

# Contents

Preface

Acknowledgments

## Unit 1 - Drives

### 1. Belts and Pulleys

1.1	Introduction	1
1.1.1	Advantages	2
1.1.2	Disadvantages	2
1.2	Types of Belts	2
1.2.1	Flat belts	3
1.2.2	V belts	3
1.2.3	Construction of V belts	4
1.3	Types of Flat Belt Drive	5
1.3.1	Open belts	5
1.3.2	Crossed belts	6
1.3.3	Quarter twist belts	6
1.3.4	Compound belts	6
1.3.5	Serpentine belts	7
1.4	Belt Materials and Construction	7
1.5	Properties of Belt Materials	9
1.6	Flat Belt Specifications	9
1.7	Flat Belt Joints	10

1.8	Angle of Contact	12
1.8.1	Open belt	12
1.8.2	Cross belt	13
1.9	Power through a Belt	14
1.10	Belt Tensions	15
1.11	Belt Tensions Ratio (Capstan Equation)	15
1.11.1	Flat belts	15
1.11.2	V belts	16
1.12	Initial Tension	17
1.13	Centrifugal Tension	19
1.14	Maximum Tension	20
1.15	Condition for Maximum Power	21
1.16	Slip of Belt	22
1.17	Creep of Belt	23
1.18	Length of Belt	23
1.19	Design of Flat Belt Drive	28
1.20	Center Distance	32
1.21	Power Rating of V Belts	32
1.22	Life of Belts	33
1.23	Design of V Belt Drive	36
1.24	Types of Pulleys	43
1.25	Flat Belt Pulleys	44
1.25.1	Solid pulley	45
1.25.2	Webbed pulley	46
1.25.3	Armed pulley	46
1.25.4	Built-up pulley	49
1.25.5	Stepped pulley	50
1.25.6	Fast and loose pulley	51
1.26	Grooved Pulleys	51
1.26.1	Single belt grooved pulley	52
1.26.2	Multibelt grooved pulley	52
1.26.3	Stepped grooved pulley	53
1.27	Toothed Pulley	53
<b>2.</b>	<b>Rope Drives</b>	
2.1	Rope Drives	68
2.2	Fibre Rope Drive	69
2.2.1	Advantages	69
2.2.2	Fibre rope materials	69

2.3	Sheave for Fiber Ropes	70
2.4	Design of Rope Drive	70
2.5	Wire Ropes	74
2.5.1	Advantages of wire ropes	74
2.5.2	Wire rope material	74
2.6	Construction of Wire Ropes	75
2.6.1	Core	75
2.6.2	Wires	75
2.6.3	Strands	76
2.7	Lay of Wire Ropes	76
2.7.1	Regular lay	76
2.7.2	Lang lay	76
2.7.3	Ordinary lay	77
2.7.4	Alternate right and left lay	77
2.8	Types of Wire Ropes	77
2.8.1	Spiral ropes	77
2.8.2	Stranded ropes	77
2.9	Designation of Ropes	78
2.10	Classification of Wire Ropes	78
2.10.1	Classification according to usage	79
2.11	Wire Rope Terminations	79
2.12	Selection of Wire Ropes	81
2.12.1	Selecting a type of wire rope center	81
2.13	Stresses in Wire Rope	82
2.14	Drum and Sheave Arrangement	84
2.14.1	Construction of sheave	85
2.14.2	Groove size	86
2.14.3	Groove hardness	86
2.14.4	Throat angle	86
2.14.5	Fleet angle	86
2.14.6	Sheave alignment	87
2.15	Design Procedure for Wire Rope Drive	87
<b>3. Chain Drives</b>		
3.1	Introduction	104
3.2	Advantages / Disadvantages	106
3.3	Classification of Chains	106
3.3.1	Hoisting chains	107
3.3.2	Conveyor chains	107

