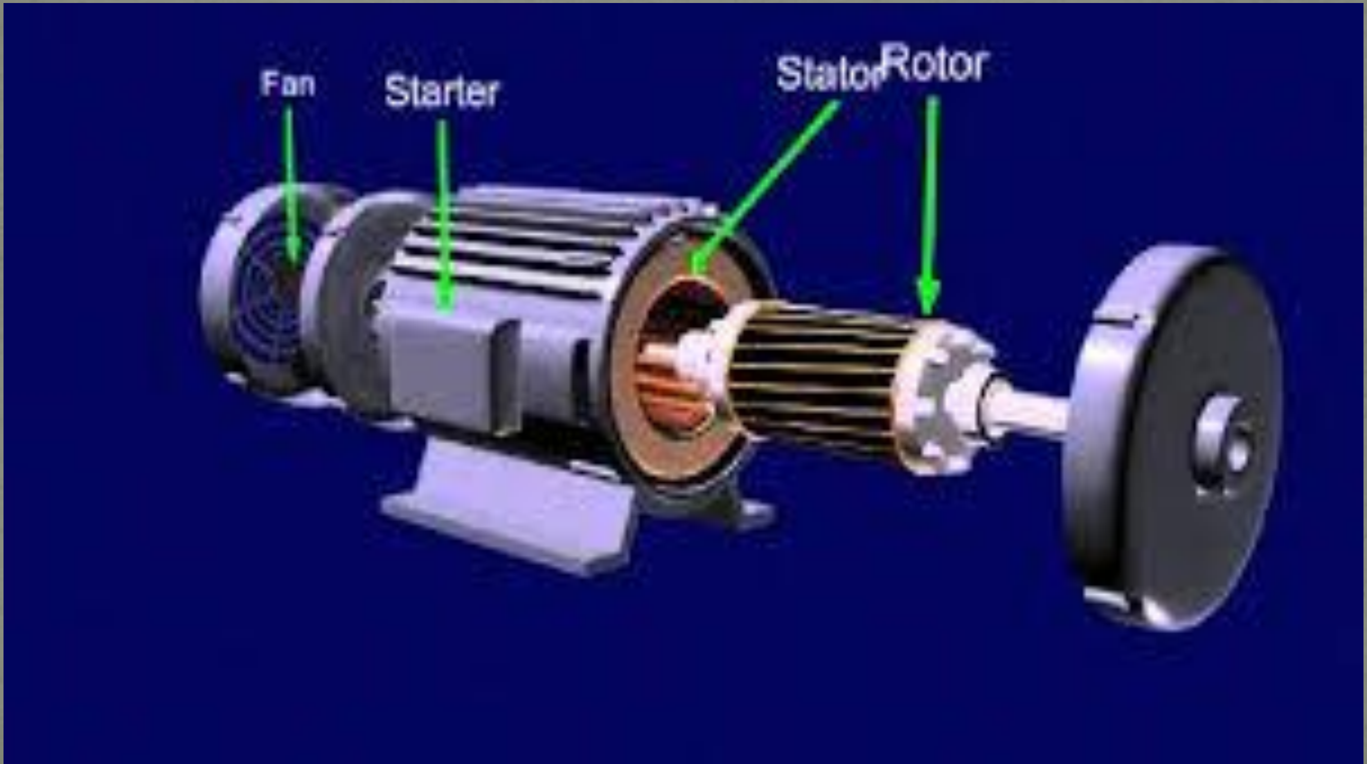
Electrical Machine

- An electrical machine is the apparatus that converts energy in three categories:

