105	12
R24	S24	620	571	1090	130	720	12	10	850	M110	115	12

*The dimension of the bolt shall be according to IS:3640

IS : 3653 – 1966

Table 6.2: Dimensions of Flexible Couplings, Bush and Disc Types (Fig. 6.4 & 6.5)

(All dimensions in millimetres)

BUSH								DISC								
Coup-ling No.	Bore D		Out side Dia	Hub Dia	Hub Length	Flange Width	Maximum Rating per 100 rpm	Coup-ling No.	Bore D		Out-side Dia	Hub Dia	Hub Length	Flange Width	Thickness of Disc	Maximum Rating per 100 rpm
	Min	Max	D_3 min	D_1 min	L min	b			min	max	D_3 min	D_1 min	L min	b	T	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)* kW	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)* kW
B_1	12	16	80	28	28	18	0.4	D_1	12	16	82	28	28	18	15	0.4
B_2	16	22	100	35	30	20	0.6	D_2	16	22	100	35	30	20	16	0.6
B_3	22	30	112	45	32	22	0.8	D_3	22	30	110	45	32	22	18	0.8
B_4	30	45	132	65	40	30	2.5	D_4	30	45	132	65	40	30	25	2.5
B_5	45	56	170	80	45	35	4.0	D_5	45	56	165	80	45	35	30	4.0
B_6	56	75	200	100	56	40	6.0	D_6	56	75	200	100	56	40	35	6.0
B_7	75	85	250	140	63	45	16.0	D_7	75	85	250	140	63	45	40	16.0
B_8	85	110	315	180	80	50	25.0	D_8	85	110	315	180	80	50	45	25.0
B_9	110	130	400	212	90	56	52.0	D_9	110	130	400	212	90	55	50	52.0
B_{10}	130	150	500	280	100	60	74.0	D_{10}	130	150	500	280	100	60	55	74.0

$$*\frac{\text{kW of power application} \times \text{service factor} \times 100}{\text{rpm of application}} = \text{max. rating at 100 rpm listed in the above table.}$$

Table 6.3: Dimensions of Flexible Couplings, Bush and Disc Types (Fig. 6.6 & 6.7)

All dimensions in millimetres										
Bush							Disc			
Coupling	Bolt	PCD	No. of	Bolt	Bush	Nominal Gap	Coupling	Bolt	PCD	*No. of Bolt

Table 6.3: Dimensions of Flexible Couplings, Bush and Disc Types (Fig. 6.6 & 6.7)

All dimensions in millimetres

Bush							Disc				
Coupling No.	Bolt Recess H Min	PCD of Bolts D_2	No. of Bolt Holes	Bolt Dia d_b	Bush Dia	Nominal Gap Between Coupling Halves c	Coupling No. H Min	Bolt Recess	PCD of Bolts D_2	*No. of Bolt Holes	Bolt Dia d
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
B_1	10	53	3	8	20	2	D_1	10	53	6	8
B_2	12	63	3	10	22	2	D_2	12	63	6	10
B_3	12	73	3	10	22	2	D_3	12	73	6	10
B_4	15	90	4	12	25	4	D_4	15	90	8	12
B_5	15	120	4	12	25	4	D_5	15	120	8	12
B_6	15	150	4	12	30	4	D_6	15	150	8	12
B_7	22	190	6	16	40	5	D_7	22	190	12	16
B_8	22	250	6	16	40	5	D_8	22	250	12	16
B_9	28	315	8	18	45	6	D_9	28	315	16	18
B_{10}	28	400	8	18	45	6	D_{10}	28	400	16	18

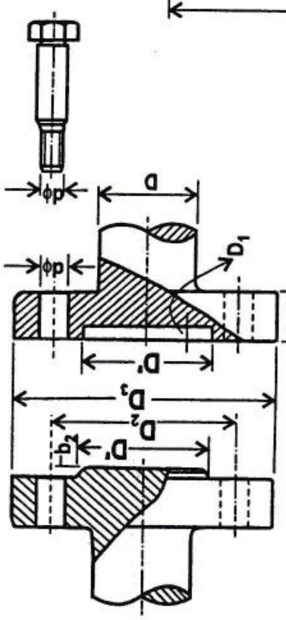
*Half the number of pinholes in each coupling half shall be clearance holes.

IS : 2693 – 1964

Table 6.4: Service Factors for use in Table 6.2

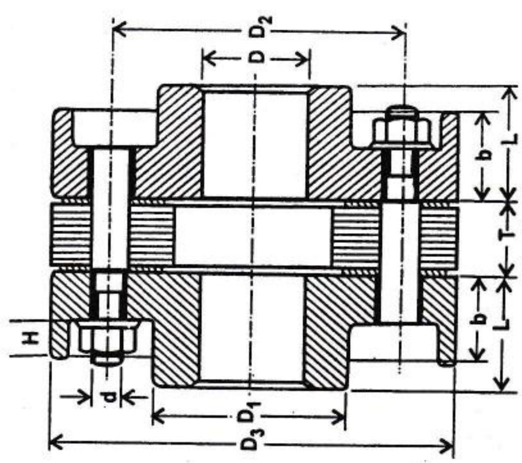
Type of Driven Machine	Service Factors for Prime-Movers					
	Electric Motor, Steam or Water Turbine	High Speed Steam or Gas Engine	Petrol Engine		Oil Engine	
			4 or more cyl.	less than 4 cyl.	6 or more cyl.	4 cycle or less
Alternators and generators (excluding welding generators), induced draught fans, printing machinery, rotary pumps compressors and exhausters, conveyors	1.5	2.0	2.5	3.0	3.5	5.0
Woodworking machinery, machine tools (cutting) excluding planing machines, calenders, mixers, elevators	2.0	2.5	3.0	3.5	4.0	5.5
Forced draught fans, high speed reciprocating compressors, high speed crushers and pulverisers, machine tools (forming)	2.5	3.0	3.5	4.0	4.5	6.0
Rotary screens, rod mills, tube, cable and wire machinery, vacuum pumps	3.0	3.5	4.0	4.5	5.0	6.5
Low speed reciprocating compressors haulage gears, metal planning machines, brick and tile machinery, rubber machinery, tube mills, generators (welding)	3.5	4.0	4.5	5.0	5.5	7.0

IS : 2693 – 1964



Forged end type rigid coupling

Fig. 6.5



Disc type cast iron flexible coupling

Fig. 6.6

Table 6.5: Characteristics of Flexible Couplings

Name of the coupling	Accommodation of misalignment			Damping capacity	Torsional flexibility	Remarks and uses
	Parallel misalignment	Angular misalignment	Axial displacement			
Oldham's	0.05 d	$\leq 1°$	–	–	–	Lubrication and cleanliness are essential.
Pin type flexible	≤ 0.5 mm	$\leq 1.5°$	3 to 5 mm	average	marginal	Widely used for ordinary equipments.
Universal or Hooke's joint	Good, if two joints are used with intermediate shaft	$\leq 30°$	–	–	–	Widely used for intersecting shafts.
Splined joint	–	–	≤ 20 mm	–	–	Propeller shaft of automobiles, clutches etc.

CHAPTER – 7

COTTER AND KNUCKLE JOINTS

Symbols: (with S.I. Units)

For Cotter Joints:

P = Applied load or Load carried by the rods, N

d = Diameter of rods, mm

d_1 = Outside diameter of socket, mm

d_2 = Diameter of spigot (or) Inside diameter of socket, mm

d_3 = Diameter of spigot collar, mm

d_4 = Outside diameter of socket collar, mm

b = Mean width of cotter, mm

t = Thickness of cotter, mm

t_1 = Thickness of spigot collar, mm

c = Thickness of socket collar, mm

a = Distance of spigot end from the slot, mm

l = Length of cotter, mm

S_t = Permissible tensile stress, N/mm^2

S_s = Permissible shear stress, N/mm^2

S_c = Permissible crushing stress, N/mm^2

For Knuckle Joints:

P = Applied load (or) Axial load acting on the rod, N

d = Diameter of rod, mm

d_1 = Diameter of knuckle pin, mm

d_2 = Outer diameter of eye, mm

d_3 = Diameter of knuckle pin head and collar, mm

t = Thickness of rod end or single eye, mm

t_1 = Thickness of fork end or double eye, mm

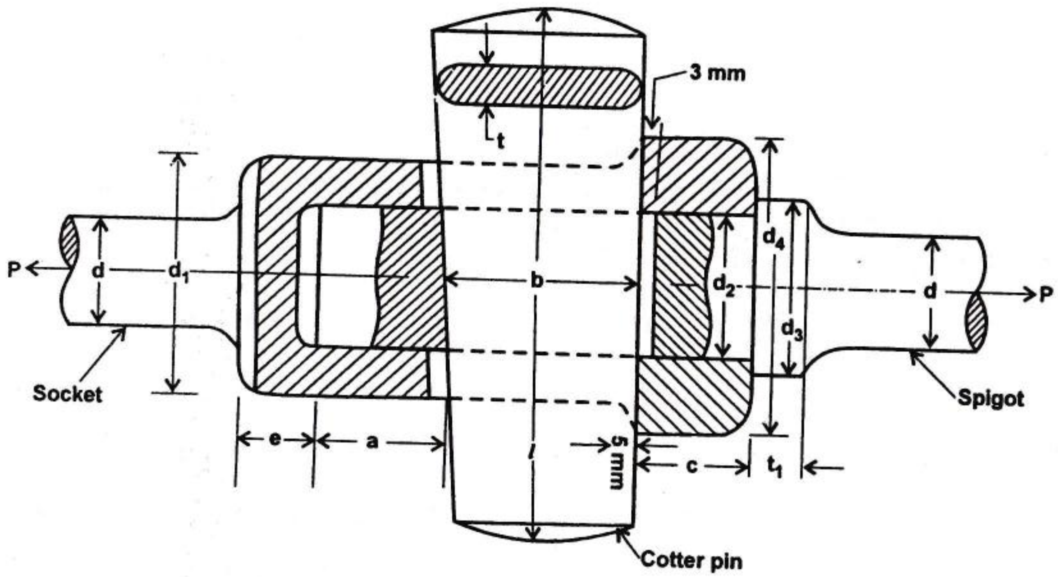
t_2 = Thickness of knuckle pin head and collar, mm

S_t = Permissible tensile stress, N/mm^2

S_s = Permissible shear stress, N/mm^2

S_c = Permissible crushing stress, N/mm^2

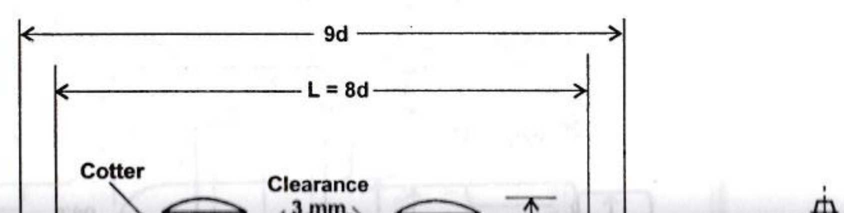
DESIGN PARTICULARS	EQUATIONS



Socket and Spigot Cotter Joint
Fig. 7.1

DESIGN PARTICULARS	EQUATIONS
Socket and Spigot Cotter Joint:	
Load capacity on the basis of	
(a) tensile strength of solid rod	$P = \frac{\pi}{4} d^2 S_t$ .... (7.1)

DESIGN PARTICULARS	EQUATIONS
(b) tensile strength of spigot through cotter hole	$P = \left(\frac{\pi}{4} d_2^2 - d_2\, t \right) S_t$ .... (7.2)
(c) crushing strength of spigot collar	$P = \frac{\pi}{4} \left(d_3^2 - d_2^2 \right) S_c$ .... (7.3)
(d) shearing strength of spigot collar	$P = \pi\, d_2\, t_1\, S_s$ .... (7.4)
(e) shearing strength of spigot rod	$P = 2a\, d_2\, S_s$ .... (7.5)
(f) tensile strength socket through cotter hole	$P = \left[\frac{\pi}{4} \left(d_1^2 - d_2^2 \right) - \left(d_1 - d_2 \right) t \right] S_t$ .... (7.6)
(g) crushing strength of socket collar	$P = \left(d_4 - d_2 \right) t\, S_c$ .... (7.7)
(h) shearing strength of socket collar	$P = 2c \left(d_4 - d_2 \right) S_s$ .... (7.8)
(i) shearing strength of cotter pin	$P = 2bt\, S_s$ .... (7.9)
(j) crushing strength of cotter pin	$P = d_2\, t\, S_c$ .... (7.10)
Usual proportions of 'Socket and spigot cotter joint'	$d_1 = 1.75\, d$; $d_2 = 1.2d$; $d_3 = 1.5\, d$; $d_4 = 2.5\, d$; $a = c = 0.75\, d$; $b = 1.3d$; $l = 4d$; $t = 0.3\, d$; $t_1 = 0.45\, d$; $e = 1.2\, d$; Taper of cotter = 1 in 25; Clearance = 3 to 5 mm.
Sleeve and cotter joint:	
Usual proportions	$d_1 = 2.5d$; $d_2 = 1.25d$; $t = 0.25\, d_2$ (or) $0.31\, d$; $b = 1.25\, d$; $l = 4d$; $a = c = 1.25d$



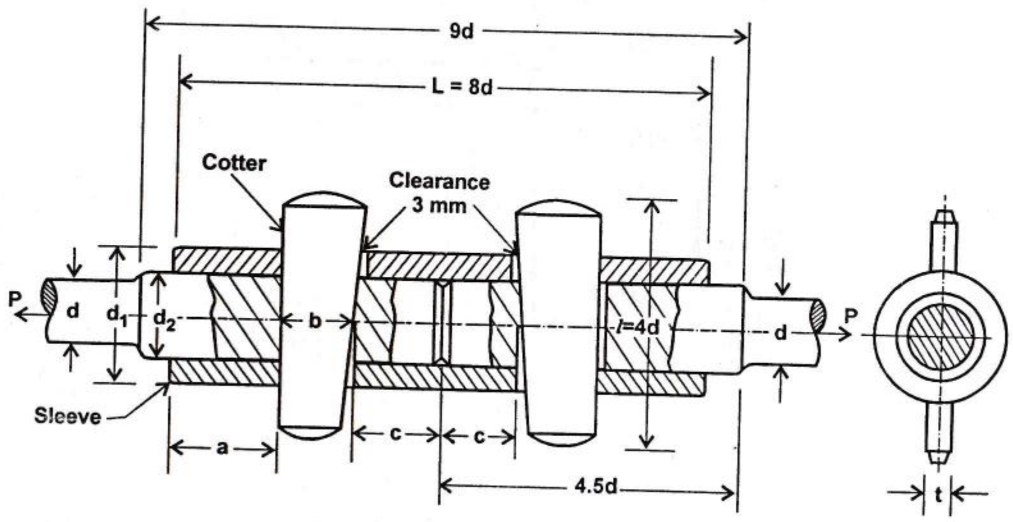


Fig. 7.2: Sleeve and Cotter Joint

DESIGN PARTICULARS	EQUATIONS
Knuckle joint:	
Load capacity on the basis of	
(a) tensile strength of solid rod	$P = \frac{\pi}{4} d^2 S_t$ .... (7.11)
(b) shearing strength of knuckle pin	$P = 2 \times \frac{\pi}{4} d_1^2 S_s$ .... (7.12)
(c) tensile strength of single eye	$P = \left(d_2 - d_1\right) t S_t$ .... (7.13)
(d) shearing strength of single eye	$P = \left(d_2 - d_1\right) t S_s$ .... (7.14)
(e) crushing strength of single eye	$P = d_1 t S_c$ .... (7.15)

DESIGN PARTICULARS	EQUATIONS
(f) tensile strength of double eye	$P = \left(d_2 - d_1\right) 2\, t_1\, S_t$ .... (7.16)
(g) shearing strength of double eye	$P = \left(d_2 - d_1\right) 2t_1\, S_s$ .... (7.17)
(h) crushing strength of double eye	$P = d_1\, 2t_1\, S_c$ .... (7.18)
Usual proportions for knuckle joint	$d_1 = d;\ d_2 = 2d;\ d_3 = 1.5\ d;\ t = 1.25\ d;\ t_1 = 0.75\ d;\ t_2 = 0.5\ d$

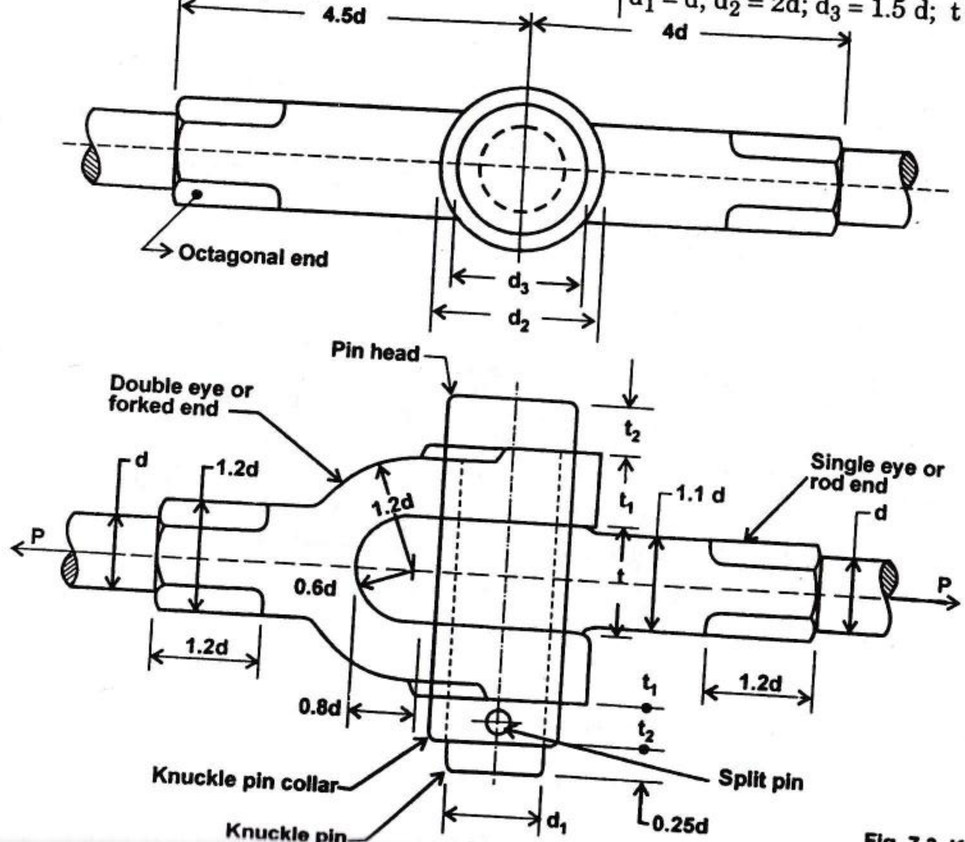


Fig. 7.3, Knuckle joint.

CHAPTER – 8

THREADED FASTENERS AND POWER SCREWS

9.8, 9, 10
(T) 9.5(b)
9.6(b)

Symbols: (with S.I. Units)

For screw threads (Standard symbols)

D	–	Major diameter of internal thread, mm
d	–	Major diameter of external thread, mm
D_1	–	Minor diameter of internal thread, mm
d_3	–	Minor diameter of external thread, mm
D_2	–	Pitch diameter of internal thread, mm
d_2	–	Pitch diameter of external thread, mm
H	–	Height of fundamental triangle, mm
H_1	–	Maximum depth of engagement, mm
h_3	–	Basic depth of external thread, mm
L	–	Lead of thread, mm
M	–	Symbol of metric thread
n	–	Number of starts
p	–	Pitch of thread, mm
α	–	Thread angle i.e., helix angle, deg.

For Screw joints and turn-buckle:

a	–	Ratio of elasticity of connected parts
d	–	Nominal diameter of bolt or tie-rod, mm
d_c	–	Core diameter of bolt or tie-rod, mm
D	–	Tip diameter of coupler-nut, mm
D_c	–	Core diameter of coupler-nut, mm
D_0	–	Outer diameter of coupler-nut, mm
D_1	–	Inside diameter of coupler, mm
D_2	–	Outside diameter of coupler, mm
L	–	Length of coupler, mm
l	–	Length of coupler-nut, mm
n	–	Number of threads per unit length
p	–	Pitch of thread, mm.
P	–	Axial load (as specified), N
P_d	–	Design load, N
T	–	Twisting moment or torque, N-mm.
(S_{t1}), (S_{s1}), (S_{c1})	–	Design or permissible tensile stress, shear stress and crushing stress for tie-rod (or) bolt material, N/mm^2
S_{t1}, S_{s1}, S_{c1}	–	Induced stresses as mentioned above.
(S_{t2}), (S_{s2}), (S_{c2})	–	Design or permissible tensile stress, shear stress and crushing stress for coupler material, N/mm^2.
S_{t2}, S_{s2}, S_{c2}	–	Induced stresses as mentioned above

For Power-s

d	–	Pi
d_c	–	Ro
d_0	–	Ti
D_0	–	M
H	–	H
L	–	E
l	–	A
n	–	N
p	–	Pi
P_b	–	B
L'	–	L
R_1	–	O
R_2	–	In
S	–	L
t_e	–	D
S_a	–	A
S_c	–	C
S_s	–	T
S_{p1}	–	M
S_{sm}	–	M
T	–	T
t	–	T
τ_s	–	D
τ_n	–	D
Z	–	N
ψ	–	N
η	–	e
α	–	L
ϕ	–	F
μ	–	C
μ_c	–	C

For Power-screws:

d	–	Pitch diameter of screw-rod, mm
d_c	–	Root diameter of screw-rod, mm
d_0	–	Tip diameter of screw-rod, mm
D_0	–	Major diameter of nut, mm
H	–	Height of the nut, mm
L	–	Equivalent length of screw-rod, mm
l	–	Actual length of screw-rod, mm
n	–	Number of threads in contact.
p	–	Pitch of thread of screw-rod, mm
P_b	–	Bearing pressure induced in the threads, N/mm^2
L'	–	Lead of thread of screw-rod, mm
R_1	–	Outside diameter of collar, mm.
R_2	–	Inside diameter of collar, mm.
S	–	Lead of the nut threads, mm
t_e	–	Depth of thread engagement, mm
S_a	–	Axial stress (Tensile or compressive), N/mm^2
S_c	–	Compressive stress, N/mm^2
S_s	–	Torsional shear stress of screw-rod, N/mm^2
S_{p1}	–	Maximum principal stress, N/mm^2
S_{sm}	–	Maximum shear stress, N/mm^2
T	–	Torque required to raise or lower the load, N-mm
t	–	Thickness of each thread, mm
τ_s	–	Direct shear stress of screw-rod threads, N/mm^2
τ_n	–	Direct shear stress of nut threads, N/mm^2
Z	–	Number of starts
ψ	–	Nut height factor.
η	–	efficiency of power-screw.
α	–	Lead angle
ϕ	–	Friction angle
μ	–	Coefficient of friction for the screw-rod.
μ_c	–	Coefficient of friction for the collar.

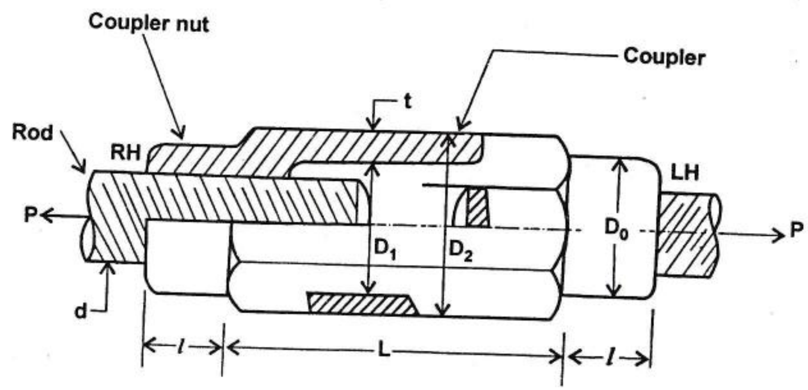
DESIGN PARTICULARS	EQUATIONS
Fluid tight joint:	
Resultant load induced in fluid tight joint (F_r)	$P_r = P_1 + \left[\frac{a}{1+a}\right] P_2 = P_1 + K P_2$ .... (8.1) For K values refer table (8.2)
Initial tension due to tight-screwing (F_1)	$P_1 = 2840d$; P_2 = Externally applied load. .... (8.2)
Core diameter of the bolt (d_c)	$d_c = \sqrt{\frac{4 P_r}{\pi (S_t) n}}$; n = Number of bolts .... (8.3)
Relation between the torque applied to the nut and axial tension in the bolt	$T = CP_1 d$ .... (8.4) where C = constant For unplated steel bolts with turned threads C = 0.10 for well lubricated, smooth surface. = 0.12 for unlubricated, smooth surface = 0.13 to 0.15 for well lubricated, unsmooth surface = 0.18 to 0.20 for unlubricated, unsmooth surface.

DESIGN PARTICULARS	EQUATIONS
Adjustable screw-joint (or) Turn-buckle:	

	... for well lubricated, unsmooth surface
	= 0.18 to 0.20 for unlubricated, unsmooth surface.

DESIGN PARTICULARS	EQUATIONS

Adjustable screw-joint (or) Turn-buckle:



Adjustable screw joint (Turn buckle)

Fig. 8.1

Nominal diameter of tie-rod	$d = 1.2\, d_c = 1.2 \times \sqrt{\dfrac{4\, P_d}{\pi\, (S_{t1})}}\,;\; P_d = 1.3\, P$	.... (8.5)
Outer diameter of coupler nut	$D_0 = \sqrt{\dfrac{4\, P_d}{\pi\, (S_{t2})} + D_c^2}\,; \quad D_c = d$	.... (8.6)

DESIGN PARTICULARS	EQUATIONS
Length of coupler-nut (l)	$l = \dfrac{P_d}{\pi D_c S_{c2}} = \dfrac{P_d}{\pi d_c S_{c1}}$ .... (8.7)
	(Select higher value of l)
Crushing strength of the threads of tie-rod and coupler-nut	$\dfrac{\pi}{4}\left(d^2 - d_c^2\right) n\, l\, S_{c1} = \dfrac{\pi}{4}\left(D_c^2 - D^2\right) n l\, S_{c2} = P_d$ .... (8.8)
	$n = \dfrac{1}{p}$
Inner diameter of coupler (D_1)	$D_1 = d + c;$ c = clearance
	$= 6$ mm to $0.25\,d$ .... (8.9)
Outer diameter of coupler (D_2)	$D_2 = \sqrt{\dfrac{4P}{\pi (S_{t2})} + D_1^2}$ .... (8.10)
Length of coupler	$L \simeq 6d$ .... (8.11)
Usual proportions of turn-buckle (For the same material of tie-rod and coupler)	$D_0 = 1.25\,d$ to $1.5\,d$
	$l = d$ to $1.25\,d$

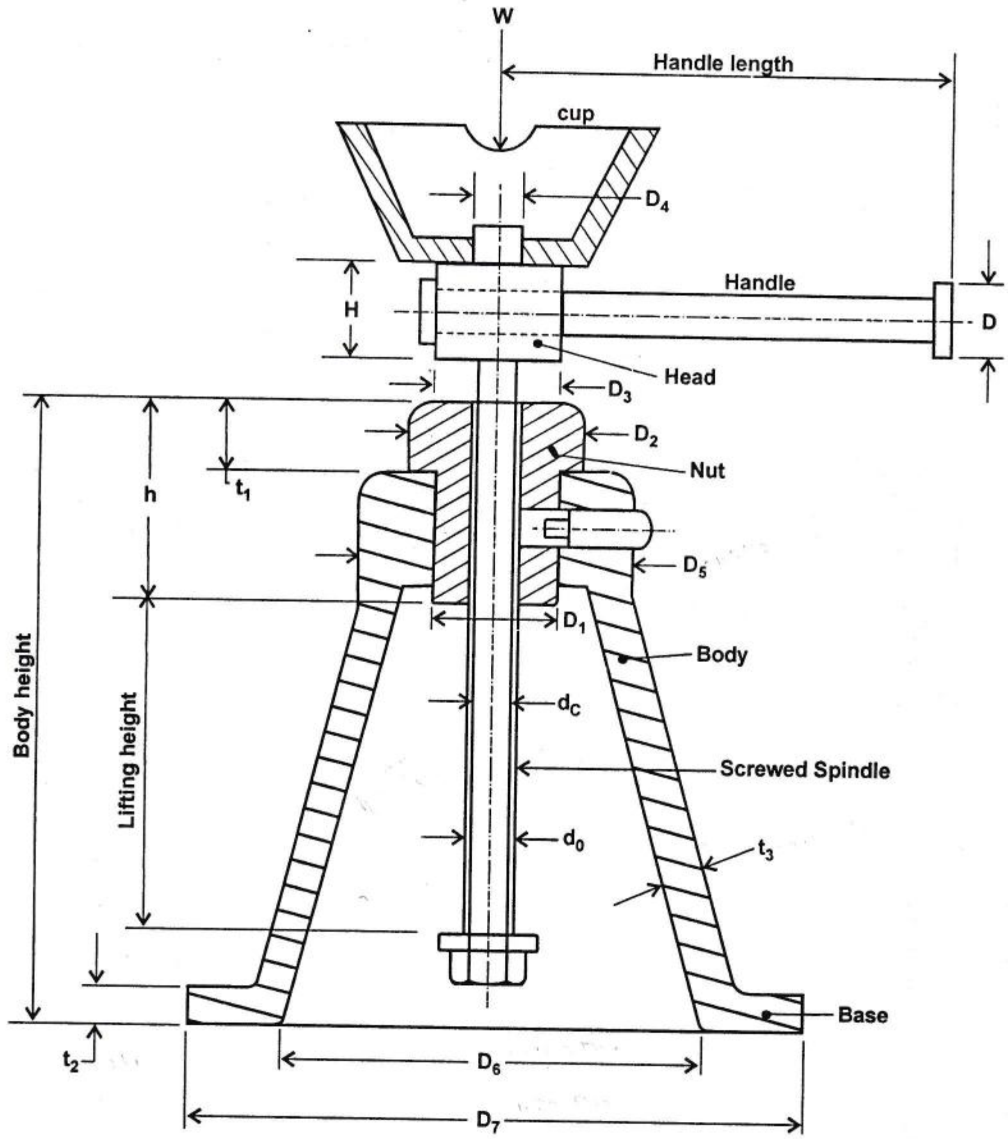
DESIGN PARTICULARS	EQUATIONS
(i.e., For $S_{t1} = S_{t2}$; $S_{s1} = S_{s2}$; $S_{c1} = S_{c2}$)	$D_1 = d + (6$ mm to $0.25\,d)$
	$D_2 = 1.5\,d$ to $1.75\,d$

DESIGN PARTICULARS	EQUATIONS	
(i.e., For $S_{t1} = S_{t2}$; $S_{s1} = S_{s2}$; $S_{c1} = S_{c2}$)	$D_1 = d + (6 \text{ mm to } 0.25\, d)$	
	$D_2 = 1.5\, d \text{ to } 1.75\, d$	
	$L = 6d \text{ to } 8d$	
Power-screws:		
Torque required to raise the load	$T_r = \frac{Wd}{2} \tan(\alpha + \phi)$	.... (8.12)
Torque required to lower the load	$T_l = \frac{Wd}{2} \tan(\phi - \alpha)$	.... (8.13)
	$\alpha = \tan^{-1} \frac{L'}{\pi d}$; $L' =$ Lead	
	$\phi = \tan^{-1} \mu$	
Efficiency of the power-screw	$\eta = \frac{\tan \alpha}{\tan(\alpha + \phi)}$	.... (8.14)
Axial compressive stress for short screw-rod	$S_a = \frac{4W}{\pi d_c^2}$	.... (8.15)
Axial compressive stress for long screw-rod	$S_a = \frac{4W\left[1 + a\left(\frac{L}{K}\right)^2\right]}{\pi d_c^2}$; a = Rankine's constant $= \frac{1}{7500}$ for steel	.... (8.16)

DESIGN PARTICULARS	EQUATIONS
Buckling or Crippling load	$F_{cr} = \dfrac{\pi d_c^2 \cdot S_c}{4\left[1 + a\left(\dfrac{L}{K}\right)^2\right]}$ .... (8.17) $L = l$ for both ends hinged $L = l/2$ for both ends fixed $L = l/\sqrt{2}$ for one end fixed and other end hinged $L = 2l$ for one end fixed and other end free.
Torsional shear stress in the screw-rod	$S_s = \dfrac{16\, T_r}{\pi d_c^3}$ .... (8.18)
Maximum principal stress in the screw-rod	$S_{p1} = \dfrac{1}{2}\left[S_a + \sqrt{S_a^2 + 4S_s^2}\right]$ .... (8.19)
Maximum shear stress in the screw-rod	$S_{sm} = \dfrac{1}{2}\sqrt{S_a^2 + 4S_s^2}$ .... (8.20)
Bearing pressure in the threads of screw-rod (or) nut	$P_b = \dfrac{W}{n \pi d t}$ .... (8.21)
Direct shear stress in the threads of screw-rod	$\tau_s = \dfrac{W}{n \pi d_c t}$ .... (8.22)
Direct shear stress in the threads of nut	$\tau_n = \dfrac{W}{n \pi D_0 t}$ .... (8.23)

Direct shear stress in the threads of nut	$\tau_n = \dfrac{W}{n \pi D_0 t}$ .... (8.23)

DESIGN PARTICULARS	EQUATIONS
Pitch circle diameter of nut or screw-rod	$d = \sqrt{\dfrac{2W}{\pi \psi [P_b]}}$ .... (8.24) $[P_b]$ – Permissible bearing pressure. $\psi = \dfrac{H}{d}$ $= 1.2$ to 2.5 for solid nuts $= 2.5$ to 3.5 for split nuts.
Torque required to overcome the collar friction	$T = \dfrac{2}{3} \mu_c W \left[\dfrac{R_1^3 - R_2^3}{R_1^2 - R_2^2} \right]$ for uniform pressure condition .... (8.25) (or) $T = \mu_c W \left(\dfrac{R_1 + R_2}{2} \right)$ for uniform wear condition .... (8.26) μ_c – Coefficient of friction for the collar.



Screw Jack (Power screw)
Fig. 8.2

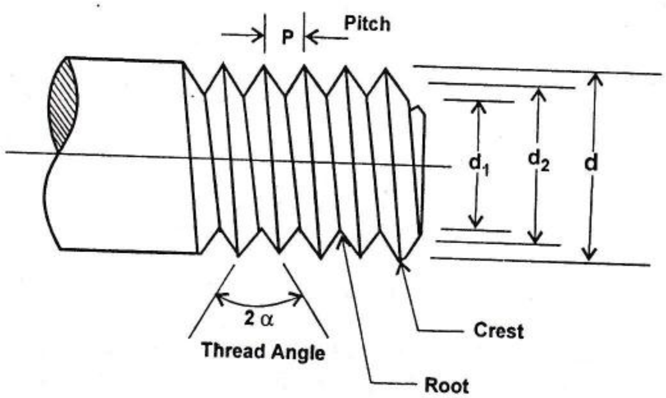


Fig. 8.3

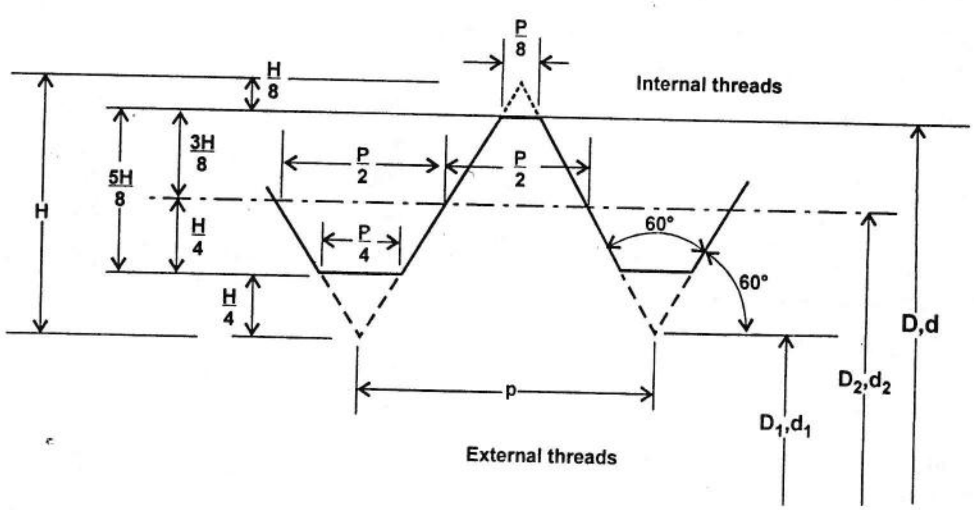


Fig. 8.4

Terminology of screw threads

Table 8.1(a): Properties of Some Bolt Materials

Material	Ultimate strength N/mm^2	Yield point N/mm^2	Elastic limit N/mm^2	Endurance limit N/mm^2
Low carbon steel	440	280	225	250
Medium carbon steel	480	316	288	240
Ni-steel	865	714	652	343
Ni-Cr steel	1030	960	652	550
Cr-Va steel	1565	1440	1170	550

Table 8.1(b): Strength of Screw Fasteners
(Properties of ASTM and SAE Grades of Steel Bolts)

Material and Heat Treatment, Size	Minimum Tensile Strength, MPa	Yield Strength / Proof Stress, MPa
Low carbon commercial bolts (0.1 to 0.2% C)	380	250
Low carbon cold headed Stress-relieved		
12 mm and under	475	380
12 mm to 18 mm	440	360
Medium carbon (0.3 to 0.4% C) (0.28 to 0.55% C, 0.04% max. P, 0.05% max. S) quenched and tempered		
12 mm and under	860	620
12 mm to 18 mm	830	585
18 mm to 24 mm	760	535
24 mm to 36 mm	725	510
Medium carbon, (0.28 to 0.55% C, 0.04% max. P, 0.05% max. S) fine grain alloy, quenched and tempered		
12 mm and under	1035	830
12 mm to 24 mm	965	760
24 mm to 36 mm	860	650
Special medium carbon oil quenched and tempered up to 16 mm	965	760
Stainless steel	620 to 850	240 to 800
Brass	340 to 480	205 to 275

Table 8.2

	Type of joint	K = a/(1 + a)
1.	Metal to metal joint with through bolts	0.00 to 0.10
2.	Hard copper gasket with long through bolts	0.25 to 0.50
3.	Soft copper gasket with long through bolts	0.50 to 0.75
4.	Soft packing with through bolts	0.75 to 1.00
5.	Soft packing with studs	1.00

Table 8.3: Working Stress and Load for Indian Metric Coarse Thread

Major Dia, (mm)	Stress Area A_r, mm^2	Design stress, MN/m^2 (kgf/mm^2)	Permissible Load, N (kgf)
16	157	19.0 (1.93)	2970 (303)
20	245	23.0 (2.33)	5590 (570)
24	353	27.2 (2.77)	9590 (978)
30	561	32.2 (3.28)	18040 (1840)
36	817	37.8 (3.85)	30890 (3150)
42	1120	43.2 (4.40)	48350 (4930)
48	1472	48.4 (4.93)	71100 (7250)
56	2030	55.2 (5.63)	111800 (11400)

Table 8.4: Safe Bearing Pressures in Power Screws

Service	Material		Safe Bearing Pressure MN/m^2 (kgf/mm^2)	Remarks
	Screw	Nut		
Hand Press	Steel	Bronze	17.2 to 24.0 (1.75 to 2.45)	Low speed, well lubricated
Jack Screw	Steel	C.I.	12.4 to 17.2 (1.26 to 1.75)	Low speed, not over 0.04 m/s
Jack Screw	Steel	Bronze	11.0 to 17.2 (1.12 to 1.75)	Low speed, not over 0.05 m/s
Hoisting Screw	Steel	C.I.	4.1 to 7.0 (0.42 to 0.70)	Medium speed, (0.1 to 0.2) m/s
Hoisting Screw	Steel	Bronze	5.5 to 9.6 (0.56 to 0.98)	Medium speed (0.1 to 0.2) m/s
Lead Screw	Steel	Bronze	1.0 to 1.6 (0.105 to 0.168)	High speed 0.25 m/s and over

Table 8.5: Coefficient of Friction for Power Screws*

Lubricant	Coefficient of friction (f)
Machine oil and graphite	0.17
Lard oil	0.11
Heavy machine oil	0.14

Table 8.6: Coefficient of Friction on Thrust Collar

Material	Coefficient of running friction	Coefficient of starting friction
Soft steel on cast iron	0.121	0.170
Hardened steel on C.I.	0.092	0.147
Soft steel on bronze	0.084	0.101
Hardened steel on bronze	0.063	0.081

Reference: 'Design of Machine Members,' by A. Vallance & V.L. Doughtie.

Table 8.7: Basic Dimensions for Design Profiles of ISO Metric Screw Threads

Basic Diameter mm	Pitch mm	Major Dia-meter mm	Pitch Diameter mm	Minor Diameter, mm		Lead Angle at Basic Pitch dia		Tensile Stress Area mm^2
				External Threads	Internal Threads	Deg	min	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	0.25	1.0	0.837620	0.693283	0.729367	5	27	0.46
	0.2	1.0	0.870096	0.756426	0.783494	4	11	0.53
1.1	0.25	1.1	0.937620	0.793283	0.829367	4	52	0.59
	0.2	1.1	0.970096	0.854626	0.883494	3	45	0.67
1.2	0.25	1.2	1.037630	0.893283	0.929367	4	24	0.73
	0.2	1.2	1.070096	0.954626	0.983494	3	24	0.82

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	0.3	1.4	1.205144	1.031939	1.075240	4	34	0.98
1.4	0.2	1.4	1.270096	1.154626	1.183494	2	52	1.17
1.6	0.35	1.6	1.372668	1.170596	1.221114	4	38	1.27
	0.2	1.6	1.470096	1.354626	1.383494	2	29	1.59
	0.35	1.8	1.572668	1.370596	1.421114	4	3	1.70
1.8	0.2	1.8	1.670096	1.554626	1.583494	2	11	2.66
	0.4	2.0	1.740192	1.509252	1.566987	4	11	2.07
2	0.25	2.0	1.837620	1.693283	1.729367	2	29	2.45
2.2	0.45	2.2	1.907716	1.647909	1.712861	4	17	2.48
	0.25	2.2	2.037620	1.893283	1.929367	2	14	3.03
	0.45	2.5	2.207716	1.947909	2.012861	3	43	3.39
2.5	0.35	2.5	2.272668	2.070596	2.121114	2	20	3.70
	0.5	3.0	2.675240	2.386565	2.458734	3	24	5.03
3	0.35	3.0	2.272668	2.570596	2.621114	2	18	5.61
	0.6	3.5	3.110289	2.763878	2.850481	3	31	6.78
3.5	0.35	3.5	3.272668	3.070596	3.121114	1	57	7.90
	0.7	4.0	3.545337	3.141191	3.242228	3	36	8.78
4	0.5	4.0	3.675240	3.386565	3.458734	2	29	9.79
	0.75	4.5	4.012861	3.579848	3.688101	3	24	11.3
4.5	0.5	4.5	4.175240	3.886565	3.958734	2	11	12.8
	0.8	5.0	4.480385	4.018505	4.133975	3	15	14.2
5	0.5	5.0	4.675240	4.386565	4.458734	1	57	16.1
	1	6.0	5.350481	4.773131	4.917468	3	24	20.1
6	0.75	6.0	5.512861	5.079848	5.188101	2	29	22.0
	1	7.0	6.350481	5.773131	5.917468	2	52	28.9
7	0.75	7.0	6.512861	6.079849	6.188101	2	6	31.3

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	1.25	8.0	7.188101	6.466413	6.646835	3	10	36.6
8	1	8.0	7.350481	6.773131	6.917468	2	29	39.2
	0.75	8.0	7.512861	7.079848	7.188101	1	49	41.8
	1.5	10.0	9.025721	8.159696	8.376202	3	2	58.0
10	1.25	10.0	9.188101	8.466413	8.646835	2	29	61.2
	1	10.0	9.350481	8.773131	8.917468	1	57	64.5
	0.75	10.0	9.512861	9.079848	9.188101	1	26	67.9
	1.75	12.0	10.863342	9.852979	10.105569	2	56	84.3
	1.5	12.0	11.025721	10.159696	10.376202	2	29	88.1
12	1.25	12.0	11.188101	10.466413	10.646835	2	2	92.1
	1	12.0	11.350481	10.773131	10.917468	1	36	96.1
	2	14.0	12.700962	11.546261	11.834936	2	52	115
	1.5	14.0	13.025721	12.159696	12.376202	2	6	125
14	1.25	14.0	13.188101	12.466413	12.646835	1	44	129
	1	14.0	13.350481	12.773131	12.917468	1	22	134
	2	16.0	14.700962	13.546261	13.834936	2	29	157
16	1.5	16.0	15.025721	14.159696	14.376202	1	49	167
	1	16.0	15.350481	14.773131	14.917468	1	11	178
	2.5	18.0	16.376202	14.932827	15.293671	2	47	192
	2	18.0	16.700962	15.546261	15.834936	2	11	204
18	1.5	18.0	17.025721	16.159696	16.376202	1	36	216
	1	18.0	17.350481	16.773131	16.917468	1	3	229
	2.5	20.0	18.376202	16.932827	17.293671	2	29	245
	2.0	20.0	18.700962	17.546261	17.834936	1	57	258
20	1.5	20.0	19.025721	18.159696	18.376202	1	26	272
	1	20.0	19.350481	18.773131	18.917468	0	57	285

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	2.5	22.0	20.376202	18.932827	19.293671	2	14	303
	2	22.0	20.700962	19.546261	19.834936	1	46	318
22	1.5	22.0	21.025721	20.159696	20.376202	1	18	333
	1	22.0	21.350481	20.773131	20.917468	0	51	348
	3	24.0	22.051443	20.319392	20.752405	2	49	353
	2	24.0	22.700962	21.546261	21.834936	1	39	384
24	1.5	24.0	23.025721	22.159696	22.376202	1	11	401
	1	24.0	23.350481	22.773131	22.917468	0	47	418
25	3	25.0	23.051443	21.319392	21.752405	2	36	385
	3	27.0	25.051443	23.319392	23.752405	2	11	459
	2	27.0	25.700962	24.546261	24.834936	1	25	496
27	1.5	27.0	26.025721	25.159696	25.376202	1	3	514
	1	27.0	26.350481	25.773131	25.917468	0	41	553
	3.5	30.0	27.726683	25.705957	26.211139	2	18	561
	3	30.0	28.051443	26.319392	26.752405	1	57	581
30	2	30.0	28.700962	27.546261	27.834936	1	16	621
	1.5	30.0	29.025721	28.159696	28.376202	0	57	642
	1	30.0	29.350481	28.773131	28.917468	0	37	663
	3.5	33.0	30.726683	28.705957	29.211139	2	5	694
	3	33.0	31.051443	29.319392	29.752405	1	46	716
33	2	33.0	31.700962	30.546261	30.834936	1	9	761
	1.5	33.0	32.025721	31.159696	31.376202	0	51	785
35	1.5	35.0	34.025721	33.159696	33.376202	0	48	886
	4	36.0	33.401924	31.092523	31.669873	2	11	817
	3	36.0	34.051443	32.319392	32.752405	1	36	865
36	2	36.0	34.700962	33.546261	33.834936	1	3	915
	1.5	36.0	35.025721	34.159696	34.376202	0	47	940

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
39	4	39.0	36.401924	34.092523	34.669873	2	0	976
	3	39.0	37.051443	35.319392	35.752405	1	29	1030
	2	39.0	37.700962	36.546261	36.834936	0	58	1080
	1.5	39.0	38.025721	37.159696	37.376202	0	43	1110
42	4.5	42.0	39.077164	36.479088	37.128607	2	6	1120
	4	42.0	39.401924	37.092523	37.669873	1	51	1150
	3	42.0	40.051443	38.319392	38.752405	1	22	1210
	2	42.0	40.700962	39.546261	39.834936	0	52	1260
	1.5	42.0	41.025721	40.159696	40.376202	0	40	1290
45	4.5	45.0	42.077164	39.479088	40.128607	1	57	1300
	4	45.0	42.401924	40.092523	40.669873	1	43	1340
	3	45.0	43.051443	41.319392	41.752405	1	16	1400
	2	45.0	43.700962	42.546261	42.834936	0	50	1460
	1.5	45.0	44.025721	43.159696	43.376202	0	37	1490
48	5	48.0	44.752405	41.865653	42.587341	2	2	1470
	4	48.0	45.401924	43.092523	43.569873	1	36	1540
	3	48.0	46.051443	44.319392	44.752405	1	11	1600
	2	48.0	46.700962	45.546261	45.834936	0	47	1670
	1.5	48.0	47.025721	46.159696	46.376202	0	35	1710
52	5	52.0	48.752405	45.865653	46.587341	1	52	1760
	4	52.0	49.401924	47.092523	47.669873	1	29	1830
	3	52.0	50.051443	48.319392	48.752405	1	6	1900
	2	52.0	50.700962	49.546261	49.834936	0	43	1970
	1.5	52.0	51.025721	50.159696	50.376202	0	32	2010

(1)	(2)
56	5.5
	4
	3
	2
	1.5
60	5.5
	4
	3
	2
	1.5
64	6
	4
	3
	2
	1.5
68	6
	4
	3
	2
	1.5
72	6
	4
	3
	2
	1.5

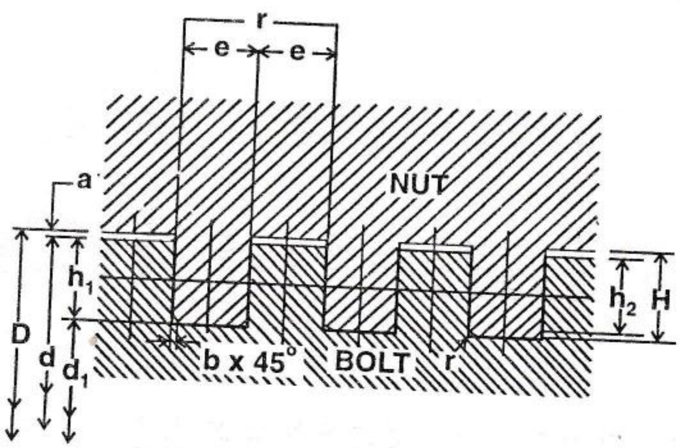
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	5.5	56.0	52.427645	49.252219	50.046075	1	55	2030
	4	56.0	53.401924	51.092523	51.669873	1	22	2140
56	3	56.0	54.051443	52.319392	52.752405	1	1	2220
	2	56.0	54.700962	53.546261	53.834936	0	40	2300
	1.5	56.0	55.025721	54.159696	54.376202	0	30	2340
	5.5	60.0	56.427645	53.252219	54.046075	1	47	2360
	4	60.0	57.401924	55.092523	55.669873	1	16	2490
60	3	60.0	58.051443	56.319392	56.752405	0	57	2570
	2	60.0	58.700962	57.546261	57.834936	0	37	2650
	1.5	60.0	59.025721	58.159696	58.376202	0	28	2700
	6	64.0	60.102886	56.638784	57.504809	1	49	2680
	4	64.0	61.401924	59.092523	59.669873	1	11	2850
64	3	64.0	62.051443	60.319392	60.752405	0	53	2940
	2	64.0	62.700962	61.546261	61.834936	0	35	3030
	1.5	64.0	63.025721	62.159696	62.376202	0	26	3080
	6	68.0	64.102886	60638784	61.504809	1	42	3060
	4	68.0	65.401924	63.092523	63.669873	1	7	3240
68	3	68.0	66.051443	64.319392	64.752405	1	50	3340
	2	68.0	66.700962	65.546261	65.834936	1	33	3430
	1.5	68.0	67.025721	66.159696	66.376202	0	24	3480
	6	72.0	68.102886	64.638784	65.504809	1	36	3460
	4	72.0	69.401924	67.092523	67.669873	1	3	3660
72	3	72.0	70.051443	68.319392	68.752405	0	47	3760
	2	72.0	70.700962	69.546261	69.834936	0	31	3860
	1.5	72.0	71.025721	70.159696	70.376202	0	23	3910

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	6	76.0	72.102886	68.638784	69.504809	1	31	3890
	4	76.0	73.401924	71.092523	71.669873	1	0	4100
76	3	76.0	74.051443	72.319392	72.752405	0	44	4210
	2	76.0	74.700962	73.546261	73.834936	0	29	4320
	1.5	76.0	75.025721	74.159696	74.376202	0	22	4370
	6	80.0	76.102886	72.638784	73.504809	1	26	4340
	4	80.0	77.401924	75.092523	75.669873	0	57	4570
80	3	80.0	78.051443	76.319392	76.752405	0	42	4680
	2	80.0	78.700962	77.546261	77.834936	0	28	4790
	1.5	80.0	79.025721	78.159696	78.376202	0	21	4850
	6	85.0	81.102886	77.638784	78.504809	1	21	4950
	4	85.0	82.401924	80.092523	80.669873	0	53	5190
85	3	85.0	83.051443	81.319392	81.752405	0	50	5310
	2	85.0	83.700962	82.546261	82.834936	0	26	5430
	6	90.0	86.102886	82.638784	83.504809	1	16	5590
	4	90.0	87.401924	85.092523	85.669873	0	50	5840
90	3	90.0	88.051443	86.319392	86.752405	0	37	5970
	2	90.0	88.700962	87.546261	87.834936	0	25	6100
	6	95.0	91.102886	87.638784	88.504809	1	12	6270
	4	95.0	92.401924	90.092523	90.669875	0	47	6540
95	3	95.0	93.051443	91.319392	91.752405	0	35	6670
	2	95.0	93.700962	92.546261	92.834936	0	23	6810
	6	100.0	96.102886	92.638784	93.504809	1	8	7000
	4	100.0	97.401924	95.092523	95.669873	0	45	7280
100	3	100.0	98.051443	96.319392	96.752405	0	33	7420
	2	100.0	98.700962	97.346261	97.834936	0	22	7560

Table: 8.8: Coarse and Fine Threads

	Size	Pitch P	Major Diameter d = D	Pitch Diameter $d_2 = D_2$	Minor Diameter Bolt, d_3	Minor Diameter Nut, D_1	Depth of Thread h	Max. Depth of Engagement, H	Stress Area S mm^2
Coarse Series	M 2.5	0.45	2.5	2.208	1.948	2.013	0.276	0.244	3.39
	M 3	0.5	3	2.675	2.387	2.459	0.307	0.271	5.03
	M 4	0.7	4	3.545	3.141	3.242	0.429	0.379	8.78
	M 5	0.8	5	4.480	4.019	4.134	0.491	0.433	14.2
	M 6	1	6	5.350	4.773	4.918	0.613	0.541	20.1
	M 8	1.25	8	7.188	6.466	6.647	0.767	0.677	36.6
	M 10	1.5	10	9.026	8.160	8.376	0.920	0.812	58.0
	M 12	1.75	12	10.863	9.853	10.106	1.074	0.947	84.3
	M 16	2	16	14.701	13.546	13.835	1.227	1.083	157
	M 20	2.5	20	18.376	16.933	17.294	1.534	1.353	245
	M 24	3	24	22.051	20.320	20.752	1.840	1.624	353
	M 30	3.5	30	27.727	25.706	26.211	2.147	1.894	561
	M 33	3.5	33	30.727	28.706	29.211	2.147	1.894	694
	M 36	4	36	33.402	31.093	31.67	2.454	2.165	817
Fine Series	M 8 × 1	1	8	7.350	6.773	6.918	0.613	0.541	39.2
	M 10 × 1.25	1.25	10	9.188	8.466	8.647	0.767	0.677	61.2
	M 12 × 1.25	1.25	12	11.188	10.466	10.647	0.767	0.677	92.1
	M 16 × 1.5	1.5	16	15.026	14.16	14.376	0.920	0.812	167
	M 20 × 1.5	1.5	20	19.026	18.16	18.376	0.920	0.812	272
	M 24 × 2	2	24	22.701	21.546	21.835	1.227	1.083	384
	M 30 × 2	2	30	28.701	27.546	27.835	1.227	1.083	621
	M 36 × 3	3	36	34.051	32.32	35.752	1.840	1.624	865

Stress area $\frac{\pi}{4}\left(\frac{d_2 + d_1}{2}\right)^2$



Basic profile of square threads

$h_1 = 0.5\ p$ $H = 0.5\ p + a$ $h_2 = 0.5\ p - b$ $e = 0.5\ p$ $D = d + 2a$

$d_1 = d - 2h_1$ Area of core $= \frac{\pi}{4} d_1^2$

Table 8.9: Basic Dimensions for Square Threads – Fine Series
(All dimensions in millimetres)

Nom. Dia.	Major Dia Bolt d	Major Dia Nut D	Minor Dia. d_1	Pitch p	e	r	h_2	b	h_1	a	H	Area of Core, mm^2
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
10	10	10.5	8									50.3
12	12	12.5	10									78.5
14	14	14.5	12	2	1	0.12	0.75	0.25	1	0.25	0.25	113
16	16	16.5	14									154
18	18	18.5	16									201
20	20	20.5	18									254
22	22	22.5	19									284
24	24	24.5	21									346
26	26	26.5	23									415
28	28	28.5	25									491
30	30	30.5	27									573

(1)	(2)
32	32
(34)	34
36	36
(38)	38
40	40
42	42
44	44
(46)	46
48	48
50	50
52	52
55	55
(58)	58
60	60
(62)	62
65	65
(68)	68
70	70
(72)	72
75	75
(78)	78
80	80
(82)	82
85	85
(88)	88
90	90
(92)	92
95	95
(98)	98
100	100
(105)	105
110	110

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
32	32	32.5	29									661
(34)	34	34.5	31									755
36	36	36.5	33	3	1.5	0.12	1.25	0.25	1.5	0.25	1.75	855
(38)	38	38.5	35									962
40	40	40.5	37									1075
42	42	42.5	39									1195
44	44	44.5	41									1320
(46)	46	46.5	43									1452
48	48	48.5	45									1590
50	50	50.5	47									1735
52	52	52.5	49									1886
55	55	55.5	52									2124
(58)	58	58.5	55	3	1.5	0.12	1.25	0.25	1.5	0.25	1.75	2376
60	60	60.5	57									2552
(62)	62	62.5	59									2734
65	65	65.5	61									2922
(68)	68	68.5	64									3217
70	70	70.5	66	4	2	0.12	1.75	0.25	2	0.25	2.25	3421
(72)	72	72.5	68									3632
75	75	75.5	71									3959
(78)	78	78.5	74									4301
80	80	80.5	76									4538
(82)	82	82.5	78	4	2	0.12	1.75	0.25	2	0.25	2.25	4778
85	85	85.5	81									5153
(88)	88	88.5	84									5542
90	90	90.5	86									5809
(92)	92	92.5	88									6082
95	95	95.5	91									6504
(98)	98	98.5	94	4	2	0.12	1.75	0.25	2	0.25	2.25	6940
100	100	100.5	96									7288
(105)	105	105.5	101									8018
110	110	110.5	106									8825

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(115)	115	115.5	109									9331
120	120	120.5	114									10207
(125)	125	125.5	119	6	3	0.25	2.5	0.5	3	0.25	3.25	11122
130	130	130.5	124									12076
(135)	135	135.5	129									13070
140	140	140.5	135									14103
(145)	145	145.5	139									15175
150	150	150.5	144									16286
(155)	155	155.5	149									17437
160	160	160.5	154	6	3	0.25	2.5	0.5	3	0.25	3.25	18627
(165)	165	165.5	159									19856
170	170	170.5	164									21124
(175)	175	175.5	169									22432
180	180	180.5	172									23235
(185)	185	185.5	177									24606
190	190	190.5	182	8	4	0.25	3.5	0.5	4	0.25	4.25	26016
(195)	195	195.5	187									27465
200	200	200.5	192									28953
210	210	210.5	202									32047
220	220	220.5	212	8	4	0.25	3.5	0.5	4	0.25	4.25	35299
230	230	230.5	222									38708
240	240	240.5	232									42272
250	250	250.5	238									44488
260	260	260.5	248									48305
270	270	270.5	258									52279
280	280	280.5	268									56410
290	290	290.5	278									60699
300	300	300.5	288	12	6	0.25	5.5	0.5	6	0.25	6.25	65144
320	320	320.5	308									74506
340	340	340.5	328									84496
360	360	360.5	348									95115
380	380	380.5	368									106362
400	400	400.5	388									118237

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
420	420	421	402									126923
440	440	441	422									139867
460	460	461	442	18	9	0.5	8	1	1	0.5	9.5	153439
480	480	481	462									167639
500	500	501	482									182467
520	520	521	496									193221
540	540	541	516									209117
560	560	561	536									225642
580	580	581	556	24	12	0.5	11	1	12	0.5	12.5	242795
600	600	601	576									260576
620	620	621	596									278986
640	640	641	616									298024

Note: Diameters indicated within brackets are of second preference. IS : 4694-1968

Table 8.10: Basic Dimensions for Square Threads – Normal Series (All dimensions in millimeters)

Nom. Dia.	Major Dia Bolt d	Major Dia Nut D	Minor Dia. d_1	Pitch p	e	r	h_2	b	h_1	a	H	Area of Core, mm^2
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
22	22	22.5	17									227
24	24	24.5	19	5	2.5	0.25	2	0.5	2.5	0.25	2.75	284
26	26	26.5	21									346
28	28	28.5	23									415
30	30	30.5	24									452
32	32	32.5	26	6	3	0.25	2.5	0.5	3	0.25	3.25	531
(34)	34	34.5	28									616
36	36	36.5	30									707
(38)	38	38.5	31									755
40	40	40.5	33	7	3.5	0.25	3	0.5	3.5	0.25	3.75	855
(42)	42	42.5	35									962
44	44	44.5	37									1075

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(46)	46	46.5	38									1134
48	48	48.5	40	8	4	0.25	3.5	0.5	4	0.25	4.25	1257
50	50	50.5	42									1385
52	52	52.4	44									1521
55	55	55.5	46									1662
(58)	58	58.5	49	9	4.5	0.25	4	0.5	4.5	0.25	4.75	1886
60	60	60.5	51									2043
(62)	62	62.5	53									2206
65	65	65.5	55									2376
(68)	68	68.5	58									2642
70	70	70.5	60									2827
(72)	72	72.5	62	10	5	0.25	4.5	0.5	5	0.25	5.25	3019
75	75	75.5	65									3318
(78)	78	78.5	68									3632
80	80	80.5	70									3848
(82)	82	82.5	72									4072
85	85	85.5	73									4185
(88)	88	88.5	76									5436
90	90	90.5	78									4778
(92)	92	92.5	80									5027
95	95	95.5	83	12	6	0.25	5.5	0.5	6	0.25	6.25	5411
(98)	98	98.5	86									5809
100	100	100.5	88									6082
(105)	105	105.5	93									6793
110	110	110.5	98									7543
(115)	115	116.0	101									8012
120	120	121.0	106									8825
125	125	126.0	111									9677

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
130	130	131.0	116	14	7	0.5	6	1	7	0.5	7.5	10568
(135)	135	136.0	121									11499
140	140	141.0	126									12469
(145)	145	146.0	131									13478
150	150	151	134									14103
(155)	155	156	139									15175
160	160	161	144	16	8	0.5	7	1	8	0.5	8.5	16286
(165)	165	166	149									17437
170	170	171	154									18627
(175)	175	176	159									19856
180	180	181	162									20612
(185)	185	186	167									21904
190	190	191	172	18	9	0.5	8	1	9	0.5	9.5	23235
(195)	195	196	177									24606
200	200	201	182									26016
210	210	211	190									28353
220	220	221	200	20	10	0.5	9	1	10	0.5	10.5	31416
230	230	231	210									34636
240	240	241	218									37325
250	250	251	228	22	11	0.5	10	1	11	0.5	11.5	40828
260	260	261	238									44488
270	270	271	246									47529
280	280	281	256	24	12	0.5	11	1	12	0.5	12.5	51472
290	290	291	266									55572
300	300	301	274	26	13	0.5	12	1	13	0.5	13.5	58965

Note: Diameters within brackets are of second preference IS 4694 – 1968

Table 8.11: Basic Dimensions for Square Threads – Coarse Series
(All dimensions in millimeters)

Nom. Dia.	Major Dia Bolt d	Major Dia Nut D	Minor Dia. d_1	Pitch p	e	r	h_2	b	h_1	a	H	Area of Core, mm^2
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
22	22	22.5	14	8	4	0.25	3.5	0.5	4	0.25	4.25	164
24	24	24.5	16									201
26	26	26.5	18									254
28	28	28.5	20									314
30	30	30.5	20	10	5	0.25	4.5	0.5	5	0.25	5.25	314
32	32	32.5	22									360
(34)	34	34.5	24									452
36	36	36.5	26									531
(38)	38	38.5	28									616
40	40	40.5	28	12	6	0.25	5.5	0.5	6	0.25	6.25	616
(42)	42	42.5	30									707
44	44	44.5	32									804
(46)	46	46.5	34									908
48	48	48.5	36									1018
50	50	50.5	38									1134
52	52	52.5	40									1257
55	55	56.0	41	14	7	0.5	6	1	7	0.5	7.5	1320
(58)	58	59.0	44									1521
60	60	61.0	46									1662
(62)	62	63.0	48									1810

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
65	65	66.0	49									1886
(68)	68	69.0	52									2124
70	70	71.0	54									2290
(72)	72	73.0	56	16	8	0.5	7	1	8	0.5	8.5	2463
75	75	76.0	59									2734
(78)	78	79.0	62									3019
80	80	81.0	64									3217
(82)	82	83.0	66									3421
85	85	86.0	67									3526
(88)	88	89.0	70									3848
90	90	91.0	72	18	9	0.5	8	1	9	0.5	9.5	4072
(92)	92	93.0	74									4301
95	95	95.0	77									4657
(98)	98	99.0	80									5027
100	100	101.0	80									5027
(105)	105	106.0	85	20	10	0.5	9	1	10	0.5	10.5	5675
110	110	111.0	90									6362
(115)	115	116.0	93									6793
120	120	121.0	98	22	11	0.5	10	1	11	0.5	11.5	7543
(125)	125	126.0	103									8332
130	130	131.0	108									9161
(135)	135	136	111									9677
140	140	141	116									10568
(145)	145	146	121	24	12	0.5	11	1	12	0.5	12.5	11499
150	150	151	126									12469
(155)	155	156	131									13478

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
160	160	161	132									13685
(165)	165	166	137									14741
170	170	171	142	28	14	0.5	13	1	14	0.5	14.5	15837
(175)	175	176	147									16972
180	180	181	152									18146
(185)	185	186	153									18385
190	190	191	158									19607
(195)	195	196	163	32	16	0.5	15	1	16	0.5	16.5	20867
200	200	201	168									22167
210	210	211	174									23779
220	220	221	184									26590
230	230	231	194	36	18	0.5	17	1	18	0.5	18.5	29559
240	240	241	204									32685
250	250	251	210									34636
260	260	261	220									38013
270	270	271	230	40	20	0.5	19	1	20	0.5	20.5	41548
280	280	281	240									45239
290	290	291	246									47529
300	300	301	256									51472
320	320	321	276	44	22	0.5	21	1	22	0.5	22.5	59828
340	340	341	296									68813
360	360	361	312									76454
380	380	381	332	43	24	0.5	23	1	24	0.5	24.5	86570
400	400	401	352									97314

Note: Diameters within brackets are of second preference

Table 8.12: Limits of Sizes for Fine Series Nut Threads Tolerance Class H5

Size	Pitch p	Major Diameter D Min	Pitch Diameter D_2			Minor Diameter D_1		
			Max	Min	Tolerance	Max	Min	Tolerance
(1)	(2) mm	(3) mm	(4) mm	(5) mm	(6) μm	(7) mm	(8) mm	(9) μm
M8 × 1	1	8.0	7.468	7.350	118	7.107	6.917	190
M 10 × 1.25	1.25	10.0	9.313	9.188	125	8.859	8.647	212
M12 × 1.25	1.25	12.0	11.328	11.188	140	10.859	10.647	212
(M14 × 1.5)	1.5	14.0	13.176	13.026	150	12.612	12.376	236
M16 × 1.5	1.5	16.0	15.176	15.026	150	14.612	14.376	236
(M18 × 1.5)	1.5	18.0	17.176	17.026	150	16.612	16.376	236
M20 × 1.5	1.5	20.0	19.176	19.026	150	18.612	18.376	236
(M22 × 1.5)	1.5	22.0	21.176	21.026	150	20.612	20.376	236
M24 × 2	2	24.0	22.881	22.701	180	22.135	21 835	300
(M27 × 2)	2	27.0	25.881	25.701	180	25.135	24.835	300
M30 × 2	2	30.0	28.881	28.701	180	28.135	27.835	300
(M33 × 2)	2	33.0	31.881	31.701	180	31.135	30.835	300
M36 × 3	3	36 0	34.263	34.051	212	33.152	32.752	400
(M39 × 3)	3	39.0	37.263	37.051	212	36.152	35.752	400

1 μ m = 0.001 mm IS: 4218 - 1967

Note: Second preference sizes are given in brackets in col 1.

Table 8.13: Limits of Sizes for Fine Series Bolt Threads – Tolerance Class h4

Size	Pitch	Major Diameter d			Pitch Diameter d_2			Minor Diameter d_3		
(1)	p (2) mm	Max (3) mm	Min (4) mm	Tolerance (5) μ m	Max (6) mm	Min (7) mm	Tolerance (8) μ m	Max (9) mm	Min (10) mm	Tolerance (11) μ m
M8 × 1	1	8.0	7.888	112	7.350	7.279	71	6.773	6.630	143
M10 × 1.25	1.25	10.0	9.868	132	9.188	9.113	75	8.466	8.301	165
M12 × 1.25	1.25	12.0	11.868	132	11.188	11.103	85	10.466	10.291	175
(M14 × 1.5)	1.5	14.0	13.850	150	13.026	12.936	90	12.160	11.962	198
M16 × 1.5	1.5	16.0	15.850	150	15.026	14.936	90	14.160	13.962	198
(M18 × 1.5)	1.5	18.0	17.850	150	17.026	16.936	90	16.160	15.962	198
M20 × 1.5	1.5	20.0	19.850	150	19.026	18.936	90	18.160	17.962	198
(M22 × 1.5)	1.5	22.0	21.850	150	21.026	20.936	90	20.160	19.962	198
M24 × 2	2	24.0	23.820	180	22.701	22.595	106	21.546	21.296	250
(M27 × 2)	2	27.0	26.820	180	25.701	25.595	106	24.546	24.296	250
M30 × 2	2	30.0	29.820	180	28.701	28.595	106	27.546	27.296	250
(M33 × 2)	2	33.0	31.820	180	31.701	31.595	106	30.546	30.296	250
M36 × 3	3	36.0	35.764	236	34.051	33.926	125	32.319	31.978	341
(M39 × 3)	3	39.0	38.764	236	37.051	36.926	125	35.319	34.978	341

1 μ m = 0.001 mm.

Second preference sizes are shown in brackets in Col.1

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Table 8.14: Limits of Sizes for Coarse Series Nut Threads – Tolerance Class H7

Size	Pitch p	Major Diameter D	Pitch Diameter D_2			Minor Diameter D_1		
		Min	Max	Min	Tolerance	Max	Min	Tolerance

Table 8.14: Limits of Sizes for Coarse Series Nut Threads – Tolerance Class H7

Size	Pitch p	Major Diameter D Min	Pitch Diameter D_2			Minor Diameter D_1		
			Max	Min	Tolerance	Max	Min	Tolerance
(1)	(2) mm	(3) mm	(4) mm	(5) mm	(6) μm	(7) mm	(8) mm	(9) μm
M1	0.25	1.000	–	–	–	–	–	–
(M1.1)	0.25	1.100	–	–	–	–	–	–
M1.2	0.25	1.200	–	–	–	–	–	–
(M1.4)	0.3	1.400	–	–	–	–	–	–
M1.6	0.35	1.600	–	–	–	–	–	–
(M1.8)	0.35	1.800	–	–	–	–	–	–
M2	0.4	2.000	–	–	–	–	–	–
(M2.2)	0.45	2.200	–	–	–	–	–	–
M2.5	0.45	2.500	–	–	–	–	–	–
M3	0.5	3.000	2.800	2.675	125	2.639	2.459	180
(M3.5)	0.6	3.500	3.250	3.110	140	3.050	2.850	200
M4	0.7	4.000	3.695	3.545	150	3.466	3.242	224
(M4.5)	0.75	4.500	4.163	4.013	150	3.924	3.688	236
M5	0.8	5.000	4.640	4.480	160	4.384	4.134	250

(1)	(2) mm	(3) mm	(4) mm	(5) mm	(6) µm	(7) mm	(8) mm	(9) µm
M6	1	6.000	5.540	5.350	190	5.217	4.917	300
(M7)	1	7.000	6.540	6.350	190	6.217	5.917	300
M8	1.25	8.000	7.388	7.188	200	6.982	6.647	335
M10	1.5	10.000	9.250	9.026	224	8.751	8.376	375
M12	1.75	12.000	11.113	10.863	250	10.531	10.106	425
(M14)	2	14.000	12.966	12.701	265	12.310	11.835	475
(M16)	2	16.000	14.966	14.701	265	14.213	13.835	475
(M18)	2.5	18.000	16.656	16.376	280	15.854	15.294	560
M20	2.5	20.000	18.656	19.376	280	17.854	17.294	560
(M22)	2.5	22.000	20.656	20.376	280	19.854	19.294	560
M24	3	24.000	22.386	22.051	335	21.382	20.757	630
(M27)	3	27.000	25.386	25.051	335	24.383	23.752	630
M30	3.5	30.000	28.082	27.727	355	26.921	26.211	710
(M33)	3.5	33.000	31.082	30.727	355	29.921	29.211	710
M36	4	36.000	33.777	33.402	375	32.420	31.670	750
(M39)	4	39.000	36.777	36.402	375	35.420	34.670	750

1 µ m = 0.001 mm

Note: Second preference sizes are shown in brackets in col. 1

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Table 8.15: Limits of Sizes for Coarse Series Bolt Threads – Tolerance Class g8

Size	Pitch	Major Diameter d			Pitch Diameter d_2			Minor Diameter d_3		
(1)	p (2) mm	Max (3) mm	Min (4) mm	Tolerance (5) μ m	Max (6) mm	Min (7) mm	Tolerance (8) μ m	Max (9) (mm)	Min (10) mm	Tolerance (11) μ m
M1	0.25	–	–	–	–	–	–	–	–	–
(M1.1)	0.25	–	–	–	–	–	–	–	–	–
M1.2	0.25	–	–	–	–	–	–	–	–	–
(M1.4)	0.3	–	–	–	–	–	–	–	–	–
M1.6	0.35	–	–	–	–	–	–	–	–	–
(M1.8)	0.35	–	–	–	–	–	–	–	–	–
M2	0.4	–	–	–	–	–	–	–	–	–
(M2.2)	0.45	–	–	–	–	–	–	–	–	–
M2.5	0.45	–	–	–	–	–	–	–	–	–
M3	0.5	–	–	–	–	–	–	–	–	–
(M3.5)	0.6	–	–	–	–	–	–	–	–	–
M4	0.7	–	–	–	–	–	–	–	–	–
(M4.5)	0.75	–	–	–	–	–	–	–	–	–
M5	0.8	4.976	4.740	236	4.456	4.306	150	3.995	3.787	208
M6	1	5.974	5.694	280	5.324	5.144	180	4.747	4.495	252

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(M7)	1	6.974	6.694	280	6.324	6.144	180	5.747	5.495	252
M8	1.25	7.972	7.637	335	7.160	6.970	190	6.438	6.158	280
M10	1.5	9.968	9.593	375	8.994	8.782	212	8.128	7.808	320
M12	1.75	11.966	11.541	425	10.829	10.593	236	9.819	9.457	362
(M14)	2	13.962	13.512	540	12.663	12.413	250	11.508	11.114	394
M16	2	15.962	15.512	540	14.663	14.413	250	13.508	13.114	394
(M18)	2.5	17.958	17.428	530	16.334	16.069	265	14.891	14.446	445
M20	2.5	19.958	19.428	530	18.334	18.069	265	16.891	16.446	445
(M22)	2.5	21.958	21.428	530	20.334	20.069	265	18.891	18.446	445
M24	3	23.952	23.352	600	22.003	21.688	315	20.271	19.740	531
(M27)	3	26.952	26.352	600	25.003	24.688	315	23.271	22.740	531
M30	3.5	29.947	29.277	670	27.674	27.339	335	25.653	25.066	587
(M33)	3.5	32.947	32.277	670	30.674	30.339	335	28.653	28.066	587
M36	4	35.940	35.190	750	33.342	32.987	355	31.033	30.390	643
(M39)	4	38.940	38.190	750	36.342	35.987	355	34.033	33.390	643

1 μ m = 0.001 mm

Note: 1 – Second preference sizes are shown in brackets in col. 1.