3.3.3	Power transmission chains	107
3.3.4	Roller chains	108
3.3.5	Multiple-strand chains	108
3.4	Pitch and Pitch Circle Diameter	109
3.5	Minimum Number of Teeth	110
3.6	Chordal Action	111
3.7	Length of Chain and Center Distance	112
3.8	Chain Designation	114
3.9	Forces on Chain	117
3.10	Breaking Load and Factor of Safety	117
3.11	Power Capacity of Chains	118
3.12	Design Power and Corrected Power	119
3.12.1	Tooth correction factor	119
3.12.2	Load factor	119
3.12.3	Service factor	120
3.12.4	Lubrication factor	120
3.13	Maximum Number of Teeth	123
3.14	Maximum Chain Speed	123
3.15	Bearing Pressures	123
3.16	Design of Chain Drive	124
3.17	Silent Chains	132
3.17.1	Comparison with roller chains	132
3.17.2	Use of silent chains	132
3.17.3	Construction of silent chains	133
3.17.4	Standard widths	134
3.17.5	Specifying a chain	134
3.17.6	Selection and design tips	134
3.17.7	Chain designation	135
3.17.8	Factor of safety	135
3.17.9	Power capacity	136
3.17.10	Maximum speed of silent chain	136
3.18	Lubrication of Chains	139
3.19	Sprockets	139
3.19.1	Body styles	140
3.19.2	Sprocket mounting	140
3.19.3	Sprocket proportions	141

**4. Gear Fundamentals**

4.1	Introduction	151
4.2	Gear Drives versus Other Drives	152

4.3	Advantages and Disadvantages of Gear Drives	153
4.4	Types of Gear Drives	153
4.4.1	Spur gears	153
4.4.2	Helical gears	154
4.4.3	Bevel gears	154
4.4.4	Worm and worm wheel	155
4.5	Terminology	155
4.6	Types of Pitches	157
4.7	Gear Tooth Proportions and Standard Modules	158
4.8	Tooth Profiles	159
4.8.1	Cycloid profile	159
4.8.2	Involute profile	160
4.8.3	Properties of involute teeth	161
4.8.4	Involute versus cycloid profile	161
4.9	Involute Gear Tooth Systems	162
4.10	Base Circle	163
4.11	Law of Gearing	164
4.12	Velocity Ratio	164
4.13	Path of Contact	165
4.14	Arc of Contact	167
4.15	Contact Ratio	169
4.16	Interference	171
4.16.1	Parameters affecting interference	172
4.17	Maximum Addendum Radius	172
4.18	Minimum Number of Teeth to Avoid Interference	173
4.18.1	Minimum teeth for a pinion	173
4.18.2	Minimum teeth for a gear wheel	174
4.18.3	Minimum teeth for a pinion with a rack	175
4.18.4	Largest gear with a specified pinion	179
4.19	Slide Velocity	179
<b>5.</b>	<b>Spur Gears</b>	
5.1	Introduction	191
5.2	Gear Materials	192
5.3	Gear Design Considerations	193
5.4	Gear Tooth Strength	193
5.4.1	Loads on gear tooth	193
5.4.2	Lewis equation	195

5.5	Dynamic Loads	199
5.5.1	Velocity factor	199
5.6	Buckingham's Equation for Dynamic Load	200
5.6.1	Dynamic load	200
5.6.2	Beam strength	201
5.6.3	Deformation factor	202
5.6.4	Errors in gears	203
5.6.5	Maximum allowable error	203
5.7	Gear Design for Wear Strength	205
5.7.1	Hertz stresses on tooth surface	205
5.7.2	Buckingham equation for wear	208
5.8	Factors Affecting Gear Design	212
5.8.1	Overload factor	212
5.8.2	Load distribution factor	212
5.8.3	Mounting factor	213
5.8.4	Surface finish factor	213
5.8.5	Rotation factor	213
5.8.6	Reliability factor	213
5.8.7	Size factor	214
5.8.8	Temperature factor	214
5.9	Design Procedure	214
5.9.1	Design procedure with given center distance	215
5.9.2	Design procedure when center distance is not given	219
5.10	Internal Gears	223
5.10.1	Advantages and disadvantages	224
5.10.2	Interference in internal gears	224
5.10.3	Design of internal gears	225
5.11	Non-circular Gears	227
<b>6.</b>	<b>Helical Gears</b>	
6.1	Introduction to Helical Gears	241
6.2	Terminology for Helical Gears	242
6.3	Types of Helical Gears	243
6.4	Face Width and Overlap	245
6.5	Gear and Tooth Proportions	245
6.6	Equivalent Number of Teeth of Helical Gears	247
6.7	Normal Modules	247
6.8	Forces on Tooth	248
6.9	Design of Helical Gears	249

