MECHANICAL DESIGN
PART 3

INTRODUCTION TO MECHANICAL & INDUSTRIAL ENGINEERING

MEC 130

Mohamed Ibrahim Shaat

Assistant Professor

Mechanical Engineering Department

Abu Dhabi University

جامعة أبوظبي
ABU DHABI UNIVERSITY

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INTRODUCTION

Proposed Topics

Collect Information
Concept Generation
Recommend a Design

- Important Machine Elements & Their Functions
- Transmission Systems & Their Operating Principle

Part 2

Detailed Design & Analysis

- **Unit Systems & Conversions**
- **Force Analysis – Stresses – Tensile Test - Engineering Materials**
- **Dynamics**
- **Factor of Safety**

Part 3 / Part 4

Communication — Graphics & Engineering Drawing

Manufacturing — Manufacturing Processes

UNIT SYSTEMS & CONVERSIONS

- **A Physical Quantity** is a measure or a description of a physical phenomenon.
- An example of a physical phenomenon is the distance and time of the trip of the earth rotating around the sun. Earth orbits the Sun at an average distance of 149.60 million km. The earth completes one cycle around the sun in 365.256 days.
- The value of a physical quantity should be expressed as a product of a ***number*** and a ***unit*** to be completely defined.
- Physical quantities are either ***base quantities*** or ***derived quantities***.
- A **Base Quantity** (or **Basic Quantity**) is independent and does not require any other quantity to be formed. It is arbitrarily defined, rather than being derived from a combination of other physical quantities.
- A **Derived Quantity** is a combination of several physical quantities. A derived quantity can be broken down to a combination of the base quantities.

UNIT SYSTEMS & CONVERSIONS

- Basic Quantities are 7 quantities, which are:

Length – Mass – Time – Electric Current – Temperature – Amount of Substance – Light Intensity

$a = \frac{L}{t^2}$

An example of a derived quantity is the force:

Force = Mass x Acceleration =Mass x Length / Time

Two unit systems are used to define physical quantities:

1. International System of Units (SI) (Known by *metric* system)
2. United States Customary System (USCS) (known by *inch* system)

10 cm
unit

weight = m * g

UNIT SYSTEMS & CONVERSIONS

International System of Units

- Basic Quantities defined using the following ***Basic Units*** in the SI unit system:

Quantity	SI Base Unit	Abbreviation
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	Kelvin	K
Amount of substance	mole	mol
Light intensity	candela	cd

UNIT SYSTEMS & CONVERSIONS

International System of Units

- Base and derived units in the SI are often combined with a *prefix*.
- Prefixes used in SI unit system:

Name	Symbol	Multiplicative Factor
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	$1000 = 10^{3}$
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	$0.000,000,000,001 = 10^{-12}$

K/m
unit
1 km = 10^3 m
c/m
K/g
1 kg = 10^3 g
m/m

UNIT SYSTEMS & CONVERSIONS

United States Customary System

- Basic Quantities defined using the following ***Basic Units*** in the USCS unit system:

Quantity	USCS Base Unit	Abbreviation
Length	foot	ft
Mass	Slug	Slug
Time	second	s
Electric current	ampere	A
Temperature	degree Rankine	°R
Amount of substance	mole	mol
Light intensity	candela	cd

Example #1

Using the basic units, derive the unit of each of the following physical quantities.

Physical Quantity	Expression	SI Unit	USCS Unit
Area	[L] x [L]	m^2	ft^2
Volume	[L] x [L] x [L]	m^3	ft^3
Density	$\frac{[M]}{[L]^3}$	$\frac{kg}{m^3}$	$\frac{slug}{ft^3}$
Velocity	[L]/[T]	$\frac{m}{s}$	$\frac{ft}{s}$
Acceleration	$[L]/[T]^2$	$\frac{m}{s^2}$	$\frac{ft}{s^2}$
Force	Mass x Acceleration $=[M] \times [L]/[T]^2$	$\frac{kg.m}{s^2}$ = N (Newton)	$\frac{slug.ft}{s^2}$ = Ib (Pound)

Example #2

Knowing that a moment is the multiplication of a force times distance, derive its unit in both the SI and USCS unit systems.

