OSNOVE ELEKTROTEHNIKE II 1 UNI

Zapiski predavanj

Šolsko leto	2010/2011
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Skeniranje	Damjan Sirnik

UREJANJE DOKUMENTA	
VERZIJA	01.01
DATUM	23.5.2012

OPOMBE

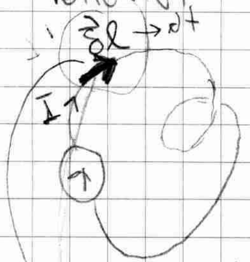
MAGNETIKA

21.2.11

MAGNETOSTATIKA

$\vec{J} = \vec{J}(T)$

TOKOVNI ELEMENT KOT GRADNIK (SPLOŠNE TOČKASTE STRUKTURE)

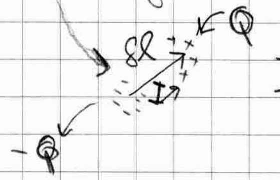


JAKOST TOKOVNEGA ELEMENTA

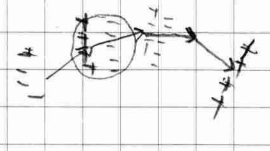
$$I\delta l$$

Težje za tanka žica merimo pa se od ostal strukture odpeljat

odsek - gradnik neke splošne strukture



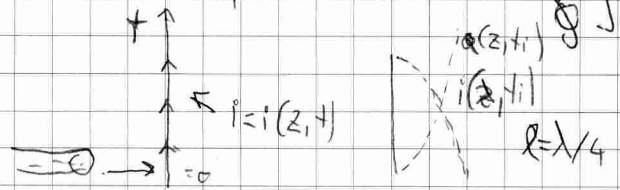
$$I = \frac{dQ}{dt}$$



} Ni kopičenja nabojev ⇒ iz kontinuitetne enačbe

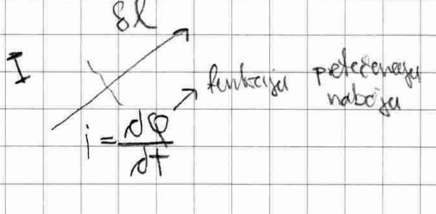
Če stalno enormno kopičenja ni.

$\frac{\partial}{\partial t}$: antena



$$\oint \vec{J} \cdot d\vec{a} = \frac{dQ_{not}}{dt}$$

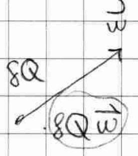
Če je $\vec{J} = \vec{J}(T) \to \oint_A \vec{J} \cdot d\vec{a} = 0$

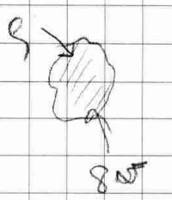


$$\frac{\delta Q}{\delta t} = I$$

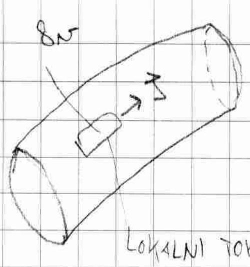
Naboj, ki v določenem času preleti neko razdaljo je

$$I\delta l = \frac{\delta Q}{\delta t}\vec{v}\,\delta t = \delta Q\vec{v}$$

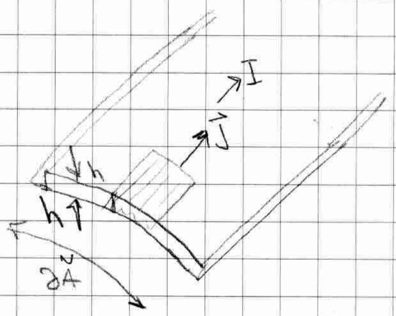




$$\delta Q \vec{w} = \frac{\delta v}{\rho\, \delta v\, \vec{w}} = \vec{J}\, \delta v$$



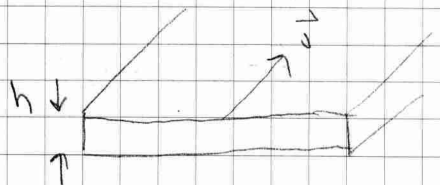
PLOŠČATI VODNIK - FOLIJE (FOLIJSKI VODNIK)



Tok $|\vec{J}| = \frac{I}{h \check{A}}$

$$\vec{J}\,\delta v = \vec{J}\, h\, \delta a = \boxed{\vec{K}\, \delta a}$$

$\vec{K}$ → Tokovna obloga



PP:

$$K = J h = \frac{I}{h \check{\delta}} = \frac{I}{\check{\delta}}$$

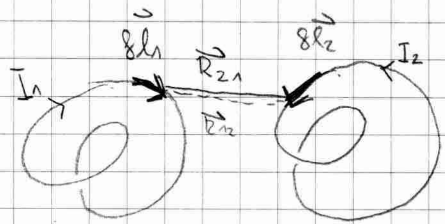
$\check{\delta} = 1\,mm$, $I = 10\,mA$

$$\boxed{K = \frac{I}{\check{\delta}} = 10\,A/m}$$

el	δQ	$q\,\delta l$	$\sigma\,\delta a$	$\rho\, dv$
mag	$\delta Q \vec{w}$	$I\,\delta\vec{l}$	$\vec{K}\,\delta a$	$\vec{J}\, dv$

AMPEROVA MAGNETNA SILA (1820)

21.2.11



$$\delta F_{m_1}^{(2)} = \frac{\mu_0}{4\pi R_{12}^3} I_1 \vec{\delta l_1} \times \left(I_2 \vec{\delta l_2} \times \vec{R_{12}} \right)$$

$$\delta F_{m_2}^{(1)} = \frac{\mu_0}{4\pi R_{21}^3} I_2 \vec{\delta l_2} \times \left(I_1 \vec{\delta l_1} \times \vec{R_{21}} \right)$$

$I_1 \vec{\delta l_1}$, $I_2 \vec{\delta l_2}$

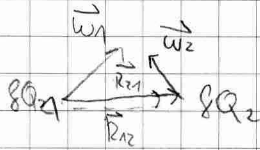
$\vec{R_{21}} = \vec{r_2} - \vec{r_1}$

$\vec{R_{12}} = -\vec{R_{21}}$

$$\frac{|\vec{R_{12}}|}{R_{12}^3} = \frac{1}{R_{12}^2}$$

$\mu_0 = 4\pi \cdot 10^{-7} \frac{Vs}{Am}$

$$\boxed{\mu_0 \varepsilon_0 c_0^2 = 1}$$



$$\delta F_{m_1}^{(2)} = \frac{\mu_0}{4\pi R_{12}^3} \delta Q_1 \vec{w_1} \times \left(\delta Q_2 \vec{w_2} \times \vec{R_{12}} \right)$$

$$\delta F_{m_2}^{(1)} = \frac{\mu_0}{4\pi R_{21}^3} \delta Q_2 \vec{w_2} \times \left(\delta Q_1 \vec{w_1} \vec{R_{21}} \right)$$

$$\delta F_{e_1}^{(2)} = \frac{\delta Q_1 \delta Q_2 \cdot \vec{R_{12}}}{4\pi \varepsilon_0 R_{12}^3}, \quad \delta F_{e_2}^{(1)} = \frac{\delta Q_1 \delta Q_2 \cdot \vec{R_{21}}}{4\pi \varepsilon_0 R_{21}^3}$$

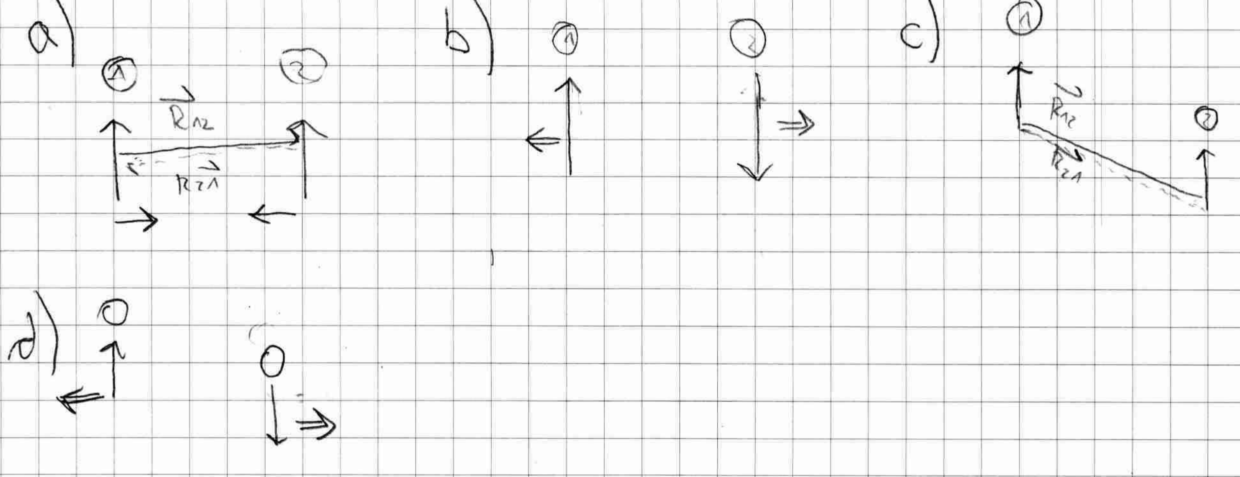
$$\boxed{\delta F_{e_2}^{(1)} + \delta F_{e_1}^{(2)} = \vec{0}}$$ → VZAJEMNI SILI

$$\vec{a} \times (\vec{b} \times \vec{c}) = (\vec{a} \cdot \vec{c})\vec{b} - (\vec{a} \cdot \vec{b})\vec{c}$$

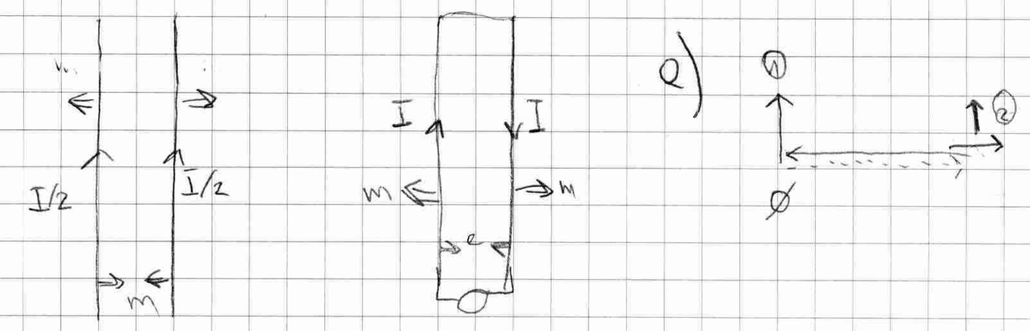
$$\vec{b} \times (\vec{a} \times -\vec{c}) = -(\vec{b} \cdot \vec{c})\vec{a} + (\vec{b} \cdot \vec{a}) \cdot \vec{c}$$

$$\boxed{\delta \vec{F}_{m_1}^{(2)} + \delta \vec{F}_{m_2}^{(1)} \neq \vec{0}}$$ → MAGNETNI SILI NISTA VZAJEMNI

KONSTELACIJE

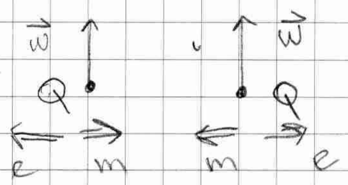


e)



24.2.11

PRIMERJAVA COL IN AMPEROVE SILE I.

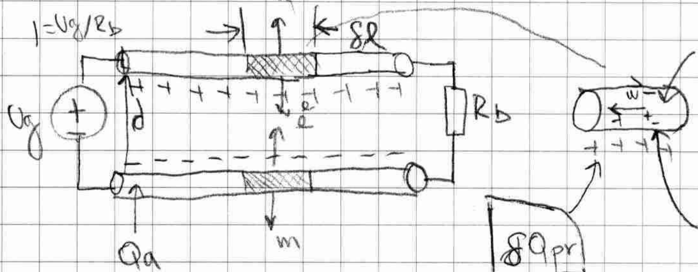


$$|\vec{F}_m| = F_m = \frac{\mu_0 (Q\omega)^2}{4\pi d^2}$$

$$|\vec{F}_e| = F_e = \frac{Q^2}{4\pi\varepsilon_0 d^2}$$

$$\frac{F_m}{F_e} = \mu_0\varepsilon_0\omega^2 = \left(\frac{\omega}{c_0}\right)^2$$

PRIMERJAVA COL IN AMPEROVE SILE II.



$\delta Q_{mobilni}$ → Odgovarja za magnetno silo.

$\delta Q_{mir} - \delta Q_{mob} = 0$

$\delta Q_{mirujoči}$

δQ_{pr} → odgovarja za el. silo

Karakteristična upornost linije → R_k

$$|\delta\vec{F}_m| = \delta F_m = \frac{\mu_0 (\delta Q_{mob}\cdot\omega)^2}{4\pi d^2}$$

$$|\delta\vec{F}_e| = \delta F_e = \frac{(\delta Q_{pr})^2}{4\pi\varepsilon_0 d^2}$$

$$\frac{\delta F_m}{\delta F_e} = \left(\frac{\omega}{c}\right)^2\left(\frac{\delta Q_{mob}}{\delta Q_{pr}}\right)^2 = \frac{(I\,\delta l)^2}{(c_0^2 (C\,\delta l\,U_g))^2}$$

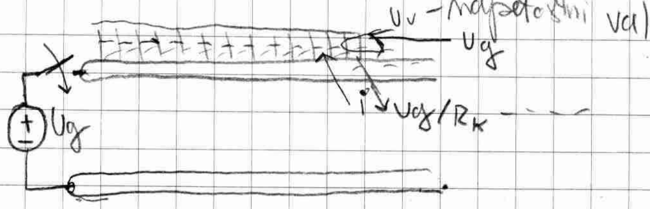
$$= \frac{\mu_0\varepsilon_0}{Rb^2}\cdot\left(\frac{1}{\frac{\pi\varepsilon_0}{\ln\frac{d}{a}}}\right)^2 = \frac{\frac{\mu_0}{\varepsilon_0}\left(\frac{1}{\pi}\ln\frac{d}{a}\right)^2}{Rb^2} = \frac{\left(\frac{1}{2\pi}\sqrt{\frac{\mu_0}{\varepsilon_0}}\ln\frac{d}{a}\right)^2}{Rb^2}$$

$$\frac{\delta F_m}{\delta F_e} = \left(\frac{R_k}{R_b}\right)^2$$

PP: R_k, $d/a = 20$

$\Rightarrow R_K = \frac{1}{\pi}\cdot 120\pi \ln 20$

$\approx \underline{360\,\Omega}$



Karakteristična upornost kabla tej linji. 50 ohmski kabel – to je njegova karakteristika. Nima nobe povezave z antenami.

$$\boxed{\sqrt{\frac{\mu_0}{\varepsilon_0}} = R_v}$$ – valovna upornost.

Za prazen prostor je to $120\pi \approx 377\,\Omega$

Razmerje med el. in mag. poljsko jakostjo

Gostota magnetnega pretoka Biot–Savartov zakon

$I'\delta\vec{l}'$ $\quad\vec{R}\quad$ $I\delta\vec{l}$ (T' → T)

$$\delta\vec{F}_m = \frac{\mu_0}{4\pi R^3} I\delta\vec{l} \times (I'\delta\vec{l}' \times \vec{R})$$

$$\delta\vec{F}_m = I\delta\vec{l} \times \left(\frac{\mu_0 I'\delta\vec{l}' \times \vec{R}}{4\pi R^3}\right) \leftarrow \delta\vec{B}(T)$$

$$= I\delta\vec{l} \times \delta\vec{B}(T)$$

$\delta F_e = \delta Q(\vec{E} + \vec{v} \times \vec{B})$
$= \delta Q\vec{E} + \delta Q\vec{v} \times \vec{B}$

$\delta Q'$ $\quad\vec{R}\quad$ δQ (T' → T)

$$\delta\vec{F}_e = \frac{\delta Q\,\delta Q'\vec{R}}{4\pi\varepsilon_0 R^3} \Rightarrow$$

$$\delta F_e = \delta Q\left(\frac{\delta Q'\vec{R}}{4\pi\varepsilon_0 R^3}\right) \nearrow \delta\vec{E}(T)$$

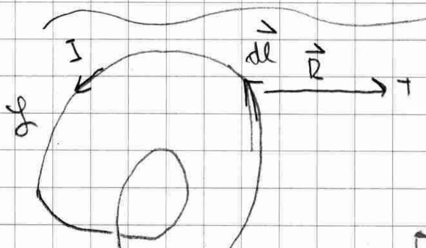
$= I'\delta l'$

$$\boxed{\delta\vec{B}(T) = \frac{\mu_0 I'\delta\vec{l}' \times \vec{R}}{4\pi R^3}}$$

$I'\delta\vec{l}$ $\quad\vec{R}\quad$ T' → T.

Naboj v neki točki povzroči poljsko jakost

$$\delta\vec{E}(T) = \frac{\delta Q'\vec{R}}{4\pi\varepsilon_0 R^3} \qquad \delta Q' \;\; T' \xrightarrow{\vec{R}} T$$



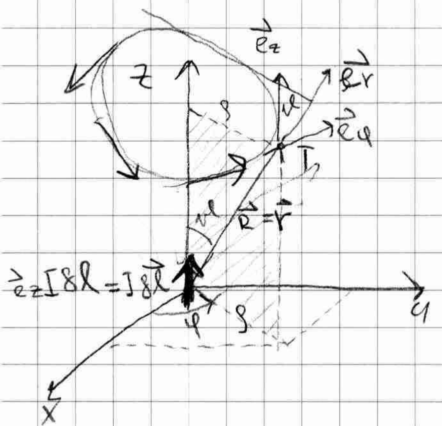
$$d\vec{B}(T') = \frac{\mu_0 I d\vec{l} \times \vec{R}}{4\pi R^3}$$

$$\vec{B}(T) = \int d\vec{B}(T)$$

$$\boxed{\vec{B}(T) = \frac{\mu_0}{4\pi}\int \frac{I d\vec{l}' \times \vec{R}}{R^3}}$$

B.S. zakon v integralni obliki

MAGNETNO POLJE TOKOVNEGA ELEMENTA

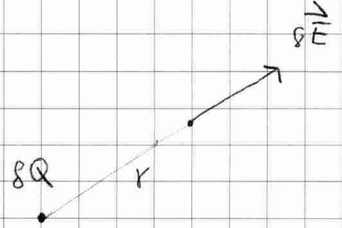


$$\delta\vec{B}(T) = \frac{\mu_0 I \delta\vec{l} \times \vec{R}}{4\pi R^3} = \frac{\mu_0 I \delta l}{4\pi r^{2}} (\vec{e}_z \times \vec{e}_r)$$

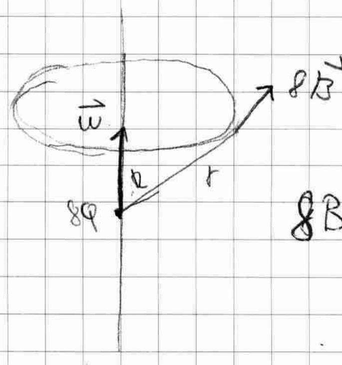
$$= \frac{\mu_0 I \delta l}{4\pi \cdot r^2} \sin\vartheta \, \vec{e}_\varphi$$

$$\downarrow$$

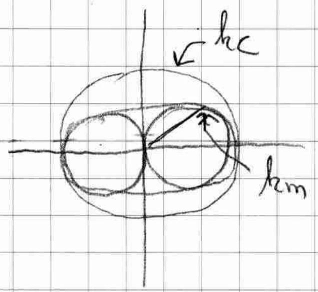
$$\delta B_\varphi(T)$$



$$E_r = \frac{\delta Q}{4\pi\varepsilon_0 r^2} \cdot \underbrace{1}_{k_e}$$



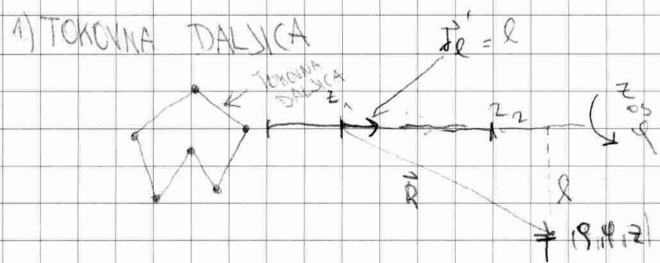
$$\delta B_\varphi = \frac{\mu_0 \delta Q w}{4\pi r^2} \cdot \underbrace{\sin\vartheta}_{k_m}$$



ZGLEDI

1.) DALJICA
2.) PREMICA
3.) OVOJ
4.) VEČ OVOJEV – TULJAVA
5.) TRAK – PLOŠČATI VODNIK

1) TOKOVNA DALJICA



$$dB_\varphi = \frac{\mu_0 I \, dz' \sin\alpha}{4\pi R^2}$$

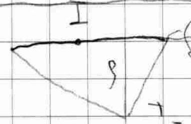
$$z - z' = \rho \tan\alpha \qquad R = \frac{\rho}{\sin\alpha}$$

$$dz' = \frac{\rho}{\sin^2\alpha} d\alpha$$

$$\frac{\mu_0 I \frac{\rho}{\sin^2\alpha} d\alpha \cdot \sin\alpha}{4\pi \frac{\rho^2}{\sin^2\alpha}} = \frac{\mu_0 I}{4\pi\rho} \sin\alpha \, d\alpha$$

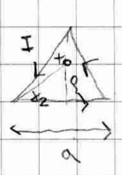
$$B(T) = \int dB(T) = \frac{\mu_0 I}{4\pi\rho} \int_{\alpha_1}^{\alpha_2} \sin\alpha \, d\alpha$$

$$= \frac{\mu_0 I}{4\pi\rho}\left(\cos\delta_1 - \cos\delta_2\right)$$



$$B_\varphi(T) = \frac{\mu_0 I}{4\pi\rho}\left(\cos\delta_1 - \cos\delta_2\right)$$

PP: Polje v težišču zanke v obliki enakostraničnega trikotnika



$a\sqrt{3}$

$$B(T) = 3\frac{\mu_0 I}{4\pi\left(\frac{1}{3}\frac{a\sqrt{3}}{2}\right)}\left(2\frac{\sqrt{3}}{2}\right) = \frac{9}{2}\frac{\mu_0 I}{\pi a}$$

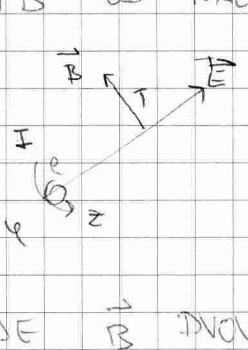
2) POLJE $\vec{B}$ TOKOVNE PREMICE

$\delta_1 \to 0$, $\delta_2 \to \pi$

$$B_\varphi(T) = \frac{\mu_0 I}{2\pi\rho}$$

Premica nastopa kot desni vijak

3.) $\vec{E}$ IN $\vec{B}$ OB NAELEKTRENI PREMICI

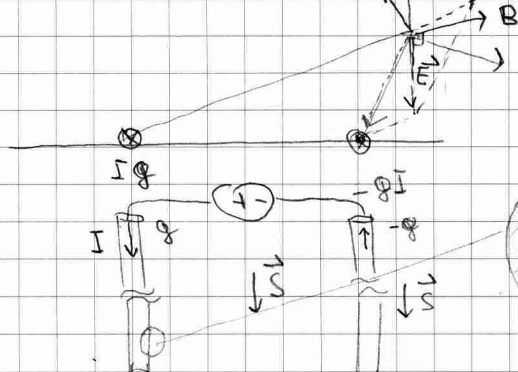


$$B_\varphi = \frac{\mu_0 I}{2\pi\rho}$$

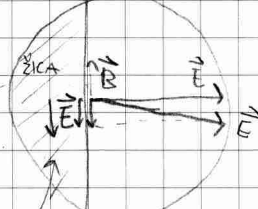
$$E_\rho = \frac{q}{2\pi\varepsilon\rho}$$

POINTINGOV VEKTOR: $\vec{E} \times \frac{\vec{B}}{\mu_0} = \vec{S}$ [W/m²]

4.) POLJE $\vec{B}$ DVOVODA



$$\vec{E} \times \frac{\vec{B}}{\mu_0} = \underbrace{\vec{E}_{\parallel} \times \frac{\vec{B}}{\mu_0}}_{\vec{S}_{\perp}} + \underbrace{\vec{E}_{\perp} \times \frac{\vec{B}}{\mu_0}}_{\vec{S}_{\parallel}}$$

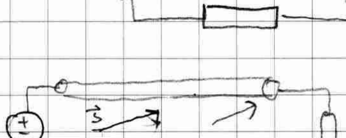


$$|\vec{E}_{\parallel}| \lll |\vec{E}_{\perp}|$$

$$|\vec{S}_{\perp}| \lll |\vec{S}_{\parallel}|$$

E rahlo obrnen v žico. Tisto, kar je prot E dovedeno je Joulska izguba ob žici.

$J = \gamma E$



BISTVEN JE PROSTOR OB ŽICI

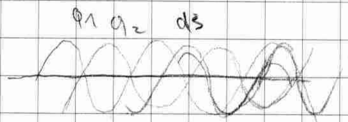
SKOZI PROSTOR OB ŽICI VSTOPA V ŽICO

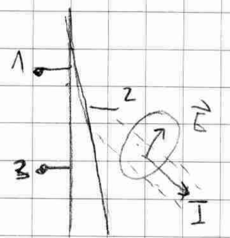
5.) $\vec{E}$ in $\vec{B}$ TROFAZNEGA SISTEMA

$q_1 = q_m \cos\omega t$ $\qquad$ $i_1 = I_m \cos(\omega t + \delta)$

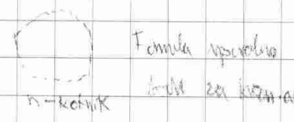
$q_2 = q_m \cos(\omega t - 2\pi/3)$ $\qquad$ $i_2 = I_m \cos(\omega t - 2\pi/3 + \delta)$

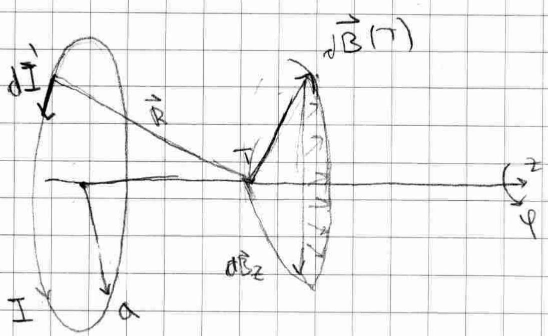
$q_3 = q_m \cos(\omega t + 2\pi/3)$ $\qquad$ $i_3 = I_m \cos(\omega t + 2\pi/3 + \delta)$





6.) $\vec{B}$ V OSI KROŽNE TOKOVNE ZANKE (KROŽNI OVOJ)





$$d\vec{B}(T) = \frac{\mu_0 I \, d\vec{l}' \times \vec{R}}{4\pi R^3}$$

$$d\vec{B}_z(T) = \frac{\mu_0 I \, dl' \times R}{4\pi R^2} \underbrace{\sin\beta}_{a/R}$$

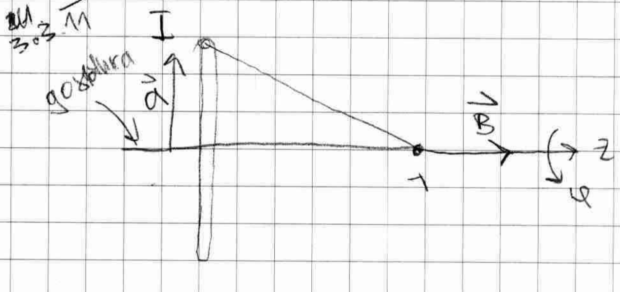
$$= \frac{\mu_0 I a \, dl'}{4\pi R^3}$$

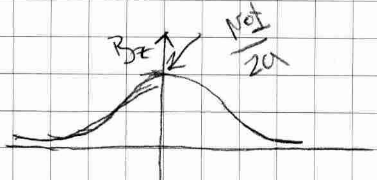
$$B_z(T) = \int dB_z(T) = \frac{\mu_0 I a}{4\pi R^3} \overbrace{\int dl'}^{2\pi a} = \frac{\mu_0 I a^2}{2\pi R^3}$$

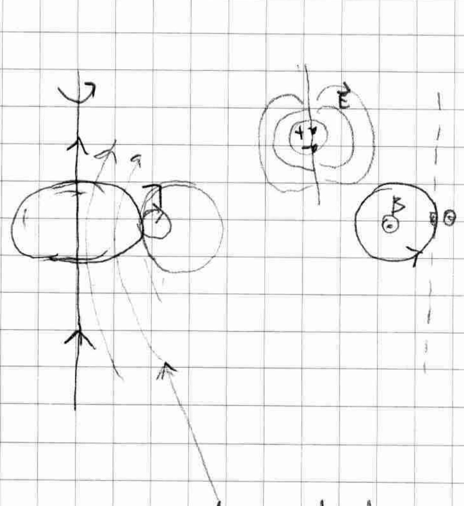
$$B_z(T) = \frac{\mu_0 I a^2}{2R^3} = \frac{\mu_0 I \cdot a^2}{2 (a^2+z^2)^{3/2}}$$

PRI $z=0$

$$\boxed{B(z=0) = \frac{\mu_0 I}{2a}}$$

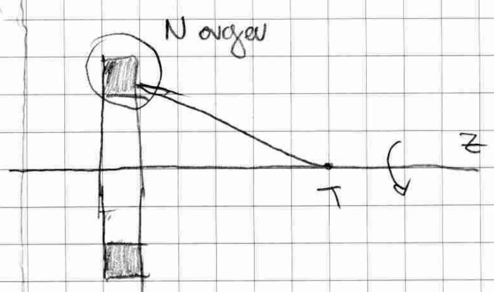




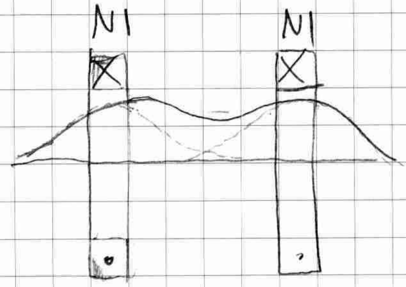


Zaradi tendence zasuka imenujemo zanko tudi magnetni dipol

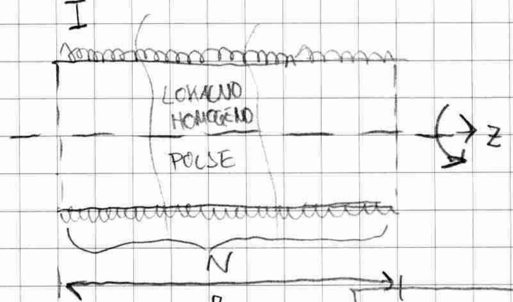
Spin se nanaša obnaša kot vrteča zanka čeprav se nič ne vrti.

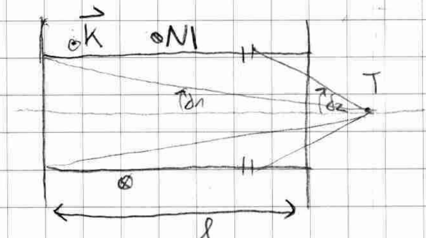


$B_z(T) = \frac{\mu_0 N I}{2} \frac{a}{R^3}$

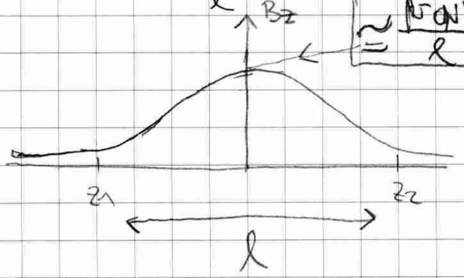


7.) $\vec{B}$ DOLGE TULJAVE



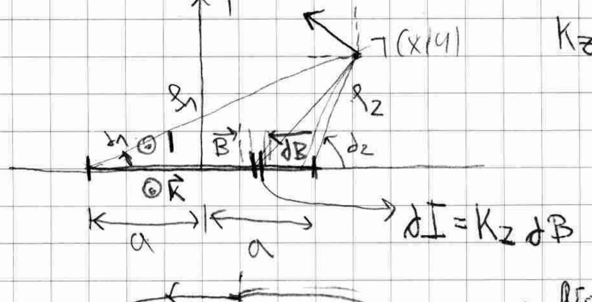


$B_z(T) = \frac{\mu_0 I N}{2l}(\cos\delta_1 - \cos\delta_2)$



$\simeq \frac{\mu_0 N I}{l}$ → če je $l >> a$ $= \mu_0 K$

8.) $\vec{B}$ TRAČNEGA VODNIKA

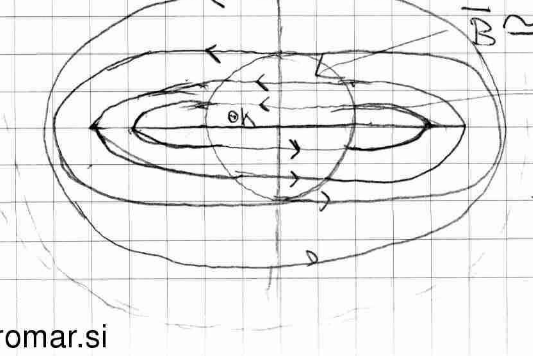


$K_z = \frac{I}{2a}$

$B_x(T) = \frac{\mu_0 K_z}{2\pi}(\delta_1 - \delta_2)$

$B_y(T) = \frac{\mu_0 K_z}{2\pi} \ln \frac{\rho_1}{\rho_2}$

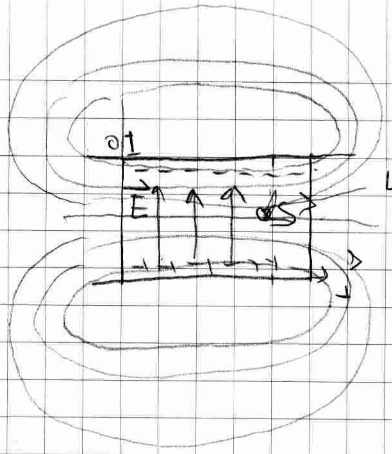
$dI = K_z \, dB$

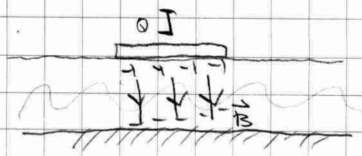


$\vec{B} \simeq \mp \frac{\mu_0 K_z}{2} \vec{e}_x$

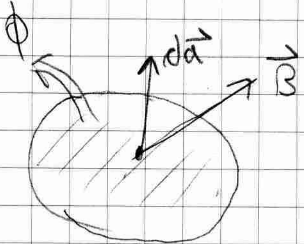
→ Lokalno homogeno polje

→ ~~Dolžk~~ stran pasterne gostolnica kroga





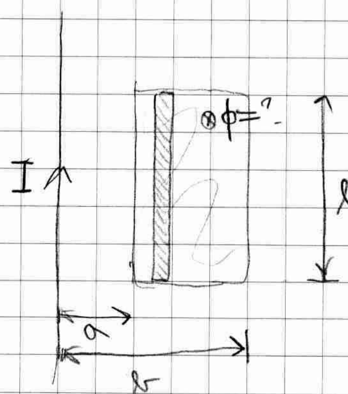
MAGNETNI PRETOK $\Phi_m = \Phi$



$$\Phi = \int_A \vec{B}\, d\vec{a}$$

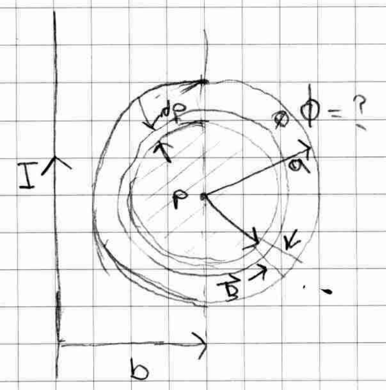
$$\left\{ \begin{array}{l} \int_A \vec{J} \cdot d\vec{a} = i \\ \int_A \vec{E} \cdot d\vec{a} = \Phi_E \end{array} \right\}$$

1. ZGLED - PRETOK SKOZI PRAVOKOTNIK OB RAVNEM TOKOVODNIKU



$$\Phi = \int \vec{B} \cdot d\vec{a} = \int_a^{\ell} \frac{\mu_0 I}{2\pi x}\, l\, dx = \frac{\mu_0 I l}{2\pi} \ln\frac{b}{a}$$

2. ZGLED - PRETOK SKOZI KROŽNO OPNO OB RAVNEM TOKOVODNIKU



$$d\phi = \vec{B}\cdot d\vec{a} = \frac{\mu_0 I}{2\pi(b+p\sin\vartheta)}\, p\, d\vartheta \times dp$$

$$\phi = 2\int_{p=0}^{a}\int_{\vartheta=-\pi}^{\pi} d\phi = \ldots = \mu_0 I\left(b-\sqrt{b^2-a^2}\right)$$

(NE)IZVORNOST POLJA $\vec{B}$

$\oint_A J\cdot da = \ldots$

$\oint \varepsilon, \vec{P}, \vec{D} \ldots$

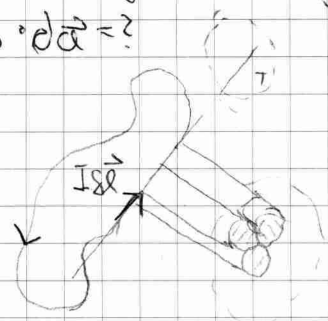
↓

Za e rovnal preperciavlmi naleyjm za P...

