1.4 ENERGY IN MAGNETIC SYSTEMS

It is often necessary in today's computer controlled industrial setting to convert an electrical signal into a mechanical action. To accomplish this, the energy in the electrical signal must be converted to mechanical energy. A variety of devices exist that can convert electrical energy into mechanical energy using a magnetic field. One such device, often referred to as a reluctance machine, produces a translational force whenever the electrical signal is applied. There are several variations of the reluctance machine but all operate on the same basic electromechanical principles.

The principles of electromechanical energy conversion are investigated. The motivation for this investigation is to show how the governing equations of an electromechanical device can be derived from a magnetic circuit analysis. An expression for the mechanical force will be derived in terms of the magnetic system parameters.

Electromechanical Energy Conversion Principles

Electromechanical-energy-conversion process takes place through the medium of the electric or magnetic field of the conversion device of which the structures depend on their respective functions.

Transducers: microphone, pickup, sensor, loudspeaker Force producing devices: solenoid, relay, electromagnet Continuous energy conversion equipment: motor, generator This chapter is devoted to the principles of electromechanical energy conversion and the analysis of the devices accomplishing this function. Emphasis is placed on the analysis of systems that use magnetic fields as the conversion medium. The concepts and techniques can be applied to a wide range of engineering situations involving electromechanical energy conversion. Based on the energy method, we are to develop expressions for forces and torques in magnetic field based electromechanical systems.

Forces and Torques in Magnetic Field Systems

The Lorentz Force Law gives the force on a particle of charge in the presence of electric and magnetic fields. F: newtons, : coulombs, : volts/meter, qEB: telsa , :

meters/second In a pure electric-field system, F=qE

In pure magnetic-field systems, F=q*(v*B)

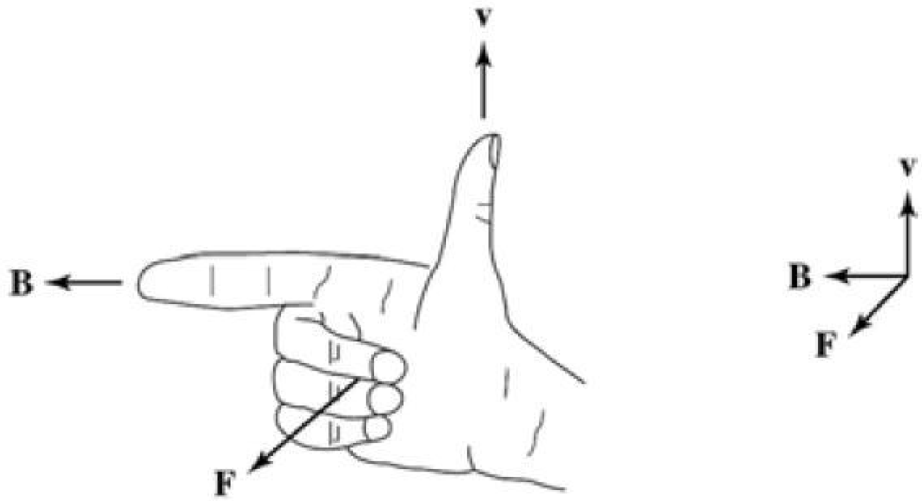

Figure 1.5.1 Right Hand rule

[Source: "Electric Machinery Fundamentals" by Stephen J. Chapman*, Page: 241]*

For situations where large numbers of charged particles are in motion F=J*V most electromechanical-energy-conversion devices contain magnetic material. Forces act directly on the magnetic material of these devices which are constructed of rigid, non deforming structures. The performance of these devices is typically determined by the net force, or torque, acting on the moving component. It is rarely necessary to calculate the details of the internal force distribution. Just as a compass needle tries to align with the earth's magnetic field, the two sets of fields associated with the rotor and the stator of rotating machinery attempt to align, and torque is associated with their displacement from alignment. In a motor, the stator magnetic field rotates ahead of that of the rotor, pulling on it and performing work. For a generator, the rotor does the work on the stator.

The Field Energy

Based on the principle of conservation of energy: energy is neither created nor destroyed; it is merely changed in form.

Energy Balance

A magnetic-field-based electromechanical-energy-conversion device. A lossless magnetic-energy-storage system with two terminals The electric terminal has two terminal variables: (voltage), (current). The mechanical terminal has two terminal variables: (force), (position) The loss mechanism is separated from the energy-storage mechanism.

- Electrical losses: ohmic losses.
- Mechanical losses: friction, windage.

A simple force-producing device with a single coil forming the electric terminal, and a movable plunger serving as the mechanical terminal.

