MA3001 Overall Summary of Key Concepts Sep 2020 v2

Machine Element Design (Nanyang Technological University)

MA3001

MACHINE ELEMENT DESIGN

Overall Summary of Key Concepts

for

Belt Drive

Chain Drive

Gears

Assoc Prof Hoon Kay Hiang

Tel: 6790 5523

Office: N3-02c-94

Email: mkhhoon@ntu.edu.sg

POWER

- Power Equation

$$P = T\,\omega$$

$$\text{same } P = T\uparrow\ \omega\downarrow$$

$$\text{same } P = T\downarrow\ \omega\uparrow$$

Summary of Key Concepts

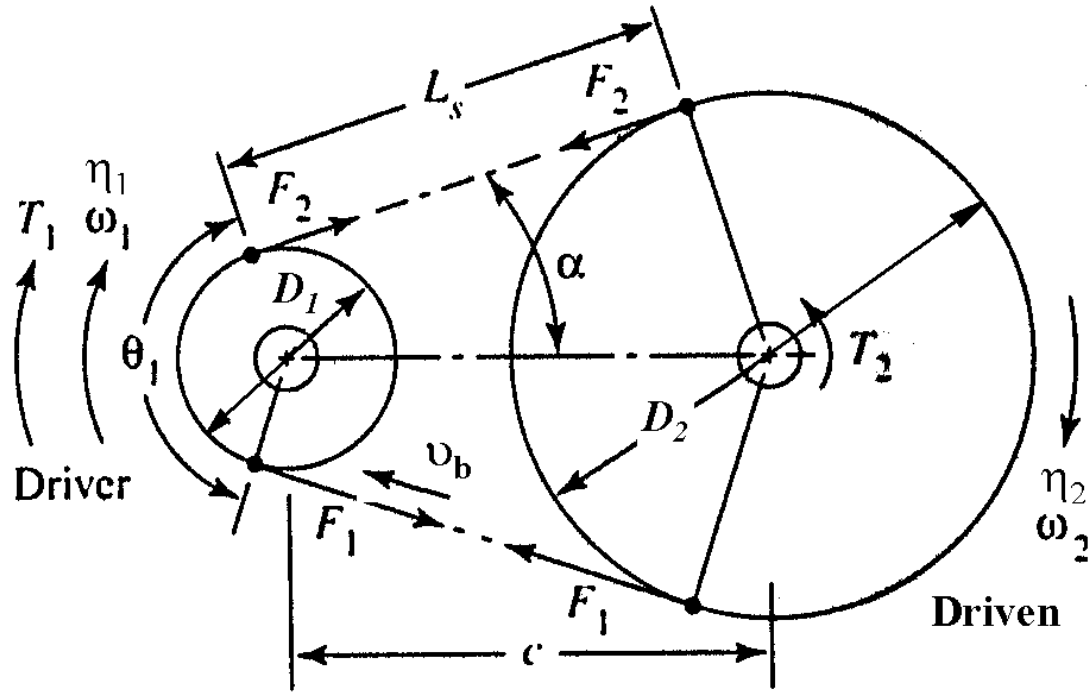
V-belt drive

- Transmitted Power,