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Table 8.16: Empirical Proportions of Hexagonal Head Bolt & Nut

Detail	Proportion
Nominal Diameter	d = Size of Bolt or Nut, mm
Width Across Flats	s = 1.5d + 3 mm
Width Across Corners	e = 2d
Thickness of Bolt Head	k = 0.8 d
Thickness of Nut	m = 0.9 d
Root Diameter	d_1 = d – (2 × Depth of Thread) or = 0.9 d (approximate)
Length of Bolt	l = As specified
Thread Length	b = 2d + 6 mm (for l < 150 mm) = 2d + 12 mm (for l > 150 mm)
Radius of Bolt End	r = d (for spherical ends)
Chamfer of Bolt End	z = Depth of Thread × 45° or = 0.1 d (Approximate)
Chamfer Angle of Bolt Head & Nut	= 30°

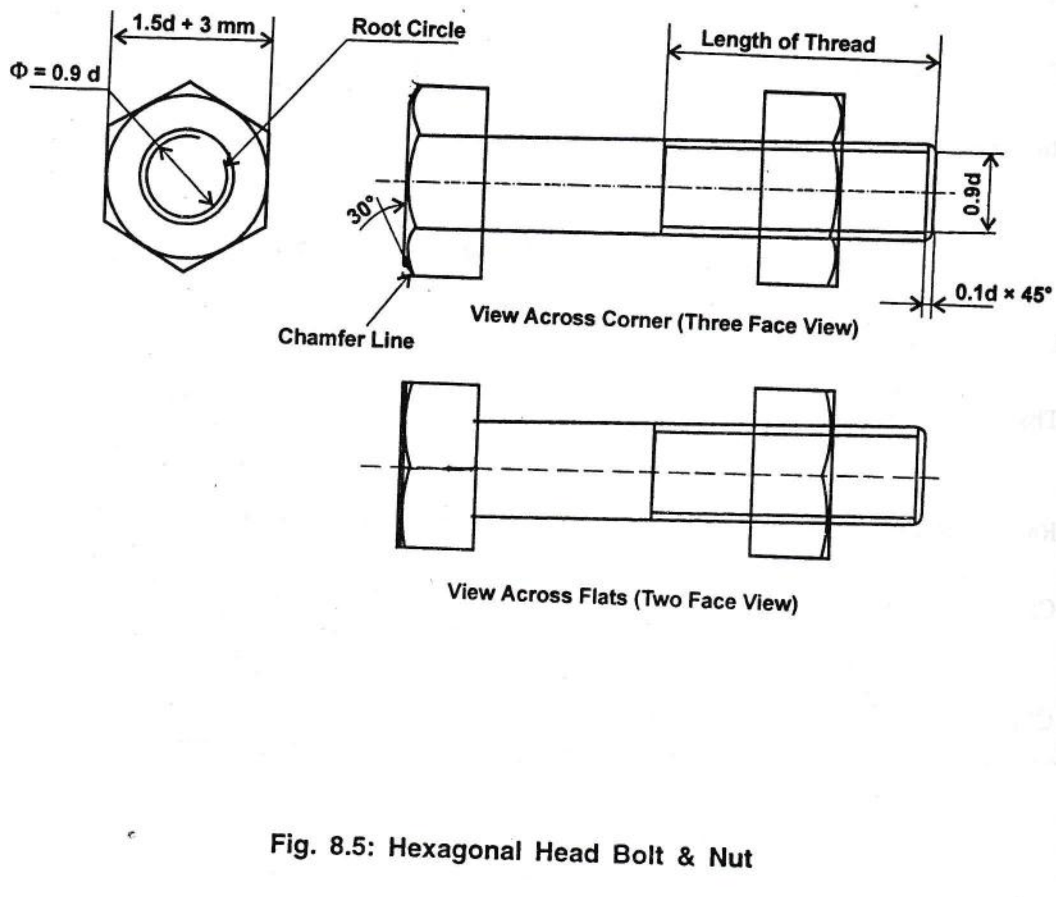


Fig. 8.5: Hexagonal Head Bolt & Nut

Symbols (with S.I

d′ – Nomi

d – Gross

l_s – Lengt

For boiler and a

t – Thickn

D – Intern

P – Pressu

p – Pitch

p_b – Back

p_d – Diagor

m – Margir

F – Streng

CHAPTER – 7

COTTER AND KNUCKLE JOINTS

Symbols: (with S.I. Units)

For Cotter Joints:

P = Applied load or Load carried by the rods, N

d = Diameter of rods, mm

d_1 = Outside diameter of socket, mm

d_2 = Diameter of spigot (or) Inside diameter of socket, mm

d_3 = Diameter of spigot collar, mm

d_4 = Outside diameter of socket collar, mm

b = Mean width of cotter, mm

t = Thickness of cotter, mm

t_1 = Thickness of spigot collar, mm

c = Thickness of socket collar, mm

a = Distance of spigot end from the slot, mm

l = Length of cotter, mm

S_t = Permissible tensile stress, N/mm^2

S_s = Permissible shear stress, N/mm^2

S_c = Permissible crushing stress, N/mm^2

For Knuckle Joints:

P = Applied load (or) Axial load acting on the rod, N

d = Diameter of rod, mm

d_1 = Diameter of knuckle pin, mm

d_2 = Outer diameter of eye, mm

d_3 = Diameter of knuckle pin head and collar, mm

t = Thickness of rod end or single eye, mm

t_1 = Thickness of fork end or double eye, mm

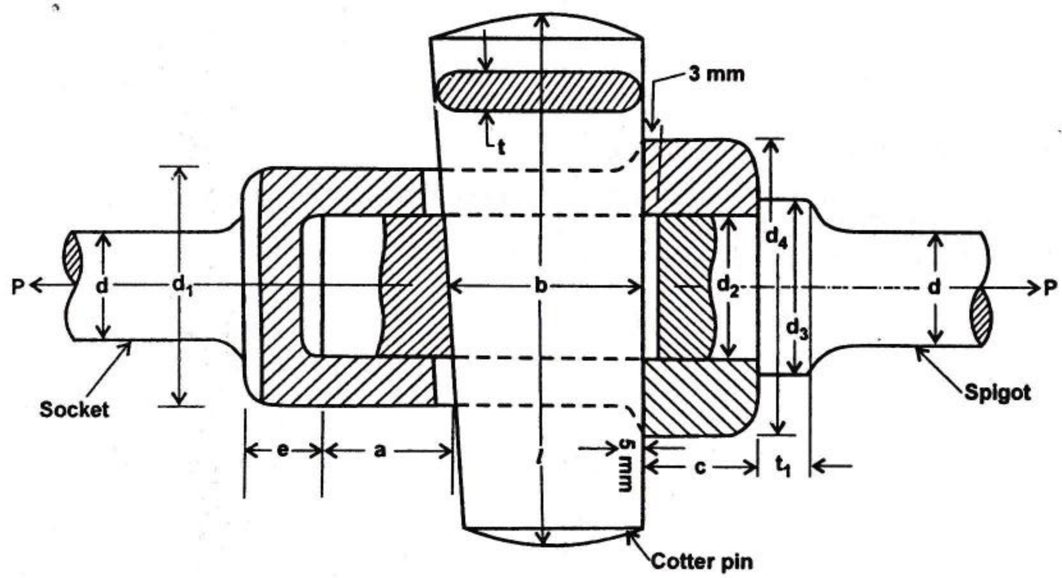
t_2 = Thickness of knuckle pin head and collar, mm

S_t = Permissible tensile stress, N/mm^2

S_s = Permissible shear stress, N/mm^2

S_c = Permissible crushing stress, N/mm^2

DESIGN PARTICULARS	EQUATIONS



Socket and Spigot Cotter Joint
Fig. 7.1

DESIGN PARTICULARS	EQUATIONS
Socket and Spigot Cotter Joint:	
Load capacity on the basis of	
(a) tensile strength of solid rod	$P = \frac{\pi}{4} d^2 S_t$ .... (7.1)

DESIGN PARTICULARS	EQUATIONS	
(b) tensile strength of spigot through cotter hole	$P = \left(\frac{\pi}{4} d_2^2 - d_2 t\right) S_t$	.... (7.2)
(c) crushing strength of spigot collar	$P = \frac{\pi}{4}\left(d_3^2 - d_2^2\right) S_c$	.... (7.3)
(d) shearing strength of spigot collar	$P = \pi d_2 t_1 S_s$	.... (7.4)
(e) shearing strength of spigot rod	$P = 2a\, d_2 S_s$	.... (7.5)
(f) tensile strength socket through cotter hole	$P = \left[\frac{\pi}{4}\left(d_1^2 - d_2^2\right) - \left(d_1 - d_2\right) t\right] S_t$	.... (7.6)
(g) crushing strength of socket collar	$P = \left(d_4 - d_2\right) t\, S_c$	.... (7.7)
(h) shearing strength of socket collar	$P = 2c\left(d_4 - d_2\right) S_s$	.... (7.8)
(i) shearing strength of cotter pin	$P = 2bt\, S_s$	.... (7.9)
(j) crushing strength of cotter pin	$P = d_2\, t\, S_c$	.... (7.10)
Usual proportions of 'Socket and spigot cotter joint'	$d_1 = 1.75$ d; $d_2 = 1.2$d; $d_3 = 1.5$ d; $d_4 = 2.5$ d; a = c = 0.75 d; b = 1.3d; l = 4d; t = 0.3 d; $t_1 = 0.45$ d; e = 1.2 d Taper of cotter = 1 in 25; Clearance = 3 to 5 mm.	
Sleeve and cotter joint:		
Usual proportions	$d_1 = 2.5$d; $d_2 = 1.25$d; t = 0.25 d_2 (or) 0.31 d; b = 1.25 d; l = 4d; a = c = 1.25d	

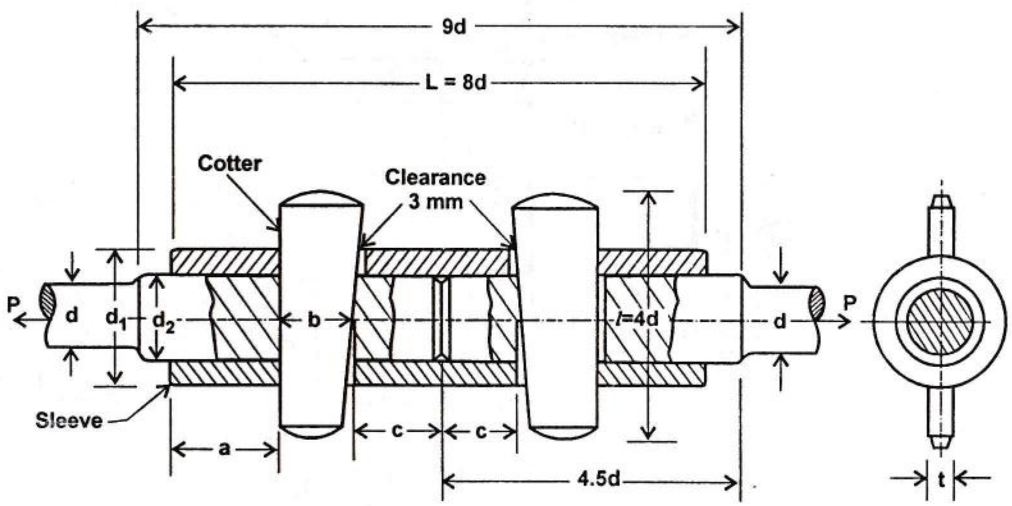


Fig. 7.2: Sleeve and Cotter Joint

DESIGN PARTICULARS	EQUATIONS	
Knuckle joint:		
Load capacity on the basis of		
(a) tensile strength of solid rod	$P = \frac{\pi}{4} d^2 S_t$	.... (7.11)
(b) shearing strength of knuckle pin	$P = 2 \times \frac{\pi}{4} d_1^2 S_s$	.... (7.12)
(c) tensile strength of single eye	$P = \left(d_2 - d_1 \right) t\, S_t$	.... (7.13)
(d) shearing strength of single eye	$P = \left(d_2 - d_1 \right) t\, S_s$	.... (7.14)
(e) crushing strength of single eye	$P = d_1\, t\, S_c$	.... (7.15)

DESIGN PARTICULARS	EQUATIONS
(f) tensile strength of double eye	$P = \left(d_2 - d_1\right) 2\, t_1\, S_t$ .... (7.16)
(g) shearing strength of double eye	$P = \left(d_2 - d_1\right) 2t_1\, S_s$ .... (7.17)
(h) crushing strength of double eye	$P = d_1\, 2t_1\, S_c$ .... (7.18)
Usual proportions for knuckle joint	$d_1 = d$; $d_2 = 2d$; $d_3 = 1.5\,d$; $t = 1.25\,d$; $t_1 = 0.75\,d$; $t_2 = 0.5\,d$

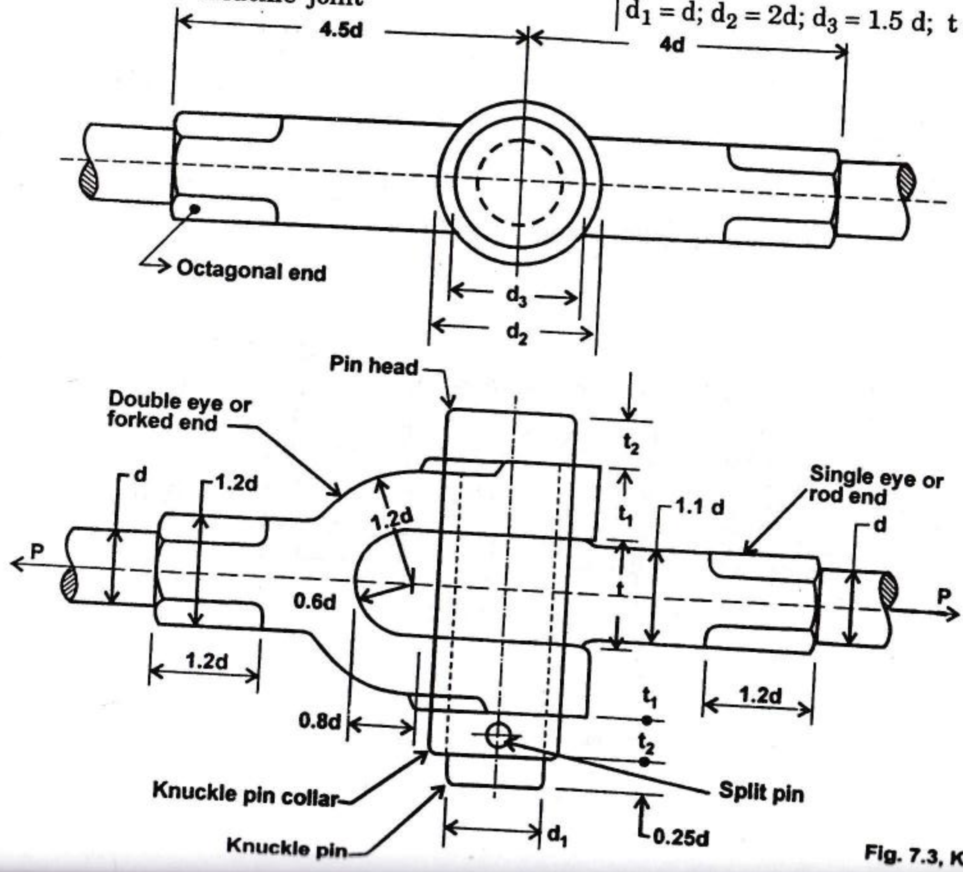


Fig. 7.3, Knuckle joint.

CHAPTER – 8

THREADED FASTENERS AND POWER SCREWS

9.8, 9.10
(T) 9.5(6)
9.6(6)

Symbols: (with S.I. Units)

For screw threads (Standard symbols)

D	–	Major diameter of internal thread, mm
d	–	Major diameter of external thread, mm
D_1	–	Minor diameter of internal thread, mm
d_3	–	Minor diameter of external thread, mm
D_2	–	Pitch diameter of internal thread, mm
d_2	–	Pitch diameter of external thread, mm
H	–	Height of fundamental triangle, mm
H_1	–	Maximum depth of engagement, mm
h_3	–	Basic depth of external thread, mm
L	–	Lead of thread, mm
M	–	Symbol of metric thread
n	–	Number of starts
p	–	Pitch of thread, mm
α	–	Thread angle i.e., helix angle, deg.

For Screw joints and turn-buckle:

a	–	Ratio of elasticity of connected parts
d	–	Nominal diameter of bolt or tie-rod, mm
d_c	–	Core diameter of bolt or tie-rod, mm
D	–	Tip diameter of coupler-nut, mm
D_c	–	Core diameter of coupler-nut, mm
D_0	–	Outer diameter of coupler-nut, mm
D_1	–	Inside diameter of coupler, mm
D_2	–	Outside diameter of coupler, mm
L	–	Length of coupler, mm
l	–	Length of coupler-nut, mm
n	–	Number of threads per unit length
p	–	Pitch of thread, mm.
P	–	Axial load (as specified), N
P_d	–	Design load, N
T	–	Twisting moment or torque, N-mm.
(S_{t1}), (S_{s1}), (S_{c1})	–	Design or permissible tensile stress, shear stress and crushing stress for tie-rod (or) bolt material, N/mm^2
S_{t1}, S_{s1}, S_{c1}	–	Induced stresses as mentioned above.
(S_{t2}), (S_{s2}), (S_{c2})	–	Design or permissible tensile stress, shear stress and crushing stress for coupler material, N/mm^2.
S_{t2}, S_{s2} , S_{c2}	–	Induced stresses as mentioned above

For Power-screws:

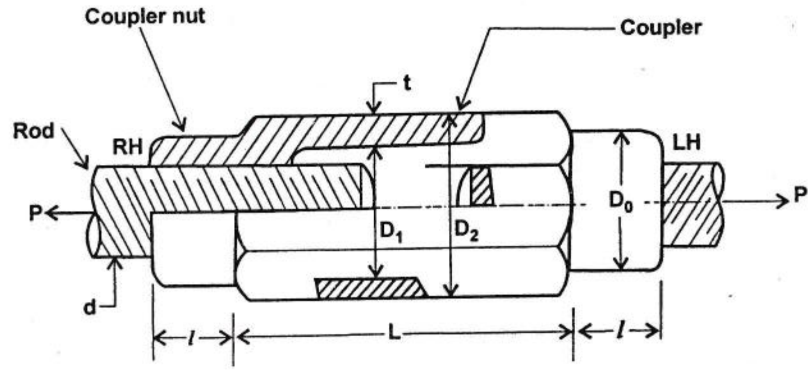
d	–	Pitch diameter of screw-rod, mm
d_c	–	Root diameter of screw-rod, mm
d_o	–	Tip diameter of screw-rod, mm
D_o	–	Major diameter of nut, mm
H	–	Height of the nut, mm
L	–	Equivalent length of screw-rod, mm
l	–	Actual length of screw-rod, mm
n	–	Number of threads in contact.
p	–	Pitch of thread of screw-rod, mm
P_b	–	Bearing pressure induced in the threads, N/mm^2
L'	–	Lead of thread of screw-rod, mm
R_1	–	Outside diameter of collar, mm.
R_2	–	Inside diameter of collar, mm.
S	–	Lead of the nut threads, mm
t_e	–	Depth of thread engagement, mm
S_a	–	Axial stress (Tensile or compressive), N/mm^2
S_c	–	Compressive stress, N/mm^2
S_s	–	Torsional shear stress of screw-rod, N/mm^2
S_{p1}	–	Maximum principal stress, N/mm^2
S_{sm}	–	Maximum shear stress, N/mm^2
T	–	Torque required to raise or lower the load, N-mm
t	–	Thickness of each thread, mm
τ_s	–	Direct shear stress of screw-rod threads, N/mm^2
τ_n	–	Direct shear stress of nut threads, N/mm^2
Z	–	Number of starts
ψ	–	Nut height factor.
η	–	efficiency of power-screw.
α	–	Lead angle
ϕ	–	Friction angle
μ	–	Coefficient of friction for the screw-rod.
μ_c	–	Coefficient of friction for the collar.

DESIGN PARTICULARS	EQUATIONS
Fluid tight joint:	
Resultant load induced in fluid tight joint(F_r)	$P_r = P_1 + \left[\frac{a}{1+a}\right] P_2 = P_1 + K P_2$ .... (8.1) For K values refer table (8.2)
Initial tension due to tight-screwing(F_i)	$P_1 = 2840d$; P_2 = Externally applied load. .... (8.2)
Core diameter of the bolt(d_c)	$d_c = \sqrt{\frac{4 P_r}{\pi (S_t) n}}$; n = Number of bolts .... (8.3)
Relation between the torque applied to the nut and axial tension in the bolt	$T = CP_1 d$ .... (8.4) where C = constant For unplated steel bolts with turned threads C = 0.10 for well lubricated, smooth surface. = 0.12 for unlubricated, smooth surface = 0.13 to 0.15 for well lubricated, unsmooth surface = 0.18 to 0.20 for unlubricated, unsmooth surface.

DESIGN PARTICULARS	EQUATIONS
Adjustable screw-joint (or) Turn-buckle:	

DESIGN PARTICULARS	EQUATIONS

Adjustable screw-joint (or) Turn-buckle:



Adjustable screw joint (Turn buckle)

Fig. 8.1

Nominal diameter of tie-rod	$d = 1.2\,d_c = 1.2 \times \sqrt{\dfrac{4\,P_d}{\pi\,(S_{t1})}}\ ;\ P_d = 1.3\,P$	.... (8.5)
Outer diameter of coupler nut	$D_0 = \sqrt{\dfrac{4\,P_d}{\pi\,(S_{t2})} + D_c^2}\ ;\qquad D_c = d$	.... (8.6)

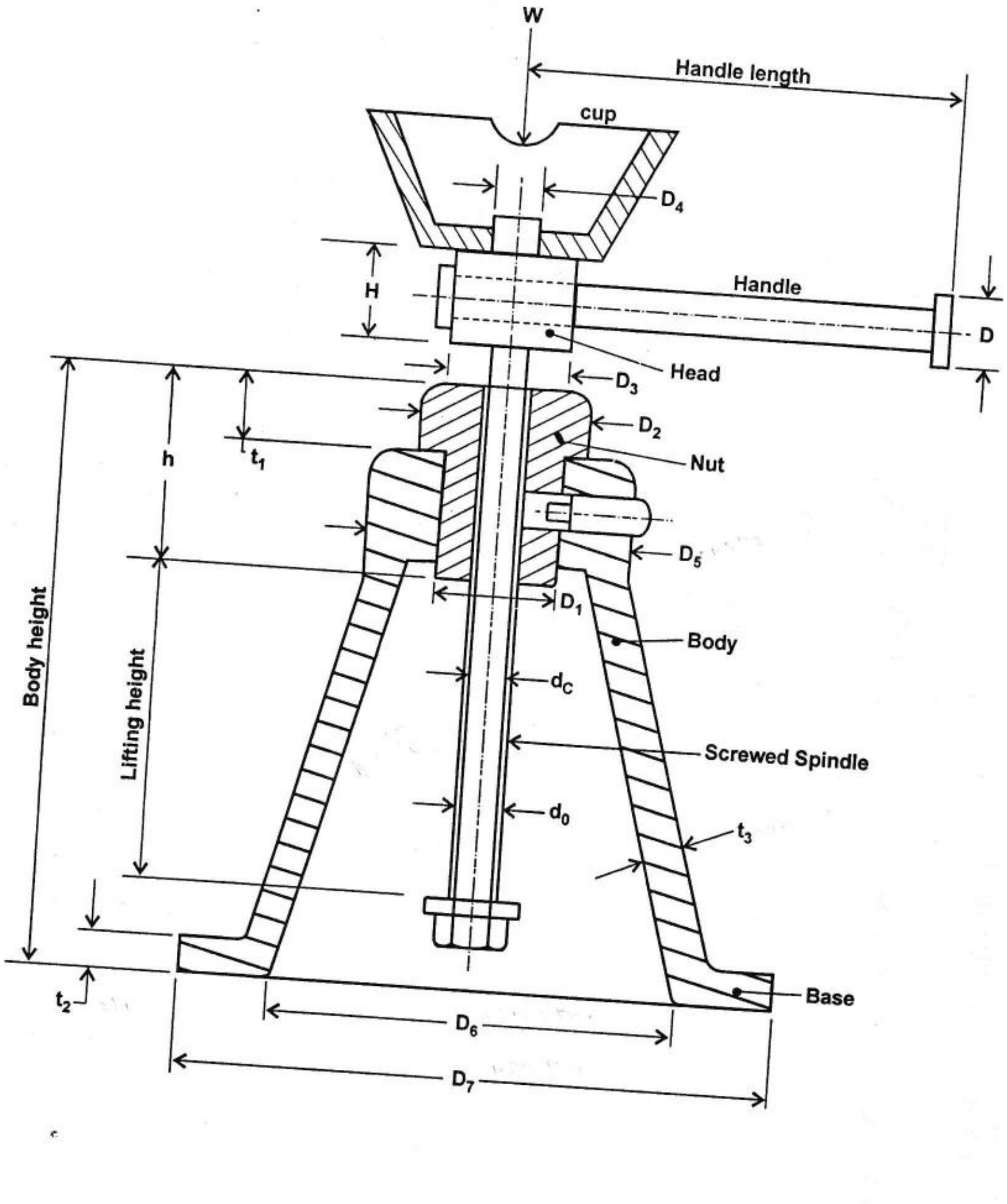
DESIGN PARTICULARS	EQUATIONS	
Length of coupler-nut (l)	$l = \dfrac{P_d}{\pi D_c S_{s2}} = \dfrac{P_d}{\pi d_c S_{s1}}$	.... (8.7)
	(Select higher value of l)	
Crushing strength of the threads of tie-rod and coupler-nut	$\dfrac{\pi}{4}\left(d^2 - d_c^2\right) n\, l\, S_{c1} = \dfrac{\pi}{4}\left(D_c^2 - D^2\right) n l\, S_{c2} = P_d$	.... (8.8)
	$n = \dfrac{1}{p}$	
Inner diameter of coupler (D_1)	$D_1 = d + c;$ $c = \text{clearance}$	
	$= 6 \text{ mm to } 0.25 \text{ d}$	.... (8.9)
Outer diameter of coupler (D_2)	$D_2 = \sqrt{\dfrac{4 P}{\pi (S_{t2})} + D_1^2}$	.... (8.10)
Length of coupler	$L = 6d$	.... (8.11)
Usual proportions of turn-buckle (For the same material of tie-rod and coupler)	$D_0 = 1.25 \text{ d to } 1.5 \text{ d}$	
	$l = d \text{ to } 1.25 \text{ d}$	

DESIGN PARTICULARS	EQUATIONS
(i.e., For $S_{t1} = S_{t2}$; $S_{s1} = S_{s2}$; $S_{c1} = S_{c2}$)	$D_1 = d + (6 \text{ mm to } 0.25 \text{ d})$

DESIGN PARTICULARS	EQUATIONS
(i.e., For $S_{t1} = S_{t2}$; $S_{s1} = S_{s2}$; $S_{c1} = S_{c2}$)	$D_1 = d + (6 \text{ mm to } 0.25\ d)$
	$D_2 = 1.5\ d \text{ to } 1.75\ d$
	$L = 6d \text{ to } 8d$
Power-screws:	
Torque required to raise the load	$T_r = \frac{Wd}{2} \tan(\alpha + \phi)$ .... (8.12)
Torque required to lower the load	$T_l = \frac{Wd}{2} \tan(\phi - \alpha)$ .... (8.13)
	$\alpha = \tan^{-1} \frac{L'}{\pi d}$; $L' = \text{Lead}$
	$\phi = \tan^{-1} \mu$
Efficiency of the power-screw	$\eta = \frac{\tan \alpha}{\tan(\alpha + \phi)}$ .... (8.14)
Axial compressive stress for short screw-rod	$S_a = \frac{4W}{\pi d_c^2}$ .... (8.15)
Axial compressive stress for long screw-rod	$S_a = \frac{4W\left[1 + a\left(\frac{L}{K}\right)^2\right]}{\pi d_c^2}$; a = Rankine's constant $= \frac{1}{7500}$ for steel .... (8.16)

DESIGN PARTICULARS	EQUATIONS
Buckling or Crippling load	$F_{cr} = \dfrac{\pi\, d_c^2 \cdot S_c}{4\left[1 + a\left(\dfrac{L}{K}\right)^2\right]}$ .... (8.17) $L = l$ for both ends hinged $L = l/2$ for both ends fixed $L = l/\sqrt{2}$ for one end fixed and other end hinged $L = 2\,l$ for one end fixed and other end free.
Torsional shear stress in the screw-rod	$S_s = \dfrac{16\, T_r}{\pi\, d_c^3}$ .... (8.18)
Maximum principal stress in the screw-rod	$S_{p1} = \dfrac{1}{2}\left[S_a + \sqrt{S_a^2 + 4S_s^2}\right]$ .... (8.19)
Maximum shear stress in the screw-rod	$S_{sm} = \dfrac{1}{2}\sqrt{S_a^2 + 4S_s^2}$ .... (8.20)
Bearing pressure in the threads of screw-rod (or) nut	$P_b = \dfrac{W}{n\,\pi\, dt}$ .... (8.21)
Direct shear stress in the threads of screw-rod	$\tau_s = \dfrac{W}{n\,\pi\, d_c\, t}$ .... (8.22)
Direct shear stress in the threads of nut	$\tau_n = \dfrac{W}{n\,\pi\, D_0\, t}$ .... (8.23)

DESIGN PARTICULARS	EQUATIONS
Direct shear stress in the threads of nut	$\tau_n = \frac{W}{n \pi D_0 t}$ .... (8.23)
Pitch circle diameter of nut or screw-rod	$d = \sqrt{\frac{2W}{\pi \psi [P_b]}}$ .... (8.24) $[P_b]$ – Permissible bearing pressure. $\psi = \frac{H}{d}$ $= 1.2$ to 2.5 for solid nuts $= 2.5$ to 3.5 for split nuts.
Torque required to overcome the collar friction	$T = \frac{2}{3} \mu_c W \left[\frac{R_1^3 - R_2^3}{R_1^2 - R_2^2} \right]$ for uniform pressure condition .... (8.25) (or) $T = \mu_c W \left(\frac{R_1 + R_2}{2} \right)$ for uniform wear condition .... (8.26) μ_c – Coefficient of friction for the collar.



Screw Jack (Power screw)
Fig. 8.2

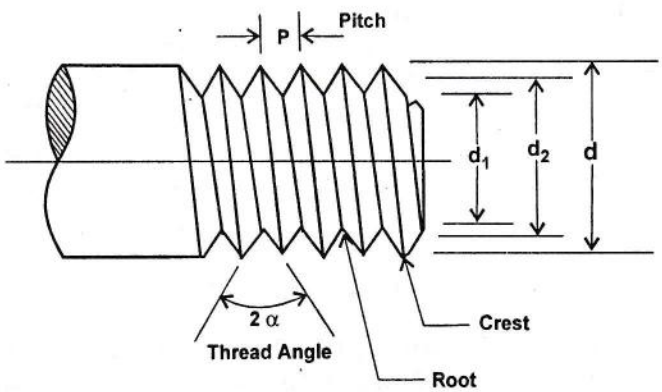


Fig. 8.3

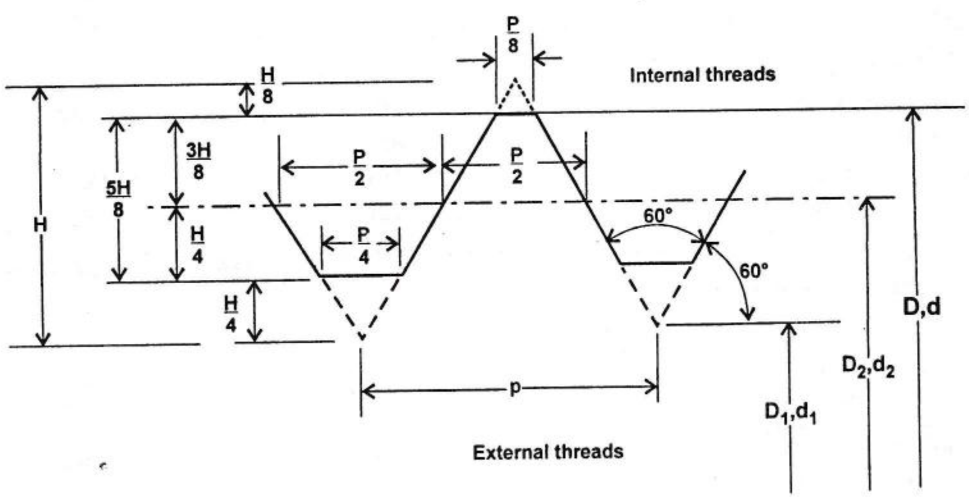


Fig. 8.4

Terminology of screw threads

Table 8.1(a): Properties of Some Bolt Materials

Material	Ultimate strength N/mm^2	Yield point N/mm^2	Elastic limit N/mm^2	Endurance limit N/mm^2
Low carbon steel	440	280	225	250
Medium carbon steel	480	316	288	240
Ni-steel	865	714	652	343
Ni-Cr steel	1030	960	652	550
Cr-Va steel	1565	1440	1170	550

Table 8.1(b): Strength of Screw Fasteners (Properties of ASTM and SAE Grades of Steel Bolts)

Material and Heat Treatment, Size	Minimum Tensile Strength, MPa	Yield Strength / Proof Stress, MPa
Low carbon commercial bolts (0.1 to 0.2% C)	380	250
Low carbon cold headed Stress-relieved		
12 mm and under	475	380
12 mm to 18 mm	440	360
Medium carbon (0.3 to 0.4% C) (0.28 to 0.55% C, 0.04% max. P, 0.05% max. S) quenched and tempered		
12 mm and under	860	620
12 mm to 18 mm	830	585
18 mm to 24 mm	760	535
24 mm to 36 mm	725	510
Medium carbon, (0.28 to 0.55% C, 0.04% max. P, 0.05% max. S) fine grain alloy, quenched and tempered		
12 mm and under	1035	830
12 mm to 24 mm	965	760
24 mm to 36 mm	860	650
Special medium carbon oil quenched and tempered up to 16 mm	965	760
Stainless steel	620 to 850	240 to 800
Brass	340 to 480	205 to 275

Table 8.2

	Type of joint	K = a/(1 + a)
1.	Metal to metal joint with through bolts	0.00 to 0.10
2.	Hard copper gasket with long through bolts	0.25 to 0.50
3.	Soft copper gasket with long through bolts	0.50 to 0.75
4.	Soft packing with through bolts	0.75 to 1.00
5.	Soft packing with studs	1.00

Table 8.3: Working Stress and Load for Indian Metric Coarse Thread

Major Dia, (mm)	Stress Area A_r, mm^2	Design stress, MN/m^2 (kgf/mm^2)	Permissible Load, N (kgf)
16	157	19.0 (1.93)	2970 (303)
20	245	23.0 (2.33)	5590 (570)
24	353	27.2 (2.77)	9590 (978)
30	561	32.2 (3.28)	18040 (1840)
36	817	37.8 (3.85)	30890 (3150)
42	1120	43.2 (4.40)	48350 (4930)
48	1472	48.4 (4.93)	71100 (7250)
56	2030	55.2 (5.63)	111800 (11400)

Table 8.4: Safe Bearing Pressures in Power Screws

Service	Material		Safe Bearing Pressure MN/m^2 (kgf/mm^2)	Remarks
	Screw	Nut		
Hand Press	Steel	Bronze	17.2 to 24.0 (1.75 to 2.45)	Low speed, well lubricated
Jack Screw	Steel	C.I.	12.4 to 17.2 (1.26 to 1.75)	Low speed, not over 0.04 m/s
Jack Screw	Steel	Bronze	11.0 to 17.2 (1.12 to 1.75)	Low speed, not over 0.05 m/s
Hoisting Screw	Steel	C.I.	4.1 to 7.0 (0.42 to 0.70)	Medium speed, (0.1 to 0.2) m/s
Hoisting Screw	Steel	Bronze	5.5 to 9.6 (0.56 to 0.98)	Medium speed (0.1 to 0.2) m/s
Lead Screw	Steel	Bronze	1.0 to 1.6 (0.105 to 0.168)	High speed 0.25 m/s and over

Table 8.5: Coefficient of Friction for Power Screws*

Lubricant	Coefficient of friction (f)
Machine oil and graphite	0.17
Lard oil	0.11
Heavy machine oil	0.14

Table 8.6: Coefficient of Friction on Thrust Collar

Material	Coefficient of running friction	Coefficient of starting friction
Soft steel on cast iron	0.121	0.170
Hardened steel on C.I.	0.092	0.147
Soft steel on bronze	0.084	0.101
Hardened steel on bronze	0.063	0.081

Reference: 'Design of Machine Members,' by A. Vallance & V.L. Doughtie.

Table 8.7: Basic Dimensions for Design Profiles of ISO Metric Screw Threads

Basic Diameter mm	Pitch mm	Major Diameter mm	Pitch Diameter mm	Minor Diameter, mm		Lead Angle at Basic Pitch dia		Tensile Stress Area mm^2
				External Threads	Internal Threads	Deg	min	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	0.25	1.0	0.837620	0.693283	0.729367	5	27	0.46
1	0.2	1.0	0.870096	0.756426	0.783494	4	11	0.53
	0.25	1.1	0.937620	0.793283	0.829367	4	52	0.59
1.1	0.2	1.1	0.970096	0.854626	0.883494	3	45	0.67
	0.25	1.2	1.037630	0.893283	0.929367	4	24	0.73
1.2	0.2	1.2	1.070096	0.954626	0.983494	3	24	0.82

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	0.3	1.4	1.205144	1.031939	1.075240	4	34	0.98
1.4	0.2	1.4	1.270096	1.154626	1.183494	2	52	1.17
1.6	0.35	1.6	1.372668	1.170596	1.221114	4	38	1.27
	0.2	1.6	1.470096	1.354626	1.383494	2	29	1.59
	0.35	1.8	1.572668	1.370596	1.421114	4	3	1.70
1.8	0.2	1.8	1.670096	1.554626	1.583494	2	11	2.66
	0.4	2.0	1.740192	1.509252	1.566987	4	11	2.07
2	0.25	2.0	1.837620	1.693283	1.729367	2	29	2.45
2.2	0.45	2.2	1.907716	1.647909	1.712861	4	17	2.48
	0.25	2.2	2.037620	1.893283	1.929367	2	14	3.03
	0.45	2.5	2.207716	1.947909	2.012861	3	43	3.39
2.5	0.35	2.5	2.272668	2.070596	2.121114	2	20	3.70
	0.5	3.0	2.675240	2.386565	2.458734	3	24	5.03
3	0.35	3.0	2.272668	2.570596	2.621114	2	18	5.61
	0.6	3.5	3.110289	2.763878	2.850481	3	31	6.78
3.5	0.35	3.5	3.272668	3.070596	3.121114	1	57	7.90
	0.7	4.0	3.545337	3.141191	3.242228	3	36	8.78
4	0.5	4.0	3.675240	3.386565	3.458734	2	29	9.79
	0.75	4.5	4.012861	3.579848	3.688101	3	24	11.3
4.5	0.5	4.5	4.175240	3.886565	3.958734	2	11	12.8
	0.8	5.0	4.480385	4.018505	4.133975	3	15	14.2
5	0.5	5.0	4.675240	4.386565	4.458734	1	57	16.1
	1	6.0	5.350481	4.773131	4.917468	3	24	20.1
6	0.75	6.0	5.512861	5.079848	5.188101	2	29	22.0
	1	7.0	6.350481	5.773131	5.917468	2	52	28.9
7	0.75	7.0	6.512861	6.079849	6.188101	2	6	31.3

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	1.25	8.0	7.188101	6.466413	6.646835	3	10	36.6
8	1	8.0	7.350481	6.773131	6.917468	2	29	39.2
	0.75	8.0	7.512861	7.079848	7.188101	1	49	41.8
	1.5	10.0	9.025721	8.159696	8.376202	3	2	58.0
10	1.25	10.0	9.188101	8.466413	8.646835	2	29	61.2
	1	10.0	9.350481	8.773131	8.917468	1	57	64.5
	0.75	10.0	9.512861	9.079848	9.188101	1	26	67.9
	1.75	12.0	10.863342	9.852979	10.105569	2	56	84.3
	1.5	12.0	11.025721	10.159696	10.376202	2	29	88.1
12	1.25	12.0	11.188101	10.466413	10.646835	2	2	92.1
	1	12.0	11.350481	10.773131	10.917468	1	36	96.1
	2	14.0	12.700962	11.546261	11.834936	2	52	115
	1.5	14.0	13.025721	12.159696	12.376202	2	6	125
14	1.25	14.0	13.188101	12.466413	12.646835	1	44	129
	1	14.0	13.350481	12.773131	12.917468	1	22	134
	2	16.0	14.700962	13.546261	13.834936	2	29	157
16	1.5	16.0	15.025721	14.159696	14.376202	1	49	167
	1	16.0	15.350481	14.773131	14.917468	1	11	178
	2.5	18.0	16.376202	14.932827	15.293671	2	47	192
	2	18.0	16.700962	15.546261	15.834936	2	11	204
18	1.5	18.0	17.025721	16.159696	16.376202	1	36	216
	1	18.0	17.350481	16.773131	16.917468	1	3	229
	2.5	20.0	18.376202	16.932827	17.293671	2	29	245
	2.0	20.0	18.700962	17.546261	17.834936	1	57	258
20	1.5	20.0	19.025721	18.159696	18.376202	1	26	272
	1	20.0	19.350481	18.773131	18.917468	0	57	285

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	2.5	22.0	20.376202	18.932827	19.293671	2	14	303
	2	22.0	20.700962	19.546261	19.834936	1	46	318
22	1.5	22.0	21.025721	20.159696	20.376202	1	18	333
	1	22.0	21.350481	20.773131	20.917468	0	51	348
	3	24.0	22.051443	20.319392	20.752405	2	49	353
	2	24.0	22.700962	21.546261	21.834936	1	39	384
24	1.5	24.0	23.025721	22.159696	22.376202	1	11	401
	1	24.0	23.350481	22.773131	22.917468	0	47	418
25	3	25.0	23.051443	21.319392	21.752405	2	36	385
	3	27.0	25.051443	23.319392	23.752405	2	11	459
	2	27.0	25.700962	24.546261	24.834936	1	25	496
27	1.5	27.0	26.025721	25.159696	25.376202	1	3	514
	1	27.0	26.350481	25.773131	25.917468	0	41	553
	3.5	30.0	27.726683	25.705957	26.211139	2	18	561
	3	30.0	28.051443	26.319392	26.752405	1	57	581
30	2	30.0	28.700962	27.546261	27.834936	1	16	621
	1.5	30.0	29.025721	28.159696	28.376202	0	57	642
	1	30.0	29.350481	28.773131	28.917468	0	37	663
	3.5	33.0	30.726683	28.705957	29.211139	2	5	694
	3	33.0	31.051443	29.319392	29.752405	1	46	716
33	2	33.0	31.700962	30.546261	30.834936	1	9	761
	1.5	33.0	32.025721	31.159696	31.376202	0	51	785
35	1.5	35.0	34.025721	33.159696	33.376202	0	48	886
	4	36.0	33.401924	31.092523	31.669873	2	11	817
	3	36.0	34.051443	32.319392	32.752405	1	36	865
36	2	36.0	34.700962	33.546261	33.834936	1	3	915
	1.5	36.0	35.025721	34.159696	34.376202	0	47	940

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	4	39.0	36.401924	34.092523	34.669873	2	0	976
	3	39.0	37.051443	35.319392	35.752405	1	29	1030
39	2	39.0	37.700962	36.546261	36.834936	0	58	1080
	1.5	39.0	38.025721	37.159696	37.376202	0	43	1110
	4.5	42.0	39.077164	36.479088	37.128607	2	6	1120
	4	42.0	39.401924	37.092523	37.669873	1	51	1150
42	3	42.0	40.051443	38.319392	38.752405	1	22	1210
	2	42.0	40.700962	39.546261	39.834936	0	52	1260
	1.5	42.0	41.025721	40.159696	40.376202	0	40	1290
	4.5	45.0	42.077164	39.479088	40.128607	1	57	1300
	4	45.0	42.401924	40.092523	40.669873	1	43	1340
45	3	45.0	43.051443	41.319392	41.752405	1	16	1400
	2	45.0	43.700962	42.546261	42.834936	0	50	1460
	1.5	45.0	44.025721	43.159696	43.376202	0	37	1490
	5	48.0	44.752405	41.865653	42.587341	2	2	1470
	4	48.0	45.401924	43.092523	43.569873	1	36	1540
48	3	48.0	46.051443	44.319392	44.752405	1	11	1600
	2	48.0	46.700962	45.546261	45.834936	0	47	1670
	1.5	48.0	47.025721	46.159696	46.376202	0	35	1710
	5	52.0	48.752405	45.865653	46.587341	1	52	1760
	4	52.0	49.401924	47.092523	47.669873	1	29	1830
52	3	52.0	50.051443	48.319392	48.752405	1	6	1900
	2	52.0	50.700962	49.546261	49.834936	0	43	1970
	1.5	52.0	51.025721	50.159696	50.376202	0	32	2010

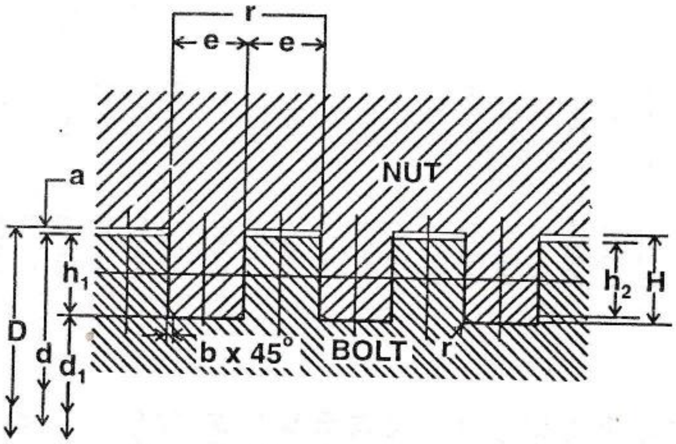
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	5.5	56.0	52.427645	49.252219	50.046075	1	55	2030
	4	56.0	53.401924	51.092523	51.669873	1	22	2140
56	3	56.0	54.051443	52.319392	52.752405	1	1	2220
	2	56.0	54.700962	53.546261	53.834936	0	40	2300
	1.5	56.0	55.025721	54.159696	54.376202	0	30	2340
	5.5	60.0	56.427645	53.252219	54.046075	1	47	2360
	4	60.0	57.401924	55.092523	55.669873	1	16	2490
60	3	60.0	58.051443	56.319392	56.752405	0	57	2570
	2	60.0	58.700962	57.546261	57.834936	0	37	2650
	1.5	60.0	59.025721	58.159696	58.376202	0	28	2700
	6	64.0	60.102886	56.638784	57.504809	1	49	2680
	4	64.0	61.401924	59.092523	59.669873	1	11	2850
64	3	64.0	62.051443	60.319392	60.752405	0	53	2940
	2	64.0	62.700962	61.546261	61.834936	0	35	3030
	1.5	64.0	63.025721	62.159696	62.376202	0	26	3080
	6	68.0	64.102886	60638784	61.504809	1	42	3060
	4	68.0	65.401924	63.092523	63.669873	1	7	3240
68	3	68.0	66.051443	64.319392	64.752405	1	50	3340
	2	68.0	66.700962	65.546261	65.834936	1	33	3430
	1.5	68.0	67.025721	66.159696	66.376202	0	24	3480
	6	72.0	68.102886	64.638784	65.504809	1	36	3460
	4	72.0	69.401924	67.092523	67.669873	1	3	3660
72	3	72.0	70.051443	68.319392	68.752405	0	47	3760
	2	72.0	70.700962	69.546261	69.834936	0	31	3860
	1.5	72.0	71.025721	70.159696	70.376202	0	23	3910

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	6	76.0	72.102886	68.638784	69.504809	1	31	3890
	4	76.0	73.401924	71.092523	71.669873	1	0	4100
76	3	76.0	74.051443	72.319392	72.752405	0	44	4210
	2	76.0	74.700962	73.546261	73.834936	0	29	4320
	1.5	76.0	75.025721	74.159696	74.376202	0	22	4370
	6	80.0	76.102886	72.638784	73.504809	1	26	4340
	4	80.0	77.401924	75.092523	75.669873	0	57	4570
80	3	80.0	78.051443	76.319392	76.752405	0	42	4680
	2	80.0	78.700962	77.546261	77.834936	0	28	4790
	1.5	80.0	79.025721	78.159696	78.376202	0	21	4850
	6	85.0	81.102886	77.638784	78.504809	1	21	4950
	4	85.0	82.401924	80.092523	80.669873	0	53	5190
85	3	85.0	83.051443	81.319392	81.752405	0	50	5310
	2	85.0	83.700962	82.546261	82.834936	0	26	5430
	6	90.0	86.102886	82.638784	83.504809	1	16	5590
	4	90.0	87.401924	85.092523	85.669873	0	50	5840
90	3	90.0	88.051443	86.319392	86.752405	0	37	5970
	2	90.0	88.700962	87.546261	87.834936	0	25	6100
	6	95.0	91.102886	87.638784	88.504809	1	12	6270
	4	95.0	92.401924	90.092523	90.669875	0	47	6540
95	3	95.0	93.051443	91.319392	91.752405	0	35	6670
	2	95.0	93.700962	92.546261	92.834936	0	23	6810
	6	100.0	96.102886	92.638784	93.504809	1	8	7000
	4	100.0	97.401924	95.092523	95.669873	0	45	7280
100	3	100.0	98.051443	96.319392	96.752405	0	33	7420
	2	100.0	98.700962	97.346261	97.834936	0	22	7560

Table: 8.8: Coarse and Fine Threads

Series	Size	Pitch P	Major Diameter $d = D$	Pitch Diameter $d_2 = D_2$	Minor Diameter Bolt, d_3	Minor Diameter Nut, D_1	Depth of Thread h	Max. Depth of Engagement, H	Stress Area S mm^2
Coarse Series	M 2.5	0.45	2.5	2.208	1.948	2.013	0.276	0.244	3.39
	M 3	0.5	3	2.675	2.387	2.459	0.307	0.271	5.03
	M 4	0.7	4	3.545	3.141	3.242	0.429	0.379	8.78
	M 5	0.8	5	4.480	4.019	4.134	0.491	0.433	14.2
	M 6	1	6	5.350	4.773	4.918	0.613	0.541	20.1
	M 8	1.25	8	7.188	6.466	6.647	0.767	0.677	36.6
	M 10	1.5	10	9.026	8.160	8.376	0.920	0.812	58.0
	M 12	1.75	12	10.863	9.853	10.106	1.074	0.947	84.3
	M 16	2	16	14.701	13.546	13.835	1.227	1.083	157
	M 20	2.5	20	18.376	16.933	17.294	1.534	1.353	245
	M 24	3	24	22.051	20.320	20.752	1.840	1.624	353
	M 30	3.5	30	27.727	25.706	26.211	2.147	1.894	561
	M 33	3.5	33	30.727	28.706	29.211	2.147	1.894	694
	M 36	4	36	33.402	31.093	31.67	2.454	2.165	817
Fine Series	M 8 × 1	1	8	7.350	6.773	6.918	0.613	0.541	39.2
	M 10 × 1.25	1.25	10	9.188	8.466	8.647	0.767	0.677	61.2
	M 12 × 1.25	1.25	12	11.188	10.466	10.647	0.767	0.677	92.1
	M 16 × 1.5	1.5	16	15.026	14.16	14.376	0.920	0.812	167
	M 20 × 1.5	1.5	20	19.026	18.16	18.376	0.920	0.812	272
	M 24 × 2	2	24	22.701	21.546	21.835	1.227	1.083	384
	M 30 × 2	2	30	28.701	27.546	27.835	1.227	1.083	621
	M 36 × 3	3	36	34.051	32.32	35.752	1.840	1.624	865

Stress area $\frac{\pi}{4}\left(\frac{d_2 + d_1}{2}\right)^2$



Basic profile of square threads

$h_1 = 0.5\ p$ $\quad H = 0.5\ p + a$ $\quad h_2 = 0.5\ p - b$ $\quad e = 0.5\ p$ $\quad D = d + 2a$

$d_1 = d - 2h_1$ $\quad$ Area of core $= \frac{\pi}{4} d_1^2$

Table 8.9: Basic Dimensions for Square Threads – Fine Series (All dimensions in millimetres)

Nom. Dia.	Major Dia Bolt d	Major Dia Nut D	Minor Dia. d_1	Pitch p	e	r	h_2	b	h_1	a	H	Area of Core, mm^2
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
10	10	10.5	8									50.3
12	12	12.5	10									78.5
14	14	14.5	12	2	1	0.12	0.75	0.25	1	0.25	0.25	113
16	16	16.5	14									154
18	18	18.5	16									201
20	20	20.5	18									254
22	22	22.5	19									284
24	24	24.5	21									346
26	26	26.5	23									415
28	28	28.5	25									491
30	30	30.5	27									573

THREADED F

(1)	(2)
32	32
(34)	34
36	36
(38)	38
40	40
42	42
44	44
(46)	46
48	48
50	50
52	52
55	55
(58)	58
60	60
(62)	62
65	65
(68)	68
70	70
(72)	72
75	75
(78)	78
80	80
(82)	82
85	85
(88)	88
90	90
(92)	92
95	95
(98)	98
100	10
(105)	10
110	11

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
32	32	32.5	29									661
(34)	34	34.5	31									755
36	36	36.5	33	3	1.5	0.12	1.25	0.25	1.5	0.25	1.75	855
(38)	38	38.5	35									962
40	40	40.5	37									1075
42	42	42.5	39									1195
44	44	44.5	41									1320
(46)	46	46.5	43									1452
48	48	48.5	45									1590
50	50	50.5	47									1735
52	52	52.5	49									1886
55	55	55.5	52									2124
(58)	58	58.5	55	3	1.5	0.12	1.25	0.25	1.5	0.25	1.75	2376
60	60	60.5	57									2552
(62)	62	62.5	59									2734
65	65	65.5	61									2922
(68)	68	68.5	64									3217
70	70	70.5	66	4	2	0.12	1.75	0.25	2	0.25	2.25	3421
(72)	72	72.5	68									3632
75	75	75.5	71									3959
(78)	78	78.5	74									4301
80	80	80.5	76									4538
(82)	82	82.5	78	4	2	0.12	1.75	0.25	2	0.25	2.25	4778
85	85	85.5	81									5153
(88)	88	88.5	84									5542
90	90	90.5	86									5809
(92)	92	92.5	88									6082
95	95	95.5	91									6504
(98)	98	98.5	94	4	2	0.12	1.75	0.25	2	0.25	2.25	6940
100	100	100.5	96									7288
(105)	105	105.5	101									8018
110	110	110.5	106									8825

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(115)	115	115.5	109									9331
120	120	120.5	114									10207
(125)	125	125.5	119	6	3	0.25	2.5	0.5	3	0.25	3.25	11122
130	130	130.5	124									12076
(135)	135	135.5	129									13070
140	140	140.5	135									14103
(145)	145	145.5	139									15175
150	150	150.5	144									16286
(155)	155	155.5	149									17437
160	160	160.5	154	6	3	0.25	2.5	0.5	3	0.25	3.25	18627
(165)	165	165.5	159									19856
170	170	170.5	164									21124
(175)	175	175.5	169									22432
180	180	180.5	172									23235
(185)	185	185.5	177									24606
190	190	190.5	182	8	4	0.25	3.5	0.5	4	0.25	4.25	26016
(195)	195	195.5	187									27465
200	200	200.5	192									28953
210	210	210.5	202									32047
220	220	220.5	212	8	4	0.25	3.5	0.5	4	0.25	4.25	35299
230	230	230.5	222									38708
240	240	240.5	232									42272
250	250	250.5	238									44488
260	260	260.5	248									48305
270	270	270.5	258									52279
280	280	280.5	268									56410
290	290	290.5	278									60699
300	300	300.5	288	12	6	0.25	5.5	0.5	6	0.25	6.25	65144
320	320	320.5	308									74506
340	340	340.5	328									84496
360	360	360.5	348									95115
380	380	380.5	368									106362
400	400	400.5	388									118237

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
420	420	421	402									126923
440	440	441	422									139867
460	460	461	442	18	9	0.5	8	1	1	0.5	9.5	153439
480	480	481	462									167639
500	500	501	482									182467
520	520	521	496									193221
540	540	541	516									209117
560	560	561	536									225642
580	580	581	556	24	12	0.5	11	1	12	0.5	12.5	242795
600	600	601	576									260576
620	620	621	596									278986
640	640	641	616									298024

Note: Diameters indicated within brackets are of second preference. IS : 4694-1968

Table 8.10: Basic Dimensions for Square Threads – Normal Series (All dimensions in millimeters)

Nom. Dia.	Major Dia Bolt d	Major Dia Nut D	Minor Dia. d_1	Pitch p	e	r	h_2	b	h_1	a	H	Area of Core, mm^2
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
22	22	22.5	17									227
24	24	24.5	19	5	2.5	0.25	2	0.5	2.5	0.25	2.75	284
26	26	26.5	21									346
28	28	28.5	23									415
30	30	30.5	24									452
32	32	32.5	26	6	3	0.25	2.5	0.5	3	0.25	3.25	531
(34)	34	34.5	28									616
36	36	36.5	30									707
(38)	38	38.5	31									755
40	40	40.5	33	7	3.5	0.25	3	0.5	3.5	0.25	3.75	855
(42)	42	42.5	35									962
44	44	44.5	37									1075

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(46)	46	46.5	38									1134
48	48	48.5	40	8	4	0.25	3.5	0.5	4	0.25	4.25	1257
50	50	50.5	42									1385
52	52	52.4	44									1521
55	55	55.5	46									1662
(58)	58	58.5	49	9	4.5	0.25	4	0.5	4.5	0.25	4.75	1886
60	60	60.5	51									2043
(62)	62	62.5	53									2206
65	65	65.5	55									2376
(68)	68	68.5	58									2642
70	70	70.5	60									2827
(72)	72	72.5	62	10	5	0.25	4.5	0.5	5	0.25	5.25	3019
75	75	75.5	65									3318
(78)	78	78.5	68									3632
80	80	80.5	70									3848
(82)	82	82.5	72									4072
85	85	85.5	73									4185
(88)	88	88.5	76									5436
90	90	90.5	78									4778
(92)	92	92.5	80									5027
95	95	95.5	83	12	6	0.25	5.5	0.5	6	0.25	6.25	5411
(98)	98	98.5	86									5809
100	100	100.5	88									6082
(105)	105	105.5	93									6793
110	110	110.5	98									7543
(115)	115	116.0	101									8012
120	120	121.0	106									8825
125	125	126.0	111									9677

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
130	130	131.0	116	14	7	0.5	6	1	7	0.5	7.5	10568
(135)	135	136.0	121									11499
140	140	141.0	126									12469
(145)	145	146.0	131									13478
150	150	151	134									14103
(155)	155	156	139									15175
160	160	161	144	16	8	0.5	7	1	8	0.5	8.5	16286
(165)	165	166	149									17437
170	170	171	154									18627
(175)	175	176	159									19856
180	180	181	162									20612
(185)	185	186	167									21904
190	190	191	172	18	9	0.5	8	1	9	0.5	9.5	23235
(195)	195	196	177									24606
200	200	201	182									26016
210	210	211	190									28353
220	220	221	200	20	10	0.5	9	1	10	0.5	10.5	31416
230	230	231	210									34636
240	240	241	218									37325
250	250	251	228	22	11	0.5	10	1	11	0.5	11.5	40828
260	260	261	238									44488
270	270	271	246									47529
280	280	281	256	24	12	0.5	11	1	12	0.5	12.5	51472
290	290	291	266									55572
300	300	301	274	26	13	0.5	12	1	13	0.5	13.5	58965

Note: Diameters within brackets are of second preference IS 4694 – 1968

Table 8.11: Basic Dimensions for Square Threads – Coarse Series (All dimensions in millimeters)

Nom. Dia.	Major Dia Bolt d	Major Dia Nut D	Minor Dia. d_1	Pitch p	e	r	h_2	b	h_1	a	H	Area of Core, mm^2
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
22	22	22.5	14									164
24	24	24.5	16	8	4	0.25	3.5	0.5	4	0.25	4.25	201
26	26	26.5	18									254
28	28	28.5	20									314
30	30	30.5	20									314
32	32	32.5	22									360
(34)	34	34.5	24	10	5	0.25	4.5	0.5	5	0.25	5.25	452
36	36	36.5	26									531
(38)	38	38.5	28									616
40	40	40.5	28									616
(42)	42	42.5	30									707
44	44	44.5	32									804
(46)	46	46.5	34	12	6	0.25	5.5	0.5	6	0.25	6.25	908
48	48	48.5	36									1018
50	50	50.5	38									1134
52	52	52.5	40									1257
55	55	56.0	41									1320
(58)	58	59.0	44	14	7	0.5	6	1	7	0.5	7.5	1521
60	60	61.0	46									1662
(62)	62	63.0	48									1810

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
65	65	66.0	49									1886
(68)	68	69.0	52									2124
70	70	71.0	54									2290
(72)	72	73.0	56	16	8	0.5	7	1	8	0.5	8.5	2463
75	75	76.0	59									2734
(78)	78	79.0	62									3019
80	80	81.0	64									3217
(82)	82	83.0	66									3421
85	85	86.0	67									3526
(88)	88	89.0	70									3848
90	90	91.0	72	18	9	0.5	8	1	9	0.5	9.5	4072
(92)	92	93.0	74									4301
95	95	95.0	77									4657
(98)	98	99.0	80									5027
100	100	101.0	80									5027
(105)	105	106.0	85	20	10	0.5	9	1	10	0.5	10.5	5675
110	110	111.0	90									6362
(115)	115	116.0	93									6793
120	120	121.0	98	22	11	0.5	10	1	11	0.5	11.5	7543
(125)	125	126.0	103									8332
130	130	131.0	108									9161
(135)	135	136	111									9677
140	140	141	116									10568
(145)	145	146	121	24	12	0.5	11	1	12	0.5	12.5	11499
150	150	151	126									12469
(155)	155	156	131									13478

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
160	160	161	132									13685
(165)	165	166	137									14741
170	170	171	142	28	14	0.5	13	1	14	0.5	14.5	15837
(175)	175	176	147									16972
180	180	181	152									18146
(185)	185	186	153									18385
190	190	191	158									19607
(195)	195	196	163	32	16	0.5	15	1	16	0.5	16.5	20867
200	200	201	168									22167
210	210	211	174									23779
220	220	221	184									26590
230	230	231	194	36	18	0.5	17	1	18	0.5	18.5	29559
240	240	241	204									32685
250	250	251	210									34636
260	260	261	220									38013
270	270	271	230	40	20	0.5	19	1	20	0.5	20.5	41548
280	280	281	240									45239
290	290	291	246									47529
300	300	301	256									51472
320	320	321	276	44	22	0.5	21	1	22	0.5	22.5	59828
340	340	341	296									68813
360	360	361	312									76454
380	380	381	332	43	24	0.5	23	1	24	0.5	24.5	86570
400	400	401	352									97314

Note: Diameters within brackets are of second preference

Table 8.12: Limits of Sizes for Fine Series Nut Threads Tolerance Class H5

Size	Pitch p	Major Diameter D Min	Pitch Diameter D_2			Minor Diameter D_1		
			Max	Min	Tole-rance	Max	Min	Tole-rance
(1)	(2) mm	(3) mm	(4) mm	(5) mm	(6) μm	(7) mm	(8) mm	(9) μm
M8 × 1	1	8.0	7.468	7.350	118	7.107	6.917	190
M10 × 1.25	1.25	10.0	9.313	9.188	125	8.859	8.647	212
M12 × 1.25	1.25	12.0	11.328	11.188	140	10.859	10.647	212
(M14 × 1.5)	1.5	14.0	13.176	13.026	150	12.612	12.376	236
M16 × 1.5	1.5	16.0	15.176	15.026	150	14.612	14.376	236
(M18 × 1.5)	1.5	18.0	17.176	17.026	150	16.612	16.376	236
M20 × 1.5	1.5	20.0	19.176	19.026	150	18.612	18.376	236
(M22 × 1.5)	1.5	22.0	21.176	21.026	150	20.612	20.376	236
M24 × 2	2	24.0	22.881	22.701	180	22.135	21 835	300
(M27 × 2)	2	27.0	25.881	25.701	180	25.135	24.835	300
M30 × 2	2	30.0	28.881	28.701	180	28.135	27.835	300
(M33 × 2)	2	33.0	31.881	31.701	180	31.135	30.835	300
M36 × 3	3	36 0	34.263	34.051	212	33.152	32.752	400
(M39 × 3)	3	39.0	37.263	37.051	212	36.152	35.752	400

1 μ m = 0.001 mm

IS: 4218 – 1967

Note: Second preference sizes are given in brackets in col 1.

Table 8.13: Limits of Sizes for Fine Series Bolt Threads – Tolerance Class h4

Size	Pitch	Major Diameter d			Pitch Diameter d_2			Minor Diameter d_3		
(1)	p (2) mm	Max (3) mm	Min (4) mm	Tolerance (5) μ m	Max (6) mm	Min (7) mm	Tolerance (8) μ m	Max (9) mm	Min (10) mm	Tolerance (11) μ m
M8 × 1	1	8.0	7.888	112	7.350	7.279	71	6.773	6.630	143
M10 × 1.25	1.25	10.0	9.868	132	9.188	9.113	75	8.466	8.301	165
M12 × 1.25	1.25	12.0	11.868	132	11.188	11.103	85	10.466	10.291	175
(M14 × 1.5)	1.5	14.0	13.850	150	13.026	12.936	90	12.160	11.962	198
M16 × 1.5	1.5	16.0	15.850	150	15.026	14.936	90	14.160	13.962	198
(M18 × 1.5)	1.5	18.0	17.850	150	17.026	16.936	90	16.160	15.962	198
M20 × 1.5	1.5	20.0	19.850	150	19.026	18.936	90	18.160	17.962	198
(M22 × 1.5)	1.5	22.0	21.850	150	21.026	20.936	90	20.160	19.962	198
M24 × 2	2	24.0	23.820	180	22.701	22.595	106	21.546	21.296	250
(M27 × 2)	2	27.0	26.820	180	25.701	25.595	106	24.546	24.296	250
M30 × 2	2	30.0	29.820	180	28.701	28.595	106	27.546	27.296	250
(M33 × 2)	2	33.0	31.820	180	31.701	31.595	106	30.546	30.296	250
M36 × 3	3	36.0	35.764	236	34.051	33.926	125	32.319	31.978	341
(M39 × 3)	3	39.0	38.764	236	37.051	36.926	125	35.319	34.978	341

1 μ m = 0.001 mm.

Second preference sizes are shown in brackets in Col.1

IS : 4218 – 1967

Table 8.14: Limits of Sizes for Coarse Series Nut Threads – Tolerance Class H7

Size	Pitch p	Major Diameter	Pitch Diameter D_2	Minor Diameter D_1		
				Max	Min	Tolerance

Second preference sizes are shown in brackets in Col.1

IS : 4218 – 1967

Table 8.14: Limits of Sizes for Coarse Series Nut Threads – Tolerance Class H7

Size	Pitch p	Major Diameter D Min	Pitch Diameter D_2			Minor Diameter D_1		
			Max	Min	Tolerance	Max	Min	Tolerance
(1)	(2) mm	(3) mm	(4) mm	(5) mm	(6) µm	(7) mm	(8) mm	(9) µm
M1	0.25	1.000	–	–	–	–	–	–
(M1.1)	0.25	1.100	–	–	–	–	–	–
M1.2	0.25	1.200	–	–	–	–	–	–
(M1.4)	0.3	1.400	–	–	–	–	–	–
M1.6	0.35	1.600	–	–	–	–	–	–
(M1.8)	0.35	1.800	–	–	–	–	–	–
M2	0.4	2.000	–	–	–	–	–	–
(M2.2)	0.45	2.200	–	–	–	–	–	–
M2.5	0.45	2.500	–	–	–	–	–	–
M3	0.5	3.000	2.800	2.675	125	2.639	2.459	180
(M3.5)	0.6	3.500	3.250	3.110	140	3.050	2.850	200
M4	0.7	4.000	3.695	3.545	150	3.466	3.242	224
(M4.5)	0.75	4.500	4.163	4.013	150	3.924	3.688	236
M5	0.8	5.000	4.640	4.480	160	4.384	4.134	250

(1)	(2) mm	(3) mm	(4) mm	(5) mm	(6) µm	(7) mm	(8) mm	(9) µm
M6	1	6.000	5.540	5.350	190	5.217	4.917	300
(M7)	1	7.000	6.540	6.350	190	6.217	5.917	300
M8	1.25	8.000	7.388	7.188	200	6.982	6.647	335
M10	1.5	10.000	9.250	9.026	224	8.751	8.376	375
M12	1.75	12.000	11.113	10.863	250	10.531	10.106	425
(M14)	2	14.000	12.966	12.701	265	12.310	11.835	475
(M16)	2	16.000	14.966	14.701	265	14.213	13.835	475
(M18)	2.5	18.000	16.656	16.376	280	15.854	15.294	560
M20	2.5	20.000	18.656	19.376	280	17.854	17.294	560
(M22)	2.5	22.000	20.656	20.376	280	19.854	19.294	560
M24	3	24.000	22.386	22.051	335	21.382	20.757	630
(M27)	3	27.000	25.386	25.051	335	24.383	23.752	630
M30	3.5	30.000	28.082	27.727	355	26.921	26.211	710
(M33)	3.5	33.000	31.082	30.727	355	29.921	29.211	710
M36	4	36.000	33.777	33.402	375	32.420	31.670	750
(M39)	4	39.000	36.777	36.402	375	35.420	34.670	750

1 µ m = 0.001 mm

Note: Second preference sizes are shown in brackets in col. 1

IS : 4218 – 1967.

Table 8.15: Limits of Sizes for Coarse Series Bolt Threads – Tolerance Class g6

Size	Pitch	Major Diameter d			Pitch Diameter d_2			Minor Diameter d_3		
	p	Max	Min	Tolerance	Max	Min	Tolerance	Max	Min	Tolerance

Table 8.15: Limits of Sizes for Coarse Series Bolt Threads – Tolerance Class g6

Size	Pitch	Major Diameter d			Pitch Diameter d_2			Minor Diameter d_3		
(1)	p (2) mm	Max (3) mm	Min (4) mm	Tolerance (5) µm	Max (6) mm	Min (7) mm	Tolerance (8) µm	Max (9) (mm)	Min (10) mm	Tolerance (11) µm
M1	0.25	–	–	–	–	–	–	–	–	–
(M1.1)	0.25	–	–	–	–	–	–	–	–	–
M1.2	0.25	–	–	–	–	–	–	–	–	–
(M1.4)	0.3	–	–	–	–	–	–	–	–	–
M1.6	0.35	–	–	–	–	–	–	–	–	–
(M1.8)	0.35	–	–	–	–	–	–	–	–	–
M2	0.4	–	–	–	–	–	–	–	–	–
(M2.2)	0.45	–	–	–	–	–	–	–	–	–
M2.5	0.45	–	–	–	–	–	–	–	–	–
M3	0.5	–	–	–	–	–	–	–	–	–
(M3.5)	0.6	–	–	–	–	–	–	–	–	–
M4	0.7	–	–	–	–	–	–	–	–	–
(M4.5)	0.75	–	–	–	–	–	–	–	–	–
M5	0.8	4.976	4.740	236	4.456	4.306	150	3.995	3.787	208
M6	1	5.974	5.694	280	5.324	5.144	180	4.747	4.495	252

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(M7)	1	6.974	6.694	280	6.324	6.144	180	5.747	5.495	252
M8	1.25	7.972	7.637	335	7.160	6.970	190	6.438	6.158	280
M10	1.5	9.968	9.593	375	8.994	8.782	212	8.128	7.808	320
M12	1.75	11.966	11.541	425	10.829	10.593	236	9.819	9.457	362
(M14)	2	13.962	13.512	540	12.663	12.413	250	11.508	11.114	394
M16	2	15.962	15.512	540	14.663	14.413	250	13.508	13.114	394
(M18)	2.5	17.958	17.428	530	16.334	16.069	265	14.891	14.446	445
M20	2.5	19.958	19.428	530	18.334	18.069	265	16.891	16.446	445
(M22)	2.5	21.958	21.428	530	20.334	20.069	265	18.891	18.446	445
M24	3	23.952	23.352	600	22.003	21.688	315	20.271	19.740	531
(M27)	3	26.952	26.352	600	25.003	24.688	315	23.271	22.740	531
M30	3.5	29.947	29.277	670	27.674	27.339	335	25.653	25.066	587
(M33)	3.5	32.947	32.277	670	30.674	30.339	335	28.653	28.066	587
M36	4	35.940	35.190	750	33.342	32.987	355	31.033	30.390	643
(M39)	4	38.940	38.190	750	36.342	35.987	355	34.033	33.390	643

1 μ m = 0.001 mm

Note: 1 – Second preference sizes are shown in brackets in col. 1.

IS : 4218 – 1967

Table 8.16: Empirical Proportions of Hexagonal Head Bolt & Nut

Detail	Proportion
Nominal Diameter	d = Size of Bolt or Nut, mm
Width Across Flats	s = 1.5d + 3 mm
Width Across Corners	e = 2d
Thickness of Bolt Head	k = 0.8 d
Thickness of Nut	m = 0.9 d
Root Diameter	d_1 = d − (2 × Depth of Thread) or = 0.9 d (approximate)
Length of Bolt	l = As specified
Thread Length	b = 2d + 6 mm (for l < 150 mm) = 2d + 12 mm (for l > 150 mm)
Radius of Bolt End	r = d (for spherical ends)
Chamfer of Bolt End	z = Depth of Thread × 45° or = 0.1 d (Approximate)
Chamfer Angle of Bolt Head & Nut	= 30°

Table 8.16: Empirical Proportions of Hexagonal Head Bolt & Nut

Detail	Proportion
Nominal Diameter	d = Size of Bolt or Nut, mm
Width Across Flats	$s = 1.5d + 3$ mm
Width Across Corners	$e = 2d$
Thickness of Bolt Head	$k = 0.8\,d$
Thickness of Nut	$m = 0.9\,d$
Root Diameter	$d_1 = d - (2 \times \text{Depth of Thread})$ or $= 0.9\,d$ (approximate)
Length of Bolt	l = As specified
Thread Length	$b = 2d + 6$ mm (for $l < 150$ mm) $= 2d + 12$ mm (for $l > 150$ mm)
Radius of Bolt End	$r = d$ (for spherical ends)
Chamfer of Bolt End	z = Depth of Thread $\times$ 45° or $= 0.1\,d$ (Approximate)
Chamfer Angle of Bolt Head & Nut	$= 30°$

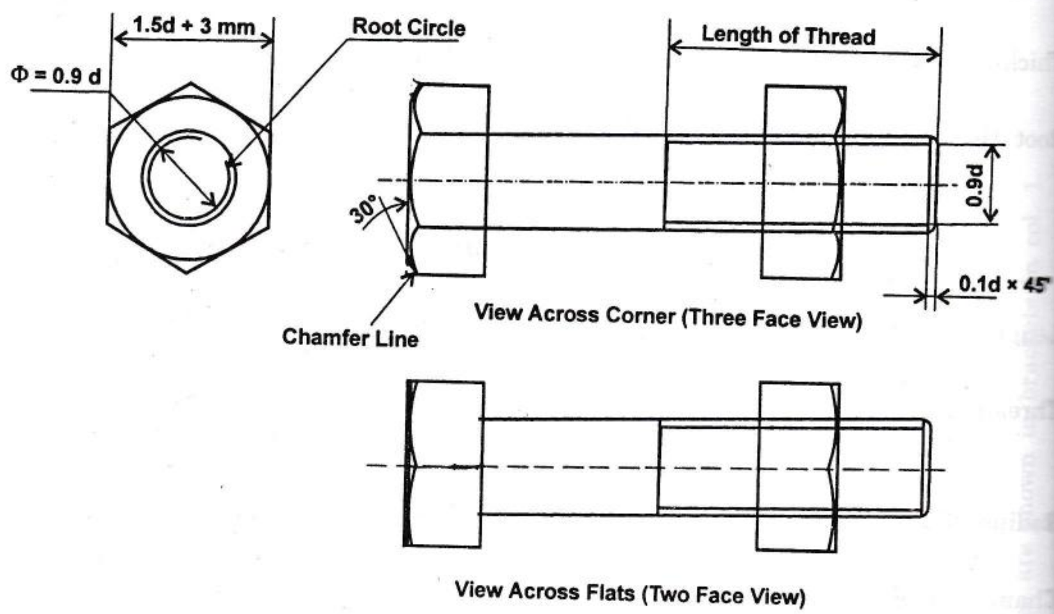


Fig. 8.5: Hexagonal Head Bolt & Nut

F_t – Tensile strength of perforated plate, N

F_s – Shearing strength of rivets, N

F_c – Crushing strength of rivets, N

S_t – Tensile stress for the plate, N/mm^2

S_s – Shear stress for the rivet, N/mm^2

S_c – Crushing stress for the rivet, N/mm^2

t_1 – Thickness of cover plate, mm.

η – Efficiency of riveted joint

η_l – Efficiency of longitudinal joint (usually butt joint) of boiler

η_c – Efficiency of circumferential joint (usually lap joint) of boiler.

For eccentrically loaded structural joint:

F – Applied eccentric load, N

F_p – Induced primary load, N

F_s – Induced secondary load, N

R – Resultant load, N

e – Eccentricity, mm

$\bar{x}$ – X co-ordinate of C.G.

$\bar{y}$ – Y co-ordinate of C.G.

