SNS COLLEGE OF TECHNOLOGY

(An Autonomous Institution)

COIMBATORE-35

Accredited by NBA-AICTE and Accredited by NAAC – UGC with A+ Grade
Approved by AICTE, New Delhi & Affiliated to Anna University, Chennai

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

COURSE NAME: 23EET203-ELECTRICAL MACHINES I

II YEAR / III SEMESTER

Unit 1 – ELECTROMECHANICAL ENERGY CONVERSION

Topic 1: Principle of electromechanical energy conversion forces

What We'll Discuss

TOPIC OUTLINE

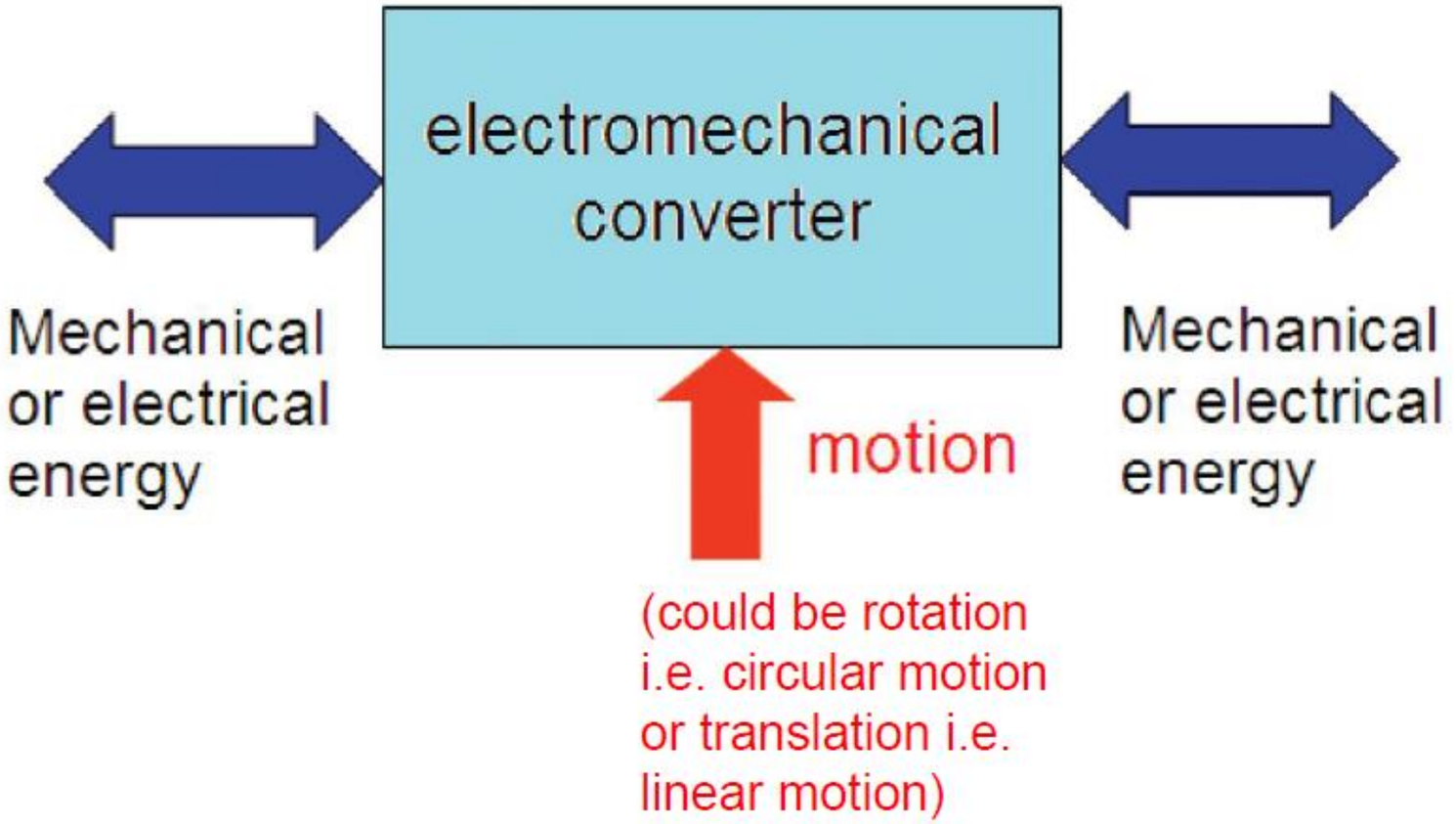
- Understanding the role of electromagnet ism in an electrical machine
- Understanding electrical/mechanical energy conversions in a machine
- Understanding the attractive forces between magnetized surfaces
- Understanding the alignment forces between magnetized surfaces

WHAT IS ELECTROMECHANICAL ENERGY CONVERSION?