  $P = T_1\omega_1 = T_2\omega_2$

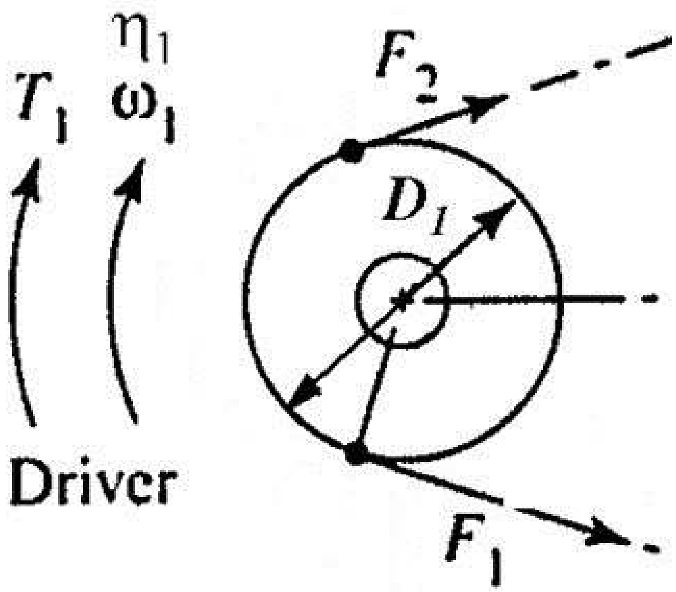
- Torque, $T_1 = (F_1 - F_2)\, D_1/2$,

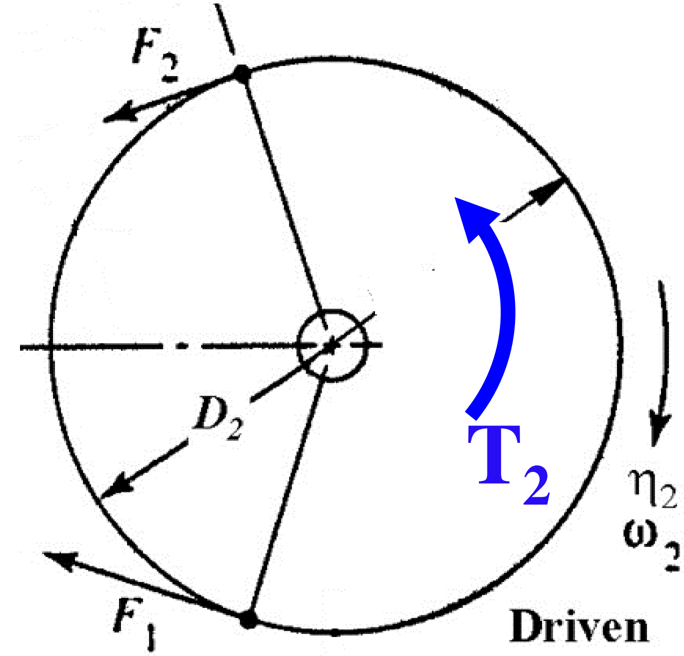
  $T_2 = (F_1 - F_2)\, D_2/2$



SUMMARY

Torque and Direction of Rotation



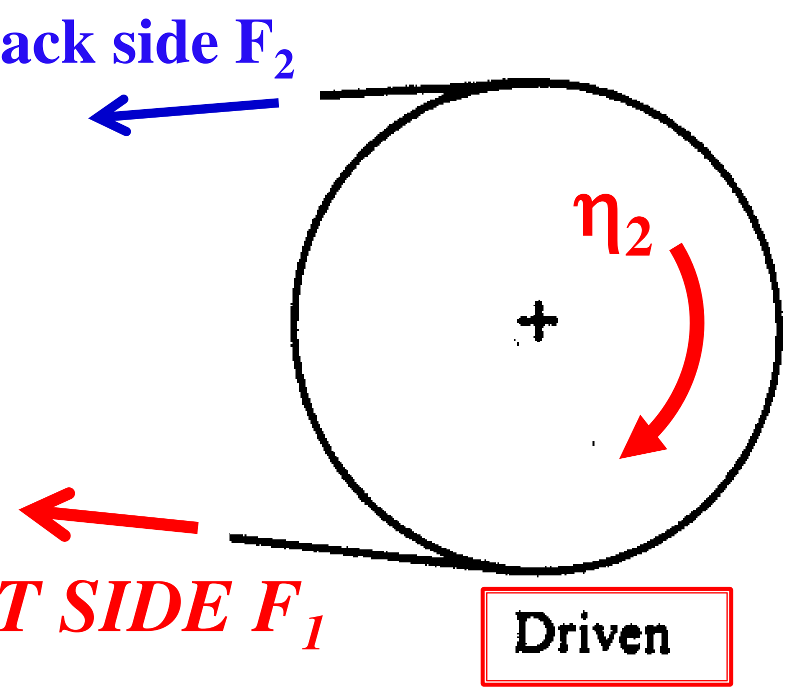


DRIVER SHEAVE:
Input Torque **SAME** direction as rotational direction

DRIVEN SHEAVE:
Output/Resisting Torque **OPPOSITE** direction as rotational direction

SUMMARY

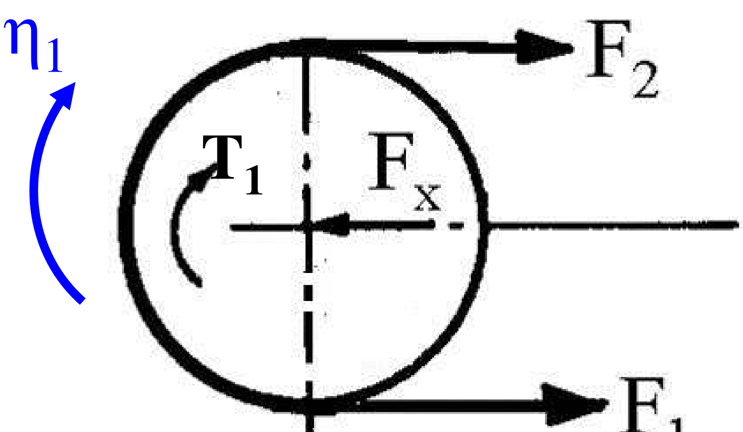
The Tighter side F_1 gives direction of η_2 rotation to ***DRIVEN*** *sheave*