6.10	Lewis Equation for Helical Gears	250
6.11	Effective Load	251
6.11.1	Service factor	251
6.11.2	Velocity factor	251
6.12	Dynamic Load	253
6.13	Wear Strength of Helical Gears	254
<b>7.</b>	<b>Bevel Gears</b>	
7.1	Introduction	271
7.2	Terminology	272
7.3	Types of Bevel Gears	273
7.4	Pitch Angle and Gear Ratio	274
7.5	Cone Distance	275
7.6	Proportions of Bevel Gear	276
7.7	Formulative Number of Teeth	276
7.8	Forces on Gear Tooth	277
7.8.1	Forces on tooth of pinion	277
7.8.2	Forces on tooth of bevel gear	279
7.9	Strength of Bevel Gear Tooth	280
7.10	Dynamic Load	283
7.11	Wear Strength	284
7.12	Spiral Bevel Gears	291
<b>8.</b>	<b>Worm Gears</b>	
8.1	Worm and Worm Wheel	300
8.2	Advantages / Disadvantages of the Drive	301
8.3	Applications	302
8.4	Terminology	302
8.5	Diameter Quotient	304
8.6	Pressure Angle	304
8.7	Types of Worms and Worm Wheels	305
8.7.1	Types of worms	305
8.7.2	Types of worm gears	305
8.8	Material Selection	306
8.8.1	Materials for worm	306
8.8.2	Materials for worm gear	307
8.9	Drive Proportions	308
8.9.1	Worm proportions	308
8.9.2	Worm gear proportions	309

8.10	Drive Designation	310
8.11	Center Distance	310
8.12	Force Analysis	314
8.13	Strength of Worm Gear Tooth	317
8.13.1	Strength in bending	317
8.13.2	Endurance strength	318
8.13.3	Strength in wear	321
8.14	Friction in Worm Drives	322
8.15	Efficiency of Worm Drive	322
8.16	Heat Generated	324
8.16.1	Heat transfer coefficient	326
8.16.2	Use of oil cooler	326
8.17	Design of Worm and Worm Wheel Drive	328
8.17.1	Approximate center distance given	328
8.17.2	Center distance not given	333
<b>9. Gear Trains and Gear Boxes</b>		
9.1	Function of a Gear Box	345
9.2	Applications	346
9.3	Construction	346
9.4	Gear Trains	346
9.4.1	Simple gear train	347
9.4.2	Compound gear train	347
9.5	Pitch Line Velocity	348
9.6	Epicyclic Gear Trains	351
9.7	Speed Ratio of Epicyclic Gear Trains	353
9.7.1	Translation method	353
9.7.2	Formula method 1	355
9.7.3	Formula method 2	356
9.7.4	Compound epicyclic gear trains	359
9.8	Torque Ratios of Epicyclic Gears	361
9.9	Classification of Gear Boxes	362
9.10	Selection of Type of Gear Box	364
9.11	Speed Ratios in Geometric Progression	365
9.12	Kinematic Diagram	367
9.13	Structural Formula	368
9.14	Structural Diagram	368
9.15	Number of Speeds and Stages	369
9.16	Alternate Structural Formulas	369

9.17	Transmission Ratio of a Stage	371
9.18	Optimum Structural Formula	372
9.19	Ray Diagram	373
9.20	Two-stage Gear Box with Fixed Ratio	384
9.21	Sliding Mesh Gear Box	384
9.22	Constant Mesh Gear Box	385
9.23	Synchromesh Gear Box	386
9.24	Gear Box Housing	387
9.25	Power Losses in Gear Box	388
9.26	Fluid Couplings	390
9.27	Torque Converters	392

**Unit 2 – Bearings**

<b>10.</b>	<b>Hydrodynamic Bearings</b>	
10.1	Introduction	406
10.2	Construction of Bearings	407
10.3	Classification of Bearings	407
10.4	Properties of Bearing Material	411
10.5	Bearing Materials	411
10.6	Properties of Lubricants	412
10.6.1	Viscosity	413
10.6.2	Units of viscosity	414
10.6.3	SAE designation of oils	414
10.6.4	Viscosity index	415
10.7	Hydrodynamic Lubrication	415
10.7.1	Terminology	415
10.7.2	Working principle	416
10.7.3	Reynolds equation	417
10.7.4	Long bearings	417
10.7.5	Short bearings	418
10.8	Finite Bearings	418
10.8.1	Eccentricity ratio and Sommerfeld number	418
10.8.2	Critical pressure	420
10.8.3	Unit load	420
10.8.4	Maximum pressure	421
10.9	Oil Flow through Bearings	423