- Electromechanical energy conversion is a **conversion of mechanical energy into electrical energy (generator)** or **vice-versa (motor)** with the aid of rotary **motion** (rotary machines) or translatory (linear) motion (linear machines and actuators)

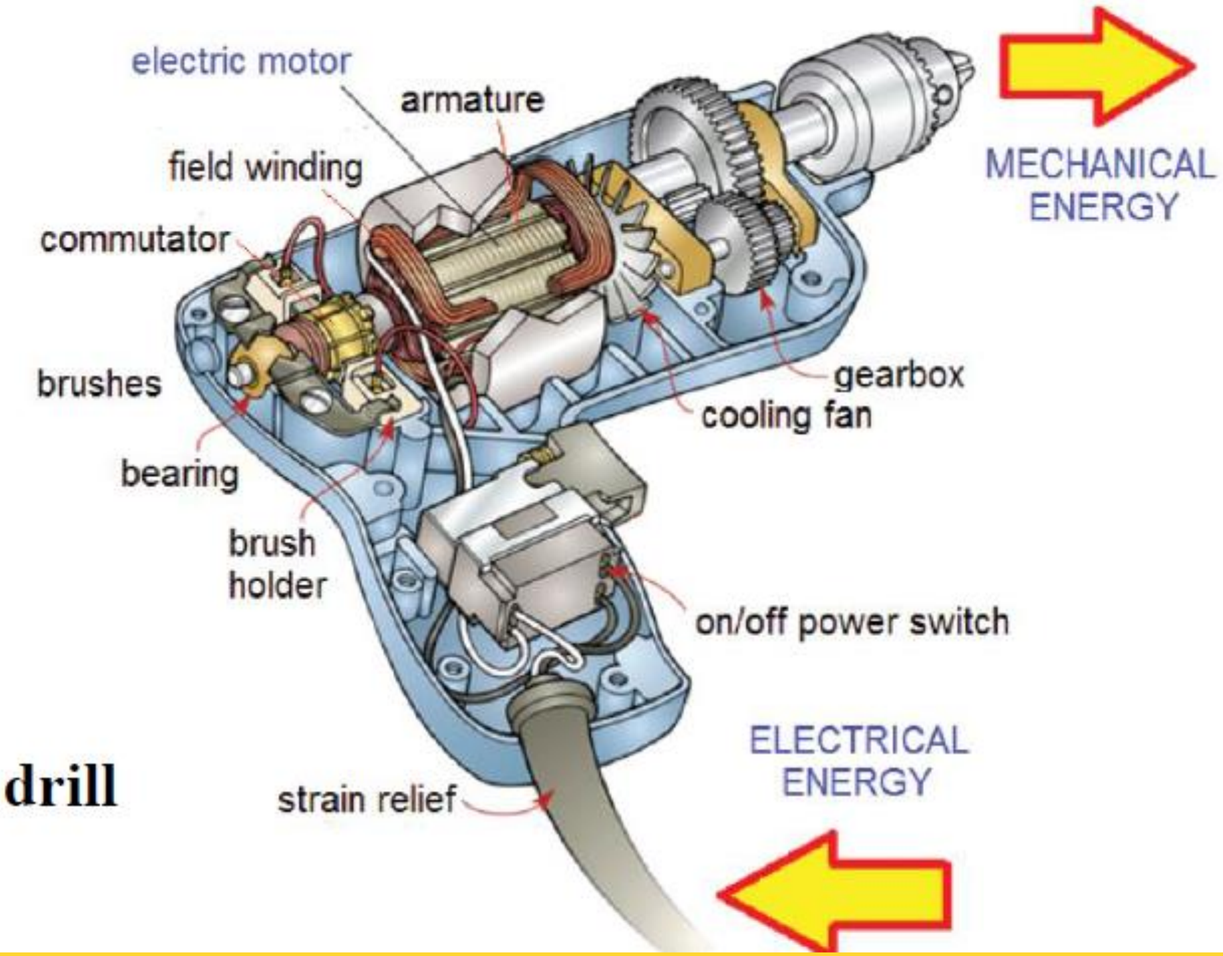
- **Electrical machines** (e.g. motors & generators), solenoid actuators and electromagnets are generally called electromechanical energy conversion devices

