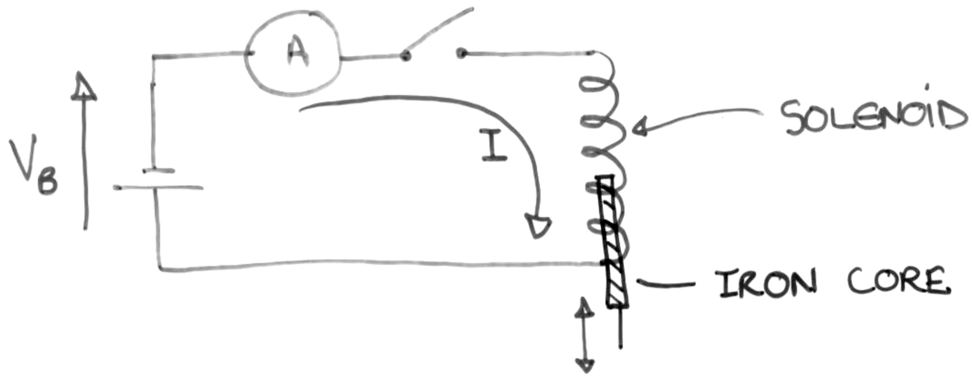
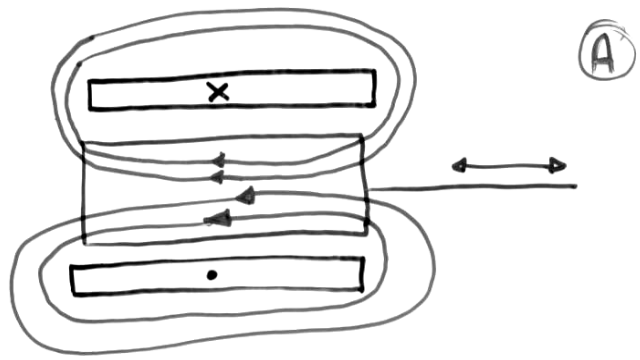
SELF EXCITED ACTUATORS



INITIALLY THE IRON CORE IS INSERTED IN SOLENOID.



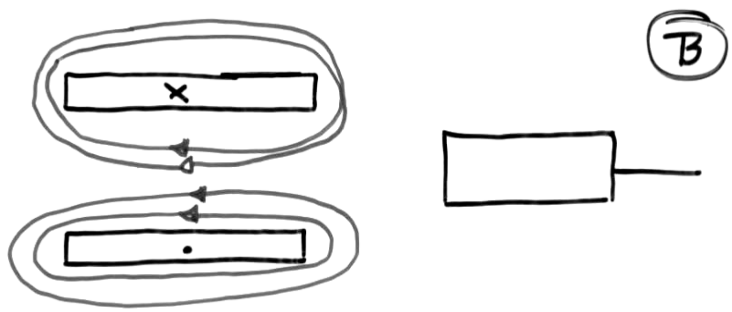
THE STRENGTH OF THE FIELD OR FLUX LINKING THE SOLENOID IS HIGH SINCE THE IRON CORE HAS A HIGH PERMEABILITY (LOW RELUCTANCE).

THE MAGNETIC STORED ENERGY IS HIGH ∴

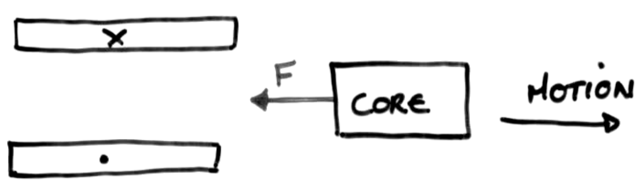
$$I = \frac{V_B}{R}$$

SOLENOID RESISTANCE

FINALLY THE IRON CORE IS FULLY REMOVED. THE AMPERE-TURNS OF THE SOLENOID NOW FORM A FIELD IN AIR, HENCE THE FIELD STRENGTH AND STORED MAGNETIC ENERGY IS LOW.

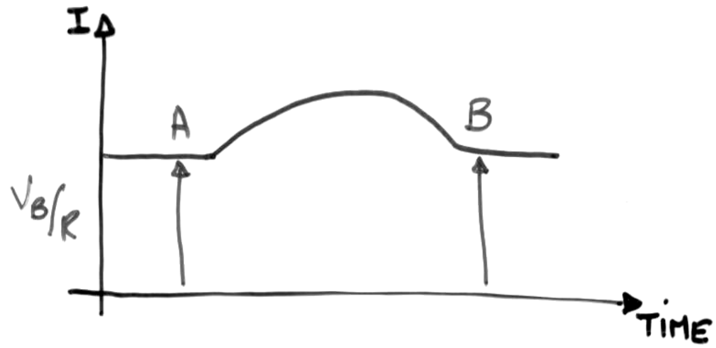


IN THE REMOVAL OF THE IRON CORE, MECHANICAL WORK HAS TO BE PERFORMED. THE ACTION OF THE SOLENOID IS TO 'SUCK' THE IRON CORE INTO ITS CENTRE.



ie. IN MOVING FROM A TO B MECHANICAL WORK IS PUT INTO THE SYSTEM.

ALSO IT IS NOTED THAT DURING THE MOTION FROM A TO B THE CURRENT IN THE SOLENOID INCREASES.



HENCE IN MOVING FROM A TO B THE BATTERY OUTPUT ENERGY INCREASES.

HIGH STORED MAGNETIC ENERGY
+ MECHANICAL ENERGY INPUT TO THE SYSTEM
+ ADDITIONAL ELECTRICAL ENERGY FROM BATTERY

$\equiv$ EQUATES

A LOW STORED MAGNETIC ENERGY
+ ADDITIONAL LOSS IN THE SOLENOID WINDING (I^2R)
+ SMALL ~~ENERGY~~ ELEMENT OF IRON LOSS IN THE CORE.

CONSIDER FLUX LINKAGE OF THE SOLENOID

FLUX LINKAGE = Ψ

FLUX $\phi = \int B \cdot dA$ ← AREA

FLUX DENSITY

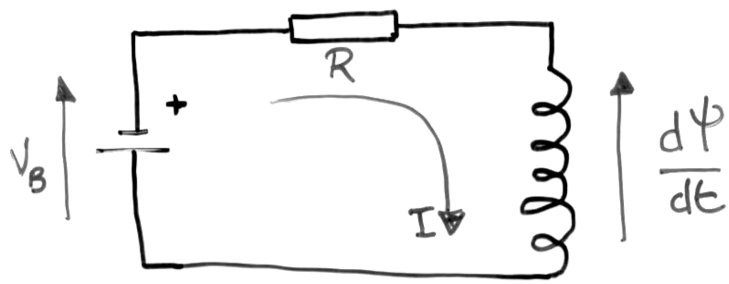
FLUX LINKAGE $\Psi = N\phi$

16. FLUX LINKAGE OF A PARTICULAR COIL SYSTEM RELATES TO THE NUMBER OF TURNS AND THE EFFECTIVE FLUX WHICH COUPLES THOSE TURNS.

FARADAY CHARGE IN FLUX LINKAGE LEADS TO AN INDUCED VOLTAGE WITH MAGNITUDE

$$\frac{d\psi}{dt}$$

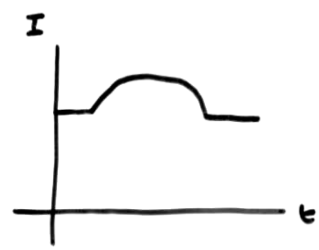
CONSIDER THE SOLENOID EXPERIMENT DURING THE MOTION



INITIALLY ψ IS A HIGH VALUE WITH THE CORE INSERTED AND AS THE CORE IS REMOVED, THE FLUX LINKAGE DECREASES.

$$\frac{d\psi}{dt} < 0$$

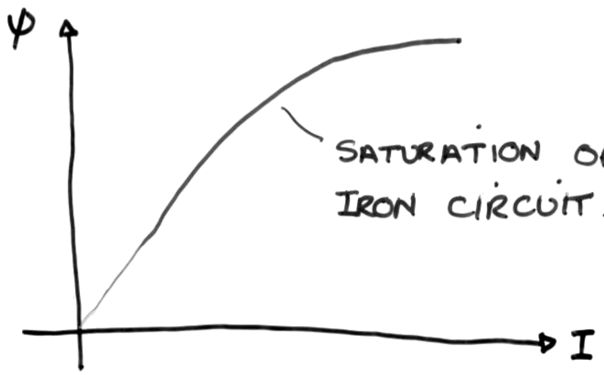
$$I = \frac{V_B - \frac{d\psi}{dt}}{R}$$



AND SINCE $\frac{d\psi}{dt} < 0$ $\quad I > \frac{V_B}{R}$ DURING THE MOTION.

ψ-I DIAGRAM

ie. CONSIDER A SOLENOID WITH AN IRON CORE (OR ANY OTHER MAGNETIC CIRCUIT)



$$V_B = IR + \frac{d\psi}{dt}$$

RESISTIVE VOLTAGE DROP

INDUCED EMF.

$$V_B I = I^2 R + I\frac{d\psi}{dt}$$

INPUT ELECTRICAL POWER

LOSS

$$\Rightarrow V_B I \, dt = I^2 R \, dt + I \, d\psi$$

ENERGY INPUT

ENERGY LOSS

ENERGY INPUT TO MAGNETIC SYSTEM.

IN THE CASE OF NO MECHANICAL MOTION THEN $I\,d\Psi$ RELATES TO THE ENERGY INPUT INTO THE MAGNETIC SYSTEM WHICH FORMS THE STORED ENERGY.

e.g. THE TOTAL MAGNETIC ENERGY STORED IN A MAGNETIC CIRCUIT IS GIVEN BY:

$$\int_{\text{INITIAL CONDITION}}^{\text{FINAL CONDITION}} I\,d\Psi$$

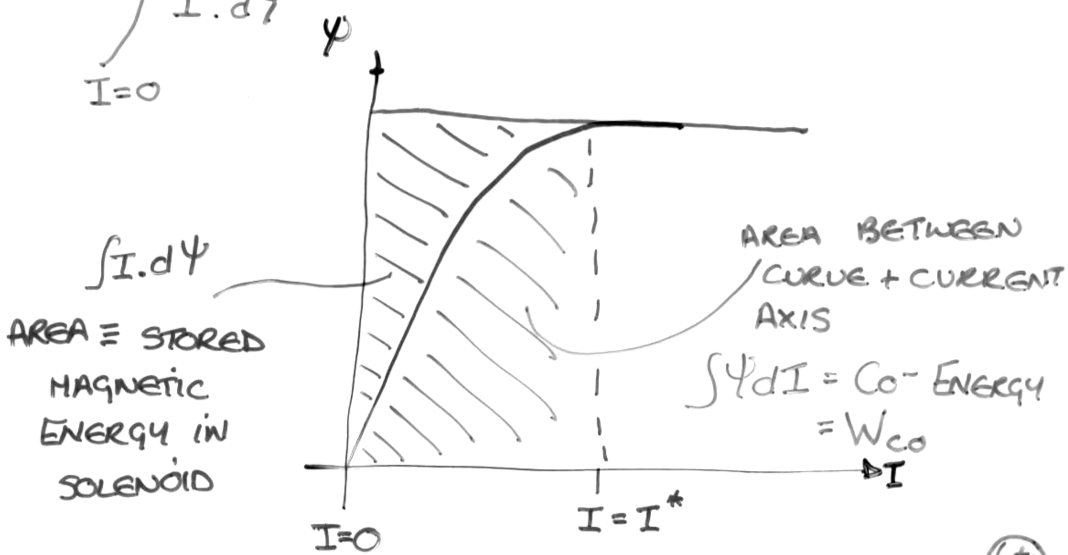
$I = 0$ OPEN CIRCUIT SOLENOID

ZERO STORED ENERGY

TO SOME FINAL VALUE

$\underline{I} = \underline{I}^{*}$ $\left(\frac{V_B}{R}\right)$

$$\int_{I=0}^{I=I^{*}} I.\,d\Psi$$



AREA BETWEEN CURVE AND CURRENT AXIS

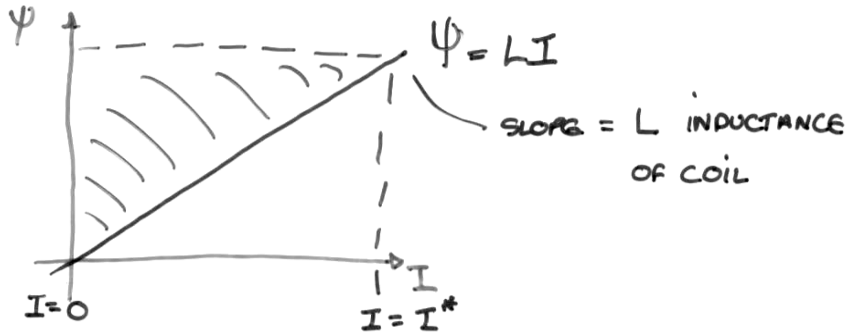
$$\int \psi . dI = \text{Co-Energy} = W_{co}$$

NOTE IN A NON-LINEAR SYSTEM

Co-ENERGY $\neq$ STORED MAGNETIC ENERGY

$$\int \psi . dI \neq \int I . d\psi$$

CONSIDER A LINEAR SYSTEM WHERE THERE IS NO SATURATION



LINEAR SYSTEM IMPLIES A CONSTANT INDUCTANCE i.e CONSTANT SLOPE.

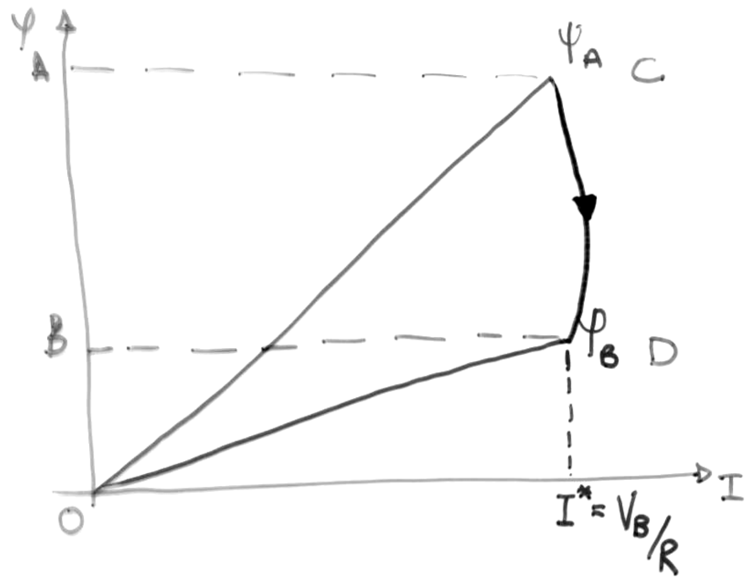
STORED MAGNETIC ENERGY $= \int_0^{I^*} I . d\psi$ SINCE $\psi = LI$, $d\psi = L dI$

$$\therefore \text{STORED ENERGY} = \int_0^{I^*} I . L . dI = L \int_0^{I^*} I . dI = L \left[\frac{1}{2} I^2 \right]_0^{I^*}$$

66

$= \frac{1}{2} L I^{*2}$ — APPLIES TO A NON-SATURATED SYSTEM ONLY.

$\psi - I$ DIAGRAM WITH MECHANICAL WORK – i.e THE CASE OF REMOVING THE IRON CORE FROM THE SOLENOID



ψ_A INITIAL FLUX LINKAGE OF THE SOLENOID WITH IRON CORE INSERTED. SLOPE $0 - \psi_A$ REPRESENTS THE INITIAL INDUCTANCE OF SOLENOID + CORE.

ψ_B FINAL FLUX LINKAGE OF SOLENOID WITH IRON CORE REMOVED. SLOPE $0 - \psi_B$ GIVES FINAL INDUCTANCE OF SOLENOID WITHOUT CORE.

DURING THE MOTION

$$V_B = IR + \frac{d\psi}{dt}$$

ENERGY SUPPLIED LOSSES MOTION

$$\int V_B I \, dt = \int I^2 R \, dt + \int I \, d\psi$$

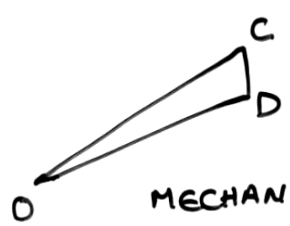
i.e. TOTAL ENERGY PUT INTO ELECTROMECHANICAL SYSTEM $= \int I \, d\psi$

i.e AREA ACDB REPRESENTS THE ENERGY INPUT TO THE SYSTEM OVER THE MOTION

IT FOLLOWS THEREFORE THAT THE AREA OCD REPRESENTS THE MECHANICAL WORK PERFORMED

INITIAL STORED ENERGY

FINAL STORED ENERGY



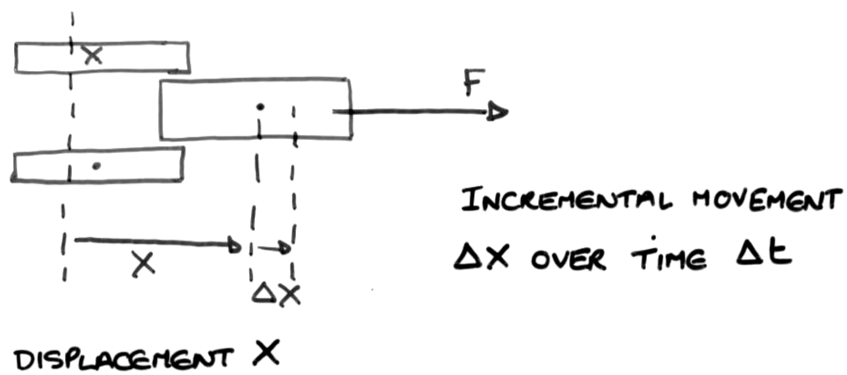
MECHANICAL WORK.

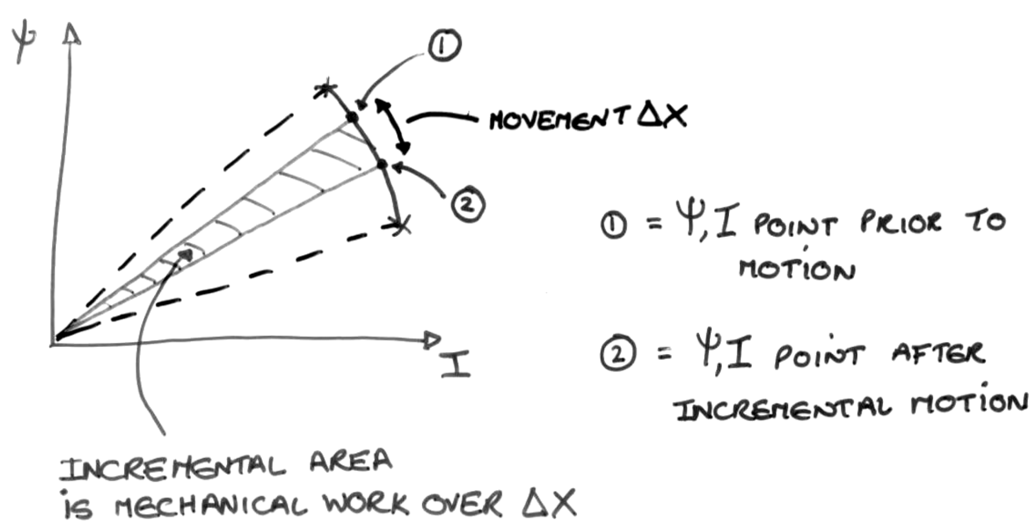
$$\text{ENERGY} = \int I \, d\psi$$

$$\text{CO-ENERGY} \quad W_{co} = \int \psi \, . \, dI$$

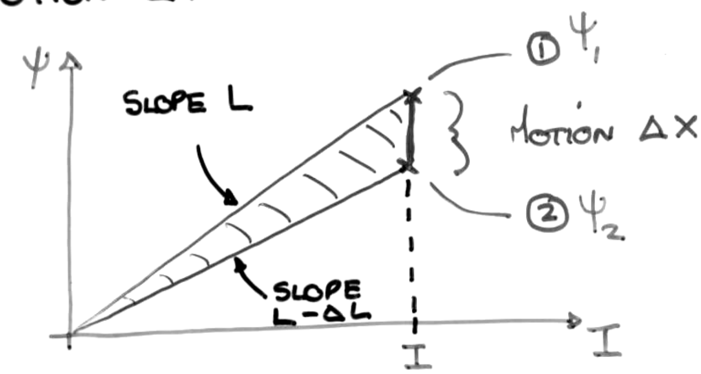
MECHANICAL WORK CAN BE CALCULATED FROM THE CHANGE IN CO-ENERGY

CONSIDER AN INSTANT IN TIME DURING THE MOTION OF THE CORE FROM ORIGINAL TO FINAL POSITION





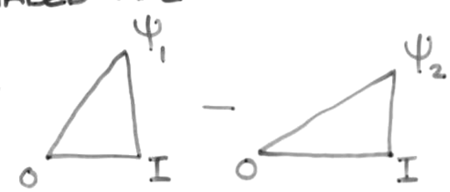
MAKING THE ASSUMPTION THAT THE CURRENT IN THE SOLENOID IS CONSTANT DURING THE MOTION ΔX



AT ① SOLENOID INDUCTANCE = L

AT ② SOLENOID INDUCTANCE = $L-\Delta L$ (REDUCES BY ΔL)

MECHANICAL WORK PERFORMED OVER MOTION ΔX IS THE SHADED AREA.

$\equiv$ 

$$W_{co} = \int \psi . dI$$
$$W_{co} = \frac{1}{2}\psi I$$

$$\equiv W_{co1} - W_{co2}$$

$$\equiv \frac{1}{2}\psi_1 I - \frac{1}{2}\psi_2 I$$

$$L = \psi / I$$
$$\psi = LI$$

$$= \frac{1}{2}(LI)I - \frac{1}{2}(L-\Delta L)I.I.$$

$$= \frac{1}{2} I^2 \Delta L$$ = MECHANICAL WORK OVER MOTION ΔX.

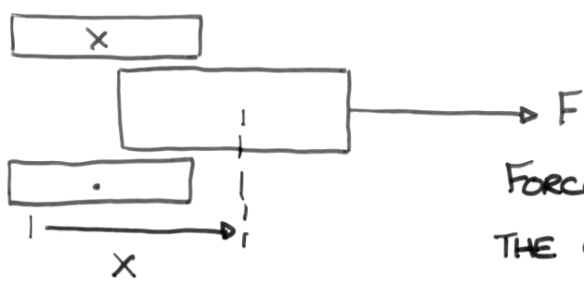
MECHANICAL WORK PERFORMED $= \frac{1}{2} I^2 \Delta L = F \Delta X$

FORCE $F = \frac{1}{2} I^2 \frac{\Delta L}{\Delta X}$ $\quad \begin{pmatrix} \Delta L \to 0 \\ \Delta X \to 0 \end{pmatrix}$

$$\boxed{F = \frac{1}{2} I^2 \frac{dL}{dX}}$$ VALID FOR ALL SYSTEMS

FORCE AT POSITION X

$= \frac{1}{2} \cdot \left(\text{CURRENT AT X}\right)^2 \cdot \left(\text{RATE OF CHANGE OF INDUCTANCE WITH POSITION}\right)$