θ – Angle between primary and secondary loads in degrees

DESIGN PARTICULARS	EQUATIONS
For boiler and axially loaded structural joints:	
Thickness of boiler plate	$t = \dfrac{PD}{2S_t\, \eta_l}$ .... (9.1)
	$\eta_l = 0.6$ to 0.8 for single riveted
	$= 0.75$ to 0.85 for double riveted
	$= 0.8$ to 0.9 for triple riveted
Diameter of rivet for $t > 8$ mm (For $t < 8$ mm, obtain d by equating the shear strength to crushing strength of rivets)	$d' = 6.05\sqrt{t}$ (Unwin's formula) .... (9.2)
Length of rivet shank	$l_s = \Sigma t + (0.7 \text{ to } 1.5)\, d'$ .... (9.3) Σt = Total thickness of plates
Minimum pitch	$p_{min} = (2.25 \text{ to } 2.5)\, d$ .... (9.4)
Maximum permissible pitch, mm	$p_{max} = Ct + 41$ .... (9.5)
	(For the values of C, refer table 9.7)

Distance between the row of rivets according to Indian Boiler code:

Condition	Chain riveted	Zig zag riveted
Equal number of rivets in all rows	$p_b \geq 2d$	$p_b \geq 0.33p + 0.67\,d$
Number of rivets in the outer row is half the number in the inner row	$p_{b1} \geq 0.33p + 0.67d$ $p_{b2} \geq 2d$	$p_{b1} \geq 0.2\,p + 1.15\,d$ $p_{b2} \geq 0.165\,p + 0.67\,d$

Thickness of cover plates:

For single cover	$t_1 = 1.125\,t$	.... (9.6)
For double cover of equal widths	$t_1 = 0.625\,t$	.... (9.7)
For single cover with the outermost row having alternate rivets	$t_1 = 1.125\,t\left(\dfrac{p-d}{p-2d}\right)$	.... (9.8)
For double cover with the outermost row having alternate rivets	$t_1 = 0.625\,t\left(\dfrac{p-d}{p-2d}\right)$	.... (9.9)
For wide cover placed inside the boiler	$t_1 = 0.75\,t$	.... (9.10)
For narrow cover placed outside the boiler	$t_1 = 0.625\,t$	.... (9.11)
Margin	$m = 1.5\,d$	.... (9.12)

Efficiency Calculation:

Efficiency Calculation:

For longitudinal butt joint of boiler: (Triple riveted unequal cover plates)

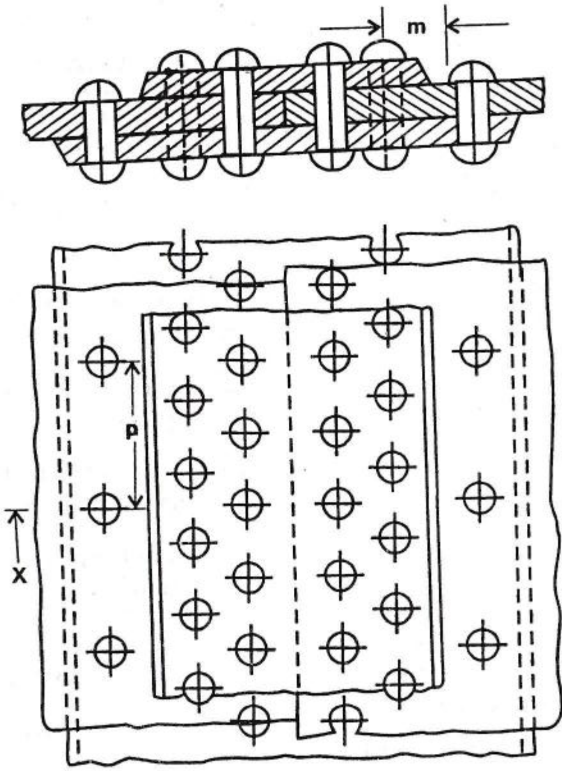
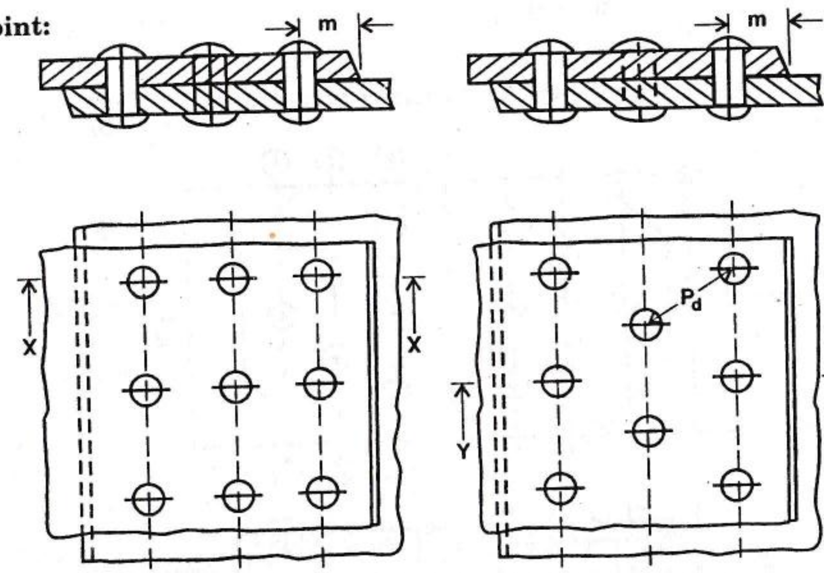


Fig. 9.1: Triple riveted double strap (unequal) butt joint

DESIGN PARTICULARS	EQUATIONS
Tearing strength of perforated plate in the outer row	$F_t = (p - d)\, t\, S_t$ .... (9.13)
Shearing strength of all the rivets	$F_s = (n_1 + 1.875\, n_2) \frac{\pi}{4} d^2 S_s$ .... (9.14)
Crushing strength of all the rivets	$F_c = n\, dt\, S_c$; $(n = n_1 + n_2)$ .... (9.15)
Combined shearing strength of rivet in the outer row and tearing strength of plate in the next inner row	$F_{st} = n_1 \frac{\pi}{4} d^2 S_s + (p - 2d)\, t\, S_t$ .... (9.16)
Combined crushing strength of rivet in the outer row and tearing strength of plate in the next inner row	$F_{ct} = n_1\, dt\, S_c + (p - 2d)\, t\, S_t$ .... (9.17)
Combined shearing strength of rivet in the outer row and crushing strength of rivets in the inner rows	$F_{sc} = n_1 \frac{\pi}{4} d^2 S_s + n_2\, dt\, S_c$ .... (9.18)
Combined crushing strength of rivet in the outer row and shearing strength of rivets in the inner rows	$F_{cs} = n_1\, dt\, S_c + (n_2 \times 1.875) \frac{\pi}{4} d^2 S_s$ .... (9.19)
Tensile strength of unriveted plate	$F = pt\, S_t$ .... (9.20)
Efficiency of longitudinal joint	η_l (or) $\eta = \frac{\text{Least strength}}{\text{Strength of solid plate (F)}}$ .... (9.21)
For circumferencial lap joint of boiler:	
Total number of rivets for the circumferential joint	$n' = \left(\frac{D}{d}\right)^2 \left(\frac{P}{S_s}\right)$; P = Steam pressure .... (9.22)
Number of rows of rivets	$r_n = \frac{n'\, p'}{\pi\,(D + t)}$; p' – Pitch of lap joint t – Thickness of boiler plate .... (9.23)
Efficiency of circumferential joint	$\eta_c = \frac{p' - d}{p'}$ .... (9.24)

DESIGN PARTICULARS	EQUATIONS
	$\eta_c = 0.45$ to 0.65 for single riveted $= 0.63$ to 0.77 for double riveted $= 0.75$ to 0.85 for triple riveted

For structural lap joint:



(a) Chain riveting

(b) Zig-zag riveting

Fig. 9.2: Triple riveted lap joint

Tearing strength of perforated plate	$F_t = (p - d)\, t\, S_t$ .... (9.25)
Shearing strength of rivets	$F_s = n \cdot \frac{\pi}{4} d^2 S_s$ .... (9.26)
Crushing strength of rivets	$F_c = ndt\, S_c$ .... (9.27)

DESIGN PARTICULARS	EQUATIONS
Tensile strength of unriveted plate	$F = pt\,S_t$ .... (9.28)
Efficiency of joint	$\eta = \dfrac{\text{Least of } F_t, F_s, F_c}{F}$ .... (9.29)

For Diamond riveting (Lozenge Joint): (Double cover butt joint – Six rivets each side)

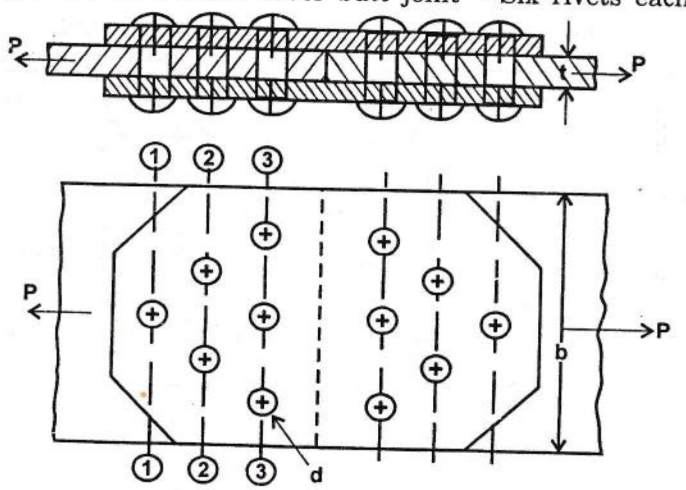


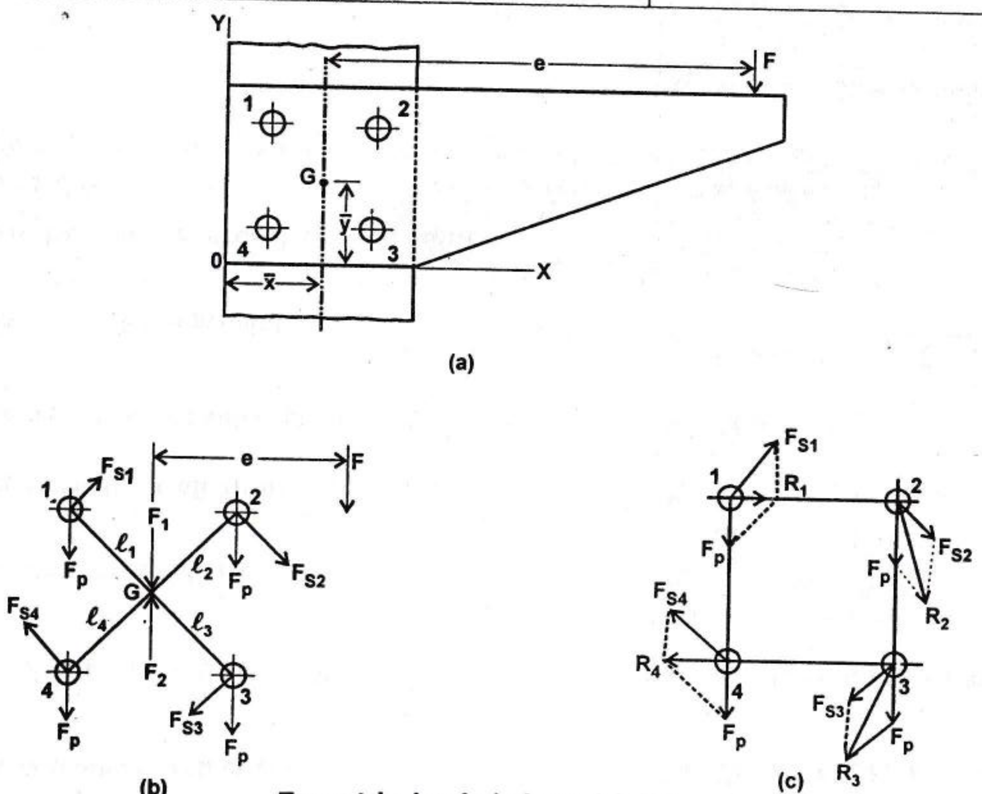
Fig. 9.3: Diamond riveted joint

Pitch of the rivets	$p = \dfrac{b - 2m}{n'' - 1}$ .... (9.30)
	n'' – Number of rivets in a row where it is maximum
Margin	$m = 1.5\,d$ .... (9.31)

DESIGN PARTICULARS	EQUATIONS
Distance between the row of rivets	$p_b \geq 2d$ .... (9.32)
	.... (9.33)

DESIGN PARTICULARS	EQUATIONS	
Distance between the row of rivets	$p_b \geq 2d$	.... (9.32)
Strength of joint at section (1 – 1)	$F_1 = (b - d)\, t\, S_t$	.... (9.33)
Strength of joint at section (2 – 2)	$F_2 = (b - 2d)\, t\, S_t + \left(1 \times 1.875 \times \frac{\pi}{4} d^2\, S_s\right)$	.... (9.34)
Strength of joint at section (3 – 3)	$F_3 = (b - 3d)\, t\, S_t + (3 \times 1.875 \times \frac{\pi}{4} d^2\, S_s)$	.... (9.35)
Shearing strength of all rivets	$F_s = 6 \times 1.875 \times \frac{\pi}{4} d^2\, S_s$	.... (9.36)
Crushing strength of all rivets	$F_c = 6\, dt\, S_c$	.... (9.37)
Tensile strength of unriveted plate	$F = bt\, S_t$	.... (9.38)
Efficiency of the Lozenge-joint	$\eta = \frac{\text{Least of } F_1, F_2, F_3, F_s, F_c}{F}$	.... (9.39)
Eccentric loaded structural riveted joint:		
Location of C.G	$\bar{x} = \frac{x_1 + x_2 + \dots x_n}{n}$; $\bar{y} = \frac{y_1 + y_2 + \dots y_n}{n}$	.... (9.40)
	$x_1, x_2 \dots x_n$ – X-co-ordinates of n rivets	
	$y_1, y_2 \dots y_n$ – Y-co-ordinates of n rivets	

DESIGN PARTICULARS	EQUATIONS



Eccentric loaded riveted joint

Fig. 9.4

DESIGN PARTICULARS	EQUATIONS
Induced primary shear load	$F_p = \frac{F}{n}$ .... (9.41)
Induced secondary shear load	$\frac{F_{s1}}{l_1} = \frac{F_{s2}}{l_2} = \ldots \frac{F_{sn}}{l_n}$ .... (9.42)

DESIGN PARTICULARS	EQUATIONS	
	$F_{s1} = \dfrac{F\,e\,l_1}{\left(l_1^2 + l_2^2 + \dots l_n^2\right)}$	.... (9.43)
Resultant shear load	$R = \sqrt{F_p^2 + F_s^2 + 2\,F_p\,F_s \cos\theta}$	.... (9.44)
Diameter of rivet	$d = \sqrt{\dfrac{4\,R_{max}}{\pi\,S_s}}$	.... (9.45)

Rivets for General Purposes (Below 12 mm diameter)

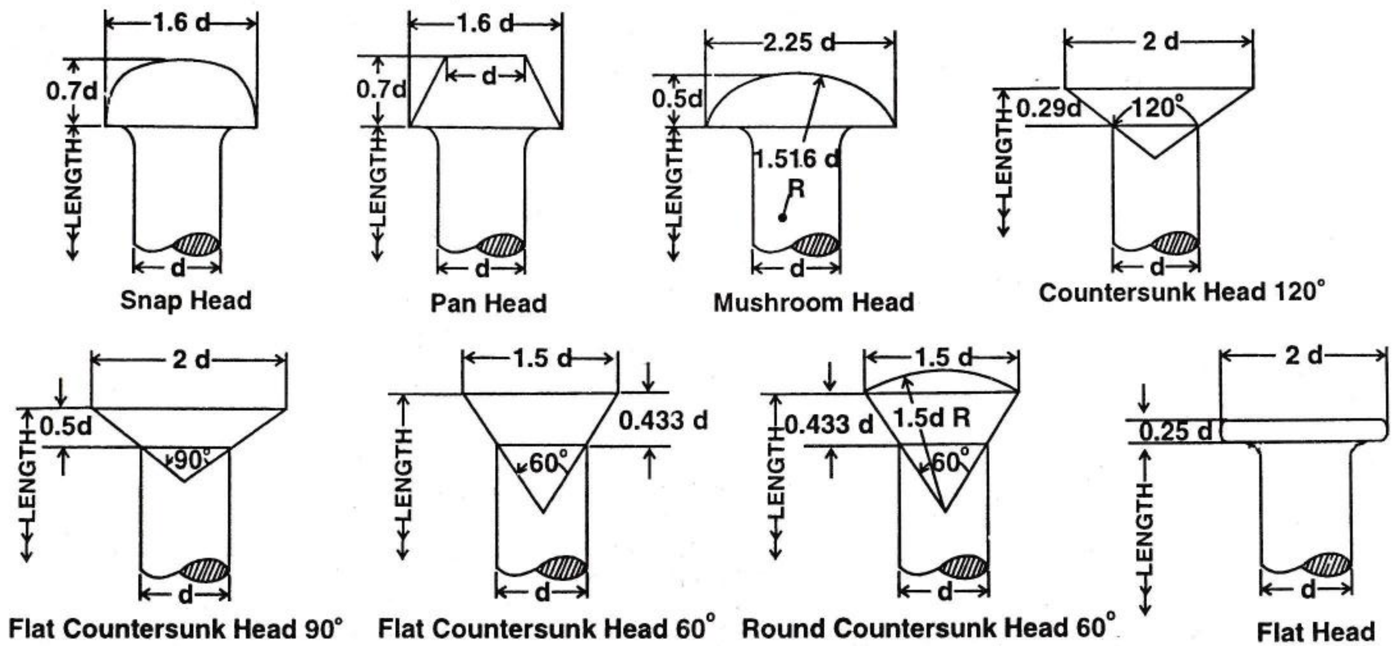


Table 9.1: Preferred Length and Diameter Combinations for Rivets

Length mm	Rivet Diameter, mm 1.6	2	2.5	3	4	5	6	8	10
5	+	–	–	–	–	–	–	–	–
6	+	+	+	+	–	–	–	–	–
7	+	+	+	+	–	–	–	–	–
8	+	+	+	+	+	–	–	–	–
9	+	+	+	+	+	–	–	–	–
10	+	+	+	+	+	+	–	–	–
12	–	+	+	+	+	+	+	–	–
14	–	–	+	+	+	+	+	+	–
16	–	–	+	+	+	+	+	+	–
18	–	–	–	+	+	+	+	+	+
20	–	–	–	+	+	+	+	+	+
22	–	–	–	+	+	+	+	+	+
24	–	–	–	+	+	+	+	+	+
26	–	–	–	+	+	+	+	+	+
28	–	–	–	+	+	+	+	+	+
30	–	–	–	+	+	+	+	+	+
35	–	–	–	+	+	+	+	+	+
40	–	–	–	–	+	+	+	+	+
45	–	–	–	–	+	+	+	+	+
50	–	–	–	–	–	–	+	+	+
55	–	–	–	–	–	–	+	+	+
60	–	–	–	–	–	–	–	+	+
65	–	–	–	–	–	–	–	+	+
70	–	–	–	–	–	–	–	+	+

Preferred combinations are indicated by +

IS 2155 – 1962

Rivets for General Purposes (12 to 48 mm diameter)

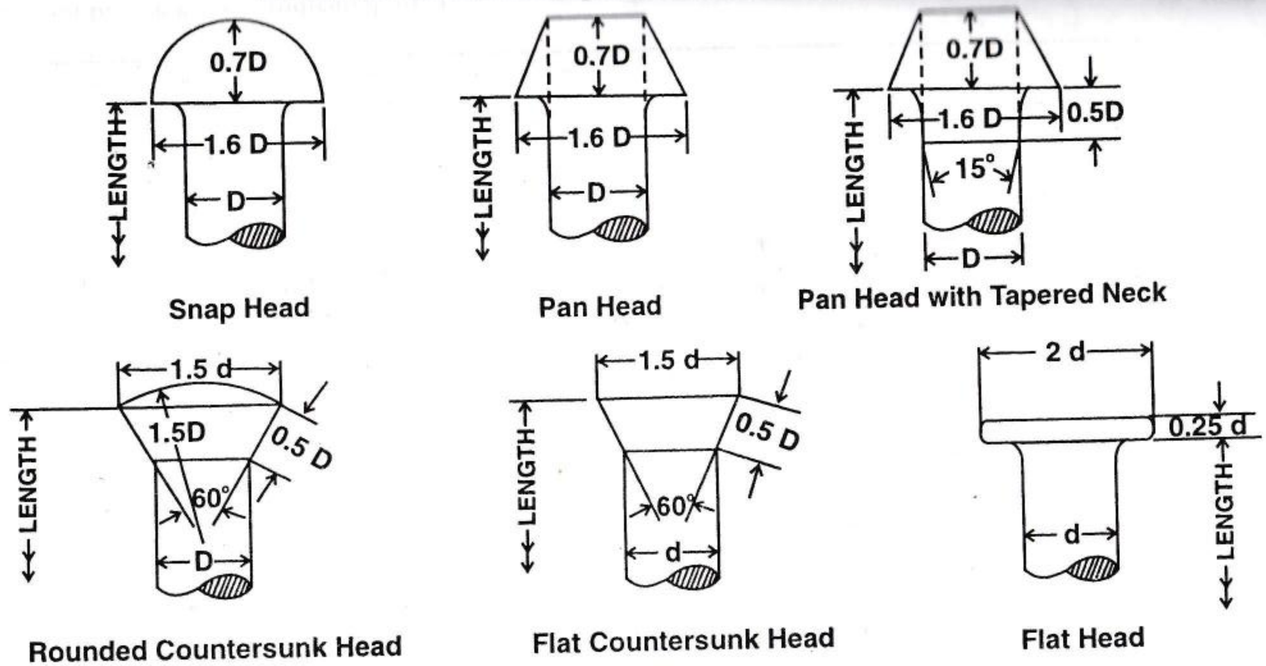


Table 9.2: Preferred Length and Diameter Combinations for Rivets

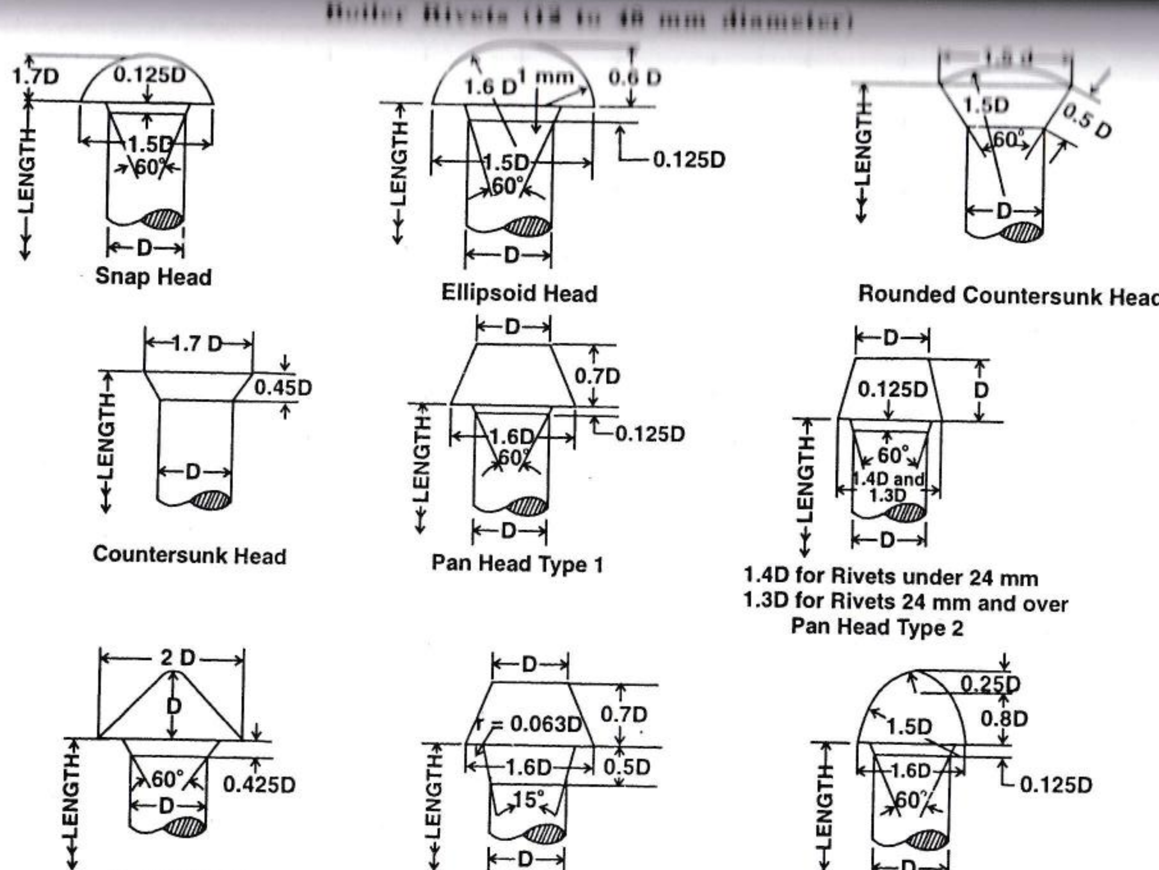
Length mm	Diameter, mm													
	12	14	16	18	20	22	24	27	30	33	36	39	42	48
28	+	–	–	–	–	–	–	–	–	–	–	–	–	–
31.5	+	+	–	–	–	–	–	–	–	–	–	–	–	–
35.5	+	+	+	–	–	–	–	–	–	–	–	–	–	–
40	+	+	+	+	–	–	–	–	–	–	–	–	–	–
45	+	+	+	+	+	–	–	–	–	–	–	–	–	–

Length mm	12	14	16	18	20	22	24	27	30	33	36	39	42	48
	Diameter, mm													
50	+	+	+	+	+	+	–	–	–	–	–	–	–	–
56	+	+	+	+	+	+	+	–	–	–	–	–	–	–
63	+	+	+	+	+	+	+	+	–	–	–	–	–	–
71	+	+	+	+	+	+	+	+	+	–	–	–	–	–
80	+	+	+	+	+	+	+	+	+	–	–	–	–	–
85	–	+	+	+	+	+	+	+	+	+	–	–	–	–
90	–	+	+	+	+	+	+	+	+	+	–	–	–	–
95	–	+	+	+	+	+	+	+	+	+	–	–	–	–
100	–	–	+	+	+	+	+	+	+	+	+	–	–	–
106	–	–	+	+	+	+	+	+	+	+	+	–	–	–
112	–	–	+	+	+	+	+	+	+	+	+	+	–	–
118	–	–	–	+	+	+	+	+	+	+	+	+	–	–
125	–	–	–	–	+	+	+	+	+	+	+	+	+	–
132	–	–	–	–	–	+	+	+	+	+	+	+	+	+
140	–	–	–	–	–	+	+	+	+	+	+	+	+	+
150	–	–	–	–	–	–	+	+	+	+	+	+	+	+
160	–	–	–	–	–	–	+	+	+	+	+	+	+	+
180	–	–	–	–	–	–	–	+	+	+	+	+	+	+
200	–	–	–	–	–	–	–	–	+	+	+	+	+	+
224	–	–	–	–	–	–	–	–	–	+	+	+	+	+
250	–	–	–	–	–	–	–	–	–	–	–	–	+	+

Preferred combinations are indicated by +

IS 1929 – 1961

Boiler Rivets (12 to 48 mm diameter)



Snap Head — Ellipsoid Head — Rounded Countersunk Head

Countersunk Head — Pan Head Type 1 — Pan Head Type 2

1.4D for Rivets under 24 mm
1.3D for Rivets 24 mm and over

Steeple Head — Pan Head with Tapered Neck — Conical Head

Designation:

A pan head rivet of 20 mm diameter having a length of 100 mm shall be designated as: Pan head rivet 20×100 IS: 1928 – 1961

Rivets of other types shall be designated in a similar manner.

Table 9.3: Preferred Length and Diameter Combinations for Boiler Rivets

Length mm	Rivet Diameter, mm													
	12	14	16	18	20	22	24	27	30	33	36	39	42	48
28	+	–	–	–	–	–	–	–	–	–	–	–	–	–
31.5	+	+	–	–	–	–	–	–	–	–	–	–	–	–
35.5	+	+	+	–	–	–	–	–	–	–	–	–	–	–
40	+	+	+	+	–	–	–	–	–	–	–	–	–	–
45	+	+	+	+	+	–	–	–	–	–	–	–	–	–
50	+	+	+	+	+	+	–	–	–	–	–	–	–	–
56	+	+	+	+	+	+	+	–	–	–	–	–	–	–
63	+	+	+	+	+	+	+	+	–	–	–	–	–	–
71	+	+	+	+	+	+	+	+	+	–	–	–	–	–
80	+	+	+	+	+	+	+	+	+	–	–	–	–	–
85	–	+	+	+	+	+	+	+	+	+	–	–	–	–
90	–	+	+	+	+	+	+	+	+	+	–	–	–	–
95	–	+	+	+	+	+	+	+	+	+	+	–	–	–

Length mm	Rivet Diameter, mm													
	12	14	16	18	20	22	24	27	30	33	36	39	42	48
100	–	–	+	+	+	+	+	+	+	+	+	–	–	–
106	–	–	+	+	+	+	+	+	+	+	+	+	–	–
112	–	–	+	+	+	+	+	+	+	+	+	+	–	–
118	–	–	–	+	+	+	+	+	+	+	+	+	+	–
125	–	–	–	–	+	+	+	+	+	+	+	+	+	+
132	–	–	–	–	–	+	+	+	+	+	+	+	+	+
140	–	–	–	–	–	+	+	+	+	+	+	+	+	+
150	–	–	–	–	–	–	+	+	+	+	+	+	+	+
160	–	–	–	–	–	–	+	+	+	+	+	+	+	+
180	–	–	–	–	–	–	–	+	+	+	+	+	+	+
200	–	–	–	–	–	–	–	–	+	+	+	+	+	+
224	–	–	–	–	–	–	–	–	–	+	+	+	+	+
250	–	–	–	–	–	–	–	–	–	–	–	–	+	+

Preferred combinations are indicated by +

Table 9.4: Types of Riveted Joints

<table>
<tr><td colspan="2">Lap Joints</td><td colspan="6">Butt Joints</td></tr>
<tr><td colspan="2">1. Single riveted</td><td colspan="2">Single cover plate</td><td colspan="4">Double cover plate</td></tr>
<tr><td colspan="2">2. Multiple riveted</td><td colspan="2">1. Single riveted</td><td colspan="2">Equal width</td><td colspan="2">Unequal width</td></tr>
<tr><td>(i) Chain riveted</td><td>(ii) Zigzag riveted</td><td colspan="2">2. Multiple riveted</td><td colspan="2">1. Single riveted</td><td colspan="2">Multiple riveted</td></tr>
<tr><td rowspan="3">(a) Double riveted
(b) Triple riveted
(c) Quadruple riveted</td><td rowspan="3">(a) Double riveted
(b) Triple riveted
(c) Quadruple riveted</td><td>(i) Chain riveted</td><td>(ii) Zig-zag riveted</td><td colspan="2">2. Multiple riveted</td><td>(i) Chain riveted</td><td>(ii) Zig-zag riveted</td></tr>
<tr><td rowspan="2">(a) Double riveted
(b) Triple riveted
(c) Quadruple riveted</td><td rowspan="2">(a) Double riveted
(b) Triple riveted
(c) Quadruple riveted</td><td>(i) Chain riveted</td><td>(ii) Zig-zag riveted</td><td rowspan="2">(a) Double riveted
(b) Triple riveted
(c) Quadruple riveted</td><td rowspan="2">(a) Double riveted
(b) Triple riveted
(c) Quadruple riveted</td></tr>
<tr><td>(a) Double riveted
(b) Triple riveted
(c) Quadruple riveted</td><td>(a) Double riveted
(b) Triple riveted
(c) Quadruple riveted</td></tr>
</table>

Table 9.5

Nominal diameter of rivet (d′) (mm)	12	14	16	18	20	22	24	27	30	33	36	39	42	48
Diameter of rivet hole (d) (mm)	13	15	17	19	21	23	25	28.5	31.5	34.5	37.5	41	44	50

Table 9.6: Recommended Longitudinal Joints for Pressure Vessels

Diameter of shell (metres)	Thickness of plate (mm)	Type of joint (Butt joint)
0.6 to 1.8	6 to 13	Double riveted
0.9 to 2.1	13 to 25	Triple riveted
1.5 to 2.7	19 to 40	Quadruple riveted

Table 9.7: Boiler Code Factor C

Number of rivets per pitch length	Value of C		
	Lap Joint	Butt Joint	
		Single Cover	Double Cover
1	1.31	1.53	1.75
2	2.62	3.06	3.50
3	3.47	4.05	4.63
4	4.17	–	5.52
5	–	–	6.00

Table 9.8: Characteristics of Strong Structural Joints

	Type of joints	Diameter of rivet (Gross diameter) (d) mm	Pitch (p) mm	Back pitch (p_b) mm	Margin (m) mm	No. of rivets in single shear (n_1)	No. of rivets in double shear (n_2)	Efficiency of joint η in %
	Lap joint :							
1.	Single riveted	2 t	3 d	—	1.5 d	1	—	50–60
2.	Double riveted	2 t	4 d	2.0–2.5 d	1.5 d	2	—	60–75
3.	Triple riveted	2 t	5 d	2.0–2.5 d	1.5 d	3	—	70–80
	Butt Joint :							
(a)	**Single Strap :**							
4.	Single riveted	2 t	3 d	2.0–2.5 d	1.5 d	1	—	55–60
5.	Double riveted	2 t	4 d	2.0–2.5 d	1.5 d	2	—	70–85
(b)	**Double Strap :**							
6.	Single riveted	1.5 t	3.5 d	—	1.5 d	—	1	55–60
7.	Double riveted (Equal width strap)	1.5 t	6 d	2.0–2.5 d	1.5 d	—	2	75–85
8.	Double riveted (Unequal width strap)	1.5 t	6 d	2.0–2.5 d	1.5 d	1	1	75–85
9.	Triple riveted (Equal width strap)	1.5 t	6 d	2.0–2.75 d	1.5 d	—	3	80–90
10.	Triple riveted (Unequal width strap)	1.5 t	8 d	2.0–2.75 d	1.5 d	1	4	80–90
11.	Quadruple riveted (Unequal width strap)	1.5 t	20 d	2.0–2.75 d	1.5 d	3	8	85–95

Table 9.9: Characteristics of Leak Proof Joints for Pressure Vessels

Table 9.9: Characteristics of Leak Proof Joints for Pressure Vessels

	Type of joint	(d) mm	(p) mm	(m) mm	(p_b) mm	(n_1)	(n_2)	(ξ) N/mm^2	(η) in %
	Lap Joint :								
(1)	Single riveted	t + 8	2d + 8	1.5 d	2 d	1	–	60–70	45–60
(2)	Double riveted	t + 8	2.6d + 15	1.5 d	2 d	2	–	60–66	60–70
(3)	Triple riveted	t + (6 – 8)	3d + 22	1.5 d	2 d	3	–	55–60	70–80
	Butt Joint :								
(4)	Double riveted (Equal width strap)	t + (5 – 6)	3.5d + 15	1.5 d	2 d	–	2	95–115	75–85
(5)	Triple riveted (Unequal width strap)	t + 5	6d + 20	1.5 d	2.0–2.75 d	1	4	95–110	80–90
(6)	Quadruple riveted (Unequal width strap)	t + 5	18 d + 20	1.5 d	2.0–2.75 d	3	8	90–100	85–95

Note : -

ξ = Co-efficient of sliding which is the force resisting the slip of plates, per unit area of rivet cross section

$$\xi = \frac{F}{\frac{n\pi}{4} d^2} \qquad .....(A)$$

where F = Force on the joint per pitch i.e. tearing strength of un-riveted (or) solid plates

n = Total number of rivets per pitch length

d = Diameter of the rivet (i.e. Gross diameter = diameter of hole).

When designing the leak proof joint, the value of ξ obtained from the expression (A) should not exceed the value given in the table 9.9

Table 9.10: Diamond Joint

Type of Joint	No. of rivets								
	3	4	5	6	8	9	10	12	15
Lap	—	1-2-1	+	1-2-2-1	1-2-2-2-1	1-2-3-2-1	—	1-2-3-3-2-1	1-2-3-3-3-2-1
Butt	1-2	—	1-2-2	1-2-3	1-2-2-3	1-2-3-3	1-2-3-4	1-2-2-3-4	1-2-3-4-5

Table 9.11: Values of Working Stress at Elevated Temperatures

Maximum temperature t, °C	Minimum of the specified range of tensile strength of the material, MN/m^2 (kgf/mm^2)				
	315 (32)	340 (35)	380 (39)	410 (42)	520 (53)
0 – 370	63 (6.40)	68 (7.00)	76 (7.80)	82 (8.40)	104 (10.60)
400	57 (5.80)	63 (6.40)	69 (7.00)	76 (7.75)	90 (9.15)
425	45 (4.60)	51 (5.15)	55 (5.60)	62 (6.30)	71 (7.20)
455	37 (3.80)	42 (4.24)	47 (4.75)	51 (5.20)	57 (5.80)
480	29 (3.00)	33 (3.40)	38 (3.85)	38 (3.90)	41 (4.20)
510	22 (2.25)	25 (2.50)	28 (2.80)	28 (2.80)	28 (2.80)

Design stresses for pressure vessels are based on a factor of safety of 5

Table 9.12: Recommended Values of Allowable Stress for Structural Joints, MN/m^2 (kgf/mm^2)

	Shop assembly	Field assembly
Tensile stress of the plate	115 (11.7)	115 (11.7)
Shear stress of the rivet	86 (8.8)	70 (7.1)
Crushing stress of the rivet	210 (21.4)	140 (14.2)

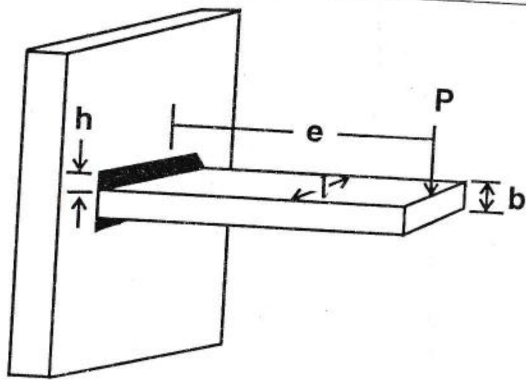
CHAPTER – 10

WELDED JOINTS

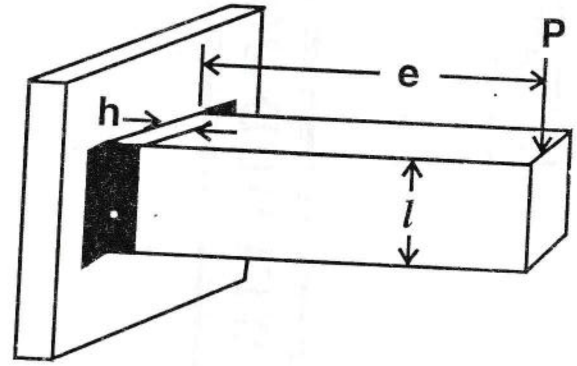
Symbols (with S.I. Units)

b	–	Width of plate, mm
d	–	Diameter of rod, mm
e	–	Eccentricity, mm
h	–	Size of weld, Plate thickness, mm.
J	–	Polar moment of inertia, mm^4
l	–	Length of weld, mm
M	–	Bending moment, N-mm
P	–	Applied load, N
r	–	Radius of rod, mm
S_{p1}	–	Maximum principal (or normal) stress, N/mm^2
S_{sm}	–	Maximum shear stress, N/mm^2
S_b	–	Bending stress, N/mm^2
S_s	–	Shear stress, N/mm^2
S_t	–	Tensile stress, N/mm^2
S_{s1}	–	Primary shear stress, N/mm^2
S_{s2}	–	Secondary shear stress, N/mm^2
T	–	Twisting moment or torque, N-mm.
t	–	Throat thickness, mm
Z	–	Section modulus, mm^3
σ	–	Normal stress, N/mm^2
τ	–	Shear stress, N/mm^2
θ	–	Angle between primary and secondary shear stresses, deg.

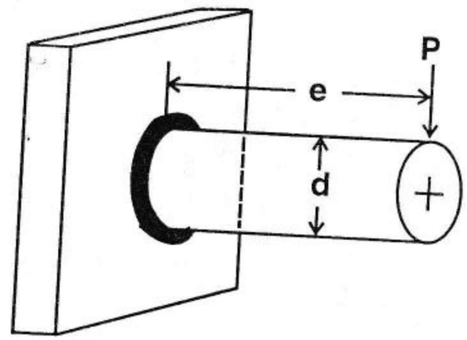
DESIGN PARTICULARS	EQUATIONS
Strength of eccentrically loaded fillet welds:	
For case 1, case 2, case 3:	



Case 1



Case 2



Case 3

Fig. 10.1

DESIGN PARTICULARS	EQUATIONS
Maximum normal stress	$S_{p1} = \frac{1}{2}\left[S_b + \sqrt{S_b^2 + 4S_s^2} \right]$ .... (10.1)

DESIGN PARTICULARS	EQUATIONS
Maximum normal stress	$S_{p1} = \frac{1}{2}\left[S_b + \sqrt{S_b^2 + 4S_s^2} \right]$ .... (10.1)
Maximum shear stress	$S_{sm} = \frac{1}{2}\sqrt{S_b^2 + 4S_s^2}$ .... (10.2)
	$\left.\begin{array}{l} S_b = P.e/0.707\,hbl \\ S_s = P/1.414\,h\,l \end{array}\right]$ for case 1
	$\left.\begin{array}{l} S_b = 4.242\,P.e/h\,l^2 \\ S_s = P/1.414\,h\,l \end{array}\right]$ for case 2
	$\left[\begin{array}{l} S_b = 5.66\,Pe/\pi\,d^2\,h \\ S_s = P/0.707\,\pi\,d\,h \end{array}\right]$ for case 3

For case 4:

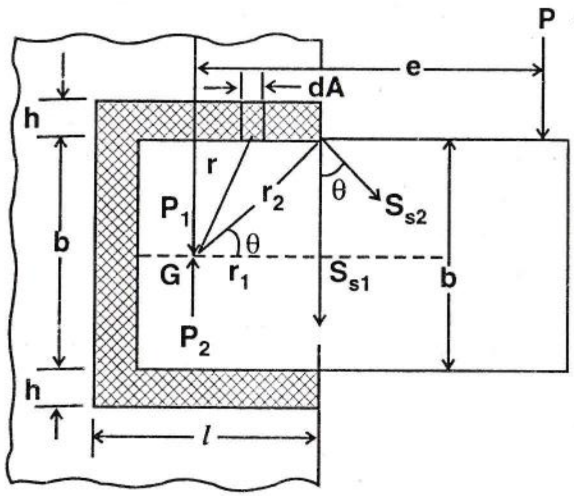


Fig. 10.2

DESIGN PARTICULARS	EQUATIONS
Maximum resultant shear stress	$S_r = \sqrt{S_{s1}^2 + S_{s2}^2 + 2\,S_{s1}\,S_{s2}\cos\theta}$ .... (10.3)
	$S_{s1} = P/[h\,(1.414\,l + 0.707\,b)]$
	$S_{s2} = Pe\,r_2/J$
	$\cos\theta = r_1/r_2$ (for the values of J, refer table 10.8)
For other types of welds, refer figure 10.4	
Throat thickness	$t = 0.707\,h$ .... (10.4)

TYPE OF WELDS AND SYMBOLS

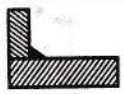
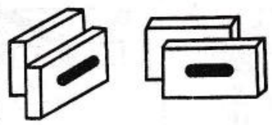
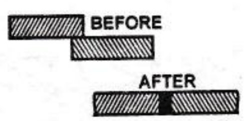
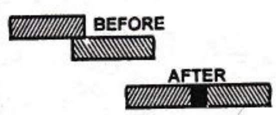
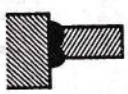
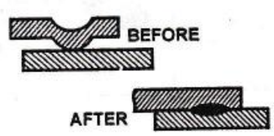
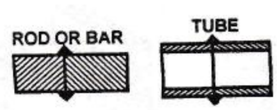
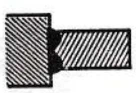
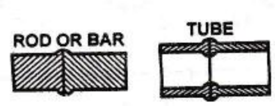
Form of weld	Sectional representation	Appropriate symbol	Form of weld	Sectional representation	Appropriate symbol
Fillet		◺	Plug or slot		⏢
Square butt		Π	Backing strip		=
Single-V butt		⌵	Spot		Ж
Double-V butt		⊗	Seam		XXX
Single-U butt		Ʊ	Mashed Seam		⋈XX
Double-U butt		8	Stitch		)(
Single bevel butt		P	Mashed Stitch		⋈
Double bevel butt		K	Projection		△
Single-J butt		P	Flash		И
Double-J butt		B	Butt resistance or Pressure (upset)		|
Stud		⊥			
Bead (edge or seal)		⌓			
Sealing run		○			

Fig. 10.3

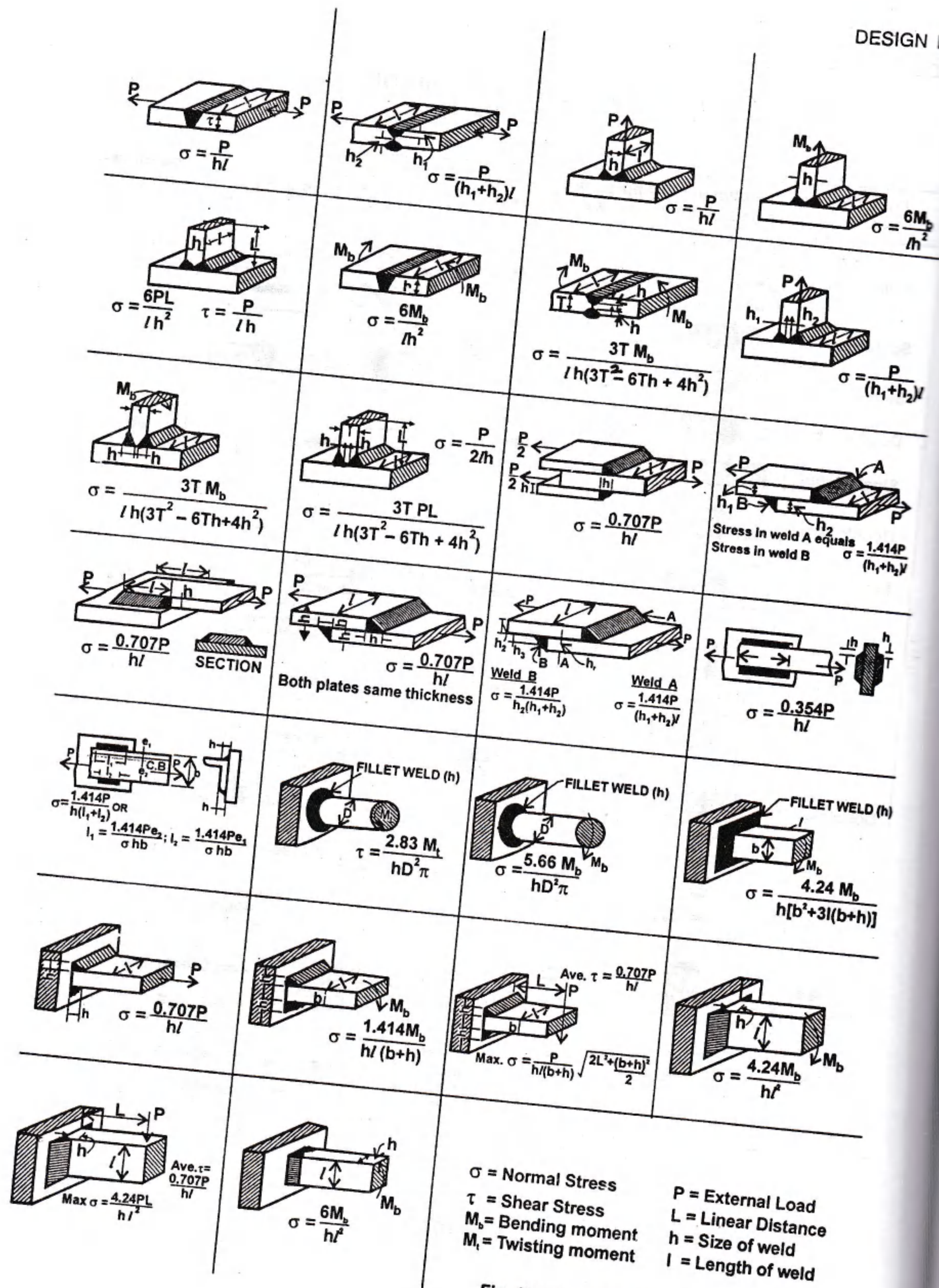


Fig. 10.4. WELD STRESS FORMULAE

Table 10.1

Master Chart of Welding Processes

Arc welding	Gas welding	Resistance welding	Solid state welding	Brazing	Other processes
(1) Carbon arc welding	(1) Oxy – acetylene welding	(1) Spot welding	(1) Cold welding	(1) Infrared brazing	(1) Electron welding
(2) Shielded metal arc welding	(2) Oxy – hydrogen welding	(2) Seam welding	(2) Diffusion welding	(2) Torch brazing	(2) Electroslag welding
(3) Flux cored arc welding	(3) Pressure gas welding	(3) Projection welding	(3) Explosion welding	(3) Furnace brazing	(3) Induction welding
(4) Gas metal arc welding		(4) Flash welding	(4) Forge welding	(4) Induction brazing	(4) Laser beam welding
(5) Gas tungsten arc welding		(5) Upset welding	(5) Friction welding	(5) Resistance brazing	(5) Thermit welding
(6) Submerged arc welding		(6) Percussion welding	(6) Ultrasonic welding	(6) Dip brazing	
(7) Plasma arc welding					
(8) Stud welding					

Table 10.2 : Design Stresses for Welded Joints Made with Mild Steel Electrodes

(in N/mm^2)

Type of weld and stress	Bare Electrode $S_u = 275 - 375\ N/mm^2$			Coated Electrode $S_u = 410 - 515\ N/mm^2$		
	Steady load	Variable loads (i.e., Fatigue)		Steady load	Variable loads (i.e., Fatigue)	
		(+F to −F)	(0 to F)		(+F to −F)	(0 to F)
Butt welds						
In tension	90	34	56	110	55	93
In compression	100	34	56	124	55	93
In shear	55	21	35	70	34	62
Fillet welds						
All types	79	21	32	96	34	50

Table 10.3: Stress Concentration Factors for Welded Joints

Type of joint	Stress concentration factor
Static loading	
Any type of joint	1.0
Fatigue loading	
Reinforced butt weld	1.2
Toe of transverse fillet weld	1.5
T-butt joint with sharp corner	2.0
End of parallel fillet weld.	2.7

Table 10.4: Recommended Minimum Size of Fillet Welds.

Plate thickness (mm)	Minimum size of weld (mm)
3 to 5	3
6 to 8	5
10 to 16	6
18 to 24	10
26 to 35	14
over 38	20

Table 10.5: Properties of Deposited Weld Metal

Property	Bare Electrode		Coated Electrode	
	Minimum	Maximum	Minimum	Maximum
Yield point, MN/m^2 (kgf/mm^2)	235 (24.0)	275 (28.0)	290 (29.5)	380 (38.7)
Ultimate strength, MN/m^2 (kgf/mm^2)	310 (31.6)	380 (38.7)	415 (42.2)	482 (49.2)
Endurance strength, MN/m^2 (kgf/mm^2)	110 (11.3)	137 (14.0)	180 (18.3)	210 (21.1)
% Elongation, 50 mm	8	15	25	35
% Reduction of area	15	20	45	65
Impact strength, Izod, N-mm (kgf-mm)	6870 (700)	20600 (2100)	53940 (5500)	67700 (6900)
Density, kg/mm^3	7.5×10^{-6}	7.6×10^{-6}	7.81×10^{-6}	7.85×10^{-6}

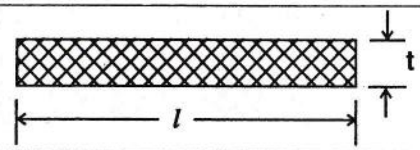
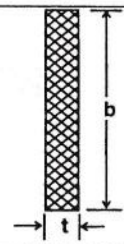
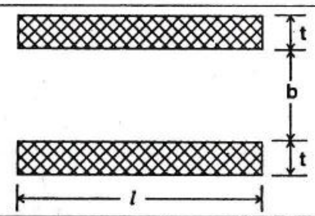
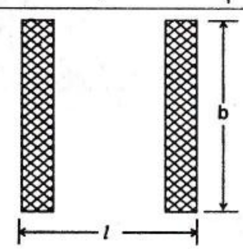
Table 10.6: Allowable Loads on Mild Steel Fillet Welds

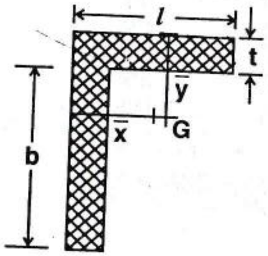
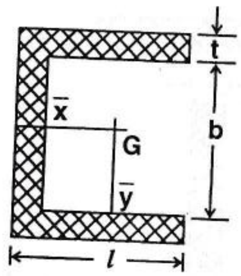
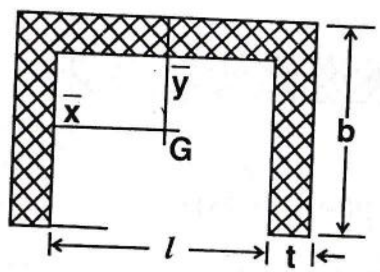
Size of weld, mm	Allowable static load per linear mm of weld, N (kgf)			
	Bare welding rod		Shield arc	
	Normal weld (Tension & compression)	Parallel weld (Shear)	Normal weld (Tension & compression)	Parallel weld (Shear)
3	165 (16.8)	132 (13.5)	206 (21.0)	165 (16.8)
5	275 (28.0)	220 (22.5)	342 (35.0)	275 (28.0)
8	440 (44.8)	350 (36.0)	550 (56.0)	440 (44.8)
10	550 (56.0)	440 (45.0)	686 (70.0)	550 (56.0)
12	660 (67.2)	530 (54.0)	825 (84.0)	660 (67.2)
15	825 (84.0)	662 (67.5)	1030 (105.0)	825 (84.0)
20	1100 (112.0)	880 (90.0)	1370 (140.0)	1100 (112.0)

Table 10.7: Allowable Loads on Mild Steel Butt Welds.

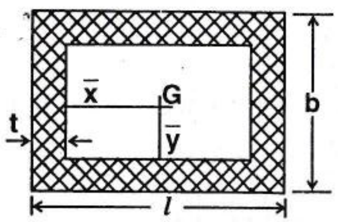
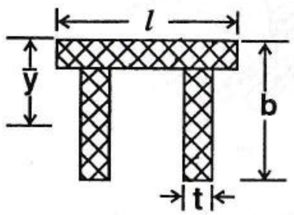
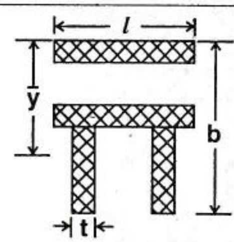
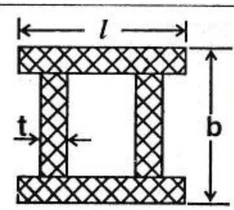
Plate thickness (or) Size of weld mm	Allowable static load per linear mm of weld, N(kgf).			
	Bare welding rod		Shield arc	
	Normal weld (Tension & compression)	Parallel weld (shear)	Normal weld (Tension & compression)	Parallel weld (shear)
3	300 (31.0)	190 (19.5)	380 (38.7)	240 (24.5)
5	450 (46.0)	285 (29.0)	570 (58.0)	360 (36.7)
10	900 (91.7)	570 (58.0)	1140 (116.0)	720 (73.4)
12	1240 (126.4)	775 (79.0)	1550 (158.0)	970 (99.0)
16	1545 (157.0)	960 (98.0)	1930 (197.0)	1200 (122.0)
20	1800 (183.5)	1140 (116.0)	2280 (232.0)	1440 (147.0)
25	2472 (252.0)	1544 (157.0)	3090 (315.0)	1930 (197.0)

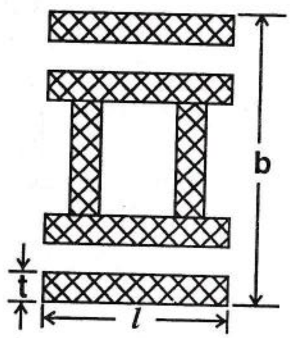
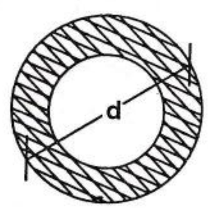
Table 10.8: Section Modulus in Bending (Z) and Polar Moment of Inertia in Torsion (J) for Typical Fillet Welded Connections.

Sl. No.	Type of weld	Section modulus in bending about horizontal axis X-X (Z) mm^3	Polar moment of inertia in torsion (J) mm^4
1.		0	$\frac{t\,l^3}{12}$
2.		$\frac{t\,b^2}{6}$	$\frac{t\,b^3}{12}$
3.		$t\,l\,b$	$\frac{t\,l\,(l^2+3b^2)}{6}$
4.		$\frac{t\,b^2}{3}$	$\frac{t\,b\,(3l^2+b^2)}{6}$

Sl. No.	Type of weld		Section modulus in bending about horizontal axis X-X (Z) mm^3	Polar moment of inertia in torsion (J) mm^4
5.		$\bar{x} = \dfrac{l^2}{2(l+b)}$ $\bar{y} = \dfrac{b^2}{2(l+b)}$	$t\left[\dfrac{4l\,b+b^2}{6}\right]$ (Top) $t\left[\dfrac{b^2(4l\,b+b)}{6(2l+b)}\right]$ (Bottom)	$t\left[\dfrac{(l+b)^4-6l^2b^2}{12(l+b)}\right]$
6.		$\bar{x} = \dfrac{l^2}{(2l+b)}$ $\bar{y} = \dfrac{b}{2}$	$t\left[l\,b+\dfrac{b^2}{6}\right]$	$t\left[\dfrac{(2l+b)^3}{12}-\dfrac{l^2(l+b)^2}{(2l+b)}\right]$
7.		$\bar{x} = \dfrac{l}{2}$ $\bar{y} = \dfrac{b^2}{l+2b}$	$t\left\{\dfrac{2lb+b^2}{3}\right\}$ (Top) $t\left\{\dfrac{b^2(2l+b)}{3(l+b)}\right\}$ (Bottom)	$t\left[\dfrac{(l+2b)^3}{12}-\dfrac{b^2(l+b)^2}{l+2b}\right]$

Sl. No.	Type of weld	Section modulus in bending about horizontal axis X-X (Z) mm^3	Polar moment of inertia in torsion (J) mm^4

Sl. No.	Type of weld		Section modulus in bending about horizontal axis X-X (Z) mm^3	Polar moment of inertia in torsion (J) mm^4
8.		$\bar{x} = \frac{l}{2}$ $\bar{y} = \frac{b}{2}$	$t\left(l\,b + \frac{b^2}{3}\right)$	$\frac{t\,(l+b)^3}{6}$
9.		$\bar{y} = \left(\frac{b^2}{l+2b}\right)$	$\frac{t\,(2lb+b^2)}{3}$ (Top) $t\left\{\frac{b^2\,(2l+b)}{3\,(l+b)}\right\}$ (Bottom)	$t\left[\frac{(l+2b)^3}{12} - \frac{b^2\,(l+b)^2}{l+2b}\right]$
10.		$\bar{y} = \frac{b^2}{2\,(l+b)}$	$\frac{t\,(4lb+b^2)}{3}$ (Top) $t\left\{\frac{4\,lb^2+b^3}{6l+3b}\right\}$ (Bottom)	$t\left[\frac{b^3\,(4l+b)}{6\,(l+b)} + \frac{l^3}{6}\right]$
11.			$t\left(l\,b + \frac{b^2}{3}\right)$	$t\left[\frac{l^3+3\,l\,b^2+b^3}{6}\right]$

Sl. No.	Type of weld	Section modulus in bending about horizontal axis X-X (Z) mm^3	Polar moment of inertia in torsion (J) mm^4
12.		$t\left(2lb + \frac{b^2}{3}\right)$	$t\left[\frac{2l^3 + 6lb^2 + b^3}{6}\right]$
13.		$\frac{\pi d^2 t}{4}$	$\frac{\pi d^3 t}{4}$

(In the above expressions, t is the throat thickness. The size of weld $h = \sqrt{2} \cdot t$.)

CHAPTER – 11

PRESSURE VESSELS AND PIPES

Symbols (with S.I. Units)

d_i – Inner diameter of cylinder or pipe, mm.

d_o – Outer diameter of cylinder or pipe, mm.

d_m – Diameter of mating (or contact) surface in compound cylinders, mm.

E – Modulus of elasticity, N/mm^2

t – Wall thickness of cylinder or pipe, mm.

p_i – Inside pressure of pressure-vessels, N/mm^2

p_o – Outside pressure of pressure-vessels, N/mm^2

p_{cr} – Critical or collapsing pressure, N/mm^2

p_m – Pressure at mating (or contact) surface in compound cylinders, N/mm^2

r_i – Inner radius of cylinder, mm.

r_o – Outer radius of cylinder, mm

r – Radius of assumed section, mm

r_m – Radius of mating surface of compound cylinders, mm.

S_c – Compressive stress, N/mm^2

S_t – Tensile stress, N/mm^2

S_s – Shear stress, N/mm^2

S_R – Radial stress, N/mm^2

S_T – Tangential stress, N/mm^2

S_{th} – Hoop stress, N/mm^2

S_{tl} – Longitudinal stress, N/mm^2

S_y – Yield stress, N/mm^2

S_u – Ultimate stress, N/mm^2

Q – Discharge or flow rate of fluid, m^3/s

v – Velocity of fluid flowing per second, m/s

μ – Poisson's ratio

η_l – Efficiency of longitudinal joint of boiler

η_c – Efficiency of circumferential joint of boiler

δ_d – Increase in diameter, mm.

δ_l – Increase in length, mm.

δ_v – Increase in volume, mm^3

δ_{ro}^{-} – Decrease in outer radius of inner cylinder.

δ_{ri}^{+} – Increase in inner radius of outer cylinder.

DESIGN PARTICULARS	EQUATIONS
PRESSURE VESSELS:	
For thin cylinders	$\frac{d_i}{t} \geq 20$ and/or $\frac{S_t}{p_i} \geq 6$ .... (11.1)
For thick cylinders	$\frac{d_i}{t} < 20$ and/or $\frac{S_t}{p_i} < 6$ .... (11.2)
Thin Cylinders:	
Induced hoop (or circumferential) stress due to gas pressure	$S_{th} = \frac{p_i\, d_i}{2t}$ .... (11.3)
Induced longitudinal stress due to gas pressure	$S_{tl} = \frac{p_i\, d_i}{4t}$ .... (11.4)
Wall thickness of engine cylinders	$t = \frac{p_i\, d_i}{2\, S_t} + 6$ to 12 mm .... (11.5)
Wall thickness of boilers	$t = \frac{p_i\, d_i}{2\, S_t\, \eta_l}$ .... (11.6)
	$\eta_l = 0.6$ to 0.8 for single riveted
	$= 0.75$ to 0.85 for double riveted
	$= 0.8$ to 0.9 for triple riveted.

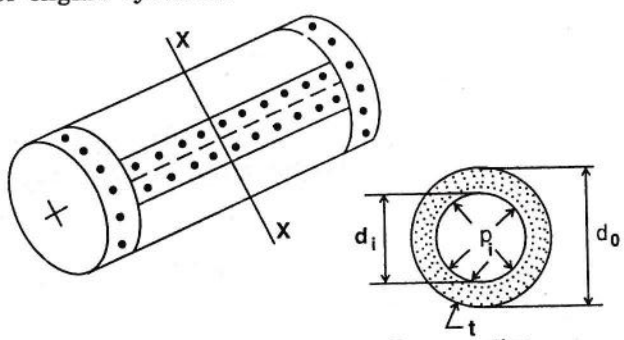
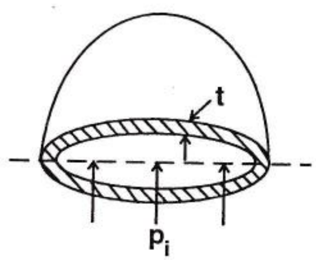


Fig. 11.1

DESIGN PARTICULARS	EQUATIONS
Permissible steam pressure on steel and iron pipes (according to ASME Boiler code)	$p = \frac{2\,S_t}{d_o}(t - 0.79)$ for d upto 125 mm .... (11.7)
	$= \frac{2S_t}{d_o}(t - 2.5)$ for d over 125 mm. .... (11.8)
Critical or collapsing pressure for seamless steel tubes (Professor A.P. Carman's formula)	$P_{cr} = 346122\,(t/d_o)^3$ for $\frac{t}{d_o} < 0.03$ .... (11.9)
	$= 658.6\,(t/d_o) - 14.5$ for $\frac{t}{d_o} > 0.03$ .... (11.10)
Increase in diameter due to internal pressure	$\delta_d = \frac{p_i\,d_i^2}{2t\,E}(1 - 0.5\,\mu)$ .... (11.11)
Increase in length due to internal pressure	$\delta_l = \frac{p_i\,d_i\,l}{2t\,E}(0.5 - \mu)$ .... (11.12)
Increase in volume due to internal pressure	$\delta_v = \frac{\pi}{4}\left(d_i^2\,\delta_l + 2\,d_i\,l\,\delta_d\right)$ .... (11.13)
Thin Spherical Sheli:	
Wall thickness  Fig. 11.2	$t = \frac{p_i\,d_i}{4\,S_t\,\eta_c}$ .... (11.14)

DESIGN PARTICULARS	EQUATIONS
Increase in diameter due to internal pressure	$\delta_d = \dfrac{p_i\, d_i^2}{4t\, E}(1-\mu)$ .... (11.15)
Increase in volume due to internal pressure	$\delta_v = \dfrac{\pi\, p_i\, d_i^4}{8\, tE}(1-\mu)$ .... (11.16)
Thick Cylinders (Single):	
Lame's equations for open and closed cylinders:	
(a) For cylinders subjected to both internal and external pressures:	
Tangential stress at any radius r	$S_T = \left[\dfrac{p_i\, r_i^2 - p_o\, r_o^2}{r_o^2 - r_i^2}\right] + \dfrac{r_i^2\, r_o^2}{r^2}\left[\dfrac{p_i - p_o}{r_o^2 - r_i^2}\right]$ .... (11.17)

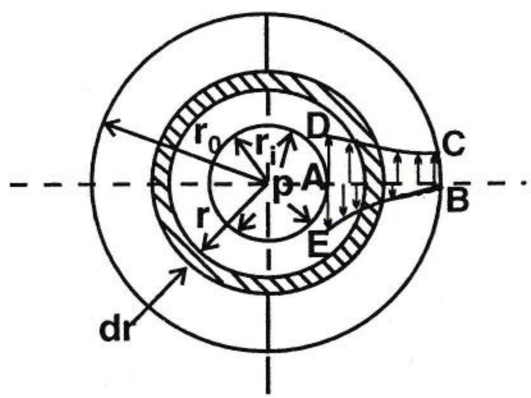


Fig. 11.3

CD – Tangential stress distribution curve.
BE – Radial stress distribution curve.
AD – Maximum tangential stress
BC – Minimum tangential stress
AE – Maximum radial stress
B – Minimum radial stress (zero)

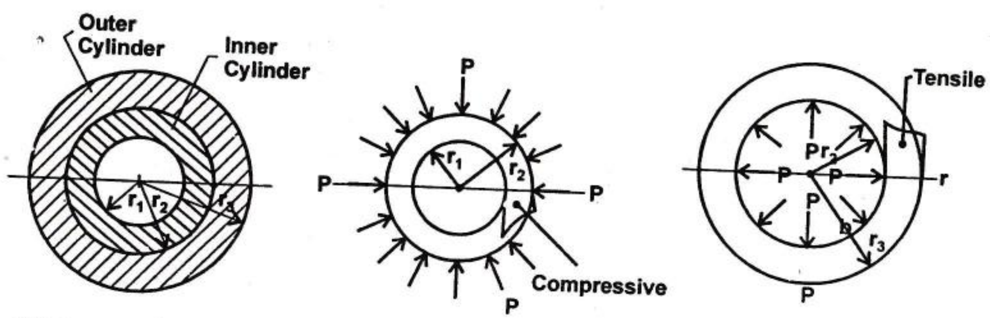
DESIGN PARTICULARS	EQUATIONS
Radial stress at any radius r	$S_R = \left[\frac{p_i r_i^2 - p_o r_o^2}{r_o^2 - r_i^2} \right] - \frac{r_i^2 r_o^2}{r^2} \left[\frac{p_i - p_o}{r_o^2 - r_i^2} \right]$ .... (11.18)
(b) For cylinders subjected to internal pressure only :	
Tangential stress at any radius r	$S_T = \frac{p_i r_i^2}{r_o^2 - r_i^2} \left[1 + \frac{r_o^2}{r^2} \right]$ .... (11.19)
Radial stress at any radius r	$S_R = \frac{p_i r_i^2}{r_o^2 - r_i^2} \left[1 - \frac{r_o^2}{r^2} \right]$ .... (11.20)
Wall thickness based on maximum principal stress	$t = r_i \left[\left\{ \frac{S_t + p_i}{S_t - p_i} \right\}^{1/2} - 1 \right]$ .... (11.21)
Wall thickness based on maximum shear stress	$t = r_i \left[\left\{ \frac{S_s}{S_s - p_i} \right\}^{1/2} - 1 \right]$ .... (11.22)
	$S_s = 0.5\, S_t$

DESIGN PARTICULARS EQUATIONS

DESIGN PARTICULARS	EQUATIONS
Birnie's equations for open cylinders subjected to internal pressures only:	
Tangential stress at any radius r	$S_T = \dfrac{p_i r_i^2}{r_o^2 - r_i^2}\left[(1-\mu) + (1+\mu)\dfrac{r_o^2}{r^2}\right]$ .... (11.23)
Radial stress at any radius r	$S_R = \dfrac{p_i r_i^2}{r_o^2 - r_i^2}\left[(1-\mu) - (1+\mu)\dfrac{r_o^2}{r^2}\right]$ .... (11.24)
Wall thickness based on maximum strain	$t = r_i\left[\left\{\dfrac{S_t + (1-\mu)p_i}{S_t - (1+\mu)p_i}\right\}^{1/2} - 1\right]$ .... (11.25)
Clavarino's equations for closed cylinders subjected to internal pressures only:	
Tangential stress at any radius r	$S_T = \dfrac{p_i r_i^2}{r_o^2 - r_i^2}\left[(1-2\mu) + (1+\mu)\dfrac{r_o^2}{r^2}\right]$ .... (11.26)
Radial stress at any radius r	$S_R = \dfrac{p_i r_i^2}{r_o^2 - r_i^2}\left[(1-2\mu) - (1+\mu)\dfrac{r_o^2}{r^2}\right]$ .... (11.27)
Wall thickness based on maximum strain	$t = r_i\left[\left\{\dfrac{S_t + (1-2\mu)p_i}{S_t - (1+\mu)p_i}\right\}^{1/2} - 1\right]$ .... (11.28)

DESIGN PARTICULARS	EQUATIONS
Barlow's equation for high pressure oil and gas pipes :	
Wall thickness of pipe	$t = \dfrac{p_i\, r_o}{S_t}$ .... (11.29)
	$S_t = 0.8\, S_y$ for ductile material
	$= 0.125\, S_u$ for brittle material.
	$\mu = 0.25$ to 0.35
Thick Cylinders (Compound) :	
Tangential stress at the inner surface of assembly	$S_{Ti} = \dfrac{p_i\,(r_o^2 + r_i^2)}{r_o^2 - r_i^2} - \dfrac{2\, p_m\, r_m^2}{r_m^2 - r_i^2}$ .... (11.30)
Tangential stress at the mating surface of assembly	$S_{Tm} = \dfrac{2 p_i r_i^2}{r_m^2}\left[\dfrac{r_o^2 + r_m^2}{r_o^2 - r_i^2}\right] + p_m \left[\dfrac{r_o^2 + r_m^2}{r_o^2 - r_m^2} - \dfrac{r_m^2 + r_i^2}{r_m^2 - r_i^2}\right]$ .... (11.31)
Tangential stress at the outer surface of assembly	$S_{To} = \dfrac{2\, p_i\, r_i^2}{r_o^2 - r_i^2} + \dfrac{2\, p_m\, r_m^2}{r_o^2 - r_m^2}$ .... (11.32)

DESIGN PARTICULARS	EQUATIONS



(a) Compound cylinder (b) Inner cylinder (c) Outer cylinder

Stresses in compound cylindrical shells.

Fig. 11.4

DESIGN PARTICULARS	EQUATIONS	
Pressure developed at the mating surfaces	$p_m = \frac{E\,\delta_r}{r_m}\left[\frac{(r_o^2 - r_m^2)\,(r_m^2 - r_i^2)}{2\,r_m^2\,(r_o^2 - r_i^2)}\right]$	.... (11.33)
Difference in change of radii.	$\delta_r = \delta_{ri}^{+} - \delta_{ro}^{-}$	
Cylinder head cover plates for thick cylinders:		
Thickness of circular flat cover plate	$t' = k_1\,d_i\sqrt{\frac{p_i}{S_t}}$	.... (11.35)

DESIGN PARTICULARS	EQUATIONS
Thickness of rectangular flat cover plate	$t' = ab\,k_2 \sqrt{\dfrac{p_i}{S_t\,(a^2+b^2)}}$ .... (11.36) a = length of plate b = width of plate. k_1 & k_2 = constants = 0.5 & 0.6 respectively
Thickness of dished cover plate	$t' = \dfrac{4.2\,p_i\,R}{S_u}$ .... (11.37) R – Radius of curvature of dished head $= 3\,d_i$
Pipes:	
Inside diameter of pipe	$d_i = \sqrt{\dfrac{4\,Q}{\pi\,v}}$ .... (11.38)
Wall thickness of thin pipe	$t = \dfrac{p_i\,d_i}{2\,S_t} + C$ .... (11.39) (For C refer table 11.2)
Wall thickness of thick pipe	$t = r_i \left[\left\{ \dfrac{S_t + p_i}{S_t - p_i} \right\}^{1/2} - 1 \right]$ .... (11.40) (For S_t refer table 11.3)

Table 11.1: Plate Thickness of Boiler

Boiler inside diameter (d_i)	Minimum plate thickness required (t)
$d_i \leq 900$ mm	6 mm
$900 < d_i \leq 1350$ mm	7.5 mm
$1350 < d_i \leq 1800$ mm	9 mm
$d_i > 1800$ mm	12 mm

Table 11.2: Value of C

Material	C in mm
Cast iron	9
Mild steel	3
Zinc and copper	4
Lead	5

Table 11.3: Allowable Tensile Stresses for Pipes

S.No.	Pipe materials	Allowable tensile stress (S_t)	
		N/mm^2	kgf/cm^2
1.	Cast-iron steam or water pipes	14	140
2.	Cast-iron steam engine cylinders	12.5	125
3.	Lap welded wrought-iron tubes	60	600
4.	Solid drawn steel tubes	140	1400
5.	Copper steam pipes	25	250
6.	Lead pipes	1.6	16

Table 11.4: Percentage Error when Thick Cylinder is Treated as Thin Cylinder

$\frac{d_i}{t}$	100	50	20	10	5	2
Error %	1	2	4.8	9.9	18.9	40

Error upto 5% can be tolerated in many practical applications.

CHAPTER – 12

SPRINGS

Symbols (with S.I. Units)

Helical springs:

b	–	Width of wire in rectangular spring, mm
C	–	Spring index, $\left(C = \frac{D}{d} \text{ (or) } \frac{D}{b}\right)$
D	–	Mean coil diameter of circular or rectangular spring, mm.
d	–	Wire diameter of circular spring, mm
e	–	Eccentricity, mm
f_s	–	Factor of safety
G	–	Modulus of rigidity, N/mm^2
g	–	Acceleration due to gravity, m/s^2
K	–	Wahl's shear stress factor
k	–	Spring rate (or) stiffness, $\left(k = \frac{P}{\delta}\right)$
K_b	–	Buckling factor
L_f	–	Free length of spring, mm

N – Total number of coils, Unit of force in newtons.

n – Number of active (i.e., cushioning) coils.

P – Axial load, N

P_d – Design load in eccentric loading, N

P_{cr} – Critical (or) Buckling load, N

P_m – Mean shear load, N

P_v – Variable shear load, N

p – Pitch of the spring coil, mm

S_e – Endurance limit in completely reversed bending load, N/mm^2

S_s – Maximum shear stress, N/mm^2

S_y – Yield tensile stress, N/mm^2

S_u – Ultimate tensile stress, N/mm^2

S_{es} – Endurance limit in shear loading, N/mm^2

S_{ys} – Yield shear stress, N/mm^2

S_{ms} – Mean shear stress, N/mm^2

S_{vs} – Variable shear stress, N/mm^2

t – Thickness of wire in rectangular spring, mm

U – Resilience (i.e., workdone) of the spring, N-mm.

x – Radial clearance in co-axial composite spring, mm

δ – Deflection produced during loading, mm

δ_{max} – Maximum deflection, mm

ρ – Density of spring material, kg/m^3

ω_n – Natural frequency of spring, Hz

Leaf spring

a –

b –

C –

d –

E –

L –

l –

L_m –

L_r –

n –

n_f –

n_g –

P –

P_b –

S_b –

S_{bf} –

S_{bg} –

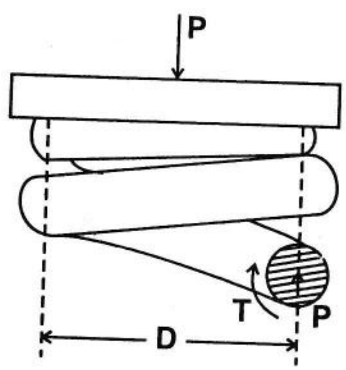
t –

W –

δ –

Leaf springs:

a	–	Width of band (i.e., ineffective length), mm
b	–	Width of leaf (i.e., spring plate), mm
C	–	Nip (or) initial gap for prestressing, mm
d	–	Eye diameter of master leaf, mm
E	–	Modulus of elasticity, N/mm^2
L	–	Span length of spring, $(L = 2l + a)$
l	–	Half of the effective length
L_m	–	Length of master leaf, mm
L_r	–	Length of r^{th} leaf from shortest leaf, mm
n	–	Total number of leaves
n_f	–	Number of full length leaves
n_g	–	Number of graduated leaves
P	–	Load acting at the end of spring i.e., at the eye $\left(P = \frac{W}{2}\right)$, N
P_b	–	Load on clipping bolts, N
S_b	–	Bending stress, N/mm^2
S_{bf}	–	Bending stress in full length leaves, N/mm^2
S_{bg}	–	Bending stress in graduated leaves, N/mm^2
t	–	Thickness of leaf, mm
W	–	Load acting at the centre $(W = 2P)$, N
δ	–	Deflection of leaf spring, mm.

DESIGN PARTICULARS	EQUATIONS
Helical springs subjected to static loading:	
For circular section:	
Maximum shear stress induced in the spring	$S_s = \frac{8K\,PD}{\pi d^3}$ (or) $\frac{8\,K\,PC}{\pi d^2}$ .... (12.1)
Deflection of spring (i.e., total deformation of all the coils)	$\delta = \frac{8\,PD^3\,n}{Gd^4}$ (or) $\frac{8\,PC^3\,n}{Gd}$ .... (12.2)
Spring rate (i.e., stiffness of spring)	$k = \frac{P}{\delta} = \frac{Gd^4}{8D^3\,n}$ (or) $\frac{Gd}{8C^3\,n}$ .... (12.3)
Free length of spring	$L_f = Nd + 1.15\,\delta_{max}$ (For compression spring) .... (12.4)
	$= nd + (n-1)\,1$ mm (For tension spring) .... (12.5)
 Fig. 12.1	$K = \frac{4C-1}{4C-4} + \frac{0.615}{C}$ and $C = \frac{D}{d}$ (Refer figure 12.3 for K i.e., Wahl's shear stress factor)

DESIGN PARTICULARS	EQUATIONS		
For non-circular section:	**Rectangular Section**	**Square section**	
Maximum shear stress induced in the spring	$S_s = \frac{KPD\,(1.5\,t + 0.9b)}{b^2\,t^2}$ for $t > b$	$S_s = \frac{2.4\,KPD}{b^3}$	.... (12.6)
	$\frac{KPD\,(1.5\,b + 0.9\,t)}{\ldots}$ (for $t < b$)	(Here $b = t$)	

DESIGN PARTICULARS	EQUATIONS: Rectangular Section	EQUATIONS: Square section	
For non-circular section:			
Maximum shear stress induced in the spring	$S_s = \dfrac{KPD\,(1.5\,t + 0.9b)}{b^2\,t^2}$ for $t > b$	$S_s = \dfrac{2.4\ KPD}{b^3}$	.... (12.6)
	$= \dfrac{KPD\,(1.5\,b + 0.9\,t)}{b^2\,t^2}$ (for $t < b$)	(Here $b = t$)	
Deflection of spring	$\delta = \dfrac{2.83\ PD^3\,n\,(b^2 + t^2)}{Gb^3\,t^3}$	$\delta = \dfrac{5.66\ PD^3\,n}{Gb^4}$	.... (12.7)
Free length of compression spring	$L_f = Nt + 1.15\,\delta_{max}$	$L_f = Nb + 1.15\,\delta_{max}$	.... (12.8)
	$K = \dfrac{4C-1}{4C-4} + \dfrac{0.615}{C}$, $C = \dfrac{D}{b}$ and $k = \dfrac{P}{\delta}$		

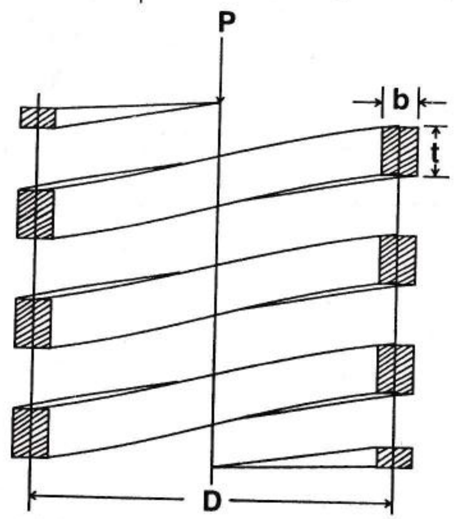


Fig. 12.2.

DESIGN PARTICULARS	EQUATIONS
Pitch of the spring coil for circular and non-circular sections	$p = \dfrac{L_f}{N-1}$ (For compression spring) .... (12.9) $= \dfrac{L_f}{n-1}$ (For tension spring) .... (12.10)

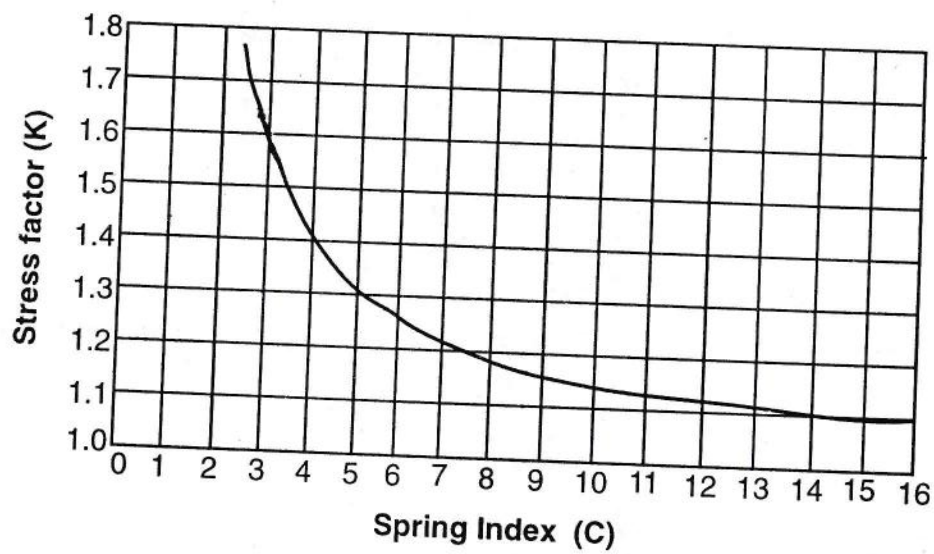
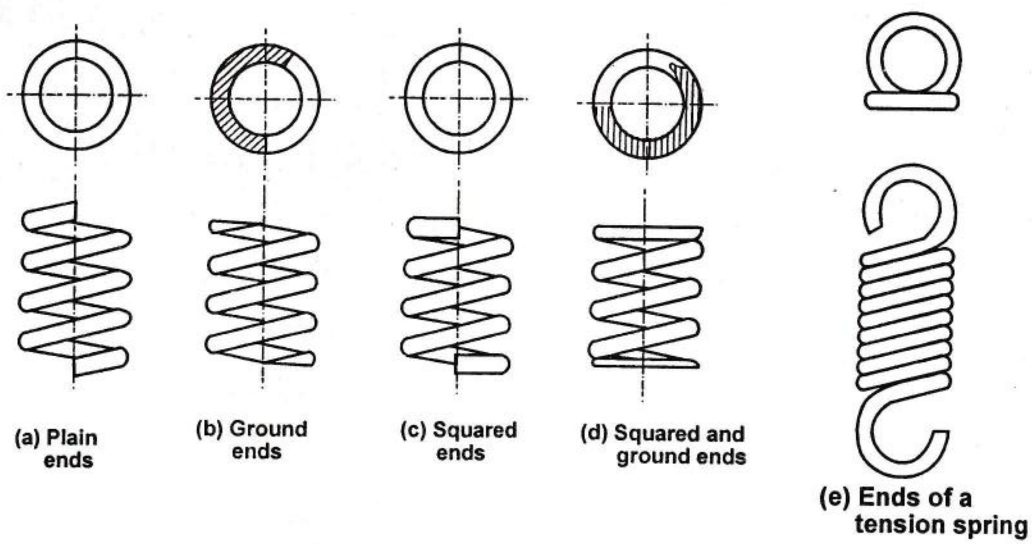


Fig. 12.3 : Wahl's stress factor for helical spring

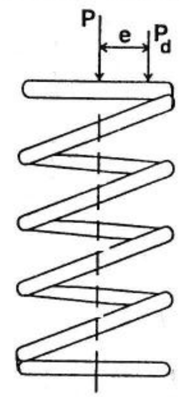
DESIGN PARTICULARS	EQUATIONS

DESIGN PARTICULARS	EQUATIONS

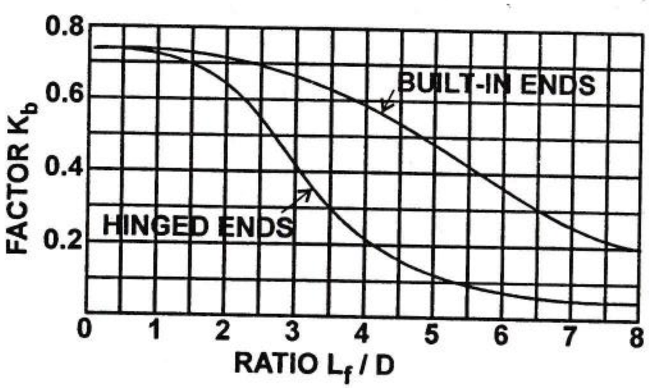


End conditions for compression springs

Fig. 12.4

DESIGN PARTICULARS	EQUATIONS
Safe (i.e., design) load for eccentric loaded springs  Fig. 12.5	$P_d = \dfrac{PD}{(2e + D)}$ .... (12.11)
Critical (or buckling) load for long springs	$P_{cr} = k \cdot K_b \cdot L_f$ (for $L_f > 4D$) .... (12.12)

For K_b, refer Fig. 12.6



Buckling factor for helical compression springs

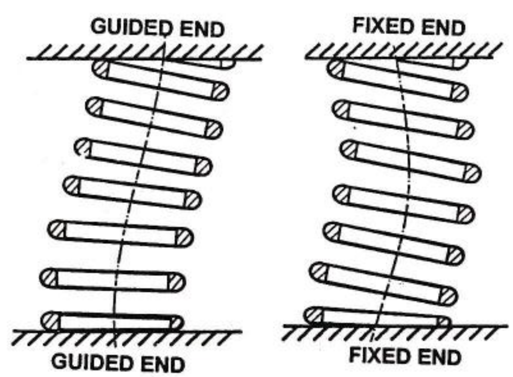
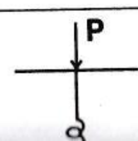


Fig. 12.6

DESIGN PARTICULARS	EQUATIONS
The resilience of the spring (i.e., workdone by the spring) 	$U = \dfrac{P\,\delta}{2}$ .... (12.13)
Resultant stiffness for	$\dfrac{1}{} = \dfrac{1}{} + \dfrac{1}{}$ (or) $k = \dfrac{k_1\,k_2}{}$ .... (12.14)

DESIGN PARTICULARS	EQUATIONS
The resilience of the spring (i.e., workdone by the spring)	$U = \frac{P\,\delta}{2}$ .... (12.13)
Resultant stiffness for springs connected in series	$\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2}$ (or) $k = \frac{k_1 k_2}{k_1 + k_2}$ .... (12.14)
Resultant stiffness for springs connected in parallel	$k = k_1 + k_2$ .... (12.15)

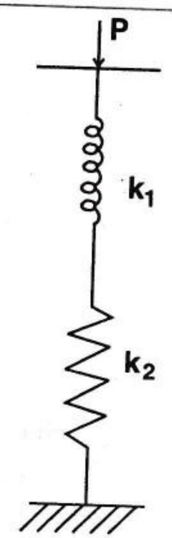


Fig. 12.7

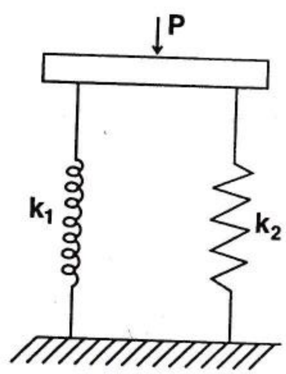
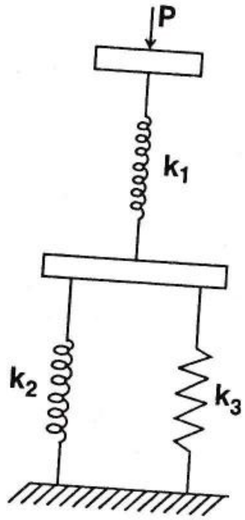
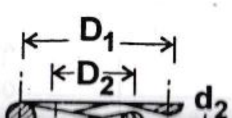
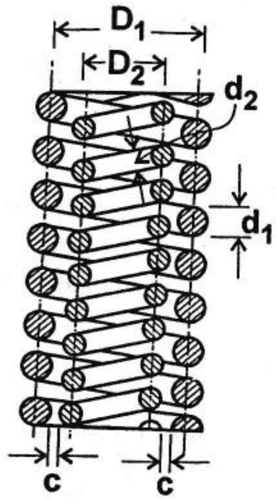


Fig. 12.8

DESIGN PARTICULARS	EQUATIONS
Resultant stiffness for springs connected in series-parallel  Fig. 12.9	$\frac{1}{k} = \frac{1}{k_1} + \frac{1}{(k_2 + k_3)}$ (or) $k = \frac{k_1 (k_2 + k_3)}{(k_1 + k_2 + k_3)}$ .... (12.16)
Natural frequency for spring clamped between two plates	$\omega_n = \frac{d}{2 \pi D^2 n} \sqrt{\frac{6\,Gg}{\rho}}$ cycles/sec. (i.e., Hz) ..... (12.17)
Concentric or co-axial springs:	
Characteristics of concentric springs made of same materials.	$S_{s1} = S_{s2}$; $\frac{P_1}{P_2} = \left(\frac{d_1}{d_2}\right)^2$ $\frac{D_1}{d_1} = \frac{D_2}{d_2} = C$; $D_1 - D_2 = 2d_1$

DESIGN PARTICULARS	EQUATIONS
	$\frac{d_1}{d_2} = \frac{C}{C - 2}$ .... (12.18) $d_1 - d_2$

DESIGN PARTICULARS	EQUATIONS
 **Concentric or composite springs** **Fig. 12.10**	$\frac{d_1}{d_2} = \frac{C}{C-2}$ .... (12.18) $x = \frac{d_1 - d_2}{2}$ (Suffixes 1, 2 refer to outer and inner springs respectively)
Helical springs subjected to variable (i.e. fatigue) loading:	
Soderberg equation for fatigue loaded springs	$\frac{1}{f_s} = \frac{S_{ms} - S_{vs}}{S_{ys}} + \frac{2\,S_{vs}}{S_{es}}$ .... (12.19) $\left.\begin{aligned} S_{ms} &= \frac{8K\,P_m D}{\pi\,d^3}; \quad P_m = \frac{P_{max} + P_{min}}{2} \\ S_{vs} &= \frac{8\,K\,P_v\,D}{\pi\,d^3}; \quad P_v = \frac{P_{max} - P_{min}}{2} \end{aligned}\right\}$ .... (12.20)

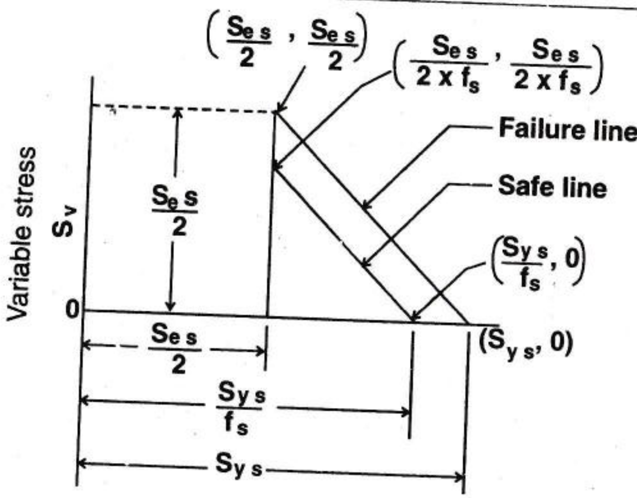
DESIGN PARTICULARS	EQUATIONS
 Fig. 12.11 : Soderberg line for fatigue loading	$S_{ys} \simeq 0.6\, S_y$; $S_{es} \simeq 0.6\, S_e$; $S_{us} = 0.6\, S_u$ $K = \frac{4C-1}{4C-4} + \frac{0.615}{C}$; $C = \frac{D}{d}$

Table 12.1: Spring Design Stresses, N/mm²

Wire diameter (mm)	Design Stress		
	Severe Service	Average Service	Light Service
Upto 2.10	414	517	640
2.10 – 4.50	380	476	586
4.50 – 8.00	330	414	510
8.00 – 13.00	290	360	448
13.00 – 25.00	248	310	386
25.00 – 38.00	220	276	345

Table 12.2: Mechanical Properties of Materials for Helical Springs

Material	Ultimate tensile strength N/mm²	Yield strength (Tensile) N/mm²	Working stress (Tensile) N/mm²	Ultimate shear strenth N/mm²	Yield strength (Shear) N/mm²	Working stress (Shear) N/mm²	Modulus of elasticity (E) N/mm²	Modulus of rigidity (G) N/mm²

Table 12.2: Mechanical Properties of Materials for Helical Springs

Material	Ultimate tensile strength N/mm^2	Yield strength (Tensile) N/mm^2	Working stress (Tensile) N/mm^2	Ultimate shear strenth N/mm^2	Yield strength (Shear) N/mm^2	Working stress (Shear) N/mm^2	Modulus of elasticity (E) N/mm^2	Modulus of rigidity (G) N/mm^2
1. Medium carbon steel (C20 to C50)	450 to	260 to	200 to	270 to	160 to	120 to	2.1×10^5 to	0.78×10^5 to
0.2 to 0.5 % C	800	400	350	480	240	200	2.05×10^5	0.80×10^5
2. High carbon steel (C60 to C95)	850 to	420 to	360 to	510 to	260 to	220 to	2.06×10^5 to	0.80×10^5 to
0.6 to 0.95 % C	1350	750	500	860	480	400	2.0×10^5	0.85×10^5
3. Chromium – vanadium steel	1600	1300	750	950	780	450	2.0×10^5	0.8×10^5
4. Silicon – manganese steel	1500	1000	700	900	600	420	2.0×10^5	0.8×10^5
5. Music wire	2000	1000	850	1200	960	500	2.0×10^5	0.78×10^5
6. Phosphor bronze	670	340	260	400	200	150	1.0×10^5	0.42×10^5
7. Brass	640	320	250	380	190	150	1.0×10^5	0.37×10^5
8. Duralumin	440	230	200	260	140	120	0.67×10^5	0.27×10^5

Table 12.3: Types of Helical Spring Ends

Sl. No.	Types of ends	Total number of turns (N)	Inactive number of turns	Solid length (L_s)	Free length (L_f)
1.	Plain ends	n	nil	(n + 1) d	pn + d
2.	Ground ends	n	nil	nd	pn
3.	Squared ends	n + 2	2	(n + 3) d	pn + 3d
4.	Squared and ground ends	n + 2	2	(n + 2) d	pn + 2d

n – Number of active turns.

p – Pitch of coil.

d – Diameter of wire.