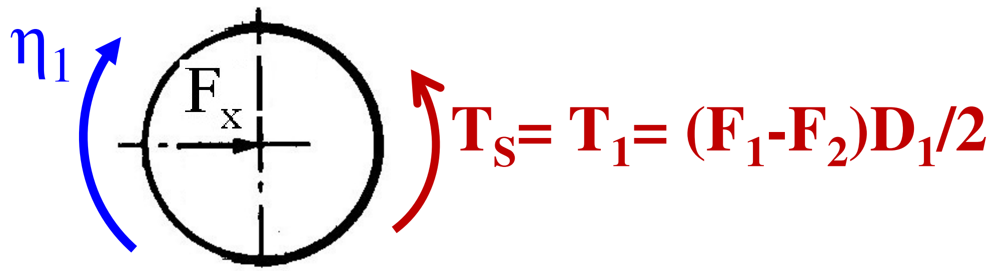
Way of determining **TIGHT** side

SUMMARY

- For typical applications, the tight and slack tensions F_1 and F_2 are assumed to be parallel.



Driver Sheave Forces



Driver Shaft Forces

$$F_x = (F_1 + F_2)$$

Summary

Belt Drive

- $\text{No of belts} = \dfrac{\text{Design Power}}{\text{Corrected Rated Power}}$

- Design Power needed to find the smallest belt cross to ensure that the required power is delivered to the driven machine:

  - Design power = Service Factor x Required Power of driven machine

- RP: rated power of belt given by manufacturer (catalogue data as shown below)

Table A-7a

kW-ratings per V-belt P [kW] at 180° arc of contact **SPZ**

Pitch diam. of smaller sheave [mm]	Speed ratio	RPM of smaller sheave 720	950	1450	2850	200	400	800	1200	1600	2000	2400	3200	3600	4000	4500	5000	5500	6000
63	1.00	0.54	0.67	0.92	1.47	0.19	0.33	0.58	0.80	0.99	1.16	1.32	1.58	1.69	1.79	1.89	1.96	2.01	2.03
	1.05	0.56	0.70	0.97	1.57	0.19	0.35	0.61	0.84	1.04	1.23	1.39	1.69	1.81	1.92	2.03	2.12	2.19	2.23
	1.20	0.60	0.76	1.06	1.75	0.21	0.37	0.66	0.90	1.14	1.35	1.55	1.89	2.04	2.17	2.32	2.44	2.54	2.61
	1.50	0.64	0.80	1.13	<1.89	0.22	0.39	0.70	0.97	1.22	1.45	1.67	2.05	2.22	2.37	2.54	2.69	2.81	2.91
	≥3.00	0.66	0.83	1.17	1.97	0.22	0.40	0.72	1.01	1.27	1.51	1.74	2.14	2.32	2.49	2.67	2.83	2.97	3.06
71	1.00	0.72	0.90	1.27	2.12	0.24	0.44	0.79	1.10	1.38	1.63	1.87	2.29	2.47	2.63	2.81	2.95	3.06	3.13
	1.05	0.75	0.94	1.32	2.21	0.25	0.46	0.81	1.13	1.43	1.70	1.95	2.39	2.59	2.76	2.95	3.11	3.24	3.33
	1.20	0.79	1.00	1.41	2.39	0.26	0.48	0.86	1.21	1.53	1.83	2.10	2.60	2.82	3.02	3.24	3.43	3.59	3.71
	1.50	0.83	1.05	1.49	2.53	0.27	0.50	0.90	1.27	[illegible]	[illegible]	2.22	2.76	3.00	3.22	3.47	3.68	3.86	4.01
	≥3.00	0.85	1.07	1.53	2.61	0.28	[illegible]	[illegible]	1.30	[illegible]	[illegible]	[illegible]	2.85	3.10	3.33	3.59	3.82	4.02	4.18
	1.00	0.93	1.18	1.67	2.82	0.31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.48	3.07	3.32	3.55	3.80	4.01	4.17	4.29

Summary

Belt Drive

- Corrected rated power, CRP = $C_\theta C_L$ x RP

C_θ - correction factor for angle of contact on small pulley

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

Table A-5: Correction Factor for Arc of Contact C_θ

Arc of contact of smaller sheave	180°	174°	167°	163°	157°	151°	145°	139°	133°	127°	120°	113°	106°	99°	91°
C_θ	1.00	0.99	0.97	0.96	0.94	0.93	0.91	0.89	0.87	0.85	0.82	0.79	0.77	0.73	0.70