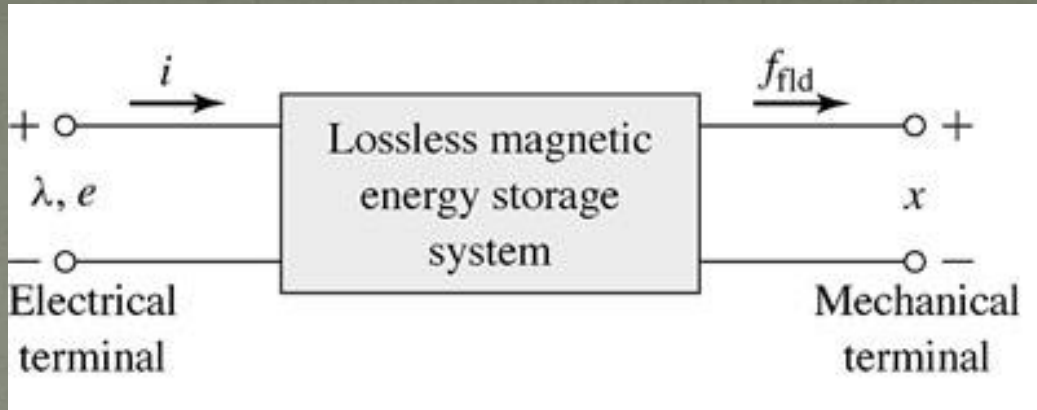
  Generators which convert mechanical energy to electrical energy.
- Motors which convert electrical energy to mechanical energy, and
- Transformers which changes the voltage level of an alternating current.

DC MACHINES

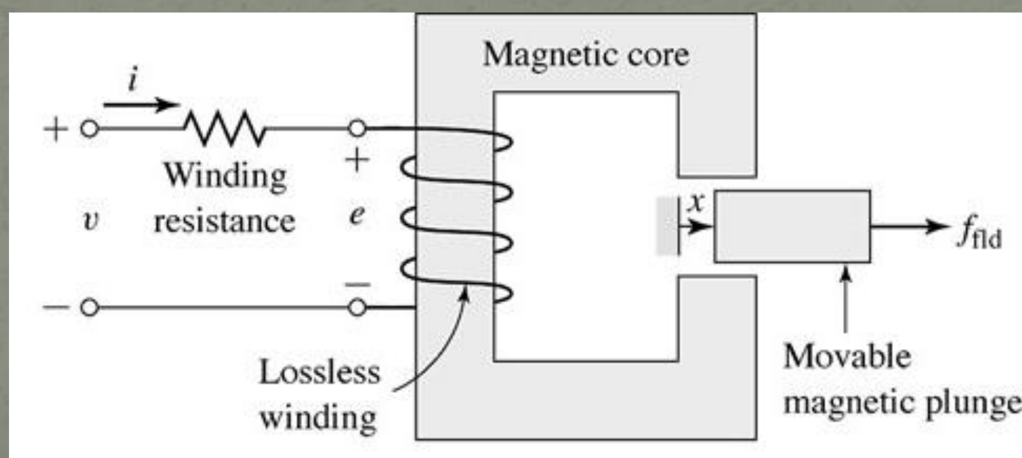


electro mechanical energy conversion DC machines

- ✓Very few problems can be solved using Lorentz force, where current-carrying elements and simple structures exist.
- ✓Most electromechanical-energy-conversion devices contain magnetic material and forces can not be calculated from Lorentz force.
- ✓Thus, We will use ENERGY METHOD based on conservation of energy.



- ✓Electrical terminals: *e* and *i*
- ✓Mechanical terminals: f_{fld} and *x*
- ✓Losses separated from energy storage mechanism
- ✓Interaction through magnetic stored energy



(b)

Time rate of change of W_{fld} (field energy) equals to the difference of input electrical power and output mechanical power for lossless systems.

$$\frac{dW_{fld}}{dt} = e\,i - f_{fld}\frac{dx}{dt}$$

or

$$dW_{fld} = i\,d\lambda - f_{fld}\,dx$$

Force can be solved as a function of flux linkage λ and position x.

ENERGY BALANCE

❖Energy neither created nor destroyed, it only changes the form.

Energy balance equation is written for motor action below

$$\begin{bmatrix}\text{Energy input}\\ \text{from electric}\\ \text{sources}\end{bmatrix} = \begin{bmatrix}\text{Mechanical}\\ \text{energy}\\ \text{output}\end{bmatrix} + \begin{bmatrix}\text{Increase in}\\ \text{energy stored}\\ \text{in magnetic field}\end{bmatrix} + \begin{bmatrix}\text{Energy}\\ \text{converted}\\ \text{to heat}\end{bmatrix}$$