Table 12.3(a): Values of Buckling Factor (K_b)

L_f / D	Hinged end spring	Built-in end spring	L_F/D	Hinged end spring	Built-in end spring
1.	0.72	0.72	5.	0.11	0.53
2.	0.63	0.71	6.	0.07	0.38
3.	0.38	0.68	7.	0.05	0.26
4.	0.20	0.63	8.	0.04	0.19

Table 12.4 : Standard Wire Gauge Number and Corresponding Diameter of Spring Wire, in Millimeters.

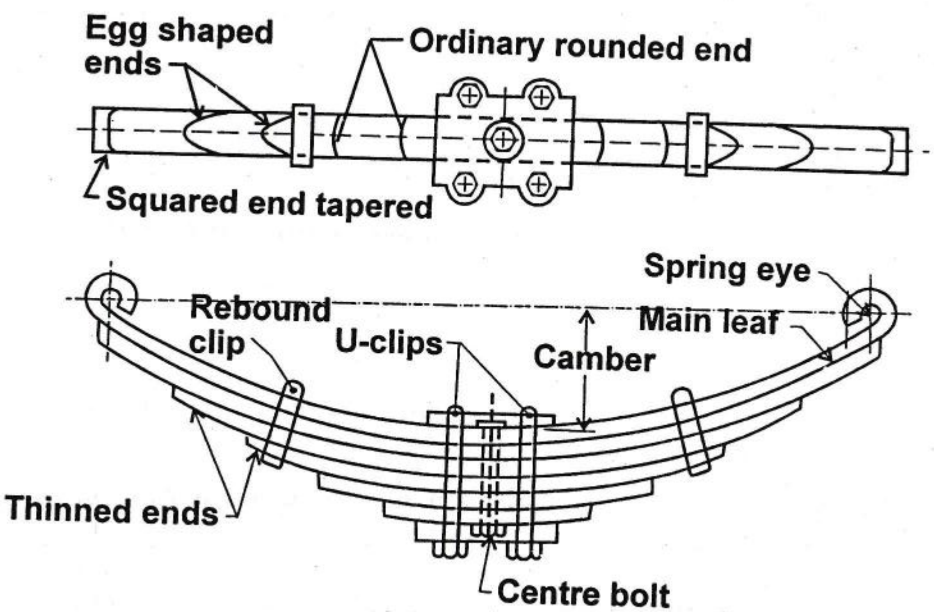
SWG	Diameter	SWG	Diameter	SWG	Diameter
7/0	12.70	11	2.95	28	0.38
6/0	11.79	12	2.64	29	0.35
5/0	10.97	13	2.34	30	0.32
4/0	10.16	14	2.02	31	0.30
3/0	9.49	15	1.83	32	0.27
2/0	8.84	16	1.63	33	0.26
0	8.23	17	1.42	34	0.23
1	7.62	18	1.22	35	0.21
2	7.01	19	1.02	36	0.19
3	6.40	20	0.91	37	0.17
4	5.89	21	0.81	38	0.15
5	5.39	22	0.71	39	0.13
6	4.88	23	0.61	40	0.12
7	4.47	24	0.56	41	0.11
8	4.06	25	0.51	42	0.10
9	3.66	26	0.46	43	0.09
10	3.25	27	0.42	44	0.08

Table 12.5: Standard Wire Sizes for Helical Springs

Size Range, mm	Common difference, mm
0.07 to 0.12	0.01
0.14 to 0.22	0.02
0.25	–
0.28 to 0.42	0.02
0.45 and 0.48	–
0.50 to 0.56	0.03
0.60 and 0.63	–
0.65 to 1.3	0.05
1.40 to 2.1	0.1
2.25	–
2.4 to 2.6	0.1
2.8 to 4.0	0.2
4.25 to 5.0	0.25
5.3 and 5.6	–
6.0 and 6.3	–
6.5 to 13.0	0.5
14.0 to 17.0	1.0

DESIGN PARTICULARS	EQUATIONS
Leaf Springs:	
Leaves (i.e., spring plates) subjected to unequal stresses:	
Bending stress in full length leaves	$S_{bf} = \dfrac{18\,Pl}{bt^2\,(3n_f + 2n_g)}$ .... (12.21)
Bending stress in graduated leaves	$S_{bg} = \dfrac{12\,Pl}{bt^2\,(3n_f + 2n_g)}$ .... (12.22)
Maximum deflection produced in the spring	$\delta = \dfrac{12\,Pl^3}{Ebt^3\,(3n_f + 2n_g)}$ .... (12.23)
Leaves subjected to equal stresses:	
Bending stress induced in the leaves	$S_b = \dfrac{6\,Pl}{nb\,t^2}$ .... (12.24)
Deflection produced in the spring	$\delta = \dfrac{6\,Pl^3}{Enbt^3}$ .... (12.25)
Total number of leaves	$n = n_f + n_g$ .... (12.26)
The nip or initial gap provided to the spring	$C = \dfrac{2\,Pl^3}{En\,bt^3}$ .... (12.27)
Load on clipping bolts	$P_b = \dfrac{2\,P\,n_f \cdot n_g}{n\,(3\,n_f + 2\,n_g)}$ .... (12.28)
Length of r^{th} leaf from shortest leaf (for spring having two full length leaves)	$l_r = \dfrac{2l}{(n-1)} \times r + a$ .... (12.29) r varies from 1 to $(n-1)$

DESIGN PARTICULARS	EQUATIONS
Length of r[th] leaf from shortest leaf, (for spring having three full length leaves)	$l_r = \frac{2l}{(n-2)} \times r + a$ .... (12.30) r varies from 1 to (n − 2)
Length of n[th] leaf or master leaf (for spring having two full length leaves)	$l_m = \frac{2l}{(n-1)} \times (n-1) + a + 2\pi(d+t)$ .... (12.31)
Length of n[th] leaf or master leaf (for spring having three full length leaves)	$l_m = \frac{2l}{(n-2)} \times (n-2) + a + 2\pi(d+t)$ .... (12.32)



Leaf spring or Laminated spring

Fig. 12.12

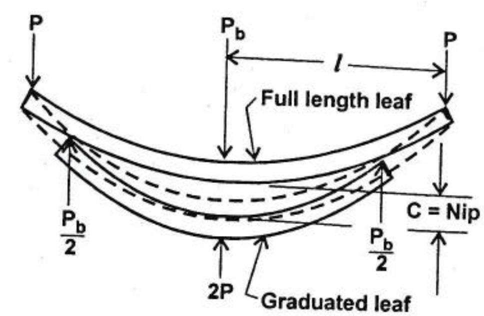


Fig. 12.13

Table 12.6: Mechanical Properties of Materials Commonly Used for Leaf Springs.

Material	Condition	Ultimate tensile strength (kgf/mm^2)	Tensile yield strength (kgf/mm^2)	Brinell hardness number
50 Cr 1	Hardened and tempered	168 – 220	154 – 175	461 – 601
50 Cr 1 V 23		190 – 220	168 – 189	534 – 601
55 Si 2 Mn 90		182 – 206	168 – 192	534 – 601

Table 12.7: Standard Sizes of Automobile Suspension Springs

Item	Sizes in mm
Nominal width (b)	32, 40, 45, 50, 55, 60, 65, 70, 75, 80, 90, 100 and 125 mm
Nominal thickness (t)	3.2, 4.5, 5, 6, 6.5, 7, 7.5, 8, 9, 10, 11, 12, 14 and 16 mm.
Bore diameter of eye in the master leaf	19, 20, 22, 23, 25, 27, 28, 30, 32, 35, 38, 50 and 55 mm.

Table 12.8: Proportions for Leaf Springs (IS: 1135 – 1966)

Breadth of leaf mm	Dia. of centre bolt, mm	Cross-section of clip mm × mm	Diameter of rivet mm	Diameter of bolt mm
32 41 45 50	8 to 10	20 × 4	6	6
55 60	8 to 10	20 × 4	8	8
65 70 75 80	12 to 16	25 × 6	10	10
90 110 125	12 to 16	32 × 6	10	10

Table 12.9: Standard Sections of Flat (Laminated Springs – Railway Rolling Stock)

All dimensions in mm

Width	Thickness	Width	Thickness	Width	Thickness
50	10	90	6	115	10
50	13	90	8	115	11
63	6	90	10	115	13
63	8	90	11	115	16
63	10	90	13	115	19
63	11	90	16	120	16
63	13	90	19	120	19
75	6	100	8	125	10
75	8	100	10	125	13
75	10	100	11	125	16
75	11	100	13	140	11
75	13	100	16	140	13
75	16	100	19	150	11
				150	13
				150	16

CHAPTER – 13

I.C. ENGINE – CYLINDERS AND PISTONS

Symbols (with S.I. Units)

Cylinders :

D	–	Inside diameter (i.e., bore diameter) of cylinder, mm
d	–	Nominal diameter of bolt or stud, mm
d_c	–	Core (i.e., root) diameter of bolt, mm.
L	–	Length of stroke, mm
L_c	–	Length of cylinder, mm
L_p	–	Length of piston, mm
N	–	Speed of the crank, rpm; Unit of force in newtons.
n	–	Number of bolts connected with cylinder head
P_B	–	Brake power, kW
P_I	–	Indicated power, kW
p	–	Maximum gas pressure, N/mm^2
p_m	–	Brake mean effective pressure, N/mm^2
S_t	–	Allowable tensile stress of cylinder material, N/mm^2

S_{tb} – Allowable tensile stress of bolt material, N/mm^2

S_{th} – Allowable tensile stress of cylinder-head material, N/mm^2

t – Thickness of cylinder, mm

t_f – Thickness of flange, mm

t_j – Thickness of water jacket, mm

t_l – Thickness of liner, mm

t_w – Water space between cylinder and jacket, mm

η_m – Mechanical efficiency $\left(\eta_m = \dfrac{P_B}{P_I}\right)$

Pistons :

A – Area of the top side (facing cylinder head) of piston, mm^2

D – Diameter of piston (i.e., bore diameter of cylinder), mm

d_1 – Diameter of piston pin, mm

F_g – Maximum gas force, N

F_s – Side thrust force, N

H – Heat flowing through the head, kW

C_v – Higher calorific value of the fuel, kJ/kg

i – Number of rings

k – Heat conductivity factor, kW/m/°C

L – Stroke length, mm

L_p – Length of piston, mm

L_r – Length of ring-section, mm

L_s – Length of skirt, mm

L_t – Length of top land, mm

l_1 – Length of piston pin, mm

M – Bending moment, N-mm

m – Mass of fuel used (i.e., fuel consumption) (kg/kW/s)

n – Number of power strokes per minute

N – Speed of crank, rpm; Unit of force in newtons.

P_B – Brake power, kW

p – Maximum gas pressure, N/mm^2

p_b – Bearing pressure for piston pin N/mm^2

p_c – Contact pressure by the piston rings, N/mm^2

p_m – Brake mean effective pressure, N/mm^2

p_s – Side thrust pressure, N/mm^2

S_b – Induced bending stress in piston pin N/mm^2

S_{br} – Allowable bending stress of ring material, N/mm^2

S_{tp} – Allowable tensile stress of piston material, N/mm^2

t_1 – Thickness of piston head, mm

t_2 – Thickness of rib, mm

t_3 – Radial thickness piston rings, mm

t_4 – Axial thickness of piston rings, mm

t_5 – Thickness of barrel nearer to piston head, mm

t_6 – Thickness of barrel at the open end of piston, mm

T_c – Temperature at the centre of piston head, °C.

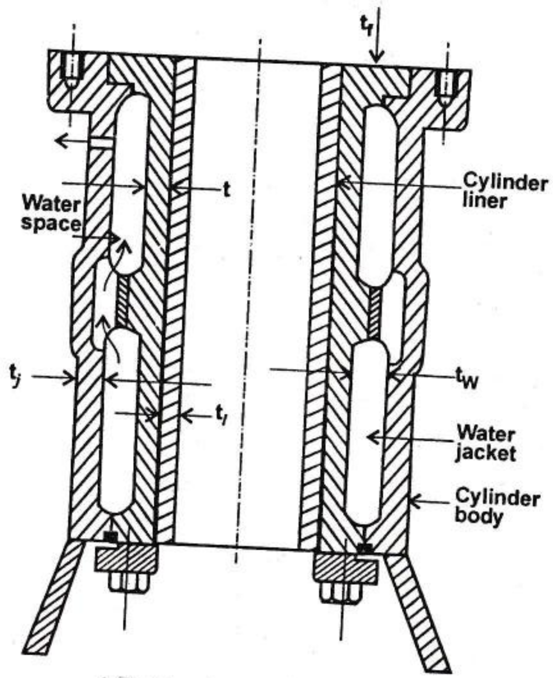
T_e – Temperature at the edge of piston head, °C.

x_1 – Number of rings

x_2 – Number of lands in between the rings.

μ – Coefficient of friction between liner and skirt

DESIGN PARTICULARS	EQUATIONS
I.C. Engine Cylinders:	
Bore diameter of two stroke cylinder	$D = \left[\dfrac{60 \times 10^6 \times 4\, P_I}{\pi\, p_m\, LN}\right]^{1/2}$ mm .... (13.1)
Bore diameter of four stroke cylinder	$D = \left[\dfrac{60 \times 10^6 \times 8\, P_I}{\pi\, p_m\, LN}\right]^{1/2}$ mm .... (13.2)
	$L = (1.2 \text{ to } 1.6)\ D$
	$P_I = \dfrac{P_B}{\eta_m}$; $\eta_m = 0.8$ to 0.9



I.C. Engine – Cylinder

Fig. 13.1

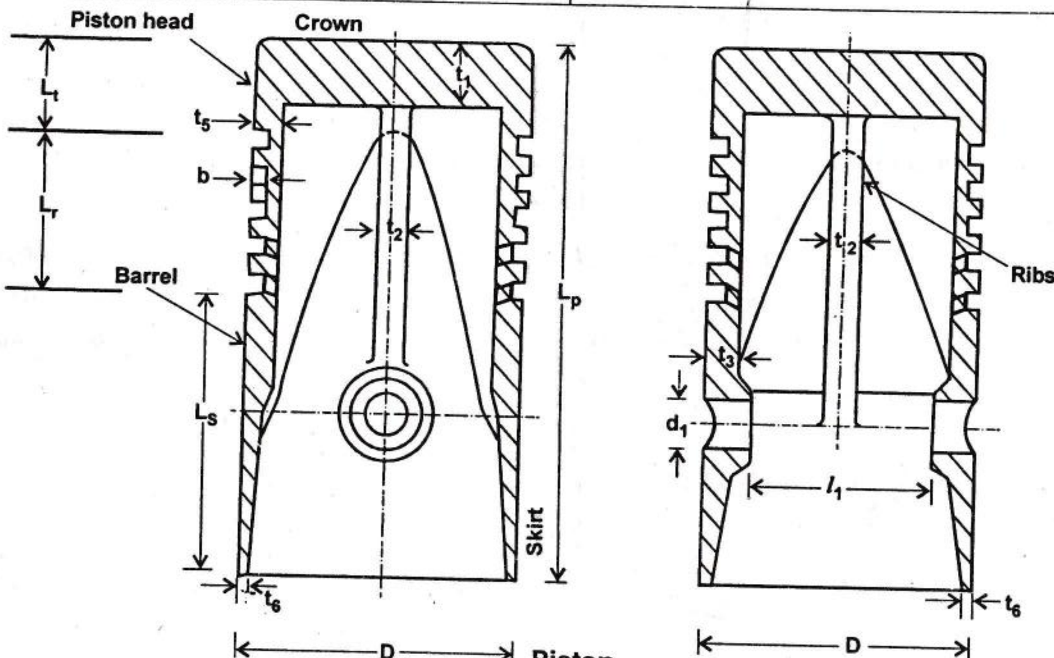
DESIGN PARTICULARS	EQUATIONS
Thickness of cylinder	$t = \dfrac{pD}{2\, S_t} + 6$ to 12 mm $\left(\text{For } \dfrac{S_t}{p} \geq 6\right)$ .... (13.3)
	$= \dfrac{D}{2}\left[\left\{\dfrac{S_t + p}{S_t - p}\right\}^{1/2} - 1\right] + 8$ mm $\left(\text{For } \dfrac{S_t}{p} < 6\right)$ .... (13.4)

DESIGN PARTICULARS	EQUATIONS	
Thickness of cylinder	$t = \frac{pD}{2 S_t} + 6 \text{ to } 12 \text{ mm} \quad \left(\text{For } \frac{S_t}{p} \geq 6 \right)$	.... (13.3)
	$= \frac{D}{2}\left[\left\{\frac{S_t + p}{S_t - p}\right\}^{1/2} - 1\right] + 8 \text{ mm} \quad \left(\text{For } \frac{S_t}{p} < 6 \right)$	.... (13.4)
For water – cooled cylinder :		
Thickness of liner	$t_l = 0.03 D$ to $0.035 D$	.... (13.5)
Thickness of jacket wall	$t_j = 0.032 D + 1.6$ mm	.... (13.6)
Water space between cylinder and jacket	$t_w = 0.08 D + 6.5$ mm	.... (13.7)
Thickness of flange	$t_f = (1.2 \text{ to } 1.4)\, t$	.... (13.8)
Thickness of cylinder head	$t_h = 0.5 D \sqrt{\frac{p}{S_{th}}}$	.... (13.9)
Nominal diameter of bolt or stud	$d \approx 1.2\, d_c\,;\; d_c = \sqrt{\frac{pD^2}{n\, S_{tb}}}$	.... (13.10)
	$n = (0.1 D \text{ to } 0.2 D) + 4$	
Length of cylinder	$L_c = L + L_p$ + Bottom clearance	.... (13.11)
	$S_t = 50$ to 60 N/mm^2 for C.I.	
	$= 80$ to 100 N/mm^2 for steel	
	$S_{tb} = 80$ to 100 N/mm^2	
	$S_{th} = 30$ to 50 N/mm^2	
	Bottom clearance ≈ 8 to 20 mm.	

DESIGN PARTICULARS	EQUATIONS
Pistons:	
Thickness of piston head based on the strength of piston material	$t_1 = \sqrt{\dfrac{3 p_{\max} D^2}{16\, \sigma_{tp}}}$ mm .... (13.13)
	$\sigma_{tp} = 35$ to 40 N/mm^2 for C.I
	$= 60$ to 100 N/mm^2 for steel
	$= 50$ to 90 N/mm^2 for aluminium alloy
Thickness of piston head due to heat dissipation	$t_1 = \dfrac{1000\,H}{12.56\,k\,(T_c - T_e)}$ mm .... (13.14)
	$H = 0.05\, m \times C_v \times P_B$ kW
	$C_v = 44 \times 10^3$ kJ/kg for diesel fuel
	$= 47 \times 10^3$ kJ/kg for petrol fuel
	$P_B = \dfrac{p_m\, LAn}{60 \times 1000 \times 1000}$ kW
	$k = 46.6 \times 10^{-3}$ kW/m/°C for C.I
	$= 51 \times 10^{-3}$ kW/m/°C for steel
	$= 175 \times 10^{-3}$ kW/m/°C for aluminium alloys
	$T_c - T_e = 220$°C for C.I
	$= 75$°C for aluminium alloys.

DESIGN PARTICULARS	EQUATIONS
Piston head Crown	

DESIGN PARTICULARS	EQUATIONS



Piston

Fig. 13.2

DESIGN PARTICULARS	EQUATIONS
Thickness of rib	$t_2 = (0.3 \text{ to } 0.5)\, t_1$ .... (13.15)
Radial thickness of piston rings	$t_r = D\sqrt{\dfrac{3\,p_c}{S_{br}}}$ .... (13.16) $S_{br} = 84$ to $112\ N/mm^2$ for alloy cast-iron.

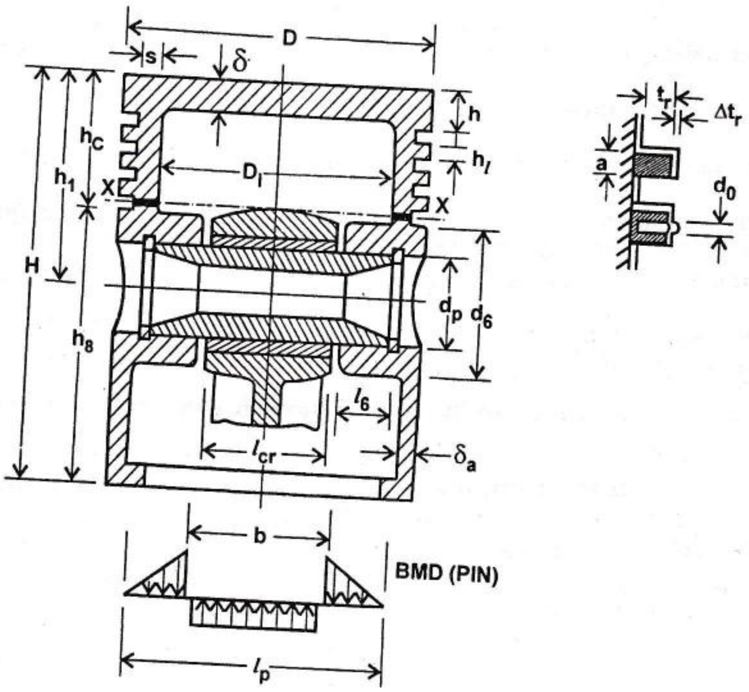
DESIGN PARTICULARS	EQUATIONS	
Axial thickness of piston rings	$t_4 = (0.7 \text{ to } 1)\, t_3$ (or) $D/10\, i$	.... (13.17)
Radial depth of ring-groove	$b = t_3 + 0.4$ mm	.... (13.18)
Thickness of barrel nearer to piston head	$t_5 = 0.03\, D + b + 4.5$ mm	.... (13.19)
Thickness of barrel at the open end of the piston	$t_6 = (0.25 \text{ to } 0.35)\, t_5$	.... (13.20)
Length of skirt	$L_s = \dfrac{\pi\, \mu\, D p}{4\, p_s}$	.... (13.21)
	$p_s \leq 0.4\ N/mm^2$ for high speed engine	
	$\mu = 0.1$	
Length of ring section	$L_r = t_4\, (x_1 + 0.8\, x_2)$	.... (13.22)
	$i t_4 + (i-1) x_2$	
Length of piston	$L_p = L_s + L_r + L_t$	.... (13.23)
	and $L_t = x_1 = t_1$	
	(or)	
	$L_p = D$ to $1.5\, D$	.... (13.24)

DESIGN PARTICULARS	EQUATIONS
Diameter of piston pin	$d_1 = \dfrac{F_g}{p_b \times l_1}$ .... (13.25) $F_g = \dfrac{\pi}{4} D^2 \cdot p$ $l_1 = 1.5\ d_1$
Induced bending stress in piston pin	$S_b = \dfrac{32\ M}{\pi\ d_1^3} \le (S_b)$ .... (13.26) $M = \dfrac{F_g \cdot D}{8}$ $(S_b) = 84\ N/mm^2$ for case hardened steel $= 140\ N/mm^2$ for heat treated alloy steel

Table 13.1: Usual Proportions for Piston, Rings and Piston Pin
Refer figure (13.3)

Description	Petrol engines	Diesel engines
Crown thickness, δ	(0.05 – 0.10) D	(0.12 – 0.20) D
Piston height, H	(0.8 – 1.3) D	(1.0 – 1.7) D
Height of top part, h_1	(0.45 – 0.75) D	(0.6 – 1.0) D
Skirt height, h_s	(0.6 – 0.8) D	(0.6 – 1.1) D
Thickness of skirt wall, δ_s	1.5 – 4.5 mm	2.0 – 5.0 mm
Thickness of crown wall, s	(0.05 – 0.1) D	(0.05 – 0.1) D
Thickness of first land, h_l	(0.03 – 0.05) D	(0.04 – 0.07) D
Distance of the first ring groove, h	(0.06 – 0.12) D	(0.11 – 0.20) D
Radial thickness of ring, t_r	(0.04 – 0.045) D	(0.040 – 0.045) D
Piston ring depth, a	2 – 4 mm	3 – 5 mm
Difference between free gap and compressed gap of ring, A_0	(2.5 – 4.0) t_r	(3.2 – 4.0) t_r
Radial clearance of ring in piston, Δt_r		
for compression ring	0.7 – 0.95 mm	0.7 – 0.95 mm
for oil control ring	0.9 – 1.1 mm	0.9 – 1.1 mm
Piston inner dia, D_i	$D - 2(s + t_r + \Delta t_r)$	
Number of oil holes, n	6 – 12	6 – 12
Oil hole diameter, d_0	(0.3 – 0.5) a	(0.3 – 0.5) a
Pin outer dia, d_p	(0.22 – 0.28) D	(0.3 – 0.38) D
Pin inner dia, d_i	(0.65 – 0.75) d_p	(0.5 – 0.7) d_p
Pin length, l_p		
for retained pin	(0.88 – 0.93) D	(0.88 – 0.93) D
for floating pin	(0.78 – 0.88) D	(0.8 – 0.9) D
Connecting rod bushing length, $l_{c,r}$		
for retained pin	(0.28 – 0.32) D	(0.28 – 0.32) D
for floating pin	(0.33 – 0.45) D	(0.33 – 0.45) D

Reference : Machine Design by Rajendra Karwa.



I.C. Engine – Piston

Fig. 13.3

Table 13.2: Recommended Piston Speed

Class of engine	Speed of piston in m/s
Ordinary direct-acting pumping engines	0.45 – 0.65
Ordinary horizontal engines	1.00 – 2.00
Herizontal compound and Triple-expansion engines	2.00 – 4.00
Ordinary marine engines	2.00 – 3.25
Locomotive engines (mail)	4.00 – 5.00
Internal combustion engine	3.25 – 18.00

Table 13.3: Stroke-Bore Ratio

Class of engine	Ratio, L_s / D
Ordinary horizontal mill engines	1.5 to 2.00
Vertical quick-running engines	1.25 to 1.6
Locomotive engines	1.2 to 1.55
Internal combustion engines	0.9 to 1.9
Air-cooled air-craft engines	1.0

Tabie 13.4: Thickness of Piston Head

Type of engine	Piston material	Four stroke	Two stroke
Compression-ignition oil engines	Cast iron	0.11D – 0.13D	0.16D – 0.18D
-do-	Aluminium	0.13D – 0.16D	0.17D – 0.20D
Spark ignition gas engines	Cast rion	0.12D – 0.14D	0.20D – 0.23D

CHAPTER – 14

PISTON ROD AND CONNECTING ROD

Symbols (with S.I. Units)

A	–	Area of cross-section of piston or connecting rod, mm^2
a	–	Rankine's constant, $(a = S_c/\pi^2 E)$
b	–	Width of cap in big end of connecting rod, mm
C	–	End fixity coefficient
D	–	Diameter of piston, mm
d	–	Diameter of piston-rod, mm
d_1	–	Diameter of piston pin, mm
d_2	–	Diameter of crank-pin, mm
d_b	–	Nominal diameter of bolt, mm
d_c	–	Core diameter of bolt, mm
d_{is}	–	Inner diameter of small end of connecting rod, mm.

d_{os} – Outer diameter of small end of connecting rod, mm

d_{ib} – Inner diameter of big end of connecting rod, mm

d_{ob} – Outer diameter of big end of connecting rod, mm.

E – Modulus of elasticity, N/mm^2

F_a – Axial load acting on the piston rod or connecting rod, N

F_{cr} – Crippling (or buckling) load, N

F_d – Design load, N

F_g – Load due to steam or gas pressure, N

F_i – Inertia force due to reciprocating parts, N

F_{im} – Maximum inertia force, N

f_s – Factor of safety

g – Acceleration due to gravity, m/s^2

I – Area moment of inertia, mm^4

k – Least radius of gyration, mm

L – Equivalent length of column, (i.e., piston rod or connecting rod, mm)

l – Actual length of piston rod or connecting rod, mm.

l_1 – Length of piston pin, mm

l_2 – Length of crank pin, mm

l' – Distance between bolt centres in the big end, mm

M_{max} – Maximum bending moment, N-mm.

p – Pressure of stream or gas, N/mm^2

p_{b1} – Design bearing pressure for small end, N/mm^2

p_{b2} – Design bearing pressure for big end, N/mm^2

r – Radius of crank shaft, mm

S_b – Bending stress induced in the connecting rod, N/mm^2

S_{bc} – Allowable bending stress of cap of big end.

S_c – Allowable compressive stress, N/mm^2

S_t – Allowable tensile stress of bolt, N/mm^2

S_y – Tensile yield stress, N/mm^2

t – Thickness of connecting rod web or flange, mm

t_b – Thickness of bush, mm

t_c – Thickness of cap, mm

t_m – Marginal thickness, mm

W_r – Weight of reciprocating parts, N

Z – Section modulus, mm^3

θ – Angle of inclination of crank from inner dead centre, deg

ϕ – Angle of inclination of connecting rod with line of stroke, deg

ω – Angular speed of crank, rad/s

ρ – Density of connecting rod material, kg/m^3

DESIGN PARTICULARS	EQUATIONS
Load due to steam or gas pressure	$F_g = \frac{\pi}{4} D^2 p$ …. (14.1)
Inertia force due to reciprocating parts	$F_i = \frac{W_r \omega^2 r}{g \times 1000} \left[\cos\theta + \frac{\cos 2\theta}{(l/r)} \right]$ …. (14.2)
Crippling load (i.e., Buckling load) for piston rod or connecting rod	
(a) By Euler's formula (For long columns, i.e., $\frac{L}{k} > 140$)	$F_{cr} = \frac{C \pi^2 EA}{\left(\frac{l}{k}\right)^2}$ (or) $\frac{\pi^2 EA}{\left(\frac{L}{k}\right)^2} \geq F_d$ …. (14.3) (For C and L, refer table 14.1)
(b) By Rankine's formula $F_d = F_g \times FS$ (For long and short columns)	$F_{cr} = \frac{S_c \cdot A}{1 + a\left(\frac{L}{k}\right)^2} \geq F_d$ …. (14.4) $a = \frac{S_c}{\pi^2 E}$ (Refer table 14.2)
(c) By Johnson's formula (For short columns, i.e., $\frac{L}{k} \leq 140$)	$F_{cr} = S_y \cdot A \left[1 - \frac{S_y}{4\pi^2 E} \left(\frac{L}{k}\right)^2 \right] \geq F_d$ …. (14.5) $F_d = F_g \times f_s$
Axial load acting on the piston rod	$F_a = F_g$ …. (14.6)

DESIGN PARTICULARS	EQUATIONS
Axial load acting on the connecting rod	$F_a = \dfrac{(F_g + F_i)}{\sqrt{1 - \left(\dfrac{\sin\theta}{l/r}\right)^2}} \simeq F_g$ .... (14.7)
	(F_i & θ are very small values)
Induced maximum bending stress on the connecting rod	$S_b = \dfrac{M_{max}}{Z}$ .... (14.8)
	$M_{max} = A\,\rho\,\omega^2\,r\,l^2 \Big/ (9\sqrt{3} \times 10^{12})$ N-mm
	(For A, k & Z, refer table 14.3)
Bolts for connecting rod big end :	
Maximum inertia force acting on bolts	$F_{im} = \dfrac{W_r}{g} \times \dfrac{\omega^2 r}{1000}\left[1 + \dfrac{1}{(l/r)}\right]$ .... (14.9)
	(i.e., $F_i = F_{im}$ at $\theta = 0$)
Root diameter of bolt	$d_c = \left(\dfrac{2\,F_{im}}{\pi\,S_t}\right)^{1/2}$ & $d_b = 1.2\,d_c$ .... (14.10)
	$S_t = S_y/f_s$
	Number of bolts $= 2$
Small end and big end of connecting rod:	
Diameter of piston-pin	$d_1 = \dfrac{F_g}{p_{b1} \times l_1}$ .... (14.11)

DESIGN PARTICULARS	EQUATIONS	
Diameter of crank-pin	$d_2 = \dfrac{F_g}{p_{b2} \times l_2}$	.... (14.12)
	$p_{b1} = 12.5$ to $15.4\ N/mm^2$	
length of piston pin	$p_{b2} = 10.8$ to $12.6\ N/mm^2$	
length of crankpin	$l_1 = (1.5$ to $2)\ d_1$	
	$l_2 = (1.0$ to $1.25)\ d_2$	
Inner diameter of small end	$D_{is} = d_1$	.... (14.13)
Outer diameter of small end	$D_{os} = d_1 + 2t_b + 2t_m$	.... (14.14)
Inner diameter of big end	$D_{ib} = d_2$	.... (14.15)
Outer diameter of big end Height of big end	$D_{ob} = d_2 + 2\ t_b + \cancel{2d_b} + 2t_m$ $H_b = D_{ob} + 2d_b + 2t_m$ $t_b = 2$ to 5 mm	.... (14.16)
	$t_m = 5$ to 15 mm	
Thickness of big-end cap	$t_c = \left(\dfrac{F_{im} \times l'}{b \cdot S_{bc}} \right)^{1/2}$	.... (14.17)
	$l' = d_2 + 2\ t_b + d_b + 2t_m$	
	$b = l_2 - 2t_b$	

Depth at big end = 1.1 to 1.2 times the depth at the mid section.

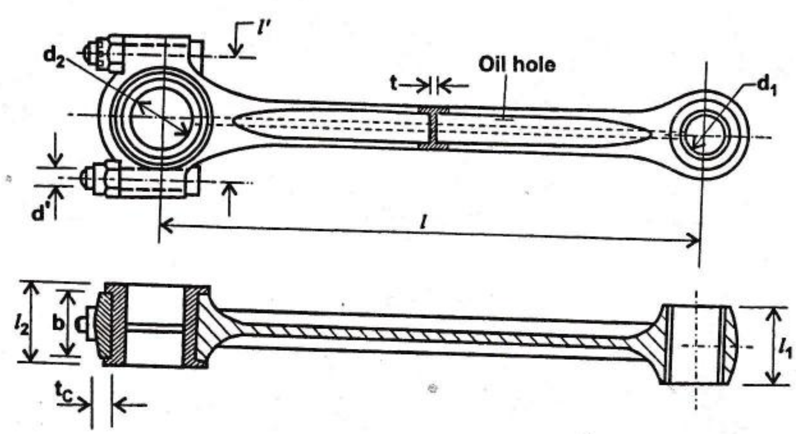


Fig. 14.1: Connecting rod of an I.C engine

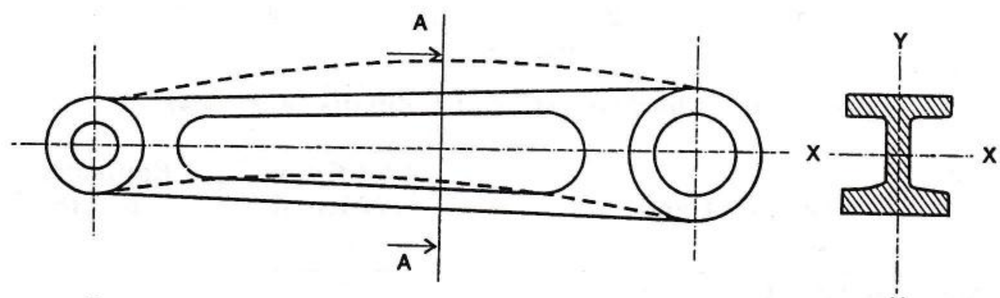
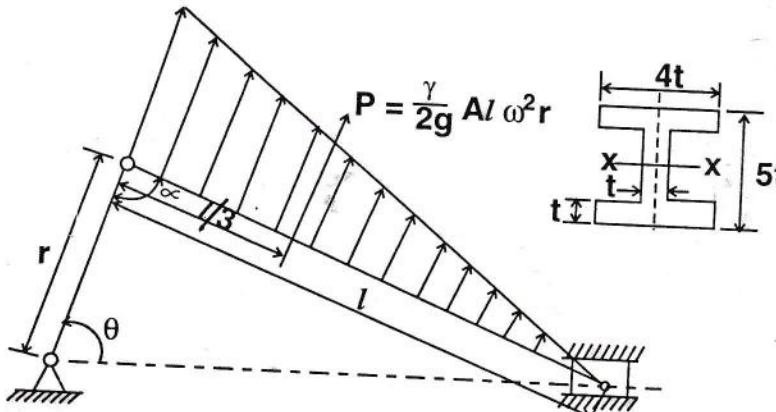


Fig. 14.2: Buckling of connecting rod



At mid section

$A = 11\,t^2$

$I_{xx} = \frac{419}{12}\,t^4$

$I_{yy} = \frac{131}{12}\,t^4$

$k_{xx}^2 = 3.18\,t^2$

Fig. 14.3

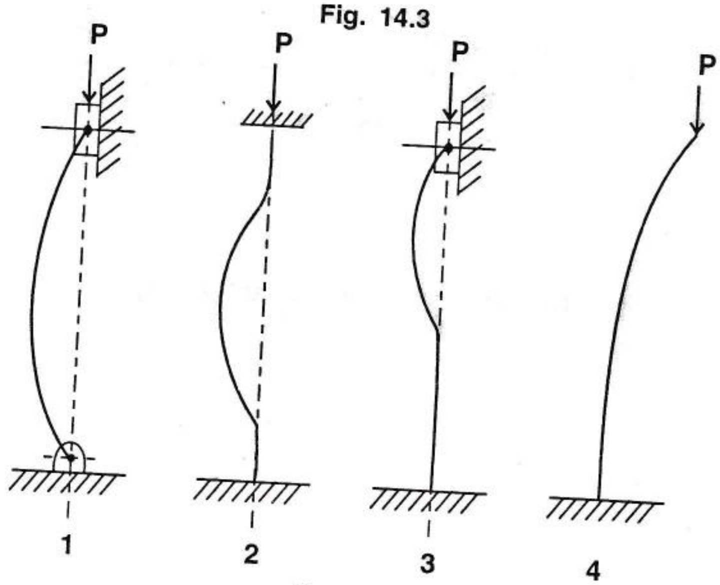


Fig. 14.4

Table 14.1: Characteristics of Columns (Fig. 14.4)

	Nature of ends	End fixity coefficient (C)	Equivalent length (L)
1.	Both ends hinged	1	l
2.	Both ends fixed	4	$l/2$
3.	One end fixed and other end hinged	2	$l/\sqrt{2}$
4.	One end fixed and other end free	0.25	$2l$

Table 14.2: (Values of S_c & a)

S.No.	Material	S_c in N/mm^2	$a = \frac{S_c}{\pi^2 E}$
1.	Wrought iron	250	1/9000
2.	Mild steel	330	1/7500
3.	Cast iron	550	1/1600

Table 14.3: Parameters of Columns

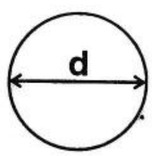
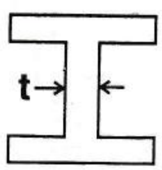
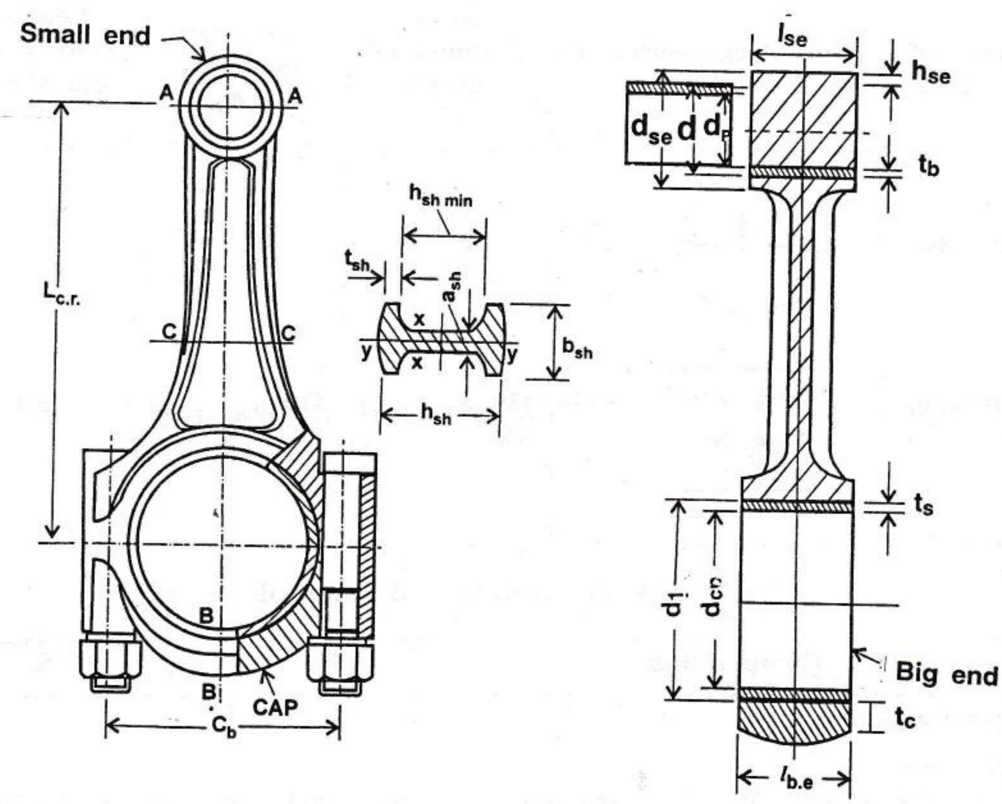
Name of column	Area of cross-section (A)	Area moment of inertia (I)	Section modulus (Z)	Least radius of gyration (k)
Piston rod	 $\frac{\pi}{4} d^2$	$\frac{\pi}{64} d^4$	$\frac{\pi}{32} d^3$	$\frac{d}{4}$
Connecting rod	 $11\, t^2$	$\frac{419}{12} t^4 \simeq 35\, t^4$	$\frac{419}{30} t^3 \simeq 14\, t^3$	1.78 t

Table 14.4: Connecting Rod Materials

Composition	S_u	S_y	S_e
Petrol engines			
1. Carbon steel			
(C = 0.37 – 0.45%, Mn = 0.5 – 0.8% + Si)	570 – 700	310 – 400	230 – 320
(C = 0.42 – 0.50%, Mn = 0.5 – 0.8% + Si)	600 – 750	340	250 – 300
2. Manganese steels			
(C = 0.41 – 0.49%, Mn = 1.4 – 1.8% + Si)	700 – 920	420	310 – 400

Composition	S_u	S_y	S_e
Diesel engines			
1. Chromium steel (C = 0.36 – 0.44%, Mn = 0.5 – 0.8%, Cr = 0.8 – 1.1% + Si)	750 – 1050	650 – 950	320 – 480
2. Alloy steel (C = 0.37 – 0.44%, Mn = 0.5 – 0.8%, Cr = 0.6 – 0.9%, Ni = 1.25 – 1.65%, Mo = 0.15 – 0.25% + Si)	1150 – 1700	850 – 1600	550 – 700



Connecting rod

Fig. 14.5

Table 14.5: Proportions of Connecting Rod

<table>
<tr><th>Description</th><th>Petrol engine</th><th>Diesel engine</th></tr>
<tr><td>Small-end :</td><td></td><td></td></tr>
<tr><td>Inner diameter with bushing, d</td><td>$(1.10 - 1.25)\ d_p$</td><td>$(1.10 - 1.25)\ d_p$</td></tr>
<tr><td>Outer diameter of end, d_{se}</td><td>$(1.25 - 1.65)\ d_p$</td><td>$(1.3 - 1.7)\ d_p$</td></tr>
<tr><td>Length of small end, $l_{s,\,e}$</td><td></td><td></td></tr>
<tr><td>for retained pin</td><td>(0.28 – 0.32) B</td><td>(0.28 – 0.32) B</td></tr>
<tr><td>for floating pin</td><td>(0.33 – 0.45) B</td><td>(0.33 – 0.45) B</td></tr>
<tr><td>Minimum radial thickness of end wall h_{se}</td><td>$(0.16 - 0.27)\ d_p$</td><td>$(0.16 - 0.27)\ d_p$</td></tr>
<tr><td>Radial thickness of bushing wall, t_b</td><td>$(0.055 - 0.085)\ d_p$</td><td>$(0.055 - 0.085)\ d_p$</td></tr>
<tr><td>Big end :</td><td colspan="2"></td></tr>
<tr><td>Crank pin diameter, $d_{c.p}$</td><td colspan="2">(0.56 – 0.75) B</td></tr>
<tr><td>Shell wall thickness, t_s</td><td colspan="2">$(0.03 - 0.1)\ d_{c.p}$</td></tr>
<tr><td>Distance between connecting rod bolts, C_b</td><td colspan="2">$(1.30 - 1.75)\ d_{c.p}$</td></tr>
<tr><td>Big end length, $l_{b,\,e}$</td><td colspan="2">$(0.45 - 0.95)\ d_{c.p.}$</td></tr>
<tr><td>Shank :</td><td colspan="2"></td></tr>
<tr><td>$h_s\ h_{min}$</td><td colspan="2">$(0.50 - 0.55)\ d_{se}$</td></tr>
<tr><td>h_{sh}</td><td colspan="2">$(1.2 - 1.4)\ h_{sh\ min}$</td></tr>
<tr><td>b_{sh}</td><td>$(0.5 - 0.6)\ h_{sh}$</td><td>$(0.55 - 0.75)\ h_{sh}$</td></tr>
<tr><td>$a_{sh} = t_{sh}$</td><td>(2.5 – 4.0) mm</td><td>(4.0 – 7.5) mm</td></tr>
</table>

Reference : Machine Design by Rajendra Karwa.

Table 14.6: Values of Inertia Factor [$\cos\theta + \cos 2\theta/(l/r)$]

Crank angle θ from top dead centre	Ratio of connecting rod length to crank length, l/r					
	3.75	4.0	4.25	4.50	4.75	5.30
0	1.267	1.253	1.235	1.222	1.210	1.200
10	1.236	1.219	1.206	1.194	1.183	1.175
20	1.144	1.131	1.120	1.110	1.101	1.093
30	0.999	0.991	0.984	0.977	0.971	0.966
40	0.812	0.809	0.807	0.804	0.803	0.801
50	0.597	0.599	0.602	0.604	0.606	0.068
60	0.367	0.375	0.382	0.389	0.395	0.400
70	0.138	0.150	0.162	0.172	0.181	0.189
80	–0.077	–0.061	–0.047	–0.350	–0.024	–0.014
90	–0.267	–0.250	–0.235	–0.222	–0.210	–0.200
100	–0.425	–0.408	–0.395	–0.382	–0.372	–0.361
110	–0.546	–0.543	–0.522	–0.512	–0.512	–0.495
120	–0.633	–0.625	–0.618	–0.611	–0.605	–0.660
130	–0.689	–0.686	–0.684	–0.681	–0.679	–0.677
140	–0.723	–0.723	–0.725	–0.727	–0.729	–0.731
150	–0.733	–0.741	–0.748	–0.755	–0.761	–0.766
160	–0.733	–0.748	–0.760	–0.769	–0.779	–0.786
170	–0.733	–0.750	–0.764	–0.776	–0.787	–0.797
180	–0.733	–0.750	–0.765	–0.778	–0.790	–0.800

CHAPTER – 15

CRANKSHAFT

Symbols (with S.I. Units)

a – Width of web nearer to crank pin, mm

b – Width of web nearer to journal, mm

D – Diameter of main journal, mm

d – Diameter of crank pin, mm

F – Force transmitted from connecting rod, N

F_r – Radial component of force, N

F_t – Tangential component of force, N

L – Length of main journal, mm

L_1 – Length of journal inside the crank, mm

l – Length of crank pin, mm

l_1 – Length of pin inside the crank, mm.

M – Bending moment, N-mm

p_b – Induced bearing pressure, N/mm^2

(p_b) – Allowable bearing pressure, N/mm^2

S – Overall stress induced in the web, N/mm^2

S_a – Axial stress (i.e; tensile or compressive stress), N/mm^2

S_b – Induced bending stress, N/mm^2

(S_b) – Allowable bending stress, N/mm^2

S_{be} – Maximum equivalent bending stress, N/mm^2

S_{br} – Bending stress by radial force, N/mm^2

S_{bt} – Bending stress by tangential force, N/mm^2

S_s – Induced shear stress, N/mm^2

(S_s) – Allowable shear stress, N/mm^2

S_{se} – Maximum equivalent shear stress, N/mm^2

T – Twisting moment, N-mm

t – Thickness of crank web, mm

W – Weight of flywheel, N

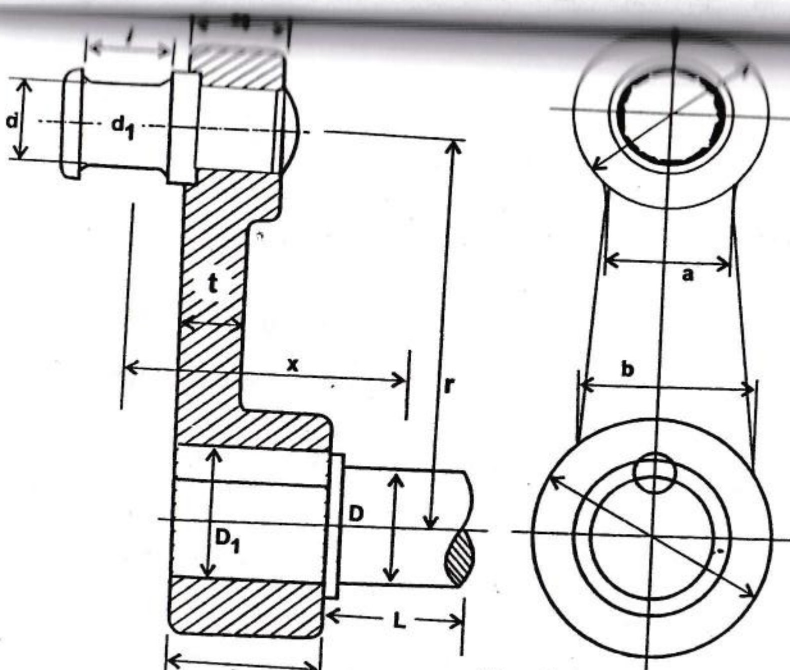
w – Width (i.e., mean width) of crank web, mm

x – Distance between the centres of crank pin and journal for overhung crankshaft (or) distance between the centres of main journals for centre crankshaft, mm

y – Distance of flywheel from main journal, mm

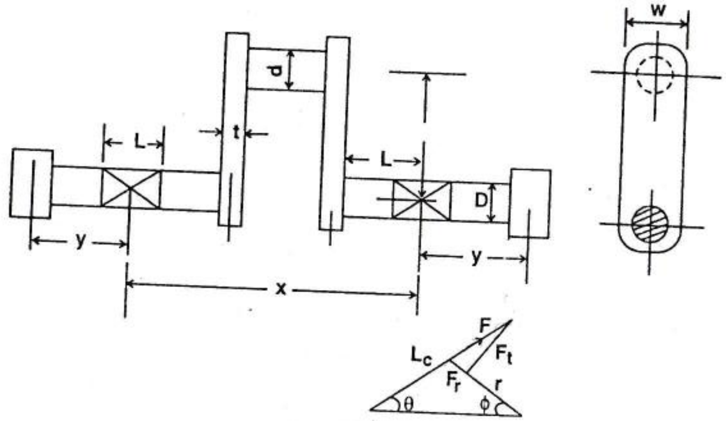
θ – Angle of inclination of the crank from inner dead centre, deg.

ϕ – Angle of inclination of the connecting rod with the line of stroke, deg.



Overhung crank shaft

Fig. 15.1



Centre crankshaft

Fig. 15.2

DESIGN PARTICULARS	EQUATIONS	
Parts of the crank shaft and their induced stresses	**Overhung crank shaft** (Side)	Centre crankshaft
Crank pin:		
Plain or direct shear stress	$S_s = \dfrac{4F}{\pi d^2} \le (S_s)$	$S_s = \dfrac{4F}{\pi d^2} \le (S_s)$ .... (15.1)

DESIGN PARTICULARS	EQUATIONS		
Parts of the crank shaft and their induced stresses	**Overhung crank shaft**	**Centre crankshaft**	
Bending stress	$S_b = \frac{16\,Fl}{\pi\,d^3} \le (S_b)$ (At fixed end)	$S_b = \frac{8\,Fx}{\pi\,d^3} \le (S_b)$ (At centre of the pin)	.... (15.2)
Bearing stress	$p_b = \frac{F}{l\,d} \le (p_b)$	$p_b = \frac{F}{l\,d} \le (p_b)$ $F_g = \frac{\pi}{4} D^2 p$	.... (15.3)
Crank-web:			
Axial stress by radial force	$S_a = \frac{F_r}{w.t} \le (S_b)$	$S_a = \frac{F_r}{2\,w.t} \le (S_b)$	.... (15.4)
Bending stress by radial force	$S_{br} = \frac{3\,F_r\,(l+t)}{wt^2} \le (S_b)$	$S_{br} = \frac{3\,F_r\,[x-(l+t)]}{wt^2} \le (S_b)$	.... (15.5)
Bending stress by tangential force	$S_{bt} = \frac{6\,F_t \cdot r}{t\,w^2} \le (S_b)$	$S_{bt} = \frac{6\,F_t \cdot r}{tw^2} \le (S_b)$	.... (15.6)
Overall stress acting on the web	$S = S_a + S_{br} + S_{bt} \le (S_b)$	$S = S_a + S_{br} + S_{bt} \le (S_b)$	.... (15.7)
Crank-shaft journal:			
Bending stress by radial force	$S_{br} = \frac{32\,F_r \cdot x}{\pi\,D^3} \le (S_b)$	–	.... (15.8)
Maximum equivalent bending stress	$S_{be} = \frac{16\,(M + \sqrt{M^2 + T^2})}{\pi\,D^3} \le (S_b)$	$S_{be} = \frac{16\,(M + \sqrt{M^2 + T^2})}{\pi\,D^3} \le (S_b)$	.... (15.9)

DESIGN PARTICULARS	EQUATIONS

Maximum equivalent bending stress	$S_{be} = \dfrac{16\,(M + \sqrt{M^2 + T^2})}{\pi\, D^3} \le (S_b)$	$S_{be} = \dfrac{16\,(M + \sqrt{M^2 + T^2})}{\pi\, D^3} \le (S_b)$ .... (15.9)

DESIGN PARTICULARS	EQUATIONS	
Parts of the crank shaft and their induced stresses	**Overhung crank shaft**	**Centre crankshaft**
Maximum equivalent shear stress	$S_{se} = \dfrac{16\,(\sqrt{M^2 + T^2})}{\pi\, D^3} \le (S_s)$	$S_{se} = \dfrac{16\,(\sqrt{M^2 + T^2})}{\pi\, D^3} \le (S_s)$ .... (15.10)
	$\begin{bmatrix} M = F_t \cdot x \\ T = F_t \cdot r \end{bmatrix}$ By tangential force	$M = W.y$ (By flywheel weight) $T = F_t \cdot r$ (By tangential force)
Radial component of force	$F_r = F \cos(\theta + \phi)$	$F_r = \dfrac{F}{2} \cos(\theta + \phi)$ .... (15.11)
Tangential component of force	$F_t = F \sin(\theta + \phi)$	$F_t = \dfrac{F}{2} \sin(\theta + \phi)$ .... (15.12)
Main bearings:		
Bearing pressure	$p_b = \dfrac{F}{L.D} \le (p_b)$	$p_b = \dfrac{F}{2\,LD} \le (p_b)$ .... (15.13)
Usual proportions of parts	$D = (1.25 \text{ to } 1.5)\, d$	$D = d$
	$L = 1.25\, D$	$L = 1.25\, D$
	$L_1 = (1.0 \text{ to } 1.25)\, D$	–
	$l = (1.0 \text{ to } 1.25)\, d$	$l = (1.0 \text{ to } 1.25)\, d$
	$l_1 = (1.0 \text{ to } 1.25)\, d$	–
	$t = (0.7 \text{ to } 1.0)\, d$	$t = (0.7 \text{ to } 1.0)\, d$

DESIGN PARTICULARS	EQUATIONS	
Parts of the crank shaft and their induced stresses	**Overhung crank shaft**	**Centre crankshaft**
	$a = 1.5\,d$	–
	$b = 1.5\,D$	–
	$w = \dfrac{(a+b)}{2}$	$w = 1.5\,d$
Allowable stresses:		
For mild steel crankshaft		
	$(S_b) = 60$ to 100 N/mm^2	
	$(S_a) = 80$ to 120 N/mm^2	
	$(S_s) = 40$ to 60 N/mm^2	
	$(p_b) = 10$ to 20 N/mm^2	
For Bearings :		
	In crank pin, $(p_b) = 4$ to 12 N/mm^2	
	In main shaft, $(p_b) = 1.5$ to 12 N/mm^2	

CHAPTER – 16

FLY WHEEL

Symbols with S.I. units :

b – Width of flywheel rim, m

C_e – Coefficient of fluctuation of energy

C_s – Coefficient of fluctuation of speed

D – Mean diameter of rim, $D = \left(\dfrac{D_i + D_0}{2}\right)$, m

D_i – Inner diameter of rim, m

D_0 – Outer diameter of rim, m

d – Outer diameter of hub, m

I – Mass moment of inertia of flywheel ($I = mk^2$); kg-m^2

k – Radius of gyration of flywheel, m

m – Mass of flywheel, kg

N – Speed (i.e; average speed) of flywheel, rpm

N_1 – Minimum speed of flywheel, rpm

N_2 – Maximum speed of flywheel, rpm

n – Number of arms

P – Power transmitted, W

S_b – Induced bending stress, N/m^2

(S_b) – Allowable bending stress, N/m^2

S_t – Induced tensile stress, N/m^2

(S_t) – Allowable tensile stress, N/m^2

T – Torque transmitted, N-m

t – Thickness of flywheel rim, m

v – Velocity of flywheel, m/s

x – Major axis of elliptical section of arm, m

y – Minor axis of elliptical section of arm, m

Z – Section modulus, m^3

ΔE – Maximum fluctuation of energy (or) Excess energy, N-m

ρ – Density of flywheel material, kg/m^3

ω – Angular velocity of flywheel, rad/s

DESIGN PARTICULARS	EQUATIONS
Maximum fluctuation of energy (i.e., Excess energy)	$\Delta E = I\,\omega^2\,C_s = mk^2\,\omega^2\,C_s$ .... (16.1)
	$k^2 = \frac{D_0^2 + (D_0 - 2t)^2}{8}$ (For rim flywheel)
	$= \frac{D^2}{4} \simeq \frac{D_0^2}{4}$ (For rim flywheel when t is very small)
	$= \frac{D_0^2}{8}$ (For disc fly wheel $\because D_i\,[= (D_0 - 2t)]$ is zero)
Mass of flywheel rim	$m = \pi\,D\,bt\,\rho$ .... (16.2)
	$b/t = 0.65$ to 2
	$\omega = \frac{2\pi N}{60}$ rad/s ; $v = \frac{\pi D N}{60}$ m/s
Coefficient of fluctuation of speed (Table 16.1)	$C_s = \frac{N_2 - N_1}{N} = \frac{v_2 - v_1}{v} = \frac{\omega_2 - \omega_1}{\omega}$ .... (16.3)
	$N = \frac{N_2 + N_1}{2}$; $v = \frac{v_2 + v_1}{2}$; $\omega = \frac{\omega_2 + \omega_1}{2}$

DESIGN PARTICULARS	EQUATIONS
Thickness of flywheel rim	$t = \left[\frac{2\,\Delta E}{\pi D^3 \rho \omega^2 C_s} \right]^{1/2}$ when $b = 2t$ .... (16.4)
Coefficient of fluctuation of energy	$C_e = \frac{\Delta E}{\text{Workdone per cycle}}$ .... (16.5)
	$= \frac{\Delta E}{\left(\frac{60\,P}{N}\right)}$ For two stroke I.C. engine
	$= \frac{\Delta E}{\left(\frac{120\,P}{N}\right)}$ (For four stroke I.C. engine)
Total stress induced in the fly wheel rim	$S_t = \rho v^2 \left[0.75 + \frac{0.25\,\pi^2 D}{n^2 t} \right] \le (S_t)$ .... (16.6)
Maximum bending stress induced in the flywheel arm	$S_b = \frac{T\,(D-d)}{DnZ} \le (S_b)\,;\ T = 2\,T_{mean}$ .... (16.7)
	$Z = \frac{\pi}{32} x^2 y$
	$n = 4$ (For small diameter flywheel)
	$= 6$ to 12 (For large diameter flywheel)

DESIGN PARTICULARS	EQUATIONS

$= 6$ to 12 (For large diameter flywheel)

DESIGN PARTICULARS	EQUATIONS
	$\rho = 7260\ kg/m^3$ (For C.I. flywheel)
	$= 7800\ kg/m^3$ (For steel flywheel)
	$(S_t) \le 30\ N/mm^2$; $(S_b) \le 15\ N/mm^2$
Section of flywheel arm	$y = \left(\frac{8Z}{\pi}\right)^{1/3}$ when $x = 2y$ .... (16.8)
Taper of arm	1 in 50 for major axis
	1 in 100 for minor axis
Maximum speed of flywheel	$v \le 30$ m/s for C.I flywheel
	≤ 50 m/s for steel flywheel
	≤ 25 m/s for power < 75 kW
	≤ 35 m/s for power > 75 kW

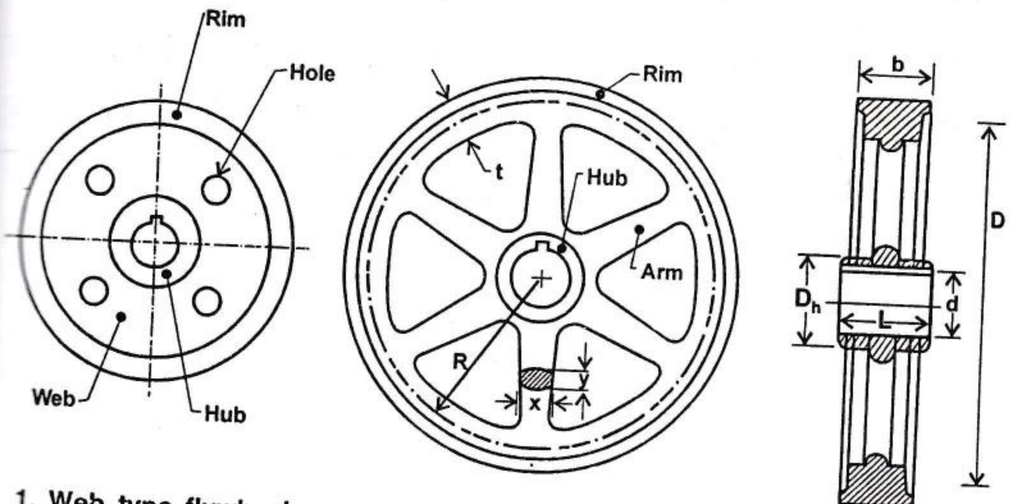
Table 16.1: Coefficient of Fluctuation of Speed, C_s

Driven Machinery	C_s^*
Punch presses, hammers, crushers-belt driven	0.1 – 0.2
Compressors-belt driven	0.1 – 0.14
Pumps, shears-belt driven	0.04 – 0.05
Metal working machinery-belt driven	0.033
Paper and textile machinery-belt driven	0.02 – 0.025
Compressors, pumps-driven through gears	0.015 – 0.02
D.C. Generators-belt driven	0.02
D.C. Generators-directly coupled	0.014
A.C. Generators-belt driven	0.0166
A.C. Generators-directly coupled	0.01
Automobile engines, idling	0.2
Normal speed	0.01

* Table gives maximum values. The minimum limit, as used in practice, is as much as 25 percent lower.

16.2: Coefficient of Fluctuation of Energy, C_e

Number of cylinders	Type of engine	C_e	
		Four-stroke engines	Two-stroke engines
1	Single acting	2.35 – 2.50	0.95 – 1.00
2	Single acting, cranks at 180°	1.40 – 1.50	0.23 – 0.25
2	Single acting, cranks at 360°	0.98 – 1.05	–
3	Single acting, vertical, cranks at 120°	0.55 – 0.60	0.13 – 0.14
4	Single acting, vertical, cranks at 180° and 90°	0.15 – 0.20	0.015 – 0.018
6	Single acting, vertical, cranks at 120° and 60°	0.04 – 0.05	0.020 – 0.025
8	Single acting vertical, cranks at 90° and 45°	0.03 – 0.04	0.005 – 0.006



1. Web type flywheel

2. Rim type flywheel

Types of flywheel

Fig. 16.1

Table 16.3: Fluctuation of Energy for Steam Engine

Cut off percentage	Fluctuation of Energy C_e		
	Single cylinder engine	Two cylinders with crank 90° apart	Three cylinders with cranks 120° apart
10	0.35	0.088	0.040
20	0.33	0.082	0.037
40	0.31	0.078	0.034
60	0.29	0.072	0.032
80	0.28	0.070	0.031
100	0.27	0.068	0.030

CHAPTER – 17

CLUTCHES

Symbols : (with S.I. units)

Friction clutches :

b	–	Width of contact surfaces, mm.
d	–	Diameter of the clutch-shaft, mm
F_a	–	Axial actuating force, N
F_f	–	Frictional force, N
F_n	–	Normal force acted in cone clutch, N
K	–	Speed factor
k_s	–	Service factor based on working conditions
k_1	–	Driver dynamic characteristic factor
k_2	–	Driven shaft dynamic characteristic factor
k_3	–	Wear factor
k_4	–	Frequency of operation factor
N	–	Speed in rpm, Unit of force in newtons
n	–	Number of friction surfaces

n_1	–	Number of driving plates
n_2	–	Number of driven plates
P	–	Rated power, kW
(p)	–	Allowable pressure, N/mm^2
p_b	–	Basic pressure, N/mm^2
p_{max}	–	Maximum induced pressure, N/mm^2
R_i	–	Inner radius of clutch plate, mm
R_m	–	Mean radius of clutch plate, mm
R_0	–	Outer radius of clutch plate, mm
S_s	–	Permissible shear stress for shaft material, N/mm^2
T	–	Transmitted torque, N-mm
T_d	–	Design torque, N-mm
t	–	Thickness of clutch plate, mm
μ	–	Coefficient of friction
α	–	Angle of friction surface with the axis of cone clutch

Claw clutches :

b	–	Width of tooth along the radial direction, mm
D_i	–	Inner diameter of clutch, mm
D_m	–	Mean diameter of clutch, mm.
D_0	–	Outer diameter of clutch, mm
d	–	Diameter of shaft, mm
F	–	Load on one pair of claws, N (under the condition that only two pairs are transmitting the entire torque).

F_d – Axial force required to disengage the clutch, N

F_e – Axial force required to engage the clutch, N

h – Width of tooth along the axial direction, mm

K_F – Load factor

L_1 – Boss length of driving claw, mm

L_2 – Boss length of driven claw, mm

l – Length of tooth along the tangential direction, mm

N – Speed in rpm, unit of load in newtons.

P – Power in kW

S_b – Induced bending stress, N/mm^2

(S_b) – Allowable bending stress, N/mm^2

S_c – Induced compressive stress, N/mm^2

(S_c) – Allowable compressive stress, N/mm^2

(S_s) – Allowable shear stress of shaft material, N/mm^2

T – Transmitted torque, N-mm

T_d – Design torque, N-mm

t – Time for engagement, ≤ 0.05 sec.

Z_{min} – Minimum number of claws or teeth

α – Tooth angle (equal to zero for square tooth), deg.

ΔN – Relative speed at the time of engagement, rpm

μ_1 – Coefficient of friction between the sliding half and shaft.

μ_2 – Coefficient of friction between claws.

λ – Friction angle, deg.

DESIGN PARTICULARS	EQUATIONS
Friction clutches:	
Transmitted torque	$T = \frac{60 \times 10^6 \times P}{2 \pi N}$ N-mm .... (17.1)
Design torque	$T_d = T \times k_s$ .... (17.2)
	$k_s = k_1 + k_2 + k_3 + k_4$ (Refer tables 17.2 to 17.5)
Diameter of clutch shaft	$d = \left[\frac{16\, T_d}{\pi\, (S_s)}\right]^{1/3}$ mm .... (17.3)
Multiple disc or plate clutch : (Fig. 17.1)	$(S_s) = 30$ to 50 N/mm^2 (For mild steel)
Proportions of plate dimensions	$R_i \approx 2d$; $R_0 \approx 1.25$ to $1.8\, R_i$ .... (17.4)
	$t = 3$ to 5 mm; $b = R_0 - R_i$
	$n = 10$ to 40; $n_1 = \frac{n}{2}$; $n_2 = \frac{n}{2} + 1$
	$n_1 < n_2$; $n = n_1 + n_2 - 1$
Axial actuating force on one pair of friction surfaces	$F_a = \frac{T_d}{n\, \mu\, R_m}$ .... (17.5)
	$= 2 \pi\, p_{max}\, R_i\, (R_0 - R_i)$ (For uniform wear)
	$= \pi\, p_{max}\, (R_0^2 - R_i^2)$ (For uniform pressure)

DESIGN PARTICULARS	EQUATIONS
Number of pairs of friction surfaces	$n = \frac{T_d}{\mu\, F_a\, R_m}$ .... (17.6)

$= 2 \pi p_{max} R_i (R_0 - R_i)$ (For uniform wear)

$= \pi p_{max} (R_0^2 - R_i^2)$ (For uniform pressure)

DESIGN PARTICULARS	EQUATIONS
Number of pairs of friction surfaces	$n = \dfrac{T_d}{\mu F_a R_m}$ .... (17.6)
	$R_m = \dfrac{R_0 + R_i}{2}$ (For uniform wear)
	$= \dfrac{2}{3}\left[\dfrac{R_0^3 - R_i^3}{R_0^2 - R_i^2}\right]$ (For uniform pressure)
	$n = 2$ (For single plate clutch)
Maximum pressure developed	$p_{max} = \dfrac{F_a}{2 \pi R_i (R_0 - R_i)}$ (For uniform wear) .... (17.7)
	$= \dfrac{F_a}{\pi (R_0^2 - R_i^2)}$ (For uniform pressure) .... (17.8)
	$< (p)$
	$(p) = K p_b$ (For K, refer graph) (Fig. 17.4)

Values of p_b and μ :

Items	p_b (N/mm^2)	μ
Steel plates (wet running)	0.6 to 0.8	0.08
Steel plates (dry running)	0.25 to 0.3	0.3
Compressed asbestos on steel (dry running)	0.2 to 0.25	0.4

DESIGN PARTICULARS	EQUATIONS
Cone clutch : (Fig. 17.2)	
Proportions of conc clutch dimensions	$R_m = (2.5 \text{ to } 5)\, d \;\&\; R_m = (2.0 \text{ to } 4.0)\, b$ .... (17.9)
	$\alpha = 12.5° \text{ to } 25°$
	$R_i = R_m - \frac{b}{2} \sin \alpha$
	$R_0 = R_m + \frac{b}{2} \sin \alpha$ (or) $R_i + b \sin \alpha$
Maximum pressure developed	$p_{max} = \frac{T_d \cdot \sin \alpha}{\pi \mu R_i (R_0^2 - R_i^2)} < (p)$ .... (17.10)
Axial actuating force	$F_a = \frac{T_d \cdot \sin \alpha}{\mu R_m}$; $R_m = \frac{R_i + R_0}{2}$ .... (17.11)
	$= 2 \pi p_{max} R_i (R_0 - R_i)$ (Uniform wear condition)
Normal force acting on the plate	$F_n = \frac{F_a}{\sin \alpha}$ .... (17.12)
Frictional force	$F_f = \mu F_n$ .... (17.13)
Claw clutch (or) Jaw clutch: (Fig. 17.3)	
Transmitted torque	$T = \frac{60 \times 10^6 \times P}{2 \pi N}$ N–mm .... (17.14)
Design torque	$T_d = T \times K_F$ .... (17.15)
	$K_F = 1.25$ for steady load
	$= 1.5$ for shock load

	.... (17.14)
	$T_d = T \times K_F$
	$K_F = 1.25$ for steady load .... (17.15)
	$= 1.5$ for shock load

DESIGN PARTICULARS	EQUATIONS
Diameter of clutch shaft	$d = \left[\dfrac{16\,T_d}{\pi\,(S_s)}\right]^{1/3} \simeq 120\left[\dfrac{P \times K_F}{N}\right]^{1/3}$ .... (17.16)
	$(S_s) = 30$ to 50 N/mm^2 (For C45 steel)
Proportions of claw clutch dimensions	$D_0 = (1.8 \text{ to } 2.5)\ d$ .... (17.17)
	$b = (0.125 \text{ to } 0.2)\ D_0$
	$D_i = D_0 - 2b$
	$D_m = \dfrac{D_0 + D_i}{2}$
	$h = (0.6 \text{ to } 1.0)\ b;\ l = \dfrac{\pi\,D_m}{2Z}$
	$L_1 = (1.3 \text{ to } 1.7)\ d$
	$L_2 = (2 \text{ to } 2.5)\ d$
Tooth flank angle (for self locking condition)	$\alpha \le \tan^{-1}\left[\dfrac{\mu_2\left(1 + \dfrac{\mu_1 D_m}{\mu_2 d}\right)}{1 - \mu_1 \mu_2\left(\dfrac{D_m}{d}\right)}\right]$; .... (17.18)
	$\alpha = 0$ for square tooth.
	$\mu_1 = 0.05$ to 0.1 when lubricated
	$= \mu_2 = 0.1$ to 0.15 when not lubricated
	$\mu_2 = \tan\lambda$

DESIGN PARTICULARS	EQUATIONS
Minimum number of claws	$Z_{min} = \dfrac{60}{t\,\Delta N}$ .... (17.19) $\Delta N = 100$ to 150 rpm $t \leq 0.05$ sec.
Axial force required to engage the clutch	$F_e = 2\,T_d \left[\dfrac{\mu_1}{d} + \dfrac{\tan(\alpha + \lambda)}{D_m} \right]$ .... (17.20)
Axial force required to disengage the clutch	$F_d = 2\,T_d \left[\dfrac{\mu_1}{d} - \dfrac{\tan(\alpha - \lambda)}{D_m} \right]$ .... (17.21)
Load on one pair of claws	$F = \dfrac{T_d}{D_m}$ .... (17.22)
Induced compressive stress	$S_c = \dfrac{F}{bh} \leq (S_c)$ .... (17.23)
Induced bending stress in square tooth	$S_b = \dfrac{9.6\,T_d \cdot h}{b\,D_m^3} \leq (S_b)$ .... (17.24)
Induced bending stress in trapezoidal tooth	$S_b = \dfrac{9.6\,T_d \cdot h}{b\,D_m\,(D_m + 1.28\,h \tan\alpha)^2} \leq (S_b)$ .... (17.25) $(S_c) = 80$ to $120\ N/mm^2$ for clutches engaged at rest $= 20$ to $30\ N/mm^2$ for clutches engaged at running. $(S_b) = 80$ to $100\ N/mm^2$ for clutches engaged at rest. $= 20$ to $25\ N/mm^2$ for clutches engaged at running.

Table 17.1: Friction Materials for Clutches

		Maximum	Coefficient of friction μ	Allowable

Table 17.1: Friction Materials for Clutches

	Materials in contact	Maximum operating temperature °C	Coefficient of friction μ			Allowable pressure in N/mm^2 (or MPa)
			Dry	Greesy	Oily	
1.	Cast Iron on Cast iron	310	0.15-0.2	0.06-0.1	0.05-0.1	1.05-1.75
2.	Bronze on Cast iron	149	–	0.05-0.1	0.05-0.1	0.56-0.84
3.	Steel on Cast iron	260	0.25-0.35	0.07-0.12	0.06-0.1	0.84-1.40
4.	Wood on C.I or Steel	149	0.20-0.35	0.08-0.12	–	0.42-0.63
5.	Cork on C.I or Steel	90	0.35-0.5	0.25-0.30	0.22-0.25	0.055-0.105
6.	Leather on C.I or Steel	70	0.3-0.5	0.15-0.20	0.12-0.15	0.07-0.28
7.	Asbestos on C.I or Steel	350	0.35-0.5	0.25-0.3	0.20-0.25	0.21-0.56
8.	Fibre on C.I or Steel	150	–	0.10-0.20	–	0.07-0.28

Table 17.2

Factor k_1

Type of driving system	Factor k_1	
	For direct coupling or when gear box is used	For belt transmissions
Electric motor directly connected to mains	0.5	0.33
Machines with low starting torque characteristics, turbines and line transmissions	0.33	

Table 17.3

Factor k_2

Type of driven system	k_2	Usage
Driven machines where often a starting torque greater than the nominal value occurs	1.25	Metal cutting machine tools, wood working machine tools, piston type compressors, centrifugal pumps.
	1.6	Metal cutting machine tools with reverse motion (planing), turbo compressors, cranes, heavy machinery, heavy drills, piston pumps etc.
	2.5	Forging machines, presses, wire drawing machines, piston pumps, paper machinery etc.

