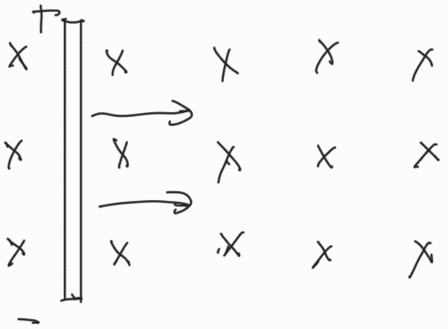
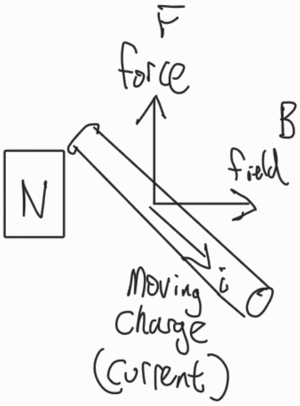
4.5 Electromagnetic Induction

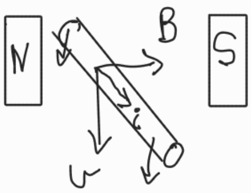


* Emf (electro motive force) is induced whenever a conductor cuts magnetic field lines.

* Emf ∝ rate of cutting the field lines.

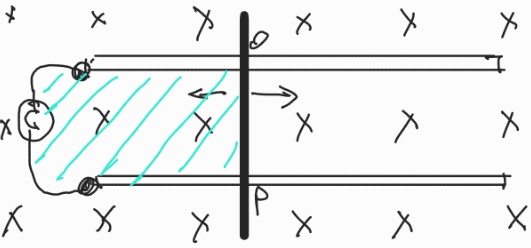


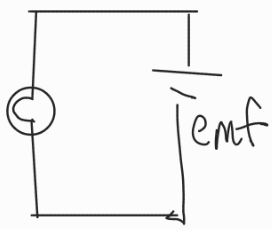
Motor effect



generator effect

Flemings right-hand rule





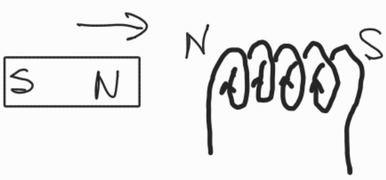
* emf is induced when there is a change in field lines enclosed by loop.

* the magnitude of induced emf ∝ the rate of change of enclosed field lines.

(Faraday's Law)

Lenz's Law

* An induced current always flow in a direction oppose to the change it produces



pushing a magnet

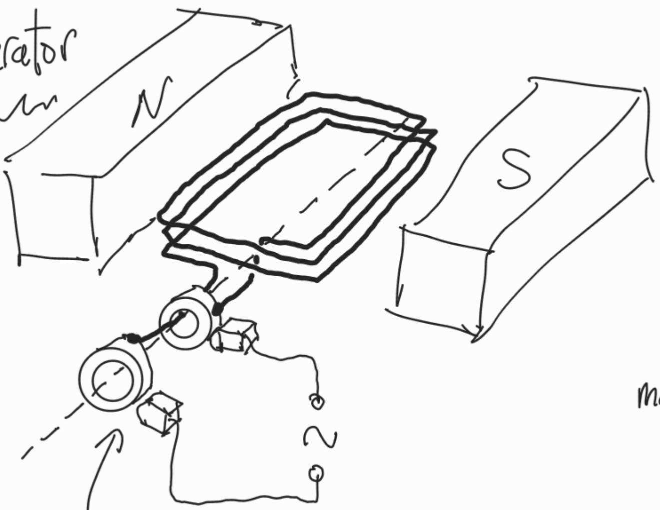
pulling a magnet

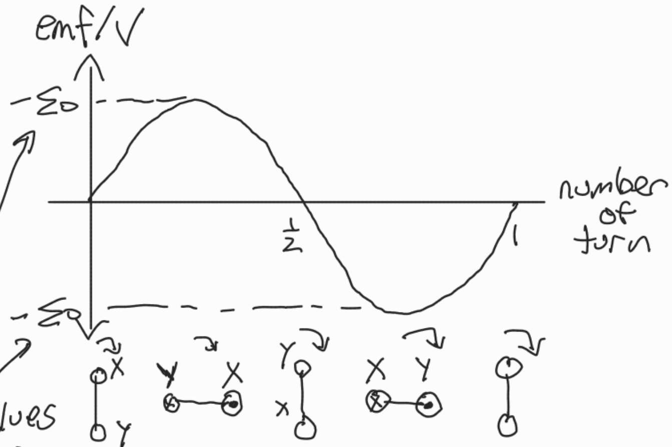
⇐ Follows the right-hand grip rule

* If you try to change the number of enclosed fields, The loop responds by sending a current that counters your effort.