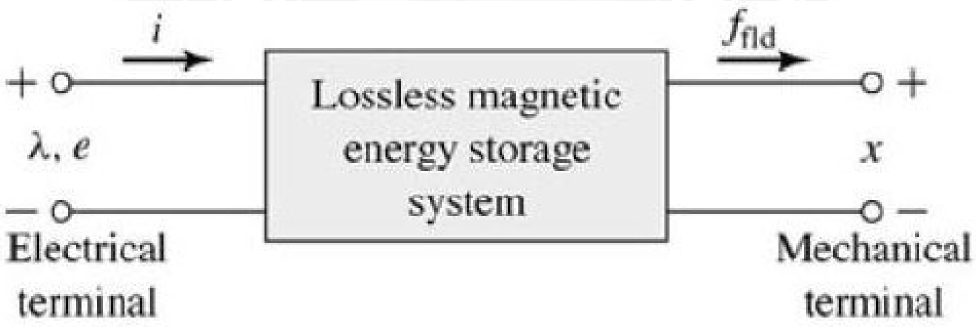

Figure 1.5.2 Schematic magnetic field

[Source: "Electric Machinery Fundamentals" by Stephen J. Chapman*, Page: 219]*

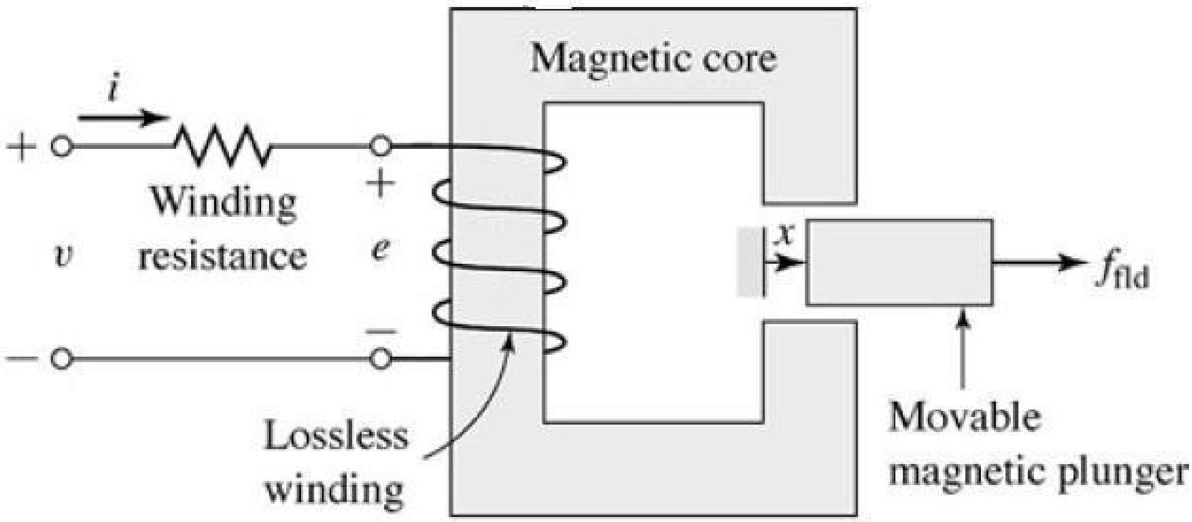

Figure 1.5.3 Simple force producing device

[Source: "'Electric Machinery Fundamentals" by Stephen J. Chapman*, Page: 220]*

The interaction between the electric and mechanical terminals, i.e. the electromechanical energy conversion, occurs through the medium of the magnetic stored energy.

Consider the electromechanical systems whose predominant energy-storage mechanism is in magnetic fields. For motor action, we can account for the energy transfer. The ability to identify a lossless-energy-storage system is the essence of the energy method. This is done mathematically as part of the modeling process. For the lossless magnetic-energy-storage system gives the expression as

$$dW_{elec}=d_{mech}+d_{fld}$$

Here E is the voltage induced in the electric terminals by the changing magnetic stored energy. It is through this reaction voltage that the external electric circuit supplies power to the coupling magnetic field and hence to the mechanical output terminals. The basic energy-conversion process is one involving the coupling field and its action and reaction on the electric and mechanical systems.

$$dW_{elec}=Ei.dt=d_{mech}+d_{fld}$$

The Co Energy

The magnetic stored energy is a state function, determined uniquely by the values of the independent state variables λ and *x*

Coenergy:

Here the force can be obtained directly as a function of the current. The selection of energy or coenergy as the state function is purely a matter of convenience.