$\oint_A \vec{B}\cdot d\vec{a} = ?$

Bodi $\delta\vec{B}$ polje tokovnega elementa $I\delta\vec{l}$.

$\oint_A \delta\vec{B}\cdot d\vec{a} = ?$



Gostotnica so soosne krožnice

Cevke so soosni toroidi (dolgi, vrešilni pasovi)

$\oint_A \delta\vec{B}\cdot d\vec{a} = 0$

$\delta\phi \quad \vec{B} = \sum_{k=1}^{n} \delta\vec{B}_k$

$\oint \vec{B}\cdot d\vec{a} = \sum_{k=1}^{n} \oint \delta\vec{B}_k\cdot d\vec{a} = 0$

$\oint \varepsilon E\cdot da = \frac{q_{not}}{\varepsilon_0}$

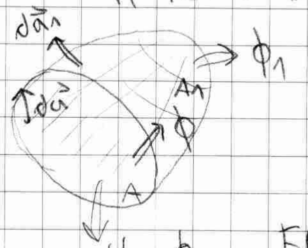
I. Maxwellova enačba

$$\oint_A \vec{B}\cdot d\vec{a} = 0$$

II. MAXWELLOVA ENAČBA

(NASPROTJ ENAČBA, POTEM EKSPERIMENT)

POVRATEK K FLUXU – (NA KRAJ ZLOŽINA)



$\phi = \oint_A \vec B \cdot d\vec a$

$\phi_1 = \oint_{A1} \vec B \cdot d\vec a$

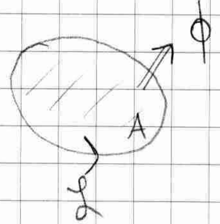
$A \cup A1 \rightarrow$ Sklenjena ploskev

$$\oint \vec B \cdot d\vec a = \underbrace{\int_A \vec B \cdot d\vec a'}_{\phi' = -\phi} + \underbrace{\int_{A1} \vec B_1 \cdot d\vec a_1}_{\phi_1} = 0$$

$\phi' = -\phi$

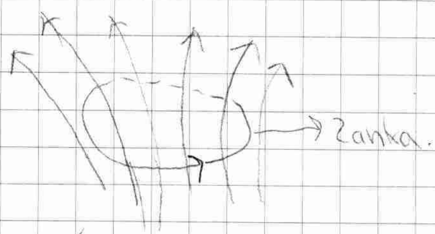
Fluks skozi ploskev ni odvisen od ploskve, ampak samo od roba ploskve (robu ploskve) → Sklenjene pentlje

$$-\phi + \phi_1 = 0 \Rightarrow \boxed{\phi_1 = \phi}$$

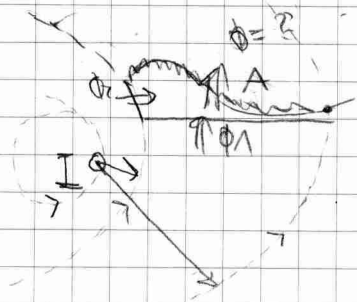


$\phi_{skozi\ A'} = \phi_{skozi\ \mathcal{L}''}$

$I = -\frac{dQ}{dt}$

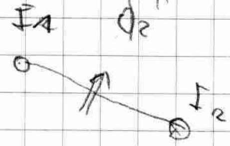


1.) ZGLED – PRETOK SKOZI ZVIJUGAN TRAK OB RAVNEM TOKOVODNIKU



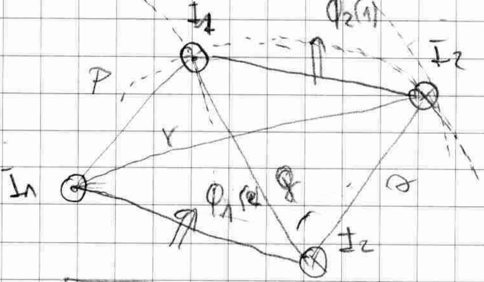
$$\phi + (-\phi_2) + (-\phi_1) = 0$$

$$\phi = \phi_1 = \frac{\mu_0 I l}{2\pi} \ln\frac{b}{a}$$



7.3.'11

2.) ZGLED – PRETOKA MED DVOVODOMA



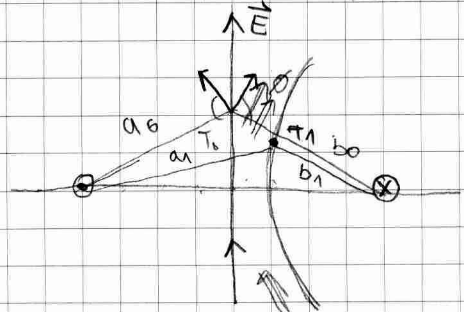
$$\phi_2^{(1)} = \frac{\mu_0 I_1 l}{2\pi}\left(\ln\frac{r}{p} - \ln\frac{s}{q}\right) = \frac{\mu_0 I_1 l}{2\pi}\ln\frac{rq}{ps}$$

$$\phi_1^{(2)} = \frac{\mu_0 I_2 l}{2\pi}\left(\ln\frac{q}{p} + \ln\frac{r}{s}\right) = \frac{\mu_0 I_2 l}{2\pi}\ln\frac{rq}{ps}$$

$$\boxed{L_{21} = \frac{\phi_2^{(1)}}{I_1} = \frac{\phi_1^{(2)}}{I_2} = L_{12}}$$

Medsebojni induktivnosti sta si paroma enaki

3. IZGLED - GOSTOTNICE DVOVODA

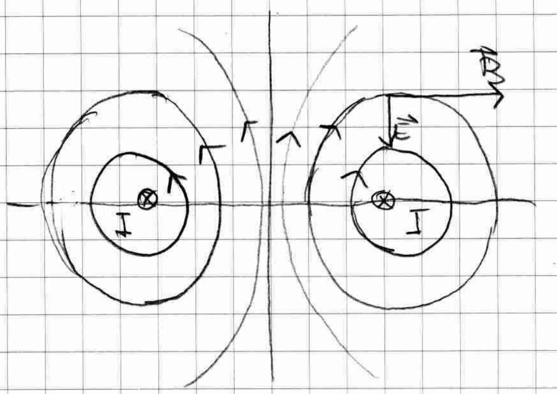


$$\phi = \frac{\mu_0 I l}{2\pi}\left(\ln\frac{a_1}{a_0} + \ln\frac{b_0}{b_1}\right) = \frac{\mu_0 I l}{2\pi}\ln\frac{a_1 b_0}{a_0 b_1}$$

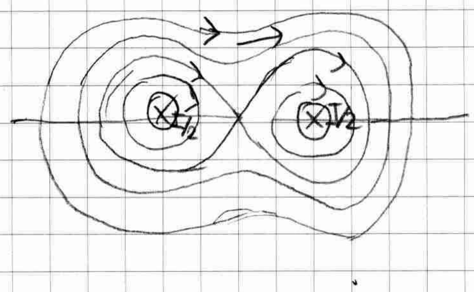
$$\boxed{\phi = \frac{\mu_0 I l}{2\pi}\ln\frac{a_1}{b_1}}$$

$\frac{a_1}{b_1} = konst$

Pretok nespremenjen ; kjer koli se premika če je $a_1 = a_2$ konst



4. GOSTOTNICE OB DVOJČKU



$d\vec{B}(T) = \frac{\mu_0 I\, d\vec{l} \times \vec{R}}{4\pi R^3}$ $\qquad B(T) = \int d\vec{B}(T)$

$\phi = \int_A \vec{B}\cdot d\vec{a} \leftarrow \oint_A \vec{B}\cdot d\vec{a} = 0!$ (mag. polje neizvorno)

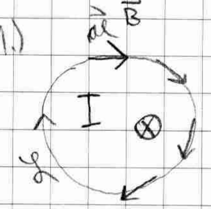
$\phi_A = \int \vec{B}\cdot d\vec{a} = \phi_L$

7.3.11

VRTINČNOST MAGNETNEGA POLJA

$\oint_g \vec{E}\cdot d\vec{l} = 0$ $\qquad \oint_g \vec{B}\cdot d\vec{l} = ?$ Ups. vrtinčnosti je ups. vrednosti tega integrala

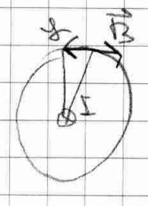
1.)



$\oint_g \vec{B}^{\parallel}\cdot d\vec{l} = \oint \frac{\mu_0 I}{2\pi a} a\, d\varphi = \mu_0 I$

zavrtinčenost sorazmerna toku, ki ovoj ga obja (?)

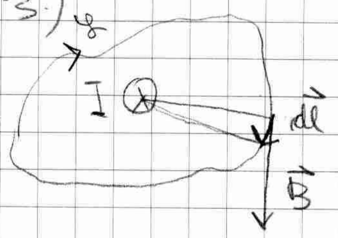
2.)



$\oint \vec{B}\, d\vec{l} = -\mu_0 I = \mu_0(-I)$ $=$

Rezultat enak toku, ki ga objemamo v pozitivnem smislu

3.)

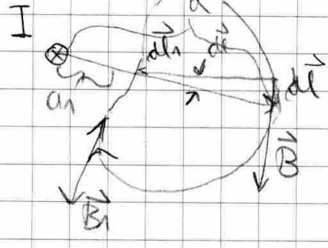


$\oint_g \vec{B}\, d\vec{l} = \int \frac{\mu_0 I}{2\pi a} a\, d\varphi = \mu_0 I$

dolžina loka pod kotom φ

$\vec{B}\cdot d\vec{l} = B\, dl_B = B\, a\, d\varphi$

4.)



$\vec{B}\cdot d\vec{l} = -\vec{B}_1\cdot d\vec{l}_1$

$\oint_g \vec{B}\cdot d\vec{l} = 0$

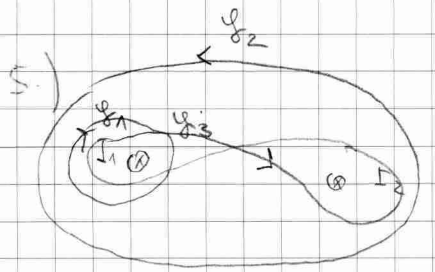
$\oint_g \vec{A}\cdot d\vec{l} \neq 0$

$\oint_g \vec{A}\cdot d\vec{l} = \langle|\vec{A}|\rangle_t\, l \neq 0$

(l – dolžina zanke; $\langle|\vec{A}|\rangle_t$ – povpr. vekt. v tang. smeri)

$\oint_g \vec{E}\cdot d\vec{l} = 0 \Rightarrow \langle\vec{E}\rangle_t = 0$

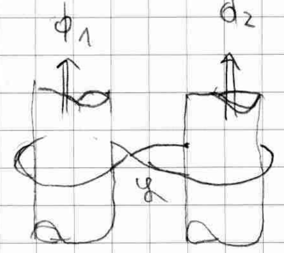
5.)



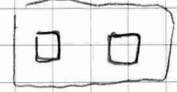
$$\oint_{g_1} \vec{B} \cdot d\vec{l} = \mu_0 I_1$$

$$\oint_{g_2} \vec{B} \cdot d\vec{l} = \mu_0 (I_2 - I_1)$$

$$\oint_{g_3} \vec{B} \cdot d\vec{l} = \mu_0 (I_1 + I_2)$$

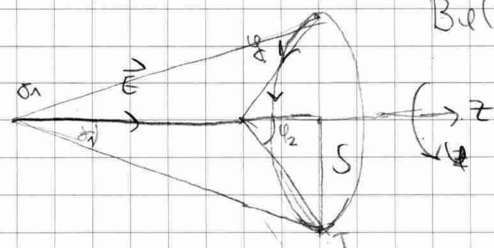


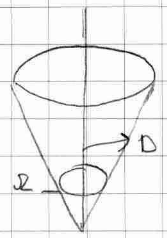
$\phi_g = \phi_1 - \phi_2$



$\oint_g \vec{B} \cdot d\vec{l}$ - tokovne daljice, ko je g krivulja okoli cele daljice.

$$B_\varphi(T) = \frac{\mu_0 I}{4\pi \rho}(\cos\vartheta_1 - \cos\vartheta_2)$$



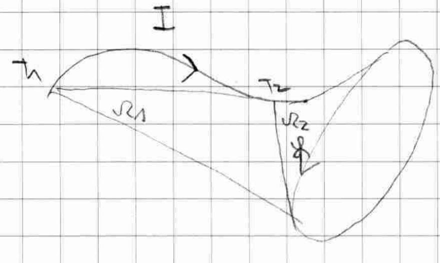


$\Omega = 2\pi(1-\cos\vartheta)$

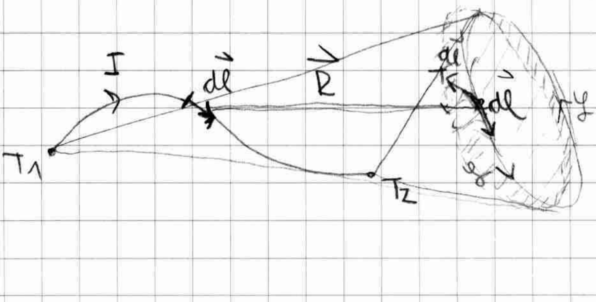
$\cos\vartheta = 1 - \frac{\Omega}{2\pi}$

$$\oint_g \vec{B} \cdot d\vec{l} = \frac{\mu_0 I}{4\pi\rho}(\cos\vartheta_1 - \cos\vartheta_2) \cdot 2\pi\rho$$

$$= \frac{\mu_0 I}{2}(\cos\vartheta_1 - \cos\vartheta_2) = \frac{\mu_0 I}{2}\left(1 - \frac{\Omega_1}{2\pi} - 1 + \frac{\Omega_2}{2\pi}\right) = \frac{\mu_0 I}{4\pi}(\Omega_2 - \Omega_1)$$



$$\oint_g \vec{B}\, d\vec{l} = \frac{\mu_0 I}{4\pi}(\Omega_2 - \Omega_1)$$ UPORABEN ZA POSEBNE KRIVULJE



$$\vec{B}(T) = \int_{T_1}^{T_2} \frac{\mu_0 I\, d\vec{l}' \times \vec{R}}{4\pi R^3}$$

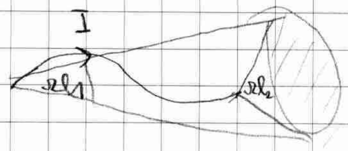
$$\oint_g \vec{B}\, d\vec{l} = \oint_g \left(\int_{T_1}^{T_2} \frac{\mu_0 I\, d\vec{l}' \times \vec{R}}{4\pi R^3} \right) d\vec{l}$$

$$= \frac{\mu_0 I}{4\pi} \int_{T_1}^{T_2} \oint \frac{(d\vec{l}' \times \vec{R}) \cdot d\vec{l}}{R^3}$$ MEŠANI PSEVDOSKALARNI PRODUKT

$$= \frac{\mu_0 I}{4\pi} \int_{T_1}^{T_2} \oint_g \frac{(d\vec{l}' \times d\vec{l}) \cdot \frac{\vec{R}}{R}}{R^2} = \frac{\mu_0 I}{4\pi} \int_{T_1}^{T_2} \oint \frac{(-d\vec{l} \times d\vec{l}') \cdot \frac{\vec{R}}{R}}{R^2}$$

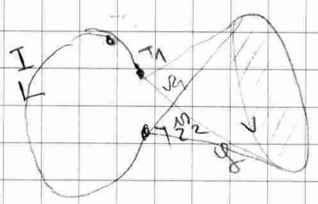
Prostorski kot ploskvice $d\Omega_{ploskvica}$

$d\Omega$ prirastku $\Omega_2 - \Omega_1$



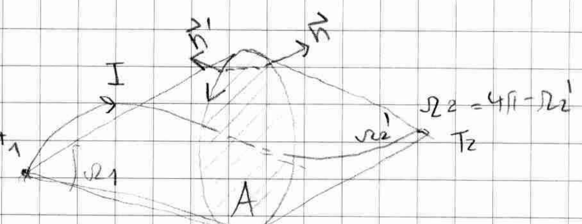
$$\oint_\gamma \vec{B}\cdot d\vec{l} = \frac{\mu_0 I}{4\pi}(\Omega_2-\Omega_1)$$

1.)



$$\oint_\gamma \vec{B}\cdot d\vec{l} = \lim_{T_1\to T_2}\frac{\mu_0 I}{4\pi}(\Omega_2-\Omega_1) = \emptyset$$

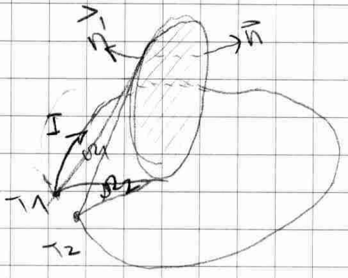
2.)



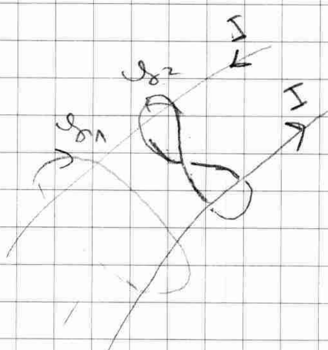
$$\oint \vec{B}\cdot d\vec{l} = \frac{\mu_0 I}{4\pi}(\Omega_2-\Omega_1) = \frac{\mu_0 I}{4\pi}(4\pi-\Omega_2'-\Omega_1)$$

$$= \mu_0 I - \frac{\mu_0 I}{4\pi}(\Omega_1+\Omega_2')$$

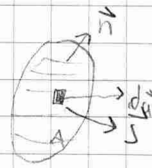
3.)



$$\oint_\gamma \vec{B}\cdot d\vec{l} = \mu_0 I - \lim_{T_2\to T_1}\frac{\mu_0 I}{4\pi}(\Omega_1+\Omega_2') = \mu_0 I$$



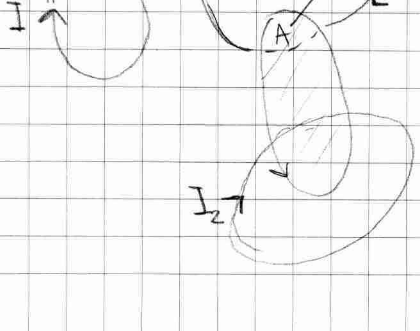
$$\oint_{\gamma_1}\vec{B}\cdot d\vec{l} = 0 \quad ; \quad \oint_{\gamma_2}\vec{B}\cdot d\vec{l} = -2\mu_0 I$$



$\oint \vec{J}\cdot d\vec{a}$

$\sum I$ skozi A v pozit. smislu.

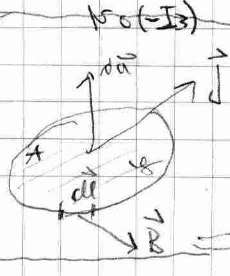
4.)



$$\vec{B} = \vec{B}_1 + \vec{B}_2 + \vec{B}_3$$

$$\oint_\gamma \vec{B}\cdot d\vec{l} = \underbrace{\oint_\gamma \vec{B}_1 d\vec{l}}_{\emptyset} + \underbrace{\oint \vec{B}_2 d\vec{l}}_{\mu_0 I_2} + \underbrace{\oint \vec{B}_3 d\vec{l}}_{\mu_0(-I_3)} = \mu_0(I_2 - I_3)$$

$$\boxed{\oint_\gamma \vec{B}\, d\vec{l} = \mu_0 \int_A \vec{J}\cdot d\vec{a}}$$

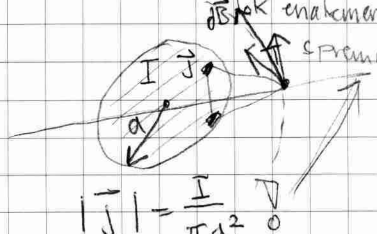


Amperov zakon vrtinčnosti mag. polja

ZGLEDI:

1.) $\vec{B}$ V/OB RAVNEM TOKOVODNIKU KROŽNEGA PRESEKA

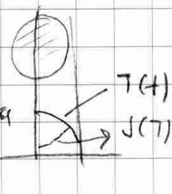
$d\vec{B}$ tok enakomerno razporejen po preseku, v praksi to ni res ker se s segrevanjem prevodnost spremenijo

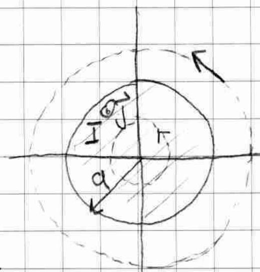


$$\Rightarrow \vec{B} = (0, B_\varphi, 0)$$

$$|\vec{J}| = \frac{I}{\pi a^2}$$

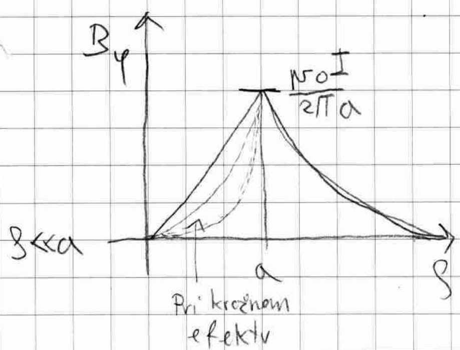
Magn. polje ima samo φ komponento - okoli osi vodnika

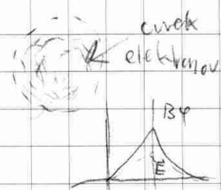




$\varrho \gtrless a$ okoli osi z

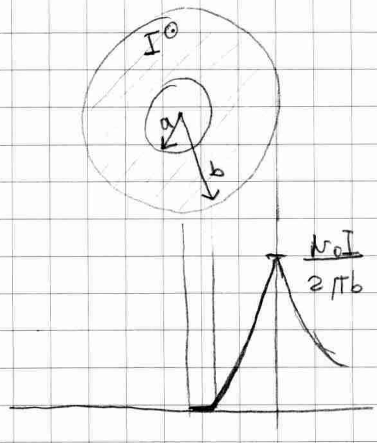
$$\oint_{\varrho} \vec{B}\, d\vec{l} = B_\varphi 2\pi\varrho = \mu_0 \begin{cases} \frac{I}{\pi a^2}\pi\varrho^2, & \varrho \le a \\ I, & \varrho > a \end{cases}$$



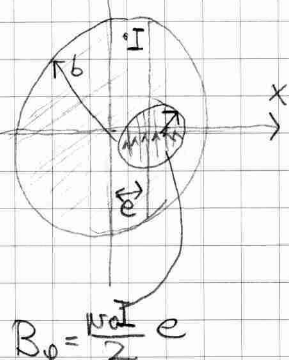


$$B_\varphi = \begin{cases} \frac{\mu_0 I}{2\pi a^2}\varrho, & \varrho \le a \\ \frac{\mu_0 I}{2\pi\varrho}, & \varrho > a \end{cases}$$

2.) CEVAST TOKOVODNIK

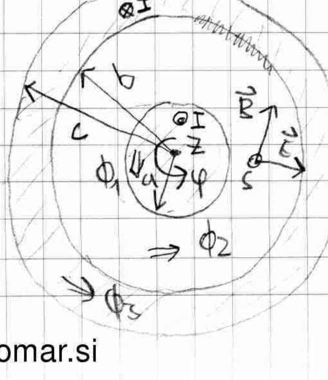


3.) MAKARON



$$B_\varphi = \frac{\mu_0 I}{2} e$$

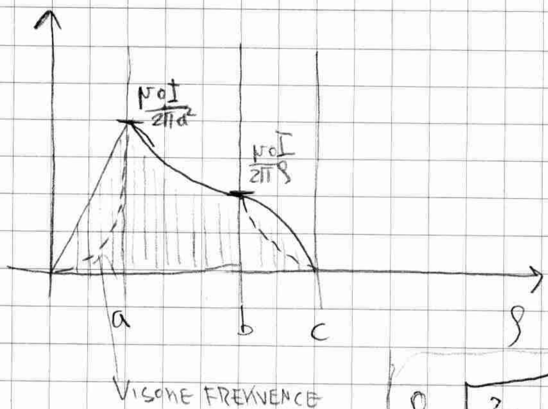
4.) KOAKSIALNI KABEL

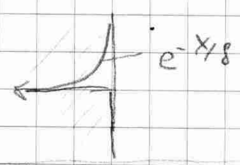


$$\vec{B} = (0, B_\varphi, 0)$$

$$\oint_{\varrho: 2\pi\varrho} \vec{B} \cdot d\vec{l} = 2\pi\varrho B_\varphi = \begin{cases} \mu_0 \frac{I}{\pi a^2}\pi\varrho^2, & \varrho \le a \\ \mu_0 I, & a < \varrho \le b \\ \mu_0\left(I - \frac{I}{\pi(c^2-b^2)}\pi(\varrho^2-b^2)\right), & b < \varrho \le c \\ \mu_0 \cdot 0 & \varrho > c \end{cases}$$

$$B_\varphi = \begin{cases} \frac{\mu_0 I}{2\pi a^2}\rho, & \rho \le a \\ \frac{\mu_0 I}{2\pi\rho}, & a < \rho \le b \\ \frac{\mu_0 I}{2\pi(c^2-b^2)}\left(\frac{c^2}{\rho}-\rho\right), & b < \rho \le c \\ 0, & \rho > c \end{cases}$$





$$\delta = \sqrt{\frac{2}{\omega\mu\gamma}}$$ Globina prodiranja (penetracije)

Za Cu, 50Hz, $\delta \simeq 1cm$

50kHz, $\delta \simeq 1mm$

5MHz $\delta = 100\mu m$

500MHz, $\delta = 10\mu m$

50GHz $\delta = 1nm$

$$\phi_1 = \int_A \vec{B} \cdot d\vec{a} = \int_0^a \frac{\mu_0 I}{2\pi a^2}\rho\, l\, d\rho = \frac{\mu_0 I l}{4\pi}$$

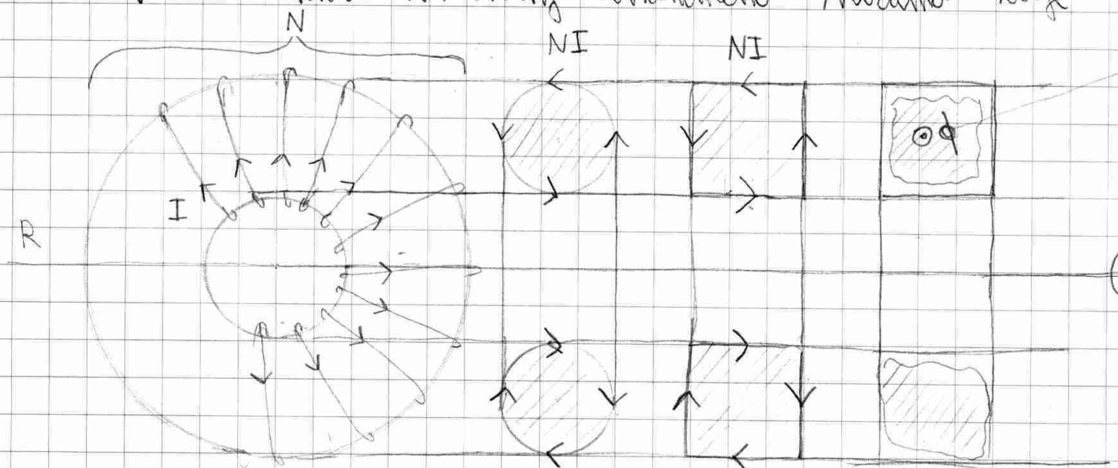
$$\phi_2 = \dots = \frac{\mu_0 I l}{2\pi}\ln\frac{b}{a}$$

$$\phi_3 = \dots = \int_b^c \frac{\mu_0 I}{2\pi(c^2-b^2)}\left(\frac{c^2}{\rho}-\rho\right) l\, d\rho = \frac{\mu_0 I l}{2\pi(c^2-b^2)}\left[c^2\ln\frac{c}{b} - \frac{c^2-b^2}{2}\right]$$

(V KNJIGI GLEJ - TOROIDNO NAVITJE)

5.) MAGNETNO POLJE TOROIDNEGA NAVITJA

Vzamemo toroid in navij enakomerno navijamo ovoje



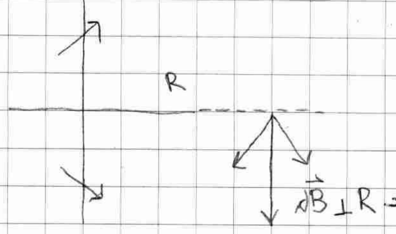
$$\phi \simeq \frac{\mu_0 NI}{2\pi\rho} S$$

⇒ Aproksimacija za toroido „divjega" preseka

$$2\pi\rho_0 = l_s$$

⇒ Srednja dolžina gostotnic polja $\vec{B}$

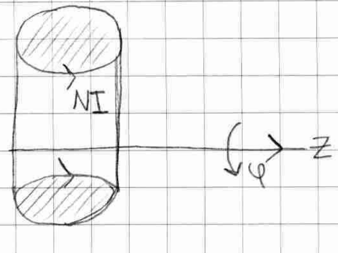
ZRCALNA TOKOVNA ELEMENTA ⇒ njuna vsota je nič



$d\vec{B} \perp R$ ⇒ magnetno polje B je vedno pravokotno na to premico ⇒ pravokotno na ravnino φ

$$\vec{B} = (0, \vec{B}_\varphi, 0)$$ mag. polje ima φ smer

Tok ni samo vzdolž toroida, ampak tudi okrog → ta tok okrog oz. zunaj je tudi en sam ovoj (čisto malo magnetnega polja je tudi zunaj)



$$\oint_{\mathcal{L}} \vec{B} \cdot d\vec{l} = \mu_0 \cdot \text{objeti tok}$$

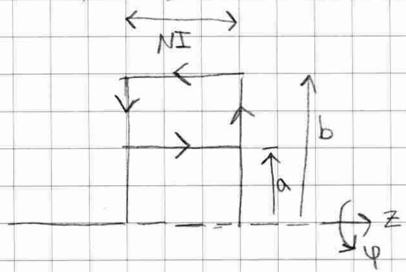
$\mathcal{L}$ KROŽNICA PLOSKVE OKOLI OSI z

$$\oint \vec{B} \parallel d\vec{l} = \mu_0 \begin{cases} 0 & , \mathcal{L}_z \\ NI & , \mathcal{L}_N \end{cases}$$

$$\boxed{B_\varphi = \begin{cases} \dfrac{\mu_0 NI}{2\pi\rho} & , \text{znotraj} \\ 0 & , \text{zunaj} \end{cases}}$$

ZGLEDI NA TEMO TOROIDA

1.) FLUKS V TOROIDNEM NAVITJU PRAVOKOTNEGA PREREZA

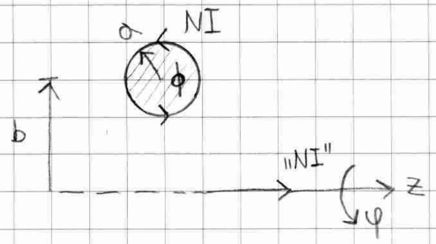


$$d\phi_m = \frac{\mu_0 NI}{2\pi\rho} C\, d\rho$$

$$\boxed{\phi} = \int d\phi = \frac{\mu_0 NIC}{2\pi} \int_a^b \frac{d\rho}{\rho} \boxed{= \frac{\mu_0 NIC}{2\pi} \ln\frac{b}{a}}$$

INDUKTIVNOST: $\psi = N\phi \Rightarrow L = \frac{\mu_0 N^2 C}{2\pi} \ln\frac{b}{a}$ Tako je def. induktivnost → magnetni sklep

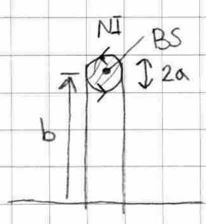
2.) FLUKS V TOROIDNEM NAVITJU KROŽNEGA PREREZA



$$\phi_m = \mu_0 (NI)\left(b - \sqrt{b^2 - a^2}\right)$$

$$L = \mu_0 N^2 I \left(b - \sqrt{b^2 - a^2}\right) \rightarrow \text{induktivnost}$$

3.) TOROID MAJHNEGA PREREZA



$a \ll b$ → ŠLANK TOROID (npr. 5x manjši, ni nujno pretirano manjši)

$\sqrt{1-x^2} \cong 1 - \frac{x}{2}$

$|x| \ll 1$

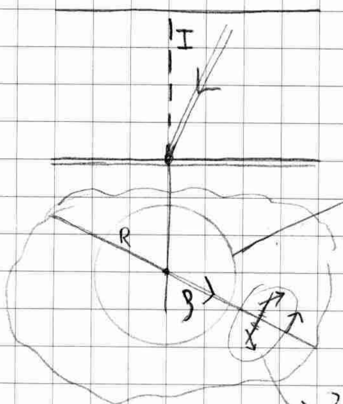
$(1 - \frac{x}{2})^2 = 1 - x + \frac{x^2}{4} \cong 1 - \frac{x}{2}$

$$\phi = \mu_0 NI b\left(1 - \sqrt{1 - (\tfrac{a}{b})^2}\right) \cong \mu_0 NI b\left(1 - \left(1 - \frac{a^2}{2b^2}\right)\right) = \frac{\mu_0 NI a^2}{2b} \frac{\pi}{\pi}$$

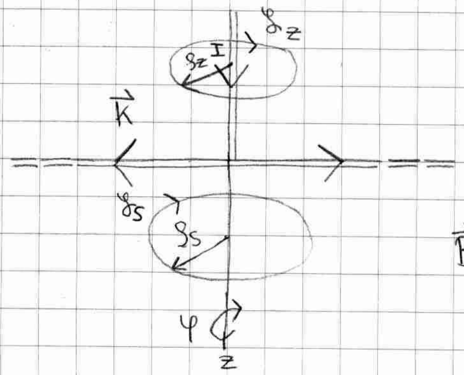
$$\Rightarrow \underbrace{\frac{\mu_0 NI}{2\pi b}}_{\simeq B_S} \cdot \underbrace{\pi a}_{\simeq S}$$

6.) MAGNETNO POLJE PLOSKOVNO RADIALNEGA TOKA

Mišljeno je da je plošča, v eni točki tok vstopa potem pa se razbeži po plošči



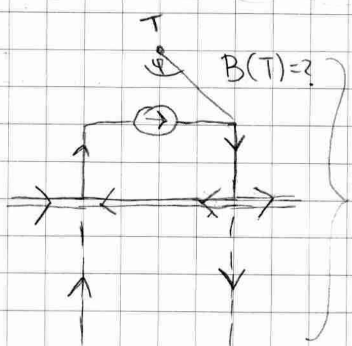
$\vec{K} = \vec{e}_s \frac{I}{2\pi\rho}$ $B_K = ?$



$\vec{B} = \vec{B}_I + \vec{B}_K$

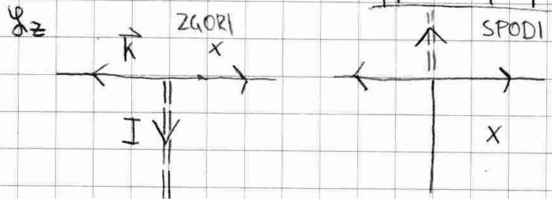
→ Zrcalno prerežemo na polovico

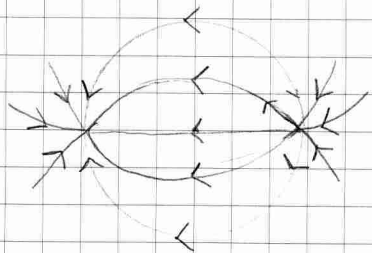
Dva zrcalna tokovna elementa ⇒ njuno magnetno polje je pravokotno na ravnino $= B_\varphi$



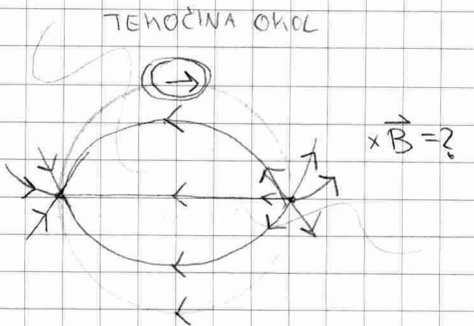
ENKRAT BLO ZA IZPIT/KOLOKVIJ

$$\oint \vec{B} \cdot d\vec{l} = 2\pi\rho_z B_\varphi = \mu_0 I \Rightarrow B_\varphi = \frac{\mu_0 I}{2\pi\rho_z}$$