Moment = Force * Distance

= (Mass * Acceleration) * Distance (Length)

Moment = Mass * $\frac{\text{Length}}{\text{Time}^2}$ * Length

SI

Moment = $\frac{[M][L][L]}{[T]^2}$

Moment ⇒ $\frac{kg \cdot m \cdot m}{s^2} = \frac{kg \cdot m^2}{s^2}$

USCS

Moment = $\frac{[M][L][L]}{[T]^2}$

Moment ⇒ $\frac{slug \cdot ft \cdot ft}{s^2} = \frac{slug \cdot ft^2}{s^2}$

Example #3

The joule is the unit of energy, and energy is the multiplication of force times distance. Derive the joule using the basic SI units.

UNIT SYSTEMS & CONVERSIONS

Example #4

* Remove → Multiply by its value

Recalculate each of the following quantities based on the unit conversion indicated to each one.

* Add → Divide by its value

Physical Quantity	Convert Unit to	Quantity after Unit Conversion
8 kN	8×10^{3} N	8000 N
25 µg	25×10^{-6} g	0.000025 g
50 µg	So $\frac{10^{-6}}{10^{3}} = 50\times10^{-9}$ kg	5×10^{-8} kg
60 kPa	60×10^{3} Pa	60×10^{3} Pa
$40\ \frac{\text{MN}}{\text{mm}^2}$	$\frac{\text{N}}{\text{m}^2}$	$40 \times \frac{10^6}{10^{-3}\text{x}10^{-3}} = 40\text{x}10^{12}\ \frac{\text{N}}{\text{m}^2}$

µg → kg: Remove µ $= 10^{-6}$; Add k $= 10^{3}$

UNIT SYSTEMS & CONVERSIONS

$$40\ \frac{MN}{mm^2} = 40\ \frac{MN}{(mm)^2} \longrightarrow \frac{N}{m^2}$$

10^6 = mega mili = 10^{-3}

$$= 40\ \frac{10^6\ N}{(10^{-3}\ m)^2} = 40\ \frac{10^6}{(10^{-3})^2}\ \frac{N}{m^2}$$

$$= 40 * \left(\frac{10^6}{10^{-6}}\right) \frac{N}{m^2} = 40 * 10^{12}\ \frac{N}{m^2}$$

Mohamed Shaat

Important Derived Quantities (in SI)

Quantity	SI Derived Unit	Abbreviation	Definition
Length	micrometer or micron	μm	1 μm = 10^{-6} m
Volume	liter	L	1 L = 0.001 m^3
Force	newton	N	1 N = 1 (kg · m)/s^2
Torque, or moment of a force	newton-meter	N · m	—
Pressure or stress	pascal	Pa	1 Pa = 1 N/m^2
Energy, work, or heat	joule	J	1 J = 1 N · m
Power	watt	W	1 W = 1 J/s
Temperature	degree Celsius	°C	°C = K − 273.15

Although a change in temperature of 1 Kelvin equals a change of 1 degree Celsius, numerical values are converted using the formula.

UNIT SYSTEMS & CONVERSIONS

Important Derived Quantities (in USCS)

Quantity	Derived Unit	Abbreviation	Definition
Length	mil	mil	1 mil = 0.001 in.
	inch	in.	1 in. = 0.0833 ft
	mile	mi	1 mi = 5280 ft
Volume	gallon	gal	1 gal = 0.1337 ft^3
Mass	slug	slug	1 slug = 1 $(lb \cdot s^2)/ft$
	pound-mass	lbm	1 lbm = 3.1081×10^{-2} $(lb \cdot s^2)/ft$
Force	ounce	oz	1 oz = 0.0625 lb
	ton	ton	1 ton = 2000 lb
Torque, or moment of a force	foot-pound	ft · lb	—
Pressure or stress	pound/inch^2	psi	1 psi = 1 lb/in^2
Energy, work, or heat	foot-pound	ft · lb	—
	British thermal unit	Btu	1 Btu = 778.2 ft · lb
Power	horsepower	hp	1 hp = 550 (ft · lb)/s
Temperature	degree Fahrenheit	°F	°F = °R – 459.67

Although a change in temperature of 1° Rankine also equals a change of 1° F, numerical values are converted using the formula.