Summary

Belt Drive

Pitch Length, $$L = 2C + 1.57(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4C} \quad \text{(m)}$$

Centre Distance $$C = \frac{B + \sqrt{B^2 - 32(D_2 - D_1)^2}}{16} \quad \text{(m)}$$

where $B = 4L - 6.28(D_2+D_1)$

C_L - correction factor for belt length

Table A-6: Standard Belt Length L (mm) and Belt Length Correction Factor C_L

Profile SPZ		Profile SPA		Profile SPB		Profile SPC	
L (mm)	Correction factor	L (mm)	Correction factor	L (mm)	Correction factor	L (mm)	Correction factor
630	0.85	800	0.81	1250	0.83	2000	0.83
710	0.87	900	0.83	1400	0.85	2240	0.85
800	0.89	1000	0.85	1600	0.87	2500	0.87
900	0.90	1120	0.87	1800	0.89	2800	0.89
1000	0.92	1250	0.89	2000	0.90	3150	0.90
1120	0.94	1400	0.90	2240	0.92	3550	0.92

Summary

Belt Drive

Select Standard Sheave Diameters

$$\text{Speed ratio} = \frac{\text{Input Speed}}{\text{Output Speed}} = \frac{\eta_1}{\eta_2} = \frac{D_2}{D_1}$$

Table A-4: **Standard Sheave Diameters (mm)**

SPZ/3V	63	71	75	80	90	100	112	125	132	140	150	160	180	200	224	250	280	315	355	400	500	630			
SPA/4V	90	95	100	106	112	118	125	132	140	150	160	180	200	224	250	280	315	355	400	450	500	560	630	710	800
SPB/5V	140	150	160	170	180	200	224	250	280	315	355	400	450	500	560	600	710	750	800	900	1000	1120			
SPC/7V	224	236	250	265	280	300	315	335	355	400	450	500	560	600	630	710	750	800	900	1000	1120	1250	1400	1600	2000

Check if speed requirement is satisfied!

Summary

Chain Drive

Very Slow Speed Applications ***(less than 100 rpm)***

- **Strength** is the design criterion for such applications.
- Allowable load is used for very slow speed drives or for applications in which the function of the chain is to apply a tensile force or support a load.

Table B-1

AMERICAN STANDARD ROLLER CHAINS-SINGLE STRAND

Upper dimension—inch
Lower dimension—mm

TSUBAKI Chain No.		ANSI No.	Pitch P	Roller Diam. R	Width between roller link plates W	Link Plate Thickness T	Link Plate Height H	Link Plate Height h	Pin Diam. D	Pin From Pin head to C.L. L_1	Pin From Pin end to C.L. L_2	Average Tensile Strength Lbs./kg	Maximum Allowable Load Lbs./kg	Approx. Weight Lbs./ft kg/mt	Number of Link per 10 Ft.	Length Per Carton Package (Ft.)
RS25	✳ ▲	25	¼ 6.35	.130 3.30	⅛ 3.18	.030 0.75	.230 5.84	.199 5.05	.0905 2.31	.148 3.85	.179 4.80	1,050 480	140 65	.094 0.14	480	400
RS35	✳ ▲	35	⅜ 9.525	.200 5.08	3/16 4.78	.050 1.25	.354 9.0	.307 7.8	.141 3.59	.230 5.85	.270 6.85	2,500 1,150	480 220	.22 0.33	320	100
RS41	✳	41	½ 12.70	.306 7.77	¼ 6.38	.050 1.25	.386 9.8	.331 8.4	.141 3.59	.266 6.75	.313 7.95	2,600 1,200	500 230	.27 0.41	240	100
RS40	✳	40	½	.312	5/16	.060	.472	.409	.156	3.25	.392	4,250	810	.43	[illegible]	[illegible]

Summary

Chain Drive *(greater than 100 rpm)*

$$\text{Design Power per strand} = \frac{\text{Power to be transmitted x Service Factor}}{\text{Multiple Strand Factor}} \quad \text{(kW)}$$

- Design Power per strand needed to find the proper smallest chain size and no. of smaller sprocket teeth to ensure that the required power is transmitted to the driven machine:

Table B-4

MAXIMUM KILOWATT RATINGS

Multi-Strand Factor

Number of Roller Chain Strands	Multi-Strand Factor
2	1.7
3	2.5
4	3.3
5	3.9
6	4.6

	Lubricating Methods
A	Manual lubrication or drip lubrication.
B	Oil bath lubrication or lubrication by slinger disc
C	Lubrication using a pump

