Zeev Bahir

Electrical Drive Control
Textbook with Applicative Aspects

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Preface

The subject of electrical drive systems is studied in several engineering faculties, such as electrical engineering, mechanical engineering, control engineering, etc., since it involves acquaintance with several fields of engineering.

To begin with, it requires acquaintance with the MO and calculation principles of DC as well as AC motors, which are not taught in all the aforementioned faculties. Therefore, these subjects are discussed in the first two chapters of this book.

Chapter 1 offers a brief introduction to the basics of electromagnetism and the operation principles of electric motors.

Chapter 2 reviews DC motor and Induction motors.

Chapters 3 to 6 discuss the main subjects of this book.

Chapters 3 and 4 discuss the behavior of open loop drive systems with different loads in static and dynamic states.

An Electrical drive system performs better when it is a part of a close loop control system. These systems are analyzed in chapters 5 and 6. Since such analysis involves the understanding of Feedback Control theory, these chapters also offer general theoretical explanations explaining the behavior of speed control and position control systems.

The main requirement of electric motor is that of speed regulation capability. To achieve this, we must be familiar with the electronic means of rotation speed change. These are discussed in chapter 7, which also reviews motion sensors and advanced motors.

The subtitle of this book is a “textbook with applicative aspects”, so its theoretical explanations, solved problems and

the problems to be solved by students refer to situations as similar to real-life industrial situations as possible.
A 40 year-long experience in teaching made me realize that student only understand the subject properly when they are required to handle calculations related to the field of engineering they study. The main mathematical tools for solving the problems in this book are differential equations. This book does not go beyond first-order, linear equations.
It is phrased in businesslike, simple English. It makes for easy learning material, due to the abundance of solved problems and problems with answers to be solved by the students.
The author, Zeev Bahir, has a Master’s degree in electrical engineering and in mathematics, and has been lecturing in Israeli academic colleges since 1975. He is also an electrical drive systems advisor to industries.

Introduction

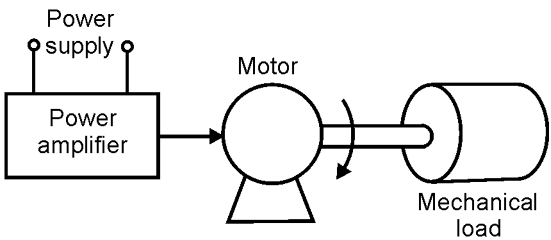
A drive system consists of four main parts:

1. Electric motor, consuming an electric power from a feed source, transforming it into mechanical energy generating a mechanical torque on the drive shaft.
2. Work machine, the mechanical load on the motor shaft requiring the generation of appropriate mechanical torque by the motor.
3. Mechanical system, connecting the shaft with the work machine, either in the form of direct connection, transmission, etc.
4. Control system, allowing the operation of the motor according to the drive system user's requirements.

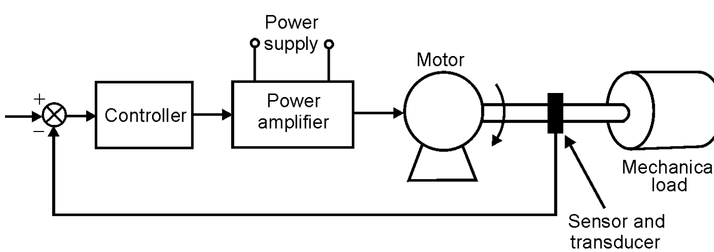
The mechanical load and motor affect each other. Therefore, the drive system must be analyzed as a whole. In other words, one must examine the load requirements, on one hand, as well as the motor's capacity to drive the work machine in various motion states, on the other hand.
Therefore, there are three major factors affecting the operation of motor driving the work machine:

1. The motor's torque-speed characteristic.
2. The work machine's torque-speed characteristic.
3. The type of motion process, such as steady speed motion, acceleration, deceleration, braking, motor speed regulation, rotation direction reverse, etc.

The following figures show two drive system configurations:



Open loop system, consisting of a motor and a work machine



Close loop controlled drive system

Chapter 1

Brief Introduction to the Basics of Electromagnetism and the Operation Principles of Electric Motors

This chapter should offer the students a general background, allowing them to better understand the contents presented later on. (This chapter is based on the book: *Electric Machinery Fundamentals*. Stephen J. Chapman. McGraw Hill).

1-1 Magnetic Circuit of Elementary Electric Motors

Magnetic fields are the basic mechanism used to convert one form of energy into another, such as in electric motors, generators, and transformers. Four basic processes allow the use of magnetic fields in these devices:

a. A current carrying wire produces a magnetic field around it.

b. Voltage induced by a magnetic field changing, in a coiled wire with time, after passing through the coil. This is the principle of transformer operation.

c. A force induced on a current carrying wire in the presence of a magnetic field. This is the principle of electric motor operation.

d. Voltage induced in a wire moving in a magnetic field. This is the principle of power generator operation.

Figure 1-1 shows a rectangular core with *N* turns of wire winding around one side of the core.