For lossless magnetic-energy-storage system

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

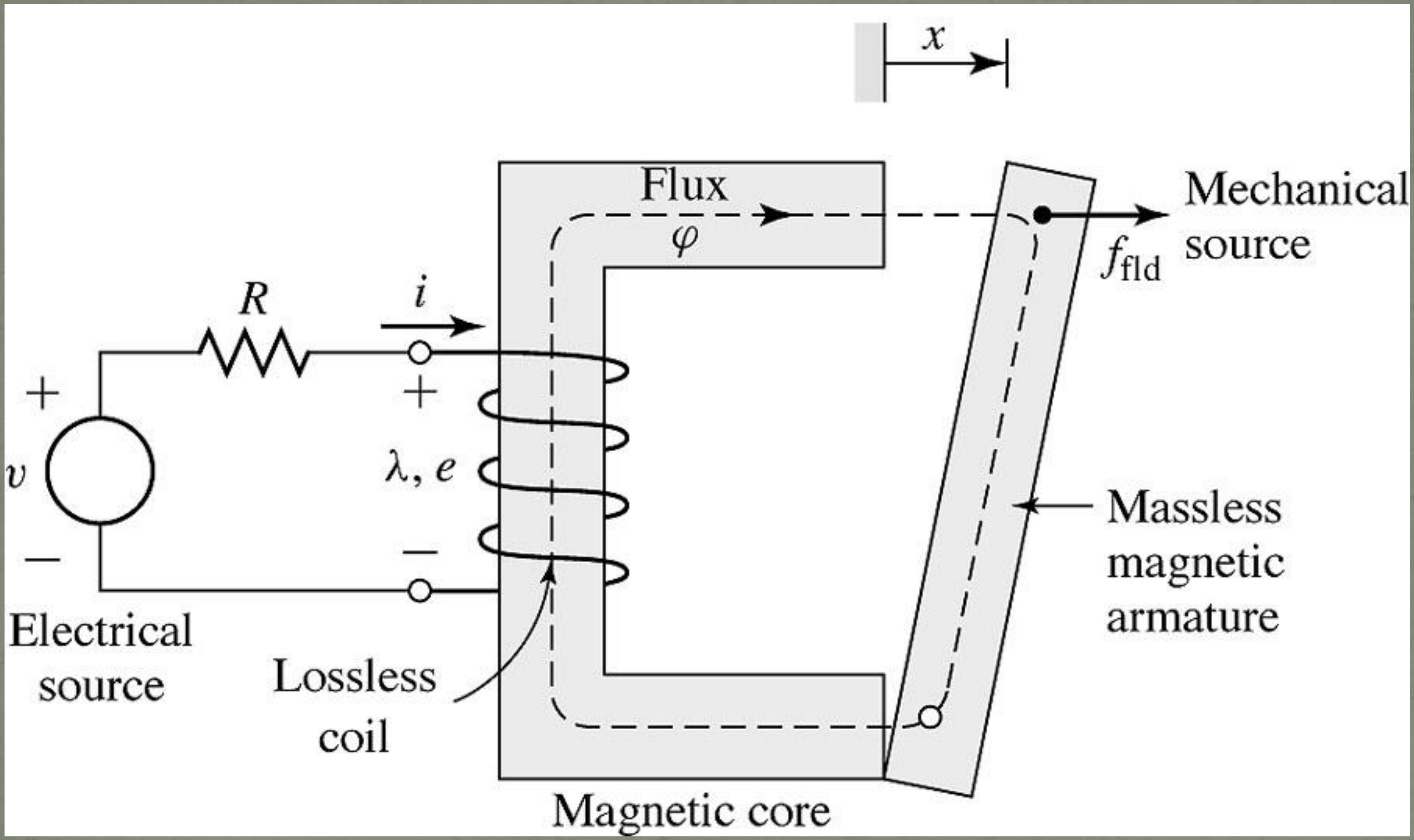
dW_{elec} : Differential electrical energy input

dW_{mech} : Differential mechanical energy output

dW_{fld} : Differential change in magnetic stored energy

ENERGY IN SINGLY-EXCITED MAGNETIC FIELD SYSTEMS

Schematic of an electromagnetic relay.



electro mechanical energy conversion DC machines

✓The magnetic circuit can be described by an inductance which is a function of the geometry and permeability of the magnetic material.

✓When air-gap exist in most cases R_{gap}>>R_{core} and energy storage occurs in the gap.

✓Magnetic nonlinearity and core losses neglected in practical devices.