NO. 25 MAXIMUM KILOWATT RATINGS

No. of Teeth Small Spkt.	Maximum r/min — Small Sprocket																								
	50	100	300	500	700	900	1200	1500	1800	2100	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500	9000	10000
	Lubrication System																								
	A										B														
9	0.02	0.03	0.08	0.13	0.18	0.23	0.30	0.36	0.43	0.49	0.57	0.67	0.78	0.76	0.64	0.54	0.47	0.42	0.37	0.33	0.30	0.27	0.25	0.22	0.19
10	0.02	0.04	0.10	0.15	0.20	0.26	0.33	0.41	0.48	0.55	0.64	0.76	0.87	0.89	0.75	0.64	0.55	0.48	0.43	0.39	0.35	0.31	0.29	0.26	0.22
11	0.02	0.04	0.11	0.17	0.23	0.28	0.37	0.45	0.53	0.61	0.71	0.84	0.96	1.03	0.87	0.74	0.64	0.56	0.50	0.45	0.40	0.37	0.34	0.31	0.26
12	0.02	0.04	0.12	0.18	0.25	0.31	0.40	0.49	0.58	0.67	0.78	0.92	1.06	1.17	0.98	0.84	0.72	0.64	0.57	0.51	0.46	0.42	0.38	0.35	0.30
13	0.03	0.05	0.13	0.20	0.27	0.34	0.44	0.54	0.63	0.73	0.85	1.00	1.15	1.30	1.11	0.95	0.82	0.72	0.64	0.57	0.51	0.47	0.43	0.40	0.34

Summary

Chain Drive

Select the Sprocket Teeth Numbers

$$\text{Speed ratio} = \frac{\text{Input Speed}}{\text{Output Speed}} = \frac{\eta_1}{\eta_2} = \frac{N_2}{N_1}$$

For quiz, there is **no restriction** on the number of larger sprocket teeth subject to the requirements specified in the question. The available number of teeth on the smaller sprocket is given in the power rating tables

Check if speed requirement is satisfied!

Summary

Chain Drive

Pitch diameters of the sprockets

$$D_1 = p / \sin (180°/N_1), \quad D_2 = p / \sin (180°/N_2)$$

Chain Pitch Length

where C is in pitches

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

- Specify an even number of pitches for the chain length, L according to requirement of centre distance or space.