ELECTROMECHANICAL ENERGY CONVERSION



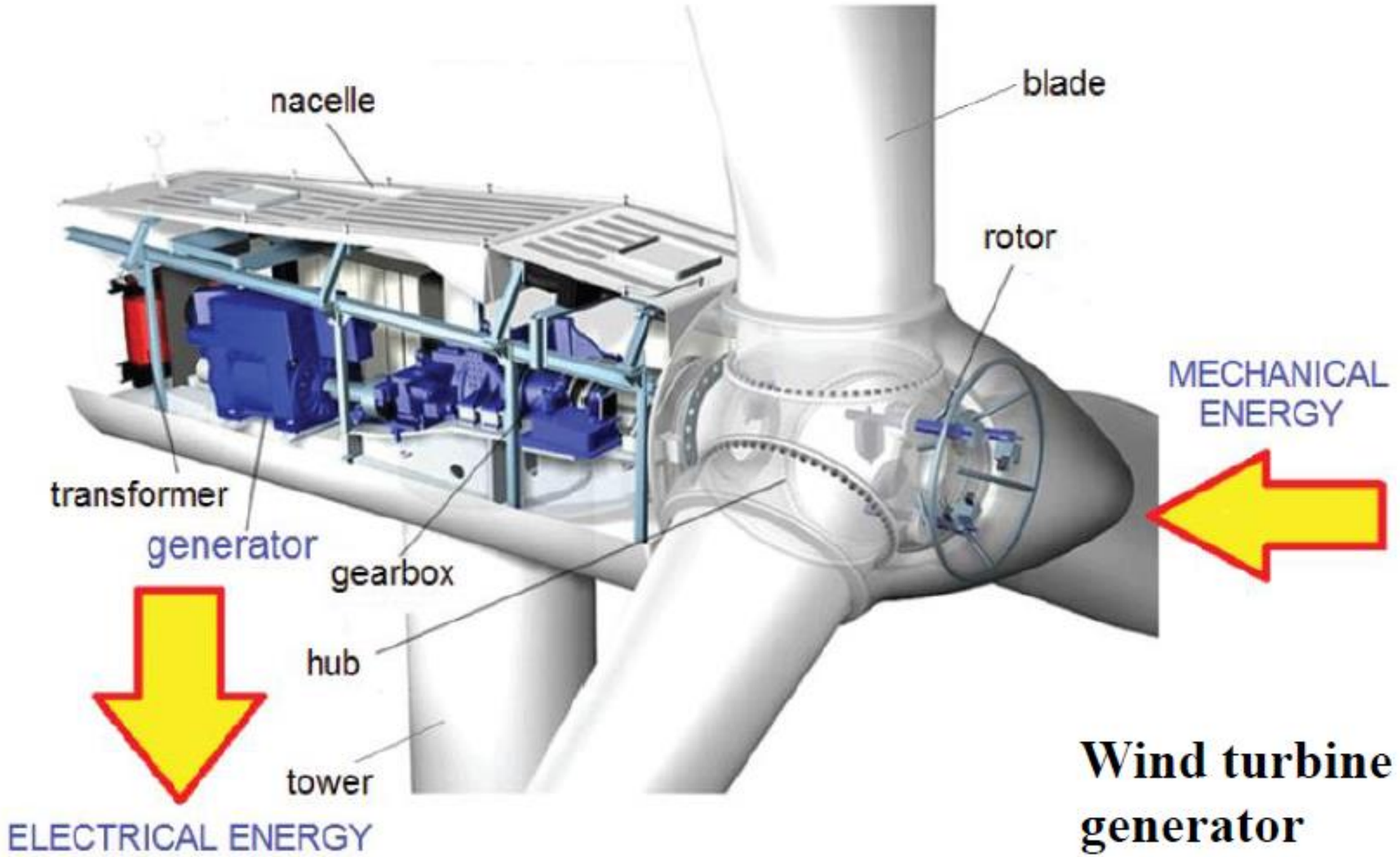
5

APPLICATIONS



Power tools
e.g. electrical drill

APPLICATIONS



Wind turbine generator

APPLICATIONS

Generators convert mechanical energy into electrical energy

Turbo generator

Diesel generator

APPLICATIONS

Ceiling fan: converts input electrical energy into output mechanical energy

APPLICATIONS

Motors convert electrical energy into mechanical energy

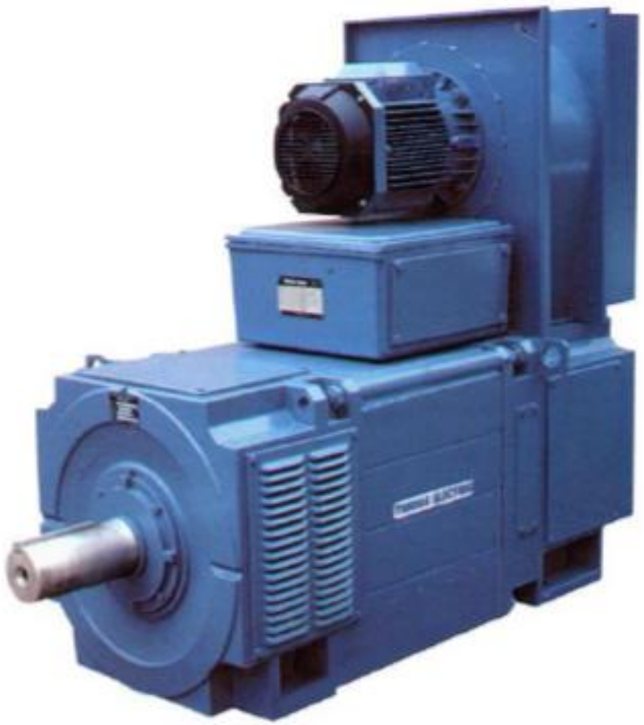
BLDC motor (Brushless DC motor)