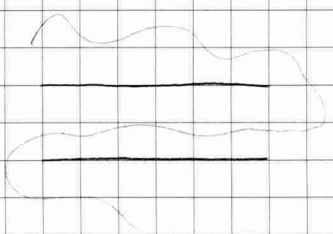
7.) MAGNETNO POLJE SFERIČNO RADIALNEGA TOKA



$R \to \vec{B}(T) \perp R$ } Povsod je pravokoten
$R' \to \vec{B}(T) \perp R'$ } samo ničelni vektor

⇒ ALSO: $\boxed{B(T) = 0}$

⇒ Uporabimo Biot-Savartov zakon: $\vec{B}(T) = \frac{\mu_0 I}{4\pi} \int_1^2 \frac{d\vec{l} \times \vec{R}}{R^3}$

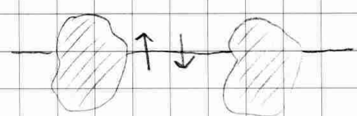


$\vec{E} = \sum$ polja točkastih nabojev

$\vec{j} = \gamma \vec{E} = \sum$ sferičnih tokov

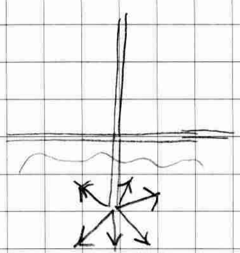
$$\boxed{W_j = W_e}$$

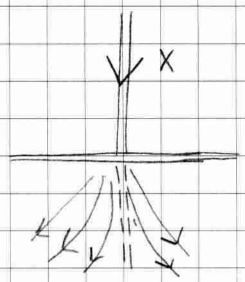
KONDENZATOR V ZRAKU



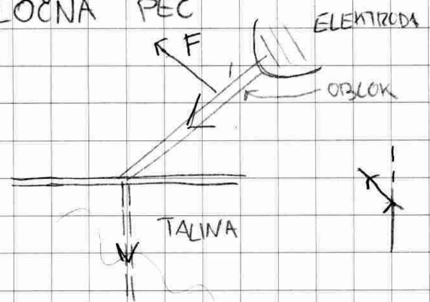
Energija se seli zgolj ob prisotnosti magnetnega polja

V KNJIGI





OBLOČNA PEČ



ODRINJENA VPRAŠANJA

1.) GIBANJE DELCA V $\vec{E}$ IN $\vec{B}$ POLJU (ČET)

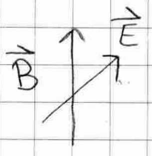
2.) SILI MED ZANKAMA (NE SAMO MED TOKOVNIMA ELEMENTOMA)
- ⇒ VPLIV ENE NA DRUGO
- ⇒ ZANKI SE ENAKO ČUTITA → SILI STA VZAJEMNI

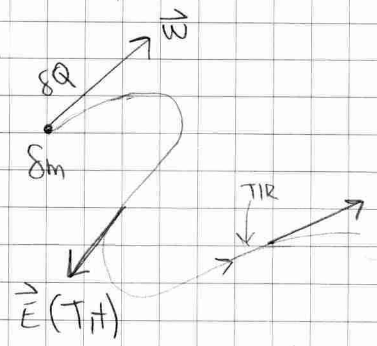
3.) DELO ZA PREMIK ZANKE

4.) ZANKA V MAGNETNEM POLJU KI DOPUŠČA ROTACIJO → NAVOR NA ZANKO

5.) FINALE → MAGNETNI DIPOL

1. GIBANJE NABITEGA DELCA V $\vec{E}$ IN $\vec{B}$ POLJU





$t_k, T_k, \vec{w}_k, \vec{w}(t_k)$

$\delta m = \frac{\vec{w}_{k+1} - \vec{w}_k}{\delta t} \approx \delta Q(\vec{E}(T_k,t_k) + \vec{w}_B \times \vec{B}(T_k,t_k))$

$\delta t = t_{k+1} - t_k$

$\Rightarrow \vec{w}_{k+1} \rightarrow T_{k+1}$

$\Rightarrow w_{k+2} \rightarrow \ldots$

NE SODI V 1. LETNIK

$$\delta \vec{F}_L = \delta Q(\vec{E} + \vec{w} \times \vec{B})$$

$$\delta m \cdot \dot{\vec{w}} = \delta \vec{F}_L = \delta Q(\vec{E} + \vec{w} \times \vec{B})$$

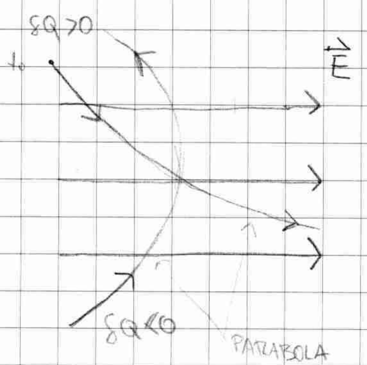
$$\vec{r}(t) = \vec{r}(t_0) + \int_{t_0}^{t} \vec{w}(t)\, \delta t$$

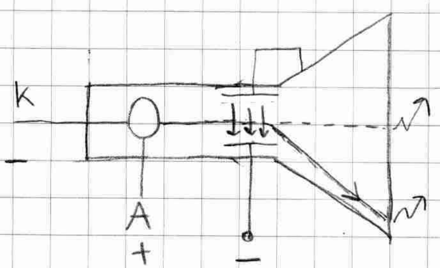
1. A. DELEC V HOMOGENEM POLJU $\vec{E}$

$$\delta m \dot{\vec{w}} = \delta Q \vec{E} \Rightarrow \dot{\vec{w}} = \vec{a} = \frac{\delta Q}{\delta m}\vec{E}$$

$$\vec{w}(t) = \vec{w}(t_0) + \frac{\delta Q}{\delta m}\vec{E}(t - t_0)$$

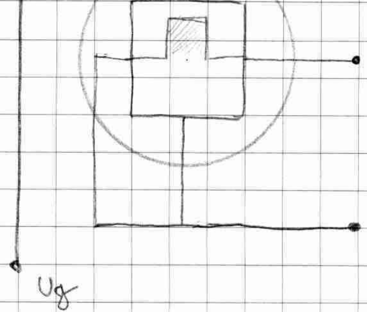
$$\vec{r}(t) = \vec{w}(t_0)(t - t_0) + \frac{1}{2}\frac{\delta Q}{\delta m}\vec{E}(t - t_0)^2 + \vec{r}(t_0)$$





$U_x = U_g \cos \omega t$

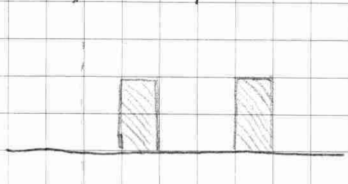
$U_y = U_g \cos(2\omega t + \alpha)$



$U_x = U_g \cos \omega t$

$U_y = U_g \cos(\omega t + \alpha)$

„ŽAGA"



OBLAK ELEKTRONOV

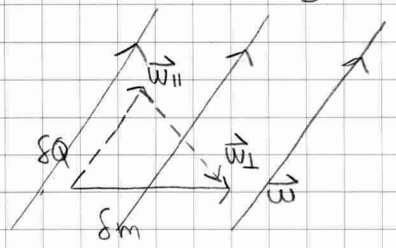
1.B. DELEC V HOMOGENEM POLJU $\vec{B}$

$\delta m \dot{\vec{w}} = \delta Q(\vec{w} \times \vec{B}) \; / \cdot \vec{w}$

$\Rightarrow \delta m \dot{\vec{w}} \vec{w} = \delta Q(\vec{w} \times \vec{B}) \cdot \vec{w} = \delta Q(\vec{w} \times \vec{w}) \cdot \vec{B} = 0$

$\Rightarrow |\vec{w}| = konst$

RAZCEP:



$\vec{w} = \vec{w}_\perp + \vec{w}_\parallel$

$\delta m(\dot{\vec{w}}_\perp + \dot{\vec{w}}_\parallel) = \delta Q \vec{w}_\perp \vec{B} + \delta Q \overbrace{\vec{w}_\parallel \times \vec{B}}^{\vec{0}}$

$\boxed{\delta m \dot{\vec{w}}_\parallel = \vec{0}}$ → Pospešek vzdolž magnetnega polja je nič. Delec se giblje enakomerno. Komponenta hitrosti magnetnega polja se ne spreminja

$w_\parallel(t) = w_\parallel(t_0)$

Enakomerno kroženje ⇐ $\boxed{\delta m \dot{\vec{w}}_\perp = \delta Q \vec{w}_\perp \times \vec{B}}$

Gibanje pri katerem se hitrost ne spreminja.

Sila je vedno pravokotna na hitrost

⇒ Delec se giblje po spirali

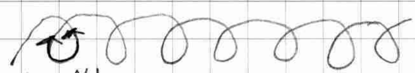
→ $\cdot / \vec{w}_\perp$: $\Rightarrow |\vec{w}_\perp| = konst$ – Obodna hitrost

$\Rightarrow \delta m \vec{w}_\perp \cdot \dot{\vec{w}}_\perp dt = \frac{\delta m}{2} d(w_\perp^2)$

RADIALNI POSPEŠEK:

$\delta m a_r = |\delta Q| w_\perp B$

$\delta m \frac{w_\perp^2}{R}$



ALI – ALI

1.) ⇒ Ugotoviti je treba smer kroženja

2.) ⇒ Ugotoviti je treba kakšen je radij

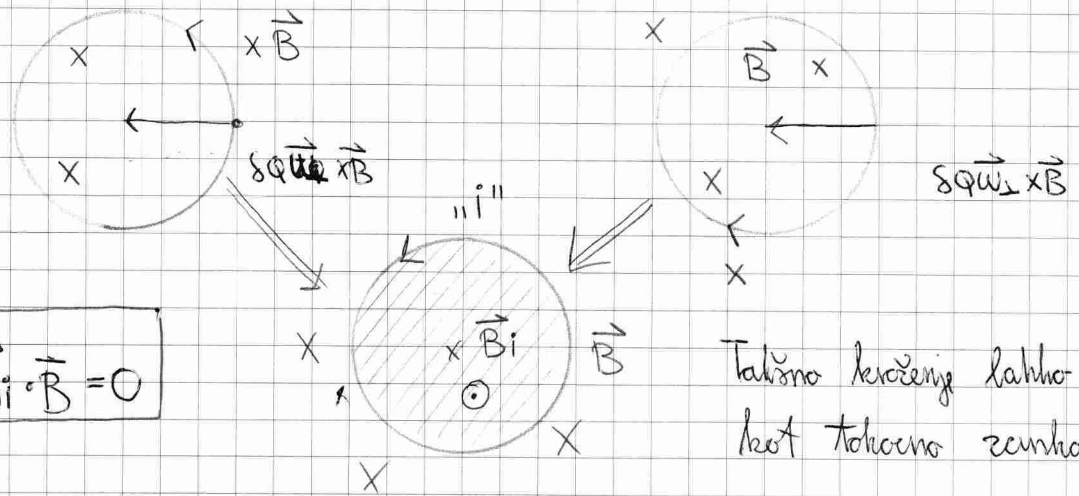
1.) KAKŠEN JE RADIJ

$\boxed{R = \frac{\delta m w_\perp}{|\delta Q| \cdot B}}$ $\Rightarrow \omega = 2\pi f = \frac{w_\parallel}{R}$

⇒ Te radiji so zelo majhni

2. KAKŠNA JE SMER KROŽENJA

POZITIVEN DELEC $\delta Q > 0$ | NEGATIVEN DELEC $\delta Q < 0$

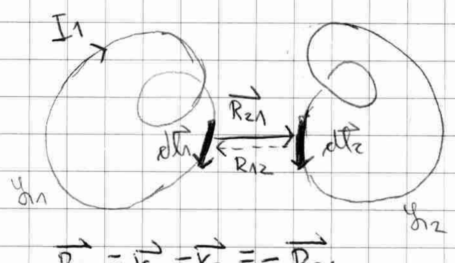


$$\boxed{\vec{B}_i \cdot \vec{B} = 0}$$

Takšno kroženje lahko predstavimo kot tokovno zanko

V takem magnetno polje rahlo manjše $\simeq 10^{-5}$

2. SILA MED TOKOKROGOMA



$$\vec{F}_{m_1}^{(2)} = \oint_{\mathcal{L}_2}\oint_{\mathcal{L}_1} \frac{\mu_0 I_1 I_2}{4\pi R_{12}^3} d\vec{l_1} \times (d\vec{l_2} \times \vec{R_{12}})$$

$$\vec{F}_{m_2}^{(1)} = \oint_{\mathcal{L}_1}\oint_{\mathcal{L}_2} \frac{\mu_0 I_1 I_2}{4\pi R_{21}^3} d\vec{l_2} \times (d\vec{l_1} \times \vec{R_{21}})$$

$$\vec{R_{12}} = \vec{r_1} - \vec{r_2} = -\vec{R_{21}}$$

$$\vec{F}_{m_1}^{(2)} + \vec{F}_{m_2}^{(1)} = \frac{\mu_0 I_1 I_2}{4\pi} \cdot \oint_{\mathcal{L}_1}\oint_{\mathcal{L}_2} \left[d\vec{l_1} \times \left(d\vec{l_2} \times \frac{\vec{R_{12}}}{R_{12}^3}\right) + d\vec{l_2} \times \left(d\vec{l_1} \times \frac{\vec{R_{21}}}{R_{21}^3}\right)\right]$$

Uporabimo: $\vec{a} \times (\vec{b} \times \vec{c}) = (\vec{a} \cdot \vec{c}) \cdot \vec{b} - (\vec{a} \cdot \vec{b}) \cdot \vec{c}$

$$[\ldots] = \left(d\vec{l_1} \cdot \frac{\vec{R_{12}}}{R_{12}^3}\right) \cdot d\vec{l_2} - \left(d\vec{l_1} \cdot d\vec{l_2}\right) \frac{\vec{R_{12}}}{R_{12}^3} + \left(d\vec{l_2} \cdot \frac{\vec{R_{21}}}{R_{21}^3}\right) d\vec{l_1} - \left(d\vec{l_2} \cdot d\vec{l_1}\right) \cdot \frac{\vec{R_{21}}}{R_{21}^3}$$

→ EL. POLJSKA JAKOST

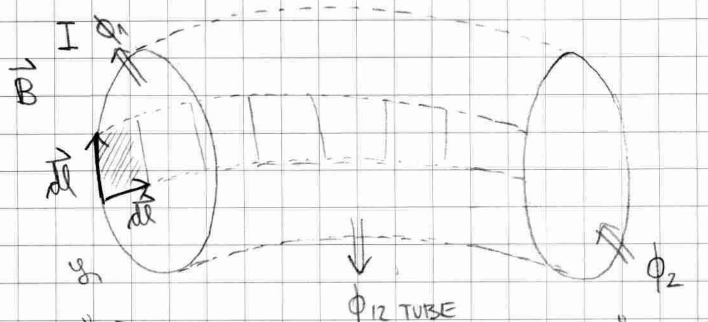
$$\oint_{\mathcal{L}_1}\oint_{\mathcal{L}_2} \left(d\vec{l_2} \cdot \frac{\vec{R_{12}}}{R_{12}^3}\right) d\vec{l_2} = \oint_{\mathcal{L}_2}\left(\oint_{\mathcal{L}_1} \frac{\vec{R_{12}}}{R_{12}^3} \cdot d\vec{l_1}\right) d\vec{l_2} = \oint_{\mathcal{L}_2}\left(\frac{Q 4\pi\varepsilon_0}{4\pi\varepsilon_0 Q} \oint \frac{\vec{R_{12}}}{R_{12}^3} \cdot d\vec{l_1}\right) d\vec{l_2}$$

$$= \oint_{\mathcal{L}_2}\left(\frac{4\pi\varepsilon_0}{Q} \underbrace{\oint_{\mathcal{L}_1} \vec{E} \cdot d\vec{l_1}}_{0}\right) \cdot d\vec{l_2} = 0$$

⇒ Magnetni sili sta vzajemni (recipročnost)

$L_{21} = L_{12}$

3. DELO ZA PREMIK TOKOVNE ZANKE V TUJEM MAGNETNEM POLJU



$$dF_m = I\,\vec{dl}\times\vec{B}$$

$$A_m = \oint_{\mathcal{L}} \int_1^2 (I\,\vec{dl}\times\vec{B})\cdot\vec{dl'}$$

Delo magnetne sile za premik iz začetne v končno lego

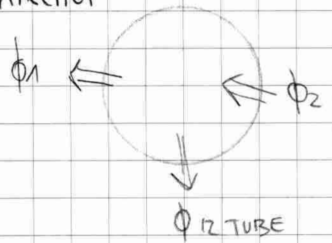
$$= I\oint\int_1^2 \underbrace{(\vec{dl'}\times\vec{dl})\cdot\vec{B}}_{d\Phi_{m\,12\,tube}}$$

$\Phi_{12\,tube}$

$$\frac{A}{I} = \Phi_2-\Phi_1$$

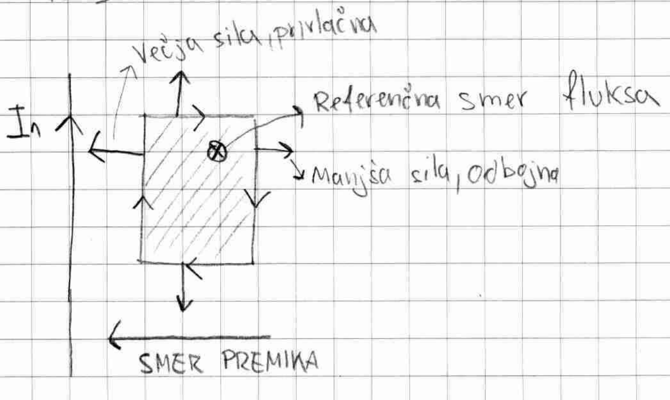
$$\Rightarrow A_m = I(\Phi_2-\Phi_1)$$

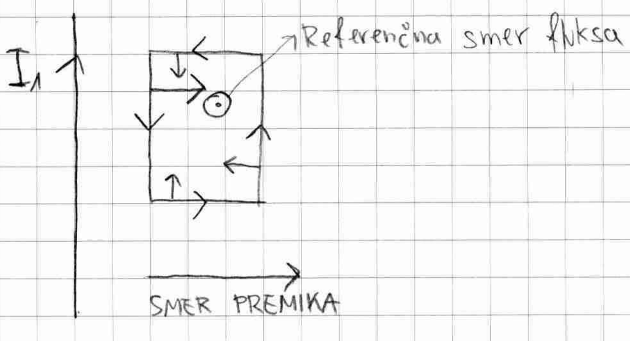
KIRCHOF



Φ_2 in Φ_1 sta označena po desnem pravilu glede na tok v zanki

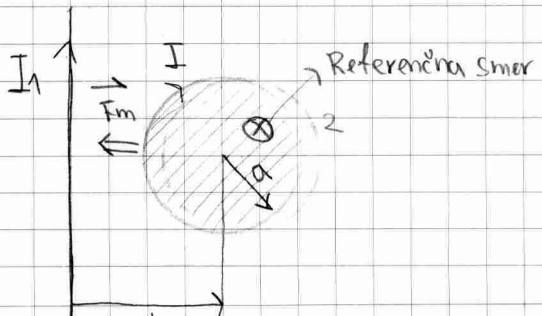
1. ZGLED:





Zanka se premika tako, da se ji fluks v referenčni smeri povečuje

2. ZGLED



$$dA_m = I(\Phi(b+db)-\Phi(b)) = I = \frac{d\Phi}{db}\cdot db$$

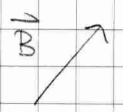
(SILA)

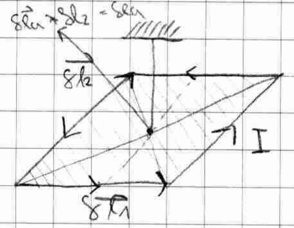
$$I\frac{d}{db}\left(\mu_0 I_1\left(b-\sqrt{b^2-a^2}\right)\right)db < 0$$

$$F_{mb} = \mu_0 I I_1\left(1-\frac{b}{\sqrt{b^2-a^2}}\right) < 0$$

21.3.11

4. NAVOR NA „MAŠNNO" TOKOVNO ZANKO (V HOMOGENEM POLJU)





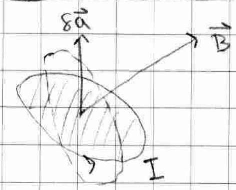
$$\delta \vec{M}_m = -\frac{\delta \vec{l_2}}{2} \times (I\delta \vec{l_1} \times \vec{B}) + \frac{\delta \vec{l_1}}{2} \times (I\delta \vec{l_2} \times \vec{B}) + \frac{\delta \vec{l_2}}{2} \times (-I\delta \vec{l_1} \times \vec{B}) - \frac{\delta \vec{l_1}}{2} \times (-I\delta \vec{l_2} \times \vec{B})$$

$$= \left[\delta \vec{l_1} \times (\delta \vec{l_2} \times \vec{B}) - \delta \vec{l_2} \times (\delta \vec{l_1} \times \vec{B})\right] I$$

$$\Rightarrow \left[(\delta \vec{l_1} \cdot \vec{B})\delta \vec{l_2} - (\delta \vec{l_1} \cdot \delta \vec{l_2})\vec{B} - (\delta \vec{l_2} \cdot \vec{B})\delta \vec{l_1} + (\delta \vec{l_2} \cdot \delta \vec{l_1})\vec{B}\right] I$$

$$= \vec{B} \times (\delta \vec{l_2} \times \delta \vec{l_1}) I = I(\delta \vec{l_1} \times \delta \vec{l_2}) \times \vec{B}$$

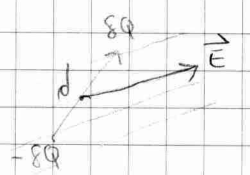
$$\boxed{\delta M_m = I \delta \vec{a} \times \vec{B}}$$



Naglede na to kakšna zanko vzamemo je rezultat enak

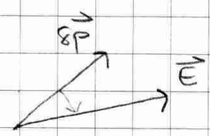
Ref. Zanka se postavi tako, da zajame največ fluksa

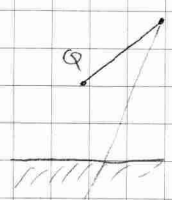
5. MAGNETNI DIPOL

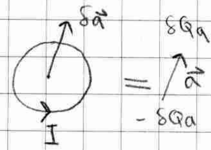


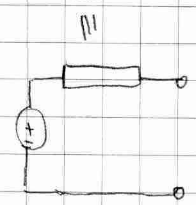
$\delta \vec{p} = \delta Q \vec{d}$

$\delta \vec{M}_e = \delta Q \vec{d} \times \vec{E} = \delta \vec{p} \times \vec{E}$

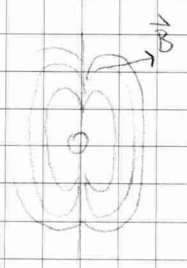




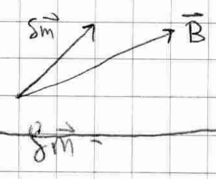




$\underbrace{I\delta \vec{a}}_{\delta m} = \delta Q_m \vec{d}$



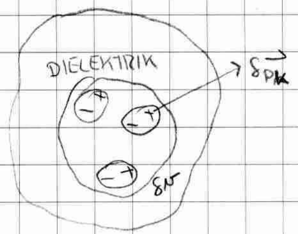
$$\boxed{\delta \vec{m} = I \delta \vec{a}}$$



Spin lahko modeliramo kot tokovno zanko. Modelno kot da je

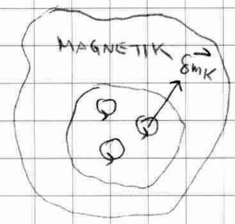
El in mag. dipol sta modela za pojasnjevanje

VEKTOR MAGNETIZACIJE



$$\vec{P} = \lim_{\text{"}\delta v \to 0\text{"}} \frac{\sum_k \delta \vec{p}_k}{\delta v} \quad [C/m^2]$$

$$\oint \vec{P} \cdot d\vec{a} = -Q_{not\text{-}pol}$$

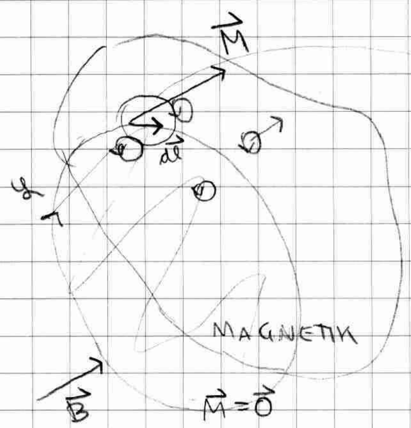


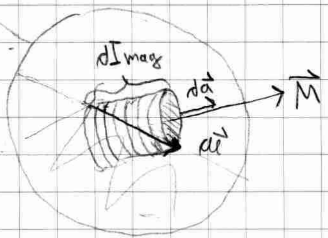
$$\vec{M} = \lim_{\text{"}\delta v \to 0\text{"}} \frac{\sum_k \delta \vec{m}_k}{\delta v} \quad [A/m]$$

$$\oint_g \vec{M} \cdot d\vec{l} \rightarrow \text{VRTINČNOST}$$

WEISSOVE DOMENE

VRTINČNOST VEKTORJA MAGNETIZACIJE





$$\vec{M} \cdot d\vec{l} = \frac{dI_{mag} \cdot d\vec{a}}{dV} \cdot d\vec{l} = dI_{mag}$$

($dV = d\vec{a} \cdot d\vec{l}$)

$$\boxed{\oint_g \vec{M} \cdot d\vec{l} = \oint_g dI_{mag} = I_{mag}}$$

ŽARKOZAVER:

$$\vec{\nabla} \times \vec{M} = \vec{J}_{mag}$$

$\vec{J}_{mag}$ → Amperovi toki

$$\boxed{\frac{\partial \vec{P}}{\partial t} = \vec{J}_{pol}}$$

VEKTOR MAGNETNE POLJSKE JAKOSTI

$\oint \vec{E} \cdot d\vec{a} = \frac{Q_{not}}{\varepsilon_0} \quad / \varepsilon_0$

$\oint_A \vec{P} \cdot d\vec{a} = -Q_{not.pol.}$

$\oint_A (\underbrace{\varepsilon_0 \vec{E} + \vec{P}}_{D}) \cdot d\vec{a} = \underbrace{Q_{not} - Q_{not\,pol}}_{Q_{not.prosti}}$

$\vec{D} = \varepsilon_0 E + P$

$\oint \vec{D} \cdot d\vec{a} = Q_{not.prosti}$

$Q_{prosti} = Q - Q_{pol}$

$\vec{B} = \mu_0 \vec{H} + \mu_0 \vec{M}$

$I = I_{pr} + I_{mag}$

$\oint_L \vec{H} \cdot d\vec{l} = \int_A \vec{J}_{pr} \cdot d\vec{a}$

$\oint_L \vec{B} \cdot d\vec{a} = \mu_0 \int_A \vec{J} \cdot d\vec{a} = \mu_0 I_{skozi\ A\ na\ L}$

$\oint_L \vec{M} \cdot d\vec{l} = I_{mag}$

TOKI MAGNETIZACIJE = AMPEROVI TOKI

$\oint_L \left(\frac{\vec{B}}{\mu_0} - \vec{M}\right) \cdot d\vec{l} = I - I_{mag} = I_{prosti}$

MAGNETNA POLARIZACIJA

$H = \frac{\vec{B}}{\mu_0} - \vec{M} \Rightarrow \boxed{B = \mu_0(\vec{H} + \vec{M})} = \mu_0 H + \vec{I}$

$\boxed{\oint_L \vec{H} \cdot d\vec{l} = \int_L \vec{J}_{prosti} \cdot d\vec{a} = I_{prosti\ skozi\ A\ na\ L}}$

24.3.11 ELEKTRIČNO POLJE

! $P \propto E$!

$\vec{P} = \varepsilon_0 \chi_e \vec{E}$

$\vec{D} = \varepsilon_0 \underbrace{(1 + \chi_e)}_{\varepsilon_r} \vec{E}$

ε

$\vec{D} = \varepsilon E = \varepsilon_0 \varepsilon_r \vec{E}$

MAGNETNO POLJE

Če je snov linearna (ali vsaj nelinearna ...):

!! $\vec{M} \propto \vec{B}, \vec{H}$!!

$\vec{M} = \chi_m \vec{H}$

$\vec{B} = \mu_0 \underbrace{(1 + \chi_m)}_{\mu_r} \vec{H}$

μ

$\vec{B} = \mu_0 \mu_r \vec{H} = \mu \vec{H}$

MAGNETIKI

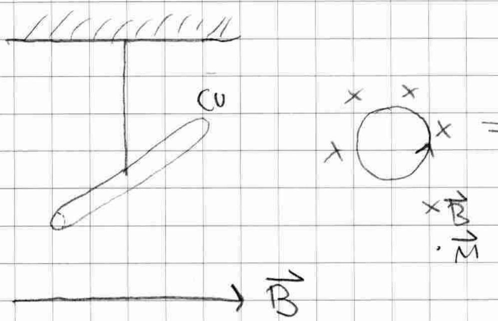
1.) Diamagnetiki (baker, srebro, zlato, voda) , 2.) Paramagnetiki (aluminij, [illegible]) 3.) Feromagnetiki (železo, kobalt, nikelj)
26, 27, 28

1. DIAMAGNETIKI

Snovi katerih atomi, kot skupek delcev ne izkazuje rezultančnega dipolnega momenta ⇒ nimajo rezultančnega dipolnega momenta (paramagnetiki ga imajo)

Poleg dipolnega odziva tudi magnetni odziv

DIA – prečno, PARA – vzdolžno – postavijo se vzdolž, tudi FERO se postavi vzdolž
FERO – železa



Vsak delec se še dodatno giblje zaradi tega magnetnega polja ⇒ zanka je v labilni legi

$\vec{M} \cdot \vec{B} < 0$

$\chi_m \sim -10^{5}$

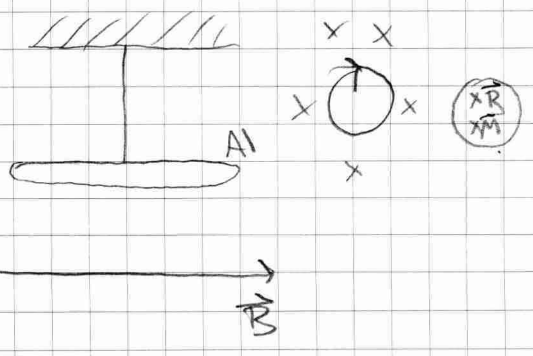
$\mu_r = 1 + \chi_m \approx 0,999xxx$

Vektor. nasproten izvornemu polju. Skalarni produkt negativen.
χ_m – magn. susceptibilnost majhna in negativna

2. PARAMAGNETIKI

Snovi, katerih atomi izkazujejo dipolni moment.

Zanke se postavijo v smer mag. polja, zavzamejo stabilno lego



$\vec{M} \cdot \vec{B} > 0$

$\chi_m \simeq +10^{-5}$

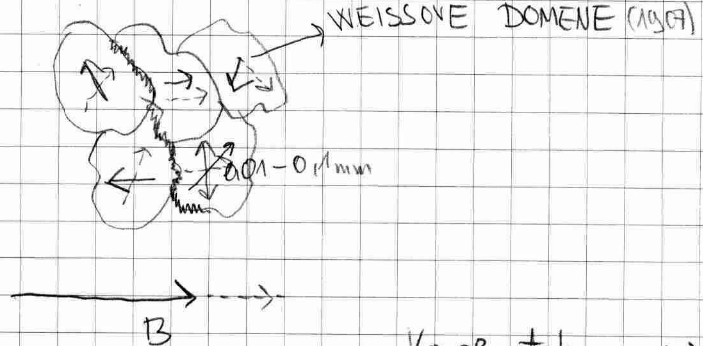
$\mu_r = 1 + \chi_m = 1,0000xx\ldots$

Dia in paramagnetiki so magnetno presevljivi. Mag. polje se spremeni, če je žica jeklena ipd.