UNIT SYSTEMS & CONVERSIONS

Important Conversions between SI and USCS

Quantity	Conversion		
Length	1 in.	=	25.4 mm
	1 in.	=	0.0254 m
	1 ft	=	0.3048 m
	1 mi	=	1.609 km
	1 mm	=	3.9370×10^{-2} in.
	1 m	=	39.37 in.
	1 m	=	3.2808 ft
	1 km	=	0.6214 mi
Area	1 in^2	=	645.16 mm^2
	1 ft^2	=	9.2903×10^{-2} m^2
	1 mm^2	=	1.5500×10^{-3} in^2
	1 m^2	=	10.7639 ft^2
Volume	1 ft^3	=	2.832×10^{-2} m^3
	1 ft^3	=	28.32 L
	1 gal	=	3.7854×10^{-3} m^3
	1 gal	=	3.7854 L
	1 m^3	=	35.32 ft^3
	1 L	=	3.532×10^{-2} ft^3
	1 m^3	=	264.2 gal
	1 L	=	0.2642 gal

UNIT SYSTEMS & CONVERSIONS

Important Conversions between SI and USCS

Mass	1 slug	=	14.5939 kg
	1 lbm	=	0.45359 kg
	1 kg	=	6.8522×10^{-2} slugs
	1 kg	=	2.2046 lbm
Force	1 lb	=	4.4482 N
	1 N	=	0.22481 lb
Pressure or stress	1 psi	=	6895 Pa
	1 psi	=	6.895 kPa
	1 Pa	=	1.450×10^{-4} psi
	1 kPa	=	0.1450 psi
Work, energy, or heat	1 ft · lb	=	1.356 J
	1 Btu	=	1055 J
	1 J	=	0.7376 ft · lb
	1 J	=	9.478×10^{-4} Btu
Power	1 (ft · lb)/s	=	1.356 W
	1 hp	=	0.7457 kW
	1 W	=	0.7376 (ft · lb)/s
	1 kW	=	1.341 hp

Forces in Machines

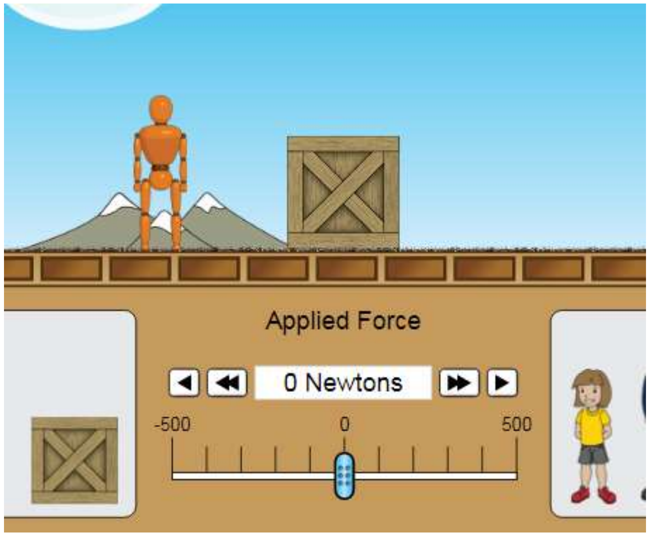
A Force is an interaction that can change the ***state*** of an object.

Galileo's Assumption:

"It is not the nature of an object to stop once set in motion but rather to continue in its original state of motion"

According to Galileo's assumption, if we pushed this box will not stop and will continue moving forever !

Galileo's assumption is not applicable in all cases !