12 V DC motor (Multipurpose Brushed Motor)

Stepper motor

APPLICATIONS

Motors convert electrical energy into mechanical energy



DC motor

Induction (AC) motor

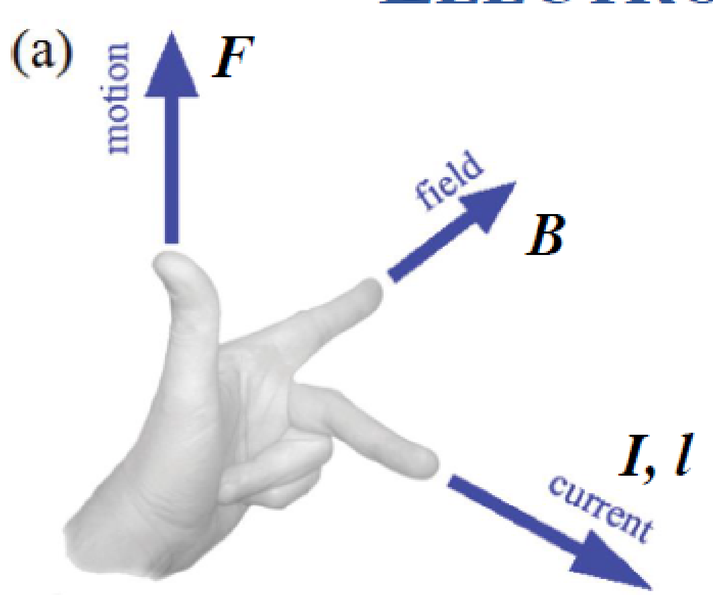
INTRODUCTION

ENERGY CONSERVATION PRINCIPLE

- **Energy can neither be created nor destroyed, it can merely be converted from one form into another**

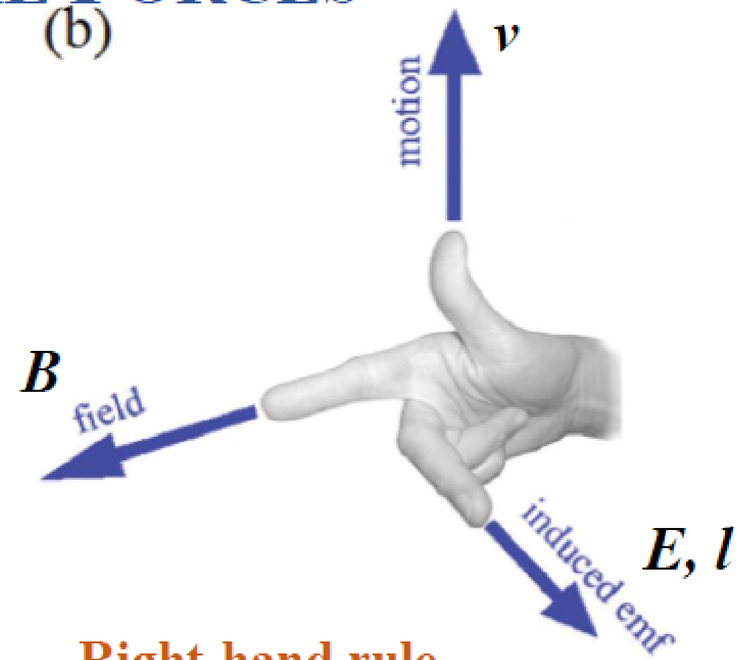
- **Energy balance equation = Function (energy input, energy output, energy stored, energy dissipated)**