Table 17.4

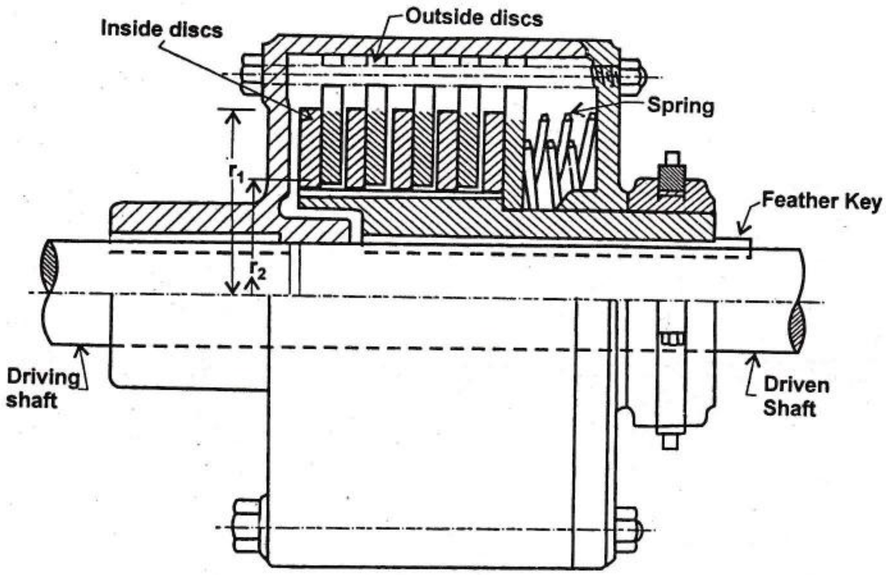
Factor k_3

rpm	100	160	240	400	620	1000	1400	1800
k_3	0.1	0.13	0.16	0.20	0.25	0.32	0.38	0.43

Table 17.5

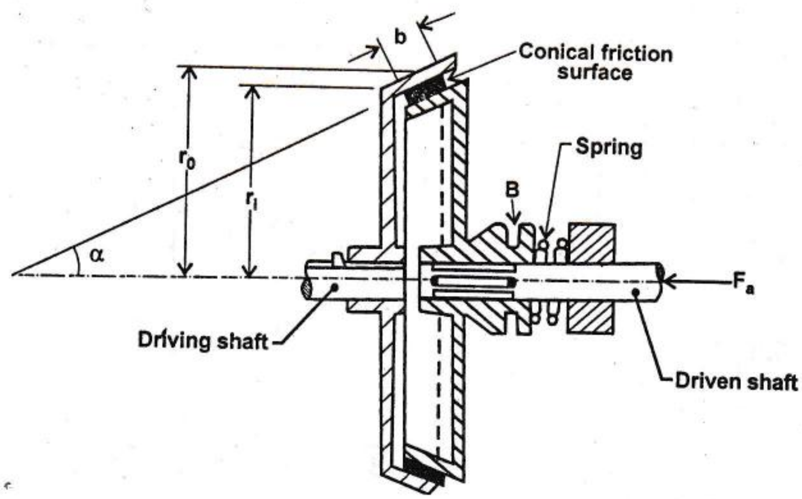
Factor k_4

Number of engagements in an 8 hour shift	1	8	16	32	48	96	240	480
Factor k_4	0	0.20	0.55	0.75	0.90	1.20	1.80	2.00



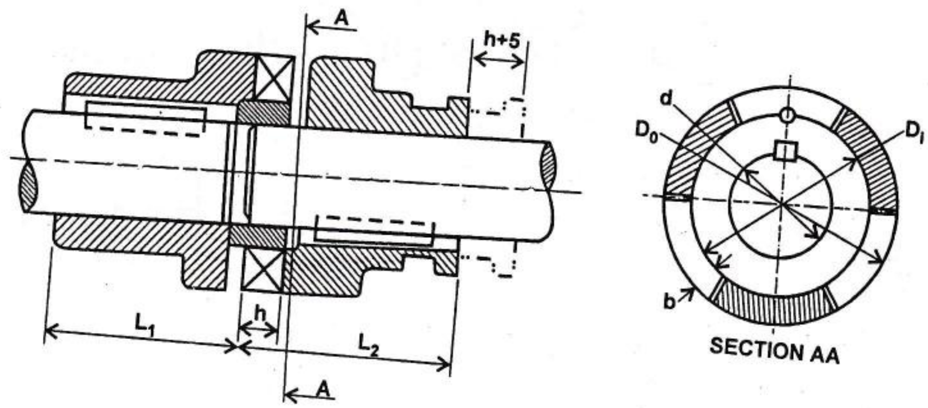
Multiple disc clutch

Fig. 17.1



Cone clutch

Fig. 17.2



Claw clutch

Fig. 17.3

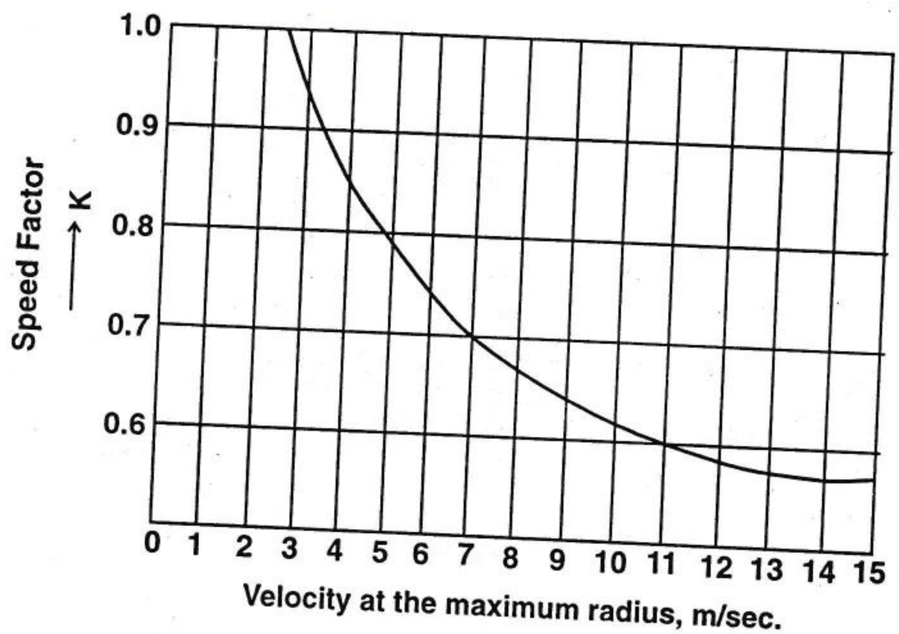


Fig. 17.4 Speed factor

CHAPTER – 18

BRAKES

Symbols : (with S.I. units)

Block Brakes :

a	–	Distance of applied force from fulcrum, mm
b	–	Distance of wheel or drum centre from fulcrum, mm
c	–	Distance of the braking force from fulcrum, mm
F_b	–	Braking or friction force, N
F_{b1}, F_{b2}	–	Braking forces on 1st and 2nd blocks in double block (or) shoe brake, N
F_n	–	Normal reaction force, N
l	–	Projected length of shoe, mm
N	–	Speed of wheel, rpm; Unit of force in newtons
P	–	Applied force at the end of lever, N
BP_{av}	–	Average braking power, kW
p_b	–	Developed bearing pressure, N/mm^2
(p_b)	–	Allowable bearing pressure, N/mm^2
R	–	Radius of brake drum or wheel, mm
R′	–	Distance of pivot from wheel centre in pivoted block brake, mm

T_b – Braking torque, N-mm

w – Width of brake shoe, mm.

2ϕ – Angle subtended by the block on the centre of wheel (i.e. Angle of contact), deg.

μ – Coefficient of friction.

μ' – Equivalent coefficient of friction as applied in pivoted block brake.

ω_i – Initial speed of wheel, $\omega_i = 2\pi N/60$ rad/s, N is in rpm.

Band Brakes :

a – Distance of applied force from fulcrum, mm.

b – Distance between fulcrum (i.e., first end) and the second end of band measured along the lever, mm

b_1, b_2 – Distances of tensions from fulcrum, mm

F_b – Braking force, N

F_1 – Tension on tight side of band, N

F_2 – Tension on slack side of band, N

n – Number of blocks in band and block brake.

$p_{b\,max}$ – Maximum bearing pressure developed, N/mm^2

(p_b) – Allowable bearing pressure, N/mm^2

R – Effective radius of brakedrum, mm

$R = r + \frac{t}{2}$ (If thickness of band (t) is considered)

$= r$ (If t is not considered)

r – Radius of brakedrum, mm

T_b – Braking torque, N-mm.

t – Thickness of band, mm

w – Width of band, mm

μ – Coefficient of friction.

θ – Angle of lap (or contact) of the band on the drum, radians, deg.

2ϕ – Angle subtended by each block at the centre of drum as in band and block brake, deg.

Internal Expanding Shoe Brakes :

a – Distance of shoe-pivot from the centre of drum, mm.

b – Face width of shoe, mm.

c – Moment arm of the actuating force, (i.e. distance of actuating force from pivot), mm

E_t – Total energy produced on the moving vehicle, N-m.

F_b – Braking force, N

g – Acceleration due to gravity, 9.81 m/s^2

h – Height of moving vehicle, m

I – Mass moment of inertia of moving body, kg-m^2

M_f – Total moment due to friction force on one shoe, N-mm.

M_n – Total moment due to normal force on one shoe, N-mm

m – Mass of moving vehicle or body, kg

N – Initial speed of brake wheel, rpm, unit of force in newtons.

P – Total actuating force, N

P_1 – Actuating force on leading shoe, N

P_2 – Actuating force on trailing shoe, N

p – Pressure developed at the contact surface at any angle θ from pivot, N/mm^2

p_m – Maximum pressure developed on the shoe, N/mm^2

r – Internal radius of brake drum, mm.

T_b – Braking torque on one shoe, N-mm.

T_B – Total braking torque on two shoes, N-mm

t – Time of application of brake in seconds.

v – Velocity of moving body, m/s.

W_b – Workdone by the brake, N-m

θ_1 , θ_2 – Centre angle of heel and toe of lining from pivot.

μ – Coefficient of friction.

ω – Angular speed of wheel, rad/s

Common to all Brakes :

H_g – Heat generated in brakes, watts

H_d – Heat dissipated in brake drum, watts

μ – Coefficient of friction

p – Contact pressure between the braking surfaces, N/mm^2

A – Contact area, mm^2

v – Rubbing velocity, m/s ($v = 2\pi RN/60000$)

C – Heat dissipation coefficient, ($W/m^2/°C$)

A_r – Heat radiating (i.e., dissipating) area, mm^2

t_d – Developed temperature in heat dissipating area, °C.

t_a – Atmospheric temperature, °C

Δt – $t_d - t_a$

DESIGN PARTICULARS	EQUATIONS	
Block Brakes:		
I. Single block or shoe brakes : (For $2\phi \le 60°$)		
Tangential braking force on the wheel :	$F_b = \mu F_n$	.... (18.1)
Braking torque	$T_b = F_b \cdot R = \mu F_n \cdot R$	.... (18.2)
Braking torque for different arrangements: (For $2\phi \le 60°$)		
Case 1: Line of action of braking force passing through fulcrum		
(a) For both clockwise and anticlockwise rotation of brake-drum (Fig. 18.1 & 18.2)	$T_b = \frac{\mu P a R}{b}$	.... (18.3)
Case 2: Line of action of braking force passing below the fulcrum		
(a) For clockwise rotation (Fig. 18.3)	$T_b = \frac{\mu P a R}{(b + \mu c)}$	.... (18.4)
(b) For anticlockwise rotation (Fig. 18.4)	$T_b = \frac{\mu P a R}{(b - \mu c)}$	.... (18.5)
Case 3: Line of action of braking force passing above the fulcrum		
(a) For clockwise rotation (Fig. 18.5)	$T_b = \frac{\mu P a R}{(b - \mu c)}$	.... (18.6)
(b) For anticlockwise rotation (Fig. 18.6)	$T_b = \frac{\mu P a R}{(b + \mu c)}$	.... (18.7)

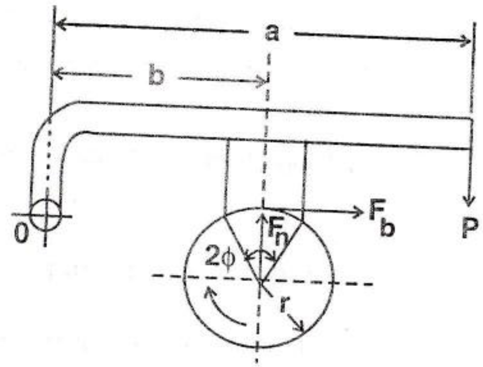


Fig. 18.1: Clockwise rotation of brake wheel.

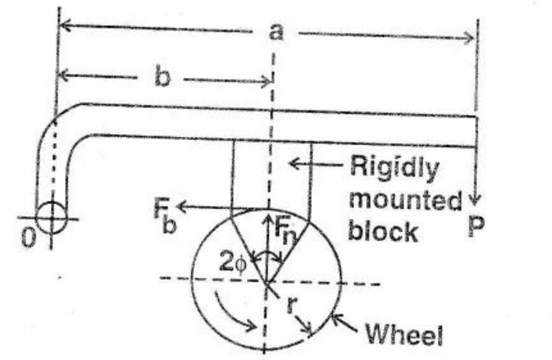


Fig. 18.2: Anticlockwise rotation of brake wheel

Single Block-brake. Line of action of braking force passing through fulcrum

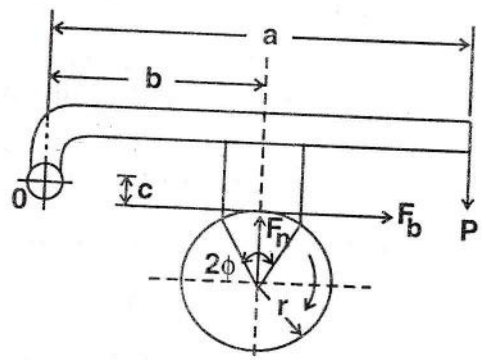


Fig. 18.3: Clockwise rotation of brake wheel.

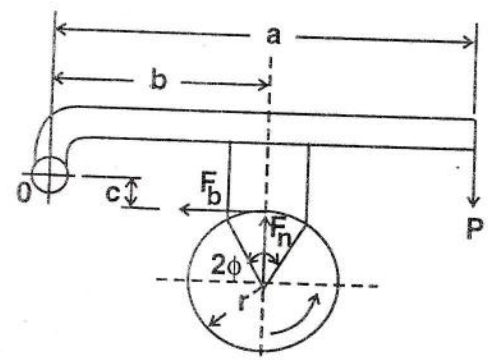


Fig. 18.4: Anticlockwise rotation of brake wheel

Single Block-brake. Line of action passing below the fulcrum

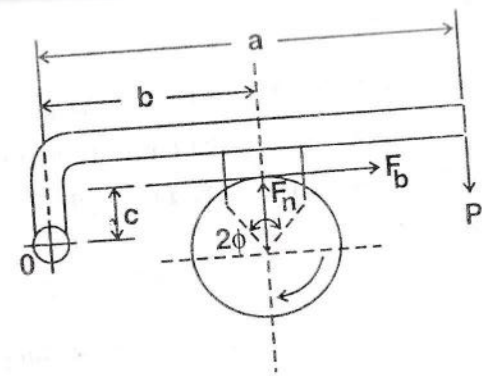


Fig. 18.5: Clockwise rotation of brake wheel.

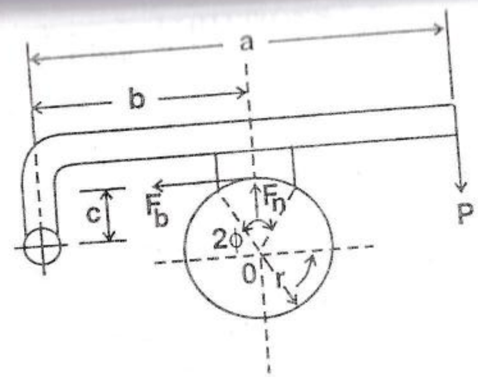


Fig. 18.6: Anticlockwise rotation of brake wheel

Single Block-brake. Line of action passing above the fulcrum

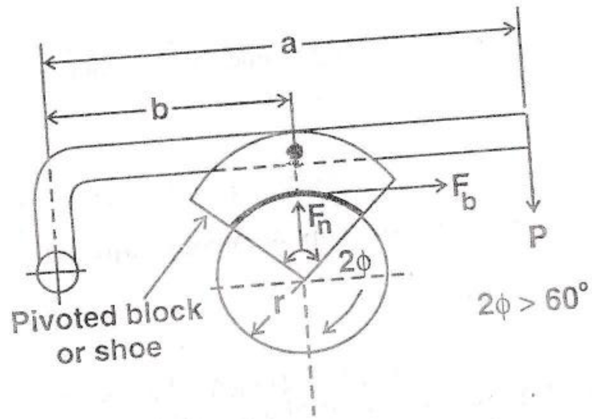


Fig. 18.7: Pivoted block of shoe brake.

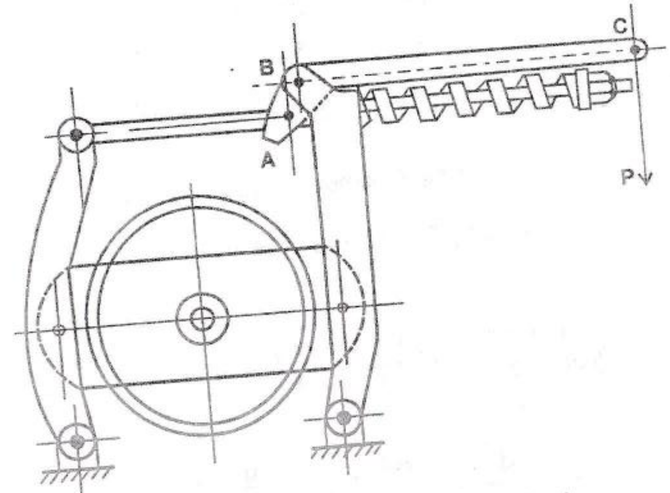


Fig. 18.8: Double block brake

DESIGN PARTICULARS	EQUATIONS
Braking torque for pivoted single block brake (i.e., for $2\phi > 60°$) (Fig. 18.7)	$T_b = F_b \cdot R = \mu F_n R'$ (or) $\mu' F_n R$ .... (18.8)
	where $R' = \dfrac{4R \sin\phi}{2\phi + \sin 2\phi}$; $\mu' = \dfrac{4\mu \sin\phi}{2\phi + \sin 2\phi}$
II Double block or shoe brake : (Fig. 18.8)	
Braking torque (For $2\phi \le 60°$)	$T_b = (F_{b1} + F_{b2}) R = \mu R (F_{n1} + F_{n2})$ .... (18.9)
	(For $2\phi > 60°$, replace μ by μ')
Average braking power for block brake	$BP_{av} = \dfrac{T_b\, \omega_i}{2 \times 10^6}$ kW .... (18.10)
Bearing pressure between contact surfaces	$p_b = \dfrac{F_n}{l \cdot w} = \dfrac{F_n}{2 R w \sin\phi} \le (p_b)$ .... (18.11)
	$l = 2R \sin\phi$
Band Brakes:	
Braking force on the drum	$F_b = F_1 - F_2$ .... (18.12)
Braking torque	$T_b = F_b \cdot R = (F_1 - F_2) R$ .... (18.13)
Ratio of tensions	$\dfrac{F_1}{F_2} = e^{\mu\theta}$ .... (18.14)
Force applied at the end of lever, P:	
(i) Simple band brake (Fig. 18.9)	
(a) For clockwise rotation of brake drum	$P = \dfrac{T_b \cdot b}{a R}\left[\dfrac{1}{e^{\mu\theta} - 1}\right]$ .... (18.15)

DESIGN PARTICULARS	EQUATIONS
(i) Simple band brake (Fig. 18.9)	
(a) For clockwise rotation of brake drum	$P = \frac{T_b \cdot b}{a\,R}\left[\frac{1}{e^{\mu\theta}-1}\right]$ .... (18.15)
(b) For anticlockwise rotation of brake drum	$P = \frac{T_b \cdot b}{a\,R}\left[\frac{e^{\mu\theta}}{e^{\mu\theta}-1}\right]$ .... (18.16)
(ii) Differential band brake: (Fig. 18.10)	
(a) For clockwise rotation of brake drum	$P = \frac{T_b\,(b_2 - b_1\,e^{\mu\theta})}{a\,R\,(e^{\mu\theta}-1)}$ .... (18.17)
(b) For anticlockwise rotation of brakedrum	$P = \frac{T_b\,(b_2\,e^{\mu\theta} - b_1)}{a\,R\,(e^{\mu\theta}-1)}$ .... (18.18)
Band and Block Brakes: (Fig. 18.11)	
Braking torque	$T_b = F_b \cdot R = (F_1 - F_2)\,R$ .... (18.19)
Ratio of tensions	$\frac{F_1}{F_2} = \left[\frac{1+\mu\tan\phi}{1-\mu\tan\phi}\right]^n$ .... (18.20)
Force applied at the end of lever	P is as explained in equations 18.15 to 18.18
Maximum tensile stress in the band	$S_t = \frac{F_1}{wt} \le (S_t)$ .... (18.21)
	$t = 3$ to 10 mm (or) 0.005D (approx)
	(S_t) for steel band $= 50$ to $80\ N/mm^2$
	For w and t, refer table 18.4
Maximum bearing pressure between the band and drum.	$p_{b\,max} = \frac{F_1}{w\,R} \le (p_b)$ .... (18.22)
	For (p_b), refer table 18.1

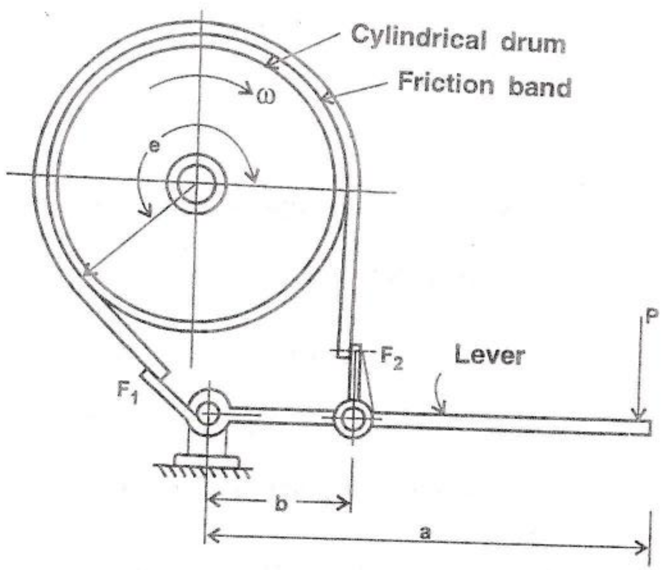


Fig. 18.9: Simple Band Brake.

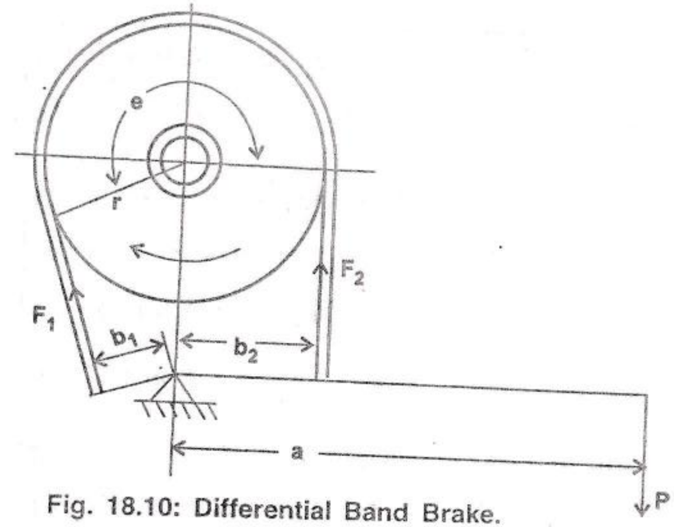


Fig. 18.10: Differential Band Brake.

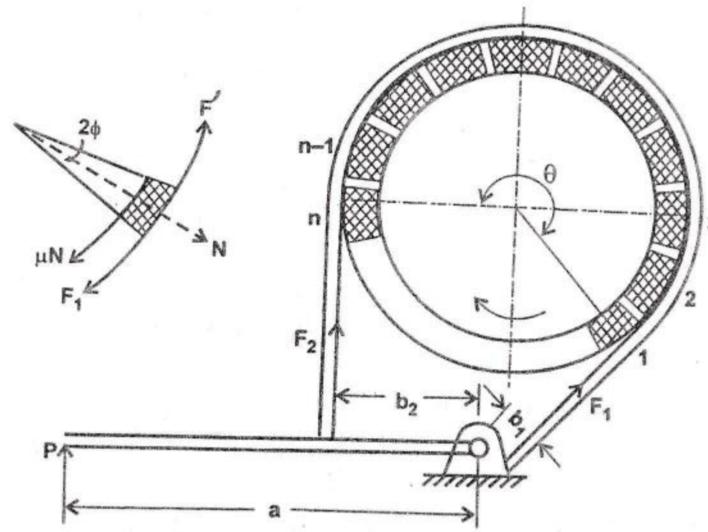


Fig. 18.11: Band and Block Brakes.

DESIGN PARTICULARS	EQUATIONS
Heat generated in brakes	$H_g = \mu\, p\, A\, v$ watts. .... (18.23)

Fig. 18.11: Band and Block Brakes.

DESIGN PARTICULARS	EQUATIONS
Heat generated in brakes	$H_g = \mu\, p\, A\, v$ watts. .... (18.23)
Heat dissipated in brake drum	$H_d = CA_r(t_d - t_a)/10^6 = C\, A_r \Delta t/10^6$ watts .... (18.24)
	where $C = 29.5$ for $\Delta t = 40°C$ (Table 18.6)
	and increase upto 44 for $\Delta t = 200°C$
Internal Expanding Shoe Brakes: (Fig. 18.12)	
Pressure intensity at any contact surface between brake and drum	$p = p_m \dfrac{\sin\theta}{\sin\theta_m}$ .... (18.25)
	$\theta_m = \theta_2$ for $\theta_2 < 90°$
	$= 90°$ for $\theta_2 > 90°$
Braking or friction force produced on one shoe	$F_b = \dfrac{\mu\, p_m\, br}{\sin\theta_m}(\cos\theta_1 - \cos\theta_2)$ .... (18.26)
Braking torque developed on one shoe	$T_b = F_b \cdot r = \dfrac{\mu\, p_m\, br^2}{\sin\theta_m}(\cos\theta_1 - \cos\theta_2)$ .... (18.27)
Total torque developed on two shoes	$T_B = 2T_b$ .... (18.28)

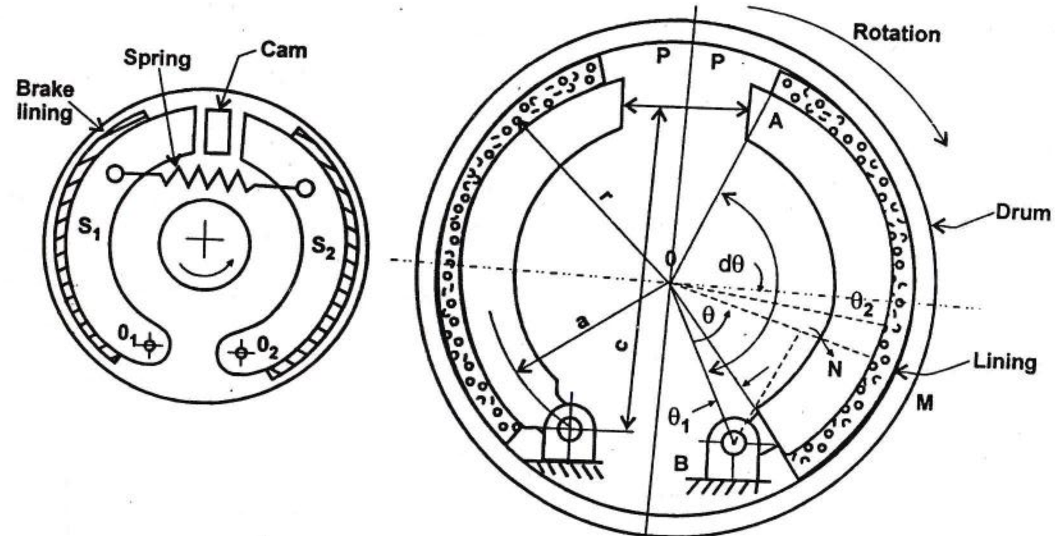


Fig. 18.12(a): Internal expanding shoe brake.

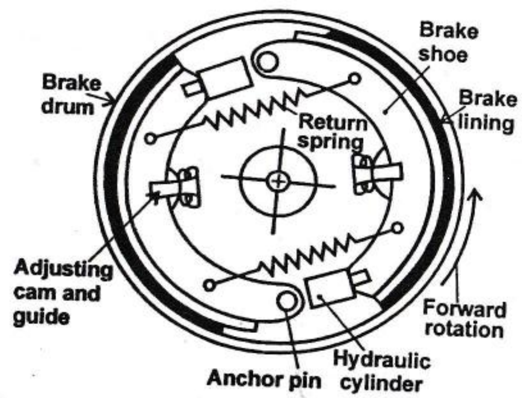


Fig. 18.12(b): Automotive brake with two hydraulic cylinders

DESIGN PARTICULARS	EQUATIONS
Total moment due to normal force on one shoe	$M_n = \frac{p_m b r a}{2 \sin \theta_m}\left[(\theta_2 - \theta_1) - \frac{1}{2}(\sin 2\theta_2 - \sin 2\theta_1)\right]$ .... (18.29)
Total moment due to friction force on one shoe	$M_f = \frac{\mu p_m b r}{\sin \theta_m}\left[r(\cos \theta_1 - \cos \theta_2) + \frac{a}{4}(\cos 2\theta_2 - \cos 2\theta_1)\right]$ .... (18.30)
Actuating force for leading (i.e., right) shoe	$P_1 = \frac{M_n - M_f}{c}$
Actuating force for trailing (i.e., left) shoe	$P_2 = \frac{M_n + M_f}{c}$
Total actuating force required	$P = P_1 + P_2 = 2P_2$ (For safety)
Total energy produced on a moving vehicle	$E_t = \frac{1}{2} m v^2 + \frac{1}{2} I \omega^2 + mgh$
Total energy absorbed by the brake (or) Workdone by the brake	$W_b = \frac{T_B}{1000} \times \frac{\pi N t}{60}$
	$E_t = W_b$ (To bring the vehicle to rest)

Table 18.1: Properties of Brake-lining (i.e., Friction) Materials

Materials in contact	Maximum operating tempe-rature (°C)	Coefficient of friction (μ)			Allowable bearing or contact pressure (p_b) (N/mm^2)
		Dry	Greasy	Oil lubricated	
Cast iron on cast iron	310	0.15 – 0.20	0.06 – 0.10	0.05 – 0.10	1.0 – 1.75
Bronze on cast iron	149	–	0.05 – 0.10	0.05 – 0.10	0.56 – 0.84
Steel on cast iron	260	0.25 – 0.35	0.07 – 0.12	0.06 – 0.10	0.84 – 1.4
Wood on cast iron	149	0.20 – 0.35	0.08 – 0.12	–	0.42 – 0.63
Asbestos on metal	350	0.35 – 0.50	0.25 – 0.30	0.20 – 0.25	0.21 – 0.56
Leather on metal	70	6.30 – 0.50	0.15 – 0.20	0.12 – 0.15	0.07 – 0.28
Fibre on metal	150	–	0.10 – 0.20	–	0.07 – 0.28
Cork on metal	90	0.35 – 0.50	0.25 – 0.30	0.22 – 0.25	0.05 – 0.10

Table 18.2: Dimensions of Brake-drum.

Power of the Motor kW (HP)	Brake-drum diameter, mm	Brake drum width, mm
7.5 (10)	160	50
10 (15)	200	65
15 (20)	250	80
25 (35)	320	100
45 (60)	400	125
75 (100)	500	160
110 (150)	630	200
130 (250)	800	250

Table 18.3: Safe Bearing-pressures for Band Brakes (p_b) N/mm^2

Type of Brake	Materials of the rubbing surfaces			
	Steel band on cast-iron or steel drum	Asbestos band on cast-Iron or steel drum	Rolled, press formed and shaped friction material on metal drum	Wood on cast-iron drum
Holding	1.5	0.6	0.8	0.6
Lowering	1.0	0.3	0.4	0.4

Table 18.4

Width of band (w) in mm	25 – 40	40 – 60	80	100	140 – 200
Thickness of band (t) in mm	3	3 – 4	4 – 6	4 – 7	6 – 10

Table 18.5: Capacity of Brakes

S.No.	Working conditions	p_{av} v
1.	Continuous application of load and poor dissipation of heat	20
2.	Intermittent application of load, comparatively long periods of rest and poor dissipation of heat	40
3.	Continuous application of load and good dissipation of heat as in an oil bath.	62.5
4.	Vehicle brakes	125

where p_{av} – Average contact pressure between the braking surfaces in MPa

v – Rubbing velocity in metres/minute.

Table 18.6: Radiating Factors for Brakes ($C = J/mm^2/s$)

Temperature difference (Degree centigrade)	Radiating factor C
50	2.95×10^{-5}
100	3.68×10^{-5}
150	4.08×10^{-5}
200	4.42×10^{-5}

CHAPTER – 19

HYDRODYNAMIC JOURNAL BEARINGS

Symbols : (with S.I. units)

A	–	Heat dissipating area, m^2
a	–	Contact area between fluid layers, m^2
C	–	Heat dissipation coefficient
c_r.	–	Diametral clearance ratio
c	–	Diametrol clearance, mm
c_p	–	Specific heat of oil
D	–	Diameter of bearing, mm
d	–	Diameter of journal, mm
e	–	Eccentricity
F	–	Force required to move one layer of fluid from its adjacent layer (or) force resisting the mutual shear of two adjacent layers of fluid, N
H_d	–	Heat dissipated by the bearing, W
H_g	–	Heat generated during operation, W
h	–	Distance between the two adjacent layers of fluid, m
h_0	–	Minimum film thickness, mm
J	–	Joule's coefficient, (1J = 427 kgf-m/kcal)

k	–	Correction factor for end leakage
l	–	Length of journal, mm
m	–	Mass of oil for heat removal, kg/s
n	–	Speed of journal in rpm
n′	–	Speed of journal in rps
p	–	Developed bearing pressure, N/mm^2
(p)	–	Allowable bearing pressure, N/mm^2
p_c	–	Critical bearing pressure, N/mm^2
p_{max}	–	Maximum bearing pressure, N/mm^2
q	–	Oil flow through the bearing, mm^3/s
q_s	–	Axial flow of oil (or) side leakage, mm^3/s
S	–	Sommer feld number
s	–	Saybolt universal seconds, s; unit of time in seconds
t_a	–	Atmospheric temperature, (i.e., temperature of surrounding air), °C.
t_b	–	Temperature of bearing surface, °C
V	–	Sliding velocity of journal, m/s
v	–	Relative velocity of adjacent layers of fluid, m/s
W	–	Load acting on the journal, N
Z	–	Absolute (or) dynamic viscosity of oil, $N\text{-}s/m^2$ (or) centipoises ($1\ N\text{-}s/m^2 = 1000$ centipoises)
ρ	–	Density of oil, kg/m^3
ρ_t	–	Specific gravity at any temperature t°C
ρ_{15}	–	Specific gravity at 15°C
γ	–	Kinematic viscosity, m^2/s
μ	–	Coefficient of friction.
Δt	–	Difference between outlet and inlet temperatures of oil, °C
ε	–	Eccentricity factor
ϕ	–	Attitude angle

DESIGN PARTICULARS	EQUATIONS
Newton's equation for viscous flow (Fig. 19.1)	$F = \frac{Z\,a\,v}{h}$ .... (19.1)
Kinematic viscosity	$\gamma = \frac{Z}{\rho}$ .... (19.2)
Absolute (or) dynamic viscosity from Saybolt universal seconds	$Z = \rho_t \left(0.00022\,s - \frac{0.18}{s} \right)$ N-s/m^2 at t°C .... (19.3)
Specific gravity of oil at any temperature t°C	$\rho_t = \rho_{15} - 0.00063\,(t° - 15)$ .... (19.4) (For ρ_{15}, refer table 19.4)
Coefficient of friction between journal and bearing	
(i) By McKees equation	$\mu = \left[\frac{33.25}{10^8} \times \frac{Zn}{p} \times \frac{d}{c} \right] + k$ .... (19.5) ... (when Z in N-s/m^2 (or) kg/m-s and p in N/mm^2) $= \left[\frac{33.25}{10^{10}} \times \frac{Zn}{p} \times \frac{d}{c} \right] + k$ .... (19.6) ... (when Z in centipoises and p in kgf/cm^2) (For k, refer fig. 19.2)

DESIGN PARTICULARS	EQUATIONS
(ii) By Petroff's equation	$\mu = 2\pi^2 \left(\frac{Zn}{60 \times 10^6\, p}\right)\left(\frac{d}{c}\right)$ .... (19.7) .... (Z in N-s/m^2, p in N/mm^2)
Sommerfeld number	$S = \frac{Zn}{60 \times 10^6\, p}\left(\frac{d}{c}\right)^2$ .... (19.8) (Table 19.7 to 19.10) Z in N-s/m^2 p in N/mm^2
Developed bearing pressure	$p = \frac{W}{l \cdot d} \leq (p)$ .... (19.9)
Heat generated during operation	$H_g = \mu\, w\, V$ watts .... (19.10) .... (when W in newtons and V in m/s) .... (19.11) $= \mu\, w\, V$ kgf-m/min (or) $\frac{\mu\, w\, V}{J}$ kcal/min .... (when W in kgf and V in m/min $J = 427$ kgf-m/kcal)

DESIGN PARTICULARS	EQUATIONS
Heat dissipated by the bearing	$H_d = CA\,(t_b - t_a)$ watts .... (19.12) where C = Heat dissipation coefficient $= 140$ to $420\ W/m^2/°C$ (or) 2 to 6 $kcal/min/m^2/°C$ [For unventilated bearings (i.e., Still air)] $= 490$ to $1400\ W/m^2/°C$ (or) 7 to 20 $kcal/min/m^2/°C$ (For well ventilated bearings) A = Projected Area ($= l \times d$) in m^2
Mass of oil for heat removal	$m = \dfrac{H_g}{c_p\,\Delta t}$ kg/s .... (19.13) (when H_g in watts c_p in J/kg/°C) $= \dfrac{H_g}{c_p\,\Delta t}$ kg/min .... (19.14) ... (when H_g in kcal/min c_p in kcal/kg/°C) c_p = Specific heat of oil $= 1840$ to 2100 J/kg/°C

DESIGN PARTICULARS	EQUATIONS
	(or) 0.44 to 0.49 kcal/kg/°C
Critical pressure (i.e., minimum operating pressure)	$p_c = \frac{Zn}{4.75 \times 10^6}\left(\frac{d}{c}\right)^2\left(\frac{l}{l+d}\right) N/mm^2$ .... (19.15)
	... (when Z in N-s/m^2)
	$= \frac{Zn}{475 \times 10^6}\left(\frac{d}{c}\right)^2\left(\frac{l}{l+d}\right) kgf/cm^2$ .... (19.16)
	... (when Z is centipoise) .... (19.17)
Geometric relations of journal bearing (Fig. 19.3)	
(i) Diametral clearance	$c = D - d$
(ii) Diametral clearance ratio	$c_r = \frac{c}{d}$ (= 0.001 usually), (Refer table 19.6)
(iii) Eccentricity	$e = \frac{c}{2} - h_0$
(iv) Eccentricity factor or attitude	$\varepsilon = \frac{2e}{c} = 1 - \frac{2h_0}{c}$
(v) Film thickness at any angle θ	$h = \frac{c}{2}(\varepsilon \cos\theta + 1)$

DESIGN PARTICULARS	EQUATIONS
(vi) Minimum film thickness	$h_0 = \frac{c}{2} - e = \frac{c}{2}(1 - \varepsilon)$
Length to diameter ratio for the bearing	$\frac{l}{d} = 1$ for square bearing
	> 1 for long bearing
	< 1 for short bearing
Dimensionless performance parameters	$\frac{\mu d}{c}$ — Coefficient of friction variable .... (19.18)
	$\frac{4q}{dc\,n'l}$ — Flow variable
	$\frac{q_s}{q}$ — Flow ratio
	$\frac{p}{p_{max}}$ — Pressure ratio
	$\frac{\rho c' \Delta t_0}{p}$ — Temperature rise variable
Design oil film temperature	60 to 95°C

Table 19.1: Journal Bearing Materials and Applications

	Material	Characteristics	Applications
1.	Babbitt or white metal alloys (tin base)	Very expensive	Used for general purp resistant to corrosive eff of acids, I.C. engi bearings.
2.	Lead-base white metals	Low cost, lower strength and susceptibility to corrosion, high coefficient of friction	General machinery purpo Used at moderately hig temperatures. Lead rang from 0.981 MN/m^2 (0.1 kgf/mm^2) to 2.158 MN (0.22 kgf/mm^2) at 1 m/s
3.	Plastic bronze	Alloy of copper and lead, resistance to seizure, conformability and embedability. Less corrodible metals. Low coefficient of friction	Used in automobil locomotive and rolling mil where there are hea loads, Max. load carryin capacity is approx. 10.2 MN/m^2 (1.05 kgf/mm^2) at 1 m/s
4.	Phosphor bronze	Good mechanical and antifriction properties	All machines. The permissible load is 68. MN/m^2 (7.0 kgf/mm^2). Ma rubbing speed 5 m/s
5.	Gun metal	Chill casting gives a finer structure and is preferable to sand casting	Light loads
6.	Brass	Low cost than babbitt material	At high pressures

	Material	Characteristics	Applications
[illegible]	Aluminium	Good corrosion fatigue resistance and thermal conductivity low embadability, high thermal expansion	Suitable for heavy loads upto about 24 MN/m^2 (2.45 kgf/mm^2 peak load and 13.73 MN/m^2) (1.40 kgf/mm^2) continuous load at moderate speeds of 4 to 6 m/s.
[illegible]	Cast Iron	Low friction, must have good lubrication	Cam shaft, light transmission Max. speed 0.65 m/s. Max. load 3.43 MN/m^2 (0.35 kgf/mm^2)
[illegible]	Cadmium base bearing metals	Allow much higher operating temperatures	Used for severe service in internal combustion engines.
[illegible]	Porous bearings	Oil impregnated bearings	Medium duty applications in small size bearings. Where supply of lubricant is difficult, inadequate or infrequent. Rubbing speed from 0.4 to 7.5 m/s with light load.
[illegible]	Wood bearing (Lignum vitae, rock maple or oak)	Low cost, self lubricating	Conveyors
[illegible]	Rubber	Low coefficient of rubbing friction	Hydraulic turbines, centrifugal and deep well pumps and washers

Table 19.2: Recommended Speeds of Some Machineries, rev./min

Location of bearing	Speed, rev/min
Automobile crank shaft	900 to 14000
Aeronautic engine crank shaft	1800 to 2000
Stationary gas-engine main	250 to 800
-do- crank pin	250 to 800
-do- cross head	250 to 800
Diesel engine main	60 to 160
-do- crank pin	60 to 160
Marine steam engine main	180
-do- crank pin	180
Stationary slow speed main	40 to 80
-do- crank pin	40 to 80
-do- cross head	40 to 80
Cotton mill spindle	8000 to 12000
Stationary high speed main	360
-do- crank pin	360
-do- cross head	360
Locomotive drive wheel	250
-do- crank pin	250
-do- cross head	250
Marine steam turbine	2000
Stationary steam turbine	2000
De Laval 5 kW steam turbine	30000
Railway car axle	300
Generator and motor	150 to 500
Rolling mill main	60
Gyroscope	800 to 1500

Table 19.3 : Product of Pressure and Velocity

Type of Bearing	Pressure × velocity	
	(MN/m^2) (m/s)	(kgf/mm^2) (m/s)
Axles, locomotive ..	4.20	(0.428)
Railway car ..	4.20	(0.428)
Crank pins, Aircraft ..	87.60	(8.933)
Crank pins, Gas engine ..	14.00	(1.428)
Crank pins, Steam, H.S. ..	14.00	(1.428)
Crank shaft and Main bearings : Aircraft ..	70.10	(7.143)
-do- : Diesel ..	35.00	(3.572)
Generators, motors ..	1.75	(0.178)
Line shafts ..	0.88	(0.089)
Reducing gears ..	3.50	(0.357)
Machine tools ..	0.35	(0.036)
Steam turbines ..	35.00	(3.572)
Mill shafting with self aligning cast iron bearing, grease or imperfect oil lubrication maximum value ..	0.43	(0.043)
Mill shafting self-aligning ring-oiled babbit bearings, maximum ..	0.85	(0.086)
Self aligning ring-oiled bearings, continuous load in one direction ..	1.40	(0.143)

Type of Bearing	Pressure × velocity	
	(MN/m^2) (m/s)	(kgf/mm^2) (m/s)
Cranksaft journals with bronze bearings ..	0.78	(0.080)
Crankshaft bearings with babbitted bearings, maximum ..	2.06	(0.210)
Excellent radiating conditions ..	4.67	(0.476)

Table 19.4: Specific Gravity at 15°C

Curve number in fig. 19.4	Type of oil	Specific gravity at 15°C
1.	Light oil for light service high speeds	0.875
2.	Turbing oil (oil rings) for light service and high speeds	0.880
3.	Turbine oil (oil rings) for light service and high speeds	0.890
4.	Extra-light motor oil for ring-oiled bearings, transmission shafting, small generators, motors, and high-speed engines.	0.935
5.	S.A.E. 20 – light transmission oil for gears	0.925
6.	S.A.E. 40-medium transmission oil for large generators, motors, steam turbines, high-speed gears, heavy motor oil	0.930
7.	Airplane 100 G-light cylinder oil	0.890
8.	S.A.E. 110-light steam cylinder oil; heavy duty gears	0.930
9.	Medium cylinder oil; slow speed worm gears	0.910
10.	S.A.E. 160-heavy cylinder oil, heavy-duty slow-speed gearing	0.935
11.	Heavy steam cylinder oil	0.930

Table 19.5: Design Values for Journal Bearing

Machinery	Bearing	Allowable bearing pressure		Absolute viscosity of lubricant (Z)		Operating values $\left(\frac{Zn}{p}\right)_{min}$		$\frac{c}{d}$	$\frac{l}{d}$
		N/mm^2	kgf/cm^2	$N\text{-}s/m^2$	Centipoise	Z in $N\text{-}s/m^2$ p in N/mm^2	Z in centipoise p in kgf/cm^2		
Stationary high speed steam engines	Main	1.75	17.5	0.015	15	3.56	356	0.001	1.5-3.0
	Crank pin	4.2	42.0	0.030	30	0.850	85		0.9-1.5
	Wrist pin	12.6	126.0	0.025	25	0.71	71		1.3-1.7
Gas and oil engines (Four stroke)	Main	4.9-8.4	49-84			2.85	285		0.6-2.0
	Crank pin	10.8-12.6	108-126	0.02-0.065	20-65	1.42	142	0.001	0.6-1.5
	Wrist pin	12.5-15.4	125-154			0.71	71		1.5-2.0
Gas and oil engines (Two stroke)	Main	3.5-12.5	35-125			3.56	356		0.6-2.0
	Crank pin	7-10.5	70-105	0.02-0.065	20-65	1.71	171	0.001	0.6-1.5
	Wrist pin	8.4-12.5	84-125			1.42	142		1.5-2.2
Aircraft and automobile engines	Main	5.6-12	56-120	0.008		2.13	213		0.8-1.8
	Crank pin	10.5-24.5	105-245	0.008	8	1.42	142	0.001	0.7-1.4
	Wrist pin	16-35	160-350	0.008		1.14	114		1.5-2.2
Reciprocating compressors and pumps	Main	1.75	17.5			4.27	427		1.0-2.2
	Crank pin	4.2	42.0	0.03-0.08	30-80	2.85	285	0.001	0.9-1.7
	Wrist pin	7	70.0			1.42	142		1.5-2.0

Machinery	Bearing	Allowable bearing pressure		Absolute viscosity of lubricant (Z)		Operating values $\left(\frac{Zn}{p}\right)_{min}$		$\frac{c}{d}$	$\frac{l}{d}$
		N/mm^2	kgf/cm^2	$N\text{-}s/m^2$	Centipoise	Z in $N\text{-}s/m^2$ p in N/mm^2	Z in centipoise p in kgf/cm^2		
Centrifugal pumps, motors and generators	Rotor	0.7-1.4	7-14	0.025	25	28.45	2845	0.0013	1.0-2.0
Machine tools	Main	2.1	21.0	0.04	40	0.140	14	0.001	1.0-4.0
Steam turbines	Main	0.7-2	7-20	0.002-0.016	2-16	14.22	1422	0.001	1.0-2.0
Railway cars	Axle	3.5	35	0.1	100	7.11	711	0.001	1.8-2.0
Marine steam	Main	3.5	35	0.03	30	2.85	285		0.7-1.5
engines	Crank pin	4.2	42	0.04	40	2.13	213	0.001	0.7-1.2
	Wrist pin	10.5	105	0.03	30	1.42	142		1.2-1.7
Transmissions	Light, Fixed	0.18	1.8	0.025	25	14.22	1422	0.001	2-3
Gyroscopes	Rotors	6	60	0.03	30	7.82	782	0.001	–
Shafting	Self aligning	1.1	11	0.06	60	4.27	427	0.001	2.5-4
	Heavy	1.1	11	0.06	60	4.27	427		2-3
Cotton mills	Spindle	0.007	0.07	0.002	2	14.24	1424	0.001	–
Punching and	Main	28	280	0.1	100	–	–		1.2
shearing machines	Crank pin	56	560	0.1	100	–	–	0.001	1-2
Rolling mills	Main	21	210	0.05	50	1.42	142	0.0015	1-1.5

Table 19.6: Typical Diametral Clearances, in Microns

Upto shaft diameter, mm	12	25	50	90	140
Automotive crank shaft :					
Babbitt lined bearing			38	63	
Cadmium Silver Copper			50	75	
Precision spindle, hardened, ground, lapped into bronze bushing; $v_m < 160$ m/min; $p < 3.5$ N/mm^2; 0.2 to 0.4 microns rms	7 to 19	19 to 38	38 to 63	63 to 88	88 to 125
Precision spindle, hardened, ground, papped into bronze bushing; $v_m > 160$ m/min; $p > 3.5$ N/mm^2; 0.2 to 0.4 microns rms	13 to 25	25 to 50	50 to 75	75 to 113	113 to 163
Electric motor or generator, ground journal in broached bronze or babbitt bushing 0.4 to 0.8 microns rms	13 to 38	25 to 50	38 to 88	50 to 100	75 to 150
General machine practice, turned or cold-rolled journal in reamed bronze or babbitt bushing; 0.8 to 1.5 microns rms	50 to 100	63 to 113	75 to 125	100 to 175	125 to 200
Rough machine practice, turned or cold-rolled journal in poured babbitt bearings; 1.5 to 3.8 microns rms	75 to 150	125 to 225	200 to 300	275 to 400	350 to 500

p, Unit load N/mm^2

v_m, Surface speed of journal

1 micron $= 10^{-6}$ metre.

Table 19.7: Dimensionless Performance Parameters for Full Journal Bearings with Side Flow

$\frac{l}{d}$	$\in$	$\frac{2h_0}{c}$	S	ϕ	$\mu\frac{d}{c}$	$\frac{4q}{dcn'l}$	$\frac{q_s}{q}$	$\frac{\rho C' \Delta t_0}{p}$	$\frac{p}{p_{max}}$
∞	0	1.0	∞	(70.92)	∞	π	0	∞	–
	0.1	0.9	0.240	69.10	4.80	3.03	0	19.9	0.826
	0.2	0.8	0.123	67.26	2.57	2.83	0	11.4	0.814
	0.4	0.6	0.0626	61.94	1.52	2.26	0	8.47	0.764
	0.6	0.4	0.0389	54.31	1.20	1.56	0	9.73	0.667
	0.8	0.2	0.021	42.22	0.961	0.760	0	15.9	0.495
	0.9	0.1	0.0115	31.62	0.756	0.411	0	23.1	0.358
	0.97	0.03	–	–	–	–	0	–	–
	1.0	0	0	0	0	0	0	∞	0
1	0	1.0	∞	(85)	∞	π	0	∞	–
	0.1	0.9	1.33	79.5	26.4	3.37	0.150	106	0.540
	0.2	0.8	0.631	74.02	12.8	3.59	0.280	52.1	0.529
	0.4	0.6	0.264	63.10	5.79	3.99	0.497	24.3	0.484
	0.6	0.4	0.121	50.58	3.22	4.33	0.680	14.2	0.415
	0.8	0.2	0.0446	36.24	1.70	4.62	0.842	8.00	0.313
	0.9	0.1	0.0188	26.45	1.05	4.74	0.919	5.16	0.247
	0.97	0.03	0.00474	15.47	0.514	4.82	0.973	2.61	0.152
	1.0	0	0	0	0	–	1.0	0	0
0.5	0	1.0	∞	(88.5)	∞	π	0	∞	–
	0.1	0.9	4.31	81.62	85.6	3.43	0.173	343.0	0.523
	0.2	0.8	2.03	74.94	40.9	3.72	0.318	164.0	0.506

$\frac{l}{d}$	$\in$	$\frac{2h_0}{c}$	S	ϕ	$\mu \frac{d}{c}$	$\frac{4q}{dcn' l}$	$\frac{q_s}{q}$	$\frac{\rho C' \Delta t_0}{p}$	$\frac{p}{p_{max}}$
	0.4	0.6	0.779	61.45	17.0	4.29	0.552	68.6	0.441
	0.6	0.4	0.319	48.14	8.10	4.85	0.730	33.0	0.365
	0.8	0.2	0.0923	33.31	3.26	5.41	0.874	13.4	0.267
	0.9	0.1	0.0313	23.66	1.60	5.69	0.939	6.66	0.206
	0.97	0.03	0.00609	13.75	0.610	5.88	0.980	2.56	0.126
	1.0	0	0	0	0	–	1.0	0	0
0.25	0.0	1.0	∞	(89.5)	∞	π	0	∞	–
	0.1	0.9	16.2	82.31	322.0	3.45	0.180	1287.0	0.515
	0.2	0.8	7.57	75.18	153.0	3.76	0.330	611.0	0.489
	0.4	0.6	2.83	60.86	61.1	4.37	0.567	245.0	0.415
	0.6	0.4	1.07	46.72	26.7	4.99	0.746	107.0	0.334
	0.8	0.2	0.261	31.04	8.80	5.60	0.884	35.4	0.240
	0.9	0.1	0.0736	21.85	3.50	5.91	0.945	14.1	0.180
	0.97	0.03	0.0101	12.22	0.922	6.12	0.984	3.73	0.108
	1.0	0	0	0	0	–	1.0	0	0

q, mm^3/s; ρ, density of oil $= 900\ kg/m^3$; C′, specific heat of the oil = 1840 to 2100 J/kg/°C, $\rho\ C' = 142 \times 10^4\ N/m^2\ °C$

Values of $\frac{2h_0}{c}$

l/d ratio	∞	1	0.5	0.25
For min. friction	0.6	0.3	0.12	0.03
For max. load	0.66	0.53	0.43	0.27

Table 19.8: Dimensionless Performance Parameters for 180° Bearing, Centrally Loaded, with Side Flow

$\frac{l}{d}$	$\in$	$\frac{2h_0}{c}$	S	ϕ	$\mu \frac{d}{c}$	$\frac{4q}{dcn' l}$	$\frac{q_s}{q}$	$\frac{\rho C' \Delta t_0}{p}$	$\frac{p}{p_{max}}$
∞	0	1.0	∞	90.0	∞	π	∞	∞	–
	0.1	0.9	0.347	72.90	3.55	3.04	0	14.7	0.778
	0.2	0.8	0.179	61.32	2.01	2.80	0	8.99	0.759
	0.4	0.6	0.0898	49.99	1.29	2.20	0	7.34	0.700
	0.6	0.4	0.0523	43.15	1.06	1.52	0	8.71	0.607
	0.8	0.2	0.0253	33.35	0.859	0.767	0	14.1	0.459
	0.9	0.1	0.0128	25.57	0.681	0.380	0	22.5	0.337
	0.97	0.03	0.00384	15.43	0.416	0.119	0	44.0	0.190
	1.0	0	0	0	0	0	0	∞	0
1	0	1.0	∞	90.0	–	π	0	∞	–
	0.1	0.9	1.40	78.50	14.1	3.34	0.139	57.0	0.525
	0.2	0.8	0.670	68.93	7.15	3.46	0.252	29.7	0.513
	0.4	0.6	0.278	58.86	3.61	3.49	0.425	16.5	0.466
	0.6	0.4	0.128	44.67	2.28	3.25	0.572	12.4	0.403
	0.8	0.2	0.0463	32.33	1.39	2.63	0.721	10.4	0.313
	0.9	0.1	0.0193	24.14	0.921	2.14	0.818	9.13	0.244
	0.97	0.03	0.00483	14.57	0.483	1.60	0.915	6.96	0.157
	1.0	0	0	0	0	–	1.0	0	0
0.5	0	1.0	∞	90.0	∞	π	0	∞	–
	0.1	0.9	4.38	79.97	44.0	3.41	0.167	177.0	0.518

$\frac{l}{d}$	ϵ	$\frac{2h_0}{c}$	S	ϕ	$\mu \frac{d}{c}$	$\frac{4q}{dcn' l}$	$\frac{q_s}{q}$	$\frac{\rho C' \Delta t_0}{p}$	$\frac{p}{p_{max}}$
	0.2	0.8	2.06	72.14	21.6	3.64	0.302	87.8	0.499
	0.4	0.6	0.794	58.01	9.96	3.93	0.506	42.7	0.438
	0.6	0.4	0.321	45.01	5.41	3.93	0.665	25.9	0.365
	0.8	0.2	0.0921	31.29	2.54	3.56	0.806	15.0	0.273
	0.9	0.1	0.0314	22.80	1.38	3.17	0.886	9.80	0.208
	0.97	0.03	0.00625	13.63	0.581	2.62	0.951	5.30	0.132
	1.0	0	0	0	0	–	1.0	0	0
0.25	0	1.0	∞	90.0	∞	π	0	∞	–
	0.1	0.9	16.3	81.40	163.0	3.44	0.176	653.0	0.513
	0.2	0.8	7.60	73.70	79.4	3.71	0.320	320.0	0.489
	0.4	0.6	2.84	58.99	35.1	4.11	0.534	146.0	0.417
	0.6	0.4	1.08	44.96	17.6	4.25	0.698	79.8	0.336
	0.8	0.2	0.263	30.43	6.88	4.07	0.837	36.5	0.241
	0.9	0.1	0.0736	21.43	2.99	3.72	0.905	18.4	0.180
	0.97	0.03	0.0104	12.28	0.877	3.29	0.961	6.46	0.110
	1.0	0	0	0	0	–	1.0	0	0

Values of $\frac{2h_0}{c}$

l/d ratio	∞	1	0.5	0.25
For min. friction	0.6	0.44	0.23	0.03
For max. load	0.64	0.52	0.42	0.28

Table 19.9: Dimensionless Performance Parameters for 120° Bearing, Centrally Loaded, with Side Flow

$\frac{l}{d}$	$\in$	$\frac{2h_0}{c}$	S	ϕ	$\mu \frac{d}{c}$	$\frac{4q}{dcn' l}$	$\frac{q_s}{q}$	$\frac{\rho C' \Delta t_0}{p}$	$\frac{p}{p_{max}}$
∞	0	1.0	∞	90.0	∞	π	0	∞	–
	0.1	0.9007	0.877	66.69	6.02	3.02	0	25.1	0.610
	0.2	0.8	0.431	52.60	3.26	2.75	0	14.9	0.599
	0.4	0.6	0.181	39.02	1.78	2.13	0	10.5	0.566
	0.6	0.4	0.0845	32.67	1.21	1.47	0	10.3	0.509
	0.8	0.2	0.0328	26.80	0.853	0.759	0	14.1	0.405
	0.9	0.1	0.0147	21.51	0.653	0.388	0	21.2	0.311
	0.97	0.03	0.00406	13.86	0.399	0.118	0	42.4	0.199
	1.0	0	0	0	0	0	0	∞	0
1	0	1.0	∞	90.0	∞	π	0	∞	–
	0.1	0.9024	2.14	72.43	14.5	3.20	0.0876	59.5	0.427
	0.2	0.8	1.01	58.25	7.44	3.11	0.157	32.6	0.420
	0.4	0.6	0.385	43.98	3.60	2.75	0.272	19.0	0.396
	0.6	0.4	0.162	35.65	2.16	2.24	0.384	15.0	0.356
	0.8	0.2	0.0531	27.42	1.27	1.57	0.535	13.9	0.290
	0.9	0.1	0.0208	21.29	0.855	1.11	0.657	14.4	0.233
	0.97	0.03	0.00498	13.49	0.461	0.694	0.812	14.0	0.162
	1.0	0	0	0	0	–	1.0	0	0
0.5	0	1.0	∞	90.0	∞	π	0	–	–
	0.1	0.9034	5.42	74.99	36.6	3.29	0.124	149.0	0.431

$\frac{l}{d}$	ϵ	$\frac{2h_0}{c}$	S	ϕ	$\mu \frac{d}{c}$	$\frac{4q}{dcn' l}$	$\frac{q_s}{q}$	$\frac{\rho C' \Delta t_0}{p}$	$\frac{p}{p_{max}}$
	0.2	0.8003	2.51	63.38	18.1	3.32	0.225	77.2	0.424
	0.4	0.6	0.914	48.07	8.20	3.15	0.386	40.5	0.389
	0.6	0.4	0.354	38.50	4.43	2.80	0.530	27.0	0.336
	0.8	0.2	0.0973	28.02	2.17	2.18	0.684	19.0	0.261
	0.9	0.1	0.0324	21.02	1.24	1.70	0.787	15.1	0.203
	0.97	0.03	0.00631	13.00	0.550	1.19	0.899	10.6	0.136
	1.0	0	0	0	0	–	1.0	0	0
0.25	0	1.0	∞	90.0	∞	π	0	∞	–
	0.1	0.9044	18.4	76.97	124.0	3.34	0.143	502.0	0.456
	0.2	0.8011	8.45	65.97	60.4	3.44	0.260	254.0	0.438
	0.4	0.6	3.04	51.23	26.6	3.42	0.442	125.0	0.389
	0.6	0.4	1.12	40.42	13.5	3.20	0.599	75.8	0.321
	0.8	0.2	0.268	28.38	5.65	2.67	0.753	42.7	0.237
	0.9	0.1	0.0743	20.55	2.63	2.21	0.846	25.9	0.178
	0.97	0.03	0.0105	12.11	0.832	1.69	0.931	11.6	0.112
	1.0	0	0	0	0	–	1.0	0	0

Values of $\frac{2h_0}{c}$

l/d ratio	∞	1	0.5	0.25
For min. friction	0.5	0.4	0.28	0.06
For max. load	0.53	0.46	0.38	0.26

Table 19.10: Dimensionless Performance Parameters for 60° Bearing, Centrally Loaded, with Side Flow

$\frac{l}{d}$	ϵ	$\frac{2h_0}{c}$	S	ϕ	$\mu\frac{d}{c}$	$\frac{4q}{dcn'l}$	$\frac{q_s}{q}$	$\frac{\rho C' \Delta t_0}{p}$	$\frac{p}{p_{max}}$
∞	0	1.0	∞	90.0	∞	π	0	∞	–
	0.1	0.9191	5.75	65.91	19.7	3.01	0	82.3	0.337
	0.2	0.8109	2.66	48.91	10.1	2.73	0	46.5	0.336
	0.4	0.6002	0.931	31.96	4.67	2.07	0	28.4	0.329
	0.6	0.4	0.322	23.21	2.40	1.40	0	21.5	0.317
	0.8	0.2	0.0755	17.39	1.10	0.722	0	19.2	0.287
	0.9	0.1	0.0241	14.94	0.667	0.372	0	22.5	0.243
	0.97	0.03	0.00495	10.58	0.372	0.115	0	40.7	0.163
	1.0	0	0	0	0	0	0	0	0
1	0	1.0	∞	90.0	∞	π	0	∞	–
	0.1	0.9212	8.52	67.92	29.1	3.07	0.0267	121.0	0.252
	0.2	0.8133	3.92	50.96	14.8	2.82	0.0481	67.4	0.251
	0.4	0.6010	1.34	33.99	6.61	2.22	0.0849	39.1	0.247
	0.6	0.4	0.450	24.56	3.29	1.56	0.127	28.2	0.239
	0.8	0.2	0.101	18.33	1.42	0.883	0.200	22.5	0.220
	0.9	0.1	0.0309	15.33	0.822	0.519	0.287	23.2	0.192
	0.97	0.03	0.00584	10.88	0.422	0.226	0.465	30.5	0.139
	1.0	0	0	0	0	–	1.0	0	0
0.5	0	1.0	∞	90.0	∞	π	0.0	∞	–
	0.1	0.9223	14.2	69.00	48.6	3.11	0.0488	201.0	0.239

$\frac{l}{d}$	ϵ	$\frac{2h_0}{c}$	S	ϕ	$\mu \frac{d}{c}$	$\frac{4q}{dcn' l}$	$\frac{q_s}{q}$	$\frac{\rho C' \Delta t_0}{p}$	$\frac{p}{p_{max}}$
	0.2	0.8152	6.47	52.60	24.2	2.91	0.0883	109.0	0.239
	0.4	0.6039	2.14	37.00	10.3	2.38	0.160	59.4	0.233
	0.6	0.4	0.695	26.98	4.93	1.74	0.236	40.3	0.225
	0.8	0.2	0.149	19.57	2.02	1.05	0.350	29.4	0.201
	0.9	0.1	0.0422	15.91	1.08	0.664	0.464	26.5	0.172
	0.97	0.03	0.00704	10.85	0.490	0.329	0.650	27.8	0.122
	1.0	0	0	0	0	–	1.0	0	0
0.25	0	1.0	∞	90.0	∞	π	0	∞	–
	0.1	0.9251	35.8	71.55	121.0	3.16	0.0666	499.0	0.251
	0.2	0.8242	16.0	58.51	58.7	3.04	0.131	260.0	0.249
	0.4	0.6074	5.20	41.01	24.5	2.57	0.236	136.0	0.242
	0.6	0.4	1.65	30.14	11.2	1.98	0.346	86.1	0.228
	0.8	0.2	0.333	21.70	4.27	1.30	0.496	54.9	0.195
	0.9	0.1	0.0844	16.87	2.01	0.894	0.620	41.0	0.159
	0.97	0.03	0.0110	10.81	0.713	0.507	0.786	29.1	0.107
	1.0	0	0	0	0	–	1.0	0	0

Values of $\frac{2h_0}{c}$

l/d ratio	∞	1	0.5	0.25
For min. friction	0.23	0.22	0.16	0.10
For max. load	0.25	0.23	0.20	0.15

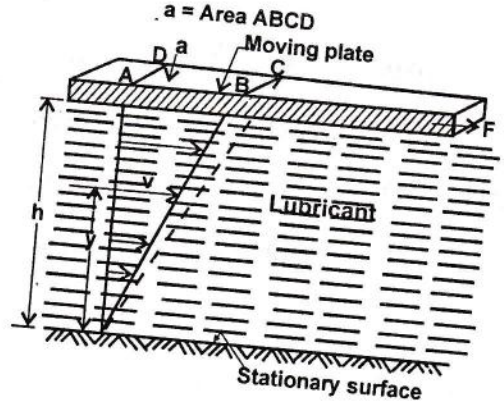


Fig. 19.1

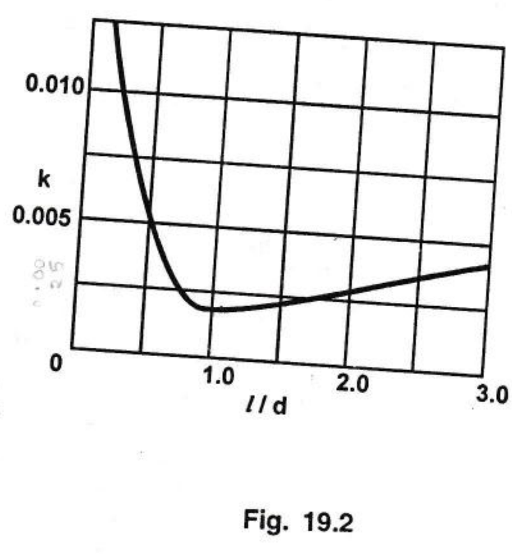
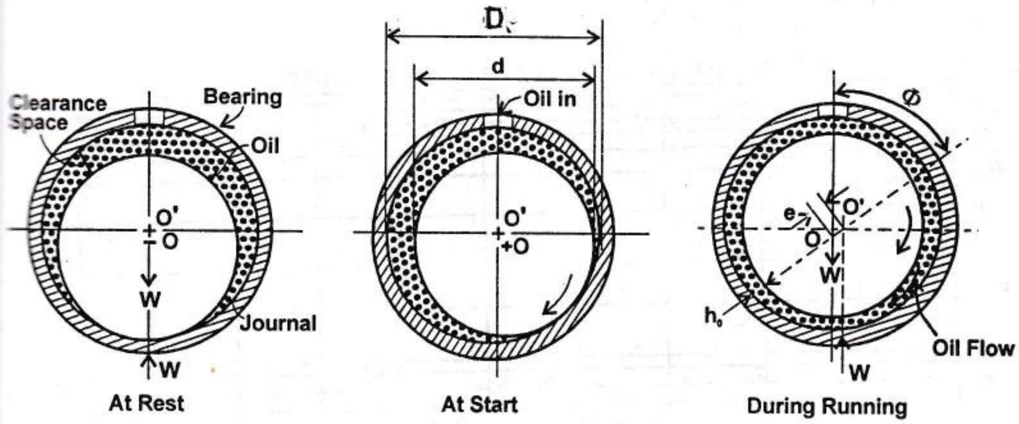
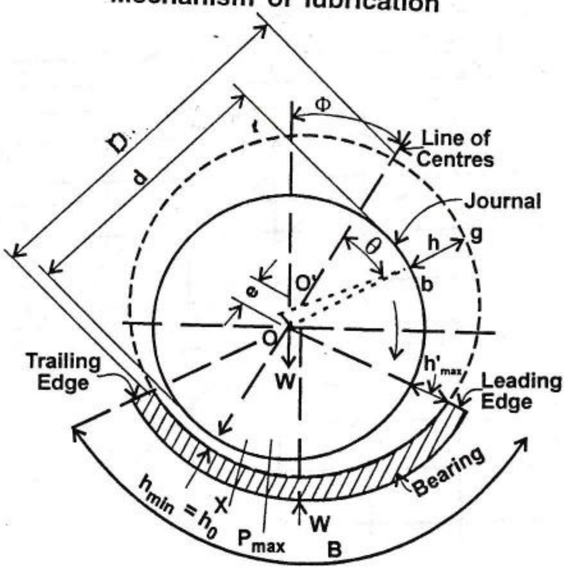


Fig. 19.2



Mechanism of lubrication



Geometric relation for any journal bearing
(Shown here partial clearance bearing)

Fig. 19.3

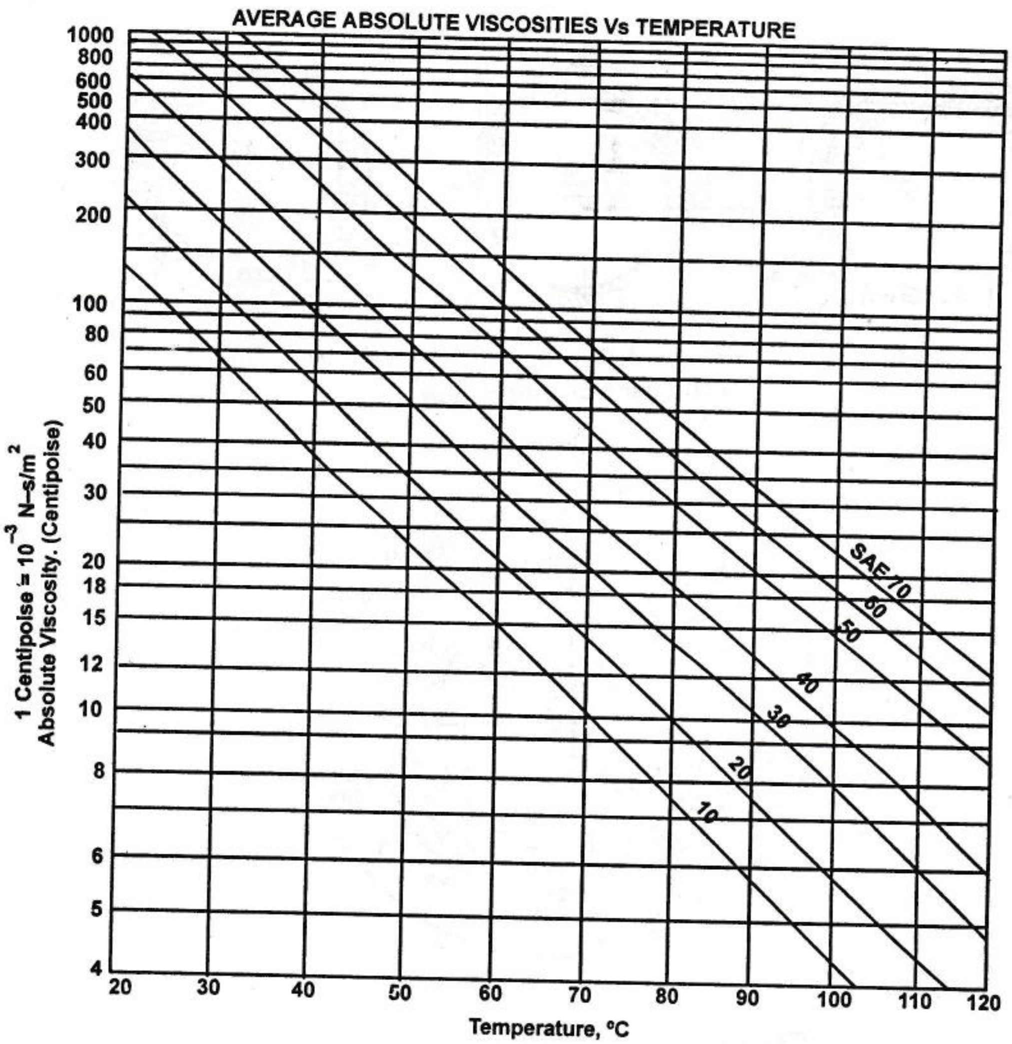

AVERAGE ABSOLUTE VISCOSITIES Vs TEMPERATURE
1000
800
600
500
400
300
200
100
80
60
50
40
30
20
18
15
12
10
8
6
5
4
1 Centipoise = 10^{-3} N–s/m^2
Absolute Viscosity. (Centipoise)
20
30
40
50
60
70
80
90
100
110
120
Temperature, °C
SAE 70
60
50
40
30
20
10

Fig. 19.4

CHAPTER - 20

BALL AND ROLLER BEARINGS

Symbols : (with S.I. units)

C	–	Dynamic capacity (i.e, dynamic load rating), N
F_a	–	Axial load, N
F_r	–	Radial load, N
k	–	Exponent
L	–	Life of bearings in million revolutions
L_h	–	Life of bearings in hours.
L_{10}	–	Life of bearing for 90% survival at 1 mr (i.e; 1 million revolutions)
n	–	Speed of the bearings, rpm
P	–	Equivalent load, N
P_m	–	Cubic mean load, N
p	–	Probability of survival
p_{10}	–	Probability of survival for 90% or 0.9
S	–	Service factor
t	–	Time, s
V	–	Race rotation factor
X	–	Radial load factor
Y	–	Axial load factor

DESIGN PARTICULARS	EQUATIONS
Dynamic capacity	$C = \left(\frac{L}{L_{10}}\right)^{\frac{1}{k}} \cdot P$ .... (20.1)
	where $k = 3$ for ball bearings
	$= \frac{10}{3}$ for roller bearings
	$L_{10} = 1$ mr.
Equivalent load	$P = \left(V X F_r + Y F_a\right) S$ .... (20.2)
	where $V = 1.0$ for inner ring rotation and outer ring stationary.
	$= 1.2$ for inner ring stationary and outer ring rotation.
	F_r, F_a – Radial and axial loads
	X, Y – Radial and axial load factors (Refer table 20.5)
	$S =$ Service factor (Table 20.3)
Life of bearings in million revolutions	$L = \left(\frac{C}{P}\right)^k$ mr [Table 20.6 (a) & (b)] .... (20.3)
Life of bearings in hours	$L_h = \frac{L \times 10^6}{60 \times n}$ hours. (Fig. 20.3, 20.4) .... (20.4)

DESIGN PARTICULARS	EQUATIONS
Dynamic capacity	$C = \left(\frac{L}{L_{10}} \right)^{\frac{1}{k}} \cdot P$ .... (20.1)
	where $k = 3$ for ball bearings
	$= \frac{10}{3}$ for roller bearings
	$L_{10} = 1$ mr.
Equivalent load	$P = \left(V\,X\,F_r + Y\,F_a \right) S$ .... (20.2)
	where $V = 1.0$ for inner ring rotation and outer ring stationary.
	$= 1.2$ for inner ring stationary and outer ring rotation.
	F_r, F_a – Radial and axial loads
	X, Y – Radial and axial load factors (Refer table 20.5)
	S = Service factor (Table 20.3)
Life of bearings in million revolutions	$L = \left(\frac{C}{P} \right)^k$ mr [Table 20.6 (a) & (b)] .... (20.3)
Life of bearings in hours	$L_h = \frac{L \times 10^6}{60 \times n}$ hours. (Fig. 20.3, 20.4) .... (20.4)

$L_h = \frac{L \times 10}{60 \times n}$ hours. (Fig. 20.3, 20.4) .... (20.4)

DESIGN PARTICULARS	EQUATIONS
Cubic mean load for periodically variable loading.	$P_m = \left[\frac{P_1^3 n_1 + P_2^3 n_2 + ... P_r^3 n_r}{n_1 + n_2 + ... n_r} \right]^{1/3}$ .... (20.5) (For revolutions varying) $= \left[\frac{P_1^3 t_1 + P_2^3 t_2 + ... P_r^3 t_r}{t_1 + t_2 + ... t_r} \right]^{1/3}$ .... (20.6) (For time varying) $n_1, n_2 .... n_r$ = Number of revolutions for the loads $P_1, P_2 ... P_r$ $t_1, t_2 .... t_r$ = Periods of rotation for the loads $P_1, P_2 .... P_r$

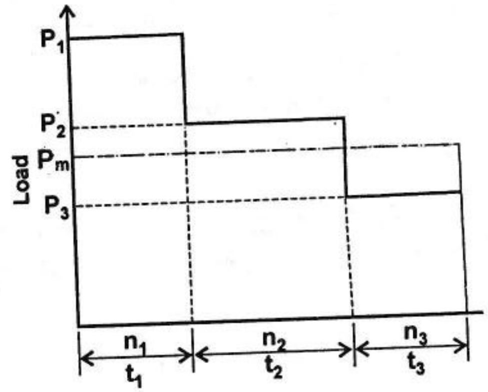


Fig. 20.1

DESIGN PARTICULARS	EQUATIONS
Mean load for linearly variable loading	$P_{mean} = \frac{P_{min} + 2\, P_{max}}{3}$ .... (20.7)

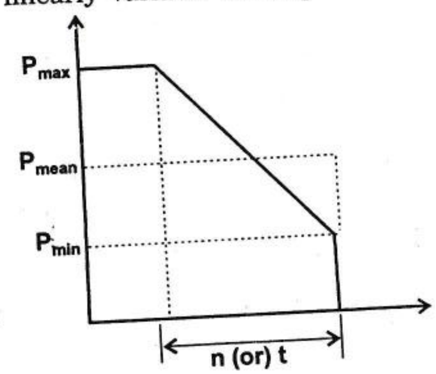


Fig. 20.2

DESIGN PARTICULARS	EQUATIONS
Probability of survival	$\frac{L}{L'_{10}} = \left[\frac{l_n (1/p)}{l_n (1/p_{10})} \right]^{1/b}$ .... (20.8)

DESIGN PARTICULARS	EQUATIONS
	where L = Required life of bearings in mr. L'_{10} = Calculated life of selected bearings, for the given load, for 90% survival. p = Probability of survival.
	$l_n(1/p_{10}) = l_n(1/0.9) = 0.1053$
	$b = 1.17$ for a median life $= 5L_{10}$ $= 1.34$ for a median life $= 4.08\ L_{10}$ (for deep groove ball bearings)
Survival probability of a system containing 'x' number of bearings each having the probability as p	$p_{system} = p^x$ .... (20.9)
Ratio of lives for two identical bearings tested under two different loads of P_1 & P_2	$\frac{L_1}{L_2} = \left[\frac{P_2}{P_1}\right]^k$ .... (20.10)

Table 20.1: Applications of Ball and Roller Bearings

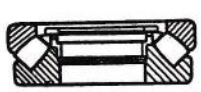
Type and Figure	Designation	Application
	Deep groove ball bearing	For considerable thrust load apart from radial load-high speed.
	Self aligning ball bearing	Minor angular displacements of shafts will not affect.
	Single row angular contact ball bearing	For heavy axial loads
	Double row angular contact ball bearing	For radial loads with heavy thrust in both directions
	Spherical roller bearing	High carrying capacity, self aligning-for heavy radial loads with considerable axial load in both directions
	Cylindrical roller bearing	For heavy radial loads at high speeds-permit slight axial displacement.
	Taper roller bearing	For combined radial and axial loads
	Single thrust ball bearing	For axial load in one direction only
	Double thrust ball bearing	For axial loads acting on both directions
	Spherical roller thrust bearing	For heavy axial loads-high speed-self aligning

Table 20.2: Life of Bearings

Class of machines	Bearing life (Working hours)
Instruments and apparatus that are used only rarely e.g. Demonstration apparatus, sliding door mechanism	500
Machines used for short periods or intermittently and whose break-down would not have serious consequences e.g. Hand tools, lifting tackle, agricultural machines, domestic appliances	4000 to 8000
Machines working intermittently and whose break-down would have serious consequences e.g. Auxiliary machines in power stations, conveyor plants, lifts, m/c tools used infrequently	8000 to 12000
Machines for use 8 hrs/day and not always fully used e.g. Stationary electric motors, general purpose gear units	12000 to 20000
Machines for use 8 hrs/day and fully utilised e.g. Machines for engg. industry – cranes of bulk goods, ventilating fans, counter shaft in gear box.	20000 to 30000
Machines for continuous use 24 hrs/day e.g. Separators, compressors, pumps, mine hoists, stationary electric machines, on-board naval vessel machines.	40000 to 60000
Machines required to work with a high degree of reliability for 24 hrs/day e.g. Pulp and paper making machinery, public power plants, mine pumps, water works, on-board merchant ship machines	100000 to 200000

Table 20.3: Service Factor (S)

Machineries	Service factor (S)
For bearings carrying geared shafts	
Rotary machines with no impact	1.1 – 1.5
Reciprocating machines	1.3 – 1.9
Machines with pronounced impact, hammer mill, presses	1.6 – 4
For electric motors:	
Stationary machines	1.5 – 2
Traction motors	1.5 – 2.5
For belt and chain drives:	
Chain drives	1.5 – 1.7
V-belt drives	2.0 – 2.5
Leather belt drives	2.5 – 3.5
Fabric belt drives	2.0 – 3.0
Steel belt drives	3.0 – 4.0

Note: The following values of service factor may be used for the lack of specifications about the machineries.