13.8	Gudgeon Pin	526
13.8.1	Fixing of gudgeon pin	527
13.8.2	Design of gudgeon pin	527
<b>14.</b>	<b>Connecting Rod</b>	
14.1	Introduction	539
14.2	Construction	540
14.3	Forces on Connecting Rod	541
14.3.1	Axial force due to gas pressure	541
14.3.2	Axial force due to inertia of reciprocating parts	541
14.3.3	Bending force due to inertia of reciprocating parts	542
14.3.4	Frictional forces due to friction between piston rings and cylinder	543
14.3.5	Frictional forces due to friction between gudgeon pin and crank pin	544
14.4	Design of Connecting Rod	544
14.4.1	Small end of the rod	544
14.4.2	Cross section of connecting rod	545
14.4.3	Big end of the rod	548
14.4.4	Cap bolts	548
14.4.5	Strap thickness	549
<b>15.</b>	<b>Crank Shaft</b>	
15.1	Introduction	560
15.2	Types of Crank Shafts	561
15.3	Crank Materials	561
15.4	Forces on Crank Shaft	562
15.5	Design of Crank Shaft	562
15.5.1	Design of crank at dead center position	562
15.5.2	Design of crank at position of maximum torque	565
15.6	Design of Side Crank	575
<b>16.</b>	<b>Valve Gears</b>	
16.1	Valve Gear Mechanism	593
16.2	Ports	594
16.3	Valves	596
16.3.1	Valve temperatures	598
16.3.2	Valve materials	598
16.3.3	Size of valves	599
16.3.4	Lift of valves	600
16.3.5	Thickness of valve	600
16.3.6	Size of valve stem	601

16.3.7	Valve Timings	601
16.3.8	Forces on valves	602
16.4	Valve Spring	607
16.5	Rocker Arm	611
16.6	Rocker Shaft	615
16.7	Push Rod	616
16.7.1	Materials	616
16.7.2	Design of push rod	617
16.8	Cam Shaft	619
16.9	Cams	619
16.9.1	Followers	620
16.9.2	Lift diagrams	621
16.10	Drawing Cam Profile	622
16.10.1	Cam profile with a roller follower	623
16.10.2	Cam profile with a flat follower	624

## 17. Fly Wheels

17.1	Function	641
17.2	Construction of a Flywheel	642
17.3	Design of Shaft, Hub, and Key	642
17.4	Fluctuation in Energy and Speed	643
17.5	Rim Velocity	648
17.6	Stresses in Flywheel	649
17.6.1	Tensile stresses due to centrifugal force	649
17.6.2	Bending stresses due to constrained arms	650
17.7	Mass and Energy Stored in Flywheel	651
17.7.1	Solid flywheel	651
17.7.2	Flywheel with web	654
17.7.3	Flywheel with arms	655
17.7.4	Split flywheel	659
17.8	Flywheels for Engines	661
17.9	Flywheels for Punches	666

## Unit 4 – Design of Miscellaneous Parts

### 18. Clutches

18.1	Definition and Function	681
18.2	Types of Clutches	682

18.3	Positive Drive Clutch	683
18.4	Friction Clutch	683
18.4.1	Friction materials	684
18.4.2	Coefficient of friction	684
18.4.3	Variation of bearing pressure	685
18.4.4	Torque transmitting capacity	685
18.4.5	Maximum torque transmitting capacity	690
18.5	Design of a Single Plate Clutch	690
18.6	Time for Clutch Engagement	692
18.7	Heat Generated during Clutching	694
18.8	Multi-plate Clutch	699
18.9	Cone Clutch	701
18.9.1	Design of a cone clutch	702
18.10	Centrifugal Clutch	704
18.10.1	Construction and working	704
18.10.2	Design of a centrifugal clutch	705
<b>19. Brakes</b>		
19.1	Definition and Functions	719
19.2	Types of Brakes	720
19.3	Materials for Brake Lining	720
19.4	Energy Absorbed by Brakes	721
19.4.1	Pure rotation	721
19.4.2	Pure translation	722
19.4.3	Combined rotation and translation	722
19.5	Heat Dissipated	723
19.6	Lining Wear ( $p_v$ Value)	724
19.7	Block Shoe Brakes	726
19.7.1	Fixed block shoe brakes	726
19.7.2	Self-energizing brakes	729
19.7.3	Self-locking	729
19.7.4	Small / long shoe brake	730
19.7.5	Pivoted block brakes	733
19.7.6	Double block shoe brakes	734
19.8	Design Procedure for Block Shoe Brakes	737
19.9	Band Brakes	738
19.9.1	Simple band brakes	738
19.9.2	Differential band brakes	741
19.9.3	Band and block brakes	743