ELECTRO-MECHANICAL FORCES



Left-hand rule

Thumb indicates the direction of induced **electrodynamic force** $F=BIl$, in response to an **applied current** I in presence of magnetic field B. (l is the length of current carrying conductor)



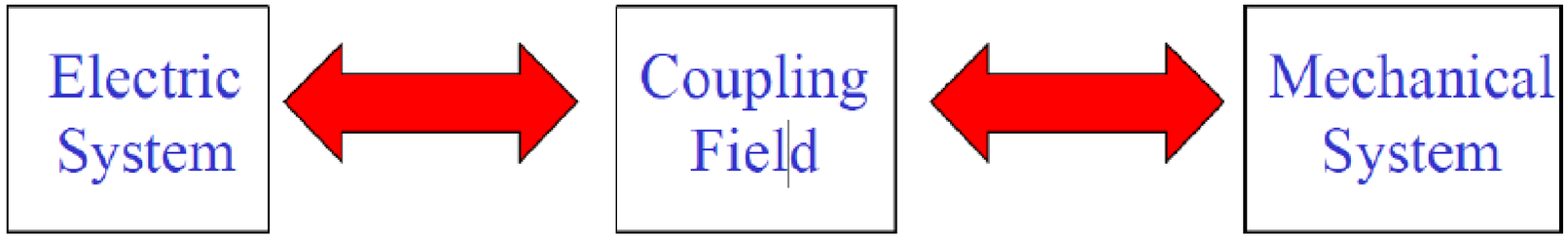
Right-hand rule

Middle finger indicates the direction of induced **electromotive force** $E=Blv$, in response to **applied motion** (velocity v) in presence of magnetic field B. (l is the length of conductor where emf is induced)

Energy Conversion Process in Machines

- An electromagnetic machine is one that links an electrical energy system to another (mechanical) energy system by providing a reversible means of energy flow via its magnetic field

- The **magnetic field** is therefore the **coupling** between the two systems and is the **mutual link** for **electro-mechanical energy conversion**



Magnetic field provides handshaking between electrical and mechanical system

ENERGY CONVERSION PROCESS IN MACHINES

- The **energy transferred** from one system is **temporarily stored** in the **magnetic field** and then released to the other system

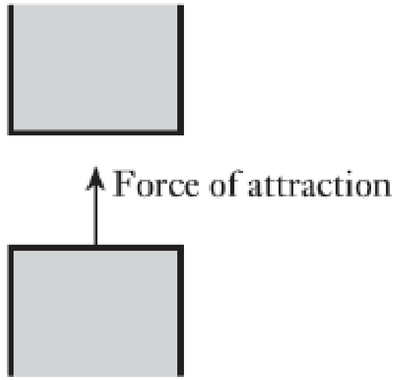
- **For Motor action**:
  Total **electrical input** = **Mechanical** energy **output** + total energy stored
  energy + total energy dissipated

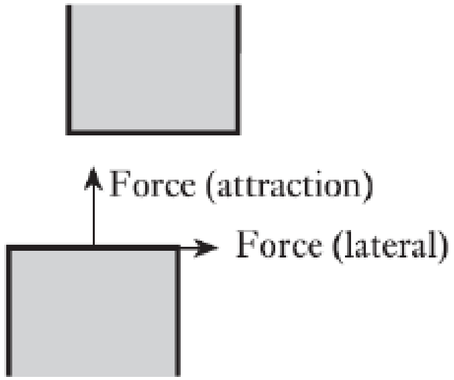
- **For Generator action**:
  Total **mechanical input** = **Electrical** energy **output** + total energy stored
  energy + total energy dissipated