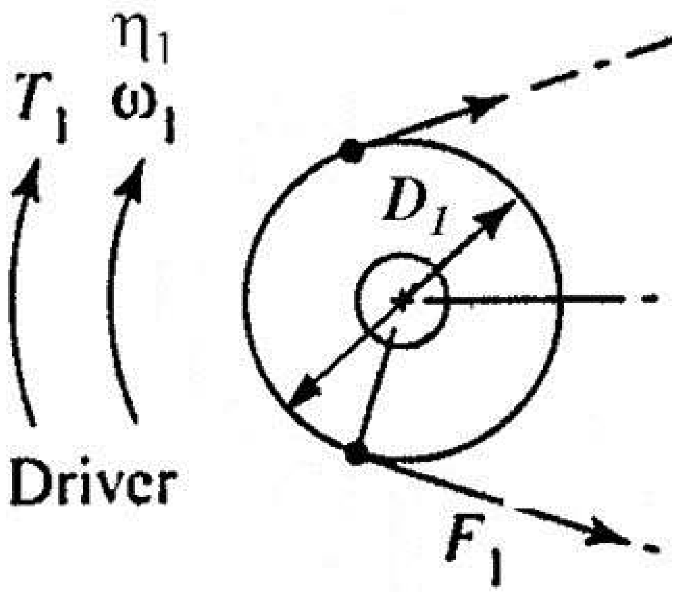
- Pitch length in millimetres = L.p mm

Centre Distance

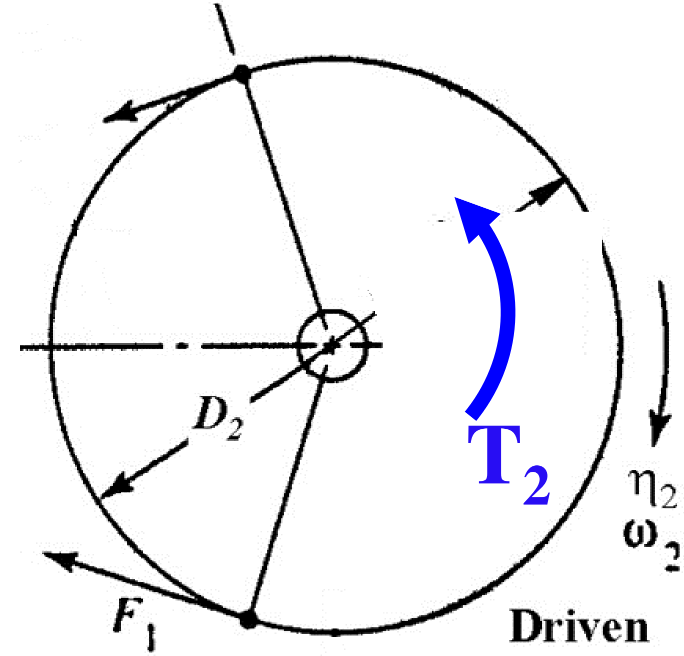
$$C = \frac{1}{4}\left\{ L - \frac{N_2 + N_1}{2} + \sqrt{\left[L - \frac{(N_2 + N_1)}{2}\right]^2 - \frac{8(N_2 - N_1)^2}{4\pi^2}} \right\} \quad \text{pitches}$$

- Centre distance in millimetres = C.p mm ; p=chain pitch

Torque and Direction of Rotation *(similar to belt)*



DRIVER SPROCKET:
Input Torque **SAME** direction as rotational direction

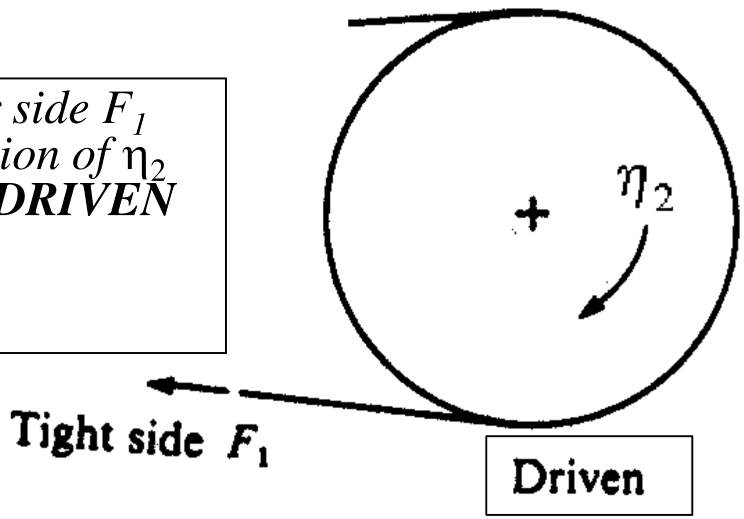


DRIVEN SPROCKET:
Output/Resisting Torque **OPPOSITE** direction as rotational direction

TIGHT TENSION SIDE

- How to determine which side is tight? *(similar to belt)*
  - Look at rotation of **driven sprocket** - tight side gives direction of rotation to driven sheave

*The Tighter side F_1 gives direction of η_2 rotation to **DRIVEN** sprocket*



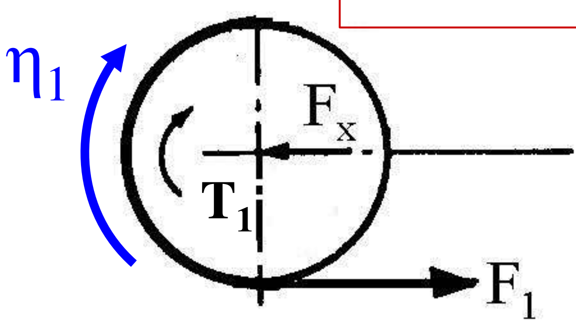
<u>Shaft Load</u>

is determined in the same way as belt drives, ie.

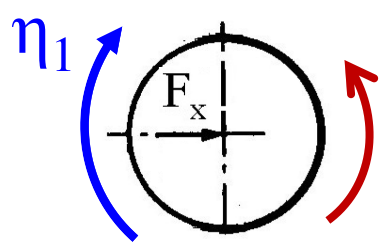
tension is assumed parallel (normal practice adopted in this course and industry)

$F_2 = 0$ – ZERO tension on slack side

$$F_x = F_1$$



Driver Sprocket Forces



$$T_S = (F_1)D_1/2$$

Driver Shaft Forces

Summary

- Spur/helical gears

  ~ Pitch diameters, $D = mN$ mm

  ~ Outside diameter, $Do = D + 2a = m(N+2)$

  ~ Centre Distance, $C = (D_G + D_P)/2 = (N_G + N_P)m/2$

  ~ Gear in mesh, tip to tip dimension $= D_G + D_P + 2a = m(N_G + N_P + 2)$

  NOTE: for helical gears, $\mathbf{m = m_n/\cos\psi}$

- Speed Ratio (SR) = input speed/output speed

  = (No. of teeth in driven gears)/(No. of teeth in driving gears)