✓Flux linkage and current linearly related.

$$\lambda = L(x)\, i$$

✓Energy equation

$$dW_{fld} = i\, d\lambda - f_{fld}\, dx$$

✓W_{fld} uniquely specified by the value of λ and x. Thus, λ and x are called STATE VARIABLES.

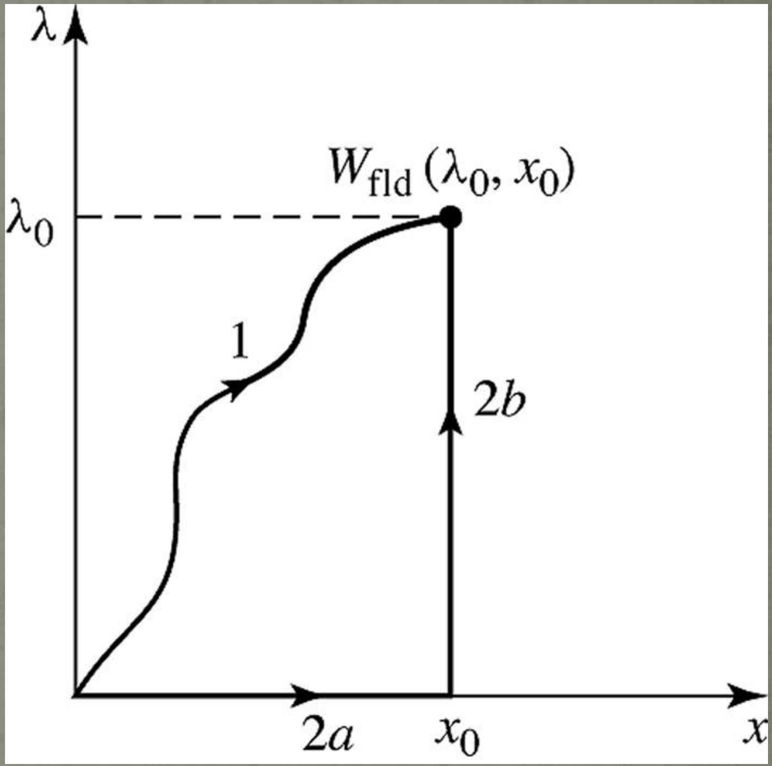
Magnetic stored energy W_{fld} uniquely determined by λ and x regardless of how they are brought to their final values.