- An **electromagnetic system** can develop a **mechanical force** in two ways:
  1. **By alignment**
  2. **By interaction**

FORCE OF ALIGNMENT

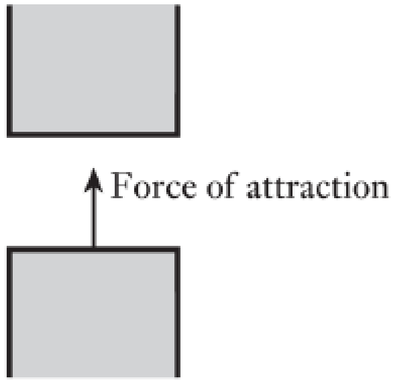
- The **force of alignment** acts in a **direction** that will **increase** the stored **magnetic energy** (or equivalently **reduce** the **reluctance**)
- E.g. In Fig. below, two poles (made of a ferromagnetic material) are situated opposite one another; each is energized via current carrying coil (to produce an *mmf*) and a flux passes from one to the other
- The surfaces through which the flux passes are said to be magnetized surfaces and they are attracted towards one another as indicated.





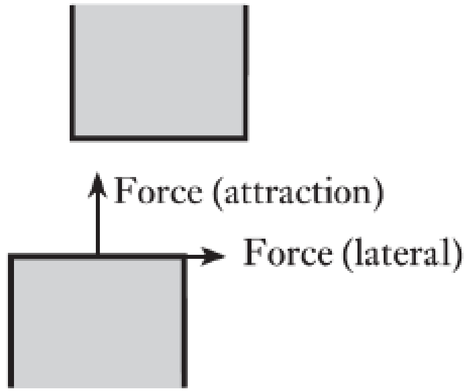
FORCE OF ALIGNMENT

In Fig. (a) below, it will try to **bring** the **poles closer** together since this **decreases the reluctance** of the air-gap in the magnetic circuit ($S \propto l$). This will increase the flux (for a given *mmf*) and also the stored energy



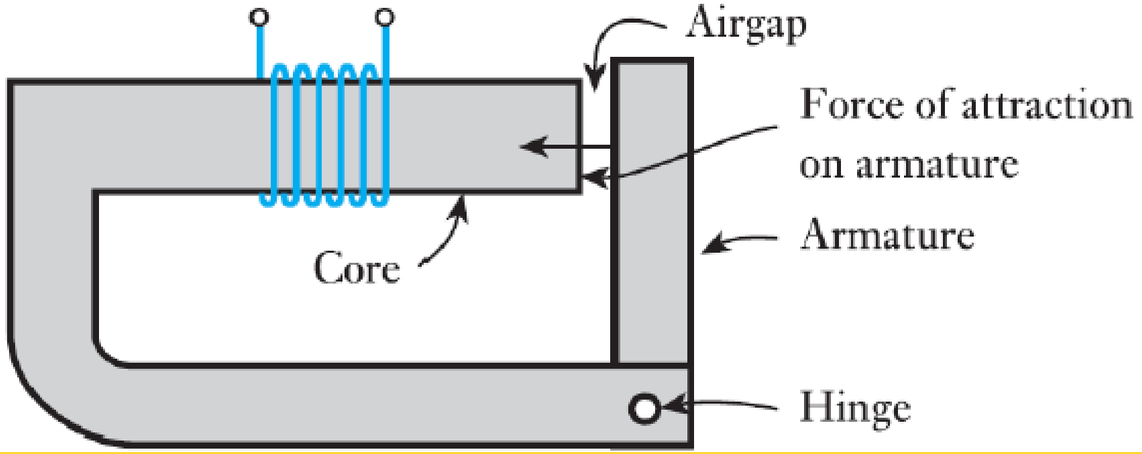
In Fig. (b) below, it will **also move** the **poles laterally**, as the **cross-sectional area** of the air-gap will be **increased** and the **reluctance** will be **reduced** ($S \propto 1/A$), thus increasing the stored magnetic energy

Force of alignment does not necessarily act in the direction of the lines of flux