3. FEROMAGNETIKI

Polarizirani paramagnetiki ⇒ Feromagnetiki

$Fe = 2 + 8 + 14 + 2$ (K L M N)

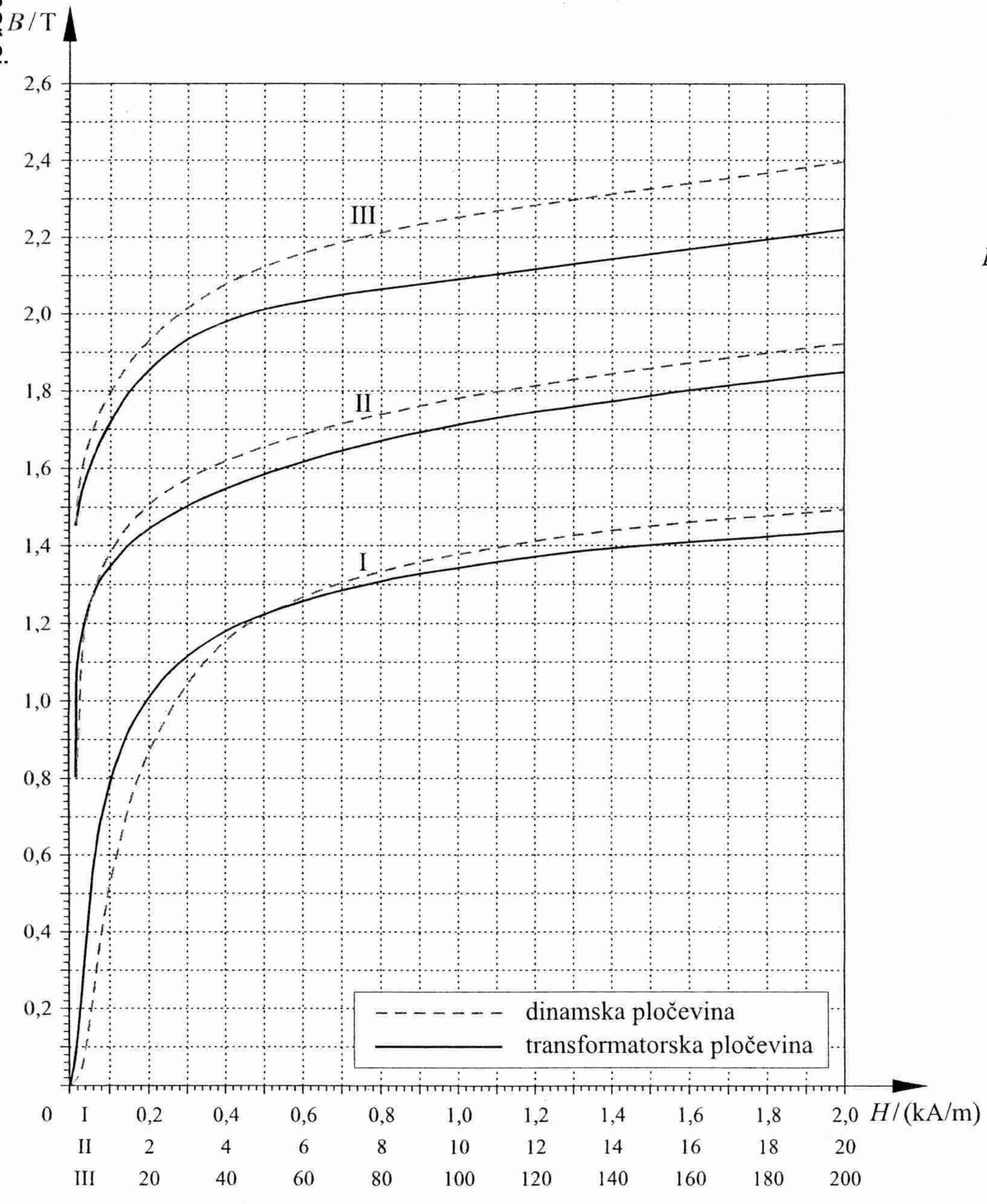


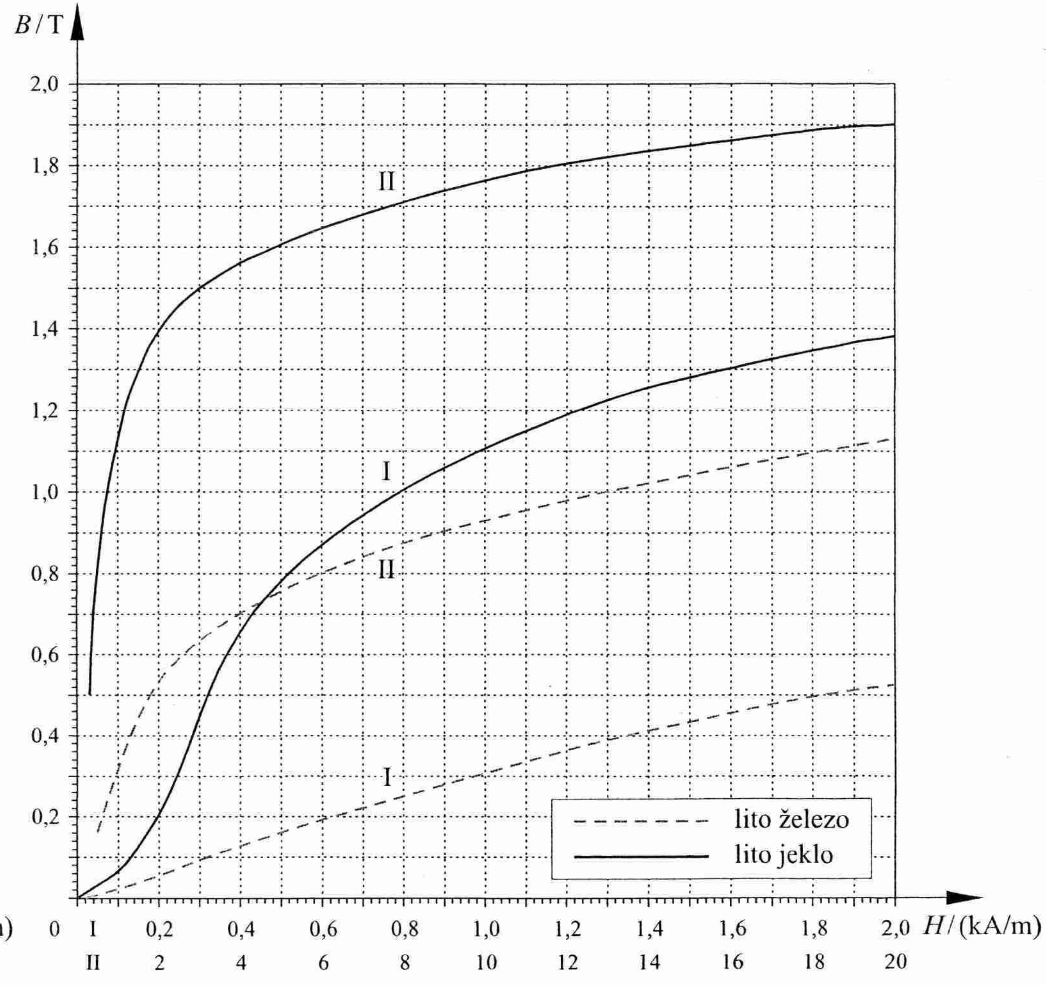
Gruče atomov se razporejajo v Weissovih domenah. Gruče reda velikosti 0,01 ÷ 0,1 mm

Atomi imajo na teh področjih isto orientacijo magnetizacije

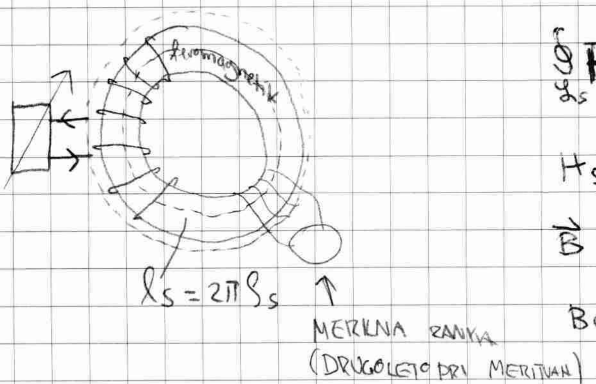
Ko se taka snov izpostavi mag. polju, potem se dogaja obračanje domen v smer magn. polja

Začetne krivulje magnetenja za mehke magnetne materiale





MERJENJE MAGNETILNIH KRIVULJ



$$\oint_{l_s} \vec{H} \cdot d\vec{l} = \underbrace{2\pi\rho_s}_{l_s} H_s = N I \quad \rightarrow \text{Merljivo}$$

$$H_s = H = \frac{NI}{l_s}$$

$$\vec{B} = \mu_0(\vec{H} + \vec{M})$$

$$B_\varphi = \mu_0(H_\varphi + M_\varphi) \; - - - - \; B_s = \mu_0 H_s + \mu_0 M_s$$

$$\Rightarrow B = \mu_0 H + \mu_0 M$$

1.) ZAČETNA (DEVIŠKA) MAGNETILNA KRIVULJA

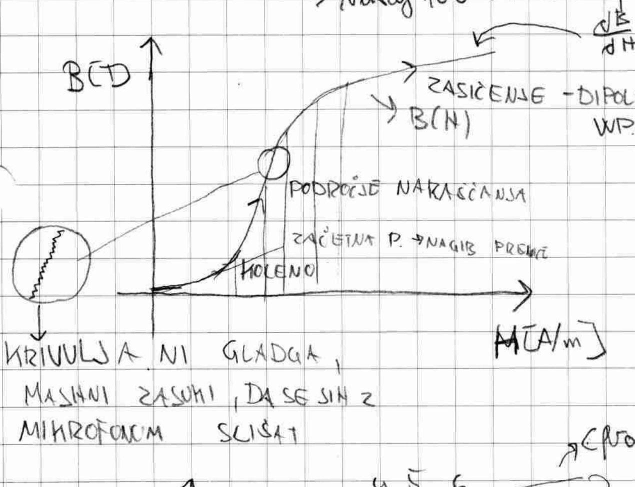
BH krivulja (glej lit.) ⇒ Dobljene pri predhodnem razmagnetenju

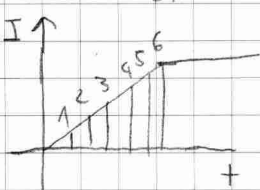
(Preprost način za Kirijevo temperaturo → Segrejemo železo nad 770°C in ohladimo, dobimo razmagneteno železo).

Začela je razmagnetena ⇒ $M = 0$

$$\vec{M} = \lim \frac{\sum \delta \vec{m}}{\delta V}$$

↳ Nekaj 100 Weissovih področij

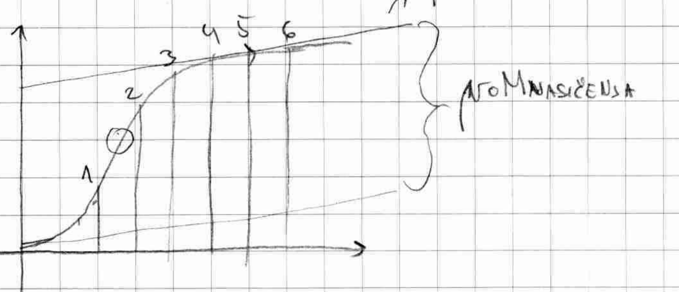




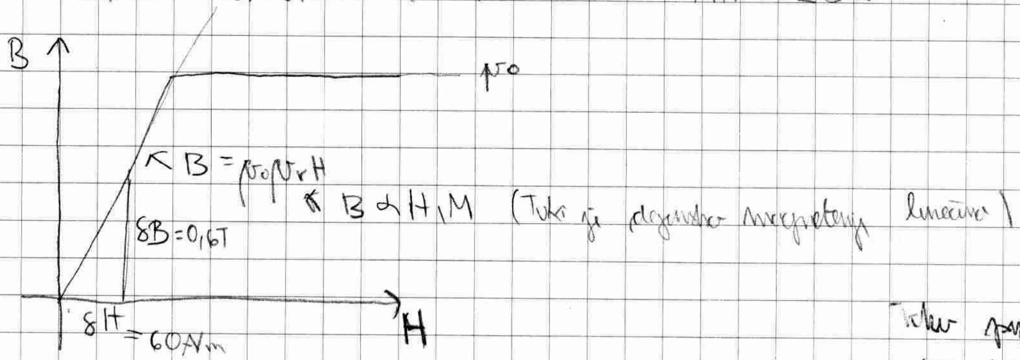
Začetna krivulja dobimo tako, da tok iz 0 počasi dvigujemo (monotono) (stalno počasi naraščal)

⇒ Monotono se dviguje tok H in potem B itd.

Pozor! Počasi dvigujemo tok, da ne izzivamo indukcije, ki bi meritve pokvarila



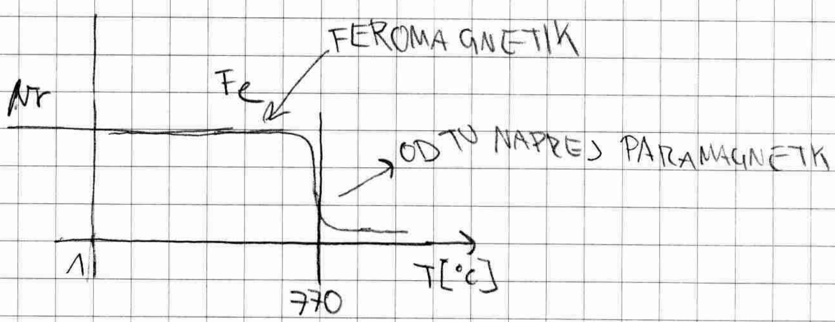
2. LINEARIZACIJA MAGNETILNE KRIVULJE



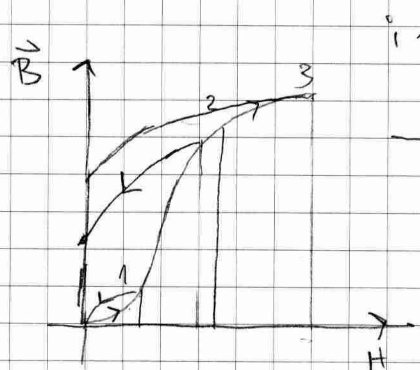
Tukaj zapišemo 10-tinko, ne štola pa prekrpecija Weissove ploskve
⇒ So seveda tudi določene izgube

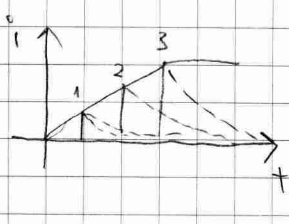
$$\mu_0 \mu_r = \frac{\delta B}{\delta H} \cong 10^{-2} \rightarrow \mu_r = \frac{10^{-2}}{4\pi \cdot 10^{-7}} = \simeq 8000$$

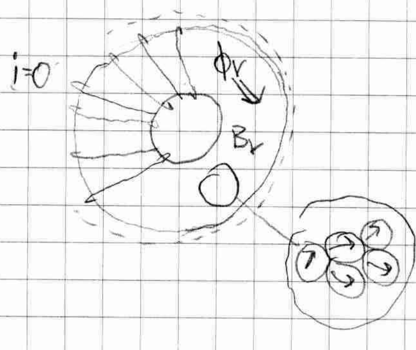
3. COURIJEVA TEMPERATURA



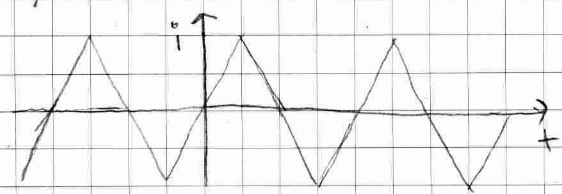
4. REMANENTNA GOSTOTA (PREOSTALA GOSTOTA)



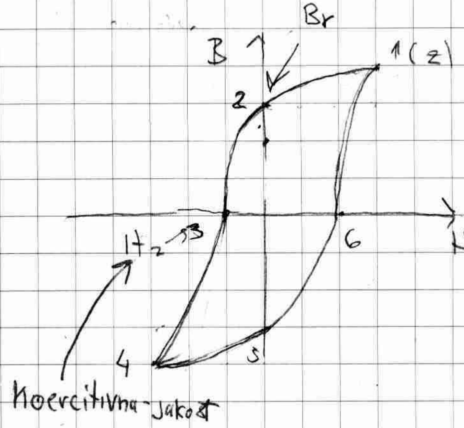




5.) HISTEREZNA ZANKA



i - periodični tok

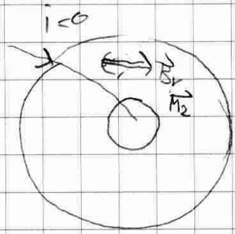


[T2]:

$B_2 = \mu_0 H_2 + \mu_0 M_2$

$H_2 = 0$

$B_2 = \mu_0 M_2$

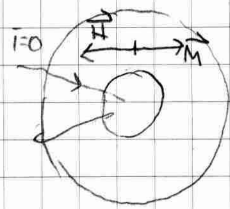


[T3]:

$B_3 = \mu_0 H_2 + \mu_0 H_3$

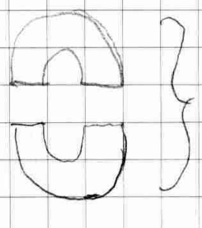
$B_3 = 0$

$H_3 = -M_3$

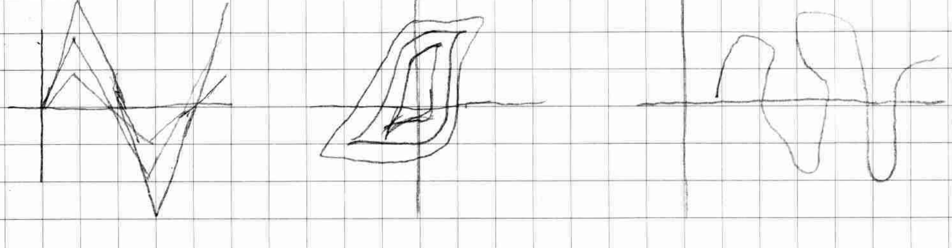


$H_e \sim 10$ A/m – MEHKOMAGNETNI MATERIALI
$H_e \sim 10^5$ A/m – TRDOMAGNETNI MATERIALI

→ Trajni magneti

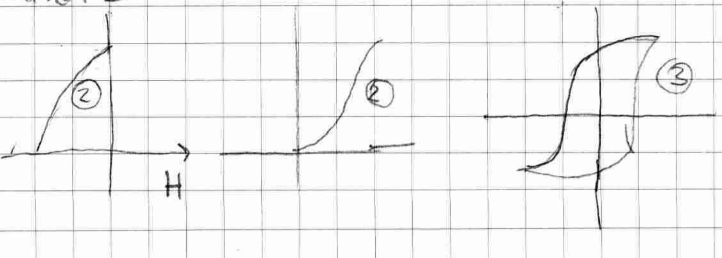


} Prežagan toroid ⇒ Trajni magnet



Magnetilni krivulji je nesimetrično

TRAJNI MAGNET B

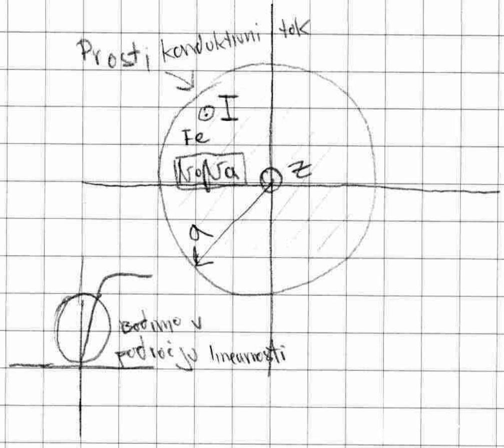


Te tri krivulje so pomembne za mag. materiale

Pomembna je krivulja

Kako smo prišli do teg..

ZGLED: MAGNETNO POLJE V/OB JEKLENEM VODNIKU KROŽNEGA PREREZA



$$\oint_L \vec{M}\cdot d\vec{l} = \int_A \vec{J}_{prosti}\cdot d\vec{a}$$

$$\vec{B} = (0, B_\varphi, 0) \rightarrow \vec{M} = (0, M_\varphi, 0), \quad \vec{H} = (0, H_\varphi, 0)$$

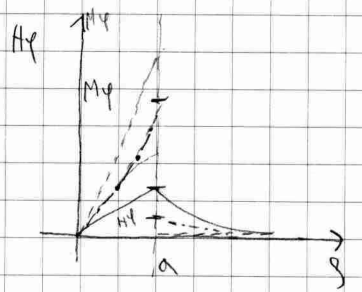
L: Krožnica okoli z-osi polmera $\rho \lesseqgtr a$

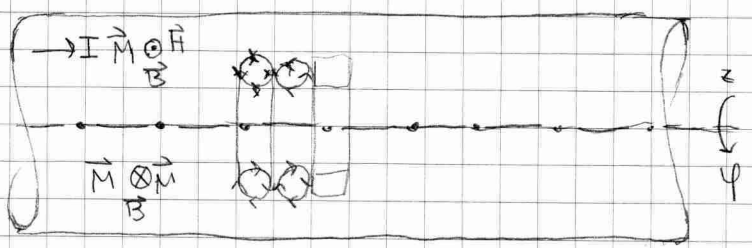
$$\oint_L \vec{M}\cdot d\vec{l} = 2\pi\rho H_\varphi = \begin{cases} \frac{I}{\pi a^2}\pi\rho^2, & \rho \leq a \\ I, & \rho > a \end{cases}$$

$$H_\varphi = \begin{cases} \frac{I}{2\pi a^2}\rho, & \rho < a \\ \frac{I}{2\pi\rho}, & \rho > a \end{cases}$$

$$B_\varphi = \mu_0\mu_r H_\varphi = \begin{cases} \frac{\mu_0\mu_r I}{2\pi a^2}\rho, & \rho < a \\ \frac{\mu_0 I}{2\pi\rho}, & \rho > a \end{cases}$$

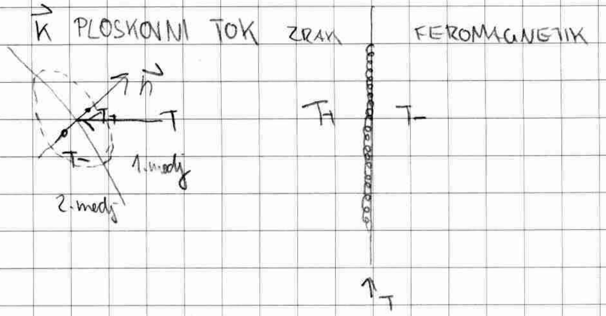
$$M_\varphi = \chi_0 H_\varphi = (\mu_r - 1) H_\varphi = \begin{cases} \frac{(\mu_r - 1) I}{2\pi a^2}\rho, & \rho < a \\ 0, & \rho > a \end{cases}$$





$$B_\varphi = \frac{\mu_0\mu_r I}{2\pi a^2}\rho = \underbrace{\frac{\mu_0 I}{2\pi a^2}\rho}_{\text{Mag. polje zaradi toka v žici}} + \underbrace{\frac{(\mu_r - 1) I\mu_0}{2\pi a^2}\rho}_{\text{Mag. polje zaradi ampereovih tokov}}$$

MEJNI POGOJI



$$\oint_A \vec{B}\cdot d\vec{A} = 0 \Rightarrow B_n(T_+) - B_n(T_-) = 0$$

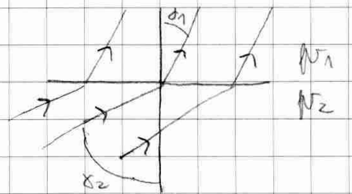
$$\oint_g \vec{H}\cdot d\vec{l} = \int_A \vec{J}_p \cdot d\vec{a} \Rightarrow \vec{n}\times\left[\vec{H}(T_+) - \vec{H}(T_-)\right] = \vec{K}_p(T)$$

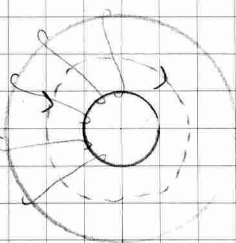
$$H_{\tau 1}(T_+) - H_{\tau 1}(T_-) = K_{\tau 2}(T)$$
$$H_{\tau 2}(T_+) - H_{\tau 2}(T_-) = K_{\tau 1}(T)$$

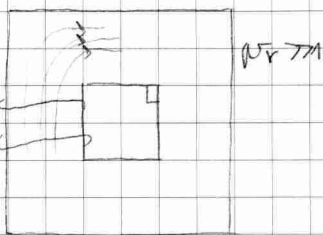
POSEBEN PRIMER: MEJA BREZ OBLOGE

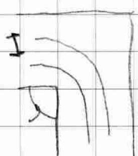
$$\left.\begin{array}{l} B_n(T_+) = B_n(T_-) \\ H_\tau(T_+) = H_\tau(T_-) \end{array}\right\} \quad \boxed{\frac{\tan\alpha_1}{\tan\alpha_2} = \frac{\mu_1}{\mu_2}}$$

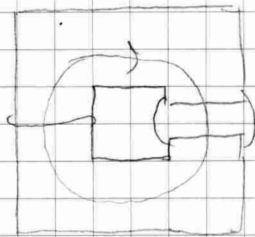
$$\frac{\tan\alpha_1}{\tan\alpha_2} = \frac{\gamma_1}{\gamma_2}$$





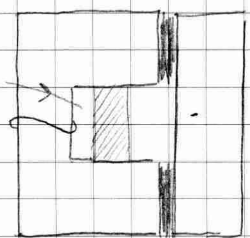






STRESANO POLJE

Namenoma ne vezje



RABIMO SAMO EL TOK ZA SPROSTITEV

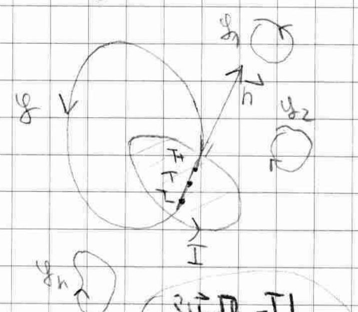
31.3.11

MAGNETNI POTENCIAL IN MAGNETNA NAPETOST

$\oint_g \vec{E}\cdot d\vec{l} \Rightarrow \vec{E} = -\vec{n}\frac{\partial V}{\partial n}$, $V(T) =$

$V(T) = \int_T^{T_\infty} \vec{E}\cdot d\vec{l}$, $U_{12} = \int_{T_1}^{T_2} \vec{E}\cdot d\vec{l}$

$\oint_g \vec{H}\cdot d\vec{l}$ = objeti tok!



Če se dogovorimo, da so zanke g takšne, da zanke g ne prestopijo, potem velja:

$\oint_g \vec{H}\cdot d\vec{l} = 0$

⇒ Vpeljemo količino, ki jo imenujemo

SKALARNI MAGNETNI POTENCIAL V_m,

da velja:

$\oint \vec{H}\cdot d\vec{l} = I$!

T+ x T-

$V_m(T+) - V_m(T-) = I$

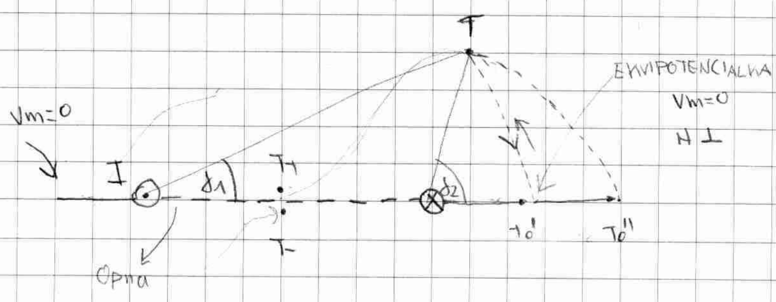
$$\boxed{H = -\vec{n}\frac{\partial V_m}{\partial n}} \quad \boxed{V_m(T) = \int_T^{T_\infty} \vec{H}\cdot d\vec{l}} \quad \boxed{U_{m12} = \int_{T_1}^{T_2} \vec{H}\cdot d\vec{l} = \Theta_{12}}$$

To smo izvedli brez kakršne fizikalne podlage. Samo zato, da zelo lahko računamo mag. veličine si predstavljamo

Funkcija potenciala mg. je NEZVEZNA ob tej opni

ZGLEDI:

1.) DVOVOD DVEH TANKIH ŽIC (glavnina prostora brez toka)



$V_m(T_0') = V_m(T_0'')$

$V_m(T) - V_m(T_0') = \int_T^{T_0'} \vec{H}\cdot d\vec{l} = \underbrace{\int_T^{T_0'} \vec{H}_1 d\vec{l}}_{-\frac{I}{2\pi}\alpha_1} + \underbrace{\int_T^{T_0'} \vec{H}_2 d\vec{l}}_{\frac{I}{2\pi}\alpha_2}$

$= \frac{I}{2\pi}\overbrace{(\alpha_2 - \alpha_1)}^{\alpha}$

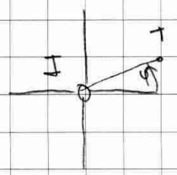
$= \frac{I}{2\pi}\alpha$

$$\boxed{V_m(T) = \frac{I}{2\pi}\alpha}$$

$V_m(T+) = \frac{I}{2\pi}\pi = \frac{I}{2}$

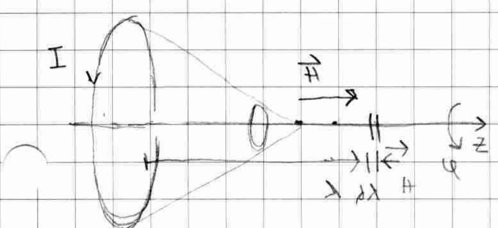
$V_m(T-) = \frac{I}{2\pi}(-\pi) = -\frac{I}{2}$

POTENCIAL ENE ŽICE



$$V_m(T) = \frac{-I}{2\pi}\varphi + C$$

2.) POTENCIAL V OSI KROŽNEGA OVOJA

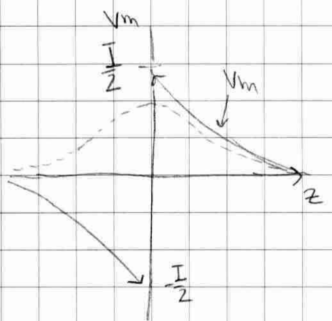


$$V_m(T) = \int_T^{T_\infty} \vec{H} \cdot \vec{dl}\,, \qquad H_z = \frac{B_z}{\mu_0} = \frac{I}{2}\frac{a^2}{(a^2+z^2)^{3/2}}$$

$$V_m(T) = \int_z^{\infty} \frac{I}{2}\frac{a^2}{(a^2+z^2)^{3/2}}\, d\lambda$$

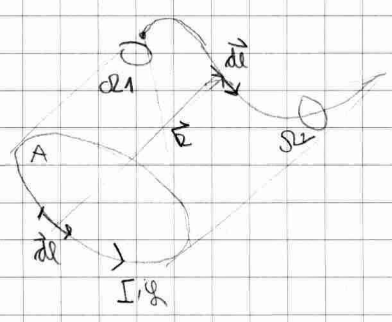
$$= \frac{Ia^2}{2}\left[\frac{\lambda}{a^2\sqrt{a^2+\lambda^2}}\right]_z^{\infty} = \frac{I}{2}\left(1 - \frac{z}{\sqrt{a^2+z^2}}\right)$$

$\cos\gamma$; $\frac{\Omega}{2\pi}$



$$V_m(T) = \frac{I}{4\pi}\Omega$$

3. POTENCIAL V OKOLICI TOKOVNE ZANKE

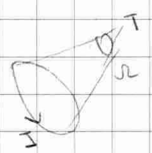


$$V_m(T_1) - V_m(T_2) = \int_{T_1}^{T_2} \vec{H}\,\vec{dl} = \int_{T_1}^{T_2}\left(\frac{I}{4\pi}\oint \frac{\vec{dl}' \times \vec{R}}{R^3}\right)\cdot \vec{dl} = \ldots$$

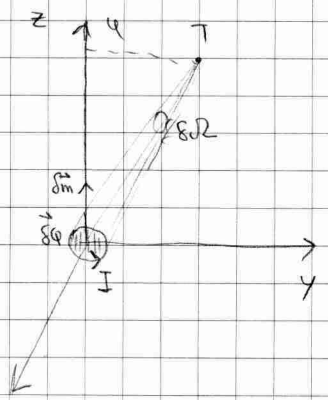
$$= \frac{I}{4\pi}(\Omega_1 - \Omega_2)$$

$T_2 \to T_\infty$, $V_m(T_\infty) = 0$

$$V_m(T) = \frac{I}{4\pi}\Omega$$



4.) MAGNETNO POLJE MAGNETNEGA DIPOLA (TOKOVNE ZANKICE)



$$\delta V_m = \frac{I}{4\pi}\delta\Omega$$

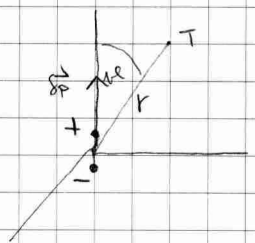
$$= \frac{I}{4\pi}\delta\Omega_{max}\cos\vartheta = \frac{I}{4\pi}\frac{\delta a}{r^2}\cos\vartheta =$$

$$\frac{I\delta a}{4\pi}\frac{\cos\vartheta}{r^2}$$

$$\delta H_r = -\frac{\partial}{\partial r}\delta V_m$$

$$\delta H_\vartheta = -\frac{1}{r}\frac{\partial}{\partial \vartheta}V_m$$

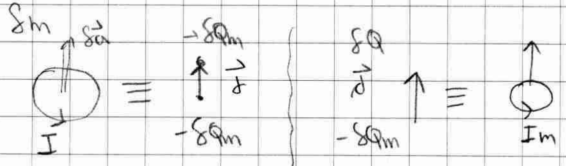
* EL. DIPOL



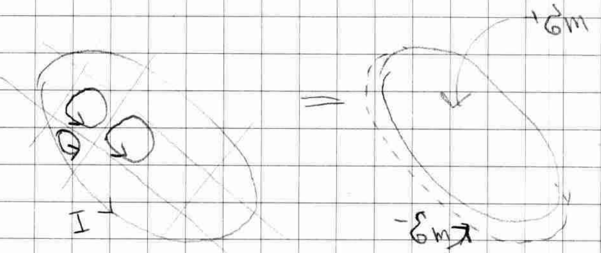
$$\delta V = \frac{\delta p}{4\pi\varepsilon_0}\frac{\cos\vartheta}{r^2}$$

$$\delta E_r = -\frac{\partial}{\partial r}\delta V$$

$$\delta E_\vartheta = -\frac{1}{r}\frac{\partial}{\partial\vartheta}\delta V$$



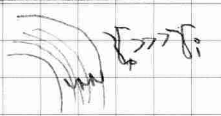
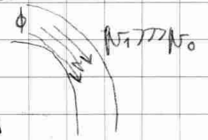
$$I\delta\vec{a} = \delta Q_m \vec{d}$$



Zanko lahko razumemo kot dogaji sloj magnetnih

MAGNETNA VEZJA

DUALNOST TOKOVNEGA IN MAGNETNEGA POLJA

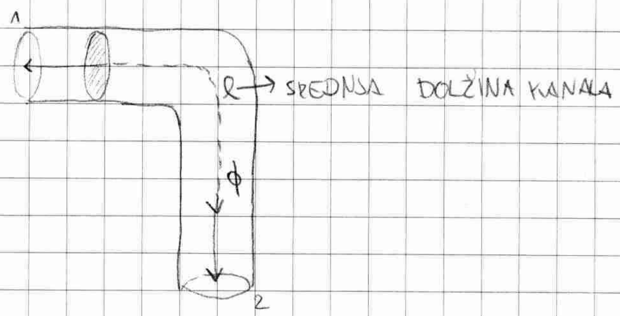
Tokovno polje	Magnetno polje
$\vec{J}$, $I = \oint_A \vec{J} \cdot d\vec{a}$, $\oint_A \vec{J} \cdot d\vec{a} = 0$ ⇓ $J_n(T+) = J_n(T-)$, $\sum (\pm) I_h = 0$	$\vec{B}$, $\phi = \oint_A \vec{B} \cdot d\vec{a}$, $\oint_A \vec{B} \cdot d\vec{a} = 0$ ⇓ $B_n(T+) = B_n(T-)$, $\sum (\pm) \phi_k = 0$
$\oint_L \vec{E} \cdot d\vec{l} = 0$, ... -11-, V, U, ... $\sum (\pm) U_l = 0$, $E_t(T+) = E_t(T-)$	! $\oint_L \vec{H} \cdot d\vec{l} = 0$! ..., V_m, Θ, ... $\sum (\pm) \Theta_l = 0$, $H_t(T+) = H_t(T-)$
$\vec{J} = \gamma \vec{E}$ ↳ „spec. el. prevodnost" 	$\vec{B} = \mu \vec{H}$ MAGNETNI OHMOV ZAKON ↳ „specifična magnetna prevodnost" 

⇓ ELEKTRIČNA VEZJA

⇓ MAGNETNA VEZJA

ELEMENTI MAGNETNIH VEZIJ

- MAGNETNI UPOR

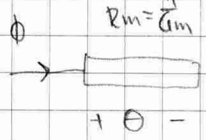


$\Theta_{12} = \int_1^2 \vec{H} \cdot d\vec{l} = Hl$!

$\phi = \int_A \vec{B} \cdot d\vec{a} = BS$

1.) LINEAREN UPOR

$\vec{B} = \mu H$
└ permeabilnost kanala

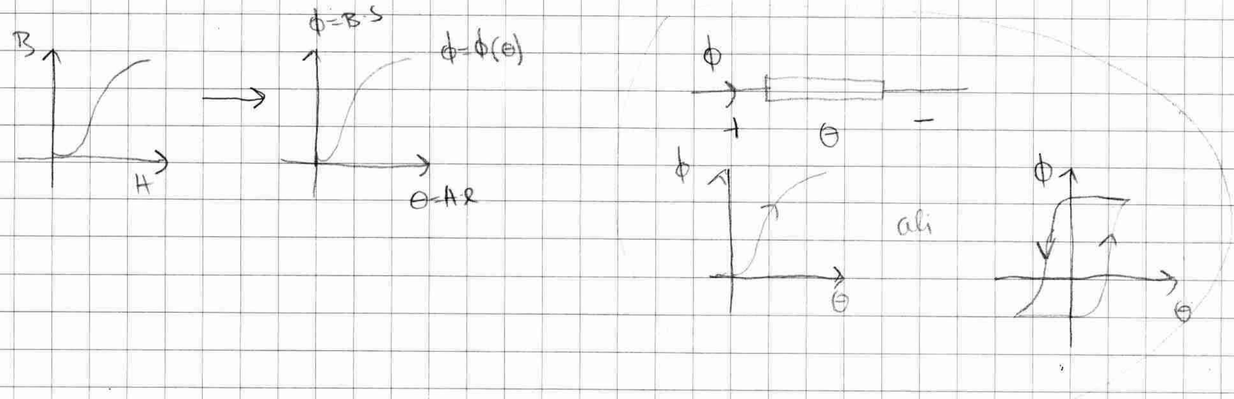


$\Theta = R_m \phi$

$R_m = \frac{\Theta_{12}}{\phi} = \frac{Hl}{\mu HS} = \frac{l}{\mu S}$ $\left(R = \frac{l}{\gamma S}\right)$

2.) NELINEAREN UPOR

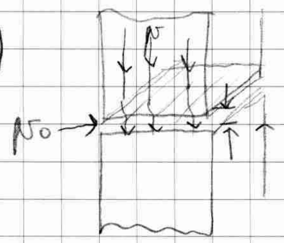
Odnos H in B → MAGNETILNA KRIVULJA (deviška in histereza)



3.) UPORNOST ZRAČNE REŽE

$\vec{B}=\mu_0\vec{H}$ $(\vec{J}=\gamma\vec{E})$

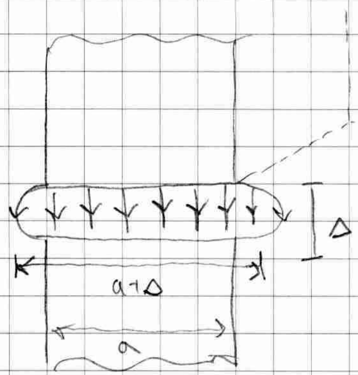
$\vec{B}=\mu_0\vec{H}$



Špranja je lahko nekaj kotnega ali pa nekaj paralitnega

$$R_m=\frac{\Delta}{\mu_0 S}$$

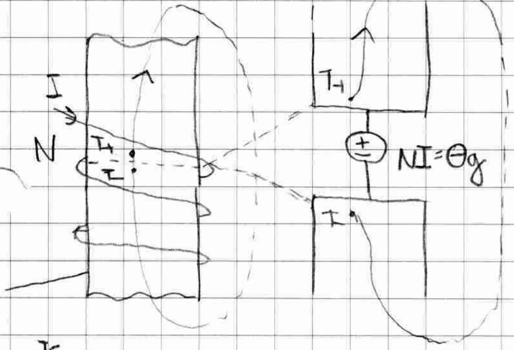
CARTERJEV FAKTOR

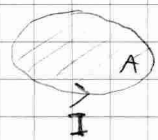


$$R_m=\frac{\Delta}{\mu_0(a+\Delta)^2}=\frac{\Delta}{\mu_0 a^2}\frac{1}{(1+\frac{\Delta}{a})^2}=C$$

$$R_m=\frac{\Delta}{\mu_0 a^2}\cdot C$$

- VIR MAGNETNE NAPETOSTI



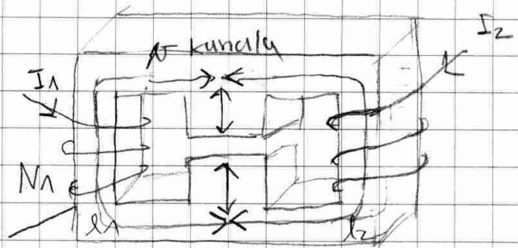


$$\int_{T-}^{T+}\vec{H}\cdot\vec{dl}=NI$$

$V_m(T+)-V_m(T-)=NI=\Theta$

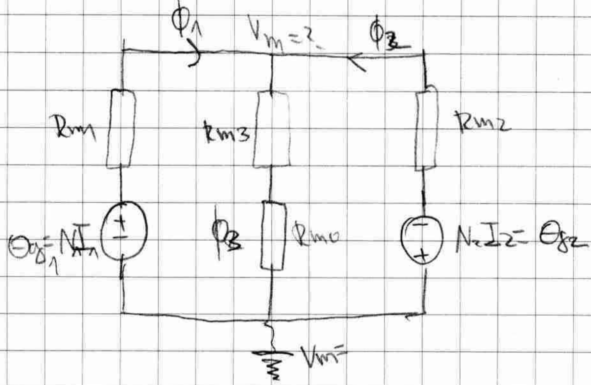
PREPROSTO NELINEARNO VEZJE BO NA KOLOKVIJU

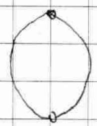
ZGLED: (iz knjige)



$$R_{m3} = \frac{l_3}{\mu S} \quad , k = 1,2,3$$

$$R_{m0} = \frac{\Delta}{\mu_0 S}$$





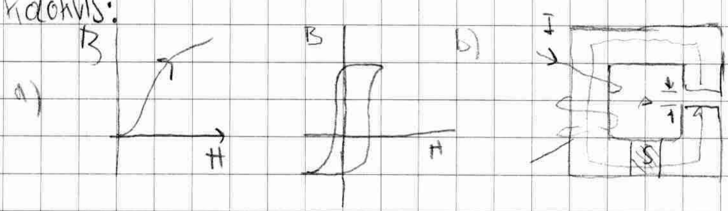
$$\phi_1 + \phi_2 + \phi_3 = 0$$

$$\frac{\Theta_{g1} - V_m}{R_{m1}} + \frac{\Theta_{g2} - V_m}{R_{m2}} + \frac{0 - V_m}{R_{m3} + R_{m0}} = 0$$

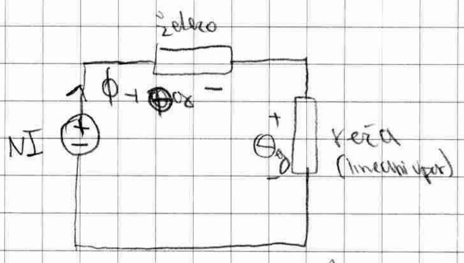
$\Rightarrow V_m \rightarrow \phi_k$

NELINEARNO MAGNETNO VEZJE

ZA KOLOKVIJ:

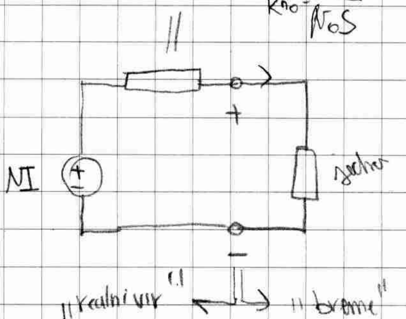


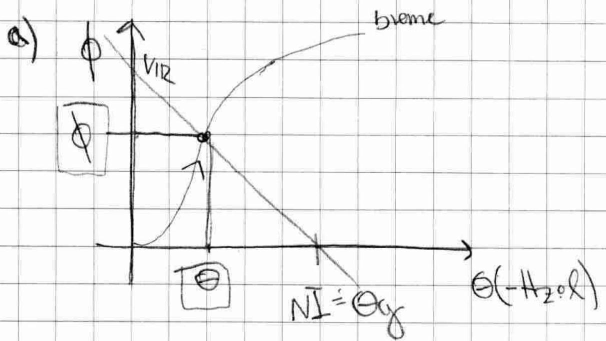
} KOLOKVIJ

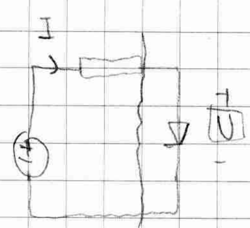


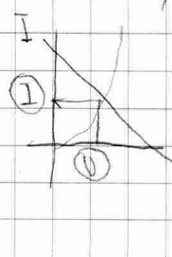
$-NI + R_m \phi + \Theta = 0$	VIR
$\Theta = \Theta(\phi) \rightarrow \phi = \phi(\Theta)$	BREME

$$R_{m0} = \frac{\Delta}{\mu_0 S}$$

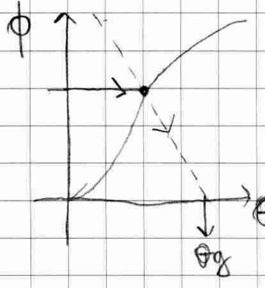






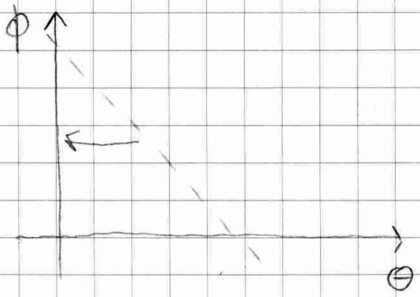


a1) želimo ϕ

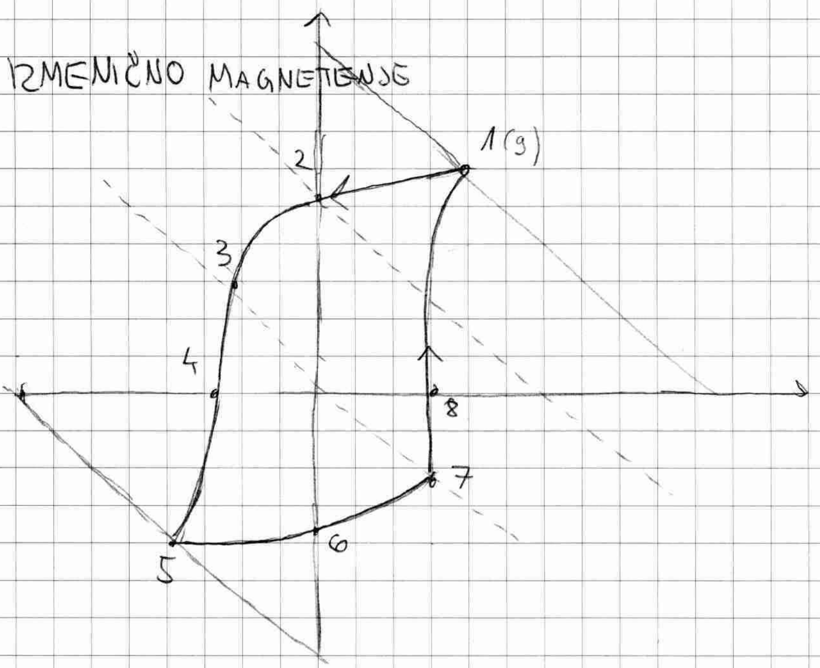


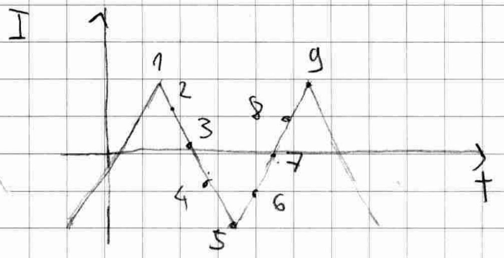
$$\frac{\delta\phi}{\delta\Theta} = \frac{1}{R_{oz}} = G_{oz}$$

a2) imam Θ_g iščem ϕ

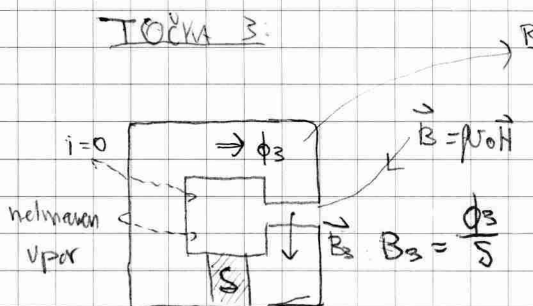


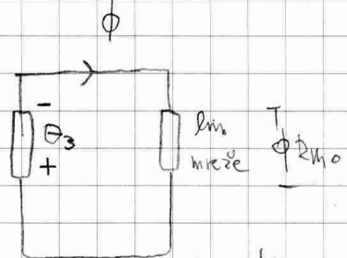
B.) IZMENIČNO MAGNETENJE





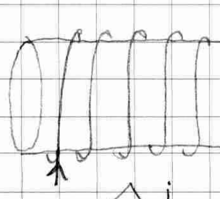
TOČKA 3:

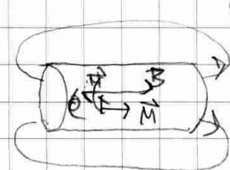


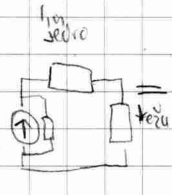


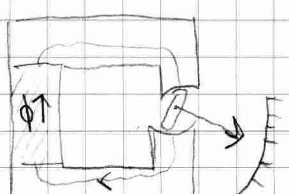
$$\Theta_3 + \phi R_{m_0} = 0$$

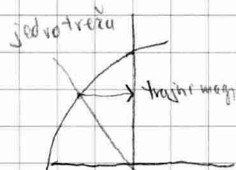
$$\Theta_3 = -R_m \cdot \phi$$











Kamenino predmet ne ga vržemo – Ali znamo ob tem meti prevedeti teg v ELM

7.4.M

DINAMIČNO POLJE

3.M $\oint_{\mathcal{L}} \vec{E}\,d\vec{l} = 0 \quad \left(= -\frac{d\phi_{\mathcal{L}}}{dt}\right)$ — $-\frac{d}{dt}\int_A \vec{B}\cdot d\vec{a}$

Ta nadgradnja je prideleh FARADAYA – 1831

Rodil se je

4.M $\oint_{\mathcal{L}} \vec{H}\cdot d\vec{l} = \int_A \vec{J}_P\,d\vec{a} \quad \left(+\int_A \frac{\partial \vec{D}}{\partial t}\cdot d\vec{a}\right)$ — $\frac{d\phi_e}{dt}$

$\varepsilon_0 \frac{\partial \vec{E}}{\partial t} + \frac{\partial \vec{P}}{\partial t}$

MAXWELL [1873]

Ubistvu je prideleh FARADAYA ZAPISAL MAXWELL

Svetloba je magnetno polje
Hertz potrdil da se da energijo da prepeljat iz enega na drugo mesto brez fizične povezave

$F_L = Q(\vec{E} + \vec{w}\times\vec{B})$ → Kako polje energija vpliva na drugega – FARADAY to MAXWELLU

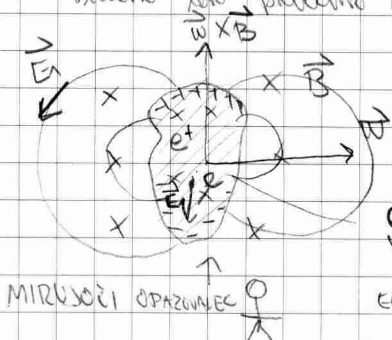
nasprotna dva zaradi razmisleka o polju in matematično zapiše → Prestok → Mat. zapis, potem šele eksperiment

24.11

FARADAYEVA – ELEKTROMAGNETNA INDUKCIJA

Vlečeno telo – prevodno telo

Prevodnik se giblje čez magnetno polje. Sila deluje na protone, ampak ti ne morejo nikamor



$\vec{F}_m = Q(\vec{w}\times\vec{B})$

$Q\vec{E}_1 + Q\vec{w}\times\vec{B} = \vec{0}$

EL. SILA — MAGN. SILA

$\Rightarrow \vec{E}_1 = -\vec{w}\times\vec{B}$

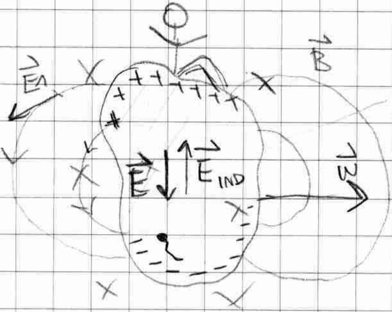
Enak pojav kot pri EL. INFLUENCI

$\vec{E} = \vec{E}_0 + \vec{E}_1 = \vec{0}$

$\vec{E}_0 = -\vec{E}_1$

$Q(\vec{E}_0 + \vec{E}_1) = 0$

GIBAJOČI OPAZOVALEC



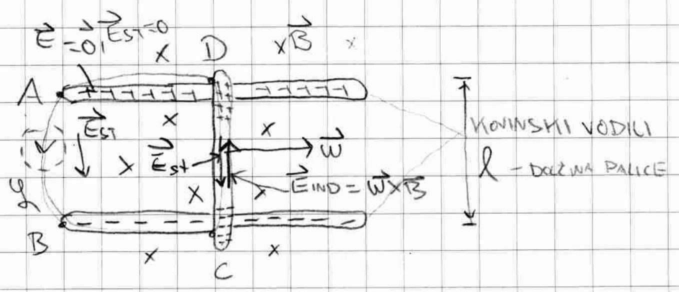
$Q(\vec{E}_1 + \vec{E}_{IND}) = \vec{0}$ — $\vec{E}$

$\vec{E}_1 = -\vec{E}_{IND}$

$\vec{E}_{IND} \equiv \vec{w}\times\vec{B}$ → Če združimo oba opazovalca

LINEARNI GENERATOR

7.4.11

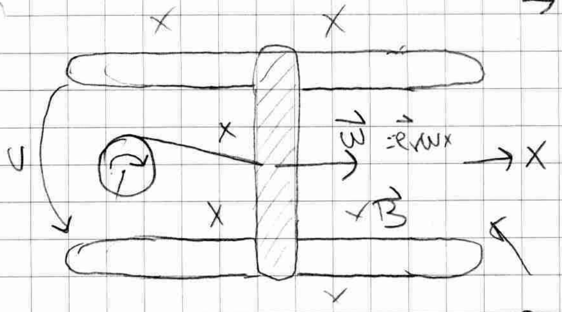


COLOUMBOVA POLJSKA JAKOST

$$\vec{E} = \vec{E}_{ST} + \vec{E}_{IND} = \vec{E}_{COL} + \vec{E}_{FAR}$$ → FARADAYEVA POLJSKA JAKOST

$$\oint_{\mathcal{L}} \vec{E}_{ST} \cdot \vec{dl} = \underbrace{\int_A^B \vec{E}_{ST} \cdot \vec{dl}}_{U} + \underbrace{\int_B^C \vec{E}_{ST} \cdot \vec{dl}}_{\emptyset} + \underbrace{\int_C^D \vec{E}_{ST} \cdot \vec{dl}}_{= -\int_C^D (\vec{w} \times \vec{B}) \cdot dl} + \underbrace{\int_D^A \vec{E}_{ST} \cdot \vec{dl}}_{\emptyset} = 0$$

$\rightarrow = -wBl \Rightarrow U - wBl = 0 \Rightarrow \boxed{U = wBl}$

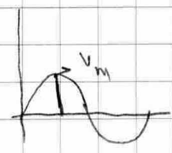


$U = \vec{w} \times Bl$

$U(t) = w_x(t) Bl$

exp ⇒ $W_x = W_{max} \cos(\omega t + \gamma)$

$\Rightarrow U_t = \underbrace{W_{max} Bl}_{U_{MAX}} \cos(\omega t + \gamma)$



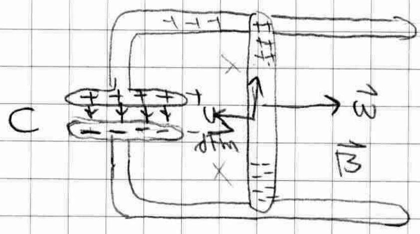
NAPETOST MED TOČKAMA - SMER

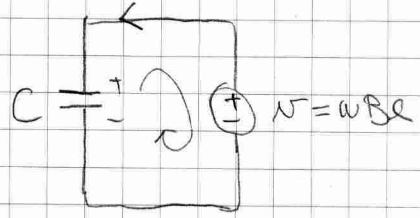
LAHKO PREDSTAVIMO KOT HARMONIČNI GENERATOR

$U(t) = V_m \cos(\omega t + \vartheta)$

↓ Amplituda; „začetni kot"

OBREMENJENI VIR





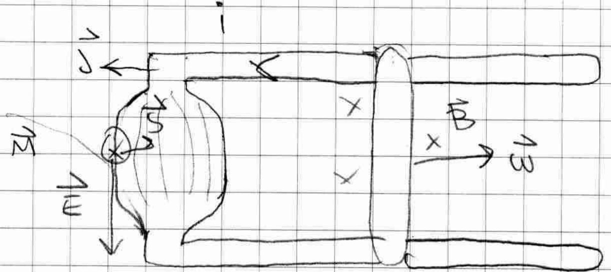
$\oint \vec{E}_{IND} \cdot \vec{dl}$

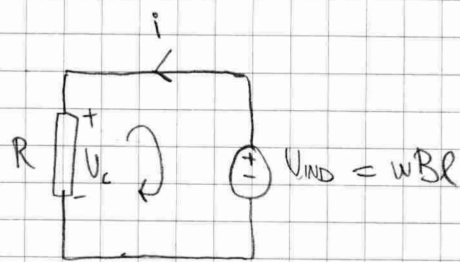
$i = C \frac{du_c}{dt} = C \frac{du_{ind}}{dt}$

$-U_C + U_{IND} = 0 \Rightarrow U_C = U_{IND}$

$p_e = U_C i \;,\; W_e' = p_e$

$i\vec{dl} \times \vec{B} = d\vec{F}_m$



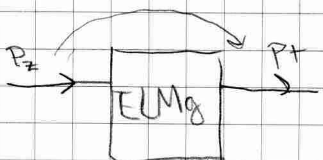


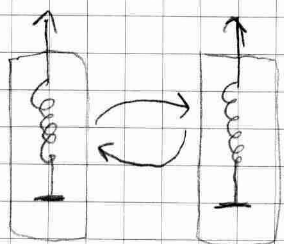
$-U_R + U_{IND} = 0 \Rightarrow \boxed{i = \frac{U_{IND}}{R}}$ ($U_R = RI$)

$|\vec{F}_m| = ilB$

$\vec{F}_z + \vec{F}_m = \vec{0} \Rightarrow |\vec{F}_z| = |\vec{F}_m| = iBl$

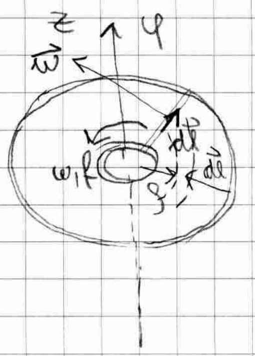
$p_z = |\vec{F}_z||\vec{w}| = iBwl = U_{IND} I = p_t$





FARADAYEV ENOSMERNI GENERATOR

11.4.11



$$(\vec{\omega} \times \vec{B}) \cdot \vec{dl}$$

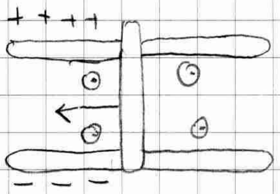
$$\vec{\omega} = (0, \omega\rho, 0) \quad \omega_\varphi$$

$$\vec{dl} = (d\rho, 0, 0)$$

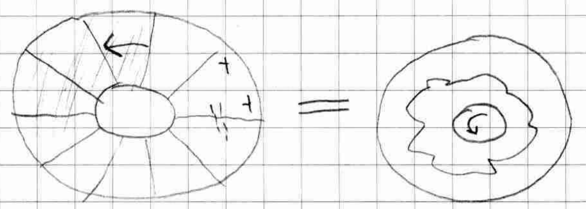
$$V_i = \int_a^b (\vec{\omega} \times \vec{B}) \cdot \vec{dl} = \int_a^b (\underbrace{\vec{dl} \times \vec{\omega}}_{e_z \omega \rho d\rho}) \cdot \vec{B}$$

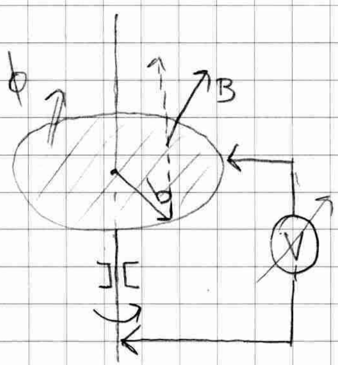
$$= \int_a^b B_z \omega \rho \, d\rho = \frac{\omega B_z (b^2 - a^2)}{2}$$

$$\boxed{V_i = \frac{\omega B_z (b^2 - a^2)}{2}}$$

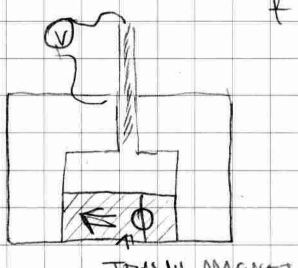


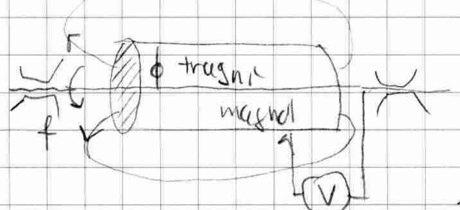
VRTEČI DISK IN KOLOBAR

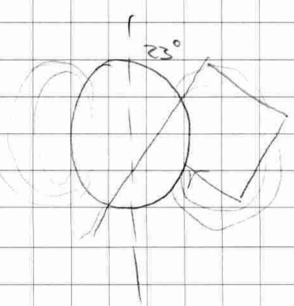




$$\boxed{U_{ind} = \frac{\omega B_z b^2}{2}} \Rightarrow \frac{\omega B_z \pi b^2}{2\pi} = \boxed{f \phi}$$

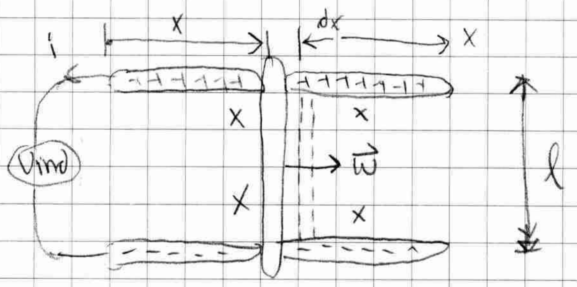






ZEMLJA

LENZOVO PRAVILO



$$U_{ind} = wBl = \frac{dx}{dt}Bl = \frac{(x+dx)Bl - xBl}{dt} = \frac{d\Phi}{dt} = -\frac{d\Phi_1}{dt}$$

$$\boxed{U_{ind} = -\frac{d\Phi_1}{dt}}$$

V zanki v katen se fluks inducira v smeri nasprotni ~~vzroku nastanka~~ fluksu v zanki.

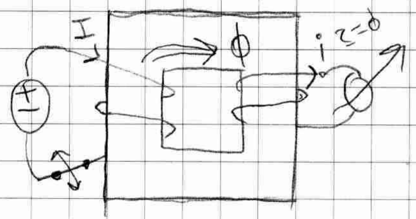
⇒ Zavira povečevanje fluksa

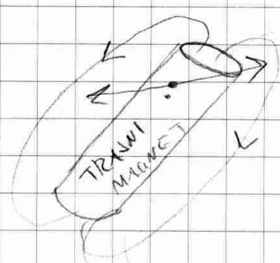
$$v = wBl = U_{ind} - \left(\oint_C (\vec{w} \times \vec{B}) \cdot d\vec{l}\right)$$

FARADAYEV INDUKCIJSKI TOK (1831)

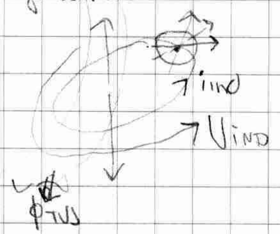
Elektroda, elektrolit - te besede Faradayev izum

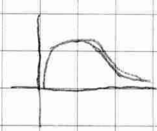
Štartna razlika je bila ob vklopu-izklopu stikala → sprememba fluksa



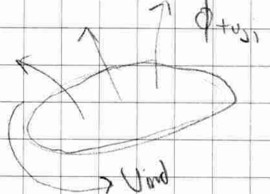


Hitreje, kot se fluks spreminja, večji so odkloni
→ Gibanje zanke



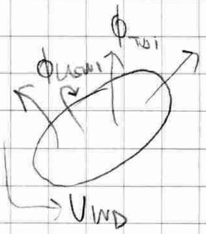


$$\boxed{U_{ind} \propto \frac{d\Phi_{tuj}}{dt}}$$



SAMOINDUKCIJA

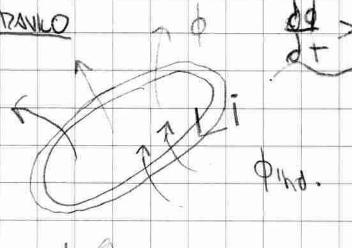
→ Henry (1852)
→ Faraday (1834)



$$U_{ind} \propto \frac{d}{dt}\left(\phi_{TUJ} + \phi_{LASTNI}\right)$$

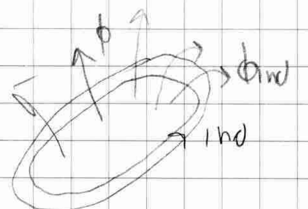
(ϕ; ϕ_{TUJ} → Medsebojna, ϕ_{LASTNI} → Lastna INDUKTIVNOST)

LENZOVO PRAVILO



$\frac{d\phi}{dt} > 0$

Reakcijski fluks se upira povečanju fluksa skozi zanko

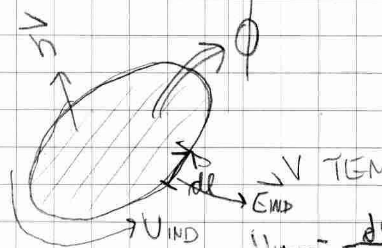


$\frac{d\phi}{dt} < 0$

NEUMANN (1845)

$|U_{ind}| = \frac{d\phi}{dt}$ ⊕ Lenzovo pravilo

$U_{ind} = \pm \frac{d\phi}{dt}$ ← ali „+" ali „−"



V TEM PRIMERU −

$U_{IND} = -\frac{d\phi}{dt}$

! Minus zaradi Lenzovega pravila in zaradi predhodnega dogovora kako smo ga označili

$$U_{ind} = \oint_{\mathcal{L}} \vec{E}_{ind} \cdot \vec{dl}$$

$$\phi = \int_A \vec{B} \cdot \vec{da}$$

$$U_{IND} = \oint_{\mathcal{L}} \vec{E}_{ind} \cdot \vec{dl} = -\frac{d}{dt}\int \vec{B}\,\vec{da} = -\frac{d\phi}{dt}$$

$$\boxed{U_{IND} = -\frac{d\phi}{dt}} \qquad \boxed{U_{IND} = \oint_{\mathcal{L}} \vec{E}_{ind}\,\vec{dl} = -\frac{d}{dt}\int \vec{B}\,\vec{da}}$$

$$\left.\begin{array}{l} \oint_{\mathcal{L}} \vec{E}_{st} \cdot \vec{dl} = 0 \\ \vec{E} = \vec{E}_{st} + \vec{E}_{ind} \end{array}\right\} \quad \boxed{\oint_{\mathcal{L}} \vec{E} \cdot \vec{dl} = -\frac{d}{dt}\int_A \vec{B} \cdot \vec{da}}$$

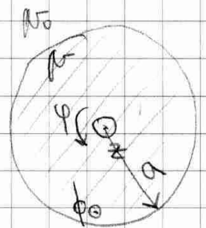
III. MAXWELLOVA ENAČBA (1867) (1831 – Faraday) → 36 let

$$\oint_L \vec{H}\cdot\vec{dl} = \int_A \vec{J}_{pr}\cdot\vec{da} + \int_A \frac{\partial \vec{D}}{\partial t}\cdot\vec{da}$$ (To tema za kasnej)

$\vec{E}_{IND} = -\frac{\partial \vec{A}}{\partial t}$ → vektorski mag. pot.

ZGLEDI:

1.) $\vec{E}_{IND}$ V/OB FEROMAGNETNEM STEBRU KROŽNEGA PREREZA

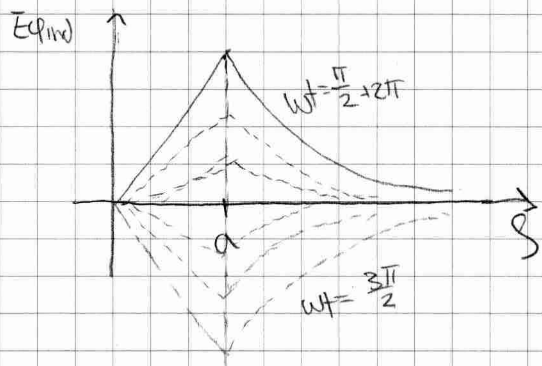


L krožnica polmera ρ okoli osi z

$$\oint_{L(2\pi\rho)} \vec{E}\cdot\vec{dl} = E_\varphi 2\pi\rho = -\frac{d}{dt}\begin{cases}\frac{\phi}{\pi a^2}\rho^2, & \rho\le a\\ \phi, & \rho > a\end{cases}$$

$$E_{\varphi IND} = E_\varphi = \begin{cases}\frac{-\frac{d\phi}{dt}}{2\pi a^2}\rho, & \rho \le a\\ \frac{-\frac{d\phi}{dt}}{2\pi\rho}, & \rho > a\end{cases}$$

$E_\varphi = E_{\varphi A} + E_{\varphi IND}$ ($E_{\varphi A} = \emptyset$)



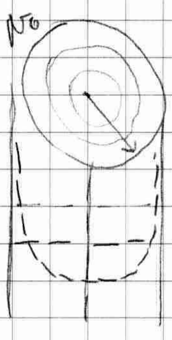
PRIMER: $\phi(t) = \phi_m \cos\omega t$

$$-\frac{d\phi}{dt} = \omega\phi_m \sin\omega t$$

$$E\varphi_{ind} = \begin{cases}\frac{\omega\phi_m}{2\pi a^2}\rho\sin\omega t, & \text{not}\\ \frac{\omega\phi_m}{2\pi\rho}\sin\omega t, & \text{zun.}\end{cases}$$

$J = \gamma E_{ind}$ → VRTINČNI TOK zaradi njih imamo vrtinčne izgube

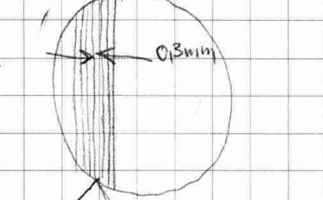
$P = \frac{J^2}{\gamma}$



Izriv fluksa na površino

Za preprečitev tega v praksi izvajamo lamelacijo

1. UKREP LAMELACIJA:

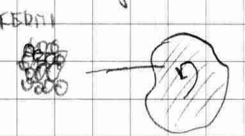


lamele prevlečene oz. polakirane → Med seboj so izolirane

Vrtinčne izgube reda 1 W na kg

2. FERITI - 2. NAČIN

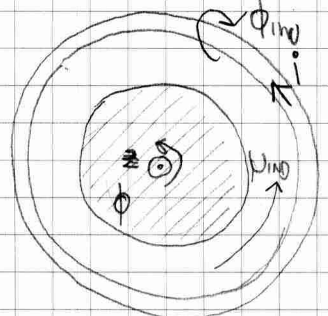
Namenjeni tudi zmanjšanju vrtinčnih tokov.



Relevantni so pri visokih frekvencah

(hkrati tudi histerezne izgube)

2.) STEBER S KROŽNIMI OVOJEM



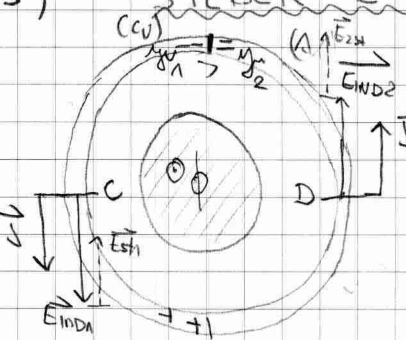
$$u_{ind} = -\frac{d\phi_m}{dt} = \omega \phi_m \sin \omega t$$

$$i \simeq \frac{u_{ind}}{R}$$

Če je samoindukcija zanemarljiva

$$|\phi_{ind}| << |\phi|$$

3.) STEBER Z DVODELNIM KROŽNIM OVOJEM

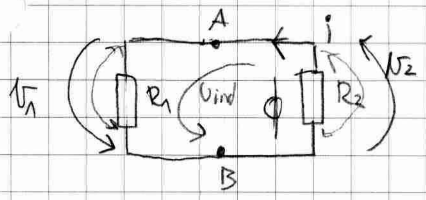


$$\vec{E} = \vec{E}_{st} + \vec{E}_{ind}$$

$$u_{ind} = -\frac{d\phi}{dt} = \omega \phi_m \sin \omega t$$

$$\Sigma R = R_1 + R_2$$

$$i \simeq \frac{u_{ind}}{\Sigma R}$$



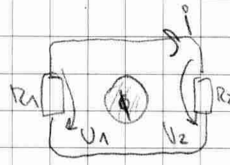
$$(C) \quad \vec{J} = \gamma_1 (\underbrace{\vec{E}_{ind1} + \vec{E}_{st1}}_{\vec{E}_1})$$

$$(D) \quad \vec{J} = \gamma_2 (\underbrace{\vec{E}_{ind2} + \vec{E}_{st2}}_{E_2})$$

$$|\vec{E}_2| > |\vec{E}_1|$$

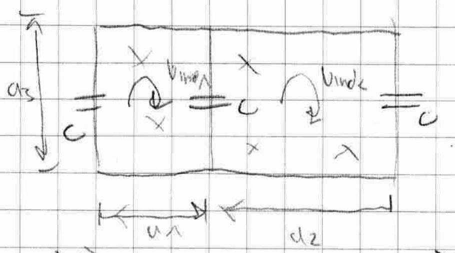
$$u_1 = iR_1$$
$$u_2 = iR_2$$

KOLOKVIJSKA NALOGA



$\Rightarrow$ Treba je dlo razumevanje U_1 in U_2

KOLOKVIJSKA



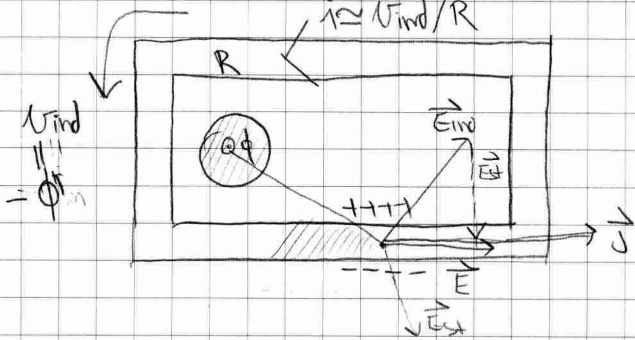
$-U_1+U_2-U_{ind1}=0$

$-U_2+U_1-U_{ind2}=0$

$\oint_{\partial A_1} \vec{E}\,d\vec{l} = -U_1+U_2=U_{ind}$

$\Rightarrow$ Tle se moje ločevati o zaporedno/vzporedno vezanih kondenzatorjih

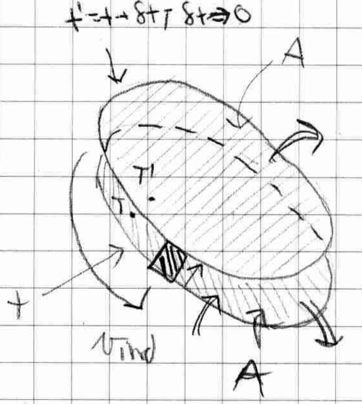
4.) STEBER S PRAVOKOTNIM OKVIRJEM/ZANKO



Na okvirju se zgodi influenca

$\vec{J}=\gamma\vec{E}=\gamma(\vec{E}_{ind}+\vec{E}_{st})$

5.) TRANSFORMATORSKA IN GIBALNA INDUCIRANA NAPETOST



$$U_{ind} = -\frac{d\phi}{dt} = -\lim_{\delta t \to 0} \frac{\phi(t+\delta t)-\phi(t)}{\delta t}$$

$$= -\lim_{\delta t \to 0} \frac{\delta t \int_{A'} \frac{\partial \vec{B}}{\partial t}\cdot d\vec{a} + \int_{A'} \vec{B}(T',t)\cdot d\vec{a} - \int_{A} \vec{B}(T,t)\,d\vec{a}}{\delta t}$$

$\phi(t+\delta t) = \int_{A'} \vec{B}(T', t+\delta t)\cdot d\vec{a}$

$\phi(t) = \int_{A} \vec{B}(T,t)\cdot d\vec{a}$

$f(x+\delta x) \cong f(x) + \delta x\, f'(x)$

$\vec{B}(T', t+\delta t) = \vec{B}(T',t) + \delta t \frac{\partial \vec{B}}{\partial t}$

Fluks skozi plašč, ki ga ta zanka zariše v kratkem času δt

$\oint (\vec{v}\cdot dt \cdot d\vec{l})\cdot \vec{B}$

$$\Rightarrow -\int_{A} \frac{\partial \vec{B}}{\partial t}\cdot d\vec{a} - \oint_{\partial A} (\vec{v}\times d\vec{l})\cdot\vec{B} = -$$

$$U_{IND} = -\frac{d\phi_m}{dt} = -\int_{A} \frac{\partial \vec{B}}{\partial t}\cdot d\vec{a} + \oint (\vec{v}\times\vec{B})\cdot d\vec{l}$$

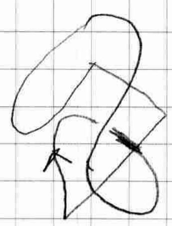
ZAPIS OBEH PRISPEVKOV K INDUKCIJI

$\to$ Hitrost tega elementa zanke

$(U_{ind})_{transformatorska}$ $(U_{ind})_{gibalna}$

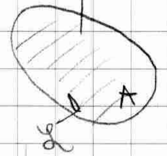
6.) MAGNETNI SKLEP – POSPLOŠITEV POJMA MAGNETNI PRETOK

18.4.'11



$\phi = ?$

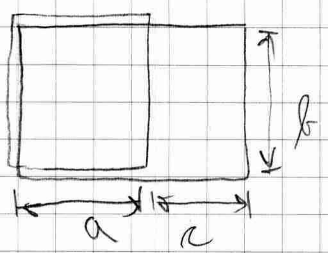
$\phi = \phi_A = \phi_\mathcal{L}$



$\phi \to \Psi$ (PSI)

$\Psi_\mathcal{L} = ?$

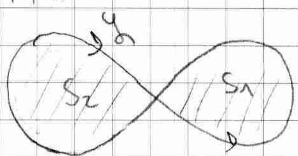
PP1



$\Psi_\mathcal{L} = \phi_{(a+c)\times b} + \phi_{a\times b} = 2\phi_{a\times b} + \phi_{c\times b}$

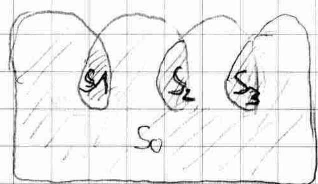
$u_{ind} = -\frac{d\Psi}{dt}$

PP2



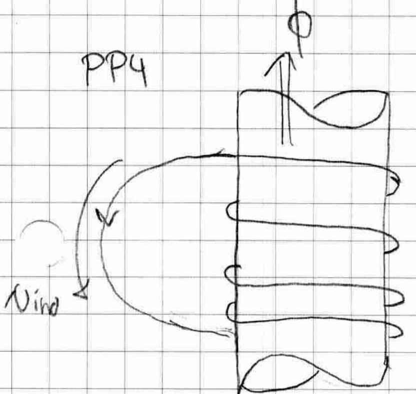
$\Psi_\mathcal{L} = \phi_{S1} + \phi_{S2}$

PP3



$\Psi = 2(\phi_{S1} + \phi_{S2} + \phi_{S3}) + \phi_{S0}$

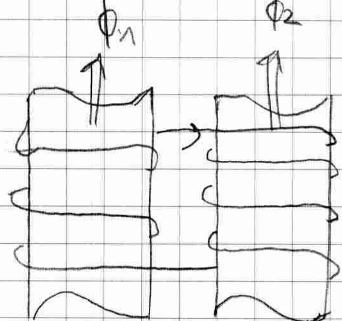
PP4



$\Psi_\mathcal{L} = -4\phi$

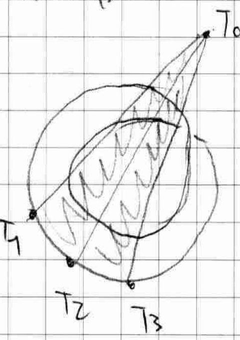
$u_{ind} = -\frac{d\Psi_\mathcal{L}}{dt} = 4\phi'$

PP5:



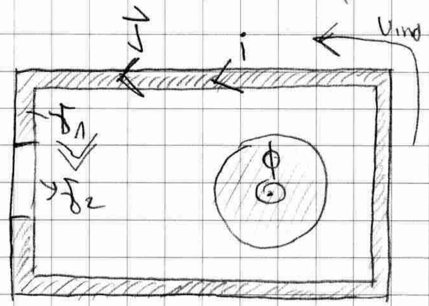
$\Psi_\mathcal{L} = -3\phi_1 + 4\phi_2$

$\Psi_{\gamma} = \Psi_A$, $A = ?$



Rezultat ni ena zanka, ker je nesklenjena

7. INDUKCIJA V ODPRTIH ZANKAH



$\gamma_2 <<< \gamma_1$

$U_{ind} = -\frac{d\phi}{dt}$

$|\vec{J_1}| = |\vec{J_2}|$

$|\gamma_1 \vec{E_1}| = |\gamma_2 \vec{E_2}|$

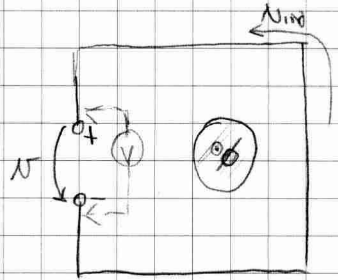
$\Rightarrow |\vec{E_2}| >>> |\vec{E_1}|$

Spomni se mejnega pogoja iz 1. semestra

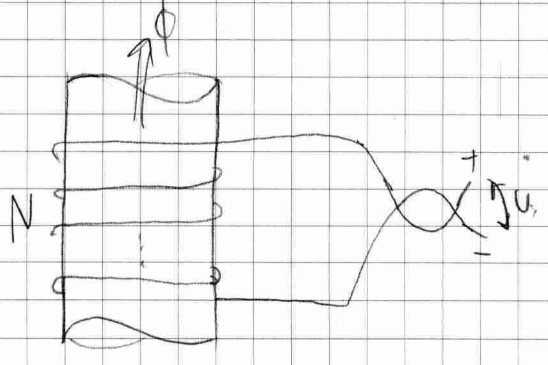
$\left(\frac{\varepsilon_1}{\gamma_1} - \frac{\varepsilon_2}{\gamma_2}\right) J_n = \sigma$

$u_{ind} = -\frac{d\phi}{dt} = \oint_{\gamma} \vec{E} \cdot d\vec{l} = \int_{T_1 \gamma_1 T_2} \vec{E_1} \cdot d\vec{l} + \int_{T_2 \gamma_2 T_1} \vec{E_2} \cdot d\vec{l}$

$\approx \int_{T_2 \gamma_2 T_1} \vec{E_2} \cdot d\vec{l} = -U_2$



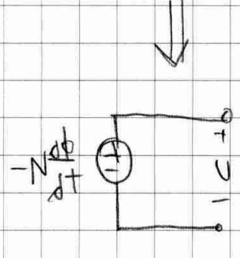
$u \approx u_{ind} = -\frac{d\phi}{dt}$



Upoštevamo se koliko fluksa objamemo s to pentljo.

$\Psi_{\gamma} = N\phi$

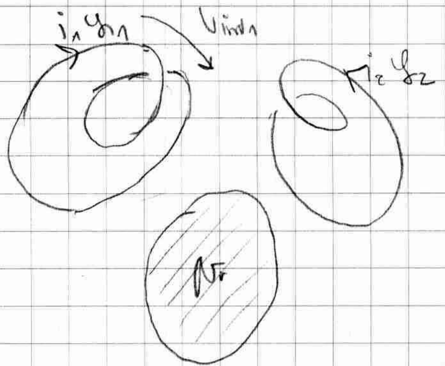
$u \cong -\frac{d\Psi_{\gamma}}{dt} = -N\dot{\phi}$



INDUKTIVNOSTI - LASTNE IN MEDSEBOJNE

18.4.11

za linearne sisteme!



$$\vec{B} = \vec{B}^{(1)} + \vec{B}^{(2)}$$

$$\psi_1 = \psi_1^{(1)} + \psi_1^{(2)} = L_{11} i_1 + L_{12} i_2$$

$$\psi_2 = \psi_2^{(1)} + \psi_2^{(2)} = L_{21} i_1 + L_{22} i_2$$

MEDSEBOJNI INDUKTIVNOSTI

$$\frac{\psi_1^{(1)}}{i_1} = L_{11} \qquad \frac{\psi_1^{(2)}}{i_2} = L_{12}$$

$$\frac{\psi_2^{(1)}}{i_1} = L_{21} \qquad \frac{\psi_2^{(2)}}{i_2} = L_{22}$$

LASTNI INDUKTIVNOSTI

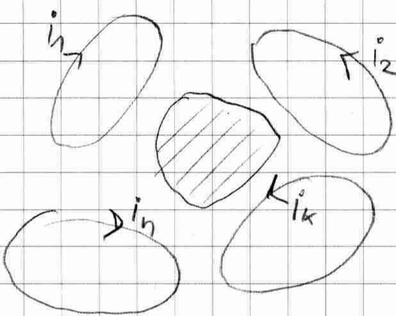
v_{ir}

$$v_{ind_1} = -\frac{d\psi_1}{dt} = -L_{11} i_1' - L_{12} i_2'$$

$$v_{ind_2} = -\frac{d\psi_2}{dt} = -\underbrace{L_{21} i_1'}_{\text{TUJA INDUKCIJA}} - \underbrace{L_{22} i_2'}_{\text{SAMOINDUKCIJA}}$$

induktivnosti merilo za akumulirano magnetne energije

POSPLOŠITEV NA N-ZANK



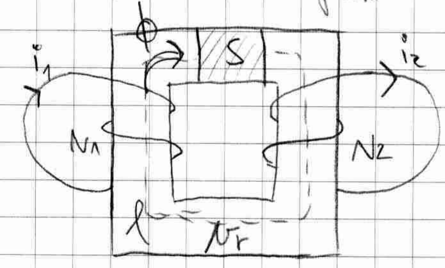
$$\psi_k = \sum_{j=1}^{n} \psi_k^{(j)} = \sum_{j=1}^{n} L_{kj} i_j$$

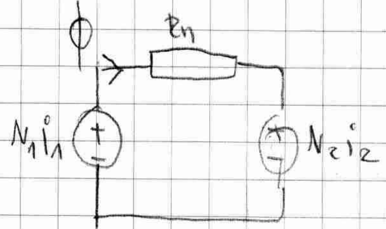
$$\boxed{L_{kj} = \frac{\psi_k^{(j)}}{i_j}}$$

$$v_{ind} = \boxed{v_{ind} = -\frac{d\psi_k}{dt} = -\sum_{j=1}^{n} L_{kj} i_j'}$$

ZGLED – TRANSFORMATOR

Linearen magnetik





$$\phi = \frac{N_1 i_1 - N_2 i_2}{R_m}$$

$$\Psi_1 = N_1 \phi = \frac{N_1^2}{R_m} i_1 - \frac{N_1 N_2}{R_m} i_2 \qquad (L_{11},\ L_{12})$$

$$\Psi_2 = -N_2 \phi = -\frac{N_1 N_2}{R_m} i_1 + \frac{N_2^2}{R_m} i_2 \qquad (L_{21},\ L_{22})$$

$$R_m = \frac{l}{\mu_0 \mu_r S}$$

Če bi izbrali drugo ref. smer bi se koeficienti nasprotno predznačili

Če so medsebojne induktivnosti negativne ako se lastni in sosedov fluks tepeta

KASNEJE

$L_{12} = L_{21}$ ⇒ To bo kasneje pravilo $L_{jk} = L_{kj}$ Ponavadi medsebojni induktivnosti vedno enaki

$|L_{12}| = |L_{21}| = \sqrt{L_{11} L_{22}}$ ⇒ Enaka geometrijski sredini obeh lastnih
($k=1$)

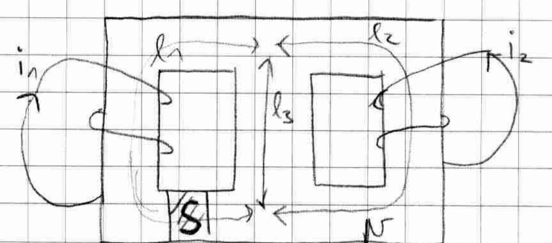
⇒ TO NI SPLOŠNO ⇒ KASNEJE $L_{12} = L_{21} = k\sqrt{L_{11} L_{22}}$

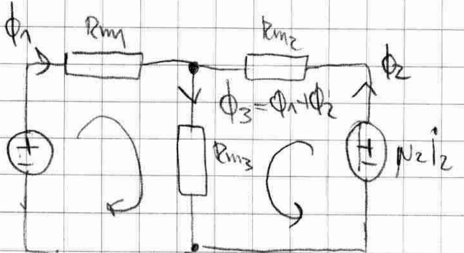
k.

Faktor sklopa → med 0 in 1, $0 \leq k \leq 1$

Idealno 1, ali pa načeloma 0 ⇒ pri telefonskih linijah da ni presluhov

ZGLED – TRISTEBERNO JEDRO Z DVEMA NAVITJEMA





$$R_{mk} = \frac{l_k}{\mu S}$$

$R_{m1} \phi_1 + R_{m3}(\phi_1 + \phi_2) = N_1 i_1$

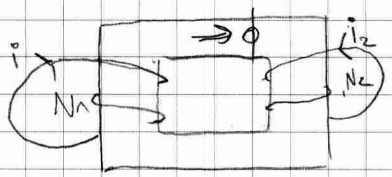
$R_{m2} \phi_2 + R_{m3}(\phi_1 + \phi_2) = N_2 i_2$

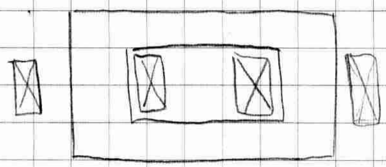
$\Psi_1 = N_1 \phi_1 = L_{11} i_1 + L_{12} i_2$

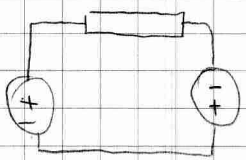
. . . . Napiši [?] rešitev [?]

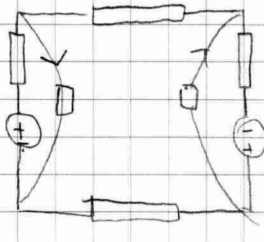
DILEME IN TEŽAVE DOLOČANJA INDUKTIVNOSTI

22.4.11

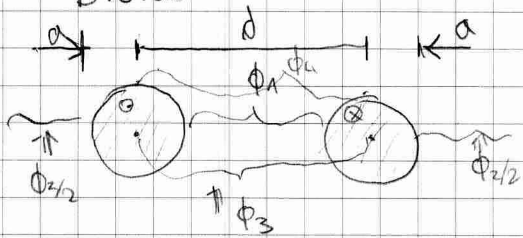








DVOVOD



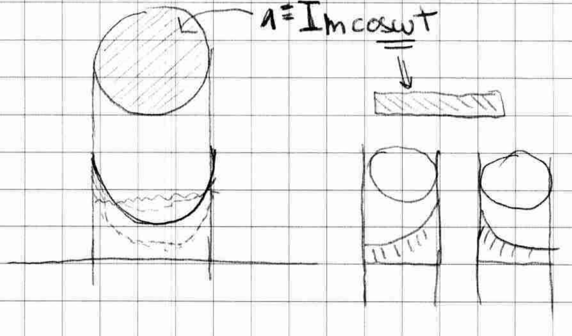
ϕ

Dilema → imamo nekakšna fluksa sam ne vemo katerega vzet. ⇒ V primeru dvovoda to rešimo s povprečjem

$\phi_x = \ldots$

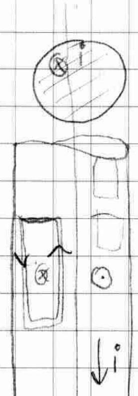
$$\phi_1 = \frac{\mu_0 I l}{\pi} \ln \frac{d-a}{a} \qquad \phi_3 = \frac{\mu_0 I l}{\pi} \left(\frac{1}{2} + \ln \frac{d}{a} \right)$$

$$\phi_2 = \frac{\mu_0 I l}{\pi} \ln \frac{d+a}{a} \qquad \phi_4 = \frac{\mu_0 I l}{\pi} \ln \frac{\sqrt{d^2+a^2}}{a}$$



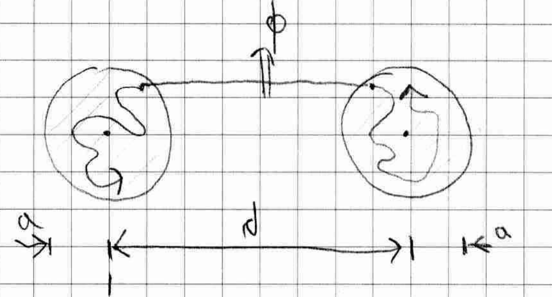
$$\delta = \sqrt{\frac{2}{\omega \mu \gamma}}$$

ZA Baker pri 50Hz ta delta → δ cca 1mm



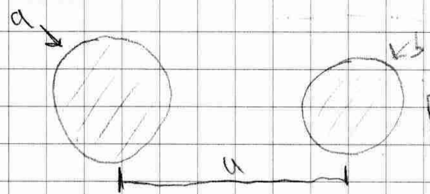
Delaj po Lenzovem smislu

INDUKTIVNOST DVOVODA



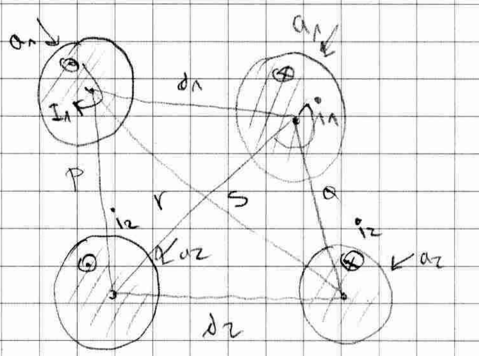
$$\langle \phi \rangle = \frac{\mu_0 I l}{\pi}\left(\frac{1}{4} + \ln\frac{d}{a}\right)$$

$$\boxed{L = \frac{\langle \phi \rangle}{I} = \frac{\mu_0 l}{\pi}\left(\frac{1}{4} + \ln\frac{d}{a}\right)}$$



$$\boxed{L = \frac{\mu_0 l}{\pi}\left(\frac{1}{4} + \ln\frac{d}{\sqrt{ab}}\right)}$$

MEDSEBOJNA INDUKTIVNOST



$$\langle \phi^{(2)} \rangle = \frac{\mu_0 i_2 l}{2\pi}\left(\ln\frac{rs}{pq}\right)$$

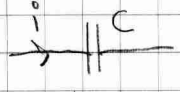
$$\boxed{L_{1,2} = \frac{\langle \phi_1^{(2)} \rangle}{i_2} = \frac{\mu_0 l}{2\pi}\left(\ln\frac{rs}{pq}\right)}$$

$$L_{21} = \frac{\langle \phi_2^{(1)} \rangle}{i_1} = L_{12} \quad \checkmark\checkmark$$

Recipročna kot je fl med zankama

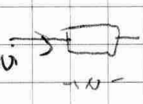
TULJAVA KOT STRNJEN ELEMENT EL. VEZIJ

21.4.11



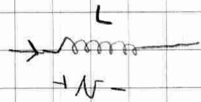
$i = Cu'$

$w_C = Cu^2/2$, $p_e = ui$



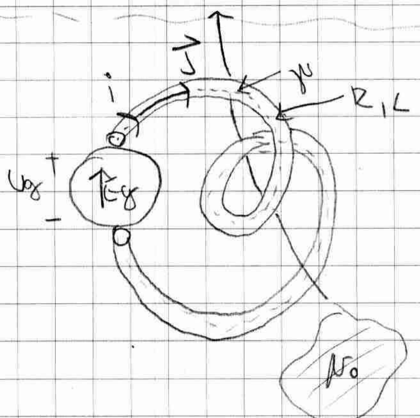
$i = Gu$

$p_t = u \cdot i = Gu^2$



$u = Li'$

$w_U = Li^2/2$, $p_m = ui$



$\vec{J} = \gamma(\vec{E} + \vec{E}_g)$ $\vec{E} = \frac{\vec{J}}{\gamma} - E_g$

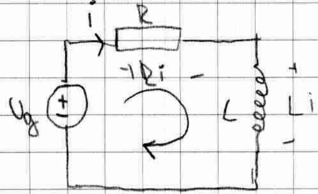
$\oint_L \vec{E} \cdot \vec{dl} = u_{ind} = -\frac{d\Psi}{dt}$

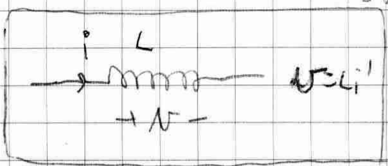
$\underbrace{\oint_L \frac{\vec{J}}{\gamma} \cdot \vec{dl}}_{Ri} - \overbrace{\oint_L \vec{E}_g \cdot \vec{dl}}^{u_g}$

$Ri - u_g = -\frac{d\Psi}{dt} = -\frac{d}{dt}(Li) = -Li'$

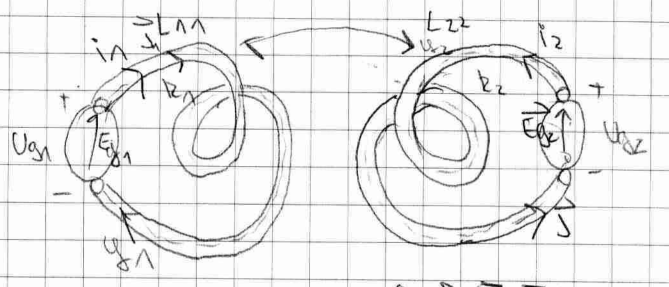
$$\boxed{-u_g + Ri + Li' = 0}$$

staro novo





SKLOP DVEH TULJAV



$$\oint_{g_1} E_1\, dl = \oint_{g_1} \frac{\vec J_1}{\gamma_1}\, d\vec l_1 - \oint_{g_1} \vec E_{g1}\, dl$$

$$= R_1 i_1 - U_{g1} = -\frac{d\Psi_2}{dt}$$

$$= -L_{11} i_1' - L_{12} i_2'$$

$$R_1 i_1 + L_{11} i_1' + L_{12} i_2' - U_{g1} = 0$$

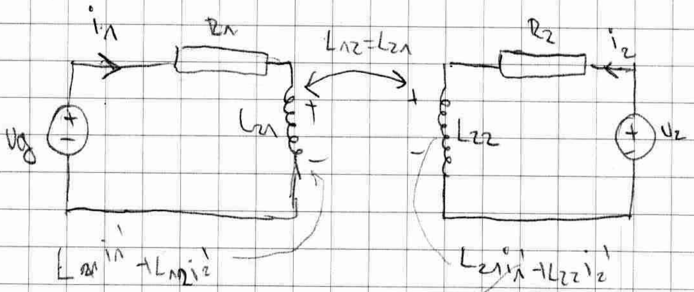
$$R_2 i_2 + L_{21} i_1' + L_{22} i_2' - U_{g2} = 0$$

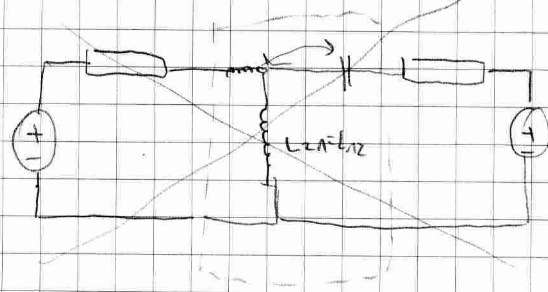
$J_1 = \gamma_1(\vec E_1 + \vec E_{g1})$

$E_1 = \frac{J_1}{\gamma_1} - \vec E_{g1}$

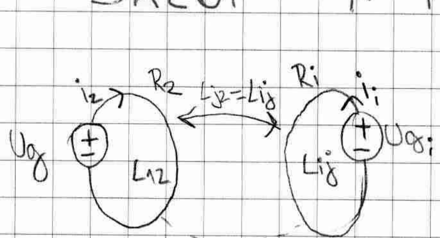
$J_2 = \gamma_2(\vec E_2 + \vec E_{g2})$

$E_2 = \frac{J_2}{\gamma_2} - \vec E_{g2}$





SKLOP N-TRANSFORMATORJEV



$$R_k i_k + \underbrace{L_{k1} i_1' + \dots + L_{kj} i_j' + \dots + L_{kk} i_k'}_{\frac{d\Psi}{dt}} + \dots + L_{kn} i_n' - U_{gk} = 0$$

SKLOPNI FAKTOR

i, j – tuljavi

$$k_{ij}^2 = \frac{\psi_i^{(j)} \psi_j^{(i)}}{\psi_i^{(i)} \psi_j^{(j)}} = \frac{L_{ij} L_{ji}}{L_{ii} L_{jj}}$$

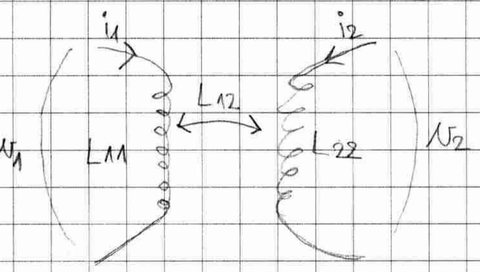
$$0 \leq k_{ij} = \frac{|L_{ij}|}{\sqrt{L_{ii} L_{jj}}} \leq 1$$

0 → popolna nepovezanost; 1 → popoln sklep

DRUGO LETO:

$1 - k^2 = \sigma$ Faktor stresanja

SKLOP DVEH TULJAV IN DOGOVOR O „PIKAH"



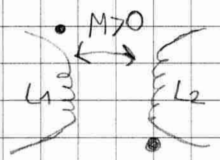
$$u_1 = L_{11} i_1' + L_{12} i_2'$$
$$u_2 = L_{21} i_1' + L_{22} i_2'$$

NOV DOGOVOR:

$L_{11} = L_1$
$L_{22} = L_2$

Tak četveropol model za asinhronski motor ipd (Precej pogosto se pojavlja)

O PIKAH

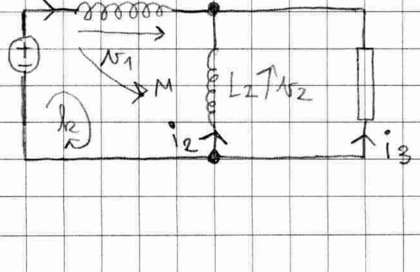


Če sta tokova izbrana v pikah kot referenčna, potem se magnetna pretoka podpirata

$$k = \frac{M}{\sqrt{L_1 L_2}}$$

$$u_1 = L_{11} i_1' + M i_2'$$
$$u_2 = M i_1' + L_{21} i_2'$$

PRIMER:

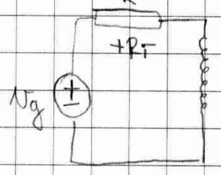


$$u_1 = L_1 i_1' + M i_2'$$
$$u_2 = M i_1' + L_2 i_2'$$

$i_1 + i_2 + i_3 = 0$
$-U_g + U_1 - U_2 = 0$
$u_2 - R i_3 = 0$

MAGNETNA ENERGIJA

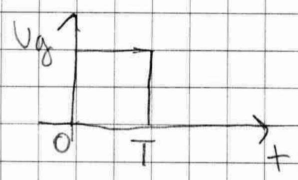
Vloženo delo se manifestira kot neka energija



$-v_g - Ri + Li' = 0$; ← $0 \le t \le T$

$v_g = Ri + L\frac{dI}{dt}$ → SAMOINDUKCIJA

$0 = Ri + Li'$; $t > T$



$t \in [0, T]$

$U_g = Ri + L\frac{dI}{dt} \; / \cdot i$

$U_g i = Ri^2 + Lii' \; / \int_{t_1}^{t_2} dt$ Močnostna energija tega vezja

$$\int_{t_1}^{t_2} v_g i\,dt = \int_{t_1}^{t_2} Ri^2\,dt + \int_{t_1}^{t_2} Lii'\,dt$$

$$A_g(t_1, t_2) = W_T(t_1, t_2) + L\int_{t_1}^{t_2} i\,di = L\frac{i^2}{2}\Big|_{t_1}^{t_2}$$

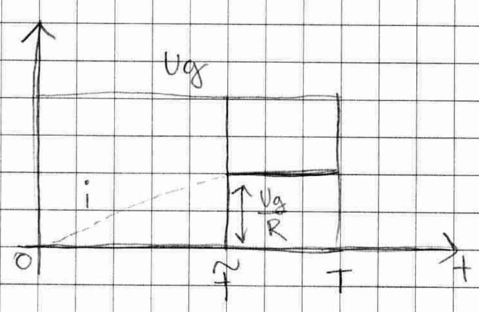
$$\Rightarrow \boxed{A_g(t_1, t_2) = W_T(t_1, t_2) + \frac{L}{2}\left[i^2(t_2) - i^2(t_1)\right]}$$

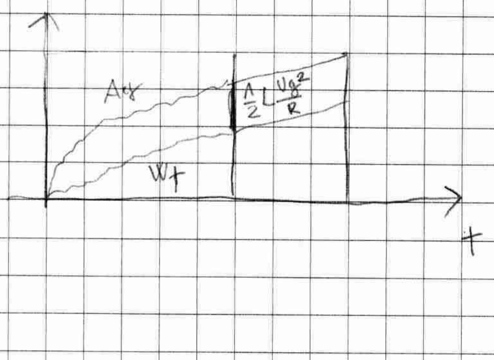
$t_1 = 0,\ t_2 = t^* < \tilde{t} < T$

$A_g(0, t^*) = W_T(0, t^*) + \frac{L}{2} i^2(t^*)$

$\tilde{t} \leftarrow i(\tilde{t}) = \frac{U_g}{R}$

$i(\tilde{t} < t < T) = \frac{U_g}{R}$





za $t' > T$:

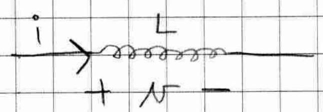
$$A_g(T,t') = 0 = W_T(T,t') + \frac{L}{2}\left[i^2(t') - I^2\right]$$

$$A_g(T,\infty) = W_T(T,\infty) - \frac{L}{2} I^2 = 0$$

⇒ Generator ne daje nove energije sistemu. Višek akumulacije se počasi izčrpa

$$A_g(t_1,t_2) = W_T(t_1,t_2) + W_m(t_2) - W_m(t_1)$$

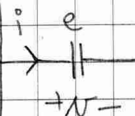
$$W_m = \frac{1}{2} L i^2 \qquad W_m(t) = \frac{1}{2} L i^2(t) \qquad W_e(t) = \frac{1}{2} C u^2(t)$$



$v = L i'$

$W_m = \frac{1}{2} L i^2$

$W_m' = \frac{1}{2} L\, 2 i i' = i v = p_m$



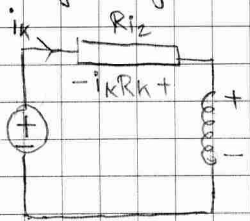
$i = C u'$

$W_e = \frac{1}{2} C u^2$

$W_e' = u i = p_e$

GLEJ ZGLED V KNJIGI

Če je tuljav več ⇒ več virov → Glej v knjigi izpeljavo

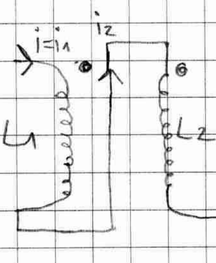


$$A_g(t_1,t_2) = W_T(t_1,t_2) + W_m(t_2) - W_m(t_1)$$

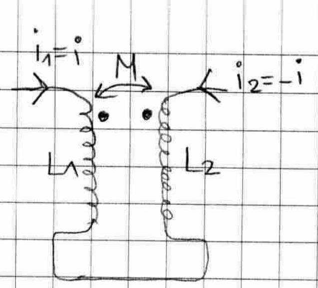
$$W_m = \frac{1}{2}\sum_{k=1}^{n} i_k \Psi_k = \frac{1}{2}\sum_{k=1}^{n}\sum_{j=1}^{n} L_{jk}\, i_j i_k$$

ZGLEDI:

1)

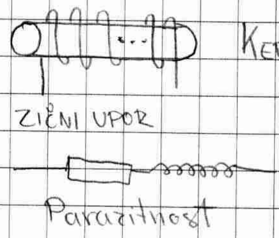


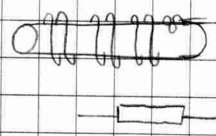
$$W_m = \frac{1}{2} L_1 i_1^2 + \frac{1}{2} M i_1 i_2 + \frac{1}{2} M i_2 i_1 + \frac{1}{2} L_2 i_2 = \frac{1}{2}(L_1 + L_2 + 2M) i^2$$

2.) 

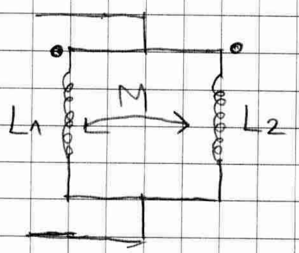
Magn. pretoka se NE podpirata

2a)

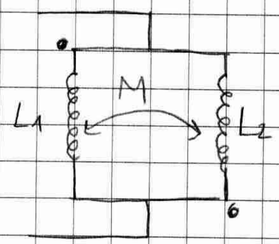




3)



$\Rightarrow L_{ind} = \frac{L_1 L_2 - M^2}{L_1 + L_2 - 2M}$



$L_{ind} = \frac{L_1 L_2 - M^2}{L_1 + L_2 + 2M}$

$$W_m = \frac{1}{2} \sum_{k=1}^{n} \sum_{j=1}^{n} L_{jk} i_k i_j$$ $\Rightarrow$ Treba gledat kot rešitev

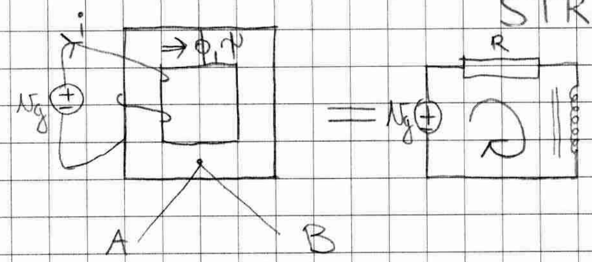
.... $W_m = \frac{1}{2} \mu H^2$

$W_e = \frac{1}{2} Q_1 V_1 + \frac{1}{2} Q_2 V_2 + \ldots \to W_e = \frac{1}{2} E \varepsilon_0$

To je blo za linearne strukture

ENERGIJSKI VLOŽEK ZA MAGNETENJE NELINEARNE STRUKTURE

9.5.XI

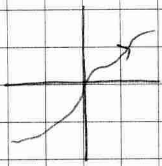


$$-v_g + Ri + \frac{d\psi}{dt} = 0$$

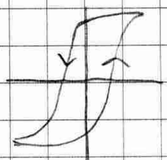
$$v_g = Ri + \frac{d\psi}{dt} \,/\, i$$

$$v_g i = Ri^2 + i\frac{d\psi}{dt} \quad \int_{t_1}^{t_2} \dots dt$$

$$A_g(t_1, t_2) = W_T(t_1, t_2) + \int_{t_1}^{t_2} i \, d\psi$$



MAGNETILNA KRIVULJA



HISTEREZA

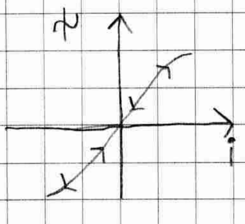
$$W_{mag} = \int_{t_1}^{t_2} i \, d\psi$$

ENERGIJSKI VLOŽEK ZA MAGNETENJE STRUKTURE

NELINEARNOST IN VIŠJI HARMONIKI

$R \to 0 \Rightarrow v_g \simeq \psi'$

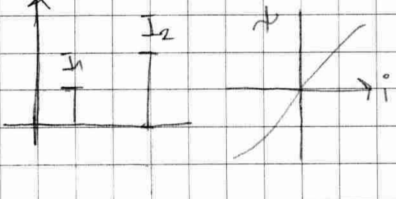
$v_g = V_m \cos \omega t \Rightarrow \psi = \frac{U_m}{\omega} \sin \omega t$



$i = K\psi^3 \qquad i = K\frac{U_m}{\omega^2} \sin^3 \omega t \qquad \{\sin^3 x = \frac{3}{4}\sin x - \frac{1}{4}\sin 3x\}$

$i = \frac{3}{4}K\left(\frac{U_m}{\omega}\right)^3 \sin \omega t - \frac{1}{4}K\left(\frac{U_m}{\omega}\right)^3 \sin 3\omega t = I_{m1} \sin \omega t - I_{m3} \sin 3\omega t$

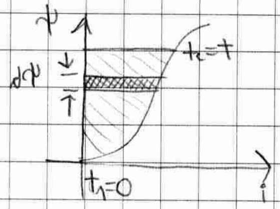
$\psi(-i) = -\psi(i) \Rightarrow$ LIHA F.



$v_g = V_m \cos \omega t$

$i = I_{m1} \sin \omega t + I_{m3} \sin 3\omega t + I_{m5} \sin 5\omega t + \dots$ VRSTA

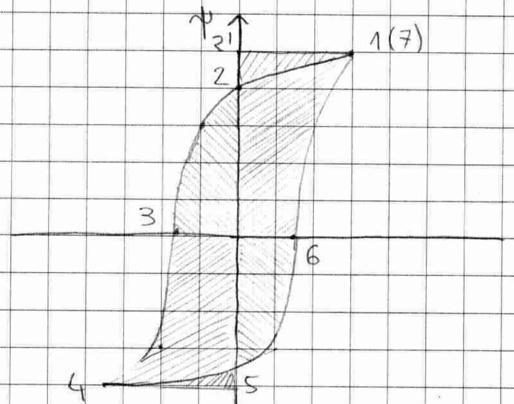
A.) MAGNETENJE PO DEVIŠKI KRIVULJI



$$W_{mag} = \int_{t_1}^{t_2} i\,d\psi$$

$$\boxed{\int_{t_1=0}^{t_2=t} i\,d\psi}$$

B.) MAGNETENJE PO HISTEREZI



$0 > \int_1^2 i\,d\psi$ = ustreza ploščini lika	1, 2, 2'	GENERATORSKI REŽIM
$0 < \int_2^3 i\,d\psi$ = ustreza ploščini lika	2, 3, 0	BREMENSKI REŽIM
$0 < \int_3^4 i\,d\psi$ = ustreza ploščini lika	3, 4, 5', 0	BREM.
$0 > \int_4^5 i\,d\psi$ = ustreza ploščini lika	4, 5, 5'	GEN.
$0 < \int_5^6 i\,d\psi$ = ustreza ploščini lika	5, 6, 0	BREM
$0 < \int_6^7 i\,d\psi$ = ustreza ploščini lika	6, 7, 2', 0	BREM

$T = t_2 - t_1 \rightarrow$ Perioda

$$W_{mag}(t, t+T) = \oint_{\mathcal{P}} i\,d\psi$$

$\mathcal{P}$ → Histerezna pentlja (kaligrafski P)

$$\boxed{P_h = \frac{W_{mag}(t, t+T)}{T}}$$

Tretja vrsta izgub

Dielektrične izgube pri histerezi → Na podlagi tega delajo mikrovalovke

, i, p razmere v toroidni tuljavi

z upoštevanjem histereze feromagnetika

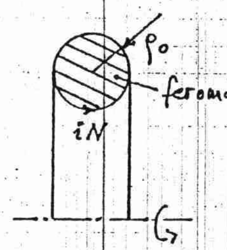
$N = 500,\ \rho_0 = 2cm,\ l = 0{,}5m$

$u(t) = 240 \sin(100\pi t)\ ;\ f = 50Hz$

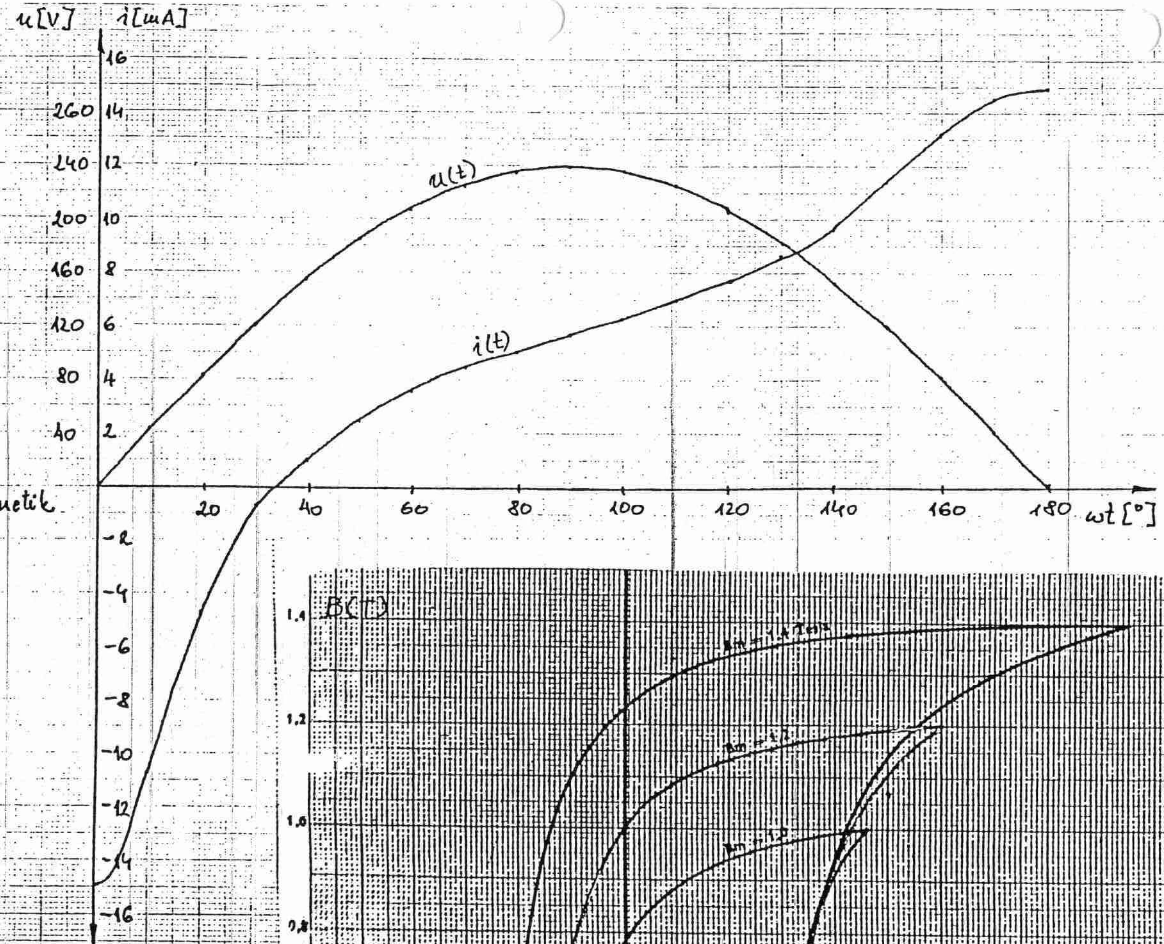
$B(t) = -\frac{240}{\omega N \pi \rho_0^2}\cos(100\pi t) = -1{,}2\cos(100\pi t)$

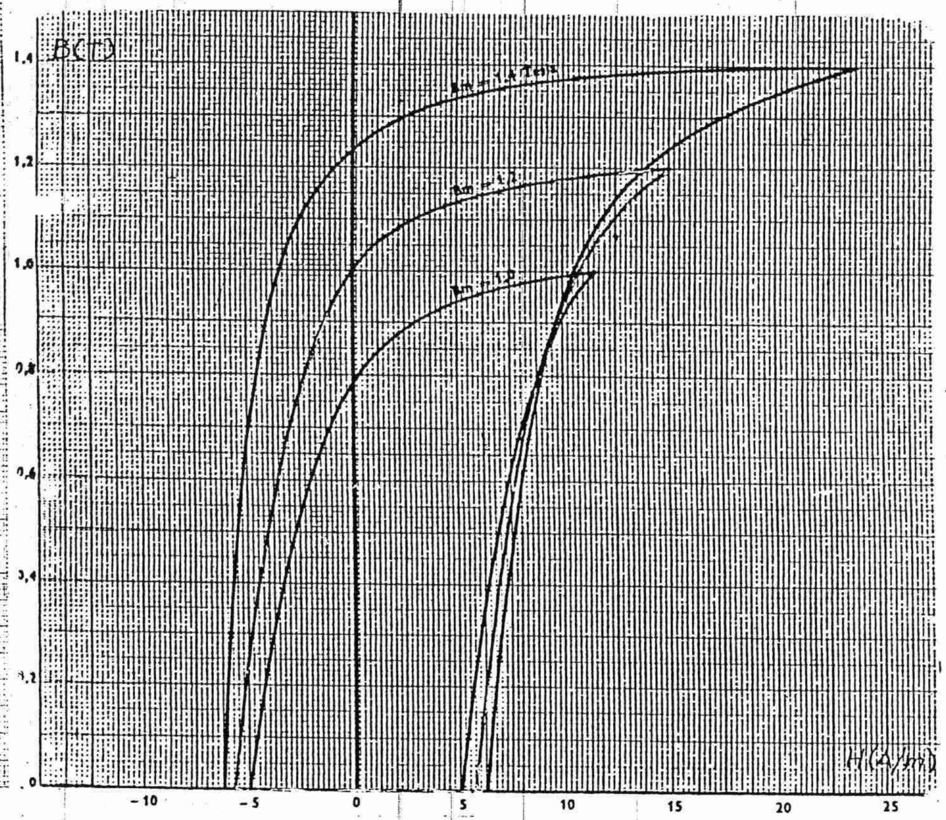
$B(t) \rightarrow H(t)$

$i(t) = \frac{l}{N} H(t) = 10^{-3} H(t)$



ωt [°]	B(t) [T]	H(t) [A/m]
0	-1,2	-15,0
10	-1,18	-10,75
20	-1,13	-4,75
30	-1,04	-0,75
40	-0,92	+1,0
50	-0,77	2,5
60	-0,6	3,5
70	-0,41	4,5
80	-0,21	5,0
90	0,0	5,75
100	0,21	6,25
110	0,41	7,0
120	0,6	7,75
130	0,77	8,75
140	0,92	9,75
150	1,04	11,5
160	1,13	13,25
170	1,18	14,5
180	1,2	15,0





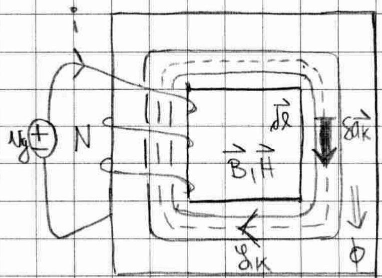
1) $P = \frac{1}{T}\int_0^T u(t)\cdot i(t)\,dt = \frac{1}{18}\sum_{K=1}^{18} u_K\, i_K = 0{,}824\ W$

2) $P = A_h(B,H)\cdot V\cdot f = A_h(B,H)\cdot \pi\rho_0^2 l\cdot f = 0{,}814\ W$

$P/m = 0{,}167\ W/kg$ (DO 0,5 W/kg) [illegible]

GOSTOTA ENERGIJSKEGA VLOŽKA

$$W_{mag}(t_1,t_2) = \int_{t_1}^{t_2} i\, d\psi$$



$$\psi = N\phi \,,\, d_t\psi = N d_t \phi$$

$$\phi = \sum_k \delta\phi_K = \sum_k \vec{B}\cdot\delta\vec{a}_K$$

$$d_t\psi = N\sum_k d_t\vec{B}\cdot\delta\vec{a}_K$$

$$i = \frac{1}{N}\oint_{g_K} \vec{H}\cdot d\vec{l}$$

$(\vec{a}\cdot\vec{b})(\vec{c}\cdot\vec{d}) = (\vec{a}\cdot\vec{c})(\vec{b}\cdot\vec{d})$ Trije vekt. od štirih so kolinearni

$$W_{mag}(t_1,t_2) = \int_{t_1}^{t_2}\left(\oint_{g_K}\vec{H}\cdot d\vec{l}\right)\left(\sum_k d_t\vec{B}\cdot d\vec{a}\right) = \int_{t_1}^{t_2}\sum_K \oint_{g_K}(\vec{H}\cdot d_t\vec{B})(\delta\vec{a}_K\cdot d\vec{l})$$

$$= \sum_k \oint_{g_K}\int_{t_1}^{t_2}(\vec{H}\cdot d_t\vec{B})\cdot dV_K$$

$$\boxed{W_{mag}(t_1,t_2) = \int_V \left(\int \vec{H}\cdot d_t\vec{B}\right) dV}$$

$$W_{mag}(t_1,t_2) = \int_{t_1}^{t_2}\vec{H}\cdot d\vec{B} \quad [J/m^3]$$

$$W_{mag}(t_1,t_2) = \int_{t_1}^{t_2} i\, d\psi \quad [J]$$

GLEJ LIST!

$$v = N\frac{d\phi}{dt} = NS\frac{dB}{dt} \rightarrow \cos$$

$\downarrow$ sin

Prepričanje → Napetost harmonična, tok pa ne

$$P_h = \frac{W_{mag}(t, t+T)}{T} \Rightarrow P_h = \frac{1}{T}\int_t^{t+T} v\, i\, dt$$

Koercitivne jakosti 5A/m → mehkomagnetni materiali

12.5.11

GOSTOTA MAGNETNE ENERGIJE

$$W_{mag}(t_1,t_2) = \int_{t_1}^{t_2} \vec{H} \cdot d_t \vec{B}$$

LINEARNI SISTEM

$\vec{B} = \mu \vec{H}$

$$W_{mag}(t_1,t_2) = \int_{t_1}^{t_2} \mu \vec{H} \cdot d\vec{H} = \frac{\mu}{2}\left(H^2(t_2) - H^2(t_1)\right)$$

$$\vec{H} \cdot d\vec{H} = H_x dH_x + H_y dH_y + H_z dH_z = \frac{1}{2} d(H_x^2 + H_y^2 + H_z^2) = \frac{1}{2} dH^2$$

$$w_m(t) = \frac{\mu H^2(t)}{2} = \frac{\vec{B} \cdot \vec{H}}{2} = \frac{B^2}{2\mu}$$

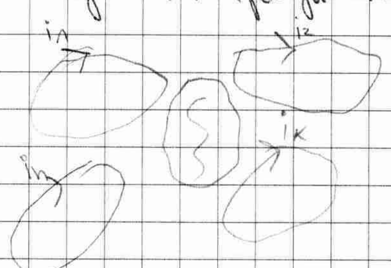
$\{ w_e(t) = \frac{\varepsilon E^2(t)}{2} \}$ ...

VZAJEMNOST = RECIPROČNOST

$L_{jk} = L_{kj}$

$$W_m = \frac{1}{2} \sum_{k=1}^{n} \sum_{j=1}^{n} L_{jk} i_j i_k = \int_V w_m dV = \frac{1}{2} \int_V \vec{H} \cdot \vec{B} dV$$

Tam kjer ni polja tudi energije ni.



$$\vec{H} = \vec{H}^{(1)} + \vec{H}^{(2)} + \dots + \vec{H}^{(n)}$$
$$\vec{B} = \vec{B}^{(1)} + \vec{B}^{(2)} + \dots + \vec{B}^{(n)}$$
$$\vec{H} = \sum_{k=1}^{n} \vec{H}^{(k)} \qquad \vec{B} = \sum_{j=1}^{n} \vec{B}^{(j)}$$

$$W_m = \frac{1}{2} \sum_{k=1}^{n} \sum_{j=1}^{n} \int_V \vec{H}^{(k)} \cdot \vec{B}^{(j)} dV$$

DOKAZ

$$L_{jk} = \frac{1}{i_j i_k} \int \vec{H}^{(k)} \cdot \vec{B}^{(j)} dV = \frac{1}{i_j i_k} \int \mu \vec{H}^{(k)} \cdot \vec{H}^{(j)} dV = \frac{1}{i_j i_k} \int \vec{H}^{(j)} \cdot \vec{B}^{(k)} dV = L_{kj}$$

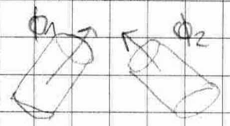
GIBALNI PROCESI

12.5.11

$W_m \leftrightarrow \vec{F}_m$

$\{W_e \leftrightarrow \vec{F}_e\}$

1. BREZ VIROV



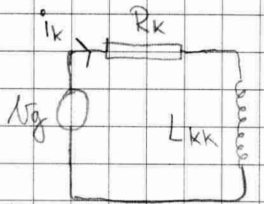
$$\boxed{\vec{F}_m \cdot \delta \vec{l} + \delta W_m = 0} \qquad \vec{F}_m = -\left(\frac{\partial W_m}{\partial x}, \frac{\partial W_m}{\partial y}, \frac{\partial W_m}{\partial z}\right)$$

2. Z VIRI

n = zank s toki i_k in sklepi ψ_k

$t, t+\delta t$ – interval v katerem se ena od zank premakne za nek $\delta \vec{l}$

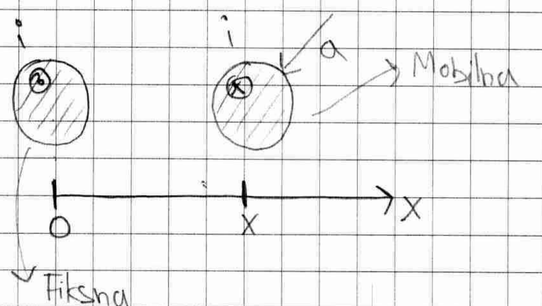
$$\delta A_g = \delta W_T + \underbrace{\frac{1}{2}\sum_{k=1}^{n} i_k \delta \psi_k}_{\delta W_m} + \vec{F}_m \cdot \delta \vec{l} \qquad W_m = 1/2 \sum_{k=1}^{n} i_k \psi_k$$



$$\delta A_g = \delta W_T + \sum_{k=1}^{n} \underbrace{\int_{t}^{t+\delta t} i_k \, d\psi_k}_{\delta t \to 0:\ \sum_{k=1}^{n} i_k \delta \psi_k} = \delta W_T + 2\,\delta W_m$$

$$\Rightarrow \boxed{\vec{F}_m \cdot \delta \vec{l} = \delta W_m} \qquad \vec{F}_m = \left(\frac{\partial W_m}{\partial x}, \frac{\partial W_m}{\partial y}, \frac{\partial W_m}{\partial z}\right)$$

ZGLED – Sila med tokovodnikoma simetričnega dvovoda

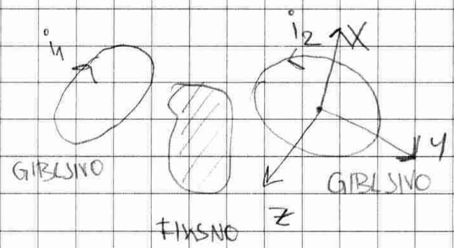


$$W_m = \frac{1}{2} L i^2 = \frac{i^2}{2}\left(\frac{\mu_0 l}{\pi}\left(\frac{1}{4} + \ln\frac{x}{a}\right)\right) = W_m(x)$$

$$F_{mx} = \frac{dW_m}{dx} = \frac{i^2}{2}\frac{\mu_0 l}{\pi x} = \boxed{\frac{\mu_0 i}{2\pi x}\, i l}$$

$$d\vec{F}_m = i\, d\vec{l} \times \vec{B}$$

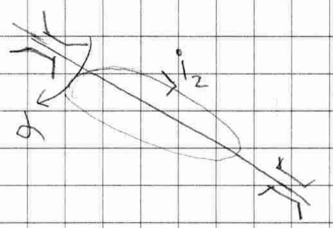
ZGLED – Sila (navor) na sosednji tokovni zanki



$$W_m = \frac{1}{2}L_{11}i_1^2 + L_{12}i_1 i_2 + \frac{1}{2}L_{22}i_2^2$$

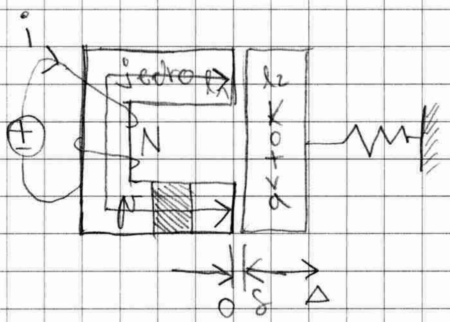
$$F_{mx} = \frac{\partial W_m}{\partial x} = i_1 i_2 \frac{\partial L_{12}}{\partial x}$$

$\left(\frac{y}{z}\right)$ $\left(\frac{y}{z}\right)$



$$\boxed{M_{m\alpha} = i_1 i_2 \frac{\partial L_{12}(\alpha)}{\partial \alpha}}$$

ZGLED – Elektromagnet



$$W_m = \frac{1}{2}L i^2 \qquad l_1 + l_2 = l$$

$$L = \frac{N^2}{R_m}$$

$$R_m = \frac{l}{\mu S} + \frac{2\delta}{\mu_0 S} = R(\delta)$$

$$W_m = \frac{i^2}{2}\frac{N^2}{R_m(\delta)} = W_m(\delta)$$

$$\vec{F}_{m\delta} = \frac{dW_m(\delta)}{d\delta} = \frac{(Ni)^2}{2}\left(-\frac{\frac{2}{\mu_0 S}}{R_m^2}\right) = -\frac{\Phi^2}{2}\frac{2}{\mu_0 S} = -2\frac{B^2}{2\mu_0}S$$

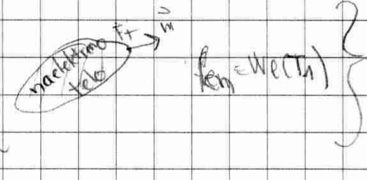
Dve reži

→ Pretezna sila

→ W_{m_0}

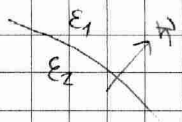
$$\boxed{\frac{F_m \delta}{2S}} = \frac{B^2}{2\mu_0} = w_{m_0}$$

TLAK

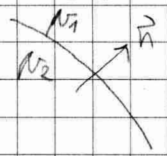


$$f_{en} = \frac{\varepsilon_0 E^2}{2}$$ pri 1MV/m je $f_{en} \simeq 4{,}4\, N/m^2$

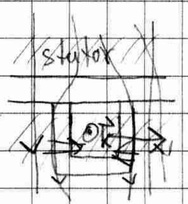
$$f_{mn} = \frac{B^2}{2\mu_0}$$ pri 1T je $f_{mn} \simeq 4\cdot 10^5\, N/m^2$ (4 atm = 4 bar)



$$f_m = \frac{1}{2}(\varepsilon_1 - \varepsilon_2)\left(E_2 + \frac{D_n^{\,2}}{\varepsilon_1\varepsilon_0}\right)$$



$$f_m = \frac{1}{2}(\mu_2 - \mu_1)\left(H_t^{\,2} + \frac{B_n}{\mu_1\mu_2}\right)$$

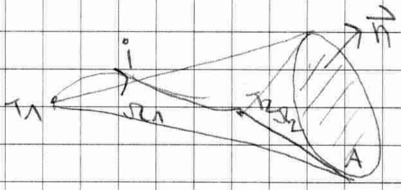


↙ MOTOR B⊥l

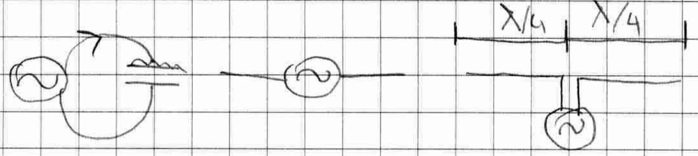
Glavne sile delujejo na stenah utora. Glavnina sil so Maxwellove sile

Zadnja Maxwellova enačba – Premikalni tok oz. razširjen Amperov zakon

$$\oint_{\mathcal{L}} \vec{H}\cdot d\vec{l} = \int_A \vec{J}_{prosti}\cdot d\vec{a} + \ldots ?$$



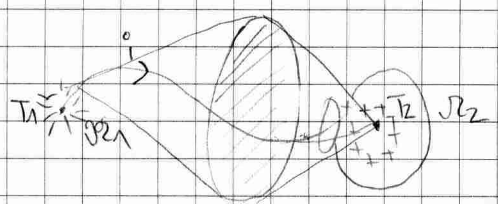
$$\oint_{\mathcal{L}} \vec{B}\cdot d\vec{l} = \frac{\mu_0 i}{4\pi}(\Omega_2 - \Omega_1)$$



$$\oint_{\mathcal{L}} \vec{B}\cdot d\vec{l} = \mu_0 \frac{\frac{dQ}{dt}}{4\pi}(\Omega_2 - \Omega_1)$$

$$= \mu_0 \frac{d}{dt}\underbrace{\left(\frac{Q}{4\pi}\Omega_2 - \frac{Q}{4\pi\varepsilon_0}\Omega_1\right)\varepsilon_0}_{\int \vec{E}\cdot d\vec{a}}$$

$$\boxed{\oint_{\mathcal{L}} \vec{B}\cdot d\vec{l} = \mu_0\varepsilon_0 \frac{d}{dt}\int \vec{E}\cdot d\vec{a}}$$



$$\oint_{\mathcal{L}} \vec{B}\cdot d\vec{l} = \frac{\mu_0 i}{4\pi}(4\pi - \Omega_2 - \Omega_1) = \mu_0 i - \mu_0 \frac{\frac{dQ}{dt}}{4\pi}(\Omega_2 - \Omega_1)$$

$$= \mu_0 i - \mu_0 \frac{d}{dt}\underbrace{\left(\frac{Q}{4\pi\varepsilon_0}\Omega_2' + \frac{Q}{4\pi\varepsilon_0}\Omega_1\right)\varepsilon_0}_{-\int_A \vec{E}\cdot d\vec{a}}$$

$$\boxed{\oint_{\mathcal{L}} \vec{B}\cdot d\vec{l} = \mu_0 i + \mu_0\varepsilon_0 \frac{d}{dt}\int_A \vec{E}\cdot d\vec{a}}$$

$$\boxed{\oint_{\mathcal{L}} \vec{B}\cdot d\vec{l} = \mu_0 \int_A \left(\vec{J} + \varepsilon_0 \frac{\partial \vec{E}}{\partial t}\right) d\vec{a}}$$ IV. Maxwellova

$$\oint_\gamma \vec{B}\cdot d\vec{l} = \mu_0\left(\int_A \vec{J}\cdot d\vec{a} + \varepsilon_0\int_A \frac{\partial E}{\partial t}\cdot d\vec{a}\right)$$

← Ampere

MAXWELL →

$$\int_A \vec{J}\cdot d\vec{a} = \int_A \vec{J}_{prosti}\cdot d\vec{a} + \int_A \frac{\partial \vec{P}}{\partial t}\cdot d\vec{a} + \oint_l \vec{M}\cdot d\vec{l}$$

($\frac{\partial \vec{P}}{\partial t}$: $\vec{J}_{polarizacijski}$)

I_{prosti} $\qquad$ $I_{polariz}$ $\qquad$ $I_{magnetizacijski}$

$$\oint_\gamma \frac{\vec{B}}{\mu_0}\cdot d\vec{l} = \int_A \vec{J}_{pr}\cdot d\vec{a} + \int_A \frac{\partial P}{\partial t}\, d\vec{a} + \oint_\gamma \vec{M}\cdot d\vec{l} + \varepsilon_0\int_A \frac{\partial E}{\partial t}\cdot d\vec{a}$$

$$\oint_\gamma \underbrace{\left(\frac{\vec{B}}{\mu_0}-\vec{M}\right)}_{\vec{H}}\cdot d\vec{l} = \int_A \left(\vec{J}_{pr} + \frac{\partial}{\partial t}\underbrace{(\varepsilon_0\vec{E}+\vec{P})}_{\vec{D}}\right)\cdot d\vec{a}$$

$$\boxed{\oint_\gamma \vec{H}\cdot d\vec{l} = \int_A \left(\vec{J}_{pr} + \frac{\partial D}{\partial t}\right)\cdot d\vec{a}} \quad \oplus \quad \oint \vec{E}\cdot d\vec{l} = -\int \frac{\partial B}{\partial t}\cdot d\vec{a}$$

$\frac{\partial D}{\partial t}$ → Gostota Maxwellovega premikalnega toka

← Vrtinčnost - Ampere

⇒ Valovna enačba ⇒ Svetloba je EMV

$$\frac{\partial D}{\partial t} = \frac{\partial P}{\partial t} + \varepsilon_0\frac{\partial E}{\partial t}$$

Tolmač se pojem etra - je tako zmotil da je prav

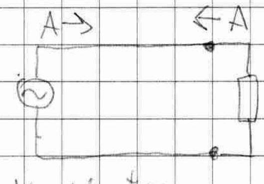
Ta enačba ne pove da tok povzroči magn. polje. Napaka. Namreč samo pove kako sta povezana, ne kdo koga povzroča

BIBLIJA - razdelki

- Rešimo M in ostalih enačb (4: kvantnost E, B, rotacija E, B) vse le o povezanosti, ne o povzročanju
kontinuitetna, divergenca

- Valovanje in difuzija - razlikuj!

$$\boxed{\varepsilon_0\mu_0 c_0^2 = 1}$$



Karakteristična upornost in čase dolžina refleksije

$$\frac{\partial^2\psi}{\partial x^2} - \mu\varepsilon\frac{\partial^2\psi}{\partial t^2} = 0 \qquad \mu\varepsilon \to \frac{1}{c^2}$$

$$\frac{\partial^2\psi}{\partial x^2} - \frac{1}{c^2}\frac{\partial^2\psi}{\partial t^2} = 0$$

VALOVNA ENAČBA

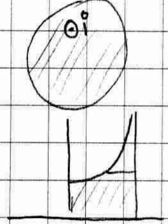
Rešitev: $\psi(t \pm \frac{x}{c})$ naključna valovna f-ja, ki je 2x odvedljiva

VALOVNA FUNKCIJA

$\psi_1(t - \frac{x}{c})$ − vzdolž osi x potuje val

$\psi_2(t + \frac{x}{c})$ − potuje v nasprotno smer $(-x)$

Difuzija → Kožni efekt



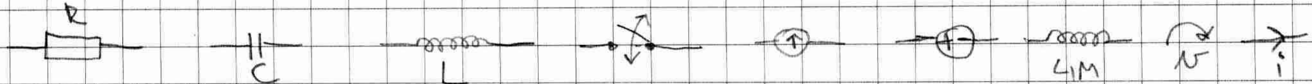
Poyntingov vektor → Površinski del v žica

Z zanemarjanjem členov

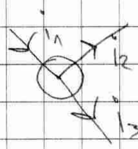
$$\frac{\partial^2 \psi}{\partial x^2} - k\frac{\partial \psi}{\partial t} = 0 \Rightarrow \text{Difuzijska enačba}$$

To je vse v učbeniku, ostalo tega se pride z reševanjem vseh teh enačb

ELEKTRIČNA VEZJA

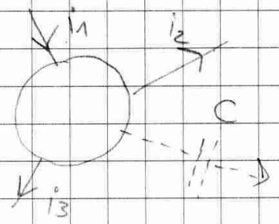


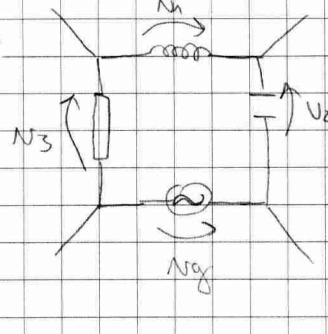
I. in II. Kirchofov zakon



$$-i_1+i_2+i_3=-\frac{dQ_{not}}{dt}=C\frac{dU_T}{dt}$$

$$-i_1+i_2+i_3=0$$

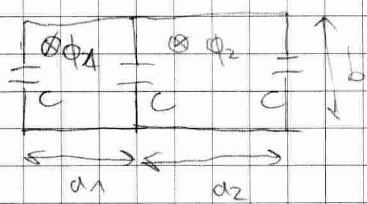




$$v_1-v_2-v_g+v_3=-\frac{d\phi}{dt}$$

V vezjih strnjenih elementov geometrija ni relevantna, površina zanke $=0$, $\phi=0$

$$v_1-v_2-v_3-v_g=0$$

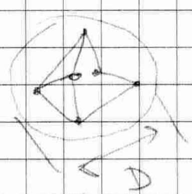


$$\sum_{k=1}^{n}(\pm)\,i_k+\frac{dQ}{dt}\,?=0$$

$$\sum_{k=1}^{n}(\pm)\,v_k+\frac{d\phi}{dt}\,?=0$$

Kdaj obravnavamo kot vezje?