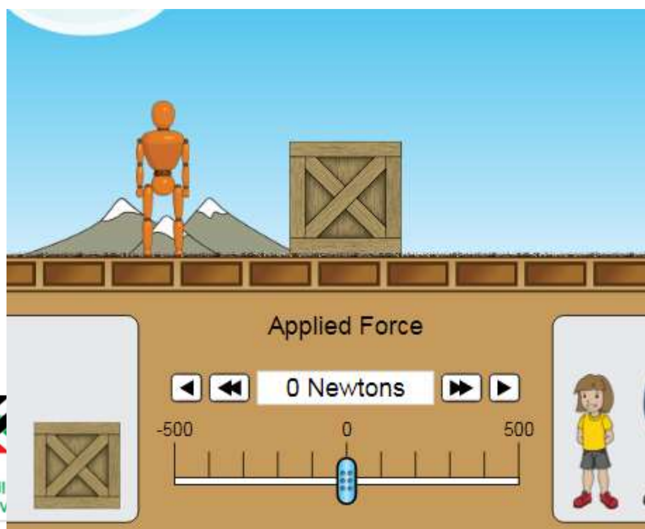
Forces in Machines

A Force is an interaction that can change the ***state*** of an object.

Newton's First Law:

"An object moves with a velocity that is constant in magnitude and direction unless a nonzero net force acts on it"

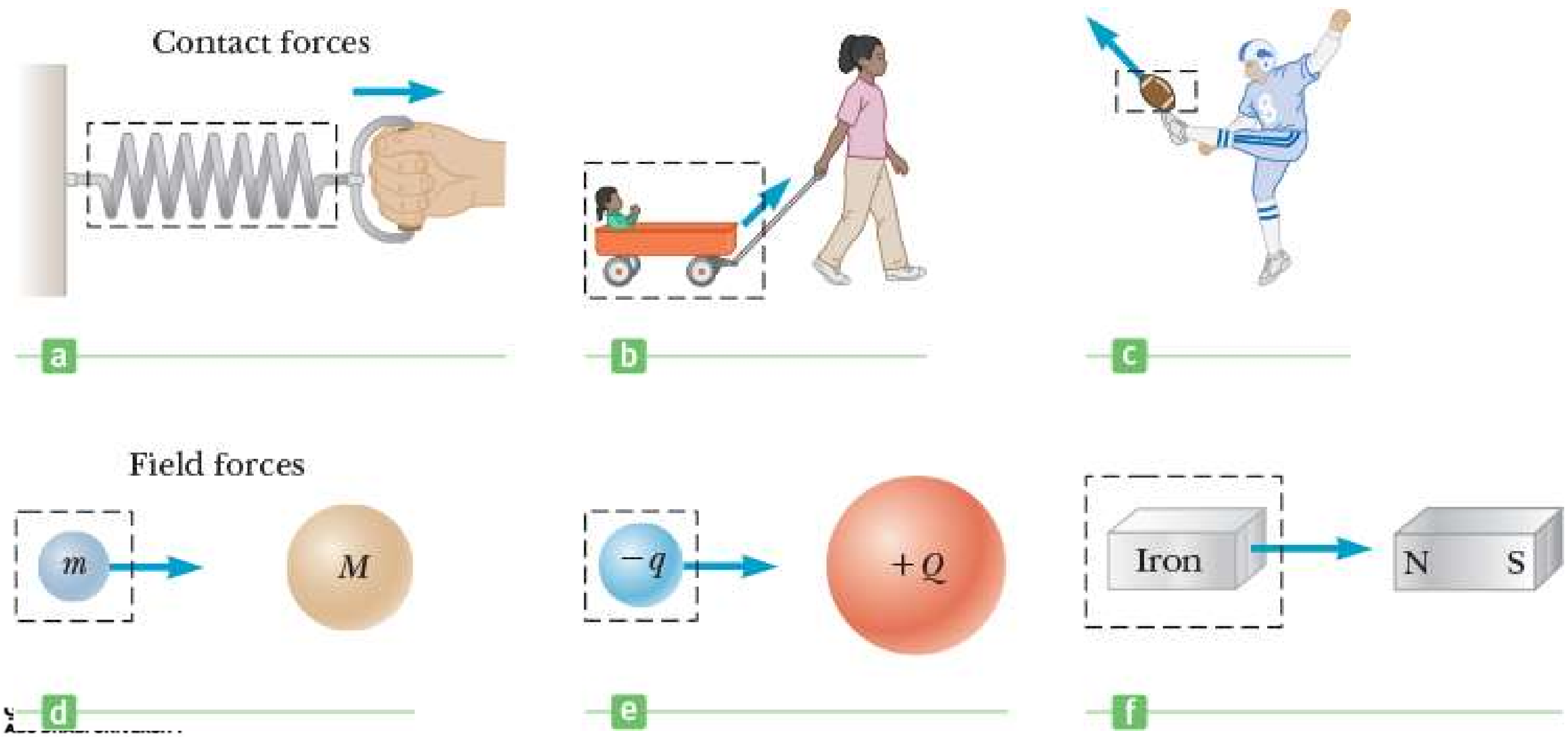
- According to Newton's first law, if the box is moving, it will stop if there is a nonzero net force acts on it and this net force tend to stop the box.
- If there is no forces act on the box, the box will not stop !