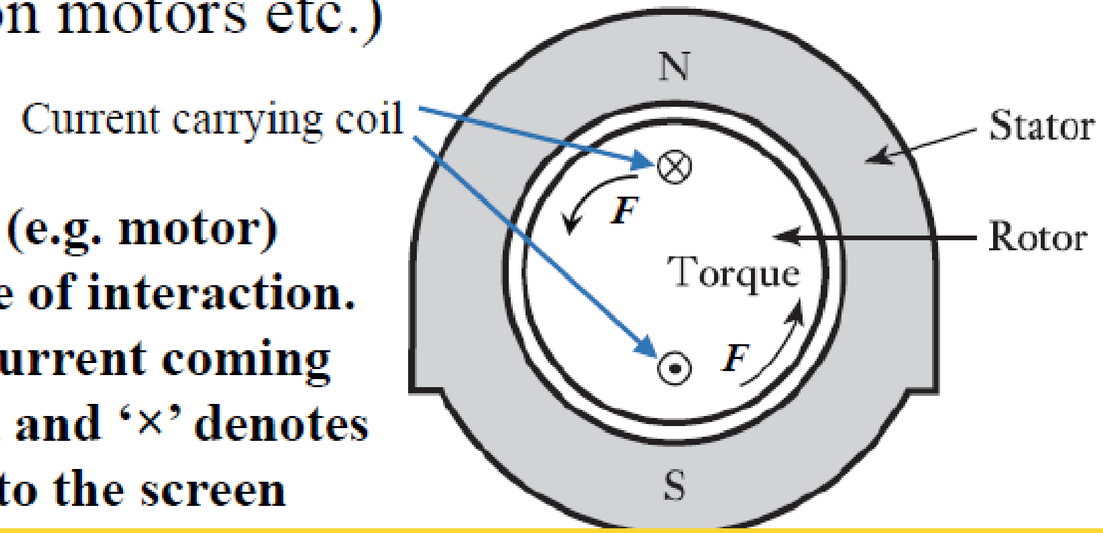
APPLICATION: ELECTROMAGNETIC RELAY

- When the **coil** is energized via a **current**, a **flux** is set up in the relay **core** and the **airgap**
- The **surfaces** adjacent to the airgap become **magnetized** and are **attracted**, hence pulling the armature plate in the direction indicated
- The relay's function is to operate **switches** and it is used extensively in **power system protection** applications and **telephone exchanges** etc.



FORCE OF INTERACTION

- The **force of interaction** can be written as $F = Bli$, where a **conductor** of **length** l carrying **current** i lying in a **magnetic field** B experiences a **Lorentz force** F (recall **directions** are determined via **left hand rule**)
- **Applications**: Involvement of the force of interaction is used to give rise to **rotary motion** in electrical **motors** (e.g. DC motors, synchronous motors, induction motors etc.)



Rotary machine (e.g. motor) working on force of interaction. The '.' denotes current coming out of the screen and '×' denotes current going into the screen

MAGNETIC FIELD ENERGY

Magnetic fields are the fundamental mechanism by which energy is converted from one form to another in electrical machines

Why do most of the electromechanical energy conversion devices use magnetic field as coupling medium??

Because it provides:

- High energy density
- Ideally no losses

MAGNETIC FIELD ENERGY

Consider a **magnetic circuit** of **length** l and **cross-sectional area** A made up of **material** with relative **permeability** μ_r that is energized by a **coil** with N **turns** carrying a **current** i, producing a **flux** ϕ

Inductance can be expressed as $$L = \frac{N\phi}{i} = \frac{\psi}{i} = \frac{N^2}{S} = \frac{N^2\mu_0\mu_r A}{l}$$

where ψ is the total **flux linkage** and S is the **reluctance**

The **energy** in a **magnetic field** is given by $$W_f = \frac{1}{2}Li^2$$

$$\Rightarrow W_f = \frac{1}{2}i\psi = \frac{1}{2}F\phi = \frac{1}{2}S\phi^2$$ where $F = Ni = S\phi$ is the ***mmf***

MAGNETIC FIELD ENERGY

- In the case of an **air-gap**, the *B-H* characteristic is a straight line ($B = \mu_0 H$) and the **stored energy density** is given by