Applications of EM induction

Generator

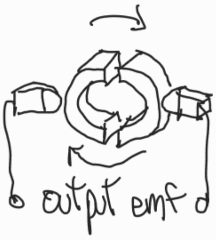


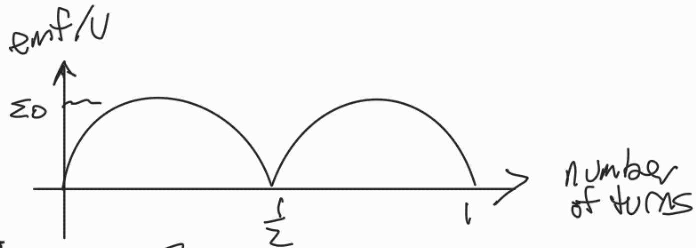


max values of emf peak

Brush and Slip Ring } to prevent twisting wires

[If a commutator replaces the slip ring]





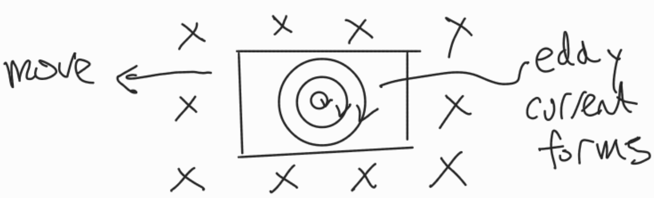
How to raise the output voltage

1. Use stronger magnet
2. Wind more turns
3. Add a soft iron core
4. Increase the area of coil
5. Rotate the coil more quickly

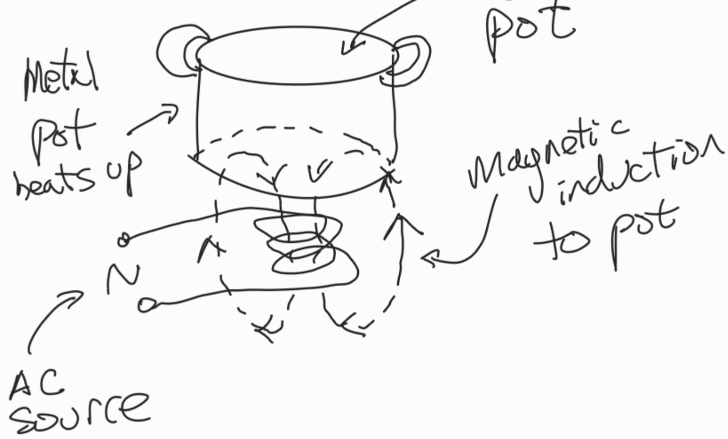
Eddy Current Applications

Electric Brakes

If a metal plate moves
Eddy Current forms on plate surface
Such Current opposes the motion



Induction Cooking



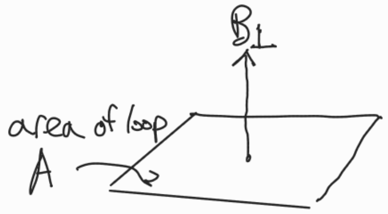
Change in Magnetic Flux (Φ) ← scalar, no direction

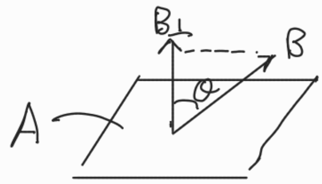
(磁通量)

$$\Phi = B_{\perp} \cdot A = BA\cos\theta$$

Unit Wb (weber)

$1\ Wb = 1\ T\ m^2$





$$B = \frac{\Phi}{A_{\perp}}$$

Unit T (Tesla)

$1\ T = 1\ Wb\ m^{-2}$

Faraday's Law (equation)

$$\varepsilon = \frac{\Delta\Phi}{\Delta t}$$

ε: emf

Flux Linkage (Coil with N turns) ← scalar

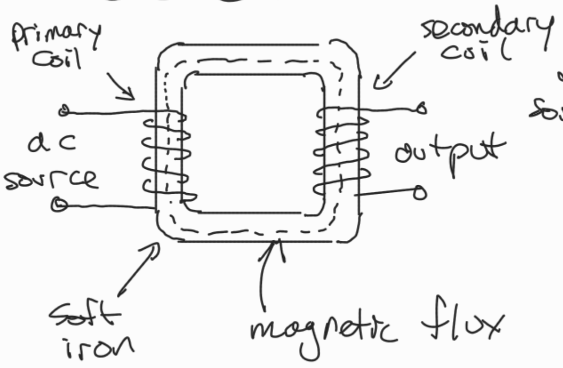
$$\varepsilon = N\frac{\Delta\Phi}{\Delta t} = \frac{\Delta(N\Phi)}{\Delta t}$$

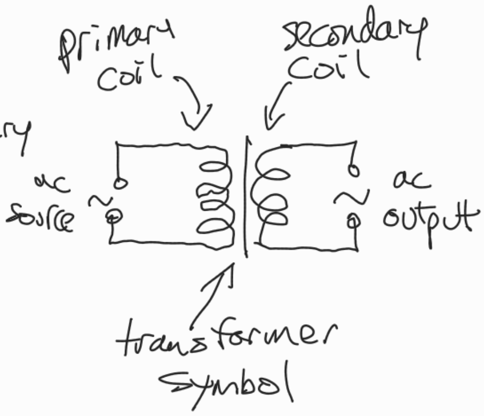
$N\Phi$: flux linkage

Lenz's Law (for magnetic flux)

* an induced current always flow in a direction so as to oppose the change in magnetic flux that produces it.