For a magnetically-linear system, the energy and coenergy (densities) are numerically equal:

$$W_{fld} + W_{fld} = \lambda i$$

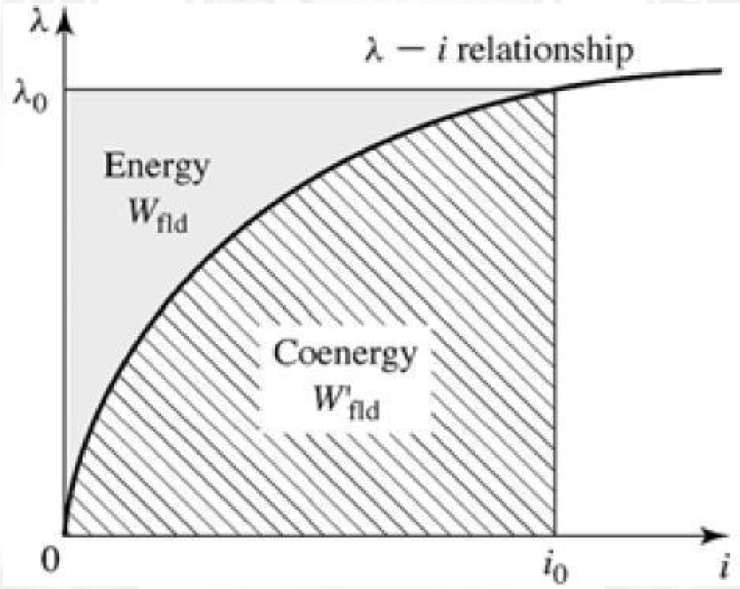

Figure 1.5.4 Energy and co energy in single excited system

[Source: "'Electric Machinery Fundamentals" by Stephen J. Chapman*, Page: 221]*

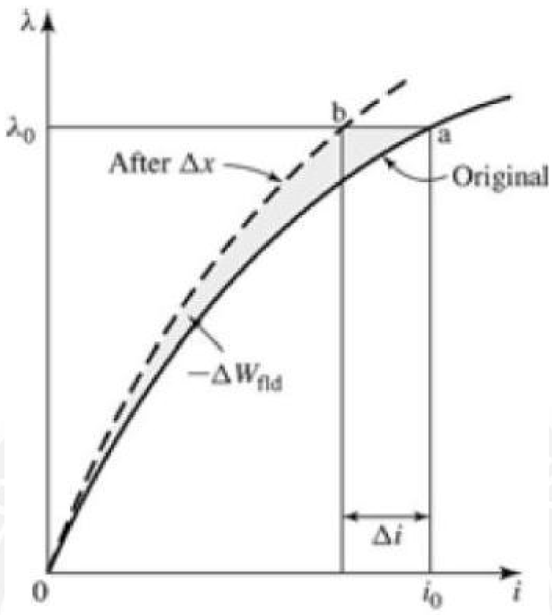

Figure 1.5.5 (a) Change of energy with λ

[Source: "'Electric Machinery Fundamentals" by Stephen J. Chapman*, Page: 223]*

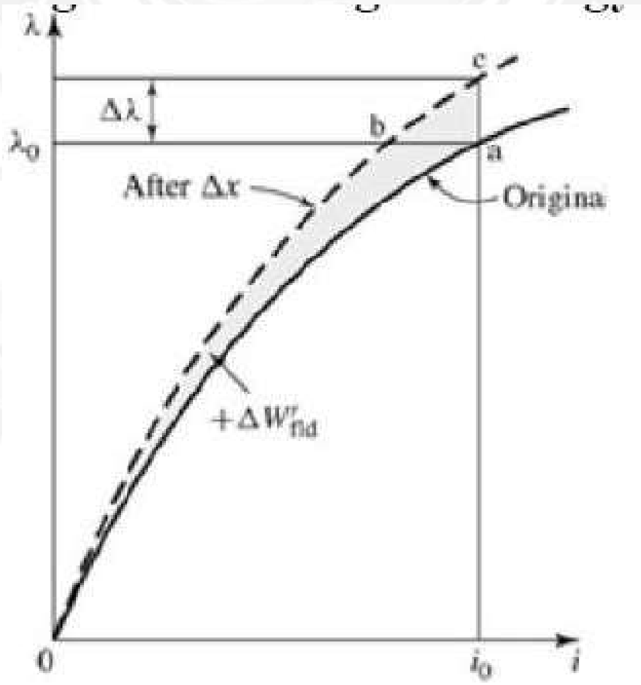

Figure 1.5.5 (b) Change of co energy with λ

[Source: "'Electric Machinery Fundamentals" by Stephen J. Chapman*, Page: 223]*

The force acts in a direction to decrease the magnetic field stored energy at constant flux or to increase the coenergy at constant current. In a singly-excited device, the force acts to increase the inductance by pulling on members so as to reduce the reluctance of the magnetic path linking the winding.