19.10 Internally Expanding Shoe	746
19.10.1 Analysis of internal shoe brakes	747
19.10.2 Shoe actuation	749
19.10.3 Shoe and brake factor	750
19.10.4 Maximum normal force for retarding wheel	751
19.11 Externally Contracting Brakes	754
19.12 Disc Brakes	755
19.12.1 Arctual pads	755
19.12.2 Disc brakes with circular pads	757
<b>20. Pressure Vessels</b>	
20.1 Introduction and Applications	772
20.2 Classification	773
20.3 Materials and Allowable Stresses	773
20.4 Corrosion Allowance	774
20.5 Class of Pressure Vessels	774
20.6 Stresses due to Internal Pressure	774
20.6.1 Circumferential stresses	774
20.6.2 Longitudinal stresses	775
20.6.3 Effect of pressure on size	777
20.7 Thick Cylinders	778
20.7.1 Lame's equation	779
20.7.2 Clavarino's equation	781
20.7.3 Birnie's equation	782
20.7.4 Barlow's equation	783
20.8 Thin Spherical Vessels	784
20.8.1 Plate thickness	784
20.8.2 Change in size of spherical pressure vessel with internal pressure	785
20.9 End Covers	787
20.9.1 Flat circular	787
20.9.2 Flat rectangular	788
20.9.3 Elliptical plate	789
20.9.4 Hemispherical	790
20.9.5 Dished	792
20.9.6 Semi-ellipsoid	793
20.9.7 Tori-spherical end cover	793
20.9.8 Conical end covers	794
20.10 Fixing of End Covers	795
20.10.1 Integral	796
20.10.2 Bolted	796

20.11 Welded Joints	797
20.12 Opening in Pressure Vessels	798
20.13 Boiler Code	798
<b>References</b>	<b>118</b>
<b>Index</b>	<b>183</b>
<hr/>	
19.10 Internally Expanding Shoe	797
19.10.1 Analysis of internal shoe brakes	798
19.10.2 Shoe actuation	798
19.10.3 Shoe and brake factor	118
19.10.4 Maximum normal force for retarding wheels for retarding wheels	183
19.11 Externally Contracting Brakes	797
19.12 Disc Brakes	797
19.12.1 Actual pads	797
19.12.2 Disc brakes with circular pads	797
<hr/>	
<b>Pressure Vessels</b>	
20.1 Introduction and Applications	797
20.2 Classification	797
20.3 Materials and Allowable Stresses	797
20.4 Corrosion Allowance	797
20.5 Class of Pressure Vessels	797
20.6 Stresses due to Internal Pressure	797
20.6.1 Circumferential stresses	797
20.6.2 Longitudinal stresses	797
20.6.3 Effect of pressure on size	797
20.7 Thick Cylinders	797
20.7.1 Lame's equation	797
20.7.2 Clavarino's equation	797
20.7.3 Birnie's equation	797
20.7.4 Barlow's equation	797
20.8 Thin Spherical Vessels	797
20.8.1 Plate thickness	797
20.8.2 Change in size of spherical pressure vessel with internal pressure	797
20.9 End Covers	797
20.9.1 Flat circular	797
20.9.2 Flat rectangular	797
20.9.3 Elliptical plate	797
20.9.4 Hemispherical	797
20.9.5 Flanged	797
20.9.6 Semi-ellipsoid	797
20.9.7 Tori-spherical end cover	797
20.9.8 Conical end covers	797
20.10 Flaring of End Covers	797
20.10.1 Internal	797
20.10.2 Bolted	797