Newton's First Law is feasible !

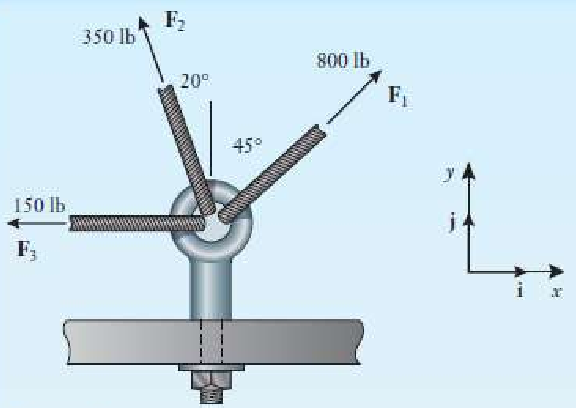
Forces in Machines

- **A Force** is an interaction that can change the ***state*** of an object.
- **A force** is what makes an object moves, or a force is what prevents an object's motion.
- The force has different forms and types:



FORCE ANALYSIS

Resultant of Several Forces



Approach

We are tasked to find the resultant force on the eyebolt. By using Equations (4.1) and (4.2), we will break each force down into its horizontal and vertical components and write them in vector form. Then we will add the respective components of the three forces to find the resultant's components. Given those, the magnitude and angle of action of **R** follow from Equation (4.7).

Solution

The components of the 800-lb force are

$$F_{x,1} = (800 \text{ lb}) \cos 45° \qquad \leftarrow [F_x = F\cos\theta]$$
$$= 565.7 \text{ lb}$$

$$F_{y,1} = (800 \text{ lb}) \sin 45° \qquad \leftarrow [F_y = F\sin\theta]$$
$$= 565.7 \text{ lb}$$

and $\mathbf{F}_1$ is written in vector form as

$$\mathbf{F}_1 = 565.7\mathbf{i} + 565.7\mathbf{j} \text{ lb} \qquad \leftarrow [\mathbf{F} = F_x\mathbf{i} + F_y\mathbf{j}]$$

By using the same procedure for the other two forces,

$$\mathbf{F}_2 = -(350 \sin 20°)\mathbf{i} + (350 \cos 20°)\mathbf{j} \text{ lb}$$
$$= -119.7\mathbf{i} + 328.9\mathbf{j} \text{ lb}$$
$$\mathbf{F}_3 = -150\mathbf{i} \text{ lb}$$

To calculate the components of the resultant, the horizontal and vertical components of the three forces are summed separately:

$$R_x = 565.7 - 119.7 - 150 \text{ lb} \qquad \leftarrow \left[R_x = \sum_{i=1}^{N} F_{x,i}\right]$$
$$= 296.0 \text{ lb}$$

$$R_y = 565.7 + 328.9 \text{ lb} \qquad \leftarrow \left[R_y = \sum_{i=1}^{N} F_{y,i}\right]$$
$$= 894.6 \text{ lb}$$