Transformer





$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

N_s: No of turns of secondary coil

N_p: no of turns of primary coil

voltage ratio = turns ratio

Step Up and Step Down Transformers

step up 升壓 | step down 降壓 | multi-tapped

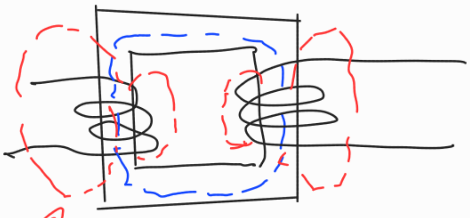
Efficiency of a transformer $\eta = \frac{\text{useful output}}{\text{input}} \times 100\%$

ideal transformer
$\eta = 100\%$

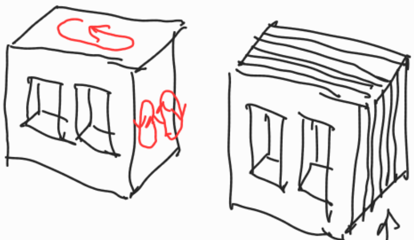
secondary side $\underline{I_s V_s} = \eta \times \underline{I_p V_p}$ Primary Side

Non-Ideal transformer

1. Heating of Coil Wire
2. Magnetization + Demagnetization of core
3. Flux Leakage
4. Eddy Current

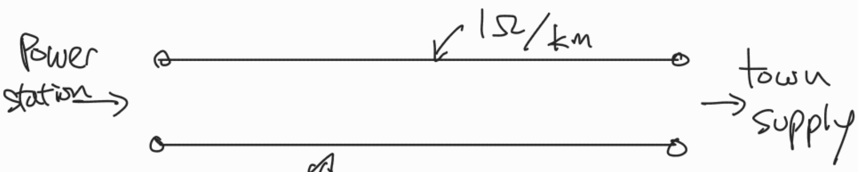


flux leakage 漏磁



疊片 lamination
to prevent eddy current

Power loss during transmission



transmission line : 1Ω per km

Transmission loss if current is 1000 A, and transmission line is 10 km

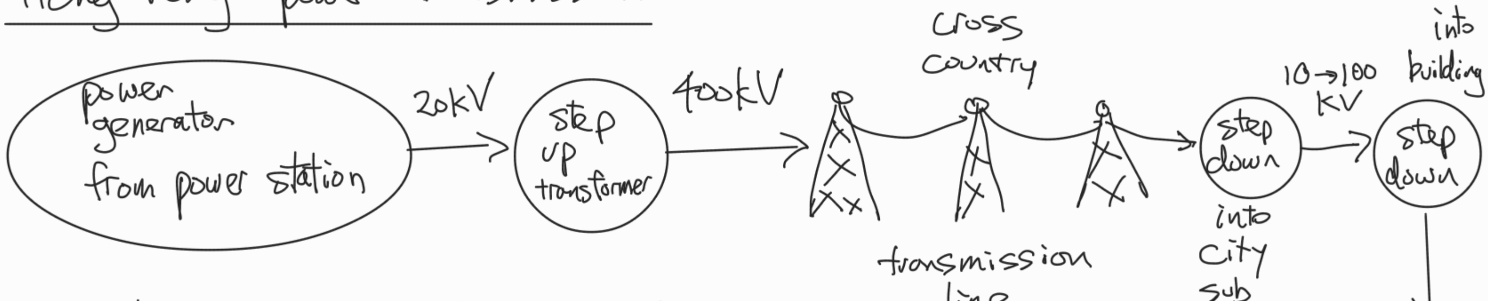
resistance : $1\Omega km^{-1} \times 2 \times 10\ km$
$= 20\ \Omega$

power loss $= I^2 R$
$= 1000 \times 1000 \times 20\ \Omega$
$= 20{,}000{,}000\ W$
$= \underline{\underline{20\ MW}}$

To reduce loss, we need to reduce I

$W = IV$ for the same power (W) $\Rightarrow$ $V\uparrow$ (increase), $I\downarrow$ (decrease)

Hong Kong power transmission



* High Voltage reduce power loss
* ac is used, because it can easily step up and down by transformer

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