(i) Constant or steady load – 1.0

(ii) Light shocks – 1.5

(iii) Medium shocks – 2.0

(iv) Heavy shocks – 2.5

Table 20.4: Carrying Capacity at High Temperatures

Bearing temperature °C	125	150	175	200	225	250
Carrying capacity in %	95	90	85	75	65	60

Table 20.5: Equivalent Bearing Load

Type of bearing	Series (SKF)		$\frac{F_a}{F_r} \le e$		$\frac{F_a}{F_r} > e$		e
			X	Y	X	Y	
Deep groove ball bearing	Series 60, 62, 63, 64	$\frac{F_a}{C_0} = 0.025$	1	0	0.56	2	0.22
		$= 0.04$	1	0	0.56	1.8	0.24
		$= 0.07$	1	0	0.56	1.6	0.27
		$= 0.13$	1	0	0.56	1.4	0.31
		$= 0.25$	1	0	0.56	1.2	0.37
		$= 0.5$	1	0	0.56	1.0	0.44
Angular contact ball bearing	72B, 73B, 32, 33		1	0	0.35	0.57	1.14
			1	0.73	0.62	1.17	0.86
Self aligning ball bearing	2200– 2204		1	1.3	0.65	2	0.5
	05– 07		1	1.7	0.65	2.6	0.37
	08– 09		1	2	0.65	3.1	0.31
	10– 13		1	2.3	0.65	3.5	0.28
	14– 20		1	2.4	0.65	3.8	0.26
	21– 22		1	2.3	0.65	3.5	0.28
	2301		1	1	0.65	1.6	0.63
	2302– 2304		1	1.2	0.65	1.9	0.52
	05– 10		1	1.5	0.65	2.3	0.43
	11– 18		1	1.6	0.65	2.5	0.39
Spherical roller bearing	22205C–22207C		1	2.1	0.67	3.1	0.32
	08C–09C		1	2.5	0.67	3.7	0.27
	10C–20C		1	2.9	0.67	4.4	0.23
	22C–44C		1	2.6	0.67	3.9	0.26
Taper roller bearing	32206–208		1	0	0.4	1.6	0.37
	09– 22		1	0	0.4	1.45	0.41
	24– 30		1	0	0.4	1.35	0.44

Table 20.6(a): Loading Ratio C/P for Different Lives Expressed in Millions of Revolutions

(a) BALL BEARINGS

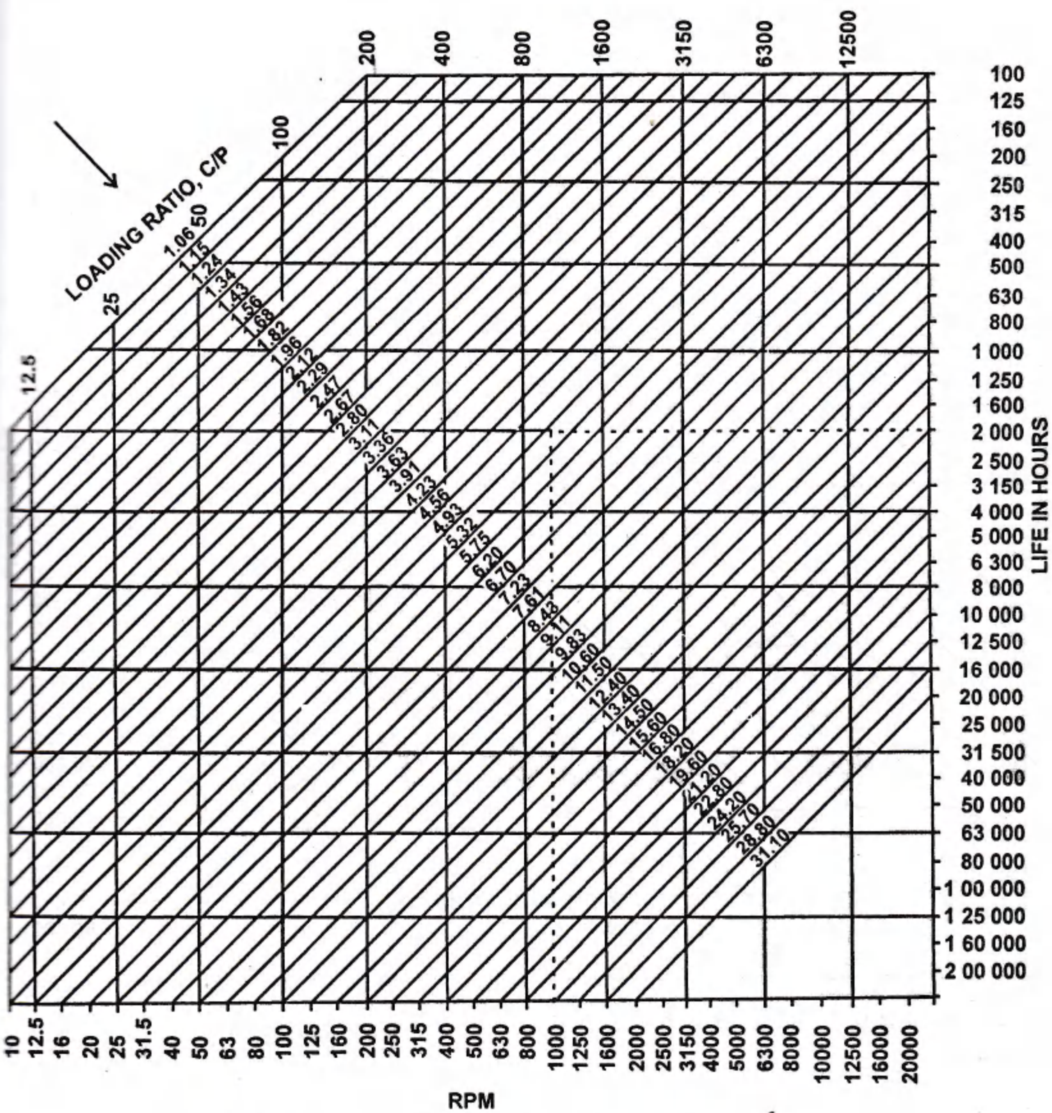
Life in millions of revolutions L	$\frac{C}{P}$	Life in millions of revolutions L	$\frac{C}{P}$	Life in millions of revolutions L	$\frac{C}{P}$	Life in millions of revolutions L	$\frac{C}{P}$
0.5	0.793	80	4.31	600	8.43	3200	14.7
0.75	0.909	90	4.48	650	8.66	3400	15.0
1	1	100	4.64	700	8.88	3600	15.3
1.5	1.14	120	4.93	750	9.09	3800	15.6
2	1.26	140	5.19	800	9.28	4000	15.9
3	1.44	160	5.43	850	9.47	4500	16.5
4	1.59	180	5.65	900	9.65	5000	17.1
5	1.71	200	5.85	950	9.83	5500	17.7
6	1.82	220	5.04	1000	10.0	6000	18.2
8	2	240	6.21	1100	10.3	6500	18.7
10	2.15	260	6.38	1200	10.6	7000	19.1
12	2.29	280	6.54	1300	10.9	7500	19.6
14	2.41	300	6.69	1400	11.2	8000	20.0
16	2.52	320	6.84	1500	11.4	8500	20.4
18	2.62	340	6.98	1600	11.7	9000	20.8
20	2.71	360	7.11	1700	11.9	9500	21.2
25	2.92	380	7.24	1800	12,2	10000	21.5
30	3.11	400	7.37	1900	12.4	12000	22.9
35	3.27	420	7.49	2000	12.6	14000	24.1
40	3.42	440	7.61	2200	13.0	16000	25.2
45	3.56	460	7.72	2400	13.4	18000	26.2
50	3.68	480	7.83	2600	13.8	20000	27.1
60	3.91	500	7.94	2800	14.1	25000	29.2
70	4.12	550	8.19	3000	14.4	30000	31.1

Table 20.6(b)

(b) ROLLER BEARINGS

Life in millions of revolutions L	$\frac{C}{P}$	Life in millions of revolutions L	$\frac{C}{P}$	Life in millions of revolutions L	$\frac{C}{P}$	Life in millions of revolutions L	$\frac{C}{P}$
0.5	0.812	80	3.72	600	6.81	3200	11.3
0.75	0.917	90	3.85	650	6.98	3400	11.5
1	1	100	3.98	700	7.14	3600	11.7
1.5	1.13	120	4.20	750	7.29	3800	11.9
2	1.24	140	4.40	800	7.43	4000	12.0
3	1.39	160	4.58	850	7.56	4500	12.5
4	1.52	180	4.75	900	7.70	5000	12.9
5	1.62	200	4.90	950	7.82	5500	13.2
6	1.71	220	5.04	1000	7.94	6000	13.6
8	1.87	240	5.18	1100	8.17	6500	13.9
10	2.00	260	5.30	1200	8.39	7000	14.2
12	2.11	280	5.42	1300	8.59	7500	14.5
14	2.21	300	5.54	1400	8.79	8000	14.8
16	2.30	320	5.64	1500	8.97	8500	15.1
18	2.38	340	5.75	1600	9.15	9000	15.4
20	2.46	360	5.85	1700	9.31	9500	15.6
25	2.63	380	5.94	1800	9.48	10000	15.8
30	2.77	400	6.03	1900	9.63	12000	16.7
35	2.91	420	6.12	2000	9.78	14000	17.5
40	3.02	440	6.21	2200	10.1	16000	18.2
45	3.13	460	6.29	2400	10.3	18000	18.9
50	3.23	480	6.37	2600	10.6	20000	19.5
60	3.42	500	6.45	2800	10.8	25000	20.9
70	3.58	550	6.64	3000	11.0	30000	22.0

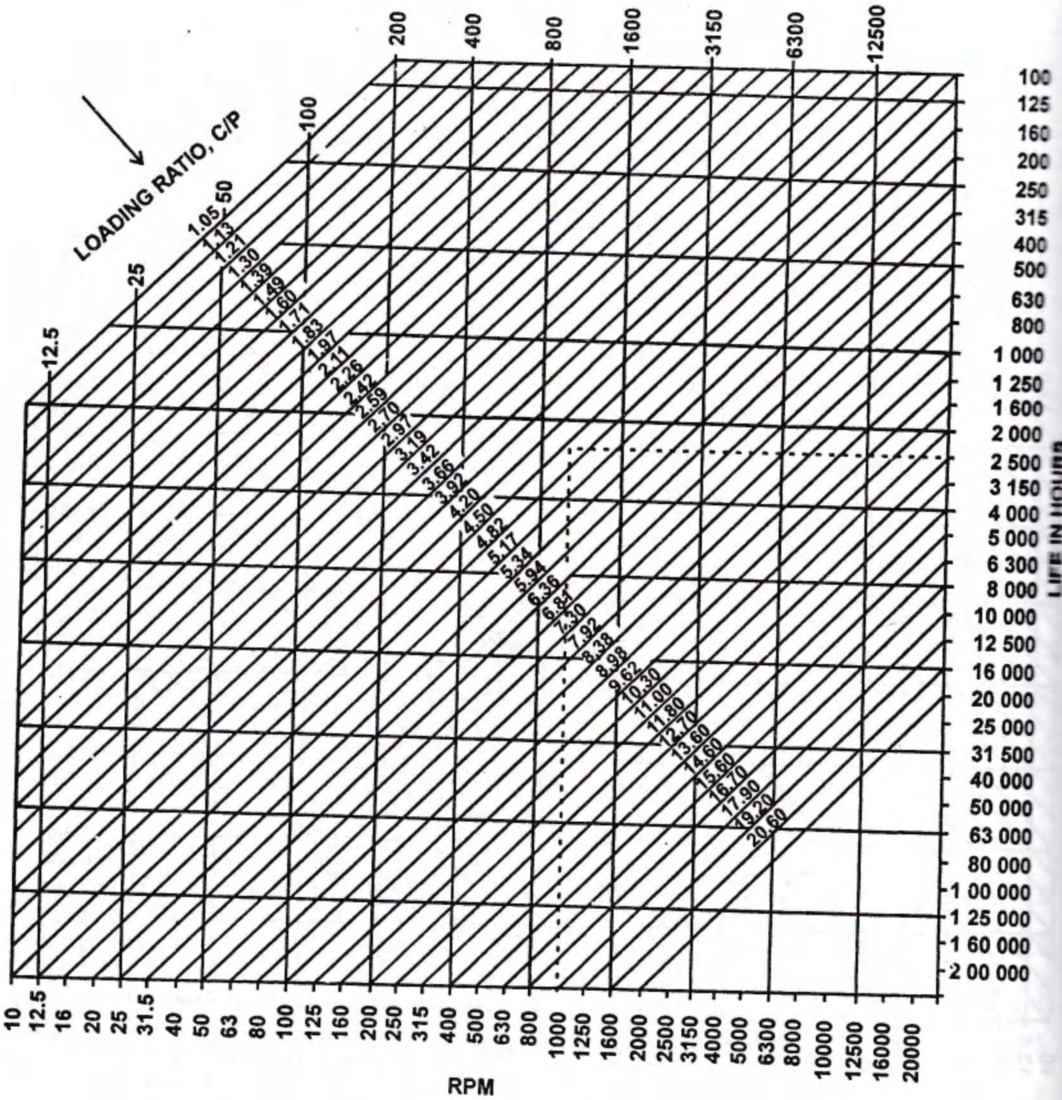
BALL BEARINGS



Example: At 1000 RPM and a life of 2000 Hrs, C/P = 4.93

Fig. 20.3

ROLLER BEARINGS



Example: At 1000 RPM and a life of 2500 Hrs, C/P = 4.50

Fig. 20.4

Table 20.7(a): Deep Groove Ball Bearings **Series 60**

Bearing of basic design No. (SKF)	d mm	D mm	B mm	r mm	Basic capacity, N Static C_0	Basic capacity, N Dynamic C	Max permissible speed-rpm
6000	10	26	8	0.5	1865	3550	20000
01	12	28	8	0.5	2160	4000	20000
02	15	32	9	0.5	2500	4400	20000
6003	17	35	10	0.5	2800	4650	20000
04	20	42	12	1	4415	7350	16000
05	25	47	12	1	5100	7800	16000
6006	30	55	13	1.5	7000	10400	13000
07	35	62	14	1.5	8840	12500	13000
08	40	68	15	1.5	9615	13200	10000
6009	45	75	16	1.5	12460	16300	10000
10	50	80	16	1.5	13440	17000	8000
11	55	90	18	2	17660	22000	8000
60012	60	95	18	2	18950	22800	8000
13	65	100	18	2	21200	24000	8000
14	70	110	20	2	25500	30000	6000
6015	75	115	20	2	28000	31000	6000
16	80	125	22	2	33500	37500	6000
17	85	130	22	2	36000	39000	5000
6018	90	140	24	2.5	41500	45500	5000
19	95	145	24	2.5	45000	47500	5000
20	100	150	24	2.5	45000	47500	4000
6021	105	160	26	3	54000	57000	4000
22	110	170	28	3	61000	64000	4000
24	120	180	28	3	65500	67000	3000
6026	130	200	33	3	83000	83000	3000
28	140	210	33	3	90000	86500	3000
30	150	225	35	3.5	104000	98000	2500
6032	160	240	38	3.5	118000	112000	2500
34	170	260	42	3.5	143000	132000	2500
36	180	280	46	3.5	166000	150000	2000
6038	190	290	46	3.5	180000	153000	2000
40	200	310	51	3.5	200000	170000	2000

Series 62

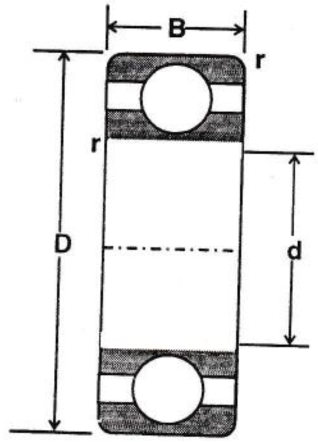


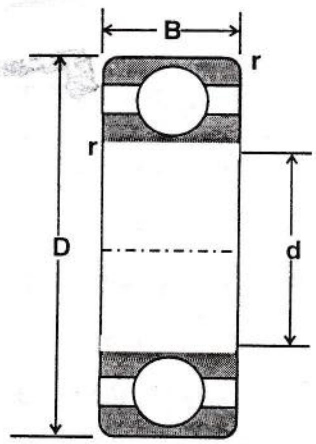
Table 20.7(b):
Deep Groove Ball Bearings

ISI No.	Bearing of basic design No. (SKF)	d mm	D mm	B mm	r mm	Basic capacity, N Static C_0	Dynamic C	Max. permissible speed rpm
10BC02	6200	10	30	9	1	2160	3925	20000
12BC02	01	12	32	10	1	2940	5250	20000
15BC02	02	15	35	11	1	3430	5980	16000
17BC02	6203	17	40	12	1	4315	7355	16000
20BC02	04	20	47	14	1.5	6375	9805	16000
25BC02	05	25	52	15	1.5	6965	10690	13000
30BC02	6206	30	62	16	1.5	9805	14710	13000
35BC02	07	35	72	17	2	13535	19615	10000
40BC02	08	40	80	18	2	15495	22165	10000
45BC02	6209	45	85	19	2	17750	24910	8000
50BC02	10	50	90	20	2	20595	27070	8000

ISI No.	Bearing of basic design No. (SKF)	d mm	D mm	B mm	r mm	Basic capacity, N Static C_0	Basic capacity, N Dynamic C	Max. permissible speed rpm
55BC02	11	55	100	21	2.5	25300	33340	8000
60BC02	6212	60	110	22	2.5	31580	40210	6000
65BC02	13	65	120	23	2.5	35715	42905	6000
70BC02	14	70	125	24	2.5	38440	47070	5000
75BC02	6215	75	130	25	2.5	41385	50600	5000
80BC02	16	80	140	26	3	44130	55505	5000
85BC02	17	85	150	28	3	53450	63745	4000
90BC02	6218	90	160	30	3	60800	74040	4000
95BC02	19	95	170	32	3.5	71100	82870	4000
100BC02	20	100	180	34	3.5	79925	97145	3000
105BC02	6221	105	190	36	3.5	90710	101500	3000
110BC02	22	110	200	38	3.5	101010	108850	3000
120BC02	24	120	215	40	3.5	101010	110815	3000
	6226	130	230	40	4	112780	120130	2500
	28	140	250	42	4	127680	126510	2500
	30	150	270	45	4	139745	135330	2500
	32	160	290	48	4	151020	140235	2000
	6234	170	310	52	5	184365	159850	2000
	36	180	320	52	5	200060	169165	1600
	38	190	340	55	5	235360	196130	1600
	40	200	360	58	5	259880	205940	1600

Series 63

Table 20.7(c):
Deep Groove Ball Bearings



ISI No.	Bearing of basic design No. (SKF)	d mm	D mm	B mm	r mm	Basic capacity, N Static C_0	Dynamic C	Max. permissible speed rpm
10BC03	6300	10	35	11	1	3570	6080	16000
12BC03	01	12	37	12	1.5	4220	7550	16000
15BC03	02	15	42	13	1.5	5100	8580	16000
17BC03	6303	17	47	14	1.5	6080	10300	13000
20BC03	04	20	52	15	2	7550	12260	13000
25BC03	05	25	62	17	2	10150	15985	10000
30BC03	6306	30	72	19	2	14220	20990	10000
35BC03	07	35	80	21	2.5	16970	25300	8000
40BC03	08	40	90	23	2.5	20990	31380	8000
45BC03	6309	45	100	25	2.5	29225	40700	8000

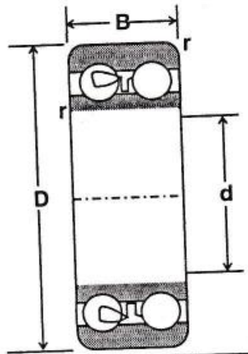
ISI No.	Bearing of basic design No. (SKF)	d mm	D mm	B mm	r mm	Basic capacity, N Static C_0	Dynamic C	Max. permissible speed rpm
50BC03	10	50	110	27	3	34720	47070	6000
55BC03	11	55	120	29	3	41190	53940	6000
60BC03	6312	60	130	31	3.5	47070	62270	5000
65BC03	13	65	140	33	3.5	53450	71100	5000
70BC03	14	70	150	35	3.5	60800	79925	5000
75BC03	6315	75	160	37	3.5	71100	89280	4000
80BC03	16	80	170	39	3.5	78450	94140	4000
85BC03	17	85	180	41	4	85810	101500	4000
90BC03	6318	90	190	43	4	96110	107870	3000
95BC03	19	95	200	45	4	107870	117680	3000
100BC03	20	100	215	47	4	129450	135330	3000
105BC03	6321	105	225	49	4	140240	140235	2500
110BC03	22	110	240	50	4	160730	152980	2500
120BC03	24	120	260	55	4	162790	157890	2500
	6326	130	280	58	5	191230	173580	2500
	28	140	300	62	5	215750	196130	2000
	30	150	320	65	5	249090	210840	2000

Table 20.7(d): Deep Groove Ball Bearings — Series 64

Bearing of basic design No. (SKF)	d mm	D mm	B mm	r mm	Basic capacity, N Static C_0	Dynamic C	Max permissible speed rpm
6403	17	62	17	2	12800	18000	10000
6404	20	72	19	2	16600	24000	8000
6405	25	80	21	2.5	20000	28250	7100
6406	30	90	23	2.5	24000	33500	6300
6407	35	100	25	2.5	32500	43000	5600
6408	40	110	27	3	38000	50000	5000
6409	45	120	29	3	46500	58500	4500
6410	50	130	31	3.5	53000	70000	4000
6411	55	140	33	3.5	64000	78500	4000
6412	60	150	35	3.5	71000	84500	3600
6413	65	160	37	3.5	80000	91500	3200
6414	70	180	42	4	91000	100000	2800
6415	75	190	45	4	101600	120000	2800
6416	80	200	48	4	128000	130000	2500
6417	85	210	52	5	138000	138000	2500
6418	90	225	54	5	166000	152000	2200

Series 22

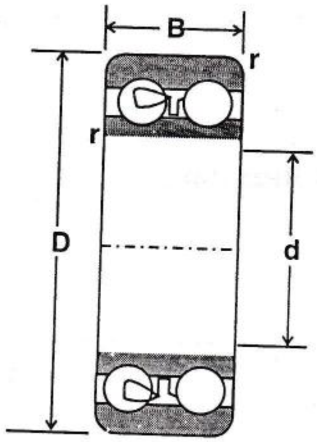
Table 20.8(a):
Self-Aligning Ball Bearings



Bearing with cylinderical bore No. (SKF)	Bearing with taper bore No. (SKF)	d mm	D mm	B mm	r mm	Basic capacity, N Static C_0	Dynamic C	Max. permissible speed rpm
2200		10	30	14	1	1670	5540	20000
01		12	32	14	1	1960	5640	20000
02		15	35	14	1	2110	5740	16000
2203		17	40	16	1	2745	7500	16000
04	2204 K	20	47	18	1.5	3825	9610	16000
05	05 K	25	52	18	1.5	4120	9610	13000
2206	2206 K	30	62	20	1.5	5390	11770	13000
07	07 K	35	72	23	2	7845	16180	10000
08	08 K	40	80	23	2	8825	16920	10000
2209	2209 K	45	85	23	2	9810	17410	8000
10	10 K	50	90	23	2	10490	17410	8000
11	11 K	55	100	25	2.5	12455	20200	8000
2212	2212 K	60	110	28	2.5	15300	25810	6000
13	13 K	65	120	31	2.5	19610	33340	6000
14	–	70	125	31	2.5	21080	34080	5000
2215	2215 K	75	130	31	2.5	21575	34080	5000
16	16 K	80	140	33	3	24520	37850	5000
17	17 K	85	150	36	3	29030	44620	4000
2218	2218 K	90	160	40	3	35550	53450	4000
19	19 K	95	170	43	3.5	42170	63740	4000
20	20 K	100	180	46	3.5	49030	76000	3000
221	–	105	190	50	3.5	53940	82870	3000
22	222 K	110	200	53	3.5	62270	96600	3000

Series 23

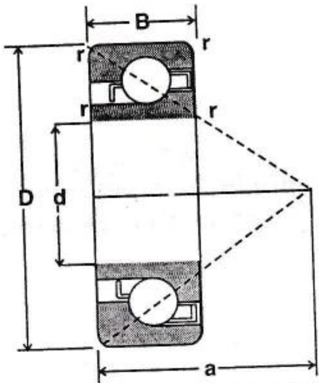
Table 20.8(b):
Self-Aligning Ball Bearings



Bearing with cylinderical bore No. (SKF)	Bearing with taper bore No. (SKF)	d mm	D mm	B mm	r mm	Basic capacity, N Static C_0	Dynamic C	Max. permissible speed rpm
2301		12	37	17	1.5	2940	8925	16000
02		15	42	18	1.5	3285	9070	13000
03		17	47	19	1.5	4070	10790	13000
2304	2304 K	20	52	21	2	5345	13730	10000
05	05 K	25	62	24	2	7600	18490	10000
06	06 K	30	72	27	2	9810	24030	8000
2307	2307 K	35	80	31	2.5	12945	29810	8000
08	08 K	40	90	33	2.5	15450	34720	6000
09	09 K	45	100	36	2.5	19220	40940	6000
2310	2310 K	50	110	40	3	23630	50750	5000
11	11 K	55	120	43	3	28050	56390	5000
12	12 K	60	130	46	3.5	32750	66693	4000
2313	2313 K	65	140	48	3.5	38490	73550	4000
14	–	70	150	51	3.5	43640	82375	4000
15	15 K	75	160	55	3.5	50750	92670	3000
16	16 K	80	170	58	3.5	56390	102970	3000
2317	2317 K	85	180	60	4	59580	106890	2500
18	18 K	90	190	64	4	68160	115720	2500

Series 72B

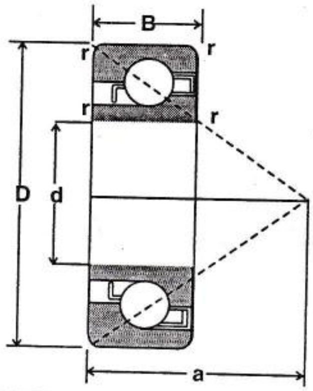
Table 20.9(a): Single Row Angular Contact Ball Bearings



ISI No.	Bearing No. (SKF)	d mm	D mm	B mm	r mm	r_1 mm	a mm	Basic capacity, N Static C_0	Basic capacity, N Dynamic C	Max. permissible speed rpm
15BA02	7202 B	15	35	11	1	0.5	16	3680	6080	13000
17BA02	03 B	17	40	12	1	0.8	18	4460	7700	13000
20BA02	04 B	20	47	14	1.5	0.8	21	6370	10150	10000
25BA02	7205 B	25	52	15	1.5	0.8	24	7700	11280	10000
30BA02	06 B	30	62	16	1.5	0.8	27	10790	15400	10000
35BA02	07 B	35	72	17	2	1	31	14710	20590	8000
40BA02	7208 B	40	80	18	2	1	34	18490	24520	8000
45BA02	09 B	45	85	19	2	1	37	21180	27655	6000
50BA02	10 B	50	90	20	2	1	39	23140	28440	6000
55BA02	7211 B	55	100	21	2.5	1.2	43	29175	36285	6000
60BA02	12 B	60	110	22	2.5	1.2	47	36285	42900	5000
65BA02	13 B	65	120	23	2.5	1.2	50	42410	49030	5000
70BA02	7214 B	70	125	24	2.5	1.2	53	44620	52470	5000
75BA02	15 B	75	130	25	2.5	1.2	56	49030	54430	4000
80BA02	16 B	80	140	26	3	1.5	59	55650	60800	4000
85BA02	7217 B	85	150	28	3	1.5	64	63740	69630	4000
90BA02	18 B	90	160	30	3	1.5	67	75760	81400	4000
95BA02	19 B	95	170	32	3.5	2	71	85810	92670	3000
100BA02	7220 B	100	180	34	3.5	2	76	90710	98070	3000
105BA02	21 B	105	190	36	3.5	2	80	101500	106890	2500
110BA02	22 B	110	220	38	3.5	2	84	112780	117680	2500

Series 73B

Table 20.9(b): Single Row Angular Contact Ball Bearings



ISI No.	Bearing No. (SKF)	d mm	D mm	B mm	r mm	r_1 mm	a mm	Basic capacity, N Static C_0	Dynamic C	Max. permissible speed rpm
17BA03	7303 B	17	47	14	1.5	0.8	21	7110	11283	10000
20BA03	04 B	20	52	15	2	1	23	8140	13580	10000
25BA03	05 B	25	62	17	2	1	27	12260	18930	10000
30BA03	7306 B	30	72	19	2	1	31	15840	24025	8000
35BA03	07 B	35	80	21	2.5	1.2	35	20005	28050	8000
40BA03	08 B	40	90	23	2.5	1.2	39	24910	34715	6000
45BA03	7309 B	45	100	25	2.5	1.2	43	33340	44620	6000
50BA03	10 B	50	110	27	3	1.5	47	40210	51485	6000
55BA03	11 B	55	120	29	3	1.5	52	46580	59820	5000
60BA03	7312 B	60	130	31	3.5	2	55	53450	69630	5000
65BA03	13 B	65	140	33	3.5	2	60	61290	78450	5000
70BA03	14 B	70	150	35	3.5	2	64	72570	87280	4000
75BA03	7315 B	75	160	37	3.5	2	68	80415	96600	4000
80BA03	16 B	80	170	39	3.5	2	72	89240	102970	4000
85BA03	17 B	85	180	41	4	2	76	98070	111550	3000
90BA03	7318 B	90	190	43	4	2	80	111500	120130	3000
95BA03	19 B	95	200	45	4	2	84	122580	129250	2500
100BA03	20 B	100	215	47	4	2	90	149060	144650	2500
105BA03	7321 B	105	225	49	4	2	94	160090	153230	2500
110BA03	22 B	110	240	50	4	2	99	188780	168920	2500

Series 33A

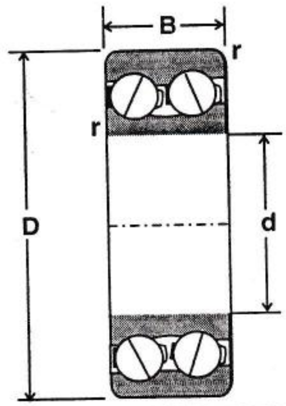
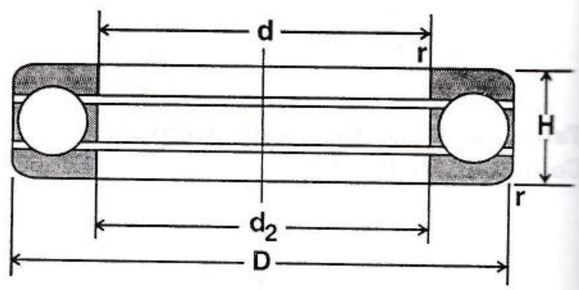


Table 20.10: Double Row Angular Contact Ball Bearings

Bearing No. (SKF)	d mm	D mm	B mm	r mm	Basic capacity N Static C_0	Dynamic C	Max permissible speed, rpm
3302 A	15	42	19.0	1.5	9070	13730	10000
03 A	17	47	22.2	1.5	12650	18930	8000
04 A	20	52	22.2	2	13730	18930	8000
3305 A	25	62	25.4	2	19615	26085	6000
06 A	30	72	30.2	2	27165	35300	6000
07 A	35	80	34.9	2.5	35600	43640	5000
3308 A	40	90	36.5	2.5	44620	53450	5000
09 A	45	110	39.7	2.5	54430	62270	4000
10 A	50	110	44.4	3	72570	80170	4000
3311 A	55	120	49.2	3	78450	85910	4000
12 A	60	130	54.0	3.5	94630	98070	3000
13 A	65	140	58.7	3.5	108950	115720	3000
3314 A	70	150	63.5	3.5	126510	135820	3000
15 A	75	160	68.3	3.5	138080	140235	2500
16 A	80	170	86.3	3.5	153965	157890	2500
3317 A	85	180	73.0	4	173580	173580	2500
18 A	90	190	73.0	4	205940	200150	2500

Series 512

Table 20.11: Single Thrust Ball Bearings (with flat housing washer)



ISI No.	Bearing No. (SKF)	d mm	D mm	H mm	d_2 min. mm	r mm	Basic capacity, N Static C_0	Basic capacity, N Dynamic C	Max. permissible speed rpm
10TA12	51200	10	26	11	10.2	1	14000	10000	10000
12TA12	01	12	28	11	12.2	1	15600	10400	8000
15TA12	02	15	32	12	15.2	1	20400	12200	8000
17TA12	51203	17	35	12	17.2	1	22000	12700	8000
20TA12	04	20	40	14	20.2	1	31000	17300	6000
25TA12	05	25	47	15	25.2	1	41500	21600	6000
30TA12	51206	30	52	16	30.2	1	48000	22800	6000
35TA12	07	35	62	18	35.2	1.5	64000	30500	5000
40TA12	08	40	68	19	40.2	1.5	76500	34500	5000
45TA12	51209	45	73	20	45.2	1.5	86500	36500	4000
50TA12	10	50	78	22	50.2	1.5	91500	37500	4000
55TA12	11	55	90	25	55.2	1.5	132000	55000	3000
60TA12	51212	60	95	26	60.2	1.5	146000	57000	3000
65TA12	13	65	100	27	65.2	1.5	156000	58500	2500
70TA12	14	70	105	27	70.2	1.5	163000	60000	2500

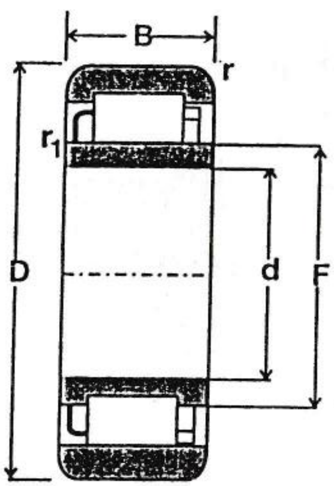
ISI No.	Bearing No. (SKF)	d mm	D mm	H mm	d_2 min. mm	r mm	Basic capacity, N Static C_0	Dynamic C	Max. permissible speed rpm
75TA12	51215	75	110	27	75.2	1.5	173000	61000	2500
80TA12	16	80	115	28	80.2	1.5	180000	62000	2000
85TA12	17	85	125	31	85.2	1.5	220000	75000	2000
90TA12	51218	90	135	35	90.2	2	270000	91500	2000
100TA12	20	100	150	38	100.2	2	340000	114000	1600
110TA12	22	110	160	38	110.2	2	375000	120000,	1600
120TA12	51224	120	170	39	120.2	2	390000	120000	1300
130TA12	26	130	190	45	130.3	2.5	510000	160000	1300
140TA12	28	140	200	46	140.3	2.5	540000	163000	1000
150TA12	51230	150	215	50	150.3	2.5	600000	176000	1000
160TA12	32	160	225	51	160.3	2.5	620000	180000	1000
170TA12	34	170	240	55	170.3	2.5	735000	212000	800
180TA12	51236	180	250	56	180.3	2.5	765000	216000	800
190TA12	38	190	270	62	190.3	3	915000	250000	800
200TA12	40	200	280	62	200.3	3	965000	255000	600
	51244	220	300	63	220.3	3	1040000	260000	600
	48	240	340	78	240.3	3.5	1430000	335000	500
	51252	260	360	79	260.3	3.5	1560000	345000	500
	56	280	380	80	280.3	3.5	1630000	355000	400
	60	300	420	95	300.3	4	2240000	455000	400
	51264	320	440	95	320.4	4	2360000	465000	400
	68	340	460	96	340.4	4	2450000	475000	300
	72	360	500	110	360.4	5	3150000	585000	300

Table 20.12: Double Thrust Ball Bearings (Flat housing washers - Series 522)

Bearing No. (SKF)	d mm	d_1 mm	D mm	H mm	d_2 min. mm	a mm	r mm	r_1 mm	Basic capacity, N Static C_0	Basic capacity, N Dynamic C	Max. Permissible speed rpm
52202	15	10	32	22	15.2	5	1	0.5	20400	12200	8000
04	20	15	40	26	20.2	6	1	0.5	31000	17300	6000
05	25	20	47	28	25.2	7	1	0.5	41500	21600	6000
52206	30	25	52	29	30.2	7	1	0.5	48000	22800	6000
07	35	30	62	34	35.2	8	1.5	0.5	64000	30500	5000
08	40	30	68	36	40.2	9	1.5	1	76500	34500	5000
09	45	35	73	37	45.2	9	1.5	1	86500	36500	4000
10	50	40	78	39	50.2	9	1.5	1	91500	37500	4000
52211	55	45	90	45	55.2	10	1.5	1	132000	55000	3000
12	60	50	95	46	60.2	10	1.5	1	146000	57000	3000
13	65	55	100	47	65.2	10	1.5	1	156000	58500	2500
14	70	55	105	47	70.2	10	1.5	1.5	163000	60000	2500
15	75	60	110	47	75.2	10	1.5	1.5	173000	61000	2500
52216	80	65	115	48	80.2	10	1.5	1.5	180000	62000	2000
17	85	70	125	55	85.2	12	1.5	1.5	220000	75000	2000
18	90	75	135	62	90.2	14	2	1.5	270000	91500	2000
20	100	85	150	67	100.2	15	2	1.5	340000	114000	1600

Table 20.13(a): Cylindrical Roller Bearings **Series NU 22**

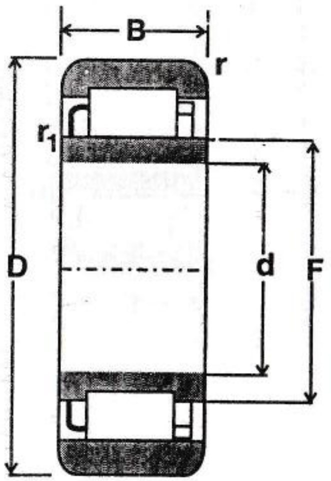
Series NU22



Bearing No. (SKF)	d mm	D mm	B mm	r mm	r_1 mm	F mm	Basic capacity N Static C_0	Dynamic C	Max. permissible speed, rpm
NU 2205	25	52	18	1.5	1	32	11030	15790	13000
2206	30	62	20	1.5	1	38.5	16970	23140	13000
2207	35	72	23	2	1	43.8	27655	35600	10000
NU 2208	40	80	23	2	2	50	32750	40700	10000
2209	45	85	23	2	2	55	35600	43640	8000
2210	50	90	23	2	2	60.4	38540	45500	8000
NU 2211	55	100	25	2.5	2	66.5	45500	52560	8000
2212	60	110	28	2.5	2.5	73.5	59820	69630	6000
2213	65	120	31	2.5	2.5	79.6	74040	81640	6000
NU 2214	70	125	31	2.5	2.5	84.5	78450	85910	5000
2215	75	130	31	2.5	2.5	88.5	84730	96350	5000
2216	80	140	33	3	3	95.3	98070	109340	5000
NU 2217	85	150	36	3	3	101.8	117680	127000	4000
2218	90	160	40	3	3	107	135820	140235	4000
2219	95	170	43	3.5	3.5	113.5	160340	173580	4000
NU 2220	100	180	46	3.5	3.5	120	184855	196130	3000
2222	110	200	53	3.5	3.5	132.5	226435	254170	3000
2224	120	215	58	3.5	3.5	143.5	271645	280470	3000
NU 2226	130	230	64	4	4	156	306700	296650	2500
2228	140	250	68	4	4	169	378540	362850	2500
2230	150	270	73	4	4	182	436400	423650	2500

Table 20.13(b): Cylindrical Roller Bearings Series NU 23

Series NU23



Bearing No. (SKF)	d mm	D mm	B mm	r mm	r_1 mm	F mm	Basic capacity, N Static C_0	Dynamic C	Max. permissible speed, rpm.
NU 2305	25	62	24	2	2	35	21280	30205	10000
2306	30	72	27	2	2	42	26430	35305	10000
2307	35	80	31	2.5	2	46.2	30695	41780	8000
NU 2308	40	90	33	2.5	2.5	53.5	47270	58840	8000
2309	45	100	36	2.5	2.5	58.5	55700	74040	8000
2310	50	110	40	3	3	65	74040	90960	6000
NU 2311	55	120	43	3	3	70.5	82965	106890	6000
2312	60	130	46	3.5	3.5	77	103460	129250	5000
2313	65	140	48	3.5	3.5	83.5	120130	142690	5000
NU 2314	70	150	51	3.5	3.5	90	138270	155925	5000
2315	75	160	55	3.5	3.5	95.5	166710	200150	4000
2316	80	170	58	3.5	3.5	103	184855	213785	4000
NU 2317	85	180	60	4	4	108	196130	227415	3000
2318	90	190	64	4	4	115	222610	254000	3000
2319	95	200	67	4	4	121.5	260760	292140	3000
NU 2320	100	215	73	4	4	129.5	309890	341170	3000
2322	110	240	80	4	4	143	423650	455030	2500
2324	120	260	86	4	4	154	499160	557510	2500
NU 2326	130	280	93	5	5	167	637430	609970	2500
2328	140	300	102	5	5	180	726670	736480	2000
2330	150	320	108	5	5	193	815910	815910	2000

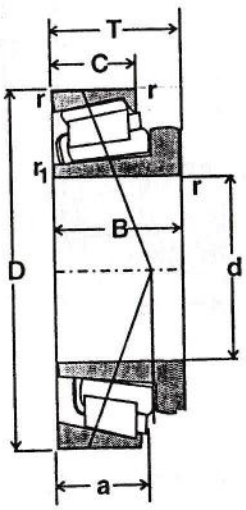
Table 20.14: Taper Roller Bearings Series 322

Bearing No.	d	D	B	T	C	r	r_1	a	Basic capacity, N	Max. permissible

Table 20.14: Taper Roller Bearings

Series 322

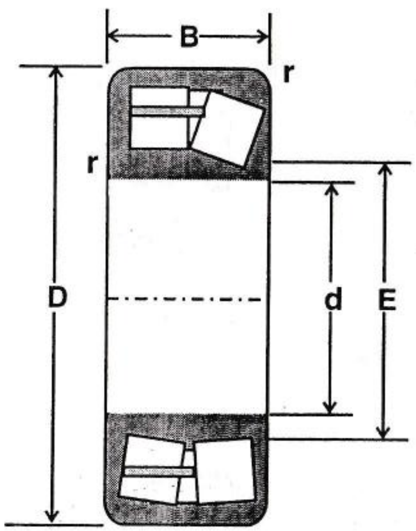
Series 322



Bearing No. (SKF)	d mm	D mm	B mm	T mm	C mm	r mm	r_1 mm	a mm	Basic capacity, N Static C_0	Basic capacity, N Dynamic C	Max. permissible speed, rpm
32206	30	62	20	21.25	17	1.5	0.85	15	27165	31675	6000
07	35	72	23	24.25	19	2	0.8	18	36285	41430	6000
08	40	80	23	24.75	19	2	0.8	19	40210	45500	6000
32209	45	85	23	24.75	19	2	0.8	20	45500	49915	5000
10	50	90	23	24.75	19	2	0.8	21	47270	51580	5000
11	55	100	25	26.75	21	2.5	0.8	22	61050	65115	4000
32212	60	110	28	29.75	24	2.5	0.8	24	75710	78450	4000
13	65	120	31	32.75	27	2.5	0.8	26	90810	96105	4000
14	70	125	31	33.25	27	2.5	0.8	28	90810	96105	3000
32215	75	130	31	33.25	27	2.5	0.8	29	99930	101450	3000
16	80	140	33	35.25	28	3	1	30	113760	117680	3000
17	85	150	36	38.5	30	3	1	33	134840	135820	2500
32218	90	160	40	42.15	34	3	1	36	160730	158080	2500
19	95	170	43	45.5	37	3.5	1.2	38	180440	180440	2500
20	100	180	46	49	39	3.5	1.2	41	207705	202510	2500
32221	105	190	50	53	43	3.5	1.2	44	241240	236340	2000
22	110	200	53	56	46	3.5	1.2	46	271645	254000	2000
24	120	213	53	61.5	50	3.5	1.2	52	334410	298120	2000
32226	130	230	64	67.75	54	4	1.5	56	407960	369710	1600
28	140	250	68	71.75	58	4	1.5	60	481510	422670	1600
30	150	270	73	77	60	4	1.5	64	534460	480525	1600

Table 20.15: Spherical Roller Bearings (Series 222 C and 222 CK)

Series 222 C



Bearing with cylindrical bore	d mm	D mm	B mm	E mm	r mm	Basic capacity, N Static C_0	Basic capacity, N Dynamic C	Maximum permissible speed rpm
*22205 C	25	52	18	32	1.5	22000	30000	8000
*06 C	30	62	20	38	1.5	31000	45000	6000
07 C	35	72	23	44	2	40500	52000	6000
22208 C	40	80	23	50	2	48000	62000	5000
09 C	45	85	23	55	2	52000	64000	5000
10 C	50	90	23	60	2	55000	67000	4000
22211 C	55	100	25	66	2.5	68000	83000	4000
12 C	60	110	28	73	2.5	85000	100000	4000
13 C	65	120	31	79	2.5	102000	118000	3000
22214 C	70	125	31	84	2.5	108000	122000	3000
15 C	75	130	31	90	2.5	112000	127000	3000
16 C	80	140	33	95	3	140000	153000	2500
22217 C	85	150	36	100	3	163000	180000	2500
18 C	90	160	40	107	3	196000	208000	2500
19 C	95	170	43	113	3.5	228000	245000	2000

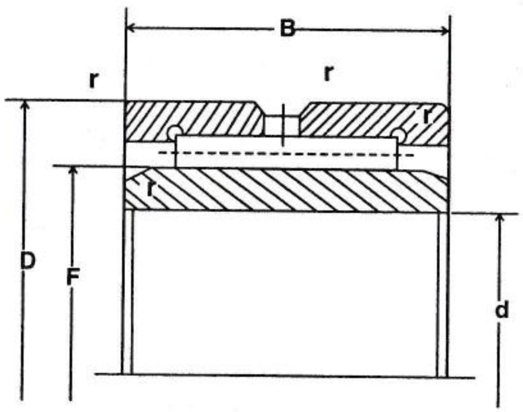
Bearing with cylindrical bore	d mm	D mm	B mm	E mm	r mm	Basic capacity, N Static C_0	Dynamic C	Maximum permissible speed rpm
22220 C	100	180	46	120	3.5	255000	270000	2000
22 C	110	200	53	132	3.5	345000	345000	2000
24 C	120	215	58	143	3.5	400000	400000	1600
22226 C	130	230	64	153	4	480000	465000	1600
28 C	140	250	68	167	4	540000	530000	1600
30 C	150	270	73	179	4	655000	640000	1300
22232 C	160	290	80	191	4	780000	735000	1300
34 C	170	310	86	204	5	900000	830000	1000
36 C	180	320	86	213	5	950000	880000	1000
22238 C	190	340	92	226	5	1020000	950000	1000
40 C	200	360	98	238	5	1160000	1080000	800
44 C	220	400	108	264	5	1430000	1290000	800

Note: For bearings with taper bore add K-Example 22208 CK. Taper 1 : 12 on diameter.

* Not available with taper bore,

Table 20.16: Needle Bearings **Series NA 49**

NA 49 Series



Brg. No.	d mm	F mm	D mm	B mm	r mm	Basic Capacity, N Static C_0	Basic Capacity, N dynamic C	Max. speed rpm
NA 49 02	15	20	28	13	0.5	7800	9400	20000
03	17	22	30	13	0.5	8200	9700	18000
04	20	25	37	17	0.5	14900	18500	16000
49/22	22	28	39	17	0.5	16900	20100	14000
05	25	30	42	17	0.5	17900	20800	13000
49/28	28	32	45	17	0.5	18900	21500	12000
06	30	35	47	17	0.5	19900	22100	11000
49/32	32	40	52	20	1	26500	27000	10000
07	35	42	55	20	1	27500	28000	9000
08	40	48	62	22	1	37000	37500	8000
09	45	52	68	22	1	39500	39000	8000
49 10	50	58	72	22	1	42500	40500	7000
12	60	68	85	25	1.5	57000	52000	6000
14	70	80	100	30	1.5	84000	74000	5000
16	80	90	110	30	1.5	94000	78000	4000
18	90	105	125	35	2	134000	100000	4000
20	100	115	140	40	2	144000	112000	3000
24	120	135	165	45	2	210000	159000	3000

Table 20.17: Geometric Relations:
(General proportions for Anti friction Bearings)

24	120	135	165	45	2	210000	159000	3000

Table 20.17: Geometric Relations:
(General proportions for Anti friction Bearings)

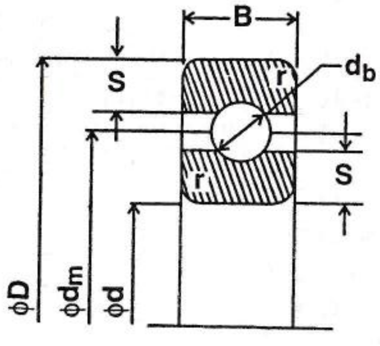
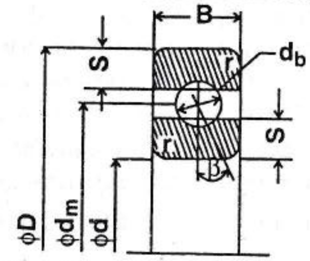
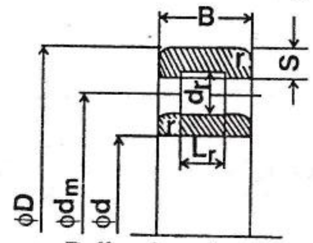
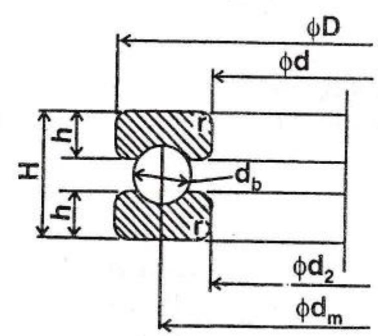
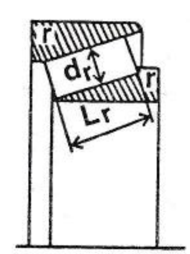
 Deep groove ball bearing	$d_m = \frac{D+d}{2}$ $d_b = 0.3\,(D-d)$ $s \approx 0.15\,(D-d) = \frac{d_b}{2}$ $r_1 = 0.5r$ $r = 0.515\,d_b$ $z \approx 2.9\left(\frac{D+d}{D-d}\right)$ d_m, mean diameter; s, radial thickness of races; d_b, diameter of ball; z, no. of balls	 Angular contact bearing  Roller bearing	$d_m = \frac{D+d}{2}$ $d_b = 0.3\,(D-d)$ $s = 0.15\,(D-d)$ $z = 4.2\left(\frac{D+d}{D-d}\right)$ $\beta = 25°$ $d_m = \frac{D+d}{2}$, $d_r = 0.25\,(D-d)$; $L_r = 1$ or $1.5d$; $s = 0.15\,(D-d)$
 Thrust bearing	$d_m = \frac{D+d}{2}$; $d_b \approx 0.5H$; $h \approx 0.3H$; $r_1 = 0.5r$; $z \approx 3.56\left(\frac{D+d}{D-d}\right)$	 Taper roller bearing	$d_r = 0.25\,(D-d)$ $L_r = 1.6\,d_r$

Table 20.18: Characteristics of Sliding and Rolling Bearings

Factors	Characteristics	Sliding	Rolling
1. Mechanical requirements	(i) Load;		
	undirectional	Excellent	Excellent
	cyclic	Excellent	Excellent
	starting	Poor	Excellent
	shock	Excellent	Good
	(ii) Speed limited by	Temperature rise	Centrifugal loading
	(iii) Misalignment tolerance	Fair	Poor in ball and cylindrical roller bearings. Good in spherical roller and ball bearings (self aligning bearings)
	(iv) Starting friction	High	Low
	(v) Space requirement		
	— radial	Small	Large
	— axial	l/d = 0.3 to 2	0.2 to 0.5
	(vi) Damping capacity	Excellent	Poor
	(vii) Type of lubricant	Oil, grease or gas	Oil or grease
	(viii) Quantity of lubricant required	Large	Very small
	(ix) Noisy	Quiet	Noisy
2. Environmental conditions	Low temp. starting	Poor	Good
	High temp. operation	Limited by lubricant	Limited by lubricant
3. Economics	(i) Life	Good, it can run "forever", if properly maintained.	Finite life due to eventual failure by fatigue.
	(ii) Maintenance	Continuous supply of clean oil is required	Only occasional attention is required.
	(iii) Cost	Low, in mass production	Intermediate
	(iv) Ease of replacement	Shaft may also need the replacement	Readily replaceable as these bearings have been standardized. Shaft need not be replaced.

CHAPTER – 21

FLAT BELT DRIVES

Symbols : (with S.I. units)

B	–	Pulley width, mm
b	–	Belt width, mm
C	–	Centre distance between pulleys, mm
D	–	Diameter of bigger pulley, mm.
d	–	Diameter of smaller pulley, mm
g	–	Acceleration due to gravity, m/s^2
K_a	–	Arc of contact factor
K_s	–	Service factor
L	–	Length of belt, mm
N	–	Speed of bigger pulley, rpm; Unit of force in newtons.
n	–	Speed of smaller pulley, rpm
P	–	Power transmitted by belt kW
P_d	–	Design Power, kW
P_r	–	Rated (i.e.; specified) power, kW
T_1	–	Tension in tight side of belt, N
T_2	–	Tension in slack side of belt, N
T_c	–	Centrifugal force, N
t	–	Thickness of belt, mm
v	–	Velocity of belt, m/s
w	–	Weight of the belt per metre length, N/m
θ	–	Angle (or Arc) of contact of the belt with the smaller pulley, deg.
μ	–	Coefficient of friction between the contact surfaces of belt and pulley.

DESIGN PARTICULARS	EQUATIONS
Power transmitted by belt	$P = \frac{(T_1 - T_2)\,v}{1000}$ kW .... (21.1)
Belt velocity	$v = \frac{\pi\, dn}{60000} = \frac{\pi\, DN}{60000}$ m/s .... (21.2)
Ratio of tensions of the belt	$\frac{T_1}{T_2} = e^{\mu\,\theta'}$ [Neglecting centrifugal force i.e., for low velocity] .... (21.3)
	$\frac{T_1 - T_c}{T_2 - T_c} = e^{\mu\,\theta'}$ [Including centrifugal force i.e., for high velocity] .... (21.4)
	$T_c = \frac{w}{g} v^2;\ \theta' = \frac{\pi\,\theta}{180}$ radians
Design power	$P_d = P_r \times K_s \times K_a$ .... (21.5)
Width of belt	$b = \frac{\text{Design power}}{\text{Belt rating per mm width}}$
	(or)
	$b = \frac{\text{Maximum tension}}{\text{Allowable tension per mm width}}$ .... (21.6)

Table 21.1

Type of belt drive	Arc of contact (θ), deg.	Length of belt (L), mm
Open belt drive	$\theta = 180° - \left(\frac{D-d}{C}\right)60°$	$L = 2C + \frac{\pi}{2}(D+d) + \frac{(D-d)^2}{4C}$
Cross belt drive	$\theta = 180° + \left(\frac{D+d}{C}\right)60°$	$L = 2C + \frac{\pi}{2}(D+d) + \frac{(D+d)^2}{4C}$
Quarter-turn drive	$\theta = 180 + \left(\frac{d}{C}\right)60°$	$L = 2C + \frac{\pi}{2}(D+d) + \left(\frac{D^2+d^2}{2C}\right)$

Table 21.2: Characteristics of Flat Belts

Quarter-turn drive	$\theta = 180 + \left(\frac{d}{C}\right)60^\circ$	$L = 2C + \frac{\pi}{2}(D+d) + \left(\frac{D^2+d^2}{2C}\right)$

Table 21.2: Characteristics of Flat Belts

Belt material	Ultimate strength N/mm^2 (S_u)	Endurance limit (S_e) N/mm^2	Factory of safety	Maximum velocity v (m/s)	Density KN/m^3 (ρ)	d/t	Width (b) mm	Thickness (t) mm	Modules of Elasticity N/mm^2
Leather	20 – 35	4	8 – 10	20 – 40	9.8	25 – 35	20 – 300	3 – 7.5	100 – 350
Rubber	35 – 45	8	6 – 10	20 – 30	12.5 – 15	30 – 40	20 – 500	2.5 – 14	80 – 120
Cotton	35 – 40	8	6 – 10	15 – 25	7.5 – 15	25 – 40	30 – 250	4.5 – 8.5	30 – 60
Woolen	30	6	8 – 10	20 – 30	9 – 12.5	25 – 30	50 – 500	2 – 10	–

Table 21.3: Allowable Tensions in newtons (N) per mm Width of Belt

	Materials of the belt	Number of plies									
		1	2	3	4	5	6	7	8	9	10
1.	Leather (Light duty)	–	16.67	–	–	–	–	–	–	–	–
2.	Leather (Medium)	14.71	24.52	–	–	–	–	–	–	–	–
3.	Leather (Heavy)	17.65	28.44	35.30	–	–	–	–	–	–	–
4.	Fabric (canvas)	–	–	–	6.86	8.83	10.79	–	11.77	–	13.73
5.	Rubber	–	–	7.85	10.79	12.75	15.69	18.63	22.56	25.50	28.44
6.	Balata	–	–	4.90	6.86	8.83	10.79	11.77	13.73	25.50	28.44

Table 21.4: Coefficients of Friction for Belts and Pulley Materials

Belt Material	Pulley Material					
	Iron-steel	Wood	Paper	Wet Iron	Greasy Iron	Oily Iron
Oak-tanned leather	0.25	0.30	0.35	0.20	0.15	0.12
Mineral-tanned leather	0.40	0.45	0.50	0.35	0.25	0.20
Canvas stitched	0.20	0.23	0.25	0.15	0.12	0.10
Balata	0.32	0.35	0.40	0.20	–	–
Cotton woven	0.22	0.25	0.28	0.15	0.12	0.10
Camel-hair	0.35	0.40	0.45	0.25	0.20	0.15
Rubber-friction	0.30	0.32	0.35	0.18	–	–
Rubber-covered	0.32	0.35	0.38	0.15	–	–
Rubber on fabric	0.35	0.38	0.40	0.20	–	–

Table 21.5

Nominal Belt Widths of Friction Surface Rubber, Transmission Belting (mm)

25	32	40	50	63	71	80	90	100	112	125	140
160	180	200	224	250	280	315	355	400	450	500	

Table 21.6: Load Correction Factor (or) Service Factor (K_s)

Nature of Load	Applications	Load correction factor
Steady load	Centrifugal pumps and fans, evaporators, belt conveyors, light machine tools, printing and textile machinery	1.2
Intermittent Load	Heavy duty fans and blowers, reciprocating pumps and conveyors, brick work machinery, saw mill and paper mill machinery, heavy machine tools, elevators and line shafts.	1.3
Shock load	Vacuum pumps, tube and ball mills, rolling mills, crushing machinery, disintegrators, stamp presses, grinders, hammers, automatic machinery	1.5

Table 21.7: Arc of Contact Factor (K_a)

Arc of contact (deg.)	90	120	130	140	150	160	170	180	190	200	210	220	230	240
Correction factor	1.68	1.33	1.26	1.19	1.13	1.08	1.04	1.00	0.97	0.94	0.91	0.88	0.86	0.84

Table 21.8: Minimum Pulley Diameters, for Given Belt Speeds and Belt, Plies in mm

No. of Plies	Maximum Belt Speed, m/s				
	10	15	20	25	30
3	90	100	112	140	180
4	140	160	180	200	250
5	200	224	250	315	355
6	250	315	355	400	450
8	450	500	560	630	710

Table 21.9: Specifications of Transmission Belting

Standard widths in millimetres

No. of Plies									
3 ply		4 ply		5 ply		6 ply		8 ply	
HI SPEED	FORT	HI SPEED	FORT	HI SPEED	FORT	HI SPEED	FORT	HI SPEED	FORT
25	25	25	–	76	76	100	–	–	200
32	–	32	–	90	–	112	112	–	250
40	40	40	40	100	100	125	125	–	305
44	–	44	44	112	112	152	152	–	355
50	50	50	50	125	125	180	180	–	400
63	63	63	63	152	152	200	200		
76	76	76	76	–	180	–	250		
90	–	90	90	200	–				
100	–	100	100	224	–				
		112	112	–	250				
		125	125						
		140	–						
		152	152						
		200	–						

Reduction of length for belt tensions :

For,

1. Belt of 3 plies – 1.5 % of L
2. Belt of 4, 5 & 6 plies – 1 % of L
3. Belt of 8 plies – 0.5 % of L

Table 21.10: Thickness of Friction Surface Rubber Transmission Belting

Number of plies	Nominal belt thickness (mm) (Hard type fabric)	Tolerance (mm)
3 ply	3.9	± 0.5
4 ply	5.1	± 0.7
5 ply	6.4	± 0.8
6 ply	7.7	± 0.9
7 ply	9.1	± 1.0
8 ply	10.4	± 1.1

Rating for Standard types of Fabric Belts:

Load rating per mm width per ply at 180° arc of contact at 10 m/s belt speed:

'HI SPEED', 878 g duck belting	0.023 kW (or) 0.0314 h.p
'FORT' 949 g duck belting	0.0289 kW (or) 0.0392 hp

Table 21.11: Pulley Width

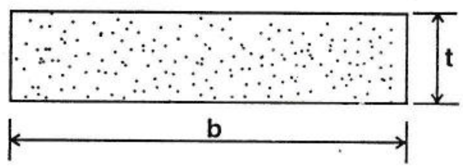
	Belt width (b)	Pulley width (B)
For	$b \leq 125$ mm	$B = b + 13$ mm
For	$125 < b \leq 250$ mm	$B = b + 25$ mm
For	$250 < b \leq 375$ mm	$B = b + 38$ mm
For	$375 < b \leq 500$ mm	$B = b + 50$ mm

Table 21.12: Width of Flat Cast Iron and Mild Steel Pulleys, mm

20	25	32	40	50	53	71	80	90	100	112	125	140
160	180	200	224	250	280	315	355	400	450	500	560	630

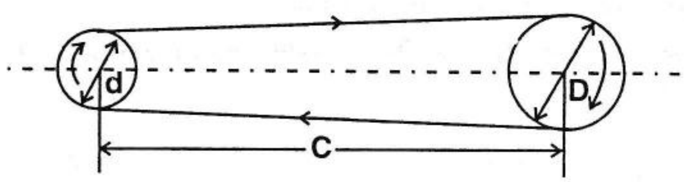
Table 21.13: Nominal Diameters of Cast Iron and Mild Steel Pulleys, mm

40	45	50	56	63	71	80	90	100	112	125	140
160	180	200	224	250	280	315	355	400	450	500	560
630	710	800	900	1000	1120	1250	1400	1600	1800	2000	

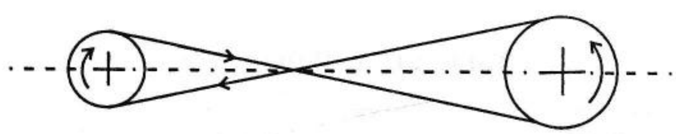


b – Width of belt
t – Thickness of belt specified in terms of plies.

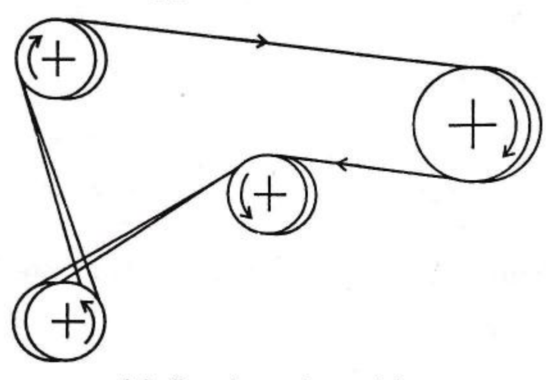
Fig. 21.1: Cross-section of flat belt



(a) Open belt drive



(b) Cross-belt drive



(c) Quarter – turn drive
Fig. 21.2: Types of belt drives

CHAPTER – 22

V-BELT DRIVES

Symbols : (with S.I. Units)

C	–	Centre distance between pulleys, mm
D	–	Diameter (i.e., pitch diameter) of bigger pulley, mm.
d	–	Diameter (i.e., pitch diameter) of smaller pulley, mm
i	–	Number of belts
K_a	–	Arc of contact factor
K_d	–	Small diameter factor
K_l	–	Pitch length (of belt) factor
K_s	–	Service factor
L	–	Length of belt, mm
N	–	Speed of bigger pulley in rpm, Unit of force in newtons.
n	–	Speed of smaller pulley in rpm
P	–	Power transmitted by belt, kW
P_d	–	Design power, kW
P_r	–	Rated (i.e., specified) power, kW
P_s	–	Belt rating (i.e., power transmitting capacity) of single belt, kW
T_1	–	Tension in tight side of belt, N
T_2	–	Tension in slack side of belt, N
t	–	Thickness of belt, mm.
v	–	Velocity of belt, m/s
α	–	Angle subtended by sides of V-belt, deg.
θ	–	Angle (or Arc) of contact of belt with the smaller pulley, deg.
μ	–	Coefficient of friction between the contact surfaces of belt and pulley.

DESIGN PARTICULARS	EQUATIONS
Power transmitted by belt	$P = \frac{(T_1 - T_2)\,v}{1000}$ kW .... (22.1)
Belt velocity	$v = \frac{\pi\, dn}{60000} = \frac{\pi\, DN}{60000}$ m/s .... (22.2)
Ratio of tensions of the belt	$\frac{T_1}{T_2} = e^{\mu\,\theta'/\sin(\alpha/2)}$; $\theta' = \frac{\pi\,\theta}{180}$ radians .... (22.3)
Design power	$P_d = \frac{P_r \times K_s}{K_a \times K_l}$ .... (22.4)
Number of belts	$i = \frac{P_d}{P_s}$ .... (22.5)
	(For P_s (i.e., belt rating) refer table 22.5)
Length of belt	$L = 2C + \frac{\pi}{2}(D + d) + \frac{(D - d)^2}{4C}$ .... (22.6)
Centre distance between pulleys	$C = A + \sqrt{A^2 - B}$ .... (22.7)
	Where $A = \frac{L}{4} - \pi\left(\frac{D + d}{8}\right)$
	$B = \frac{(D - d)^2}{8}$

Design of V-belt :

A V-belt of cross-section D and of nominal inside length of 3048 mm (120 inches) shall be designated as D 3048/120 IS:2494.

Table 22.1: Types of V-belts and Their Standard Dimensions (Fig. 22.1)

Cross Section	Usual load	Recommended minimum pitch	Nominal top width	Nominal Thickness	Nominal area of cross	Weight per metre length

A V-belt of cross-section D and of nominal inside length of 3048 mm (120 inches) shall be designated as D 3048/120 IS:2494.

Table 22.1: Types of V-belts and Their Standard Dimensions (Fig. 22.1)

Cross Section Symbol	Usual load of drive (KW)	Recommended minimum pitch diameter of smaller pulley d (mm)	Nominal top width B (mm)	Nominal Thickness t (mm)	Nominal area of cross section A (mm^2)	Weight per metre length (N)
A	0.5 – 5	75	13	8	88	1.05
B	2 – 15	125	17	11	119	1.90
C	7.5 – 75	200	22	14	280	3.45
D	22 – 150	355	32	19	536	5.96
E	30 – 190	500	38	23	729	7.85

Table 22.2: Correction Factors for Industrial Service, K_s

Severity of Service	Type of Driven machines	Types of Driving units					
		AC Motors; Normal torque. Squirrel cage, Synchronous and split phase DC Motors; Shunt wound multiple cylinder Internal combustion engines over 10 rev/s			AC Motors; High torque, High slip repulsion induction, Single phase series wound and slip ring DC Motors; Series wound and compound wound, Single cylinder internal combustion engines. Multiple cylinder internal combustion engines under 10 rev/s, Line shafts, Clutches, Brakes, Direct on Line starting.		
		Upto 10 hr	Over 10 hr to 16 hr	Over 16 hr and continuous service	Upto 10 hr	Over 10 hr to 16 hr	Over 16 hr and continuous service
Light-duty	Agitators for liquids, blowers and exhausters, centrifugal pumps and compressors, fans upto 7.5 kW (10 h_p), and light-duty conveyors	1.0	1.1	1.2	1.1	1.2	1.3

Medium duty	Belt conveyors for sand, grain etc; dough mixers; fans over 7.5 kW (10 h_p); generators; line shafts; laundry machinery; machine tools; punches, presses and shears; printing machinery; positive displacement rotary pumps; and revolving and vibrating screens.	1.1	1.2	1.3	1.2	1.3	1.4
Heavy duty	Brick machinery, bucket elevators, exciters, piston compressors, conveyors (drag-pan-screw), hammer mills, paper mill beaters, piston pumps, positive displacement blowers, pulverizers, sawmill and wood-working machinery, and textile machinery.	1.2	1.3	1.4	1.4	1.5	1.6
Extra-heavy duty	Crushers (gyratory-jaw-roll), mills (ball-rod-tube), hoists, and rubber (calenders-extruders -mills)	1.3	1.4	1.5	1.5	1.6	1.8

Note 1: The table gives only a few examples of particularly representative machines.

Note 2: If an idler pulley is used, the following values must be added to the service factor:

Idler pulley on the slack side: inside : 0, outside : 0.1

Idler pulley on the tight side: inside : 0.1, outside : 0.2

Note 2: If an idler pulley is used, the following values must be added to the service factor:

Idler pulley on the slack side	inside : 0 outside : 0.1	Idler pulley on the tight side	inside : 0.1 outside : 0.2

Table 22.3

Arc of contact angle $= 180° - \left(\frac{D - d}{C}\right) 60°$

D, pitch diameter of larger pulley
d, pitch diameter of smaller pulley
C, centre distance

Correction factor for arc of contact, (K_a)

Arc of contact on smaller pulley (in degrees)	Correction factor (Proportion of 180° rating)	
	V–V	V–Flat
180	1.00	0.75
177	0.99	0.76
174	0.99	0.76
171	0.98	0.77
169	0.97	0.78
166	0.97	0.79
163	0.96	0.79
160	0.95	0.80
157	0.94	0.81
154	0.93	0.81
151	0.93	0.82
148	0.92	0.83
145	0.91	0.83
142	0.90	0.84
139	0.89	0.85
136	0.88	0.85
133	0.87	0.86
130	0.86	0.86
127	0.85	0.85
123	0.83	0.83
120	0.82	0.82
117	0.81	0.81
113	0.80	0.80
110	0.78	0.78
106	0.77	0.77
103	0.75	0.75
99	0.73	0.73
95	0.72	0.72
91	0.70	0.70
87	0.68	0.68
83	0.65	0.65

Note 1: Arcs of contact below 120° should not be used unless full drive details are first submitted to the V-drive manufacturer concerned for confirmation.

Note 2: It should be noted that the advantage of using V-Flat drives diminishes increasingly for arc of contact greater than 133° and the use of such drives is usually not found to be practical for arcs of contact greater than 151°.

Table 22.4: Nominal Inside Length, Nominal Pitch Length and Correction Factors

Nominal inside length	Nominal pitch length: Cross-section A	Cross-section B	Cross-section C	Cross-section D	Cross-section E	Pitch length variation: Pitch-length limits	Maximum variation in length within a matched set	Correction factor (K_l), Belt cross-section symbols: A	B	C	D	E
mm	mm	mm	mm	mm	mm	mm	mm					
965	1 001	1 008	—	—	—	+14.0 −8.9	2.5	0.88	0.83	—	—	—
991	1 026	—	—	—	—			0.88	—	—	—	—
1 016	1 051	1 059	—	—	—			0.89	0.84	—	—	—
1 067	1 102	1 110	—	—	—			0.90	0.85	—	—	—
1 092	1 128	—	—	—	—			0.90	—	—	—	—
1 168	1 204	1 212	—	—	—			0.92	0.87	—	—	—
1 219	1 255	1 262	—	—	—	+16.0 −9.0	5.0	0.93	0.88	—	—	—
1 295	1 331	1 339	1 351	—	—			0.94	0.89	0.80	—	—
1 372	—	1 415	—	—	—			—	0.90	—	—	—
1 397	1 433	1 440	—	—	—			0.96	0.90	—	—	—
1 422	1 458	1 466	—	—	—			0.96	0.90	—	—	—
1 473	1 509	—	—	—	—			0.97	—	—	—	—
1 524	1 560	1 567	1 580	—	—			0.98	0.92	0.82	—	—
1 600	1 636	—	—	—	—	+17.8 −12.5		0.99	—	—	—	—
1 626	1 661	—	—	—	—			0.99	—	—	—	—
1 651	1 687	1 694	—	—	—			1.00	0.94	—	—	—
1 727	1 763	1 770	1 783	—	—			1.00	0.95	0.85	—	—
1 778	1 814	1 821	—	—	—			1.01	0.95	—	—	—
1 905	1 941	1 948	1 961	—	—	+17.8 −12.5	7.5	1.02	0.97	0.87	—	—
1 981	2 017	2 024	—	—	—	+30 −16		1.03	0.98	—	—	—
2 032	2 068	—	—	—	—			1.04	—	—	—	—
2 057	2 093	2 101	2 113	—	—			1.04	0.98	0.89	—	—
2 159	2 195	2 202	2 215	—	—			1.05	0.99	0.90	—	—
2 286	2 322	2 329	2 342	—	—			1.06	1.00	0.91	—	—
2 438	2 474	—	2 494	—	—			1.08	—	0.92	—	—

2 057	2 093	2 101	2 113	—	—	+30	7.5	1.04	0.98	0.89	—	—
2 159	2 195	2 202	2 215	—	—	−16		1.05	0.99	0.90	—	—
2 286	2 322	2 329	2 342	—	—			1.06	1.00	0.91	—	—
2 438	2 474	—	2 494	—	—			1.08	—	0.92	—	—

Nominal pitch length						Pitch length variation		Correction factor (K_l)				
Nominal inside length mm	Cross-section A mm	Cross-section B mm	Cross-section C mm	Cross-section D mm	Cross-section E mm	Pitch-length limits mm	Maximum variation in length within a matched set mm	Belt cross-section symbois A	B	C	D	E
2 464	—	2 507	—	—	—			—	1.02	—	—	—
2 540	—	2 583	—	—	—			—	1.03	—	—	—
2 667	2 703	2 710	2 723	—	—	+34 −18		1.10	1.04	0.94	—	—
2 845	2 880	2 888	2 901	—	—			1.11	1.05	0.95	—	—
3 048	3 084	3 091	3 104	3 127	—			1.13	1.07	0.97	0.86	—
3 150	—	—	3 205	—	—		10	—	—	0.97	—	—
3 251	3 287	3 294	3 307	3 330	—	+38 −21		1.14	1.08	0.98	0.87	—
3 404	—	—	3 459	—	—			—	—	0.99	—	—
3 658	3 693	3 701	3 713	3 736	—			—	1.11	1.00	0.90	—
4 013	—	4 056	4 069	4 092	—	+43 −24		—	1.13	1.02	0.92	—
4 115	—	4 158	4 171	4 194	—			—	1.14	1.03	0.92	—
4 394	—	4 437	4 450	4 473	—	+43 −24		—	1.15	1.04	0.93	—
4 572	—	4 615	4 628	4 651	—			—	1.16	1.05	0.94	—
4 953	—	4 996	5 009	5 032	—		12.5	—	1.18	1.07	0.96	—
5 334	—	5 377	5 390	5 413	5 426	+49 −28		—	1.19	1.08	0.96	0.94
6 045	—	—	6 101	6 124	6 137			—	—	1.11	1.00	0.96
6 807	—	—	6 863	6 886	6 899	+56 −32		—	—	1.14	1.03	0.99
7 569	—	—	7 625	7 648	7 661	+56 −32		—	—	1.16	1.05	1.01
8 331	—	—	8 387	8 410	8 423	+65	15	—	—	1.19	1.07	1.03
9 093	—	—	9 149	9 172	9 185	−37		—	—	1.21	1.09	1.05
9 855	—	—	—	9 934	9 947	+65 −37		—	—	1.23	1.11	1.07
10 617	—	—	—	10 696	10 709	+76		—	—	1.24	1.12	1.09
12 141	—	—	—	12 220	12 233	−43		—	—	—	1.16	1.12
13 665	—	—	—	13 744	13 757	+89	17.5	—	—	—	1.18	1.14
15 189	—	—	—	15 268	15 281	−50		—	—	—	1.20	1.17
16 713	—	—	—	16 792	16 805	+105 −59		—	—	—	1.23	1.19

Table 22.5: Formulae for Power Transmitting Capacities of Single Belt

The maximum power in Kilowatt which the V-belts of sections A, B, C, D and E can transmit shall be calculated from the following formula:

Belt cross-section symbol	Belt rating (kW) Formula	Maximum value of d_e in the formula mm
A	$P_s = \left(0.45\,v^{-0.09} - \dfrac{19.62}{d_e} - 0.765 \times 10^{-4}\,v^2\right)v$	125
B	$P_s = \left(0.79\,v^{-0.09} - \dfrac{50.8}{d_e} - 1.32 \times 10^{-4}\,v^2\right)v$	175
C	$P_s = \left(1.47\,v^{-0.09} - \dfrac{142.7}{d_e} - 2.34 \times 10^{-4}\,v^2\right)v$	300
D	$P_s = \left(3.22\,v^{-0.09} - \dfrac{506.7}{d_e} - 4.78 \times 10^{-4}\,v^2\right)v$	425
E	$P_s = \left(4.58\,v^{-0.09} - \dfrac{952}{d_e} - 7.05 \times 10^{-4}\,v^2\right)v$	700

where

P_s maximum power in kW at 180° arc of contact for a belt of average length

v belt speed, m/s

d_e equivalent pitch diameter $= d \times K_d$

d pitch diameter of the smaller pulley, mm

K_d the small diameter factor to account for variation of arc of contact, from table below.