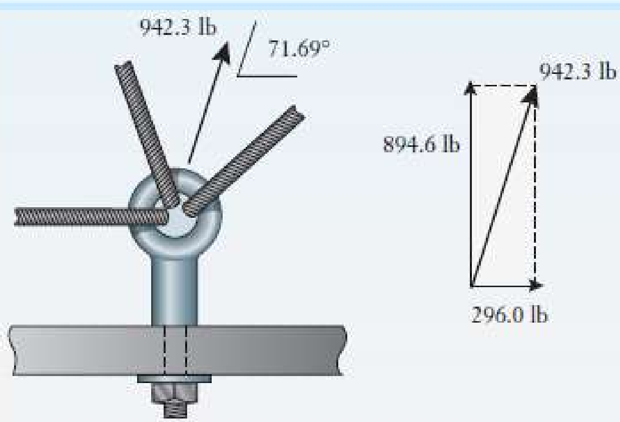
The magnitude of the resultant force is

$$R = \sqrt{(296.0 \text{ lb})^2 + (894.6 \text{ lb})^2} \qquad \leftarrow \left[R = \sqrt{R_x^2 + R_y^2}\right]$$
$$= 942.3 \text{ lb}$$

and it acts at the angle

$$\theta = \tan^{-1}\left(\frac{894.6 \text{ lb}}{296.0 \text{ lb}}\right) \qquad \leftarrow \left[\theta = \tan^{-1}\left(\frac{R_y}{R_x}\right)\right]$$
$$= \tan^{-1}\left(3.022 \frac{\text{lb}}{\text{lb}}\right)$$
$$= \tan^{-1}(3.022)$$
$$= 71.69°$$

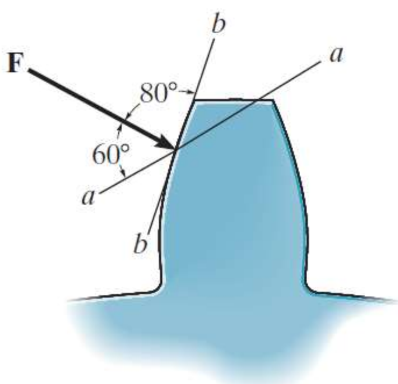
which is measured counterclockwise from the x-axis. (See Figure 4.7.)

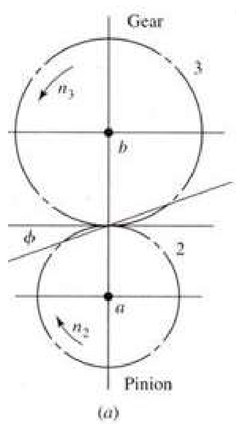


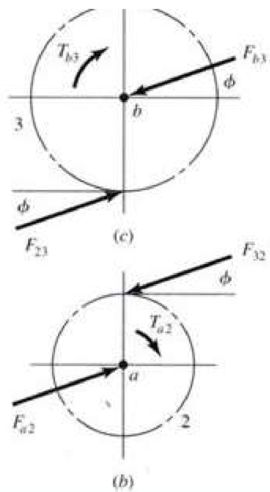
FORCE ANALYSIS

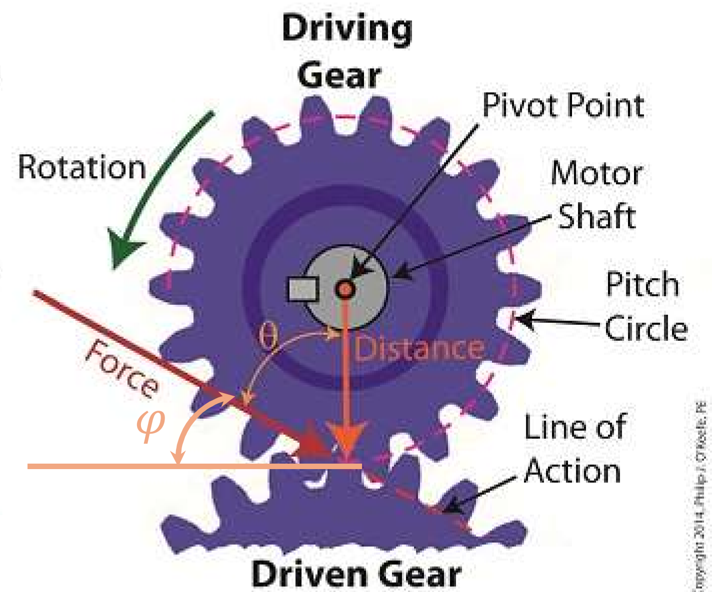
Forces Acting on Gears

- **A Spur Gear** is subjected to ***one force resultant in one plane*** as shown.
- This force produces between the driver and the driven gears.
- This force is required to transmit the energy between one shaft to another one through the gears.
- This force can be decomposed into ***two components***.