$$W_{fld} = \int_{path\,2a} dW_{fld} + \int_{path\,2b} dW_{fld}$$

$$W_{fld}(\lambda_0, x_0) = \int_0^{\lambda_0} i(\lambda, x_0)\, d\lambda$$

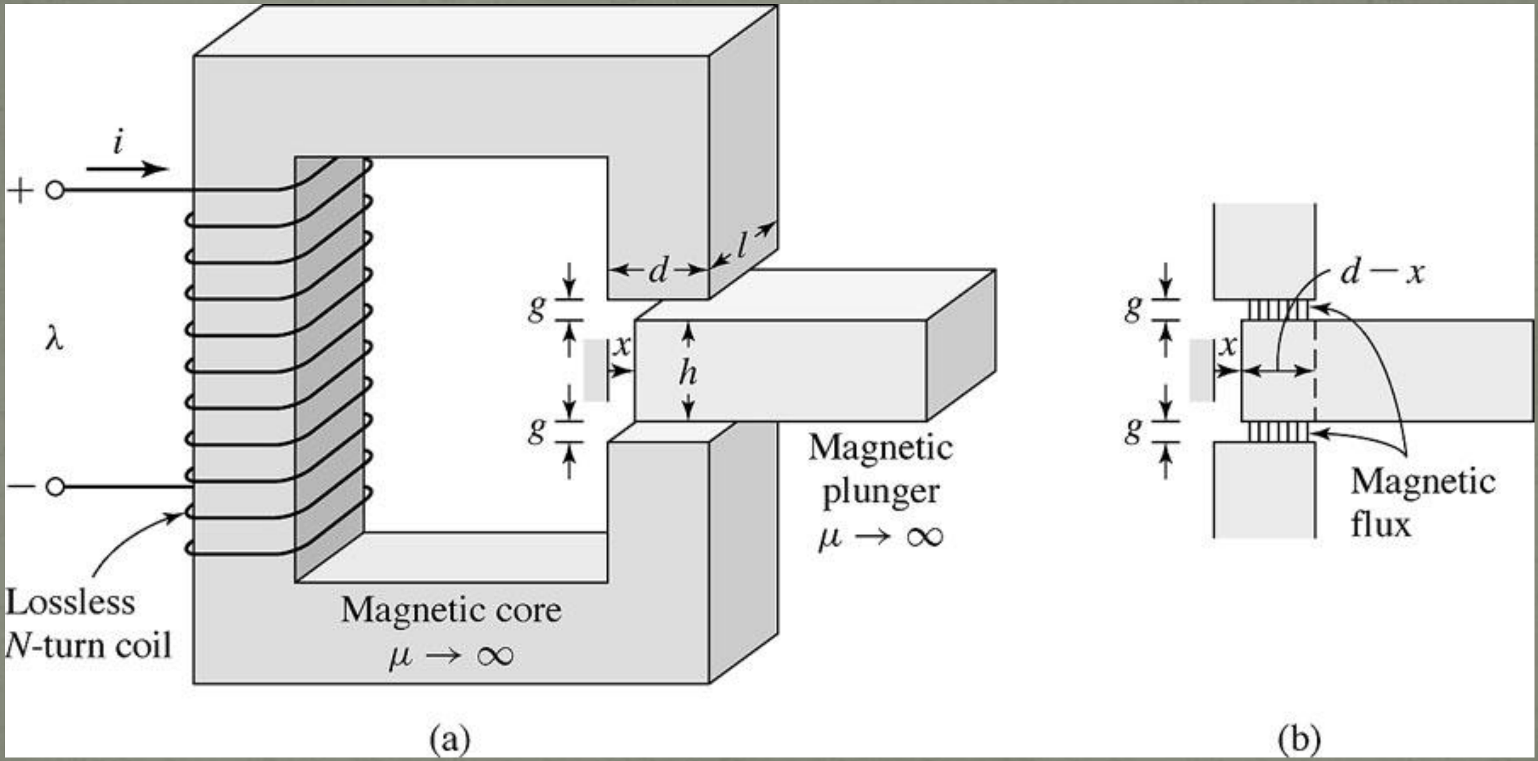
OR magnetic stored energy:

$$W_{fld} = \int_V \left(\int_0^B H\, dB' \right) dV$$



Integration paths for W_{fld}. Figure 3.5

Example :The relay shown on the figure is made of infinitely-permeable magnetic material with a movable plunger, also of infinitely-permeable material. The height of the plunger is much greater than the air-gap length (h>>g). Calculate the magnetic stored energy W_{fld} as a function of plunger position (0<x<d) for N=1000 turns, g=2 mm, d=0.15 m, *l*=0.1 m, and i=10 A.



DETERMINATION OF MAGNETIC FORCE AND TORQUE FROM ENERGY

Consider any state function $F(x_1, x_2)$, the total differential of F with respect to the two variables x_1 and x_2

$$dF(x_1, x_2) = \left.\frac{\partial F}{\partial x_1}\right|_{x_2} dx_1 + \left.\frac{\partial F}{\partial x_2}\right|_{x_1} dx_2$$

Similarly, for energy function $W_{fld}(\lambda, x)$

$$dW_{fld}(\lambda, x) = \left.\frac{\partial W_{fld}}{\partial \lambda}\right|_{x} d\lambda + \left.\frac{\partial W_{fld}}{\partial x}\right|_{\lambda} dx$$

$$dW_{fld}(\lambda, x) = i\, d\lambda - f_{fld}\, dx$$

$$i = \left. \frac{\partial W_{fld}}{\partial \lambda} \right|_{x} \qquad f_{fld} = - \left. \frac{\partial W_{fld}}{\partial x} \right|_{\lambda}$$

Once we know the energy, current and more importantly force can be calculated.

For a system with rotating mechanical terminal

$$f_{fld} \rightarrow T_{fld} \qquad x \rightarrow \theta$$

$$d\,W_{fld}(\lambda, \theta) = i\,d\lambda - T_{fld}\,d\theta$$

$$T_{fld} = - \left. \frac{\partial W_{fld}(\lambda, \theta)}{\partial \theta} \right|_{\lambda}$$

Types of electrical machine