$$w_f = \frac{1}{2}BH = \frac{\mu_0 H^2}{2} = \frac{B^2}{2\mu_0}$$

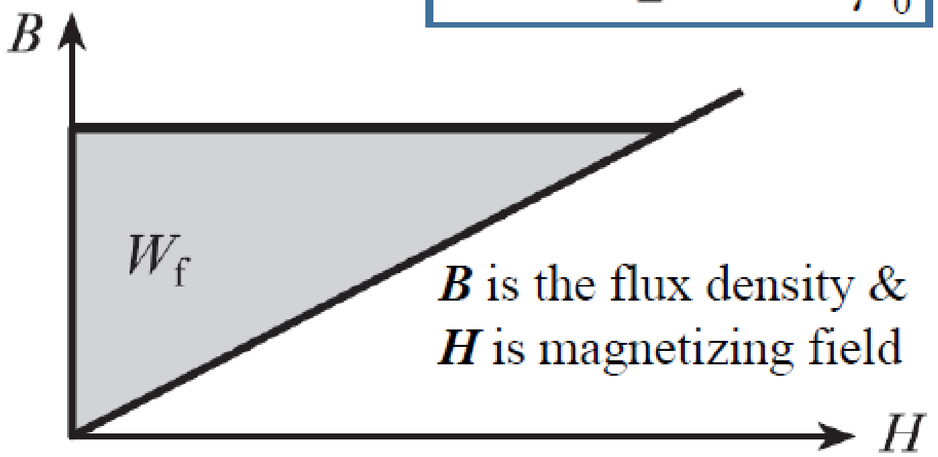
=> **Total stored energy**:

$$W_f = \frac{1}{2}BH \times \text{volume of airgap}$$

- If the **air-gap** has a **cross-sectional area** A and **length** l, then

$$W_f = \frac{1}{2}BH \times Al = \frac{1}{2}F\phi$$

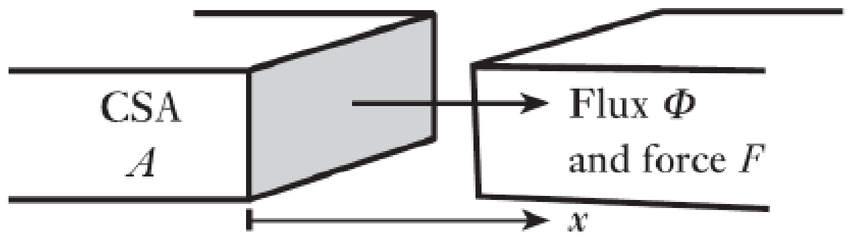
(since $F = H.l$ and $\phi = B.A$)



SIMPLE ANALYSIS OF FORCE OF ALIGNMENT

- Let there be a flux Φ in the airgap, then the uniform **flux density** in the **airgap** is then given by

$$B = \frac{\Phi}{A}$$



Airgap of length *x* between two magnetic poles

- Let the magnetic **poles** be **moved** further **away** from each other by a small **distance d*x*** by the application of a **mechanical force *F***

  => The **mechanical work done** on the system is $dW_M = F \cdot dx$

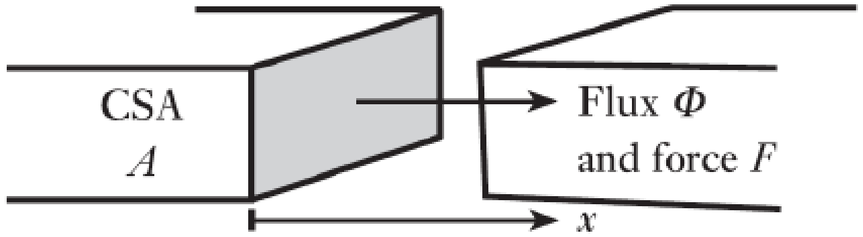
- Since the **airgap** has been **increased** by a **volume *A*.d*x***, the **increase** in the **stored magnetic** field **energy** is $dW_f = \frac{B^2}{2\mu_0} \times A \cdot dx$

SIMPLE ANALYSIS OF FORCE OF ALIGNMENT

- If the **system** is **ideal** with **no losses** (the motion has taken place slowly from one point of rest to another), the **change in magnetic energy** must be **due to the input** of **mechanical energy** (work done)

$$dW_M = dW_f$$

$$F \cdot dx = \frac{B^2 A}{2\mu_0} \cdot dx \Rightarrow \boxed{F = \frac{B^2 A}{2\mu_0}}$$



Airgap of length x between two magnetic poles

$$dW_M = F \cdot dx = dW_f \Rightarrow \boxed{F = \frac{dW_f}{dx}}$$

$dW_f/dx < 0$ => **force of alignment is attractive**

The **force of alignment** is given by the **rate of change** of **stored field energy** with respect to a **small displacement** in the **position** of the ferromagnetic **poles**

Recall

List the forces developed

THANK YOU