  $= SR_1\ SR_2\ SR_3$ etc

Summary

- Spur Gear Forces

  $W_t = T/(D/2)$ $\qquad$ $W_r = W_t \tan \phi$

  - direction of W_t can be derived from the rotation of the driven gear

  - W_r always acts towards the centre of the gear

- Helical Gear Forces

  For the parallel shaft arrangement, the helix angle is the same on each gear, but one gear must have a right hand helix and the other a left hand helix

  $W_t = T/(D/2)$ $\qquad$ $W_r = W_t \tan \phi_{t;}$ $\quad$ $\tan \phi_t = \tan \phi_n / \cos \psi$

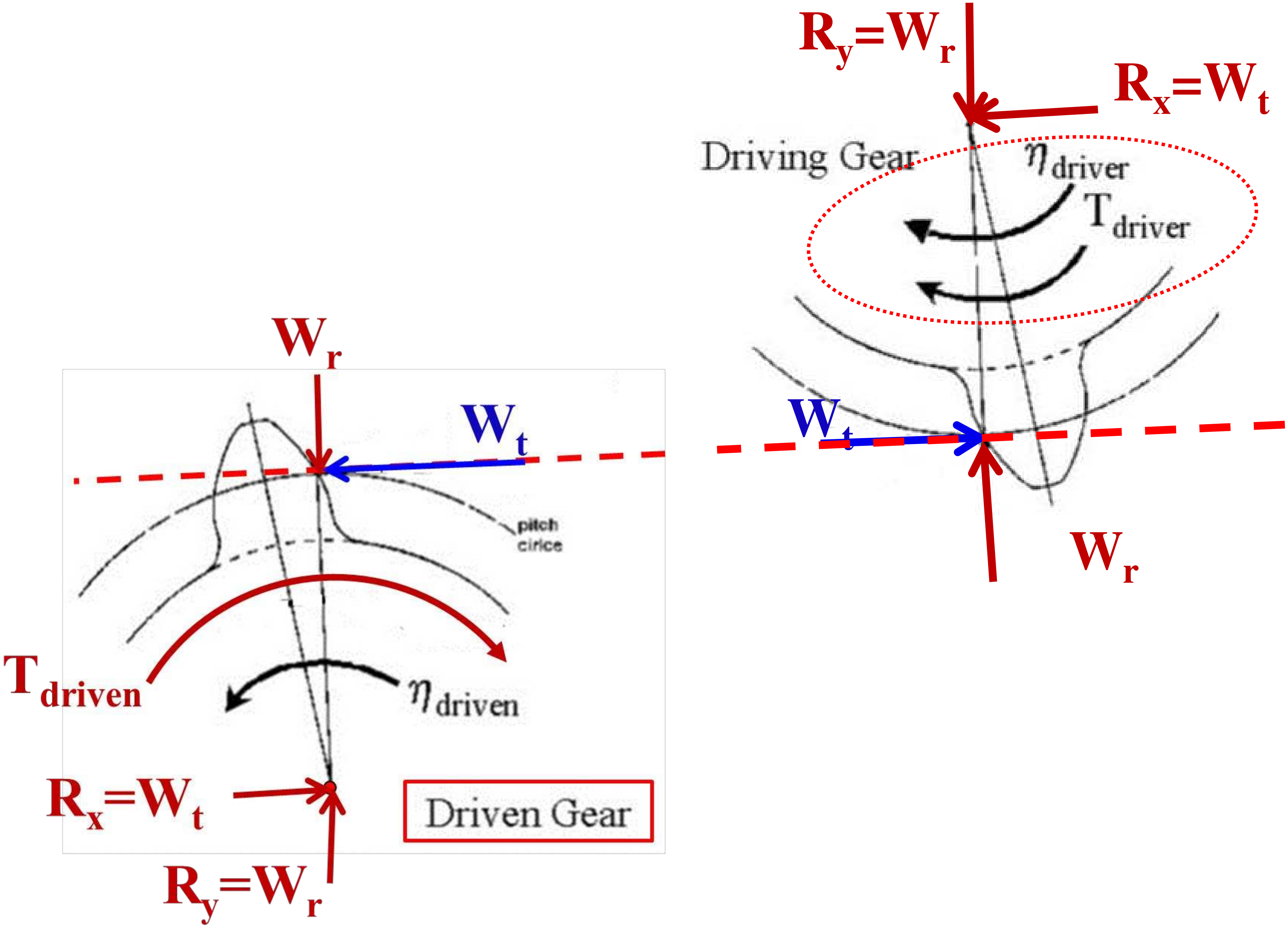
  $W_a = W_t \tan \psi$

  ~ directions of W_t and W_r as in spur gears

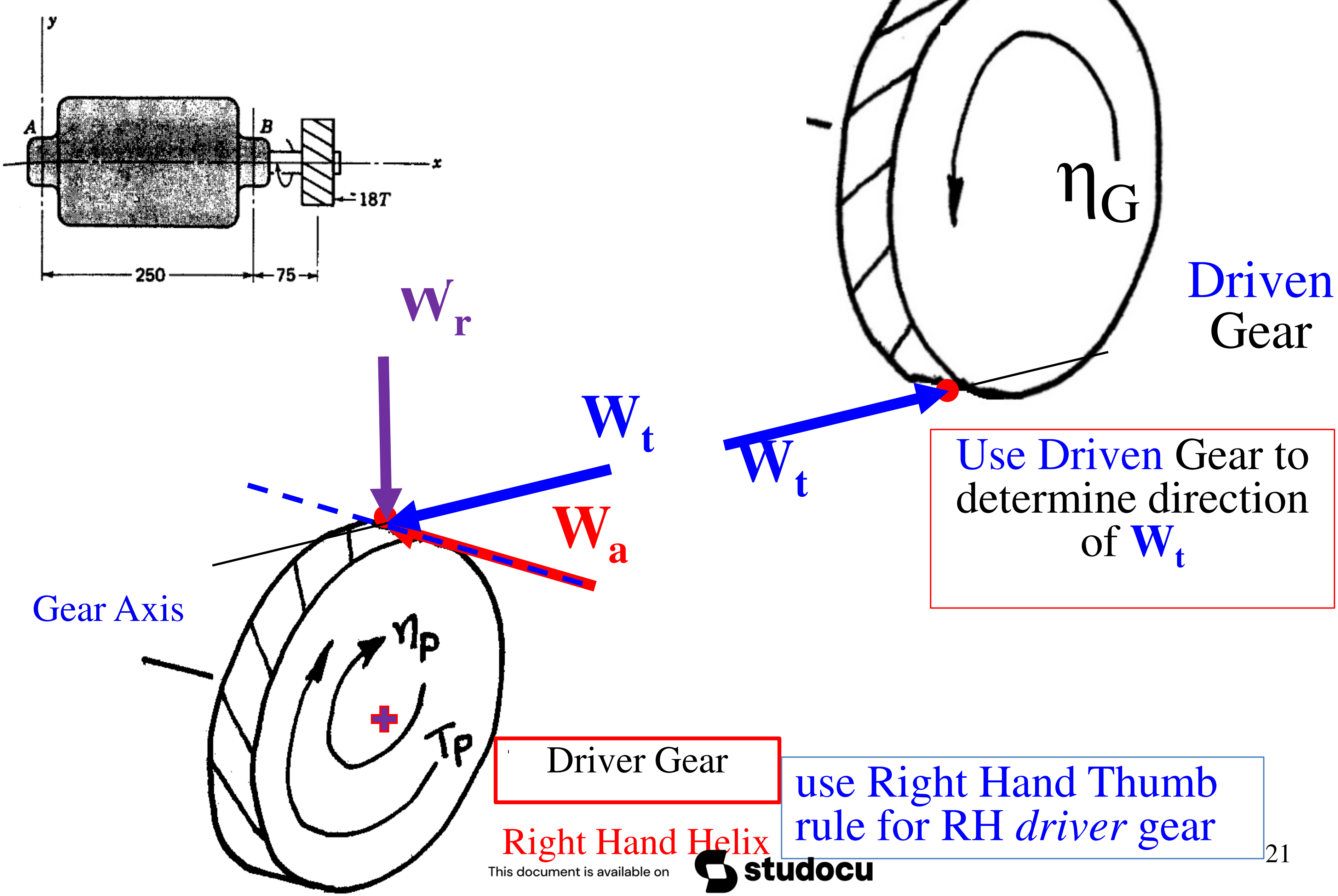
  ~ direction of W_a - use Right Hand Thumb rule for RH *driver* gear,

  use Left Hand Thumb for LH *driver* gear

FORCES ON THE DRIVER AND DRIVEN GEARS



DETERMINE W_t, W_r



Summary

- Bevel Gear

  ~ SR = (No. of teeth in driven gears)/(No. of teeth in driving gears)

- Worm and worm gear

  ~ $SR = N_G/N_W$

  ~ direction as shown: