

1 Introductory concepts

1.1 Introduction

This is the first topic of course Electromechanics and Machines, as represented in Table 1.1.

Table 1.1: Focus on Module 1

Electromechanics and Machines	
1	Introductory concepts
2	Electromagnetic fields
3	Magnetic circuits
4	Transformer
5	Introduction to electric power systems
6	Electromechanical energy conversion
7	DC machines
8	AC machines
9	Illumination

In this module, the basic concepts supporting the foundations for energy conversion are given.

At the end of the topic, students should be able to:

- 1) Describe the physical quantities for mechanics and electricity;
- 2) Explain how relationships are expressed by equations;
- 3) Differentiate scalars, vectors and phasors;
- 4) State the basic laws of mechanics and electromagnetism as applied to electromechanical energy conversion.

1.1 Physical quantities, dimensions and units

Physical quantities in electrical engineering describe in a quantitative way what happens to the electrical, mechanical and thermal properties of matter. The focus on electrical properties considers the physical effects which occur in conductors, insulators, magnetic and non magnetic materials. The focus on mechanics permits the description of the motion of pieces of matter following the application of forces. The thermal effects are important to consider as they describe the condition of matter at specified temperatures. All these effects require to be quantified in order to describe the specification and performance of the electrical engineering apparatus.

Some examples of physical quantities used in mechanics and electrics are given in Table 1.2.

Table 1.2: Some physical quantities

Mechanics		Electrics	
Quantity	Symbol	Quantity	Symbol
length	l, x	voltage	v, V
force	F	resistance	R
momentum	I	capacitance	C
acceleration	a	inductance	L
torque	T	electric charge	q, Q
angular speed	ω	current density	J
mass	m	magnetic flux	ϕ

Dimensions and units are used to describe physical quantities. A **dimension** is characteristic of a physical quantity while a **unit** indicates how the physical quantity is to be measured in terms of standard quantities.

Traditionally, there are three reference dimensions in mechanics, namely 1) length, 2) mass and 3) time. Two more dimensions are needed to complete the considerations in electrical engineering. One of these is for electromagnetism (e.g. current) and the other is for thermodynamics (e.g. temperature).

A number of base units, corresponding to the number of independent dimensions, need to be **chosen** and carefully **defined**. The international adoption of the choice and definition of the units is by the International System of Units, so-called SI system. In the SI system, there are seven base units and two supplementary units, as given in Table 1.3.

Table 1.3: SI quantities and units

	Quantity	Unit name	Symbol
Base	time	second	s
	length	metre	m
	mass	kilogram	kg
	electric current	Ampere	A
	thermodynamic temperature	Kelvin	K
	luminous intensity	candela	cd
	amount of substance	mole	mol
Supplementary	plane angle	radian	rad
	solid angle	steradian	sr

The definition of each unit is precise. In this course, you are required to only remember the definition of the Ampere. The Ampere is defined as “*That constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length*”.

Units of all physical quantities can be expressed in terms of the base and supplementary units. In practice, it is better to define derived units in the following cases.

- 1) the quantity is used frequently;
e.g. **Hz** derived from s^{-1} for frequency
- 2) the units are lengthy;
e.g. **N** for kgm/s^2
- 3) a new physical concept is introduced ;
e.g. **V** for $kgm^2s^{-3}A^{-1}$.

The numerical values of many quantities may be many orders of magnitude away from unity (bigger or smaller). It may therefore be more convenient to either use power of 10 or to use decimal prefixes with the unit. Powers in steps of 3 are preferred, but some others have common usage (e.g. centimetre, cm; decibel, dB), as given in Table 1.4.

Table 1.4: SI quantities and units

Order	Name	Symbol	Order	Name	Symbol	Order	Name	Symbol
10^{18}	exa	E	10^2	hecto	h	10^{-3}	milli	m
10^{15}	peta	P	10^1	deca	da	10^{-6}	micro	μ
10^{12}	tera	T	10^{-1}	deci	d	10^{-9}	nano	n
10^9	giga	G	10^{-2}	centi	c	10^{-12}	pico	p
10^6	mega	M				10^{-15}	femto	f
10^3	kilo	k				10^{-18}	atto	a

1.2 Relationships and equations

Equations are a compact and effective way of stating relationships between various quantities.

Equations may arise in four different ways:

- 1) a statement of a basic law, which has been tested and accepted;

e.g. Faraday's law,

$$v = N \frac{d\phi}{dt} \quad (1.1)$$

- 2) a definition of a new quantity or concept;

e.g. electric current density,

$$J = \frac{I}{A} \quad (1.2)$$

- 3) description of material property ;

e.g. permeability,

$$\mu = \frac{B}{H} \quad (1.3)$$

- 4) derivation from other equations, using mathematical processes.

1.3 Scalars, vectors and phasors

A **scalar** quantity has magnitude only. It is specified by a single numerical value together with its unit, for example, mass.

A **vector** quantity has a magnitude and direction. It needs two values to specify it, if it is confined to a plane, or three values, if it is in general three-dimensional space. The quoted values for the vector quantity depend on whether it is the Cartesian system (x , y [and z]) or the polar system (r , θ) [r , ω].

A **phasor** is a representation of a sinusoidally varying quantity. For a sinusoidal quantity y represented in time at time t , as

$$y = y_m \cos(\omega t + \varphi) \quad (1.4)$$

its phasor representation is a phasor with magnitude or peak value y_m , rotating at angular speed ω , onto a fixed reference unit with angle φ , from the reference.

1.4 Basic laws

The main laws applicable in electromechanics are as follows.

1) Faraday's law:

The magnitude of the induced voltage is equal to the rate of change of flux-linkages;

$$v = \frac{d(N\phi)}{dt} \quad (1.5)$$

2) Ampere's circuital law:

The mmf (magnetomotive force) around a closed path is equal to the current enclosed by the path.

$$\text{mmf} = Ni = Hl \quad (1.6)$$

3) Newton's second law of motion:

The acceleration (or angular acceleration) of a system is directly proportional to, and in the same direction as, the net external force (or torque) acting on the system;

$$F = ma \quad (1.7)$$

$$T = J\alpha \quad (1.8)$$

4) Law of conservation of mass:

In any closed system subjected to no external forces, the mass is constant irrespective of its changes in form.

5) Law of conservation of energy:

The total energy of an isolated system remains constant.

6) Law of conservation of electric charge:

The net electric charge of an isolated system will always remain constant.

7) Law of conservation of magnetic flux:

The total magnetic flux through a closed surface is equal to zero.

Review questions

- 1) Define the following: physical quantity, dimension and unit.
- 2) List the seven base units and the two supplementary units.
- 3) Describe four situations where derived units are used.
- 4) State, with examples, how equations are used to state relationships.
- 5) Differentiate between a scalar and vector quantity.
- 6) How is a phasor quantity different from a vector quantity?
- 7) State the following:
 - i. Faraday's law;
 - ii. Ampere's circuital law;
 - iii. Newton's second law.