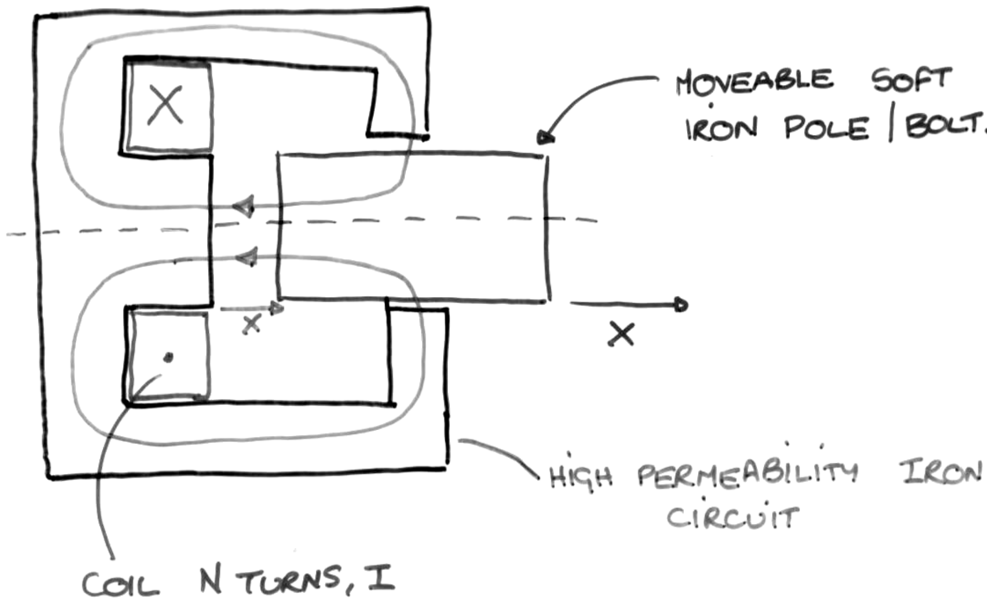
For x increasing

$\frac{dL}{dx}$ (−ve)

FORCE IMPOSED ON THE CORE BY THE SOLENOID SHOWN IN A DIRECTION $F>0$

IN THIS CASE, $\frac{dL}{dx} < 0$ i.e $F<0$ AND THE FORCE ACTS TO SUCK THE IRON CORE TOWARDS THE SOLENOID CENTRE.

TYPICAL CYLINDRICAL SOLENOID ACTUATOR (71)



m.m.f = RELUCTANCE × FLUX.

NI = RELUCTANCE OF AIRGAP $\times \phi$

$$= \frac{x}{\mu_0 A} \times \phi$$

$$\phi = \frac{NI}{\frac{x}{\mu_0 A}} = \frac{NI\mu_0 A}{x}$$

HENCE $L = \frac{\psi}{I} = \frac{N\phi}{I} = \frac{N^2\mu_0 A}{x}$

$\therefore$ FORCE ON IRON SLUG $= \frac{1}{2} I^2 \frac{dL}{dt}$

$$= \frac{1}{2} I^2 \left(\frac{-N^2\mu_0 A}{x^2} \right)$$

$$\Rightarrow \quad F = -\frac{1}{2}\,\frac{I^2 N^2 \mu_0 A}{x^2}$$

FORCE IS TOWARDS CENTRE.

CONSIDER THE FLUX DENSITY IN THE AIRGAP

$$\phi = B_g A.$$

$$\phi = \frac{N I \mu_0 A}{x}$$

$$B_g = \frac{N I \mu_0}{A}$$

i.e. $$F = -\frac{1}{2}\,\frac{B_g^2}{\mu_0}\,A$$

$$\left| F/A \right| = \frac{1}{2}\,\frac{B_g^2}{\mu_0}$$

EXAMPLE

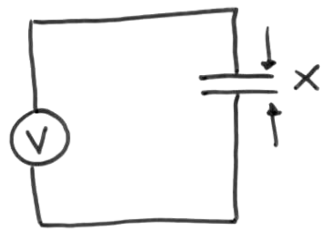
$$B_g = 1.0\,T.$$

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

$$\therefore \left| F/A \right| = 39.8 \times 10^4 \ N/m^2 \ (Pa)$$

$$\approx 4 \text{ Tonnes}/m^2.$$

ELECTROSTATIC SYSTEM.



$$F = \frac{1}{2} V^2 \frac{dC}{dx}$$

CHANGE IN CAPACITANCE

APPLIED VOLTS

$$\left|\frac{F}{AREA}\right| = \frac{1}{2} E^2 \varepsilon_0$$

PERMITTIVITY OF FREE SPACE

$$E = 3 \times 10^6 \ V/m$$

$$F/AREA = 39 \cdot 8 \ N/m^2$$

i.e. 10^4 LESS THAN A MAGNETIC DEVICE

TIME CONSTANT OF MAGNETIC SYSTEM

$$L/R \approx ms$$

TIME CONSTANT OF ELECTROSTATIC SYSTEM.

$$CR \approx \mu s.$$