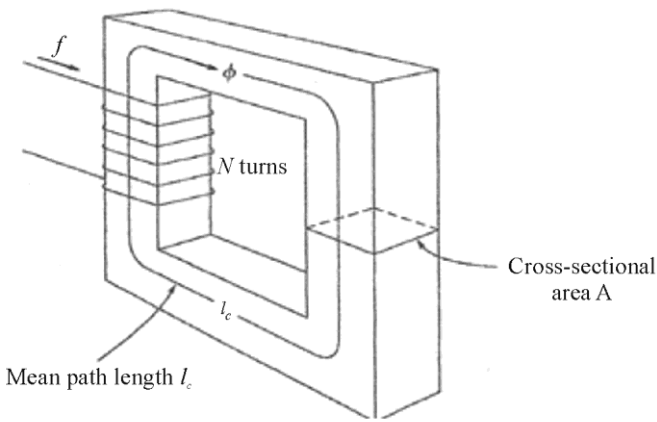


Figure 1-1. Rectangular core with coil

If the core is made of iron or other metals of the group called ferromagnetic materials, then, basically, all the magnetic fields produced by the current will remain inside the core.
The magnetic field produced by a current is described as Ampere's Law:

$$H \cdot l_c = N \cdot i$$

Wherein: H = the magnetic field intensity
i = applied current

Therefore, the magnetic field intensity is expressed by the following formula:

$$H = \frac{N \cdot i}{l_c}$$

In a way, H measures the effort made by the current in creating the magnetic field.

The relationship between magnetic flux φ and magnetic flux density B is expressed by the following equation:

$$\varphi = B \cdot A$$

Wherein: A is the core's cross-section area.

Therefore, $B = \varphi / A$.

The quantity of the core magnetic flux depends on the core material. The following formula expresses the relationship between magnetic field intensity H and magnetic flux density *B*, produced in a core of a certain material:

$$B = \mu \cdot H$$

Wherein:
H = magnetic field intensity
μ = magnetic permeability of the core material
B = the produced magnetic field intensity
The effective magnetic flux density produced in the core of a specific material is the product of two factors:
H, the effort made by the current to form a magnetic field, and μ, the relative ease of forming a magnetic field in a certain material.
Magnetic field intensity is measured in ampere by turns per meter;
Permeability is measured in Henrys per meter;

Magnetic flux density is measured in Webers per square meter, or Teslas (T).
The value of an empty space permeability μ_0 is:

$$\mu_0 = 4\pi \cdot 10^{-7}\ Hm$$

Relative permeability μ_r is the permeability of any other material compared to that of an empty space, and is expressed by the following equation:

$$\mu_r = \frac{\mu}{\mu_0}$$

Relative permeability helps in comparing the magnetization capability of different materials. For example, a latest model machine steel may have a relative permeability of at least 2000 to 6000. Naturally, the metals that a transformer or a motor core is made of greatly help to increase and concentrate the flux in the device.

In addition, since iron has a much higher permeability than air, most of the flux in an iron core, such as shown in Figure 1-1, remains in the core and doesn't leak through the air. The small amount of flux that does leak outside the core greatly affects the flux flowing between the coils and the self-inductance of the coils in transformers and motors.

In a core such as shown in Figure 1-1, the flux density is expressed as:

$$B = \mu \cdot H = \frac{\mu \cdot N \cdot i}{l_c}$$

$$\varphi = B \cdot A$$

In a way, the magnetic flux produced by a current in a wire wound around a core is similar to the current produced by a voltage in an electric circuit. The behavior of a magnetic field is described by equations similar to those describing that of an electric circuit.

In a simple electric circuit like the one shown in Figure 1-2a, the source of voltage V sends current I around the circuit through resistance R. The relation between these quantities is given by Ohm's Law:

$$V = I \cdot R$$

Similarly, in a magnetic circuit, magnetomotive force $\mathfrak{F}$ produces flux φ through reluctance $\mathfrak{R}$. Therefore, the relation between these quantities is:

$$\mathfrak{F} = \varphi \cdot \mathfrak{R}$$

Wherein:

$\mathfrak{F}$ = the magnetomotive force of the circuit;

φ = the flux of the circuit;

$\mathfrak{R}$ = the reluctance of the circuit.

Reluctance in a magnetic circuit is similar to resistance in an electric circuit. It is measured by ampere turns per Weber.

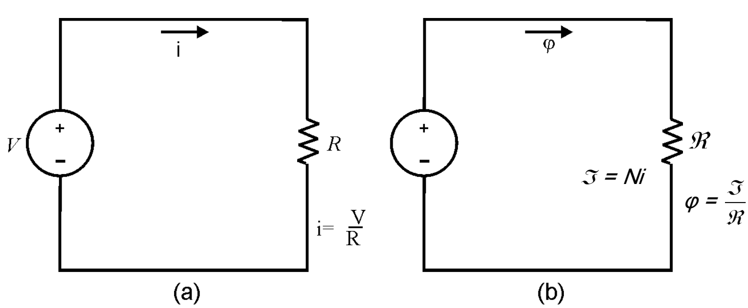


Figure 1-2. Electric circuit and magnetic circuit