Speed ratio range, D/d	Small dia. factor, K_d	Speed ratio range, D/d	Small dia. factor, K_d
1.0 to 1.019	1.00	1.223 to 1.274	1.08
1.02 to 1.032	1.01	1.275 to 1.340	1.09
1.033 to 1.055	1.02	1.341 to 1.429	1.10
1.056 to 1.081	1.03	1.43 to 1.562	1.11
1.082 to 1.109	1.04	1.563 to 1.814	1.12
1.11 to 1.142	1.05	1.815 to 2.948	1.13
1.143 to 1.178	1.06	2.949 and over	1.14
1.179 to 1.222	1.07		

Table 22.6: Ratings for V-Belts in Kilowatt
Cross-section A

Belt Speed (m/s)	Equivalent pitch diameter d_e in mm					
	80	90	100	110	120	125 and over
0.5	0.13	0.13	0.14	0.14	0.15	0.15
1	0.22	0.24	0.25	0.27	0.28	0.29
2	0.37	0.40	0.43	0.46	0.49	0.51
3	0.51	0.58	0.64	0.68	0.72	0.74
4	0.58	0.74	0.81	0.88	0.93	0.96
5	0.74	0.85	0.95	1.04	1.13	1.18
6	0.81	0.94	1.05	1.15	1.25	1.32
7	0.88	1.08	1.25	1.39	1.50	1.54
8	0.96	1.17	1.35	1.50	1.62	1.69
9	1.03	1.32	1.54	1.69	1.77	1.84
10	1.10	1.40	1.62	1.77	1.91	1.99
11	1.18	1.47	1.69	1.91	2.06	2.13
12	1.25	1.54	1.84	2.06	2.21	2.28
13	1.32	1.62	1.91	2.13	2.35	2.43
14	1.32	1.69	1.99	2.28	2.50	2.50
15	1.32	1.77	2.06	2.35	2.57	2.65
16	1.40	1.84	2.13	2.43	2.65	2.79
17	1.40	1.84	2.21	2.50	2.79	2.87
18	1.40	1.84	2.28	2.57	2.87	2.94
19	1.40	1.84	2.28	2.65	2.94	3.02
20	1.32	1.91	2.35	2.72	3.02	3.09
21	1.32	1.91	2.35	2.72	3.02	3.16
22	1.25	1.91	2.35	2.72	3.09	3.24
23	1.25	1.84	2.35	2.79	3.09	3.24
24	1.18	1.84	2.35	2.79	3.16	3.31
25	1.10	1.77	2.28	2.79	3.16	3.31
26	1.03	1.69	2.28	2.72	3.16	3.31
27	0.88	1.62	2.20	2.72	3.09	3.31
28	0.81	1.54	2.13	2.65	3.09	3.24
29	0.66	1.47	2.06	2.57	3.02	3.24
30	0.51	1.32	1.99	2.50	2.94	3.16

Table 22.7: Ratings for V-Belts in Kilowatt
Cross-section B

Belt Speed (m/s)	Equivalent pitch diameter d_e in mm					
	130	140	150	160	170	180 and over
0.5	0.22	0.22	0.22	0.22	0.29	0.29
1	0.37	0.44	0.44	0.44	0.51	0.51
2	0.66	0.74	0.81	0.81	0.88	0.88
3	0.96	1.03	1.10	1.17	1.25	1.39
4	1.18	1.32	1.40	1.47	1.50	1.62
5	1.47	1.54	1.69	1.84	1.91	1.99
6	1.62	1.84	1.99	2.06	2.21	2.28
7	1.91	2.13	2.21	2.35	2.50	2.65
8	2.06	2.28	2.43	2.65	2.79	2.94
9	2.21	2.43	2.65	2.87	3.02	3.16
10	2.35	2.65	2.87	3.09	3.31	3.46
11	2.50	2.79	3.09	3.31	3.53	3.75
12	2.65	3.02	3.31	3.53	3.75	3.97
13	2.79	3.16	3.46	3.75	3.97	4.19
14	2.87	3.16	3.60	3.90	4.19	4.56
15	2.94	3.38	3.75	4.05	4.34	4.63
16	3.02	3.46	3.90	4.19	4.49	4.78
17	3.09	3.60	3.97	4.34	4.71	4.92
18	3.16	3.60	4.04	4.49	4.78	5.07
19	3.16	3.68	4.19	4.56	4.92	5.22
20	3.16	3.75	4.19	4.63	5.00	5.44
21	3.16	3.75	4.27	4.71	5.07	5.44
22	3.16	3.75	4.27	4.78	5.15	5.52
23	3.09	3.75	4.27	4.78	5.22	5.59
24	3.02	3.68	4.27	4.78	5.22	5.66
25	2.94	3.60	4.19	4.78	5.22	5.66
26	2.79	3.53	4.19	4.71	5.22	5.66
27	2.65	3.46	4.12	4.63	5.15	5.66
28	2.50	3.31	3.97	4.56	5.15	5.59
29	2.43	3.16	3.82	4.49	5.00	5.52
30	2.13	2.94	3.68	4.34	4.92	5.44

Table 22.8: Ratings for V-Belts in Kilowatt
Cross-section C

Belt Speed (m/s)	Equivalent pitch diameter d_e in mm						
	180	200	220	240	260	280	300 and over
0.5	0.37	0.44	0.44	0.51	0.51	0.51	0.51
1	0.64	0.73	0.81	0.88	0.88	0.96	0.96
2	1.15	1.32	1.47	1.50	1.69	1.77	1.84
3	1.62	1.84	2.06	2.21	2.35	2.50	2.57
4	2.06	2.35	2.57	2.79	3.02	3.16	3.31
5	2.35	2.79	3.09	3.38	3.60	3.75	3.97
6	2.72	3.16	3.60	3.90	4.19	4.41	4.63
7	3.02	3.60	4.05	4.40	4.71	5.00	5.22
8	3.31	3.97	4.49	4.84	5.22	5.59	5.81
9	3.60	4.27	4.85	5.37	5.81	6.10	6.40
10	3.82	4.56	5.22	5.81	6.25	6.62	6.99
11	4.04	4.92	5.59	6.18	6.69	7.13	7.58
12	4.19	5.15	5.96	6.62	7.13	7.72	8.00
13	4.34	5.44	6.25	6.96	7.58	8.16	8.46
14	4.49	5.59	6.55	7.28	7.94	8.53	8.97
15	4.63	5.81	6.77	7.58	8.31	8.90	9.41
16	4.71	5.96	7.06	7.87	8.61	9.27	9.78
17	4.78	6.10	7.21	8.09	8.90	9.56	10.15
18	4.78	6.25	7.35	8.38	9.19	9.93	10.51
19	4.78	6.33	7.58	8.53	9.41	10.15	10.81
20	4.78	6.33	7.65	8.68	9.63	10.44	11.11
21	4.71	6.33	7.72	8.83	9.86	10.66	11.33
22	4.56	6.33	7.80	8.90	10.00	10.81	11.62
23	4.34	6.25	7.80	8.97	10.08	11.03	11.77
24	4.19	6.18	7.72	9.05	10.15	11.11	11.91
25	4.05	6.03	7.72	9.05	10.15	11.18	11.99
26	3.82	5.88	7.58	8.97	10.15	11.18	12.06
27	3.60	5.66	7.43	8.90	10.15	11.18	12.13
28	3.24	5.44	7.35	8.75	10.08	11.18	12.13
29	2.79	5.15	7.06	8.60	9.93	11.03	12.06
30	2.43	4.78	6.77	8.38	9.71	10.80	11.99

Table 22.9: Ratings for V-Belts in Kilowatt
Cross-section D

Belt Speed (m/s)	Equivalent pitch diameter d_e in mm							
	300	320	340	360	380	400	420	430 and over
0.5	0.81	0.88	0.96	0.96	1.03	1.03	1.10	1.10
1	1.47	1.54	1.69	1.77	1.84	1.91	1.91	1.99
2	2.50	2.79	2.94	3.09	3.24	3.38	3.53	3.53
3	3.46	3.75	4.04	4.34	4.56	4.71	4.92	5.00
4	4.34	4.78	5.15	5.44	5.74	6.03	6.25	6.40
5	5.07	5.66	6.10	6.55	6.91	8.21	7.58	7.65
6	5.81	6.55	7.06	7.51	7.94	8.38	8.75	8.90
7	6.47	7.28	7.94	8.46	8.97	9.41	9.86	10.08
8	7.13	7.94	8.68	9.34	10.00	10.52	10.96	11.25
9	7.65	8.68	9.49	10.22	10.96	11.47	12.06	12.28
10	8.23	9.34	10.22	11.03	11.84	12.43	13.02	13.31
11	8.68	9.86	10.88	11.84	12.58	13.39	14.05	14.34
12	9.12	10.37	11.47	12.50	13.39	14.19	14.93	15.30
13	9.49	10.88	12.06	13.16	14.05	15.00	15.74	16.11
14	9.79	11.25	12.58	13.75	14.56	15.74	16.55	16.99
15	10.00	11.62	13.09	14.34	15.44	16.40	17.28	17.72
16	10.30	11.91	13.46	14.78	15.96	16.99	18.02	18.46
17	10.44	12.21	13.83	15.22	16.55	17.58	18.61	19.05
18	10.51	12.43	14.12	15.59	16.99	18.09	19.20	19.71
19	10.51	12.50	14.27	15.89	17.36	18.53	19.86	20.23
20	10.51	12.58	14.49	16.11	17.65	18.98	20.15	20.74
21	10.37	13.31	14.56	16.40	17.87	19.27	20.52	21.11
22	10.22	12.58	14.56	16.47	18.02	19.49	20.81	21.48
23	9.93	12.43	14.56	16.40	18.17	19.71	21.11	21.70
24	9.63	12.21	14.34	16.40	18.24	19.78	21.26	21.99
25	9.19	11.91	14.27	16.25	18.17	19.78	21.33	22.06
26	8.68	11.47	13.97	16.11	17.87	19.78	21.33	21.99
27	8.16	11.03	13.53	15.81	17.80	19.56	21.26	21.99
28	7.51	10.51	13.09	15.44	17.43	19.34	21.11	21.84
29	6.77	9.86	12.58	15.00	17.14	19.12	20.89	21.62
30	5.96	9.12	11.91	14.42	16.70	18.68	20.52	21.33

Table 22.10: Ratings for V-Belts in Kilowatt
Cross-section E

Belt Speed (m/s)	Equivalent Pitch Diameter d_e in mm					
	450	500	550	600	650	700 and over
0.5	1.40	1.47	1.54	1.62	1.69	1.77
1	2.43	2.65	2.87	2.94	3.09	3.24
2	4.34	4.78	5.15	5.44	5.66	5.88
3	6.03	6.69	7.21	7.65	8.02	8.38
4	7.58	8.46	9.19	9.78	10.22	10.74
5	9.05	10.15	11.03	11.77	12.36	13.02
6	10.44	11.69	12.80	13.68	14.49	15.07
7	11.77	13.32	14.49	15.51	16.40	17.14
8	13.02	14.78	16.11	17.28	18.31	19.05
9	14.12	16.11	17.72	18.98	20.15	21.11
10	15.22	17.43	19.12	20.59	21.85	22.95
11	16.25	18.61	20.59	22.20	23.61	24.71
12	17.21	19.78	21.92	23.68	25.15	26.40
13	18.02	20.81	23.17	25.08	26.69	28.02
14	18.84	21.85	24.35	26.40	28.10	29.57
15	19.56	22.80	25.45	27.65	29.49	31.04
16	20.15	23.61	26.60	28.83	30.82	32.44
17	20.74	24.42	27.36	29.86	31.99	33.76
18	21.18	25.08	28.24	30.89	33.10	35.01
19	21.55	25.60	28.97	31.77	34.13	36.72
20	21.77	26.11	29.71	32.58	35.08	37.22
21	21.99	26.48	30.23	33.17	35.97	38.17
22	22.06	26.77	30.74	33.90	36.70	38.98
23	21.99	27.07	31.04	34.42	37.29	39.72
24	21.92	27.07	31.33	34.79	37.88	40.38
25	21.71	26.99	31.48	35.08	38.25	40.89
26	21.25	26.92	31.48	35.30	38.54	41.26
27	20.74	26.62	31.41	35.38	38.69	41.56
28	20.15	25.89	31.18	35.30	38.83	41.78
29	19.49	25.74	30.89	35.08	38.76	41.78
30	18.61	25.08	30.45	34.79	38.54	41.70

Note 1: Belt speed is calculated using the pitch diameter and revolutions per second of one of the pulleys on the drive.

Note 2: If belt speeds are over 25 metres per second, the pulleys may require special construction or special material. They may also require dynamic balancing. Such applications should be referred to the manufacturer.

Recommended standard pulley pitch diameters, mm R-20 series (80 mm-2500 mm)

Diameter of larger pulley

$$D = d\frac{n}{N}\eta$$

D, diameter of larger pulley, mm

d, diameter of smaller pulley, mm

n, rpm of smaller pulley

N, rpm of larger pulley

$\eta \approx 0.98$, efficiency (assumed)

Table 22.11: Selection of Centre Distance, C

Speed ratio, $i = \frac{D}{d}$	1	2	3	4	5	6 to 9
Recommended $\frac{C}{D}$ ratio	1.5	1.2	1.0	0.95	0.9	0.85

$$C_{min} = 0.55\,(D + d) + t$$

$$C_{max} = 2\,(D + d)$$

Minimum allowance for the adjustment of the centres for two transmission pulleys:

Lower limiting value = Nominal centre distance minus 1.5% of L

Higher limiting value = Nominal centre distance plus 3% of L

Initial tension:

In order to give the initial tension, the belts may be stretched to 0.5% to 1% of L

22.12: Dimensions of Standard V — Grooved Pulleys (Refer fig. [illegible])

Groove Cross Section	Pitch width I_p mm	Minimum distance down to pitch line b mm	Pulley pitch diameter d_p	Angle Tolerance $\pm 1/2°$	Minimum depth below pitch line h mm	Centre to centre distance of grooves e mm	Tole-rance on e^* mm	Edge of pulley to first groove centre f mm	Tole-rance on f mm
			Under 75 mm to 67 mm	32°					
A	11	3.3	**Recommended min. 75 min and under 125 mm	34°	8.7	15	± 0.3	10	+ 2
			125 mm and over	38°					− 1
			Under 125 mm to 117 mm	32°					
B	14	4.2	**Recommended min. 125 mm and under 220 mm	34°	10.8	19	± 0.4	12.5	+ 2
			200 mm and over	38°					− 1
			Under 200 mm to 175 mm	34°					
C	19	5.7	**Recommended min. 200 mm and under 300 mm	36°	14.3	25.5	± 0.5	17	+ 2
			300 mm and over	38°					− 1
			Under 355 mm to 300 mm	34°					
D	27	8.1	**Recommended min. 355 min and under 500 mm	36°	19.9	37	± 0.6	24	+ 3
			500 mm and over	38°					− 1
E	32	9.6			23.4	44.5	± 0.7	29	+ 4
									− 1

$W = (n-1)e + 2 \times f$

* The tolerances on dimension 'e' apply to the distance between the centres of any two grooves whether consecutive or not.

** The pitch diameter marked with two asterisks is the recommeneded minimum for a standard use, but the larges possible pulleys should be used for long belt life, provided that the belt speed does not exceed 25 metres per second.

The values given above have been calculated subject to certain approximations, from the following formulae :-

$b = 0.3\ I_p$ $e = 1.35\ I_p$ $f = 0.9\ I_p$ $h = 0.71\ I_p + 1$ (expressed in millimetres)

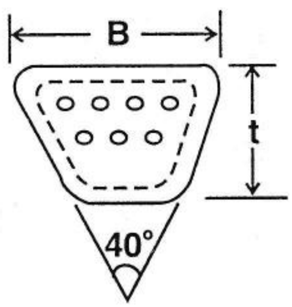


Fig. 22.1

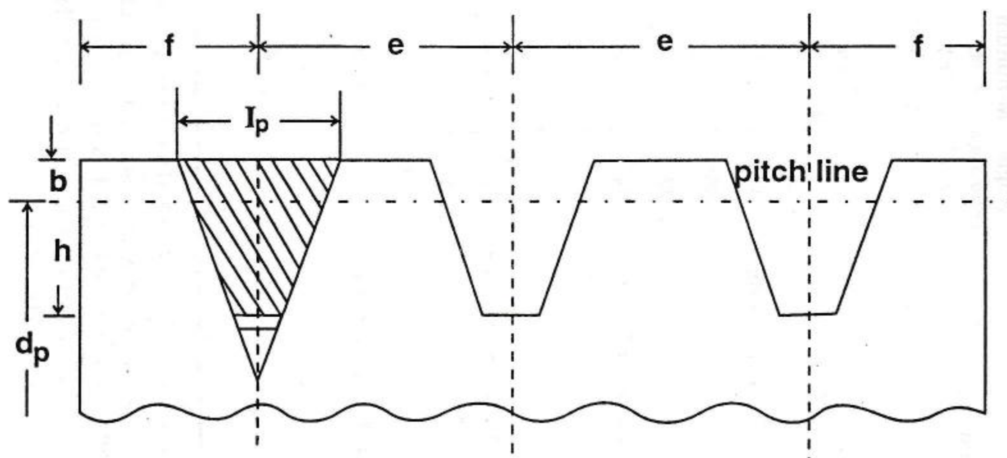
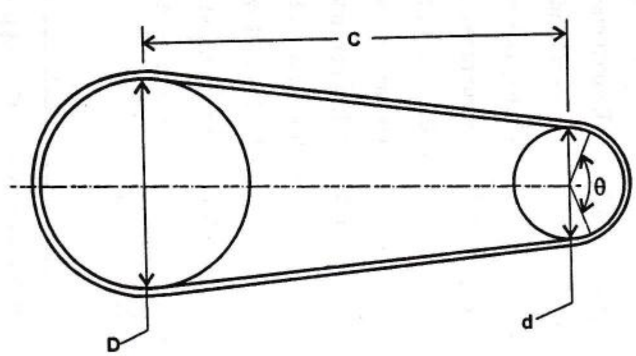


Fig. 22.2



V-Belt drive

Fig. 22.3

Symbols

A –
C –
C_p –
d_1 –
d_2 –
F –
F_c –
F_s –
F_t –
g –
i –
k –
K_n –
(K_n) –
K_s –

CHAPTER – 23

CHAIN DRIVES

Symbols : (with S.I. Units)

A	–	Projected bearing area, mm^2
C	–	Centre distance between sprockets, mm
C_p	–	Centre distance in multiples of pitches.
d_1	–	Pitch diameter of pinion-sprocket, mm.
d_2	–	Pitch diameter of wheel-sprocket, mm.
F	–	Load due to design power, N
F_c	–	Centrifugal tension, N
F_s	–	Tension due to sagging, N
F_t	–	Tangential force due to power transmission, N
g	–	Acceleration due to gravity, m/s^2
i	–	Transmission ratio or speed ratio.
k	–	Coefficient for sag.
K_n	–	Assumed factor of safety related with speed
(K_n)	–	Actual factor of safety
K_s	–	Service factor

K_1	–	Load factor
K_2	–	Factor for distance regulation.
K_3	–	Factor for centre distance of sprockets.
K_4	–	Factor for position of sprockets
K_5	–	Lubrication factor
K_6	–	Rating factor.
L	–	Length of chain, mm.
L_p	–	Length of chain in multiples of pitches
n_1	–	Speed of pinion-sprocket, rpm.
n_2	–	Speed of wheel-sprocket, rpm.
n'	–	Speed of pinion-sprocket, rps (i.e., $n_1/60$)
P_d	–	Design power, kW
P_r	–	Rated power, kW
p	–	Pitch of the chain, mm.
Q	–	Maximum operating load, N
(Q)	–	Breaking load for the chain, N
v	–	Velocity of chain, m/s
w	–	Weight of chain per metre length, N/m
Z_1	–	Number of teeth of pinion sprocket
Z_2	–	Number of teeth of wheel sprocket.
σ	–	Induced bearing stress, N/mm^2
(σ)	–	Allowable bearing stress, N/mm^2
Δ	–	Centre distance decrement, mm.

DESIGN PARTICULARS	EQUATIONS
Design power	$P_d = P_r \times K_s$ .... (23.1) $K_s = K_1 \cdot K_2 \cdot K_3 \cdot K_4 \cdot K_5 \cdot K_6$
Load applied in the chain due to design power	$F = \dfrac{P_d \times 1000}{v}$ .... (23.2)
Maximum operating load	$Q = F \times K_n < (Q)$ .... (23.3)
Induced bearing stress due to power transmission	$\sigma = \dfrac{F}{A} < (\sigma)$ .... (23.4)
Chain velocity	$v = \dfrac{Z_1 n_1 p}{60 \times 1000} = \dfrac{Z_2 n_2 p}{60 \times 1000}$ .... (23.5) $= \dfrac{\pi d_1 n_1}{60 \times 1000} = \dfrac{\pi d_2 n_2}{60 \times 1000}$
The empirical formula to determine pitch in mm	$p \le 10 \left[\dfrac{60.67}{n'} \right]^{2/3}$ .... (23.6) where n' = speed of small sprocket, rps ($n' = n_1/60$)
Pitch diameter of pinion-sprocket	$d_1 = \dfrac{p}{\sin\left(\dfrac{180^\circ}{Z_1}\right)}$ .... (23.7)
Pitch diameter of wheel-sprocket	$d_2 = \dfrac{p}{\sin\left(\dfrac{180^\circ}{Z_2}\right)}$ .... (23.8)
Transmission ratio	$i = \dfrac{Z_2}{Z_1} = \dfrac{n_1}{n_2}$ .... (23.9)

DESIGN PARTICULARS	EQUATIONS
Actual factor of safety (for checking)	$(K_n) = \frac{(Q)}{\Sigma F}$ where $\Sigma F = F_t + F_c + F_s$ .... (23.10)
	$F_t = \frac{P_r}{v}$; $F_c = \frac{w\,v^2}{g}$; $F_s = \frac{k.w.C}{1000}$
Approximate centre distance in multiples of pitches	$C_p = \frac{C_0}{p}$ .... (23.11)
	where C_0 is initially assumed centre distance
Length of chain in multiples of pitches (i.e., approximate number of links)	$L_p = 2\,C_p + \frac{Z_1 + Z_2}{2} + \frac{\left(\frac{Z_2 - Z_1}{2\,\pi}\right)^2}{C_p}$ .... (23.12)
	(to be corrected to even number)
Actual length of chain	$L = L_p \cdot p$ mm. .... (23.13)
Final centre distance corrected to even number of pitches	$C = \left(\frac{e + \sqrt{e^2 - 8m}}{4}\right) p$ .... (23.14)
	where $e = L_p - \frac{Z_1 + Z_2}{2}$
	$m = \left(\frac{Z_2 - Z_1}{2\,\pi}\right)^2$, constant
	(For the value of m, refer table 23.6)
Centre distance decrement (i.e., allowance) to provide initial sag	$\Delta = 1\,\%$ of C (i.e., 0.01 C) .... (23.15)

Table 23.1: Service Factor (K_s)

$$K_s = K_1 \cdot K_2 \cdot K_3 \cdot K_4 \cdot K_5 \cdot K_6$$

Load factor	K_1
Constant load	1.0
Variable load or load with mild shocks	1.25
Variable load or load with heavy shocks	1.5
Factor for distance regulation	K_2
Adjustable supports	1.0
Drive using idler sprocket	1.1
Fixed centre distance	1.25
Factor for centre distance of sprockets	K_3
$\frac{L_p}{Z_1 + Z_2} > 1$ or $C_p < 25p$	1.25
$\frac{L_p}{Z_1 + Z_2} = 1.5$ or $C_p = 30$ to 50 p	1
$\frac{L_p}{Z_1 + Z_2} \geq 2.0$ or $C_p = 60$ to 80 p	0.8
Factor for the position of sprockets	K_4
Inclination of the line joining the centres of the sprockets to the horizontal upto 60°	1
more than 60°	1.25
Lubrication factor	K_5
Continuous (oil-bath or forced lubrication)	0.8
Drop-lubrication	1.0
Periodic	1.5
Rating factor	K_6
Single shift of 8 hours a day	1.0
Double shift of 16 hours a day	1.25
Continuous running	1.5

Table 23.2

Preferred transmission ratio, i

1 1.12 1.25 1.4 1.6 1.8 2 2.25 3.15 4 4.5 5 5.6 6.3 7.1

Recommended Z_1

Transmission ratio, i	1-2	2-3	3-4	4-5	5-7
Number of teeth on sprocket, Z_1	30-27	27-25	25-23	23-21	21-17

Where space is problem, Z_1 minimum $= 7$

Number of teeth on sprocket wheel, Z_2.

$Z_2 = i\, Z_1$

$Z_{2\,max} = 100$ to 120

Note : When Z_2 is very large, chain slips off the sprocket for a smallpull.

Table 23.3: Minimum Value of Factor of Safety, K_n (for $K_s = 1$ & $Z_1 = 15$ to 30)

	Speed of rotation of small sprocket, rpm										
n_1	< 50	200	400	600	800	1000	1200	1600	2000	2400	2800
K_n	7.0	7.8	8.55	9.35	10.2	11.0	11.7	13.2	14.8	16.3	18.0

Table 23.4: Allowable Bearing Stress, (σ), N/mm^2 (for $K_s = 1$ & $Z_1 = 15$ to 30)

	Speed of rotation of small sprocket, rpm										
n_1	< 50	200	400	600	800	1000	1200	1600	2000	2400	2800
(σ)	34	31	28	26	24	22	21	18	16	15	14

Table 23.5: Coefficient for Sag, k

Coefficient for sag	Position of chain drive			
	horizontal	upto 40°	more than 40°	vertical
k	6	4	2	1

Table 23.6: Value of $m = \left(\dfrac{Z_2 - Z_1}{2\pi} \right)^2$

$Z_2 - Z_1$	m	$Z_2 - Z_1$	m	$Z_2 - Z_1$	m	$Z_2 - Z_1$	m
1	0.025	26	17.12	51	66.0	76	146.3
2	0.101	27	18.47	52	68.5	77	150.2
3	0.228	28	19.86	53	71.2	78	154.1
4	0.405	29	21.3	54	73.9	79	158.1
5	0.633	30	22.8	55	76.6	80	162.1
6	0.912	31	24.3	56	79.4	81	166.2
7	1.24	32	25.9	57	82.3	82	170.3
8	1.62	33	27.6	58	85.2	83	174.5
9	2.05	34	29.3	59	88.2	84	178.7
10	2.53	35	31.0	60	91.2	85	183.0
11	3.07	36	32.8	61	94.3	86	187.3
12	3.65	37	34.7	62	97.4	87	191.7
13	4.28	38	36.6	63	100.5	88	196.2
14	4.97	39	38.5	64	103.8	89	200.6
15	5.70	40	40.5	65	107.0	90	205.2
16	6.49	41	42.6	66	110.3	91	209.8
17	7.32	42	44.7	67	113.7	92	214.4
18	8.21	43	46.8	68	117.1	93	219.1
19	9.14	44	49.0	69	120.6	94	223.8
20	10.13	45	51.3	70	124.1	95	228.6
21	11.17	46	53.6	71	127.7	96	233.4
22	12.26	47	56.0	72	131.3	97	238.3
23	13.40	48	58.4	73	135.0	98	243.3
24	14.59	49	60.8	74	138.7	99	248.3
25	15.83	50	63.3	75	142.9	100	253.3

Table 23.7: Chain Nos. with prefix R & B denote simplex, DR & DB denote duplex and TR & TB denote triplex roller and bush chains.

A. Roller Chains

Chain No. ISO/ DIN	Chain No. Rolon	Pitch p	Roller dia max D_r	Width between Inner Plates min b	Pin Body dia max D_p	Plate Depth max G	Trans-verse pitch p_t	Overall over joint max A_1, A_2 A_3	Bearing Area A	Weight per Meter w	Brea-king Load min (Q)
		mm	mm	mm	mm	mm	mm	mm	mm^2	N	N
08B-2	DR1278	12.7	8.51	8.00	4.45	11.70	13.92	34.40	100	13.2	31800
08B-3	TR1278	12.7	8.51	8.00	4.45	11.70	13.92	48.30	150	19.5	45400
	R1278H	12.7	8.51	8.00	4.45	11.70	–	22.50	54	7.5	21000
	R1548	15.875	7.75	4.90	3.68	9.90	–	12.80	26	2.9	8200
	R1564	15.875	10.16	6.65	5.08	14.30	–	20.10	51	8.0	22700
10A-1	R50	15.875	10.16	9.55	5.08	15.05	–	25.90	70	10.1	22200
10A-2	DR50	15.875	10.16	9.55	5.08	15.05	18.11	44.00	140	17.8	44400
10A-3	TR50	15.875	10.16	9.55	5.08	15.05	18.11	62.00	210	30.2	66600
10B-1	R1595	15.875	10.16	9.85	5.08	14.30	–	23.50	67	9.1	22700
10B-2	DR1595	15.875	10.16	9.85	5.08	14.30	16.59	39.90	134	18.2	45400
10B-3	TR1595	15.875	10.16	9.85	5.08	14.30	16.59	56.40	201	27.3	68100
12A-1	R60	19.05	11.90	12.70	5.95	17.95	–	29.40	105	14.7	32000
12A-2	DR60	19.05	11.90	12.70	5.95	17.95	22.78	52.60	210	29.0	63600
12A-3	TR60	19.05	11.90	12.70	5.95	17.95	22.78	75.40	315	42.8	95400
12B-1	R1911	19.05	12.07	11.70	5.72	15.95	–	26.70	89	11.7	29500
12B-2	DR1911	19.05	12.07	11.70	5.72	15.95	19.46	46.30	178	23.6	59000
12B-3	TR1911	19.05	12.07	11.70	5.72	15.95	19.46	65.80	267	35.4	88500
16A-1	R80	25.40	15.88	15.90	7.92	24.10	–	37.50	179	25.7	57000
16A-2	DR80	25.40	15.88	15.90	7.92	24.10	29.29	66.80	358	50.1	114000
16A-3	TR80	25.40	15.88	15.90	7.92	24.10	29.29	96.10	537	74.7	171000
16B-1	R2517	25.40	15.88	15.90	8.27	21.00	–	40.40	210	27.0	65000
16B-2	DR2517	25.40	15.88	15.90	8.27	21.00	31.88	72.40	420	53.0	130000
16B-3	TR2517	25.40	15.88	15.90	8.27	21.00	31.88	104.40	630	78.5	195000
20A-1	R100	31.75	19.05	19.10	9.53	30.10	–	47.20	262	38.0	88500
20A-2	DR100	31.75	19.05	19.10	9.53	30.10	35.76	83.10	524	76.0	177000

Chain No. ISO/DIN	Chain No. Rolon	Pitch p	Roller dia max D_r	Width between Inner Plates min b	Pin Body dia max D_p	Plate Depth max G	Trans-verse pitch p_t	Overall over joint max A_1, A_2, A_3	Bearing Area A	Weight per Meter w	Brea-king Load min (Q)
		mm	mm	mm	mm	mm	mm	mm	mm^2	N	N
20A-3	TR100	31.75	19.05	19.10	9.53	30.10	35.76	119.10	786	112.0	265500
	R100H	31.75	19.05	19.10	9.53	30.10	–	50.20	277	46.0	100000
	DR100H	31.75	19.05	19.10	9.53	30.10	39.10	89.20	554	92.0	200000
	TR100H	31.75	19.05	19.10	9.53	30.10	39.10	130.00	831	136.0	300000
20B-1	R3119	31.75	19.05	19.60	10.17	25.60	–	47.60	258	36.5	95000
20B-2	DR3119	31.75	19.05	19.60	10.17	25.60	36.45	84.10	516	72.0	190000
20B-3	TR3119	31.75	19.05	19.60	10.17	25.60	36.45	121.10	774	119.0	285000
24A-1	R120	38.10	22.23	25.50	11.10	36.20	–	57.40	393	54.0	127000
24A-2	DR120	38.10	22.23	25.50	11.10	36.20	45.44	102.90	786	108.0	254000
24A-3	TR120	38.10	22.23	25.50	11.10	36.20	45.44	148.30	1179	161.0	381000
B. Bush Chains											
04C-1	B25	6.35	3.30	3.18	2.31	5.75	–	11.60	11	1.4	3506
	B25H	6.35	3.30	3.18	2.31	5.75	–	12.60	12	1.6	4500
	B748	7.77	4.57	4.80	3.15	7.35	–	14.00	24	2.2	10000
06C-1	B35	9.525	5.08	4.77	3.59	8.65	–	15.10	27	4.0	10300
06C-2	DB35	9.525	5.08	4.77	3.59	8.65	10.15	27.30	54	7.1	20500
06C-3	TB35	9.525	5.08	4.77	3.59	8.65	10.15	35.80	81	10.1	23700
	B975	9.525	5.00	7.50	3.54	9.20	–	17.50	39	5.3	13000
	B995	9.525	6.00	9.52	4.45	9.75	–	19.30	58	6.3	12000
	B995H	9.525	6.00	8.00	4.45	9.75	–	20.00	58	7.6	15500
	B980	9.525	6.00	8.00	4.45	9.75	–	21.50	58	8.0	18000
	DB957	9.525	6.35	5.75	4.45	9.55	–	26.60	76	6.6	17300
	B1511	15.875	10.07	11.40	7.00	16.75	–	34.00	149	20.8	47500
	B1278	12.70	6.25	7.75	4.45	11.70	–	20.50	50	6.0	18200
	B1595	15.875	7.08	9.85	5.08	14.30	–	23.50	67	7.2	22700
	B1911	19.05	8.41	11.70	5.72	15.95	–	26.70	89	18.7	29500
	B2517	25.40	11.63	17.02	8.27	21.00	–	40.40	210	21.8	65000

SPECIFICATION OF CHAINS

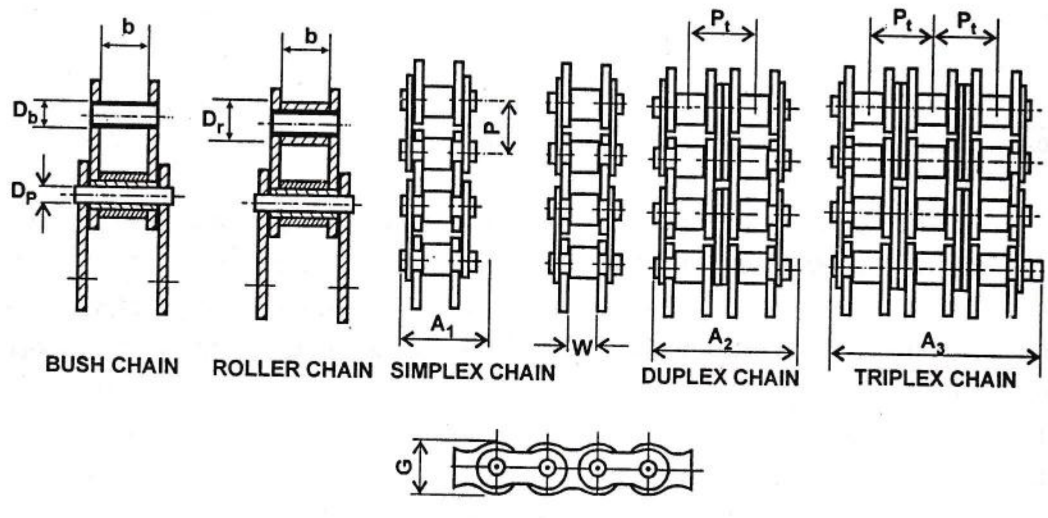
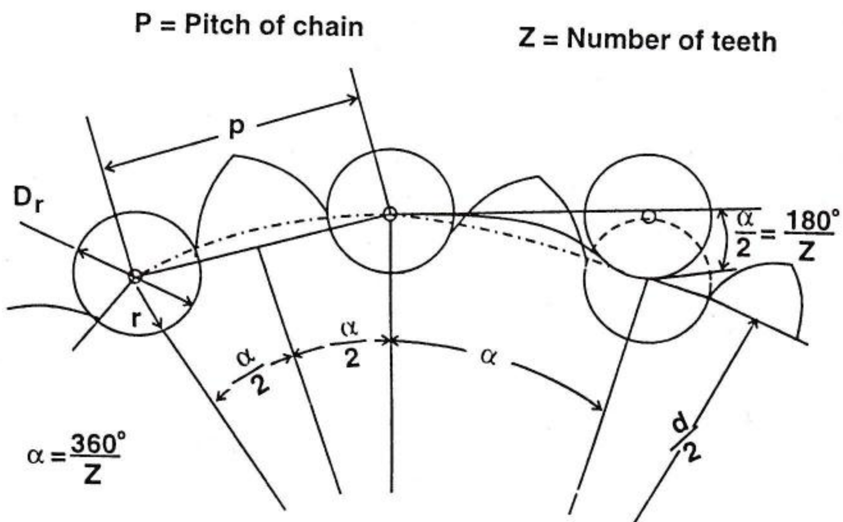


Fig. 23.1



d = Pitch circle diameter of sprocket $= \dfrac{p}{\sin(\alpha/2)}$

$= \dfrac{p}{\sin(180/Z)}$

Fig. 23.2: Action of chain engaging sprocket teeth

CHAPTER – 24

WIRE ROPES

Symbols : (with S.I. Units)

A	–	Net cross sectional area of the rope, mm^2
a	–	Acceleration of the rope and load, m/s^2
D_{min}	–	Minimum diameter of drum or pulley, mm.
d	–	Diameter of rope, mm.
d_w	–	Diameter of wire, mm.
E	–	Modulus of elasticity = 2.1×10^5 N/mm^2
E′	–	Modified modulus of elasticity $= (3/8)\,E = 0.8 \times 10^5$ N/mm^2
F_a	–	Force due to acceleration, N
F_b	–	Bending load, N
F_{st}	–	Load at starting, N
F_t	–	Direct tensile load, N

g	–	Acceleration due to gravity, m/s^2
h	–	Height of slack, mm
i	–	Number of wires in the rope
K_d	–	Duty factor
l	–	Length of rope, mm.
n	–	Factor of safety
P	–	Breaking strength of rope, N
P_d	–	Design load
P_r	–	Rated (i.e. specified) load, N; $(P_r = W_1 + W_2)$
t	–	Time for acceleration, s
v	–	Rope velocity, m/s
W_1	–	Weight or load to be lifted, N
W_2	–	Weight of bucket, crane hook, lift cabin etc.
w	–	Weight of the rope per metre length, N/m
σ_a	–	Stress due to acceleration, N/mm^2
σ_b	–	Bending stress, N/mm^2
σ_{st}	–	Stress at starting, N/mm^2
σ_t	–	Tensile stress, N/mm^2
σ_u	–	Ultimate stress, N/mm^2

DESIGN DATA

DESIGN PARTICULARS	EQUATIONS
Design load	$P_d = P_r \times n \times K_d = (W_1 + W_2) \times n \times K_d$ .... (24.1)
Net cross-sectional area of rope	$A = \frac{P_d}{\sigma_u} \simeq 0.4 \times \frac{\pi}{4} d^2 = \frac{\pi}{4} d_w^2\, i$ .... (24.2)
Diameter of the rope	$d \simeq 1.5\, d_w \sqrt{i}$ .... (24.3)
Effective loads acting on the rope:	
(a) During normal working	$F = F_t + F_b \le \frac{P}{n}$ .... (24.4)
(b) During acceleration of load	$F = F_t + F_b + F_a \le \frac{P}{n}$ .... (24.5)
(c) During starting	$F = F_{st} + F_b \le \frac{P}{n}$ .... (24.6)
	where $F_t = P_r + (w \times l)$
	$F_b = A \cdot \frac{d_w}{D_{min}} E'$
	$F_a = F_t \frac{a}{g}$ where $a = \frac{v}{t}$
	$F_{st} = 2\, F_t$ (for no slack condition)
	$= F_t \left[1 + \sqrt{1 + \frac{2\, ah\, E'}{\sigma_t \cdot lg}} \right]$ (for there is a slack)

DESIGN PARTICULARS	EQUATIONS
Resultant induced stress:	
(a) During normal working	$\sigma = \sigma_t + \sigma_b \le \dfrac{\sigma_u}{n}$ .... (24.7)
(b) During acceleration of load	$\sigma = \sigma_t + \sigma_b + \sigma_a \le \dfrac{\sigma_u}{n}$ .... (24.8)
(c) During starting	$\sigma = \sigma_{st} + \sigma_b \le \dfrac{\sigma_u}{n}$ .... (24.9)
	where $\sigma_t = \dfrac{F_t}{A}$
	$\sigma_b = \dfrac{F_b}{A}$ (or) $\sigma_b = \dfrac{d_w}{D_{min}} \times E'$
	$\sigma_a = \dfrac{F_a}{A}$
	$\sigma_{st} \approx 2\,\sigma_t$ (for no slack)
	$= \sigma_t \left[1 + \sqrt{1 + \dfrac{2ah\,E'}{\sigma_t \cdot lg}} \right]$ (for there is a slack)
	$E' = \dfrac{3}{8} \times E = 0.8 \times 10^5\ \mathrm{N/mm^2}$

Table 24.1: General Properties of Rope

(Approximate values)

Type of rope	Wire diameter 'd_w' (mm)	Area of rope 'A' (mm^2)	Ultimate strength 'P' (N)	Drum or pulley diameter (D)		Applications
				Minimum (mm)	Optimum (mm)	
6×7	0.11 d	$0.38\ d^2$	$480\ d^2$	45 d	72 d	Mines, Trame ways.
6×19	0.07 d	$0.4\ d^2$	$510\ d^2$	30 d	45 d	Hoisting ropes.
6×19	0.07 d	$0.4\ d^2$	$510\ d^2$	60 d	100 d	Cargo cranes, quaries, mines' hoist.
6×37	0.041 d	$0.4\ d^2$	$480\ d^2$	18 d	27 d	Cranes, elevators
8×19	0.05 d	$0.35\ d^2$	$440\ d^2$	21 d	31 d	Extra flexible hoisting rope.

d = Diameter of rope in millimetres.

Table 24.2

Nature of duty	Light	Medium	Heavy	Very Heavy
Approximate number of switching on operations per hour	60	120	240	300 – 720

Normal operating speeds of cranes

1. Hoisting speed – 25 to 30 m/min.
2. Trolly travel speed – 35 to 50 m/min.
3. Bridge travel speed – 100 to 120 m/min.

Table 24.3

No. of bends	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\frac{D_{min}}{d}$	16	20	23	25	26.5	28	30	31	32	33	34	35	36	37	37.5	38

Table 24.4

Type of Duty	Factor of safety (n)	Duty factor (K_d)	$\left(\frac{D_{min}}{d}\right)$	Average life		Applications
				Running hours per day	Total life in hours	
For cranes and Hoists						
Light	3 to 5	1.0	15 to 19	0.5	3000	Fixed guys, auxiliary applications
Medium	4 to 6	1.2	17 to 23	1.5	10,000	Hoisting systems, Lifts, cranes
Heavy	4 to 8	1.4	20 to 25	3	28,000	Cranes and hoists in general hoists blocks.
Very Heavy	6 to 10	1.6	22 to 27	over 6	40,000	Hot ladle cranes
For mining ropes	10	1.5	100	–	–	Mining Installations

Specifica

Diamete of rope (mm) (d)
d
10
12
14
16
18
20
22
24
25
28
32
35
38
41
44
48
54

Table 24.5: Group 6×7 Wire Ropes

Specifications of wire-ropes.

Diameter of rope (mm)	Approximate weight of rope per metre length N/m	Nominal Breaking strength of rope (P) in KN	
		Tensile strength of wire (1600 to 1750 N/mm^2)	Tensile strength of wire (1750 to 1900 N/mm^2)
(d)	(w)	(σ_u)	(σ_u)
d	**$0.035\ d^2$**	**$P = 0.53\ d^2$**	**$P = 0.6\ d^2$**
10	3.5	53	62
12	5.1	76	86
14	6.9	104	118
16	9.0	136	154
18	11.3	172	195
20	14.0	212	242
22	16.9	256	291
24	20.2	305	346
25	21.9	331	375
28	27.4	416	471
32	35.8	543	614
35	42.9	649	735
38	50.5	765	866
41	58.8	891	1009
44	67.8	1026	1162
48	80.6	1221	1382
54	102.1	1546	1750

Table 24.6: Group 6 × 19 Wire Ropes

Specifications of wire-ropes.

Diameter of rope (mm) (d)	Approx weight of rope per metre length (N/m) (w)	Nominal Breaking strength of rope (P) is KN	
		For tensile strength of wire (1600 to 1750 N/mm^2) (σ_u)	For tensile strength of wire (1750 to 1900 N/mm^2) (σ_u)
d	**$0.0375\ d^2$**	**$P = 0.54\ d^2$**	**$P = 0.59\ d^2$**
10	4.4	66	72
12	5.4	86	94
14	7.6	109	119
16	9.4	134	147
18	12.5	193	211
20	14.7	226	246
22	18.4	259	284
24	21.3	300	330
25	24.1	340	376
29	30.5	432	472
32	37.6	533	584
35	45.5	645	706
38	54.3	767	843
41	63.7	904	991
44	73.8	1047	1148
48	84.8	1199	1321
51	96.4	1372	1504
54	108.9	1544	1697
57	119.8	1689	1825
64	148.2	2238	2345
70	180.4	2561	2864

Table 24.7: Group 6×37 Wire-ropes

Specifications of wire-ropes.

Diameter of rope (mm) (d)	Approx weight of rope per metre length (N/m) (w)	Nominal Breaking strength of rope (P) in KN: For tensile strength of wire (1600 to 1750 N/mm^2) (σ_u)	Nominal Breaking strength of rope (P) in KN: For tensile strength of wire (1750 to 1900 N/mm^2) (σ_u)
d	**$0.038\ d^2$**	**$P = 0.51\ d^2$**	**$P = 0.55\ d^2$**
10	4.5	62	68
12	6.0	81	89
14	7.4	103	113
16	9.2	127	139
18	13.2	183	200
20	15.8	214	235
22	18.1	246	269
24	21.0	284	310
25	23.7	325	356
29	29.9	406	447
32	36.9	503	554
35	44.8	610	671
38	53.2	726	798
41	62.5	853	935
44	72.5	991	1087
48	83.2	1138	1250
51	94.6	1291	1422
54	106.8	1463	1605
57	119.8	1636	1798
64	147.9	2022	2215
70	178.8	2449	2682

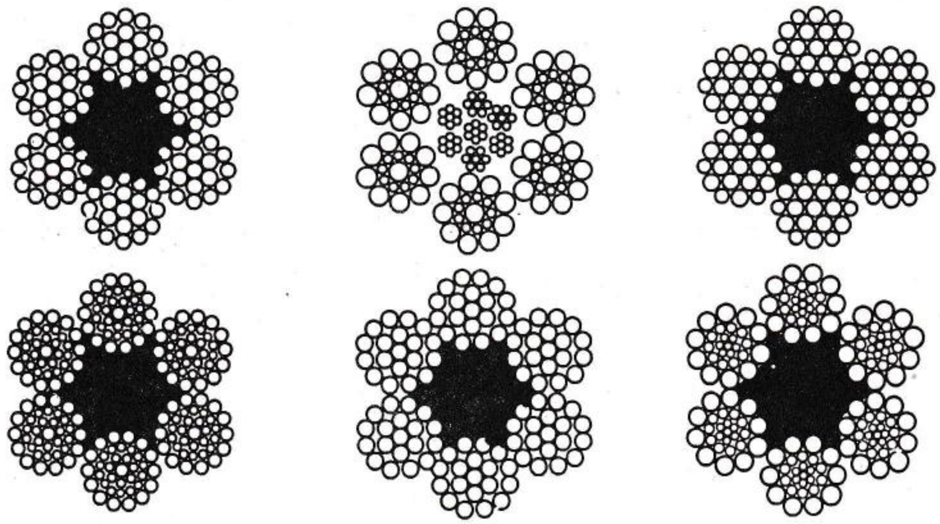
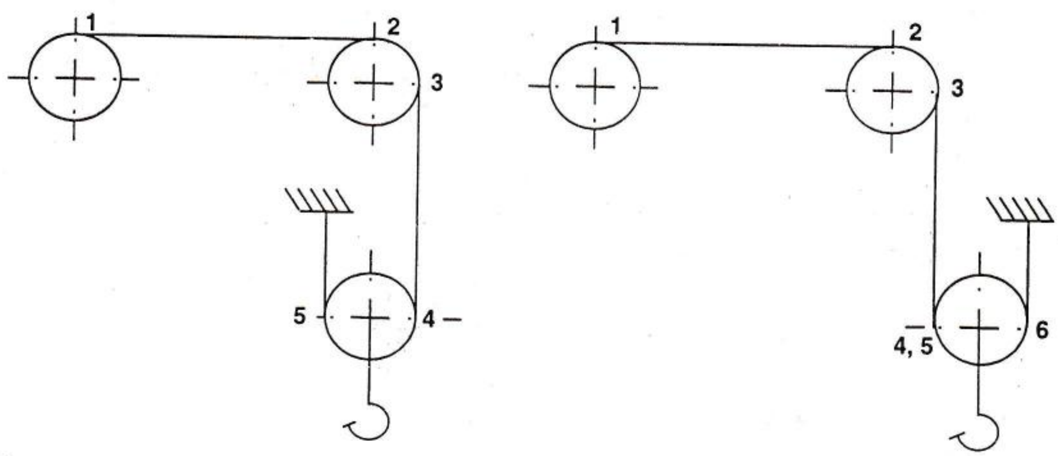


Fig. 24.1: Steel wire ropes of various constructions



Same side bending
No. of bends = 5

Reverse bending
No. of bends = 6

Fig. 24.2

CHAPTER – 25

SPUR AND HELICAL GEAR DRIVES

Symbols : (with S.I. Units)

b	–	Face width of the tooth, mm
C	–	Centre distance between the axes of pinion and gear, mm
c	–	Bottom clearance, mm
d_1	–	Pitch circle diameter of pinion, mm
d_2	–	Pitch circle diameter of gear, mm
d_{a1}	–	Tip circle diameter of pinion, mm
d_{a2}	–	Tip circle diameter of gear, mm
d_{f1}	–	Root circle diameter of pinion, mm
d_{f2}	–	Root circle diameter of gear, mm.
E	–	Equivalent Young's modulus, N/mm^2
E_1	–	Young's modulus of pinion material, N/mm^2
E_2	–	Young's modulus of gear material, N/mm^2
h	–	Tooth height, mm
h_a	–	Addendum, mm.
h_f	–	Dedendum, mm
i	–	Transmission ratio or gear ratio
k	–	Load concentration factor
k_d	–	Dynamic load factor

M_t – Nominal twisting moment, N-mm

$[M_t]$ – Design twisting moment, N-mm

m – Module (for spur gears), mm

m_n – Normal module (for helical gears), mm

m_t – Transverse module (for helical gears), mm

n_1 – Speed of pinion, rpm

n_2 – Speed of gear, rpm

P – Power transmitted, kW

p_c – Circular pitch, mm; $\left(p_c = \frac{\pi d}{Z}\right)$

p_d – Diametral pitch; $\left(p_d = \frac{Z}{d}\right)$

y – Form factor

y_v – Form factor for virtual number of teeth

Z_1 – Number of teeth of pinion

Z_2 – Number of teeth of gear

Z_v – Virtual number of teeth.

α – Pressure angle of gear ($\alpha = 20°$, Standard value)

β – Helix angle for helical and herring bone gears, deg.

σ_b – Induced bending stress, N/mm^2

$[\sigma_b]$ – Design bending stress, N/mm^2

σ_c – Induced compressive stress, N/mm^2

$[\sigma_c]$ – Design compressive stress, N/mm^2

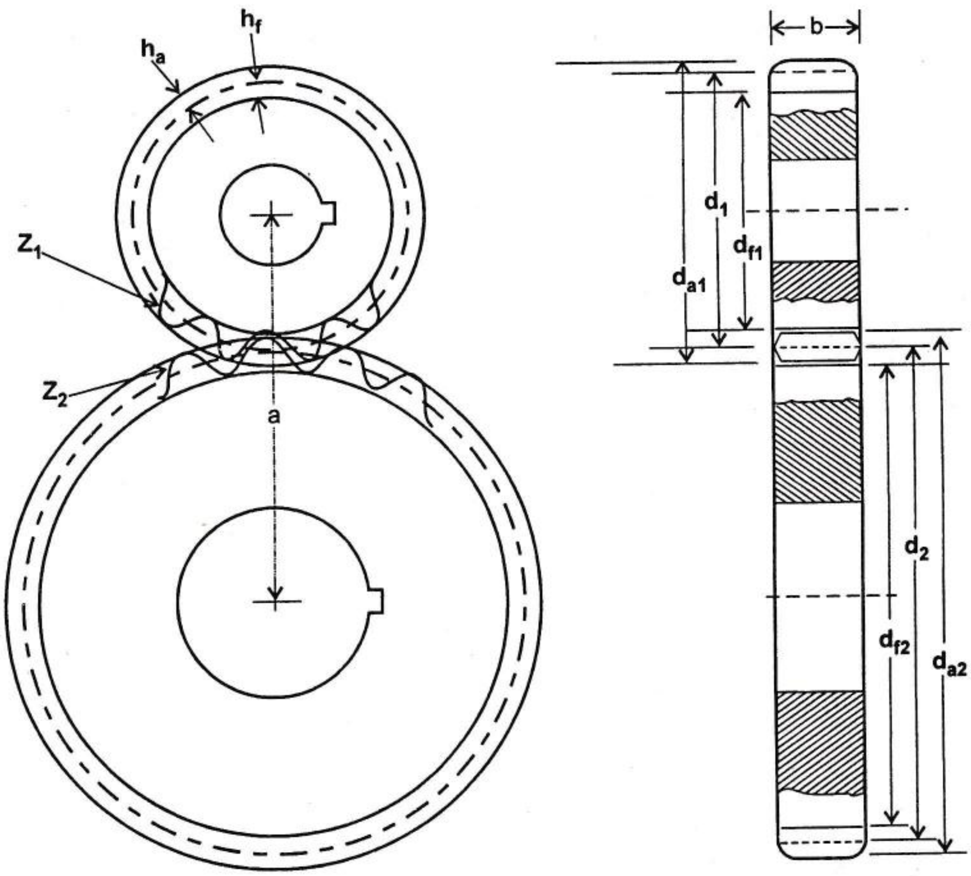
ψ – Ratio of face width to centre distance, $\left(\psi = \frac{b}{C}\right)$

ψ_m – Ratio of face width to module, $\left(\psi_m = \frac{b}{m} \text{ or } \frac{b}{m_n}\right)$

ϕ – Progression ratio or step ratio, $\phi = \left(\frac{N_{max}}{N_{min}}\right)^{\frac{1}{r-1}}$

DESIGN PARTICULARS	EQUATIONS
Spur Gears	
Nominal twisting moment transmitted by pinion	$M_t = \frac{60 \times 10^6 \times P}{2 \pi n_1}$ N-mm .... (25.S1) (where P in kW and n_1 in rpm)
Design twisting moment	$[M_t] = M_t \cdot k \cdot k_d$ .... (25.S2) (Assume $k \cdot k_d = 1.3$ initially)
Centre distance based on surface compressive strength of weaker gear	$C \geq (i \pm 1) \sqrt[3]{\left(\frac{0.74}{[\sigma_c]}\right)^2 \frac{E\,[M_t]}{i\,\psi}}$ .... (25.S3) S3 25.5
Module based on bending strength of weaker gear	$m \geq 1.26 \sqrt[3]{\frac{[M_t]}{y\,[\sigma_b]\,\psi_m\,Z_1}}$ .... (25.S4)
Induced compressive stress on gear tooth	$\sigma_c = 0.74 \left(\frac{i \pm 1}{C}\right) \sqrt{\left(\frac{i \pm 1}{ib}\right) E\,[M_t]} \leq [\sigma_c]$ .... (25.S5)
Induced bending stress on gear tooth	$\sigma_b = \frac{(i \pm 1)\,[M_t]}{Cm\,by} \leq [\sigma_b]$ .... (25.S6) 28.6.
Number of teeth	$Z_1 = \frac{2C}{m\,(i+1)}$ & $Z_2 = iZ_1$ .... (25.S7) 28.7
Centre distance related with number of teeth	$C = \frac{m\,(Z_1 + Z_2)}{2}$ .... (25.S8)
Addendum for standard teeth	$h_a = f_0\,m = 1m$ .... (25.S9)

DESIGN PARTICULARS	EQUATIONS		
Dedendum for standard teeth	$h_f = f_0\, m + c = 1.25\ m$	.... (25.S10)	
Tooth height	$h = h_a + h_f = 2.25\ m$	.... (25.S11)	
Height factor	$f_0 = 1$ for standard teeth	.... (25.S12)	
	$= 0.8$ for stub teeth		
Bottom clearance	$c = 0.25\ m$ for standard teeth	.... (25.S13)	
	$= 0.3\ m$ for stub teeth		28.10
Pitch circle diameter or reference diameter	$d_1 = m\, Z_1$ & $d_2 = m\, Z_2$	.... (25.S14)	
Tip circle diameter	$d_{a1} = d_1 + 2h_a$ & $d_{a2} = d_2 + 2h_a$	.... (25.S15)	25.6
Root circle diameter	$d_{f1} = d_1 - 2\, h_f$ & $d_{f2} = d_2 - 2\, h_f$	.... (25.S16)	
Transmission ratio	$i = \dfrac{Z_2}{Z_1} = \dfrac{d_2}{d_1} = \dfrac{n_1}{n_2}$	.... (25.S17)	
Circular pitch	$p_c = \dfrac{\pi\, d}{Z}$	.... (25.S18)	17
Diametral pitch	$p_d = \dfrac{Z}{d}$	.... (25.S19)	
Progression ratio for the output speeds of gear box No. of teeth required for pinion in order to avoid interference $Z_1 = \dfrac{2A_w}{i\left[\left\{1+\frac{1}{i}\left(\frac{1}{i}+2\right)\sin^2\alpha\right\}^{1/2}-1\right]}$	$\phi = \left(\dfrac{N_{max}}{N_{min}}\right)^{\frac{1}{r-1}}$	.... (25.S20)	
	where N_{max} – Maximum output speed		
	N_{min} – Minimum output speed		
	r – Number of speeds.		



Spur - gear drive

Fig. 25.1

DESIGN PARTICULARS	EQUATIONS
Helical & Herring bone Gears	
Nominal twisting moment transmitted by pinion	$M_t = \dfrac{60 \times 10^6 \times P}{2\,\pi\, n_1}$ .... (25.H1)
Design twisting moment	$[M_t] = M_t\, k.k_d$ .... (25.H2) 25.5 (Assume $k.k_d = 1.3$ initially)
Centre distance based on surface compressive strength of weaker gear	$C \geq (i \pm 1)\ \sqrt[3]{\left(\dfrac{0.7}{[\sigma_c]}\right)^2 \dfrac{E\,[M_t]}{i\,\psi}}$ .... (25.H3) 53
Module based on bending strength of weaker gear	$m_n \geq 1.15 \cos\beta\ \sqrt[3]{\dfrac{[M_t]}{y_v\,[\sigma_b]\,\psi_m\, Z_1}}$ .... (25.H4)
Induced compressive stress on gear tooth	$\sigma_c = 0.7\left(\dfrac{i \pm 1}{C}\right)\sqrt{\left(\dfrac{i \pm 1}{ib}\right) E\,[M_t]} \leq [\sigma_c]$ .... (25.H5)
Induced bending stress on gear tooth	$\sigma_b = \dfrac{0.7\,(i \pm 1)\,[M_t]}{Cb\, m_n\, y_v} \leq [\sigma_b]$ (For Helical) .... (25.H6)
	$= \dfrac{0.85\,(i \pm 1)\,[M_t]}{Cb\, m_n\, y_v} \leq [\sigma_b]$ (For Herring bone) ... (25.H7)
Number of teeth	$Z_1 = \dfrac{2C \cos\beta}{m_n\,(i+1)}$ & $Z_2 = i\, Z_1$ .... (25.H8)

DESIGN PARTICULARS	EQUATIONS
	$C = \dfrac{m_n}{}\left(\dfrac{Z_1+Z_2}{}\right)$ .... (25.H9)

Number of teeth	$Z_1 = \frac{2C \cos \beta}{m_n (i+1)}$ & $Z_2 = i Z_1$	.... (25.H8)

DESIGN PARTICULARS	EQUATIONS	
Centre distance related with number of teeth	$C = \frac{m_n}{\cos \beta}\left(\frac{Z_1 + Z_2}{2}\right)$	.... (25.H9)
Transverse module	$m_t = \frac{m_n}{\cos \beta}$	.... (25.H10)
Addendum	$h_a = 1\ m_n$	.... (25.H11)
Dedendum	$h_f = 1.25\ m_n$	.... (25.H12)
Tooth height	$h = h_a + h_f = 2.25\ m_n$	.... (25.H13)
Bottom clearance	$c = 0.25\ m_n$	.... (25.H14)
Pitch circle diameter or reference diameter	$d_1 = \frac{m_n Z_1}{\cos \beta}$ & $d_2 = \frac{m_n Z_2}{\cos \beta}$	.... (25.H15)
Tip circle diameter	$d_{a1} = d_1 + 2h_a$ & $d_{a2} = d_2 + 2h_a$	.... (25.H16)
Root circle diameter	$d_{f1} = d_1 - 2h_f$ & $d_{f2} = d_2 - 2h_f$	.... (25.H17)
Transmission ratio	$i = \frac{Z_2}{Z_1} = \frac{d_2}{d_1} = \frac{n_1}{n_2}$	.... (25.H18)
Virtual number of teeth	$Z_{v1} = \frac{Z_1}{\cos^3 \beta}$ & $Z_{v2} = \frac{Z_2}{\cos^3 \beta}$	.... (25.H19)
Helix angle	$\beta = 8°$ to $25°$ (For helical gears) $= 25°$ to $40°$ (For herringbone gears)	.... (25.H20)

Note : In equations 25.S3 to 25.S6 and 25.H3 to 25.H7, take $(i + 1)$ for external gearing and $(i - 1)$ for internal gearing.

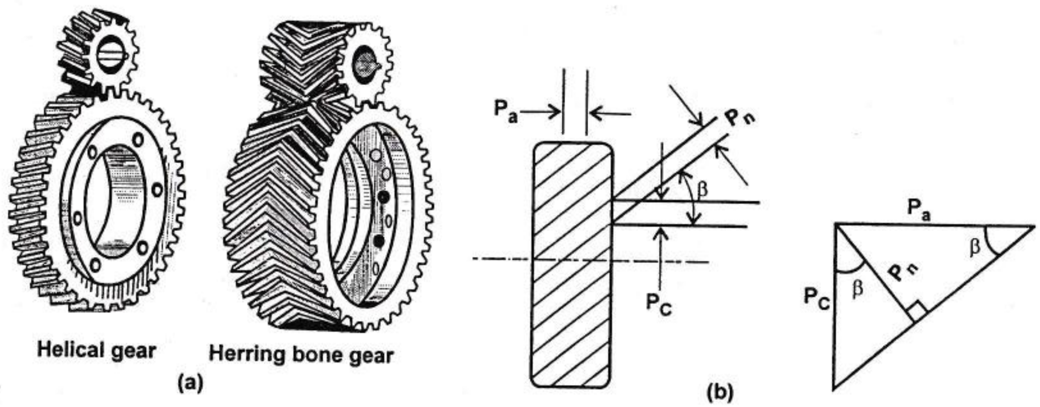


Fig. 25.2: Helical gear drive

Table 25.1: Design Stress for Gear Materials

Fig. 25.2: Helical gear drive

Table 25.1: Design Stress for Gear Materials

I.S. Classification		Heat treatment	σ_u kgf/mm^2 (N/mm^2)	Endurance limit σ_e min. kgf/mm^2 (N/mm^2)	Number of cycles	Surfaces hardness HB	Design Stress: $[\sigma_b]$, kgf/cm^2 (N/mm^2), Module, m, in mm: m upto 6	Design Stress: $[\sigma_b]$, kgf/cm^2 (N/mm^2), Module, m, in mm: m = 7 to 10	Design Stress: $[\sigma_c]$ kgf/cm^2 (N/mm^2)
Cast iron	Grade 20	–	≥ 20 (200)	10 (100)	10^7	179 – 223	500 (50)	460 (46)	5000 (500)
	Grade 25	–	≥ 25 (250)	12 (120)	10^7	197 – 241	600 (60)	550 (55)	6000 (600)
	Grade 35	–	≥ 35 (350)	13 (130)	10^7	207 – 241	600 (60)	550 (55)	6000 (600)
	Grade 35	Heat Treated	≥ 35 (350)	16 (160)	10^7	300 Min.	800 (80)	750 (75)	7500 (750)
	C 45	–	≥ 63 (630)	27 (270)	10^7	175 – 215	1400 (140)	1350 (135)	5000 (500)
Steel	15 Ni 2 Cr 1 Mo15	Carburized	≥ 90 (900)	55 (550)	25×10^7	case (500) core (250)	3200 (320)	3000 (300)	9500 (950)
	40 Ni 2 Cr 1 Mo28	Case hardened	≥ 155 (1550)	60 (600)	25×10^7	case (600) core (250)	4000 (400)	3800 (380)	11000 (1100)

σ_u, Ultimate tensile strength, kgf/mm^2 (N/mm^2)

σ_e min., Minimum endurance limit stress for complete reversal of stresses, kgf/mm^2 (N/mm^2)

$[\sigma_c]$, Design surface stress, kgf/cm^2 (N/mm^2)

$[\sigma_b]$, Design bending stress, kgf/cm^2 (N/mm^2)

Note : 1 N/mm^2 = 100 N/cm^2 ≈ 10 kgf/cm^2

28.5

28.53

Table 25.2: Recommended Series of Modules (mm)

Preferred	Choice 2	Choice 3
1		
1.25	1.125	
1.5	1.375	
2	1.75	
2.5	2.25	
3	2.75	(3.25)
4	3.5	(3.75)
5	4.5	
6	5.5	(6.5)
8	7	
10	9	
12	11	
16	14	
20	18	
25	22	
32	28	
40	36	
50	45	

Note: The modules given in the above table apply to all types of gears. In case of helical gears and double helical gears, the modules represent normal modules.

Table 25.3 : Mechanical Properties of Commonly Used Gear Materials.

Carbon steels:

Designation	Tensile strength (σ_u) N/mm^2	Yield stress (σ_y) N/mm^2	Modulus of elasticity (E) N/mm^2	Modulus of rigidity (G) N/mm^2	BHN
C15	370 – 490	240	2.08×10^5	0.79×10^5	137
C20	440 – 520	260	2.08×10^5	0.80×10^5	156
C25	440 – 540	280	2.07×10^5	0.81×10^5	170
C30	500 – 600	300	2.07×10^5	0.82×10^5	179
C35	520 – 620	310	2.06×10^5	0.83×10^5	187
C40	580 – 680	330	2.06×10^5	0.85×10^5	217
C45	630 – 710	360	2.05×10^5	0.87×10^5	229
C50	660 – 780	380	2.05×10^5	0.88×10^5	241
C60	750 min	420	2.04×10^5	0.89×10^5	255

Grey iron castings:

ISI Grade	Tensile strength (σ_u) N/mm^2	BHN
30	270 – 310	207 – 241
35	320 – 350	207 – 241
40	370 – 400	241 – 320

Table 25.4: Standard Gear Ratio, i

Single	Double stage reduction	Triple	Single	Double Stage reduction	Triple
1.25	8	40	3.55	20	112
1.4	9	45	4	22.4	125
1.6	10	50	4.5	25	140
1.8	11	56	5	28	160
2	12	63	5.6	31.5	180
2.24	12.5	71	6.3	35.5	200
2.5	14	80	7.1	40	250
2.8	16	90	8	45	280
3.15	18	100	9	50	315
			10		355
					400

Table 25.5

Equivalent Young's Modulus, $E_{eq} = \dfrac{2 E_1 E_2}{E_1 + E_2}$

Pinion, 1		Wheel, 2			
Material	Young's modulus E_1, N/mm^2	Material	Tensile strength σ_u, N/mm^2	Young's modulus E_2, N/mm^2	Equivalent young's modulus E_{eq} N/mm^2
Steel	2.15×10^5	Steel		2.15×10^5	2.15×10^5
		CI	≤ 280	1.1×10^5	1.46×10^5
			> 280	1.4×10^5	1.7×10^5
		Bronze		1.2×10^5	1.55×10^5
		Nylon		7×10^3	1.36×10^5

For other combination of materials, use Formula, given above the table.

Table 25.6

Type of gear transmission		$\psi = \frac{b}{C}$
Open type gearing		0.1 to 0.3
Speed reducers (Closed type)		
a. High speed	8 to 25 m/s	upto 0.3
b. Medium speed	3 to 8 m/s	upto 0.6
c. Low speed	1 to 3 m/s	upto 1.0
Gear boxes with sliding gears		0.12 to 0.15

Note : For light and medium duty $b \leq d_1$
For heavy duty $b \leq 1.5\, d_1$

Where b, face width and d_1, pinion diameter

Recommended ψ values

$\psi =$	0.20	0.25	0.30	0.40	0.50	0.60	0.80	1.0	1.2

Table 25.7

Type of gear transmission	$\psi_m = \frac{b}{m}$
Non-ground gears	6
Ground gears,	
a. Sliding gears	10 to 20
b. Gears in rigid housing	upto 45
c. Planetary gears	8 to 20

In general : $\psi_m = 10$ or $b = 10$ m   For Nylon gears $\psi_m = 10$ to 20

Table 25.8

Form Factor, y for $\alpha = 20^\circ$ and $f_0^* = 1$

(y includes $\cos \alpha$ term)

Z or Z_v	External pinion, wheel & Internal pinion								Annulus
	Addendum modification coefficient, X								
	– 0.6	– 0.4	– 0.2	0	+ 0.2	+ 0.4	+ 0.6	+ 1.0	
12	–	–	0.239	0.308	0.378	–	–	–	–
14	–	–	0.266	0.330	0.392	0.458	–	–	–
16	–	–	0.302	0.355	0.408	0.461	–	–	–
18	–	–	0.330	0.377	0.424	0.470	–	–	–
20	–	–	0.348	0.389	0.431	0.471	0.513	–	–
22	–	–	0.367	0.402	0.437	0.473	0.509	–	–
24	–	0.355	0.384	0.414	0.445	0.475	0.504	–	–
26	–	0.373	0.400	0.427	0.455	0.481	0.509	–	–
28	0.358	0.383	0.408	0.434	0.458	0.484	0.509	–	0.942
30	0.369	0.392	0.416	0.440	0.464	0.486	0.511	–	0.916
35	0.390	0.411	0.431	0.452	0.473	0.494	0.514	0.556	0.863
40	0.406	0.426	0.445	0.465	0.485	0.503	0.523	0.562	0.825
45	0.415	0.434	0.452	0.471	0.490	0.509	0.528	0.565	0.795
50	0.423	0.441	0.459	0.477	0.495	0.513	0.531	0.568	0.769
60	0.440	0.456	0.474	0.490	0.507	0.523	0.540	0.574	0.731
80	0.457	0.471	0.485	0.499	0.512	0.526	0.541	0.569	0.688
100	0.464	0.481	0.490	0.505	0.517	0.530	0.542	0.566	0.660
150	0.492	0.499	0.508	0.515	0.521	0.531	0.540	0.556	0.620
300	0.517	0.519	0.521	0.521	0.523	0.523	0.524	0.526	0.585

Note: For height factor, $f_0 = 0.8$ (stub teeth) the above values should be divided by 0.8.

Table 25.9

Load Concentration Factor, k for Steel Gears of Quality IS. 8 having HB > 350

(a) Cylindrical gears

$\psi_p = \frac{b}{d_1}$	Bearings close to gears and symmetrical	Asymmetrical		Over hung pinion
		*Very rigid Shaft	**Less rigid Shaft	
0.2	1	1	1.05	1.15
0.4	1	1.04	1.1	1.22
0.6	1.03	1.08	1.16	1.32
0.8	1.06	1.13	1.22	1.45
1.0	1.1	1.18	1.29	–
1.2	1.14	1.23	1.36	–
1.4	1.19	1.29	1.45	–
1.6	1.25	1.35	1.55	–

* $l/d_s < 3$, l – length of the shaft.

** $l/d_s > 3$, d_s – diameter of shaft

$$\psi_p = \frac{\psi}{2}(i \pm 1)$$

(b) Bevel gears

Surface hardness of gears HB	$b/d_{1\,av}$ ratio		
	=< 1	1 to 1.6	1.6 to 1.8
> 350 for both the gears	1.6	–	–
≤ 350 for both the gears or atleast for wheel	1.1	1.2	1.3

d_{1av}– Average pitch diameter of bevel pinion $= m_t Z_1 \left(\frac{R - 0.5\,b}{R}\right)$ mm,

Pitch line velocity, $V = \frac{\pi\, d_{1\,av}\, n_1}{60 \times 1000}$ m/sec

Table 25.10

Dynamic Load Factor, k_d

IS quality		Pinion surface hardness HB	Spur & Straight bevel				Helical & Spiral bevel			
Cylindrical gear	Conical gear		Pitch line velocity, m/s, upto							
			1.0	3.0	8.0	12.0	3.0	8.0	12.0	18.0
5	–	≤ 350	–	–	1.2	1.4	–	1	1.1	1.2
		> 350	–	–	1.2	1.3	–	1	1.0	1.1
6	5	≤ 350	–	1.25	1.45	–	1	1	1.2	1.3
		> 350	–	1.2	1.3	–	1	1	1.1	1.2
8	6	≤ 350	1	1.35	1.55	–	1.1	1.3	1.4	–
		> 350	–	1.3	1.4	–	1.1	1.2	1.3	–
10	8	≤ 350	1.1	1.45	–	–	1.2	1.4	–	–
		> 350	–	1.4	–	–	1.2	1.3	–	–
	10	≤ 350	1.2	–	–	–				

Table 25.11 : Standard Tooth Proportions of Involute Spur Gears

Gear terms	Proportions of machine cut teeth		
	Circular pitch p_c	Diametral pitch p_d	Module m
Addendum	$0.3183\ p_c$	$1/p_d$	m
Dedendum	$0.3977\ p_c$	$1.25/p_d$	1.25 m
Tooth thickness	$0.5\ p_c$	$1.5708/p_d$	1.5708 m
Tooth space	$0.5\ p_c$	$1.5708/p_d$	1.5708 m
Working depth	$0.6366\ p_c$	$2/p_d$	2 m
Whole depth	$0.7160\ p_c$	$2.25/p_d$	2.25 m
Clearance	$0.0794\ p_c$	$0.25/p_d$	0.25 m
Pitch diameter	Zp_c/π	Z/p_d	Zm
Outside diameter	$(Z+2)\ p_c/\pi$	$(Z+2)/p_d$	(Z + 2) m
Root diameter	$(Z-2.5)\ p_c/\pi$	$(Z-2.5)/p_d$	(Z – 2.5) m
Fillet radius	$0.1273\ p_c$	$0.4/p_d$	0.4 m

Table 25.12

Design Surface (contact compressive) Stress $[\sigma_c]$

$[\sigma_c] = C_B\ HB\ k_{cl}$, kgf/cm^2	C_B or C_R	Coefficient depending on the surface hardness
$[\sigma_c] = C_R\ HRC\ k_{cl}$, kgf/cm^2	HB or HRC	Brinell or Rockwell 'C' hardness number
	k_{cl},	life factor

Coefficient, C_B & C_R

Wheel material	Heat treatment	Surface hardness	Coefficient C_B or C_R
Carbon steels and alloy steel or any type	Normalised or hardened and tempered	$HB \leq 350$	$C_B = 25$
High strength alloy nickel chromium steels	Case hardened	$HRC = 55$ to 63	$C_R = 310$
Alloy steels	"	"	$C_R = 280$
Carbon & manganese steels C15; C20; C15 Mn85; C20 Mn 85	"	"	$C_R = 220$
Alloy steels, carbon steels C40; C45	Hardened & tempered	$HRC = 40$ to 55	$C_R = 265$
"	Surface hardened	"	$C_R = 230$
Cast iron, grade 20, 25	–	$HB = 170$ to 200	$C_B = 20$
Cast iron, grade 30, 35	–	$HB = 200$ to 260	$C_B = 23$

Table 25.13

Equivalent Mean Life

Condition	Formula	Notation
Constant loading	$N = 60\ nT$	N, life in number of cycles T, life in hours
Variable loading	$N = \dfrac{60}{M^3\ t1} \Sigma M_{ti}^3 T_i n_i$	n, rpm

When the load comprises of a maximum sustained wheel or pinion torque M_{t1} acting for T_1 hours at a mean speed of n_1 and small sustained torques M_{t_2}, M_{t3} ..... acting for T_2, T_3, ... hours, at mean speeds of n_2, n_3, ... the equivalent number of cycles at the maximum sustained load is N_{eq}.

$$N_{eq} = 60\left[T_1 n_1 \left(\frac{M_{t1}}{M_{t1}}\right)^3 + T_2 n_2 \left(\frac{M_{t2}}{M_{t1}}\right)^3 + T_3 n_3 \left(\frac{M_{t3}}{M_{t1}}\right)^3 + ...\right]$$

Table 25.14

Life Factor for Surface (Contact Compressive) Strength $k_{cl} = \sqrt[6]{\frac{10^7}{N}}$

Material	Surface hardness, HB	Life in number of cycles	Life factor, k_{cl}
Steel	≤ 350	$\geq 10^7$	1
		$< 10^7$	$\sqrt[6]{\frac{10^7}{N}}$
	> 350	$\geq 25 \times 10^7$	0.585
		$< 25 \times 10^7$	$\sqrt[6]{\frac{10^7}{N}}$
Cast iron			$\sqrt[6]{\frac{10^7}{N}}$

Table 25.15

Design Bending Stress (Tension $[\sigma_b]$)

Rotation in one direction only,	k_{bl},	Life factor for bending 25.19
$[\sigma_b] = \frac{k_{bl}}{n \cdot k_\sigma}\sigma_0 = \frac{1.4\, k_{bl}}{n\, k_\sigma}\sigma_e$	k_σ,	Fillet stress concentration factor, table 25.18
	$\sigma_0 =$	$1.4\,\sigma_e$
Rotation in both directions,	σ_0,	Endurance limit stress in bending for repeated stress, kgf/cm^2
$[\sigma_b] = \frac{k_{bl}}{n \cdot k_\sigma}\sigma_e$	σ_e,	Endurance limit stress in bending for complete reversal of stresses, kgf/cm^2 table 25.16
	n,	factor of safety, table 25.17

Table 25.16 : Value of σ_e

Material of mating gear	σ_e, Endurance limit stress in bending for complete reversal of stresses, kgf/cm^2
Forged steels	$\sigma_e = 0.25\,(\sigma_u + \sigma_y) + 500$
Cast steels	$\sigma_e = 0.22\,(\sigma_u + \sigma_y) + 500$
Alloy steels	$\sigma_e = 0.35\,\sigma_u + 1200$
Cast iron	$\sigma_e = 0.45\,\sigma_u$

σ_u, ultimate tensile stress, kgf/cm^2

σ_y, yield stress, kgf/cm^2

Table 25.17 : Factor of Safety, n

Material	Mode of manufacture	Heat treatment	Factor of safety, n
Steel, Cast iron		No heat treatment	2.5
	Cast	Tempered or normalised	2.0
	Cast or forged	Case hardened	2.0
Steel	Forged	Surface hardened	2.5
		Normalised	2.0

Table 25.18 : Stress Concentration Factor for the Fillet, k_σ

Material and heat treatment	Addendum modification coefficient, X		
	$X < 0$	$0 \le X \le 0.1$	$X > 0.2$
Steel, normalised, surface hardened	1.4	1.5	1.6
Steel case hardened	1.1	1.2	1.3
Cast iron	1.2	1.2	1.3

Table 25.19: Life Factor for Bending, k_{bl}

Material	Surface hardness HB	Life in number of cycles, N	k_{bl}
Steel	≤ 350	$\geq 10^7$	1
		$< 10^7$	$\sqrt[9]{\frac{10^7}{N}}$
	> 350	$\geq 25 \times 10^7$	0.7
		$< 25 \times 10^7$	$\sqrt[9]{\frac{10^7}{N}}$
Cast iron			$\sqrt[9]{\frac{10^7}{N}}$

Note : If the case hardness HB > 350 and the core hardness HB < 350, then the coefficient k_{bl} is obtained for HB < 350.