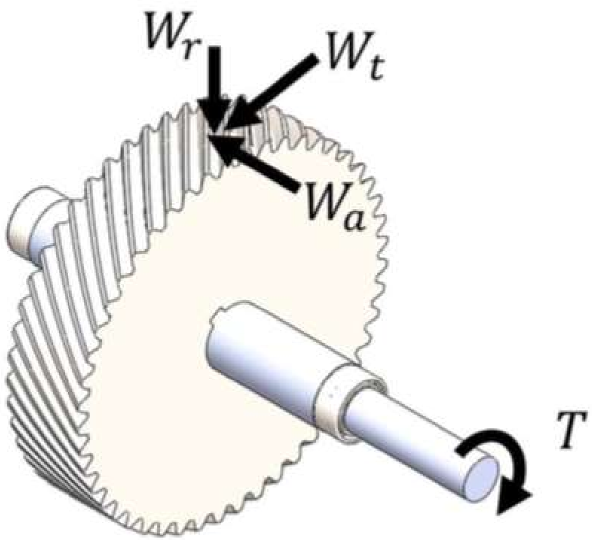


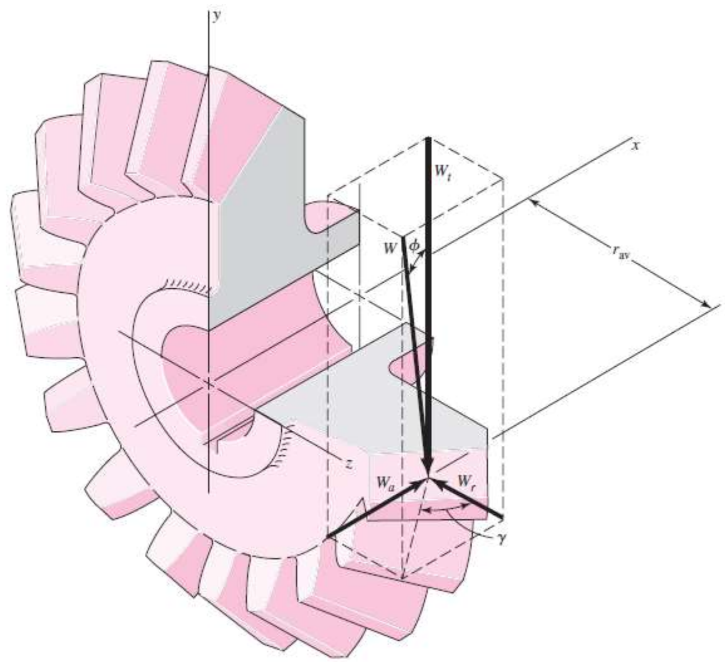


FORCE ANALYSIS

Forces Acting on Gears

- Both the **helical** and **bevel** gears are subjected to ***3 components*** of forces.



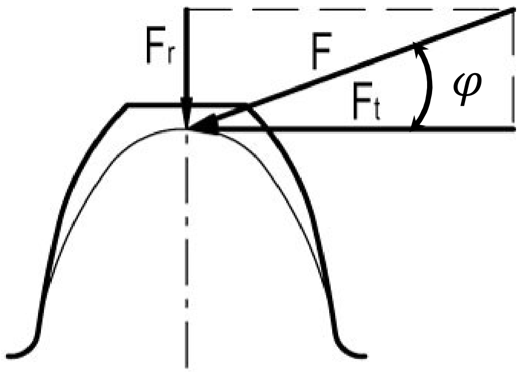


FORCE ANALYSIS

Forces Acting on Gears

- The resultant force acting on a spur gear can be decomposed into two components as shown.
- The tangential force (F_t) produces a torque on the gear, which is then transmitted to the shaft to give it rotation.

$$F_t = F\cos\varphi$$
$$F_r = F\sin\varphi$$
$$T = F_t\frac{d}{2}$$



F_t = is the tangential force.
F_r = is the radial force.
T = is the torque.
d = Gear diameter.