For non-metallic materials [Nylon, textolite, plastic],

$[\sigma_b] = \frac{\sigma_u}{n}$ σ_u, ultimate tensile strength, kgf/cm^2

$n = 2.5$ to 3, factor of safety

Table 25.20 : Design Bending Stress for Non-metallic Materials

Material	$[\sigma_b]$, kgf/cm^2
Textolite	500
Valcanised fibre gears	360
Plastic	600
Bakelite	560

Table 25.21 : Recommended Series of Diametral Pitches

Preferred	Choice 2
20	
16	18
12	14
10	11
8	9
6	7
5	5.50
4	4.50
3	3.50
2.50	2.75
2	2.25
1.50	1.75
1.25	
1	
0.75	0.875
0.625	
0.50	

Table 25.22: Properties of Involute Teeth

Tooth characteristics	Cast teeth	14 ½° system	Full depth 20° system	Stub teeth system
Pressure angle (deg)	15	14 ½	20	20
Addendum (mm)	0.943 m	m	m	0.8 m
Minimum dedendum (mm)	1.257 m	1.157 m	1.157 m	m
Minimum total depth (mm)	2.2 m	2.157 m	2.157 m	1.8 m
Minimum clearance (mm)	0.314 m	0.157 m	0.157 m	0.2 m
Thickness of the tooth (mm)	1.493 m	1.571 m	1.571 m	1.571 m
Backlash (mm)	0.157 m	0	0	0
Outside diameter (mm)	(Z + 2) m	(Z + 2) m	(Z + 2) m	(Z + 1.6) m
Approximate fillet radius (mm)	0.209 m	0.209 m	0.209 m	0.209 m

m = module, mm

Number of Teeth in a Drive for Standard Ratios:

Z, Total number of teeth $= Z_1 + Z_2$

Z_1, Number of teeth in driving gear

Z_2, Number of teeth in driven gear

i, Standard ratio, $\frac{Z_2}{Z_1}$

S, % deviation $= \left[\frac{\text{Actual ratio} - \text{Standard ratio}}{\text{Standard ratio}}\right] \times 100$

Values tabulated are :

$$Z_1 : Z_2^{\pm S}$$

Table 25.23: Number of Teeth for Pinion and Gear (For Gear box design)

i \ Z	30	31	32	33	34	35	36	37	38	39
1	15:15		16:16		17:17		18:18		19:19	
1.06		– 0.7 15:16		– 0.3 16:17		17:18		0.4 18:19		0.6 19;20
1.12			– 1.0 15:17		– 0.3 16:18		0.4 17:19		1.0 18:20	
1.26					– 0.6 15:19		0.7 16:20			
1.41					– 1.1 14:20		0.9 15:21			
1.58							0.9 14:22			0.9 15:24
1.78							0.5 13:23			0.4 14:25
2							– 0.2 12:24			– 0.2 13:26
2.24										– 0.5 12:27

i \ Z	40	41	42	43	44	45	46	47	48	49
1	20:20		21:21		22:22		23:23		24:24	
1.06		0.9 20:21		1.1 21:22		1.3 22:23		1.5 23.24		– 0.7 23.26
1.12	1.5 19:21							– 1.3 22:25		
1.26		– 1.5 18:23		– 0.5 19:24		0.7 20:25				
1.41		0.1 17:24					– 0.5 19:27			
1.58		1.4 16:25			– 0.2 17:27					0.4 19:30
1.78			– 0.2 15:27					0.8 17:30		
2.0			– 0.2 14:28			– 0.2 15:30			– 0.2 16:32	
2.24			0.4 13:29			1.1 14:31				0.5 15:34
2.5			0.5 12:30				– 1.0 13:33			0.5 14:35
2.82							0.5 12:34			

i \ Z	50	51	52	53	54	55	56	57	58	59
1	25:25		26:26		27:27		28:28		29:29	
1.06							0.4 27:29		– 1.1 28:30	
1.12		– 0.3 24:27		0.2 25:28		0.5 26:29		1.0 27:30		1.3 28:31
1.26	– 1.1 22:28		– 0.2 23:29		0.7 24:30		1.5 25:31			0.5 26:33
1.41		– 1.1 21:30		0.2 22.31		1.5 23:32			– 0.3 24:34	
1.58		– 0.3 19:32	– 0.5 20:32		0.9 21:33			– 0.4 22:35		1.3 23:36
1.78	18:32			– 0.5 19:34			– 1.2 20:36		0.9 21:37	
2		– 0.2 17:34			– 0.2 18:36			– 0.2 19:38		
2.24			– 0.5 16:36			0.2 17:38			0.7 18:40	
2.51				– 0.8 15:38			0.5 16:40			
2.82	– 1.0 13:37			1.2 14:39	– 1.4 14:40			0.7 15:42		
3.16	– 0.1 12:38				0.2 13:41				0.5 14:44	
3.55					1.4 12:42	– 1.1 12:43				0.3 13.46
3.98										1.5 12:47

i \ Z	60	61	62	63	64	65	66	67	68	69
1	30:30		31:31		32:32		33:33		34:34	
1.06	– 0.9 29:31		– 0.7 30:32		– 0.5 31:33		– 0.3 32:34		– 0.1 33:35	
1.12			– 1.4 29:33		– 1.0 30:34		– 0.6 31:35		– 0.3 32:36	
1.18		– 0.8 28:33		1.4 29:34	– 1.5 29:35		– 1.0 30:36		– 0.4 31:37	
1.26		27:34		0.7 28:35		1.4 29:36	– 1.3 29:37		– 0.6 30:38	
1.41	0.9 25:35			– 0.7 26:37		0.4 27:38		1.4 28:39	– 1.1 28:40	
1.58	– 1.5 23:37		0.1 24:38			– 0.9 25:40		0.5 26:41		
1.78		– 1.0 22:39			– 0.2 23:41			– 0.7 24:43		1.0 25:44
2.0	– 0.2 20:40			– 0.2 21:42			– 0.2 22:44			– 0.2 23:46
2.24		1.3 19:42	– 1.1 19:43			– 0.5 20:45			21:47	
2.51	– 0.7 17:43			0.5 18:45			1.5 19:47	– 1.6 19:48		
2.82		0.2 16:45				– 0.2 17:48			1.5 18:50	– 0.5 18:51
3.16			0.9 15:47	– 1.2 15:48			1.2 16:50	– 0.8 16:51		
3.55				1.4 14:49	– 0.7 14:50				0.4 15:53	– 1.4 15:54
3.98	– 0.5 12:48				1.5 31:51	– 0.5 13:52				– 1.3 14:55
5.01								– 1.6 11:56		

i \ Z	70	71	72	73	74	75	76	77	78	79
1	35:35		36:36		37:37		38:38		39:39	
1.06	34:36		− 0.2 35:37		0.4 36:38		0.5 37:39		0.6 38:40	
1.12	0.1 33:37		0.4 34:38		0.7 35:39		1.0 36:40	1.5 36:41	1.3 37:41	− 1.2 37:42
1.26	0.1 31:39		0.7 32:40		1.3 33:41	− 1.1 33:42		− 0.5 34:43		0.1 35:44
1.41	− 0.1 29:41		− 0.9 30:42	− 1.5 30;43		− 0.5 31:44		0.4 32:45		1.3 33:46
1.58	− 0.5 27:43		0.9 28:44	− 1.4 28:45		− 0.1 29:46		− 1.2 30:42	− 0.9 30:48	
1.78	− 1.2 25:45		0.5 26:46			27:48			− 0.4 28:50	
2.0			− 0.2 24:48			− 0.2 25:50			− 0.2 26:52	
2.24		0.5 22:49	− 1.5 22:50		1.0 23:51	− 1.0 23:52		1.4 24:53	− 0.5 24:54	
2.51	0.5 20:50	− 1.5 20:51		1.4 21:52	− 0.5 21:53			0.5 22:55	− 1.3 22:56	
2.82			1.1 19:53	− 0.8 19:54			0.7 20:56	− 1.1 20:57		
3.16	1.4 17:53	− 0.4 17:54				− 0.1 18:57				0.1 19:60
3.55			1.4 16:56	0.4 16:57				0.5 17:60	1.1 17:61	
3.98	− 0.5 14:56				1.2 15:59	0.5 15:60				− 1.1 16:63
5.01		1.9 12:59	0.2 12:60	− 1.4 12:61				1.8 13:64	0.2 13:65	− 1.3 13:66

i \ Z	80	81	82	83	84	85	86	87	88	89
1	40:40		41:41		42:42		43:43		44:44	
1.06	0.8 39:41		0.9 40:42	– 1.5 40:43	1.0 41:43	– 1.3 41:44	1.1 42:44	– 1.1 42:45	1.2 43:45	– 1.0 43:46
1.12	1.5 38:42	– 0.8 38:43		– 0.5 39:44		– 0.3 40:45		41:46		0.3 42:47
1.26		0.7 36:45	– 1.5 36;46	1.3 37:46	– 0.9 37:47		– 0.3 38:48		0.2 39:49	
1.41	– 0.8 33:47		0.1 34:48		– 0.9 35:49	0.1 35:50		– 0.3 36:51		– 0.5 37:52
1.58	0.3 31:49		1.4 32:50	– 0.6 32:51		0.5 33:52	– 1.3 33:53		– 0.2 34:54	
1.78	1.1 29:51	– 0.8 29:52		0.7 30:53	– 1.2 30;54		0.2 31:55			– 0.2 32:57
2.0		– 0.2 27:54			– 0.2 28:56		1.5 29:57	– 0.2 29:58		1.5 30;59
2.24		– 0.1 25:56			0.4 26:58	– 1.3 26;59		0.7 27:60	– 0.9 27:61	
2.51	1.4 23:57	– 0.4 23:58			– 0.5 24:60	– 1.2 24:61		1.3 25:62	– 0.3 25:63	
2.82	0.3 21:59	– 1.4 21:60			22:62			1.3 23:64	– 0.3 23:65	
3.16	– 1.5 19:61			0.4 20:63	– 1.2 20:64			0.6 21:66	– 0.9 21:67	
3.55		1.4 18:63	– 0.2 18:64	– 1.7 18:65			0.5 19:67	– 0.9 19:68		
3.98	– 0.5 16:64	2.0 16:65			1.0 17:67	– 0.5 17:68	– 1.9 17:69			0.9 18:71
5.01				1.7 14:69	0.2 14:70	– 1.2 14:71				– 1.5 15:74

i \ Z	90	91	92	93	94	95	96	97	98	99
1	45:45		46:46		47:47		48:48	2.0 49:48	49:49	2.0 50:49
1.06	−1.3 44:46	−0.8 44:47	1.4 45:47	−0.7 45:48	1.5 46:48	−0.5 46:49	1.6 47:49	−0.4 47:50		−0.3 48:51
1.12		0.5 43:48	−1.5 43:49	−0.8 44:49	−1.3 44:50	1.0 45:50	−1.0 45:51	1.12 46:51	−0.7 46:52	1.4 47:52
1.26	0.7 40:50	−1.3 40:51	1.2 41:51	−0.7 41.52		−0.2 42:53		−0.2 43:54		0.7 44:55
1.41	−1.4 37:53	1.3 38:53	−0.6 38:54		0.2 39:55		0.9 40:56	−0.9 40:57		−0.1 41:58
1.58	0.9 35:55	−0.9 35:56		0.1 36:57		1.1 37:58	−0.6 37:59		1.4 38:50	−1.3 38:61
1.78		1.2 33:58	−0.5 33:59		0.8 34:60	−0.3 34:61		0.4 35:62	−1.2 35:63	
2.0	−0.2 30:60		1.4 31.61	−0.2 31.62		1.3 32:63	−0.2 32:64		1.3 33:65	−0.2 33.66
2.24	1.1 28:62	−0.5 28:63		1.4 29:64	−0.1 29:65			0.2 30:67	−1.2 30.68	—
2.51		0.5 26:65	−1.0 26:66		1.2 27:67	−0.3 27:68			0.5 28:70	−0.9 28:71
3.16		0.8 22:69	−0.6 22:70			1.0 23:72	−0.4 23:73			−1.2 24:75
3.55	1.4 20:70	−0.1 20:71	−1.4 20:72			0.7 21:74	−0.7 21:75			1.4 22:77
3.98	−0.5 18:72	−1.8 18:73			0.9 19:75	−0.5 19:76	−1.8 19:77			0.8 20:79
5.01	0.2 15:75	−1.1 15:76				1.5 16:79	0.2 16:80	−1.0 16:81		

CHAPTER – 26

BEVEL GEAR DRIVES

Symbols : (with S.I. units)

b	–	Face width of tooth, mm
c	–	Bottom clearance, mm
d_1	–	Pitch circle diameter of pinion at its outer portion, mm
d_2	–	Pitch circle diameter of gear at its outer portion, mm
d_{a1}	–	Tip circle diameter of pinion at its outer portion, mm
d_{a2}	–	Tip circle diameter of gear at its outer portion, mm
E	–	Equivalent youngs modulus, N/mm^2
E_1	–	Youngs modulus of pinion material, N/mm^2
E_2	–	Youngs modulus of gear material, N/mm^2
h	–	Tooth height at outer portion, mm
h_a	–	Addendum at outer portion, mm
h_f	–	Dedendum at outer portion, mm
i	–	Transmission ratio or gear ratio
k	–	Load concentration factor
k_d	–	Dynamic load factor
M_t	–	Nominal twisting moment, N-mm.
$[M_t]$	–	Design twisting moment, N-mm

m_{av} – Average module (i.e.; module based on pitch circle diameter at the centre portion of teeth), mm

m_t – Transverse module (i.e.; module based on pitch circle diameter at outer portion), mm

n_1 – Speed of pinion, rpm

n_2 – Speed of gear, rpm

P – Power transmitted, kW

R – Cone distance (i.e.; distance of outer portion of teeth from apex), mm

y – Form factor

y_v – Form factor for virtual number of teeth

Z_1 – Number of teeth of pinion

Z_2 – Number of teeth of gear

Z_v – Virtual number of teeth

α – Pressure angle of gear ($\alpha = 20°$, Standard value)

δ_1 – Pitch angle for pinion, deg.

δ_2 – Pitch angle for gear, deg.

δ_{a1} – Tip angle for pinion, deg.

δ_{a2} – Tip angle for gear, deg.

δ_{f1} – Root angle for pinion, deg.

δ_{f2} – Root angle for gear, deg.

θ_a – Addendum angle for pinion and gear

θ_f – Dedendum angle for pinion and gear

σ_b – Induced bending stress, N/mm^2

$[\sigma_b]$ – Design bending stress, N/mm^2

σ_c – Induced compressive stress

$[\sigma_c]$ – Design compressive stress

ψ_y – Ratio of cone distance to face width $\left(\text{i.e., } \psi_y = \dfrac{R}{b}\right)$

DESIGN PARTICULARS	EQUATIONS
Straight bevel gears	
Nominal twisting moment transmitted by pinion	$M_t = \dfrac{60 \times 10^6 \times P}{2 \pi n_1}$ .... (26.1)
Design twisting moment	$[M_t] = M_t \cdot k \cdot k_d$ .... (26.2) (Assume $k.\,k_d = 1.5$ initially)
Cone distance based on surface compressive strength of weaker gear	$R \geq \psi_y \sqrt{i^2+1}\ \sqrt[3]{\left\{\dfrac{0.72}{(\psi_y - 0.5)\,[\sigma_c]}\right\}^2 \dfrac{E\,[M_t]}{i}}$ .... (26.3)
Average module based on bending strength of weaker gear	$m_{av} \geq 1.26\ \sqrt[3]{\dfrac{[M_t]}{y_v\,[\sigma_b]\,\psi_m\,Z_1}}$ .... (26.4)
Transverse module	$m_t = m_{av}\left(\dfrac{\psi_y}{\psi_y - 0.5}\right)$ .... (26.5)
Induced compressive stress on gear tooth	$\sigma_c = \dfrac{0.72}{(R - 0.5b)}\sqrt{\dfrac{(i^2+1)^{3/2}}{ib} \cdot E\,[M_t]} \leq [\sigma_c]$ .... (26.6)
Induced bending stress on gear tooth	$\sigma_b = \dfrac{R\sqrt{i^2+1}\ [M_t]}{(R - 0.5b)^2\, b\, m_t\, y_v \cdot \cos\alpha} \leq [\sigma_b]$ .... (26.7)

DESIGN PARTICULARS	EQUATIONS	
Number of teeth	$Z_1 = \dfrac{R}{0.5\, m_t \sqrt{i^2 + 1}}$ & $Z_2 = i\, Z_1$	.... (26.8)
Cone distance related with number of teeth	$R = 0.5\, m_t\, Z_1 \sqrt{i^2 + 1} = 0.5\, m_t \sqrt{Z_1^2 + Z_2^2}$	.... (26.9)
Pitch circle diameter or reference diameter	$d_1 = m_t\, Z_1$ & $d_2 = m_t\, Z_2$	.... (26.10)
Tip circle diameter	$d_{a1} = m_t(Z_1 + 2\cos\delta_1)$ & $d_{a2} = m_t\,(Z_2 + 2\cos\delta_2)$	.... (26.11)
Face width	$b \simeq 0.3\,R$ or R/ψ_y	.... (26.12)
Reference angle	$\delta_2 = \tan^{-1} i$ & $\delta_1 = 90° - \delta_2$	.... (26.13)
Addendum angle	$\theta_a = \tan^{-1}\left(\dfrac{m_t}{R}\right)$	.... (26.14)
Dedendum angle	$\theta_f = \tan^{-1}\left(\dfrac{1.2\, m_t}{R}\right)$	.... (26.15)
Tip angle	$\delta_{a1} = \delta_1 + \theta_a$ & $\delta_{a2} = \delta_2 + \theta_a$	.... (26.16)
Root angle	$\delta_{f1} = \delta_1 - \theta_f$ & $\delta_{f2} = \delta_2 - \theta_f$	.... (26.17)
Addendum	$h_a = 1\, m_t$	.... (26.18)
Dedendum	$h_f = 1.124\, m_t$	.... (26.19)
Virtual number of teeth	$Z_{v1} = \dfrac{Z_1}{\cos\delta_1}$ & $Z_{v2} = \dfrac{Z_2}{\cos\delta_2}$	.... (26.20)

DESIGN DATA

Virtual number of teeth $\quad Z_{v1} = \frac{Z_1}{\cos \delta_1}$ & $Z_{v2} = \frac{Z_2}{\cos \delta_2}$ .... (26.20)

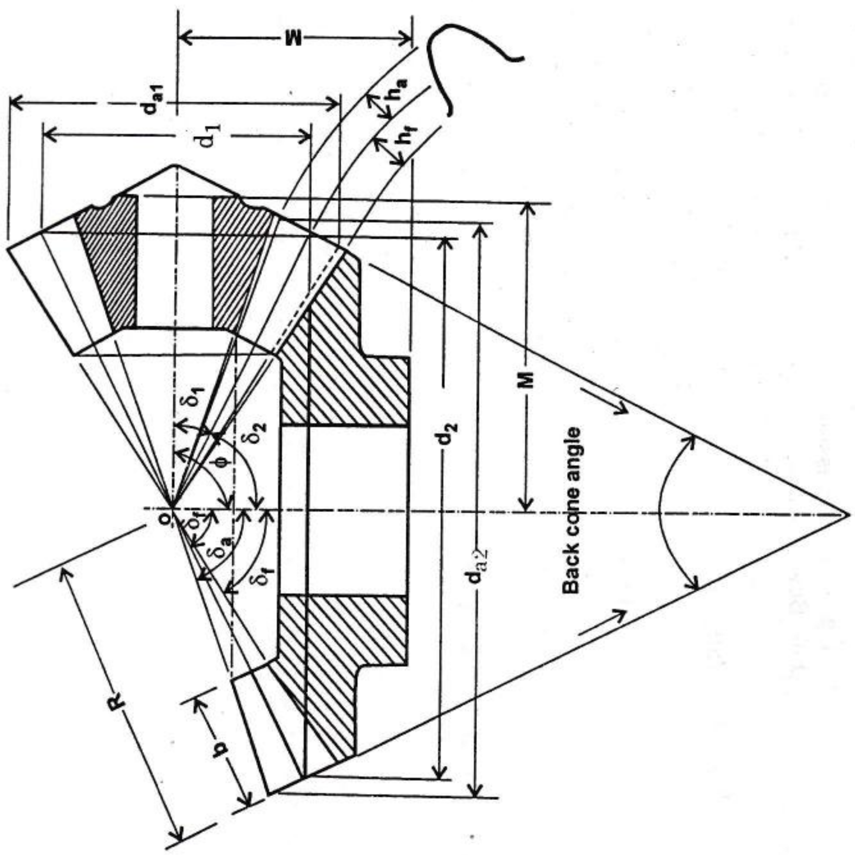


Fig. 26.1: Bevel gear drive

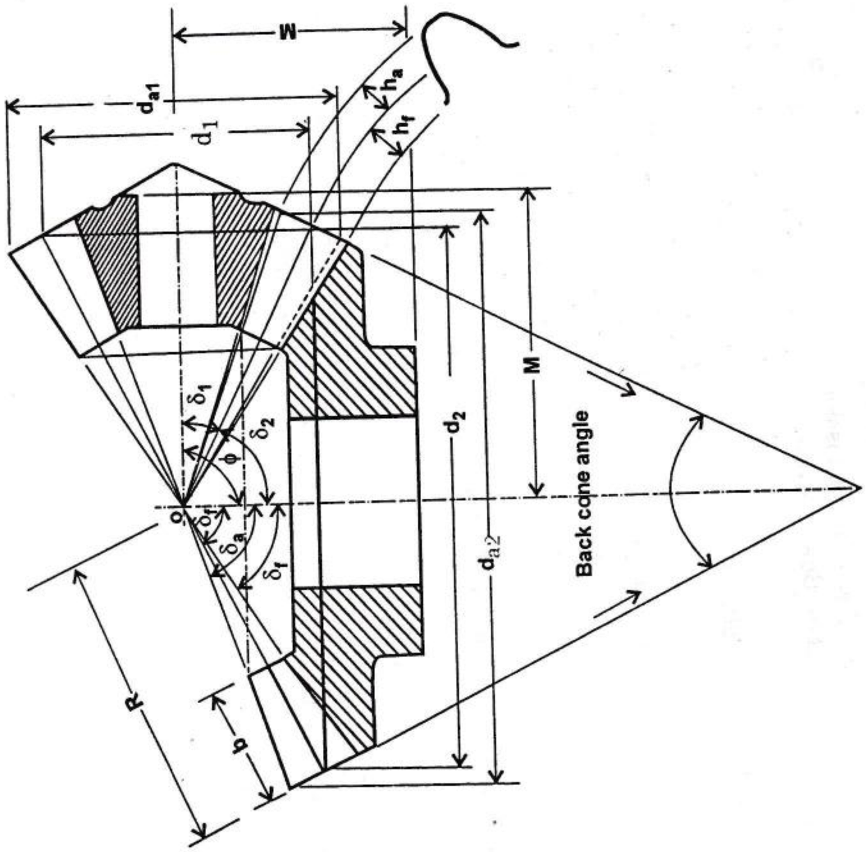


Fig. 26.1: Bevel gear drive

Table 26.1

Type of gear transmission (For Bevel gears)	$\psi_y = \frac{R}{b}$
(a) Housed in roller bearings	
i = 1 to 4	3
i = 4 to 6	4
(b) Housed in journal & thrust bearings	
i = 6	5

Note : Also refer the tables 25.1 to 25.5, 25.8 to 25.10, 25.12 to 25.19 for bevel gear design.

Table 26.2: Peripheral Speeds of Gears

Table 26.2: Peripheral Speeds of Gears

Accuracy	Cutting method	Finishing operation for tooth contact surface	Nature of service	Peripheral velocities		Efficiency
				Spur gear	Bevel gear	
Low	Form cut or generated	None	Ordinary power transmission with moderate load and low speed.	Upto 2 m/s	Upto 4 m/s	94%
Medium	Form cut or generated	Machine cut, run in or lapped in pairs	General use requiring no special accuracy. Example: Gears for unimportant industrial machinery, tractors, agricultural equipment haulage machinery etc.	Upto 6 m/s	Upto 10 m/s	96%
High	Teeth generated on precision machines	Teeth ground, shaved or lapped after machining depending on nature of service	Gear wheels operating at high velocity and medium load or high load at moderate velocity. Example : Gear wheels of machine tools, reduction gears, automobiles, aircraft etc.	Upto 10 m/s	Upto 15 m/s	98%
Very high	Teeth generated on high precision machines	Precision ground or shaved	Gear wheels for smooth and noiseless operation or for operations at high velocities under heavy loads. Example: Gear wheels of machine tools, automobiles, aircrafts, highspeed reduction gears, indexing or dividing gears, turbine gears etc.	Upto 15 m/s	Upto 30 m/s	99%

Table 26.3: Recommended Backlash for Straight Bevel Gears

Module m_t (mm)	over		1.25	2.5	3.5	4.5	5	6.5	7	8	10	12	14
	to	1.25	2.5	3.5	4.5	5	6.5	7	8	10	12	14	16
Backlash (mm)		0.025 to 0.075	0.05 to 0.1	0.075 to 0.125	0.1 to 0.15	0.15 to 0.175	0.15 to 0.2	0.175 to 0.225	0.2 to 0.275	0.25 to 0.325	0.3 to 0.4	0.35 to 0.45	0.4 to 0.55

CHAPTER – 27

WORM GEAR DRIVES

Symbols : (with S.I. units)

b – Face width of wheel, mm

C – Centre distance between the axes of worm and wheel, mm

d_1 – Pitch circle diameter of worm, mm

d_2 – Pitch circle diameter of wheel, mm.

d_{a1} – Tip circle diameter of worm, mm

d_{a2} – Tip circle diameter of wheel, mm

d_{f1} – Root circle diameter of worm, mm

d_{f2} – Root circle diameter of wheel, mm

h – Tooth height, mm

h_a – Addendum, mm

h_f – Dedendum, mm

i – Transmission ratio or gear ratio

k – Load concentration factor

k_d – Dynamic load factor

M_t – Nominal twisting moment, N-mm

$[M_t]$ – Design twisting moment, N-mm

m_x – Axial module, mm

n_1 – Speed of worm, rpm

n_2 – Speed of wheel, rpm

P – Power transmitted, kW

q – Diameter factor $\left(q = \frac{d_1}{m_x}\right)$

V_s – Sliding velocity of worm, m/s.

y – Form factor

y_v – Form factor for virtual number of teeth of wheel

Z_1 – Number of starts of worm

Z_2 – Number of teeth of wheel

Z_v – Virtual number of teeth of wheel

α – Pressure angle of gear in axial section ($\alpha = 20°$)

γ – Lead angle (i.e.; helix angle) for wheel, deg.

σ_b – Induced bending stress, N/mm^2

$[\sigma_b]$ – Design bending stress, N/mm^2

σ_c – Induced compressive stress, N/mm^2

$[\sigma_c]$ – Design compressive stress, N/mm^2

λ – Number of teeth of worm

η – Efficiency of worm gear drive

DESIGN PARTICULARS	EQUATIONS
Nominal twisting moment transmitted by worm-wheel	$M_t = \dfrac{60 \times 10^6 \times P}{2\,\pi\, n_2} \times \eta$ .... (27.1) where $n_2 = \dfrac{n_1}{i}$
Design twisting moment	$[M_t] = M_t \,.\, k \,.\, k_d$ .... (27.2) (Assume $k.k_d = 1$ initially)
Centre distance based on surface compressive stress	$C \geq \left(\dfrac{Z_2}{q} + 1\right) \sqrt[3]{\left[\dfrac{540}{\dfrac{Z_2}{q}[\sigma_c]}\right]^2 [M_t]}$ .... (27.3) (For steel worm and bronze wheel) (and) $C \geq \left(\dfrac{Z_2}{q} + 1\right) \sqrt[3]{\left[\dfrac{978}{\dfrac{Z_2}{q}[\sigma_c]}\right]^2 [M_t]}$ .... (27.4) (For steel worm and cast-iron wheel)
Axial module based on bending stress	$m_x \geq 1.24 \sqrt[3]{\dfrac{[M_t]}{y_v\,[\sigma_b]\, q\, Z_2}}$ .... (27.5) where y_v = Form factor corresponding to $Z_{v2} = \dfrac{Z_2}{\cos^3 \gamma}$ (for y_v, refer table 25.8)

DESIGN PARTICULARS	EQUATIONS
Induced compressive stress	$\sigma_c = \dfrac{540}{\left(\dfrac{Z_2}{q}\right)} \sqrt{\left[\dfrac{\dfrac{Z_2}{q}+1}{C}\right]^3 [M_t]} \le [\sigma_c]$ .... (27.6)
	(For steel worm and bronze wheel)
	(For steel worm and cast-iron wheel, replace the value 540 by 978)
Induced bending stress	$\sigma_b = \dfrac{1.9\,[M_t]}{m_x^3\, q\, Z_2\, y_v} \le [\sigma_b]$ .... (27.7)
Sliding velocity of worm	$V_s = \dfrac{\pi\, d_1\, n_1}{60 \times 1000 \times \cos\gamma}$ .... (27.8)
Number of teeth of worm-wheel	$Z_2 = iZ_1$ where Z_1 = Number of starts of worm .... (27.9) = 1 to 4
Number of teeth of worm	$\lambda = \dfrac{L}{\pi\, m_x}$ (For L, refer table 27.5) .... (27.10)
Addendum	$h_a = 1\, m_x$ .... (27.11)
Dedendum	$h_f = 1.25\, m_x$ .... (27.12)
Pitch circle diameter or reference diameter	$d_1 = q\, m_x$ & $d_2 = Z_2\, m_x$ .... (27.13)
Tip circle diameter	$d_{a1} = d_1 + 2h_a$ & $d_{a2} = d_2 + 2h_a$ .... (27.14)
Root circle diameter	$d_{f1} = d_1 - 2h_f$ & $d_{f2} = d_2 - 2h_f$ .... (27.15)

Tip circle diameter	$d_{a1} = d_1 + 2h_a$ & $d_{a2} = d_2 + 2h_a$	.... (27.14)
Root circle diameter	$d_{f1} = d_1 - 2h_f$ & $d_{f2} = d_2 - 2h_f$	.... (27.15)

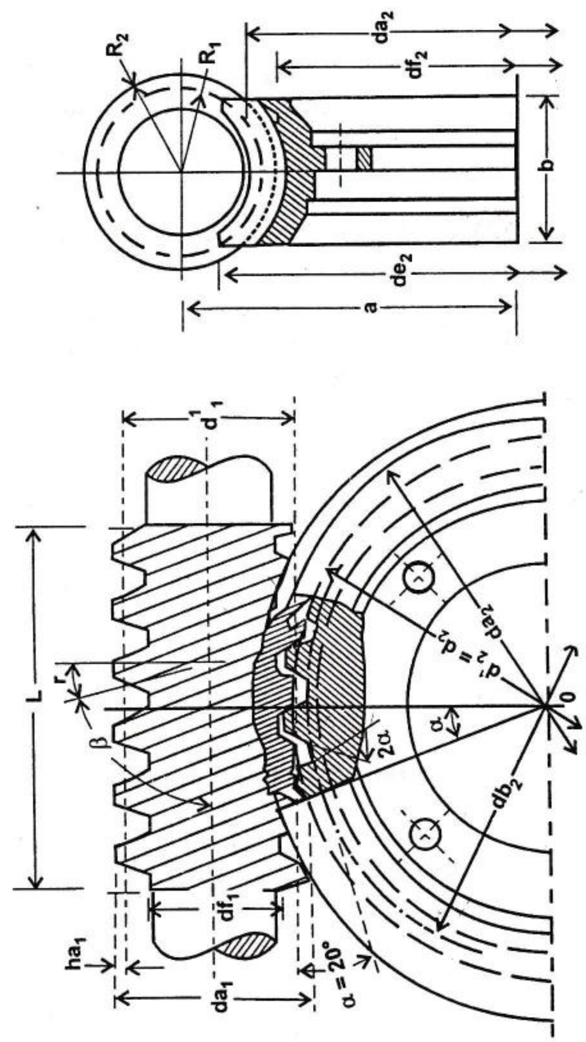


Fig. 27.1: Worm gear

Table 27.1: Design Surface Stress*, $[\sigma_c]$, N/mm^2 (For worm gear drive)

Material		Sliding Velocity, V_s, m/s					
Worm	Wheel	0.25	0.5	1	2	3	4
Steel	Cast Iron	170 – 140	120	100	70	–	–
	Bronze	190	185	175	170	160	150

***Note:** The above values are for accurately cut and well lubricated worm gear pair. If these two conditions are not satisfied, reduce the above values by 30%. The above values need not be modified for fatigue life, as the main failure in worm gearing is due to seizure.

Table 27.2: Design Bending Stress, $[\sigma_b]$, N/mm^2

Material of wheel	Method of casting of wheel	σ_u, N/mm^2	Rotation in one direction only	Rotation in both directions
Bronze	Sand	$\sigma_u > 390$	78	64
	Chill		110	90
	Sand	$\sigma_u < 390$	50	35
	Chill		55	40
	Centrifugally cast		60	47
Cast Iron	Grade 25	250	30	20
	Grade 35	350	40	28

Table 27.3: Lead Angle, γ

No. of starts Z	Diameter Factor, q: 13	12	11	10	9	8
1	4° 23′ 55″	4° 45′ 49″	5° 11′ 40″	5° 42′ 38″	6° 20′ 25″	7° 07′ 30″
2	8° 44′ 46″	9° 27′ 44″	10° 18′ 17″	11° 18′ 36″	12° 31′ 44″	14° 02′ 10″
3	12° 59′ 41″	14° 02′ 10″	15° 15′ 18″	16° 41′ 57″	18° 26′ 06″	20° 33′ 22″
4.	17° 06′ 10″	18° 26′ 06″	19° 58′ 59″	21° 48′ 05″	23° 57′ 45″	26° 33′ 54″

Table 27.4 : Selection of Number of Teeth, Z_2, on the Worm Wheel**

m_x, mm	4	5	5	6	6	8	8	10	10	12	12	16	20
q → / C, mm ↓	11	10	12	9	11	8	11	8	11	8	11	9	8
100	39	30	28	–	–	–	–	–	–	–	–	–	–
120	49	38	36	31	29	–	–	–	–	–	–	–	–
150	64	50	48	41	39	29*	–	–	–	–	–	–	–
180	79	62	60	51	49	37	34	28	–	–	–	–	–
210	–	74	72	61	59	44*	41*	34	31	–	–	–	–
240	–	–	–	71	69	52	49	40	37	32	29	–	–
270	–	–	–	81	79	59*	56*	46	43	37	34	–	–
300	–	–	–	–	–	67	64	52	49	42	39	28*	–
360	–	–	–	–	–	82	79	64	61	52	49	36	28
420	–	–	–	–	–	–	–	76	73	62	59	43*	34
480	–	–	–	–	–	–	–	–	–	72	69	51	40
540	–	–	–	–	–	–	–	–	–	82	79	58*	46
600	–	–	–	–	–	–	–	–	–	–	–	66	52

** Z_2 could be ± 2 teeth from values found from the table above except numbers marked with* where the deviation permissible is -1 or $+2$ teeth.

Table 27.5

Number of starts of worm (Z)	Face width of the wheel (b)	Length of the worm (L)	Approximate efficiencies in worm-gear drive (η)
1.	$0.75\ d_1$	$L \geq (11 + 0.06\ Z_2)\ m_x$	0.70 to 0.75
2.	$0.75\ d_1$	$L \geq (11 + 0.06\ Z_2)\ m_x$	0.70 to 0.82
3.	$0.75\ d_1$	$L \geq (12.5 + 0.09\ Z_2)\ m_x$	0.80 to 0.92
4.	$0.67\ d_1$	$L \geq (12.5 + 0.09\ Z_2)\ m_x$	0.80 to 0.92

Note: For ground worm, increase L to get L_1

For $m_x < 10$ mm by 25 mm

$m_x = 10$ to 16 by 35 to 40 mm

$m_x > 16$ mm by 50 mm

To avoid dynamic unbalance, length of the cut portion of worm must be multiples of axial pitch.

$\lambda = \dfrac{L_1}{\pi \, m_x}$ should be rounded off

so that the final length of cut portion of worm $L_2 = \lambda \, \pi \, m_x$

Efficiency of worm gear drive (when worm is driving)

$$\eta = \frac{\tan \gamma}{\tan (\gamma + \rho)}$$

γ, lead angle, deg.

ρ, friction angle deg.

μ, $\tan \rho$, from graph in fig. 27.2

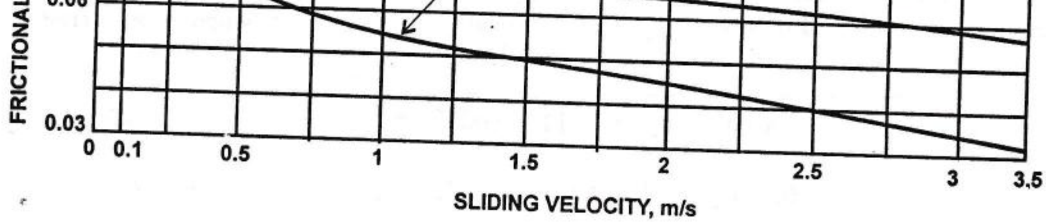


Fig. 27.2

CHAPTER – 28

CAM DRIVES

Symbols : (with S.I. units).

A	–	Over hang length, mm (Fig. 28.3)
B	–	Follower bearing length, mm (Fig. 28.3)
b	–	Face width of cam
E_1	–	Modulus of elasticity of cam material, N/mm^2
E_2	–	Modulus of elasticity of follower material, N/mm^2
e	–	Follower offset from cam axis, mm.
F	–	Lifting force supplied by the cam on the follower, N
F_n	–	Normal force acting on the cam surface, N
f	–	Cam factor
h	–	Light or maximum displacement of the follower, mm.
n	–	Speed of cam shaft, rpm
P	–	Power supplied to the cam, kW
R	–	Distance of trace point from the cam centre, mm
R_a	–	Radius of pitch circle, mm

R_b – Radius of base circle, mm

R_p – Radius of prime circle, mm

R_r – Radius of roller of the follower, mm

T – Torque transmitted by the camshaft, N-mm

v – Velocity of follower, m/s

W – External force acting on the follower, N

y – Follower motion expressed in terms of angle θ (i.e., displacement of follower), mm

$\frac{dy}{dt}$ – Velocity of follower $\left(\text{i.e., } \frac{dy}{dt} = v\right)$

$\frac{d^2y}{dt^2}$ – Acceleration of follower

$\frac{dy}{d\theta}$ – Change of displacement with respect to cam angle

α – Pressure angle, deg.

α_{max} – Maximum pressure angle, deg.

β – Cam angle for rise h, deg.

θ – Cam angle for displacement y, deg.

μ – Coefficient of friction

$\rho_{c\,min}$ – Minimum radius of curvature of cam profile, mm.

ρ_k – Radius of curvature of the pitch curve, mm

$\rho_{k\,min}$ – Minimum radius of curvature of the pitch curve, mm.

σ_c – Induced contact stress, N/mm^2

$[\sigma_c]$ – Allowable contact stress, N/mm^2

ω – Angular velocity of the cam, rad/s.

DESIGN PARTICULARS	EQUATIONS
Radial cam with translating Roller follower	
Torque transmitted by the cam-shaft	$T = \dfrac{60 \times 10^6 \times P}{2 \pi n}$ .... (28.1)
Lifting force supplied by the cam on the follower along the line of stroke	$F = \dfrac{T \omega}{1000 \times v}$ .... (28.2)
Normal force at the point of contact	$F_n = \dfrac{F}{\cos \alpha - \mu \left(\dfrac{2A + B}{B} \right) \sin \alpha}$ .... (28.3)
Maximum pressure angle (For parabolic, harmonic and cycloidal cams)	$\alpha_{max} = \tan^{-1} \left[\dfrac{\left(\dfrac{dy}{dt} \right)_{max}}{(R_p + y)\, \omega} \right]$ (For no offset condition) .... (28.4) $= \tan^{-1} \left[\dfrac{\left(\dfrac{dy}{d\theta} \right) - e}{\left(\sqrt{R_p^2 - e^2} \right) + y} \right]$ (For offset follower) .... (28.5)
Minimum radius of curvature of pitch curve (a) (For roller follower, convex profile and also for y at point of maximum negative acceleration)	$\rho_{k\,min} = \dfrac{\left[(R_p + y)^2 + \left(\dfrac{1}{\omega} \cdot \dfrac{dy}{dt} \right)^2 \right]^{3/2}}{(R_p + y)^2 + 2 \left(\dfrac{1}{\omega} \cdot \dfrac{dy}{dt} \right)^2 - (R_p + y) \left(\dfrac{1}{\omega^2} \dfrac{d^2 y}{dt^2} \right)}$ .... (28.6) $> R_r$ to avoid undercutting

DESIGN PARTICULARS	EQUATIONS
(b) For roller follower, concave profile	$\rho_{k\,min} = \dfrac{R_p^2}{R_p - \dfrac{1}{\omega^2}\left(\dfrac{d^2 y}{dt^2}\right)}$ at $\theta = 0$ .... (28.7) > 0 to avoid under cutting
Base circle radius	$R_b = R_p - R_r$ .... (28.8)
Pitch circle radius in terms of cam-factor	$R_a = \dfrac{fh}{\beta}$ (Here β in radians) .... (28.9)
Minimum radius of curvature of cam profile	$\rho_{c\,min} = \rho_{k\,min} - R_r$ .... (28.10)
Face width of cam	$b = 0.35\left[\dfrac{F_n E_1 E_2}{[\sigma_c]^2 (E_1 + E_2)}\left\{\dfrac{1}{R_r} \pm \dfrac{1}{\rho_{c\,min}}\right\}\right]$ .... (28.11)
Induced contact stress	$\sigma_c = 0.591\sqrt{\dfrac{F_n E_1 E_2}{b\,(E_1 + E_2)}\left\{\dfrac{1}{R_r} \pm \dfrac{1}{\rho_{c\,min}}\right\}} \le [\sigma_c]$ .... (28.12) (In equations 28.11 & 28.12, plus sign for convex profile and minus sign for concave profile)

Table 28.1: Characteristic Equations of Basic Curves of Cam

Curves	Displacement, y	Velocity, v	Acceleration, a

Table 28.1: Characteristic Equations of Basic Curves of Cam

Curves	Displacement, y	Velocity, v	Acceleration, a
St. line	$h\,\theta/\beta$	$\omega\,h/\beta$	$\infty, 0, -\infty$
Circular arc	$H - \left[H^2 - R_a^2\,\theta^2\right]^{1/2}$	$\omega\,R_a^2\,\theta / \left[H^2 - (R_p^2\,\theta^2)\right]^{1/2}$	$(\omega\,R_a\,H)^2 / \left[H^2 - (R_a^2\,\theta^2)\right]^{3/2}$
SHM	$\frac{h}{2}\left(1 - \cos\frac{\pi\,\theta}{\beta}\right)$	$\frac{h\,\pi\,\omega}{2\,\beta}\left(\sin\frac{\pi\,\theta}{\beta}\right)$	$\frac{h}{2}\left(\frac{\pi\,\omega}{\beta}\right)^2 \cos\frac{\pi\,\theta}{\beta}$
Double harmonic	$\frac{h}{2}\left[\left(1 - \cos\frac{\pi\theta}{\beta}\right) - \frac{1}{4}\left(1 - \cos\frac{2\pi\theta}{\beta}\right)\right]$	$\frac{h\,\pi\,\omega}{2\,\beta}\left(\sin\frac{\pi\,\theta}{\beta} - \frac{1}{2}\sin\frac{2\,\pi\,\theta}{\beta}\right)$	$\frac{h}{2}\left(\frac{\pi\,\omega}{\beta}\right)^2\left(\cos\frac{\pi\,\theta}{\beta} - \cos\frac{2\pi\theta}{\beta}\right)$
Cycloidal	$\frac{h}{\pi}\left(\frac{\pi\,\theta}{\beta} - \frac{1}{2}\sin\frac{2\,\pi\,\theta}{\beta}\right)$	$\frac{h\,\omega}{\beta}\left(1 - \cos\frac{2\,\pi\,\theta}{\beta}\right)$	$\frac{2h\,\pi\,\omega^2}{\beta^2}\sin\frac{2\,\pi\,\theta}{\beta}$
Parabolic or Const. Accn.	$\frac{\theta}{\beta} \le 0.5$: $2h\left(\frac{\theta}{\beta}\right)^2$	$4h\,\omega\,\theta/\beta^2$	$4h\,\omega^2/\beta^2$
	$\frac{\theta}{\beta} \ge 0.5$: $h\left[1 - 2\left(1 - \frac{\theta}{\beta}\right)^2\right]$	$\frac{4h\,\omega}{\beta}(1 - \theta/\beta)$	$-4h\,\omega^2/\beta^2$
Cubic no. 1 or Const. pulse no. 1	$\frac{\theta}{\beta} \le 0.5$: $4h\left(\frac{\theta}{\beta}\right)^3$	$\frac{12h\,\omega}{\beta}\left(\frac{\theta}{\beta}\right)^2$	$\frac{24h\,\omega^2}{\beta^2}\left(\frac{\theta}{\beta}\right)$
	$\frac{\theta}{\beta} \ge 0.5$: $h\left[1 - 4\left(1 - \frac{\theta}{\beta}\right)^3\right]$	$\frac{12\,h\,\omega}{\beta}\left(1 - \frac{\theta}{\beta}\right)^2$	$-\frac{24h\,\omega^2}{\beta^2}\left(1 - \frac{\theta}{\beta}\right)$
Cubic or Const. pulse no. 2	$h\left(\frac{\theta}{\beta}\right)^2\left(3 - 2\frac{\theta}{\beta}\right)$	$\frac{6h\,\omega\,\theta}{\beta^2}\left(1 - \frac{\theta}{\beta}\right)$	$\frac{6h\,\omega^2}{\beta^2}\left(1 - 2\frac{\theta}{\beta}\right)$
2-3 Polynomial	$h\left[3\left(\frac{\theta}{\beta}\right)^2 - 2\left(\frac{\theta}{\beta}\right)^3\right]$	$\omega\,h\left[6\frac{\theta}{\beta} - 6\left(\frac{\theta}{\beta}\right)^2\right]$	$\omega^2\,h\left[6 - 12\frac{\theta}{\beta}\right]$
3-4-5 Polynomial	$h\left[10\left(\frac{\theta}{\beta}\right)^3 - 15\left(\frac{\theta}{\beta}\right)^4 + 6\left(\frac{\theta}{\beta}\right)^5\right]$	$\frac{\omega h}{\beta}\left[30\left(\frac{\theta}{\beta}\right)^2 - 60\left(\frac{\theta}{\beta}\right)^3 + 30\left(\frac{\theta}{\beta}\right)^4\right]$	$\frac{h\omega^2}{\beta^2}\left[60\frac{\theta}{\beta} - 180\left(\frac{\theta}{\beta}\right)^2 + 120\left(\frac{\theta}{\beta}\right)^3\right]$

h – maximum rise of follower
β – cam angle for rise h
ω – angular velocity of cam
θ – cam angle for displacement y
H – Radius of circular arc
R_a – Radius of pitch circle

Table 28.2: Displacement Ratio y/h*

Cam angle divisions	Parabolic	Simple harmonic motion (SHM)	Cycloidal
0	0.000000	0.000000	0.000000
1	0.003472	0.004278	0.000474
2	0.013889	0.017037	0.003756
3	0.031250	0.038060	0.012461
4	0.055556	0.066987	0.028835
5	0.086806	0.103323	0.054602
6	0.125000	0.146447	0.090845
7	0.170139	0.195629	0.137935
8	0.222222	0.250000	0.195501
9	0.281250	0.308658	0.262461
10	0.347222	0.370590	0.337089
11	0.420139	0.434737	0.417141
12	0.500000	0.500000	0.500000
13	0.579861	0.565263	0.582859
14	0.652778	0.629410	0.662911
15	0.718750	0.691341	0.737539
16	0.777778	0.750000	0.804499
17	0.829861	0.804371	0.862065
18	0.875000	0.853553	0.909155
19	0.913194	0.896677	0.945398
20	0.944444	0.933013	0.971165
21	0.968750	0.961940	0.987539
22	0.986111	0.982963	0.996244
23	0.996528	0.995722	0.999526
24	1.000000	1.000000	1.000000

* y = rise of cam for the respective angle division.

h = total rise of cam for 24 divisions.

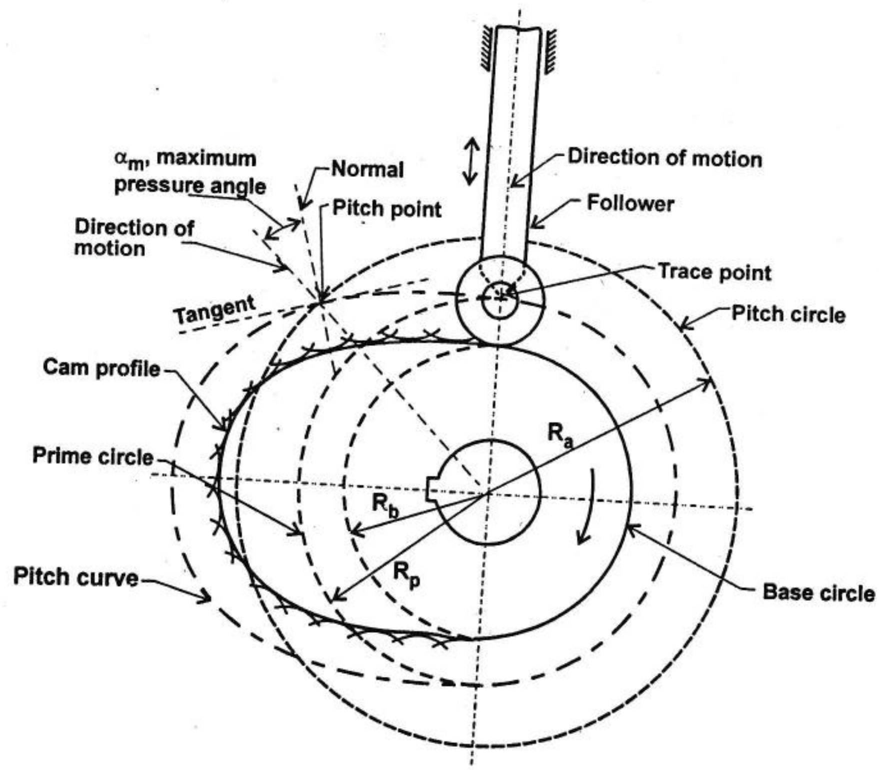
ycloidal
.000000
.000474
.003756
.012461
.028835
.054602
.090845
.137935
.195501
.262461
.337089
.417141
.500000
.582859
.662911
.737539
.804499
.862065
.909155
.945398
.971165
.987539
.996244
.999526
.000000

Table 28.3: Cam Factor, f

Basic curve	f
Straight line	$\cot \alpha_m$
Straight line-circular arc (circular arc radius = total rise)	$2 \tan \frac{\alpha_m}{2} + \cot \alpha_m$
Circular arc	$\cot \frac{\alpha_m}{2}$
Simple harmonic	$\frac{\pi}{2} \cot \alpha_m$
Double harmonic	$2 \cot \alpha_m$
Cycloidal	$2 \cot \alpha_m$
Parabolic	$2 \cot \alpha_m$
Cubic No. 1	$3 \cot \alpha_m$
Cubic No. 2	$3/2 \cot \alpha_m$

Table 28.4: Allowable Contact Stress Values for Cam Materials:

Cam material fitted with hardened steel roller	Allowable (i.e., design) contact stress $[\sigma_c]$ N/mm^2
Gray iron casting (140 – 160 HB) (phosphate coated)	400
Gray iron casting (200 – 220 HB)	500
Gray iron casting (225 – 255 HB)	600
Gray iron casting (255 – 300 HB) (Heat treated)	670
C20 (130 – 150 HB)	630
C20 Carburised (50 – 58 HRC)	1770
40 Cr 1 Mo 28 Heat treated to (270 – 300 HB)	1470



CAM Nomenclature

Fig. 28.1

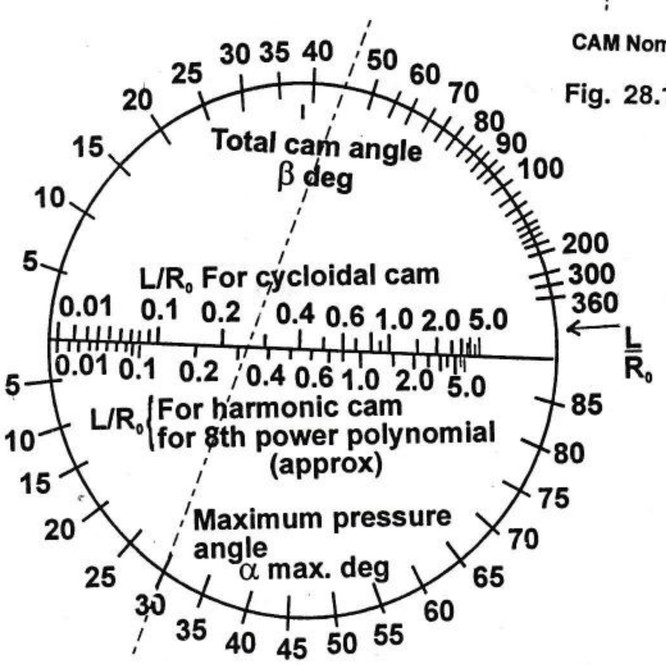


Fig. 28.2 Vamum's Nomogram

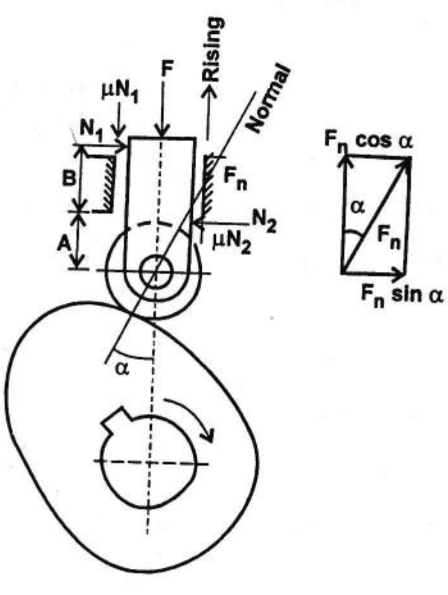
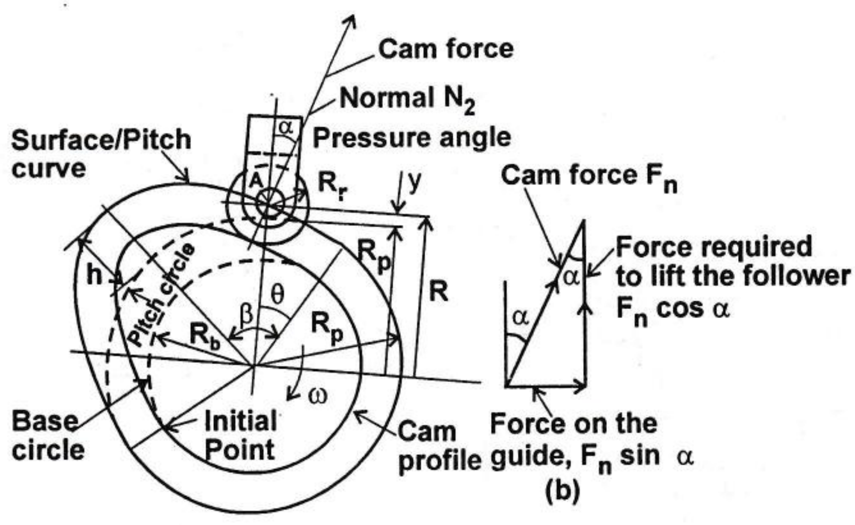


Fig. 28.3



(a)

Fig. 28.4: Radial cam with translating roller follower

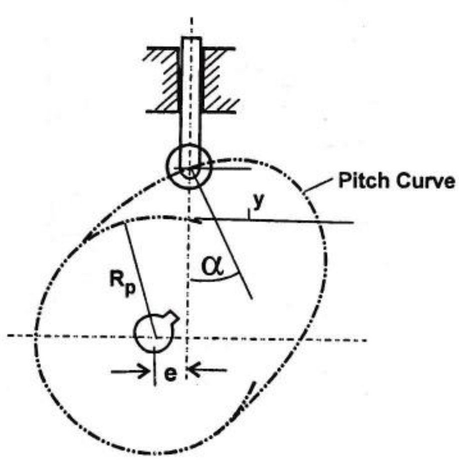
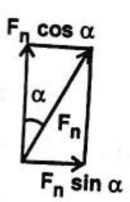
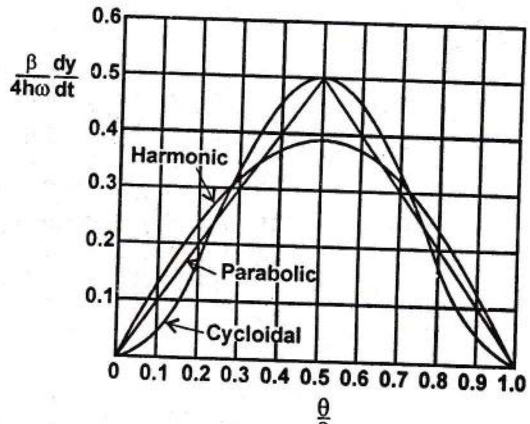
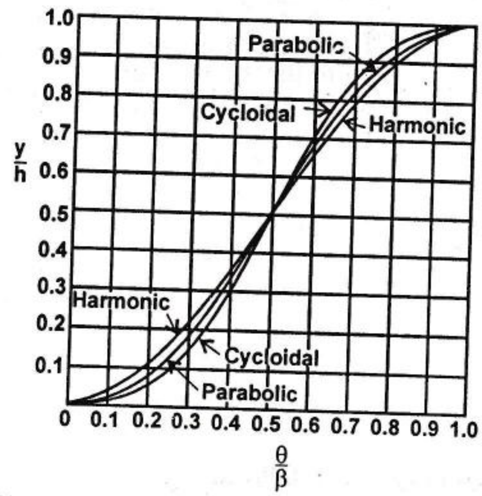


Fig. 28.5

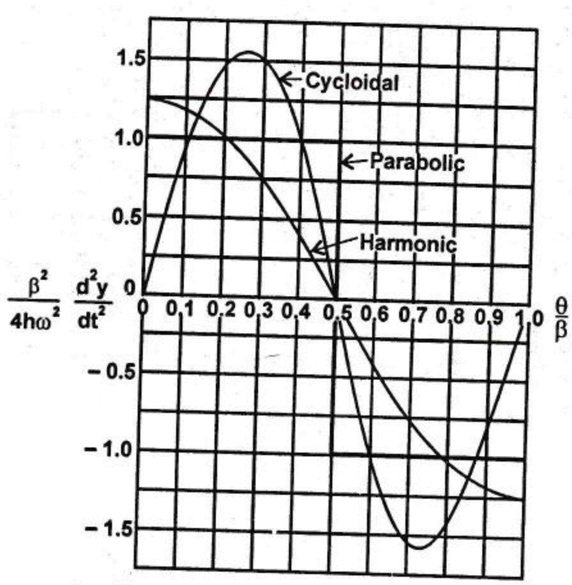




Velocity of follower for various types of cams

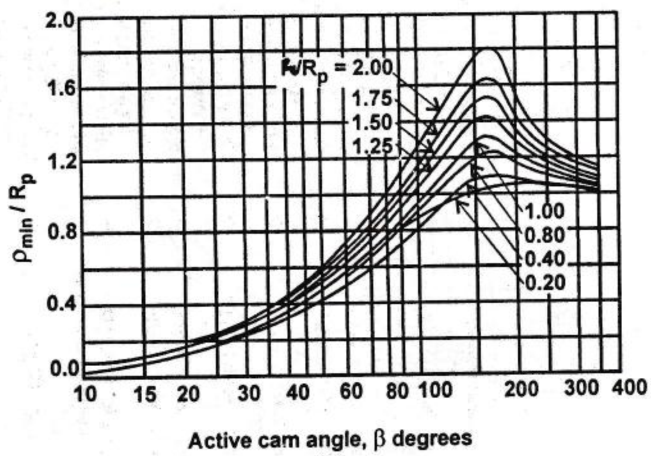


Displacement of follower for various types of cams

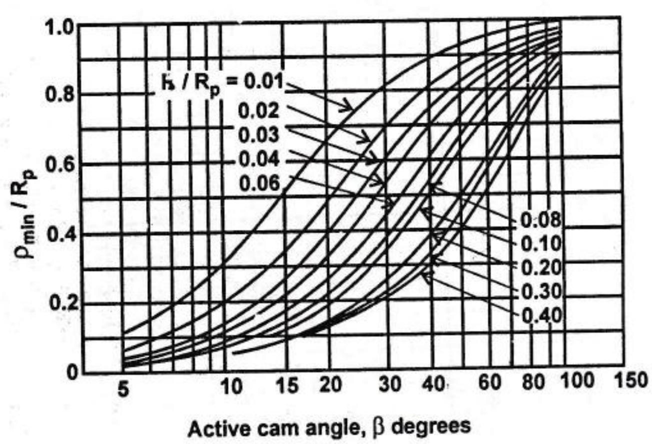


Acceleration of follower for various types of cams

Fig. 28.6

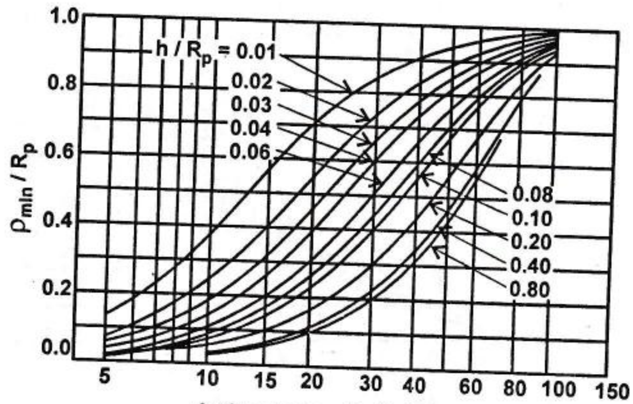


(a)

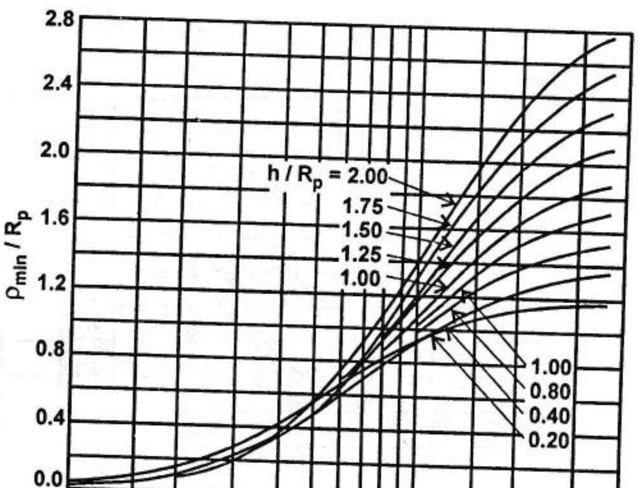


(b)

Fig. 28.7. Determination of ρ_{min} for a Cam having follower motion of Cycloid



(a)



(b)

Fig. 28.8. Determination of ρ_{min} for a Cam having follower motion of an eighth power polynomial

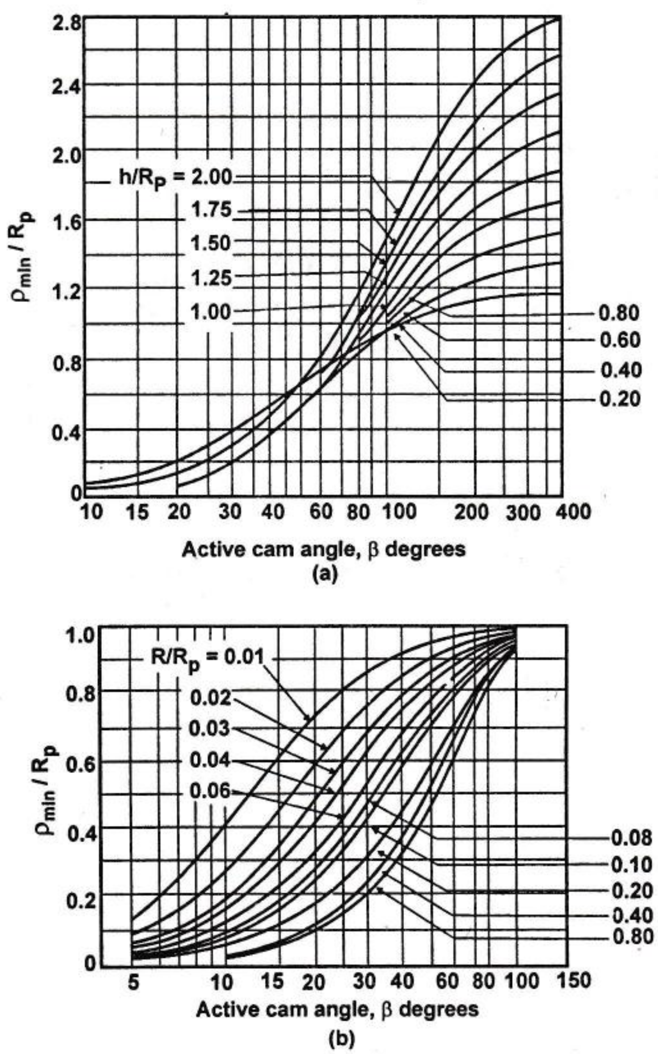


Fig. 28.9. Determination of ρ_{min} for a Cam Having Simple Harmonic Follower Motion

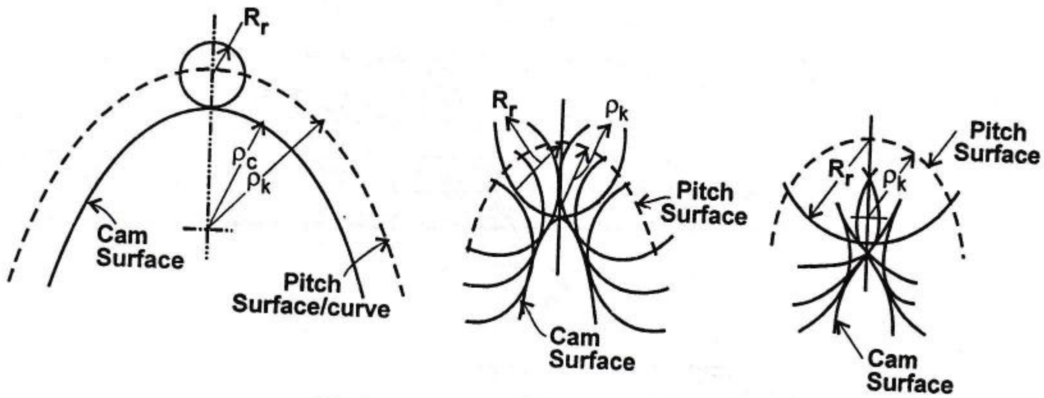


Fig. 28.10. Cam profiles for undercutting

Pitch
urface

CHAPTER – 29

ARRESTING GEAR (RATCHET & PAWL MECHANISM)

Symbols : (with S.I. Units)

a	–	Tooth thickness of ratchet, mm
a_1	–	Clearance between the ratchet & pawl setup and frame, mm
b	–	Face width of ratchet tooth, mm
D	–	Outer (or Tip) circle diameter of ratchet, mm
d	–	Diameter of pawl-pin, mm
F	–	Peripheral force, N
h	–	Tooth height of ratchet, mm
L	–	Length of pawl, mm
M_t	–	Torque to be arrested or nullified, N-mm
m	–	Module for ratchet tooth, mm
n	–	Speed of motor shaft which produces the torque M_t, rpm.
P	–	Power of motor or engine, kW
p	–	Induced unit pressure, N/mm ($p = F/b$)
[p]	–	Design linear unit pressure, N/mm (Table – 29.2)
p_c	–	Circular pitch, mm
x	–	Thickness of free end of pawl, mm (Fig. 29.1)
Z	–	Number of teeth of ratchet
$[\sigma_b]$	–	Design bending stress of ratchet material, N/mm^2
$[\sigma_{b1}]$	–	Design bending stress of pawl material, N/mm^2
ϕ	–	Ratchet tooth angle, deg. ($\phi = 14°$ to $17°$)
ρ	–	Friction angle, deg. ($\rho = \tan^{-1} \mu$)
ψ	–	Ratio of face width to module ($\psi = b/m$)
μ	–	Coefficient of friction between ratchet tooth and pawl
μ_1	–	Coefficient of friction between pawl and pin.

DESIGN PARTICULARS	EQUATIONS
Torque developed (which is to be nullified i.e., arrested by the Ratchet & pawl mechanism)	$M_t = \dfrac{60 \times 10^6 \times P}{2 \pi n}$ .... (29.1)
Ratchet:	
Module for ratchet teeth	$m = 2 \times \sqrt[3]{\dfrac{M_t}{Z \psi [\sigma_b]}}$ .... (29.2)
	where $\psi = b/m = 1.5$ to 3.0
	$[\sigma_b] = 30$ to 50 N/mm^2 for C45 steel
	For Z, refer table 29.1
Outer diameter of ratchet	$D = mZ$ .... (29.3)
Face width of tooth	$b = \psi \cdot m$ .... (29.4)
Tooth thickness	$a = m$ .... (29.5)
Tooth height	$h = 0.75$ m .... (29.6)
Circular pitch of ratchet	$p_c = \pi m$ .... (29.7)
Induced unit pressure	$p = \dfrac{2 M_t}{D.b} \le [p]$ .... (29.8)
Pawl:	
Diameter of pawl-pin	$d = 2.71 \times \sqrt[3]{\dfrac{F}{2\left[\sigma_{b1}\right]}\left(\dfrac{b}{2} + a_1\right)}$ .... (29.9)

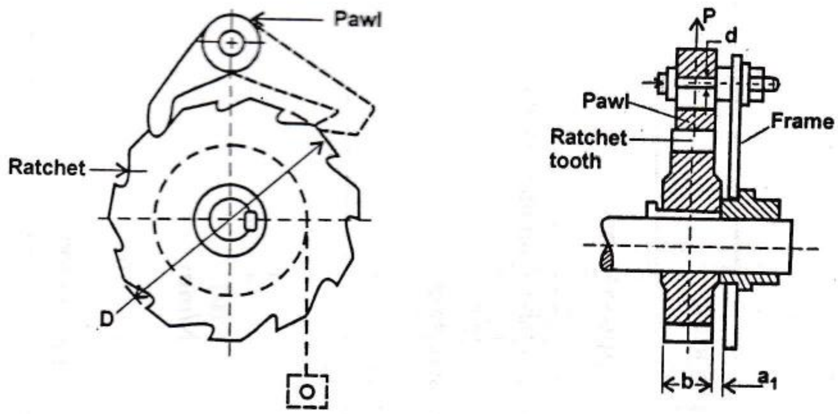


Fig. 29.1(a): Ratchet and pawl mechanisms.

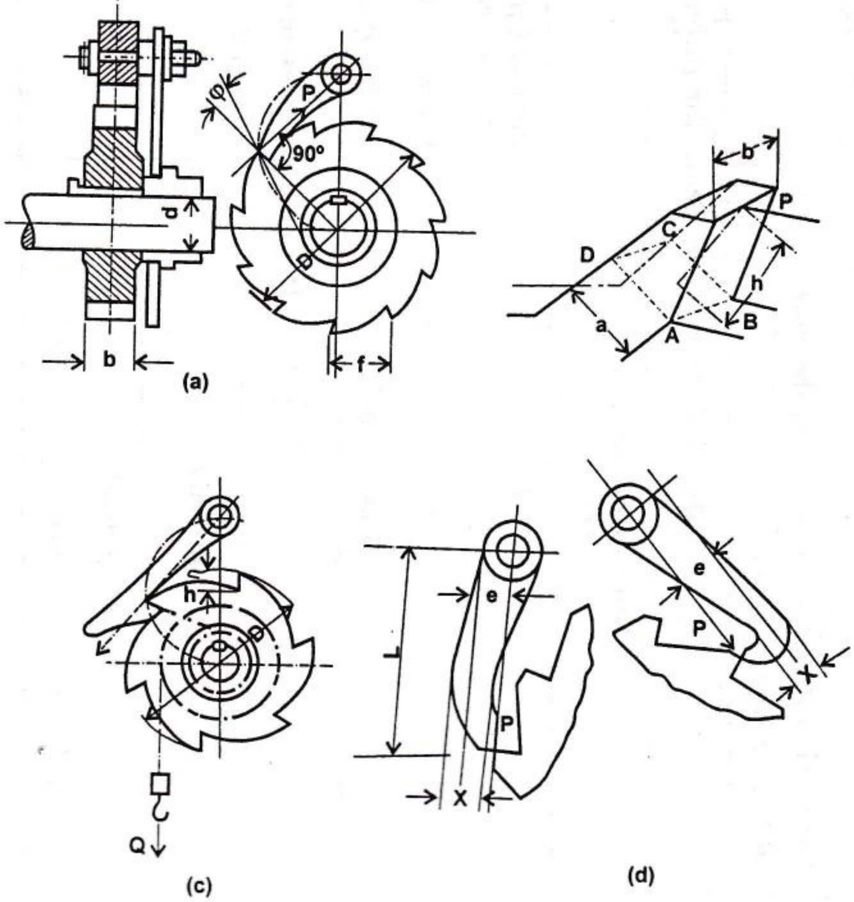


Fig. 29.1(b): Ratchet gearing with external teeth.

DESIGN PARTICULARS	EQUATIONS
Length of pawl	$L > \frac{\mu_1 d}{2(\tan\phi - \mu)\cos^2\phi}$ & $L \geq 2\,p_c$ ... (29.10)
Combined tensile and bending stress	$\sigma = \frac{F}{bx} + \frac{6\,Fe}{bx^2} \leq [\sigma_{b1}]$ ... (29.11)
Note: For best conditions of sliding, the ratchet tooth angle $\phi > \rho$ where $\rho = \tan^{-1}\mu$	

Table 29.1: Number of Teeth for Different Applications

Number of teeth (Z)	Applications
6 to 8	Rack and pinion jack, ratchets applied to the lifted loads (worm hoists)
12 to 20	Independent ratchet arresters.
16 to 25 and more	Ratchet type brakes.

29.2: Design Unit Pressure [p]

Material	[p] N/mm
Steel pawl and cast-iron ratchet	50 to 100
Steel pawl and steel ratchet	150 to 300

CHAPTER – 30

FINITE ELEMENT TECHNIQUES

Symbols : (with S.I. Units)

A	–	Area of cross-section of bar, mm^2
E	–	Modulus of elasticity of bar, beam, frame etc, N/mm^2
F_a	–	Axial force, N
F_s	–	Shear force, N
F_1, F_2, F_3	–	One directional forces at nodes 1, 2, 3 respectively, N
F_{1x}, F_{2x}, F_{3x}	–	Forces acting at nodes 1, 2, 3 in x-direction, N
F_{1y}, F_{2y}, F_{3y}	–	Forces acting at nodes, 1, 2, 3 in y-direction, N
$\{F\}$	–	Column vector for denoting nodal forces of system.
$\{f\}$	–	Column vector for denoting nodal forces of an element.
I	–	Moment of inertia of the cross sectional area, mm^4
k_1, k_2, k_3	–	Stiffnesses of elements or springs 1, 2, 3 respectively.
[K]	–	Stiffness matrix of a system containing many elements
[k]	–	Stiffness matrix of an element.
L	–	Length of bar, beam, frame etc., mm.
M	–	Bending moment about Z-axis, N-mm.

u_1, u_2, u_3	–	Linear displacements in x directions at nodes 1, 2, 3 respectively.
v_1, v_2, v_3	–	Linear displacements in y-directions at nodes 1, 2, 3 respectively
$\{U\}$	–	Column vector denoting nodal displacements of system containing many elements.
$\{u\}$	–	Column vector denoting nodal displacements of an element.
$\theta\left(=\frac{dv}{dx}\right)$	–	Slope (or rotation about the Z-axis)

General Finite Element (F.E) equation for linear element relating force with displacement:

Element F.E. equation : $[k]\{u\}=\{f\}$

F.E equation for complete system : $[K]\{U\}=\{F\}$

where $[K] = \Sigma\,[k]$

$[U] = \Sigma\{u\}$

$\{F\} = \Sigma\{f\}$

and

$[K]$ & $[k]$	–	Square matrices denoting system stiffness and element stiffness respectively
$\{U\}$ & $\{u\}$	–	Column vectors denoting nodal displacement of system and element respectively
$\{F\}$ & $\{f\}$	–	Column vectors denoting nodal forces of system and element respectively.

Spring System :

(i) Single – spring system : (Fig. 30.1)

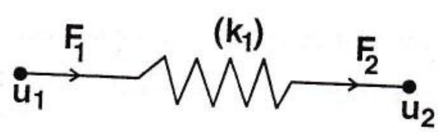


Fig. 30.1

$$\begin{bmatrix} k_1 & -k_1 \\ -k_1 & k_1 \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix} = \begin{Bmatrix} F_1 \\ F_2 \end{Bmatrix}$$

(ii) Two spring system : (Fig. 30.2)

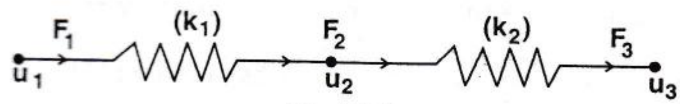


Fig. 30.2

$$\begin{bmatrix} k_1 & -k_1 & 0 \\ -k_1 & k_1+k_2 & -k_2 \\ 0 & -k_2 & k_2 \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \\ u_3 \end{Bmatrix} = \begin{Bmatrix} F_1 \\ F_2 \\ F_3 \end{Bmatrix}$$

(iii) n – spring system : (Fig. 30.3)

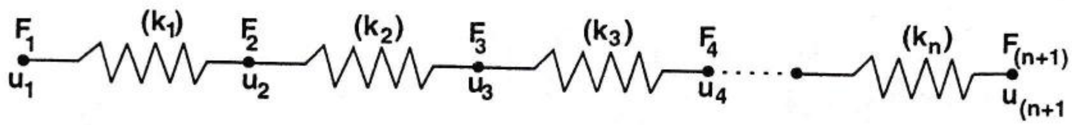


Fig. 30.3

$$\begin{bmatrix} k_1 & -k_1 & 0 & 0 & 0 & 0 & 0 & 0 \\ -k_1 & (k_1+k_2) & -k_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & -k_2 & (k_2+k_3) & -k_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & -k_3 & (k_3+k_4) & \cdot & \cdot & \cdot & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & -k_n \\ 0 & 0 & 0 & 0 & \cdot & \cdot & -k_n & k_n \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \\ u_3 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ u_{n+1} \end{Bmatrix} = \begin{Bmatrix} F_1 \\ F_2 \\ F_3 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ F_{n+1} \end{Bmatrix}$$

Note :

For	n	elements (i.e., springs)
there are	n	stiffnesses
	n + 1	nodes,
	n + 1	nodal displacements,
and	n + 1	nodal forces

(iv) One dimensional bar element: (Fig. 30.4)

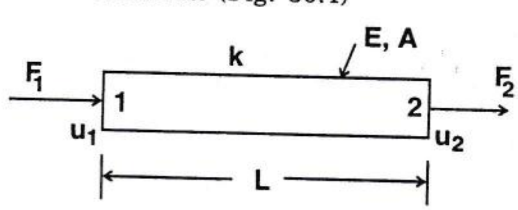


Fig. 30.4

$$\frac{AE}{L}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}\begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix} = \begin{Bmatrix} F_1 \\ F_2 \end{Bmatrix}$$

Note:

One dimensional bar element is similar to spring system where k is replaced by $\left(\frac{AE}{L}\right)$ i.e., $k = \frac{AE}{L}$ in bar element

Trusses:

General F.E. equation:- $[K]\{U\} = \{F\}$ for complete system

and $[k]\{u\} = \{f\}$ for any element

Element stiffness matrix (i.e., for single truss) (Fig. 30.5)

$$[k]_e = \frac{AE}{L}\begin{bmatrix} C^2 & CS & -C^2 & -CS \\ CS & S^2 & -CS & -S^2 \\ -C^2 & -CS & C^2 & CS \\ -CS & -S^2 & CS & S^2 \end{bmatrix}$$

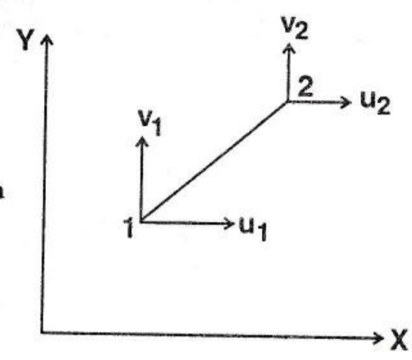


Fig. 30.5

(v) Element F.E. equation for single truss system

$$\frac{AE}{L}\begin{bmatrix} C^2 & CS & -C^2 & -CS \\ CS & S^2 & -CS & -S^2 \\ -C^2 & -CS & C^2 & CS \\ -CS & -S^2 & CS & S^2 \end{bmatrix}\begin{Bmatrix} u_1 \\ v_1 \\ u_2 \\ v_2 \end{Bmatrix} = \begin{Bmatrix} F_{1x} \\ F_{1y} \\ F_{2x} \\ F_{2y} \end{Bmatrix}$$

where $C = \cos\theta$

$S = \sin\theta$

θ measured in anticlockwise direction

(vi) F.E. equation for multi (say three) truss system (Fig. 30.6)

$$\left[k_{e1} + k_{e2} + k_{e3}\right]\begin{Bmatrix} u_1 \\ v_1 \\ u_2 \\ v_2 \\ u_3 \\ v_3 \end{Bmatrix} = \begin{Bmatrix} F_{1x} \\ F_{1y} \\ F_{2x} \\ F_{2y} \\ F_{3x} \\ F_{3y} \end{Bmatrix}$$

where $k_{ei} = \frac{A_i E_i}{L_i}\begin{bmatrix} C^2 & CS & -C^2 & -CS \\ CS & S^2 & -CS & -S^2 \\ -C^2 & -CS & C^2 & CS \\ -CS & -S^2 & CS & S^2 \end{bmatrix}$

$C = \cos\theta_i$; $S = \sin\theta_i$ and $i = 1, 2, 3$

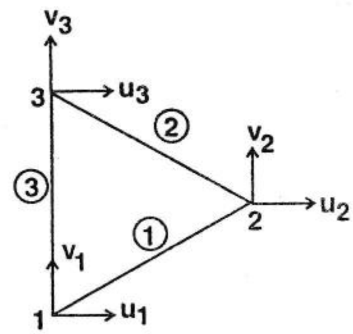


Fig. 30.6

(vii) Beam element: (Fig. 30.7)

F.E. equation for single beam

$$\frac{EI}{L^3}\begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^2 & -6L & 2L^2 \\ -12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L^2 \end{bmatrix}\begin{Bmatrix} v_1 \\ \theta_1 \\ v_2 \\ \theta_2 \end{Bmatrix} = \begin{Bmatrix} F_{s1} \\ M_1 \\ F_{s2} \\ M_2 \end{Bmatrix}$$

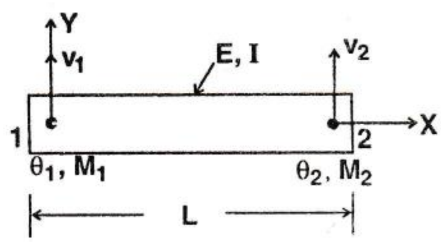


Fig. 30.7

(viii) **Plane – Frame element (Fig. 30.8)**

F.E. equation for single plane-frame element

$$\frac{EI}{L^3}\begin{bmatrix} \frac{AL^2}{I} & 0 & 0 & -\frac{AL^2}{I} & 0 & 0 \\ 0 & 12 & 6L & 0 & -12 & 6L \\ 0 & 6L & 4L^2 & 0 & -6L & 2L^2 \\ -\frac{AL^2}{I} & 0 & 0 & \frac{AL^2}{I} & 0 & 0 \\ 0 & -12 & -6L & 0 & 12 & -6L \\ 0 & 6L & 2L^2 & 0 & -6L & 4L^2 \end{bmatrix}\begin{Bmatrix} u_1 \\ v_1 \\ \theta_1 \\ u_2 \\ v_2 \\ \theta_2 \end{Bmatrix} = \begin{Bmatrix} F_{a1} \\ F_{s1} \\ M_1 \\ F_{a2} \\ F_{s2} \\ M_2 \end{Bmatrix}$$

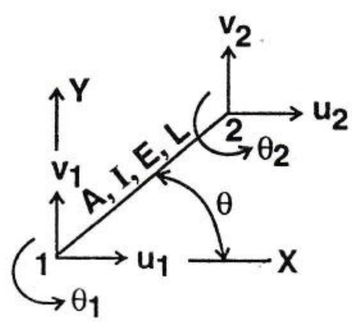


Fig. 30.8

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