KRITERIJ KONCEPTA VEZJA:



$$D \ll \lambda=\frac{c}{\nu}$$

Višje frekvence za manjše razsežnosti

$D \not\subset \lambda$

(A)LV
aktivno linearno vezje
- aktivni elementi
- pasivni el.
- stikala

⇐

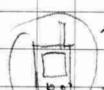
I. Kz
II Kz
Vezni tok
Vezni napetosti
moči
energije

TELLEGENOV STAVEK

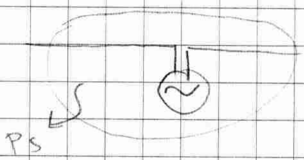
$$\sum_{k=1}^{n} v_k i_k = 0 \qquad v_k i_k = p_{bk} - p_{gk}$$

$$\sum_{k=1}^{n} p_{gk} = \sum_{k=1}^{m} p_{bk} = P_{\text{na uporih}} + P_{\text{elektrenja}} + p_{\text{za magnetenje}}$$

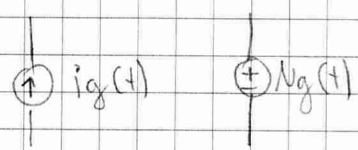
Za $D \not\subset \lambda$ to ne drži



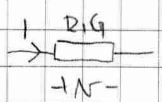
Poyntingov stavek - dodamo še moč sevanja



AKTIVNI ELEMENTI



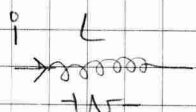
PASIVNI ELEMENTI



$i = Gv$

$p = vi$

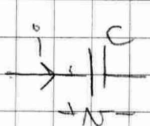
$\int_{t_1}^{t_2} p(t)dt = W(t_2) - W(t_1)$



$v = Li'$

$p_m = vi = \frac{dW_m}{dt}$

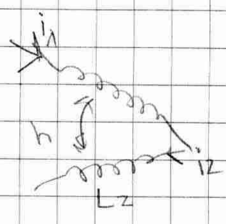
$W_m = \frac{Li^2}{2}$



$i = Cv'$

$p_e = vi = \frac{d}{dt} W_e$

$W_e = \frac{Cv^2}{2}$



$v_1 = L_1 i_1' + M i_2'$

$v_2 = M i_1' + L_2 i_2'$

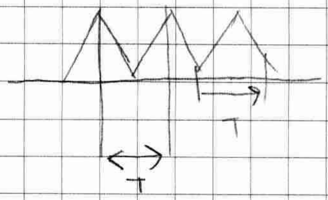
$p_m = v_1 i_1 + v_2 i_2$

$W_m = \frac{1}{2} L_1 i_1^2 + \frac{1}{2} L_2 i_2^2 + M i_1 i_2$

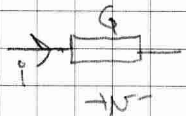
$p_m = W_m'$

SREDNJA IN EFEKTIVNA VREDNOST PERIODIČNEGA TOKA OZ. NAPETOSTI

$v(t+T) = v(t) \quad \forall t$



$$v_{sr} = \frac{1}{T}\int_{t_1}^{t_1+T} v(t)\,dt = \overline{v}$$



$p = Gv^2$ če periodičen v, je tudi p $\quad p(t'+T) = p(t')$

$$P_{sr} = \frac{1}{T}\int_{t_1}^{t_1+T} Gv^2(t)\,dt = G\,\frac{1}{T}\int_{t_1}^{t_1+T} v^2(t)\,dt = G\,U_{ef}$$

$$U_{ef}^2 = \frac{1}{T}\int_{t_1}^{t_1+T} v^2(t)\,dt = \overline{v^2}$$

KONDENZATOR

$W_e = \frac{Cu^2}{2}$ $\quad$ če $v(t+T) = v(t) \Rightarrow \overline{W_e} = C\frac{\overline{v^2}}{2} = \frac{CU_{ef}^2}{2}$

TULJAVA

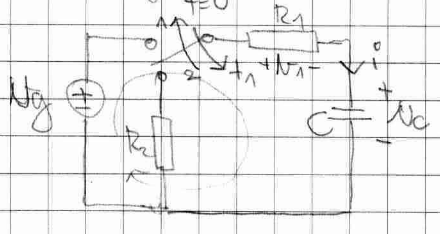
$W_m = \frac{Li^2}{2}$ $\quad$ če $i(t+T) = i(t) \Rightarrow \overline{W_m} = L\frac{\overline{i^2}}{2} = L\frac{I_{ef}^2}{2}$

PREHODNI POJAVI V EL. VEZJIH

19.5.11

Hipni odzivi – vklop/izklop
– Sami mamo tu zadnjič začeli pogoj pri diferencialkah. N

1) Zgled – Vklop in izklop RC vezja



$v_C(t \leq 0) = U_0$, Predhodno nabit kondenzator

Položaj 1: $0 \leq t \leq t_1$

Kirchof-zančna enačba

$-U_g + R_1 i + v_C = 0$; $i = C v_C'$

$R_1 C u_C' + u_C = U_g$ — L.D.E (Nehomogena)

Napetost na kond. se zvezno spreminja

④ $v_C(0) = U_0 = v_C(0+)$

Reševanje DE: $R_1 C v_{ch}' + v_{ch} = 0$; $v_{ch} = Ae^{\lambda t}$

$(\lambda R_1 C + 1)\,Ae^{\lambda t} = 0$

$\rightarrow \lambda = -\frac{1}{R_1 C}$ $\quad \frac{1}{R_1 C} = \tau^{-1}$

$\tau_1 = R_1 C$

↓

Časovna konstanta

Partikularni del

$v_{cp} = U_g$

$v_C = Ae^{\lambda t} + U_g$, Splošna rešitev

$v_C(0) = U_0 = Ae^{0} + U_g$

$\Rightarrow A = U_0 - U_g$

$v_C(t \geq 0) = U_g + (U_0 - U_g)\,e^{-t/\tau_1}$

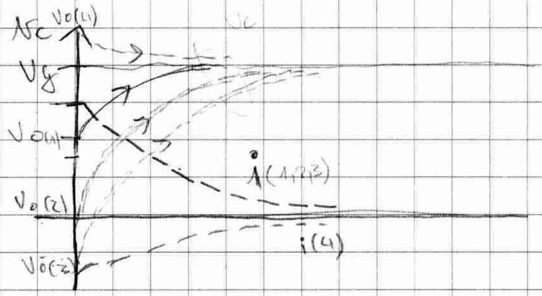
$$\boxed{V_c(t \geq 0) = V_0 + (V_g - V_0)(1 - e^{-t/T_1})}$$

V_0 → Napetost tik pred vklopom

$-t/T_1$ → Neka značaj tega časa za majhne čase → 0. Po določenem času ta funkcija ...

$$i = C V_c' = \frac{V_g - V_0}{RC} C e^{-t/T_1} = \frac{V_g - V_0}{R_1} e^{-t/T}$$

Startna vrednost toka



2. POLOŽAJ $t_1 \leq t < \infty$

$v_c(t_1) = V_1$ (izračunana naša začetna vrednost)

$R_1 i + v_c + R_2 i = 0$

$(R_1 + R_2) i + v_c = 0$, $i = C v_c'$

$$\boxed{R_{12} C V_c' + V_c = 0} \quad (4) \quad \boxed{v_c(t \geq t_1) = V_1}$$

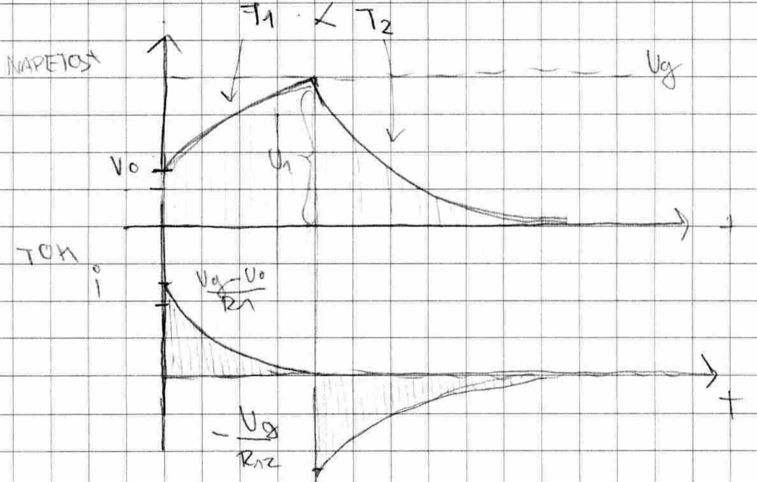
T_{12}

$v_c(t \geq t_1) = B e^{-t/RC}$

$v_c(t_1) = V_1 = B e^{-t_1/T_{12}} \Rightarrow B = V_1 e^{t_1/T_{12}}$

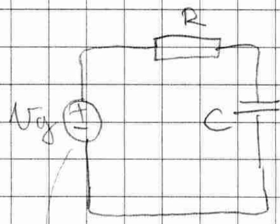
$$v_c(t \geq t_1) = V_1 e^{-(t-t_1)/T_{12}}$$

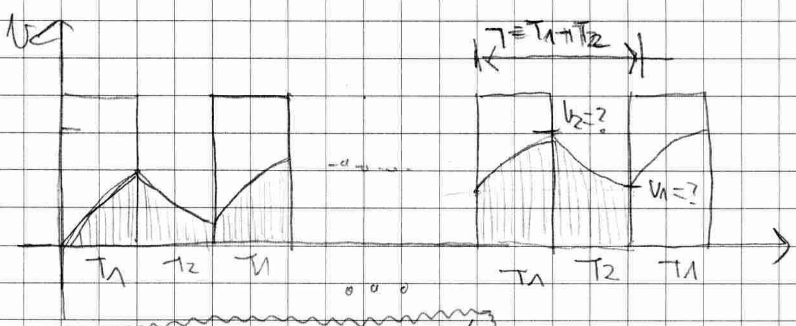
$$i(t \geq t_1) = -\frac{V_1}{R_{12}} e^{-(t-t_1)/T_{12}}$$



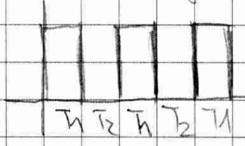
$$W_e = \frac{C v_c^2}{2} \qquad p_e = V_c i$$

2. Zgled – Funkcijski generator





> Funkcijski generator



$$V_2 = U_1 + (U_g - U_1)(1 - e^{-T_1/\tau}) \; ; \; \tau = RC$$

$$V_1 = U_2 e^{-T_2/\tau} \Rightarrow U_1, U_2$$

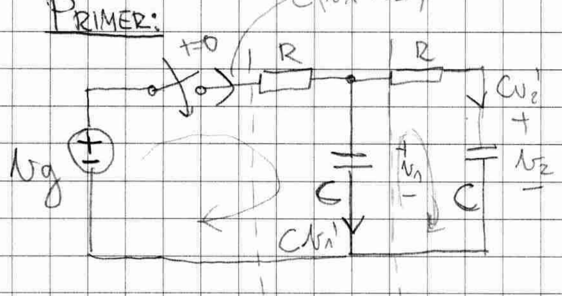
$T_1 = T_2 = T$

Enkrat bla taksna izpitna naloga

$$U_2 = U_1 + (U_g - V_1)(1 - e^{-1})$$

$$U_1 = V_2 e^{-1}$$

PRIMER:



Edino kar imamo so Kirchoffove enačbe

$$-V_1 + RCV_2'' + V_2' = 0$$

$$-V_g + RC(V_1' + V_2') + V_1 = 0 \Rightarrow V_1 = RCV_2' + V_2$$

$$-V_g + RC(V_1' + V_2') + V_1 = 0$$

$$(RC)^2 V_2'' + 3(RC) V_2' + V_2 = V_g$$ Dobili smo DE II. Reda

ZAČ. POGOJ

$$V_2(0-) = V_1(0-) = 0 \Rightarrow V_2(0+) = V_2(0-), \; V_1(0+) = V_1(0-) \Rightarrow V_2'(0+) = 0$$

Do prehodnih pojavov prihaja, ker imamo v teh vezjih akumulativne elemente ⇒ Kondenzatorji in tuljave.

$$\Rightarrow V_2(0+) = 0, \; V_2'(0+) = 0$$ Začetni pogoji

V R-vezjih nimamo takih problemov

Št. akumulativnih elementov nam določa stopnjo diferencialne

Reševanje DE: $V_{2h} = Ae^{\lambda t}$; $RC = T$

$$\lambda_{1,2} = \frac{-3T \pm \sqrt{9T^2 - 4T^2}}{2T^2} \Rightarrow \lambda_1, \lambda_2$$

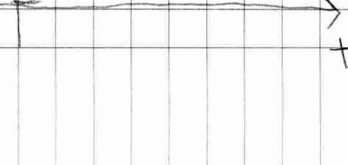
$$(T^2\lambda + 3T\lambda + 1) Ae^{\lambda t} = 0$$

$$U_{2h} = A_1 e^{\lambda_1 t} + A_2 e^{\lambda_2 t}$$

$$V_{2p} = V_g$$

$$0 = A_1 e^0 + A_2 e^0 + V_g \Rightarrow A_1, A_2$$

$$0 = \lambda_1 A_1 e^0 + \lambda_2 A_2 e^0$$



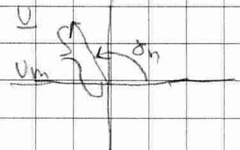
KAZALEC - KOMPLEKSOR

30.05.11

$v(t) = U_m \cos(\omega t + \vartheta_m)$ | $v(t) = \mathrm{Re}[\underline{U} e^{j\omega t}]$

$\underline{U} = U_m e^{j\vartheta_m}$

AMPLITUDNI KAZALEC



$$\sum_{k=1}^{n} (\pm) i_k = 0 = \sum_{k=1}^{n} (\pm) \mathrm{Re}[\underline{I}_k e^{j\omega t}] =$$

$$= \mathrm{Re}\left[\left(\sum_{k=1}^{n} (\pm) \underline{I}_k\right) e^{j\omega t}\right] = 0$$

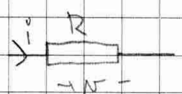
$\sum_{k=1}^{n} (\pm) \underline{I}_k = 0$	$\sum_{v=1}^{l} (\pm) \underline{U}_v = 0$

TOKOVNO - NAPETOSTNE RELACIJE

$v(t) = v = U_m \cos(\omega t + \vartheta_v) \iff \underline{U} = U_m e^{j\vartheta_v} \in \mathbb{C}$, $U_m, \vartheta_v \in \mathbb{R}$

$i(t) = i = I_m \cos(\omega t + \vartheta_i) \iff \underline{I} = I_m e^{j\vartheta_i}$

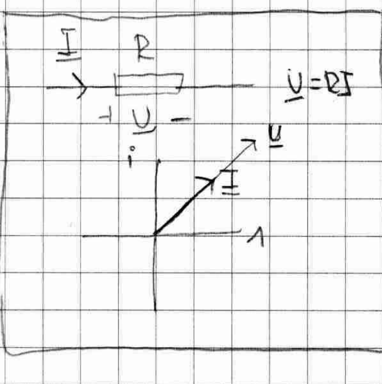
1.) UPOR



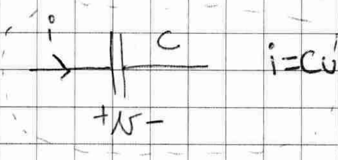
$v = Ri$

$v = Ri = RI_m e^{j\vartheta_i} = U_m e^{j\vartheta_v}$

$U_m = RI_m$, $\vartheta_v = \vartheta_i$



2.) KONDENZATOR



$i = Cv'$

$i = Cv' = C(U_m \cos(\omega t + \vartheta_v))'$

$= -\omega C U_m \sin(\omega t + \vartheta_v)$

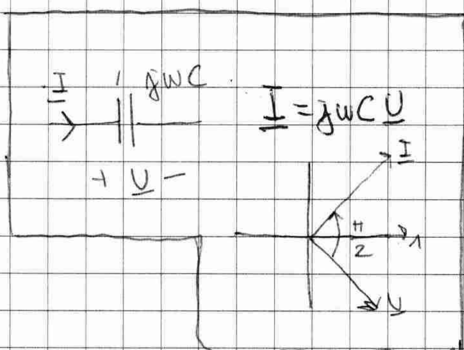
$= \omega C U_m \cos(\omega t + \vartheta_v + \pi/2) =$

$= I_m \cos(\omega t + \vartheta_i)$

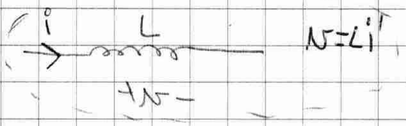
$I_m = \omega C U_m$; $\vartheta_i = \vartheta_v + \pi/2$

$\underline{I} = I_m e^{j\vartheta_i} = \omega C \underbrace{U_m e^{j\vartheta_v}}_{\underline{U}} \underbrace{e^{j\pi/2}}_{j} = j\omega C \underline{U}$

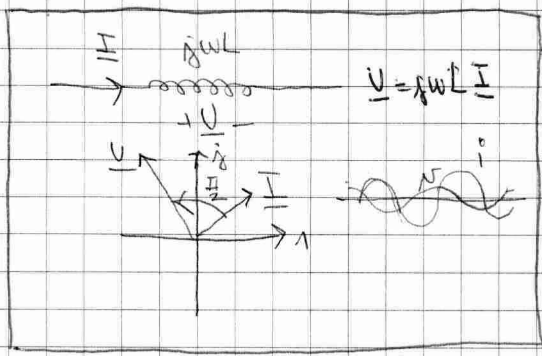
$v = \mathrm{Re}(\underline{U} e^{j\omega t})$



3.) TULJAVA

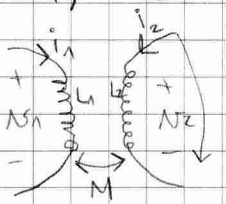


$v = L i'$



$U = j\omega L I$

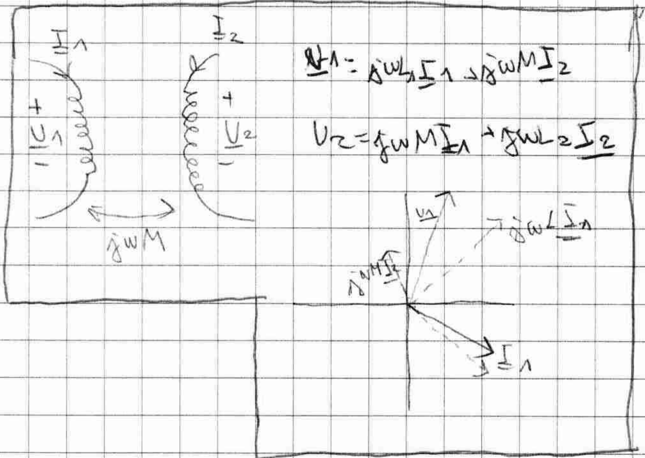
4.) SKLOP TULJAV (DVEH)



$v_1 = L_1 i_1' + M i_2'$

$v_2 = M i_1' + L_2 i_2'$

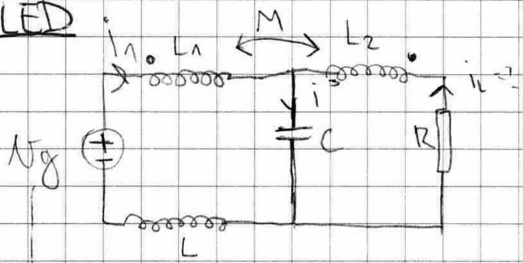
$\frac{d}{dt}(e^{j\omega t}) = j\omega (e^{j\omega t})$

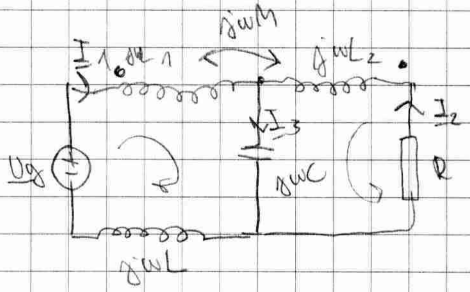


$U_1 = j\omega L_1 I_1 + j\omega M I_2$

$U_2 = j\omega M I_1 + j\omega L_2 I_2$

ZGLED





$v_g = V_{gm} \cos(\omega t + \vartheta_g)$

$i_k = I_{mk} \cos(\omega t + \vartheta_{ik})$

$k = 1, 2, 3 \ldots$

$i_k \Rightarrow I_k = I_{mk} e^{j\vartheta_{ik}}$

$U_g = U_{gm} e^{j\vartheta_g}$

$-I_1 - I_2 - I_3 = 0$

1: $-U_g + j\omega L_1 I_1 + j\omega M I_2 + \frac{I_3}{j\omega C} + j\omega L I_1 = 0$

2: $j\omega M I_1 + j\omega L_2 I_2 + \frac{I_3}{j\omega C} + R I_2 = 0$

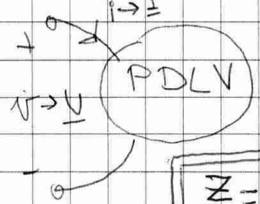
$I_1 \rightarrow i_1$, $I_2 \rightarrow i_2$, $I_3 \rightarrow i_3$

IMITANCA (IMPEDANCA IN ADMITANCA)

30.05.'11

(Kompl. upornost) (Kompl. prevodnost)

PASIVNO DVOPOLNO LIN. VEZJE



$i = I_m \cos(\omega t + \vartheta_i) \to \underline{I} = I_m e^{j\vartheta_i}$

$u = U_m \cos(\omega t + \vartheta_u) \to \underline{U} = U_0 e^{j\vartheta_u}$

$\underline{Z} = \underline{U}/\underline{I}$ IMPEDANCA

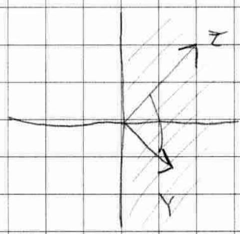
$\underline{Y} = \underline{I}/\underline{U} = \underline{Z}^{-1}$ ADMITANCA

$\underline{Z}\,\underline{Y} = 1$

$$\underline{Z} = \frac{\underline{U}}{\underline{I}} = \frac{U_m}{I_m}\frac{e^{j\vartheta_u}}{e^{j\vartheta_i}} = \frac{U_m}{I_m} e^{j(\vartheta_i - \vartheta_u)}$$

$\varphi = \mathrm{abs}(\underline{Z}) = \vartheta_u - \vartheta_i$

$Z = \mathrm{abs}(\underline{Z}) = |\underline{Z}|$

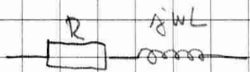


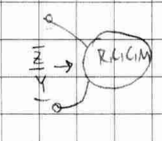
$\mathrm{Re}(\underline{Z}) \geq 0$

ELEMENT	Impedanca	Admitanca
Upor	R	$1/R = G$
Kondenzator	$\frac{1}{j\omega C}$	$j\omega C$
Tuljava	$j\omega L$	$\frac{1}{j\omega L}$

ZGLEDI DVOPOLOV

1.)



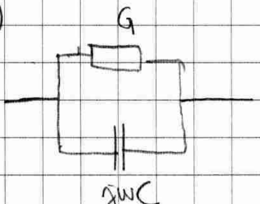


Pri vsaki frekvenci se vezje obnaša z drugačno upornostjo

$\underline{Z} = R + j\omega L$

$$\underline{Y} = \frac{1}{R + j\omega L}\cdot\frac{R - j\omega L}{R - j\omega L} = \frac{R - j\omega L}{R^2 + (\omega L)^2} = \frac{R}{R^2 + (\omega L)^2} - \frac{j\omega L}{R^2 + (\omega L)^2}$$

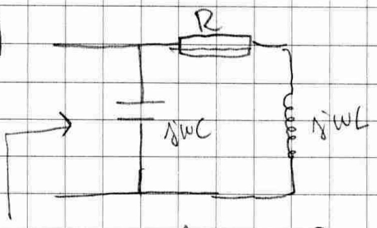
2.)



$\underline{Y} = G + j\omega C$

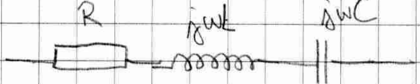
$$\underline{Z} = \frac{G - j\omega C}{G^2 + (\omega C)^2}$$

3.)

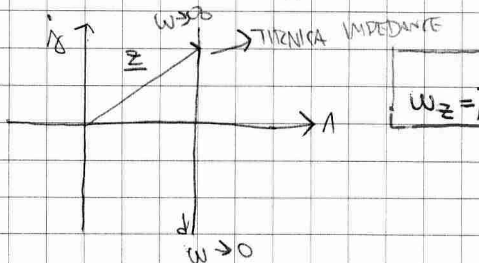


$$\underline{Y} = j\omega C + \frac{1}{R+j\omega L} = \frac{R}{R^2+(\omega C)^2} + j\omega\left(C - \frac{L}{R^2+(\omega L)^2}\right)$$

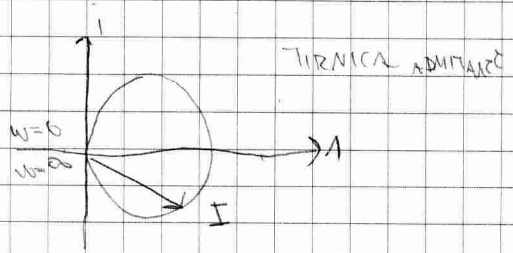
4.)



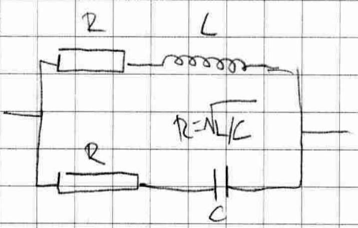
$$\underline{Z} = R + j\left(\omega L - \frac{1}{\omega C}\right)$$



$$\boxed{\omega_z = \frac{1}{\sqrt{LC}}}$$



5.)



$$\boxed{\underline{Z} = R}$$

To bo ena od kolokvijskih nalog

$$\underline{Z} = \underbrace{Re(\underline{Z})}_{R} + j\,\underbrace{Im(\underline{Z})}_{X}$$

REZISTANCA REAKTANCA

$$\underline{Y} = \underbrace{Re(\underline{Y})}_{G} + j\,\underbrace{Im(\underline{Y})}_{B}$$

KONDUKTANCA SUSCEPTANCA

6.6.XI

Kompenzacijski kondenzatorji - kompenzirajo jalovo moč.

STAVKI V HARMONSKO VZBUJANIH VEZJIH
(v kompleksnem)

1.) SUPERPOZICIJA (KOHERENTNI VIRI)
2.) NADOMESTITEV
3.) TELLEGEN
4.) THEVENIN-NORTON (KOHERENTNI VIRI)
5.) PRILAGODITEV (MAKSIMUM)
6.) RECIPROČNOST

1.) SUPERPOZICIJA

Možna, če so viri koherentni. Če ne pa vezje rešujemo za vsak vir posebej (samo časovni prostor)

2.) NADOMESTITEV

Tokovni / napetostni viri

3.) TELLEGEN

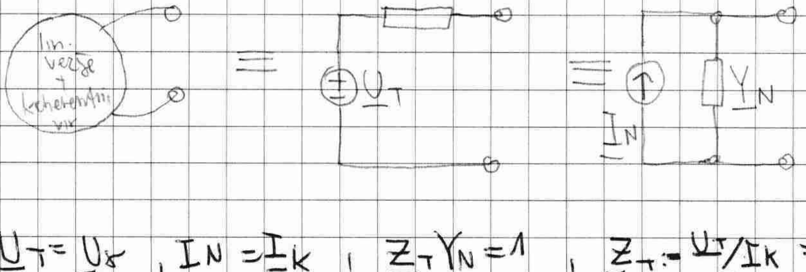
$$\sum_{k=1}^{n} i_k u_k = 0 \Rightarrow \sum_{k=1}^{n} \frac{1}{2} \underline{U}_k \underline{I}_k^* = 0$$

$$\underline{S}_{gk} - \underline{S}_{bk}$$

$$\sum_{k=1}^{n} \underline{S}_{gk} = \sum_{k=1}^{n} \underline{S}_{bk}$$

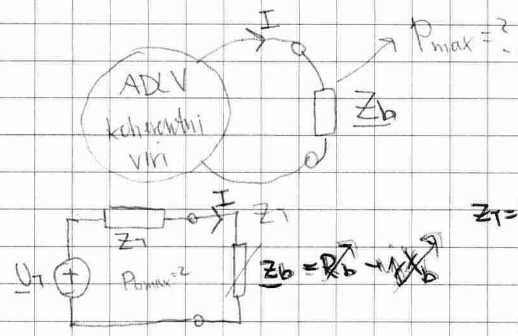
$$\sum_k P_{gk} = \sum_k P_{bk} \qquad \sum_k Q_{gk} = \sum_k Q_{bk}$$

4.) THEVENIN-NORTON



$\underline{U}_T = \underline{U}_o$, $\underline{I}_N = \underline{I}_k$, $\underline{Z}_T \underline{Y}_N = 1$, $\underline{Z}_T = \underline{U}_T / \underline{I}_k = \underline{Z}_{notr}$ → Pri deaktiviranih virih

5.) PRILAGODITEV



$$P_b = Re(\underline{S}_b) = Re\left[\frac{1}{2}(R_b + jX_b)|\underline{I}|^2\right]$$

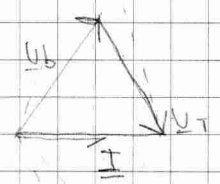
$$P_b = \frac{1}{2} R_b \frac{|\underline{U}_T|^2}{(R_T+R_b)^2 + (X_T+X_b)^2} = P_b(R_b, X_b)$$

$\underline{Z}_T = R_T + jX_T$

$$\frac{\partial P_b}{\partial R_b} = 0 \wedge \frac{\partial P_b}{\partial X_b} = 0 \Rightarrow X_b = -X_T \Rightarrow R_b = R_T$$

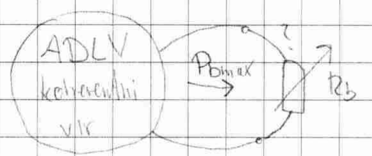
$\underline{Z}_T + \underline{Z}_B = 2R_T$

$$\boxed{\underline{Z}_b = \underline{Z}_T^*}$$



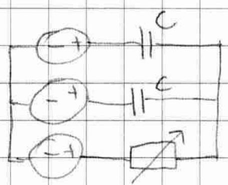
$P_{bmax} = ?$

$$\boxed{P_{bmax} = \frac{1}{8}\frac{|\underline{U}_T|^2}{R_T}} = \frac{|\underline{U}_T|^2/2}{R_T} \cdot \frac{1}{4}$$



$$P_b = \frac{1}{2} R_b \frac{|\underline{U}_T|^2}{(R_T+R_b)^2 + X_T^2} = P_b(R_b)$$

$$\frac{\partial P_b}{\partial R_T} = 0 \Rightarrow R_b = \sqrt{R_T^2 + X_T^2} = |\underline{Z}_T|$$

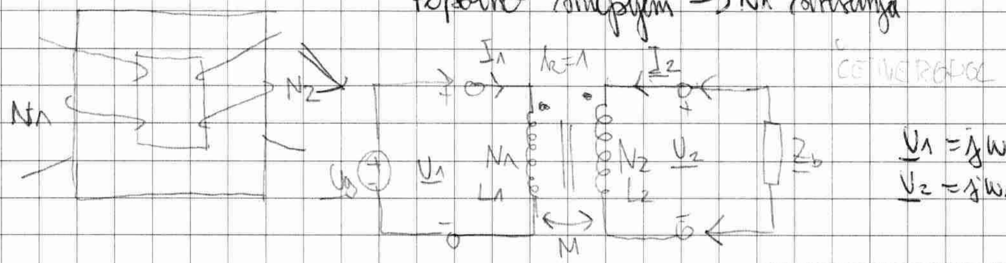


Trifazni sistem

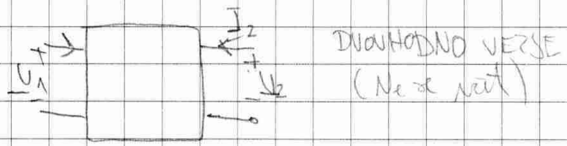
$P_{izg} = 0$ $(k=1)$

BREZIZGUBNI POPOLNO SKLOPLJENI TRANSFORMATOR → IDEALNI TRANSFORMATOR

Popolno sklopljeni ⇒ Ni stresanja



$$\underline{U}_1 = j\omega L_1 \underline{I}_1 + j\omega M \underline{I}_2$$
$$\underline{U}_2 = j\omega M \underline{I}_1 + j\omega L_2 \underline{I}_2$$



$$\underline{I}_1 = \frac{\underline{U}_2}{j\omega M} - \frac{L_2}{M}\underline{I}_2$$

$$\underline{U}_1 = j\omega L_1\left(\frac{\underline{U}_2}{j\omega M} - \frac{L_2}{M}\underline{I}_2\right) + j\omega M \underline{I}_2 = \frac{L_1}{M}\underline{U}_2 + j\omega\underbrace{\left(M - \frac{L_1 L_2}{M}\right)}_{0}\underline{I}_2$$

$M^2 = L_1 L_2$

$L_1 = \frac{M^2}{L_2}$

$$\underline{U}_1 = \frac{L_1}{M}\underline{U}_2 \qquad \underline{I}_1 = \frac{\underline{U}_2}{j\omega M} - \frac{L_2}{M}\underline{I}_2$$

$$\begin{bmatrix}\underline{U}_1\\ \underline{U}_2\end{bmatrix} = \begin{bmatrix} j\omega L_1 & j\omega M \\ j\omega M & j\omega L_2\end{bmatrix}\begin{bmatrix}\underline{I}_1\\ \underline{I}_2\end{bmatrix}$$ Impedančna matrika

$$\begin{bmatrix}\underline{U}_1\\ \underline{I}_1\end{bmatrix} = \begin{bmatrix} \frac{L_1}{M} & 0 \\ \frac{1}{j\omega M} & \frac{L_2}{M}\end{bmatrix}\begin{bmatrix}\underline{U}_2\\ (-\underline{I}_2)\end{bmatrix}$$ Verižna matrika

1.) $\underline{U}_1 = \frac{L_1}{M}\underline{U}_2 = \frac{N_1}{N_2}\underline{U}_2$, $\frac{\underline{U}_1}{\underline{U}_2} = \frac{N_1}{N_2} = n$ ← Prestava

2.) $\underline{Z}_b \to \infty \Rightarrow \underline{I}_2 = 0 \Rightarrow \underline{I}_1 = \frac{\underline{U}_2}{j\omega M} - \frac{L_2}{M}\cdot 0 = \frac{M\underline{U}_1}{j\omega M L_1} = \frac{\underline{U}_1}{j\omega L_1} = \underline{I}_m$ (magnetilni tok)

3.) $|\underline{Z}_b|$ - končen: $\underline{I}_1 = \underline{I}_m - \frac{N_2}{N_1}\underline{I}_2 = \underline{I}_m - n^{-1}\underline{I}_2$ $\qquad \underline{I}_r = \frac{1}{n}\underline{I}_2$

$\underline{I}_r$ → Reakcijski tok = Ravnotežni tok

4.) $\underline{\Theta} = N_1\underline{I}_1 + N_2\underline{I}_2 = N_1\underline{I}_m - \underbrace{N_1\frac{1}{n}\underline{I}_2 + N_2\underline{I}_2}_{0} = N_1\underline{I}_m$

5.) $\underline{Z}_{vh} = \frac{\underline{U}_1}{\underline{I}_1} = \frac{n\underline{U}_2}{\frac{\underline{U}_2}{j\omega M} - \frac{1}{n}\underline{I}_2}\cdot\frac{\frac{1}{n}(-\underline{I}_2)}{\frac{1}{n}(-\underline{I}_2)} = \frac{n\underline{Z}_b}{\frac{\underline{Z}_b}{j\omega M} + \frac{1}{n}}$

6.) $\left[\underline{S}_1 = \frac{1}{2}\underline{U}_1\underline{I}_1^* = \frac{1}{2}\underline{U}_1\left(\underline{I}_m^* - \frac{1}{n}\underline{I}_2^*\right) = \underbrace{\frac{1}{2}\underline{U}_1\underline{I}_m^*}_{jQ_{1m}\text{ - jalova moč}} + \overbrace{\frac{1}{2}\underline{U}_2(-\underline{I}_2)^*}^{\underline{S}_2 = \underline{S}_b} = jQ_{1m} + \underline{S}_2\right]$

$|\underline{I}_m| \ll |\underline{I}_1|$ reda 100 manjši $\Rightarrow \underline{I}_1 \simeq -\frac{1}{n}\underline{I}_2 \qquad \frac{\underline{U}_1}{\underline{U}_2} = n \qquad \frac{\underline{I}_1}{\underline{I}_2} \simeq -\frac{1}{n}$

Transformator pomembna za ekonomičnejši prenos energije $\qquad \tan\varphi = \sqrt{1 - \frac{1}{\cos^2\varphi}}$

IDEALNI TRANSFORMATOR

$R_m \to 0$, $\mu_r \to \infty$; $L_1, L_2, M \to \infty$

1.) $\frac{\underline{U}_1}{\underline{U}_2} = n = \frac{N_1}{N_2}$ KAZALČNI DIAGRAM ZA

2.) $\underline{I}_{1m} \to 0$

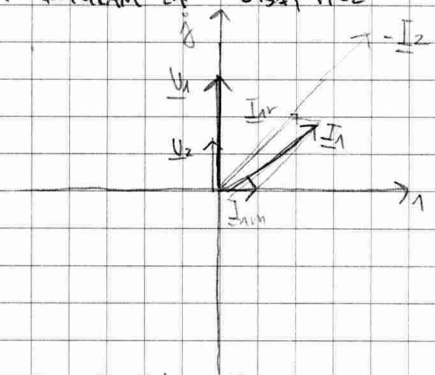
3.) $\underline{I}_1 = -\frac{1}{n}\underline{I}_2 = -\frac{N_2}{N_1}\underline{I}_2$

4.) $\underline{\Theta} \to 0$

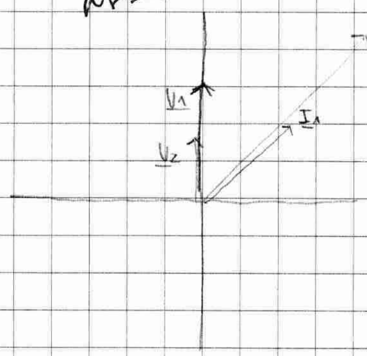
5.) $\underline{Z}_{vh} = n^2 \underline{Z}_b$

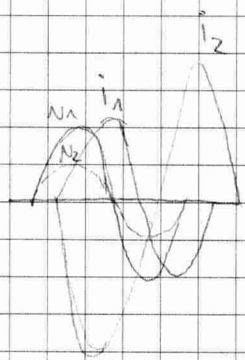
6.) $\underline{S}_1 = \underline{S}_2$

KAZALČNI DIAGRAM ZA OBR., $n=2$



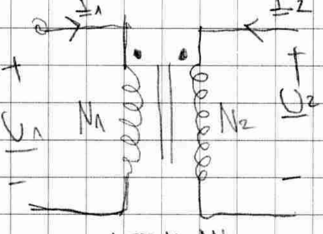
$\mu_r \to \infty$





9.6.

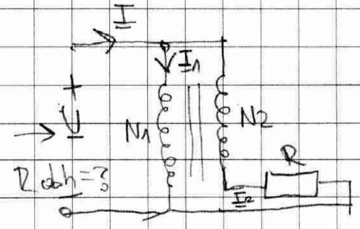
SIMBOLI IDEALNEGA TRANSFORMATORJA



$$\frac{\underline{U}_1}{\underline{U}_2} = -\frac{\underline{I}_2}{\underline{I}_1} = n$$

$n = N_1 : N_2$

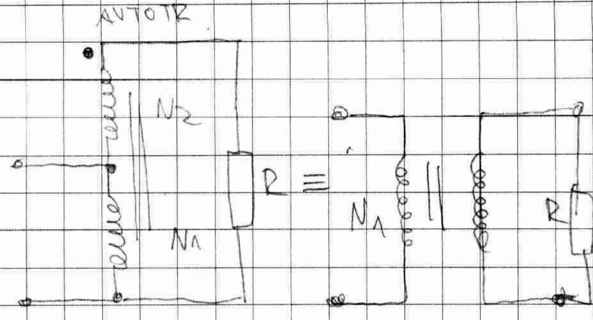
ZGLED – 6.56 P.N.



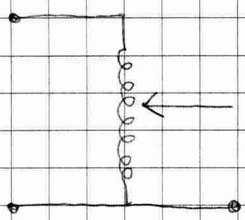
$$\underline{I}_1 - \underline{I}_2 = \underline{I}, \quad \frac{\underline{I}_2}{\underline{I}_1} = -N$$

$$\underline{U}_1 = \underline{U}, \quad \underline{U}_2 = \frac{\underline{U}_1}{n}$$

$$R\,\underline{I}_2 + \underline{U}_2 + \underline{U} = 0$$



AVTOTRANSFORMATOR



VARIAK
(AVTOTRANSFORMATOR)

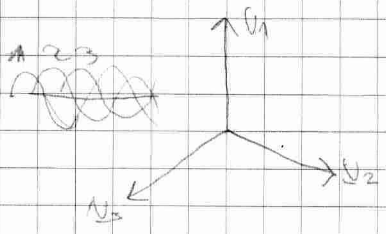
③ TRIFAZNI SISTEM

$v_1 = U_m \cos(\omega t + \vartheta)$
$v_2 = U_m \cos(\omega t + \vartheta \mp \frac{2\pi}{3})$
$v_3 = U_m \cos(\omega t + \vartheta \pm \frac{4\pi}{3})$

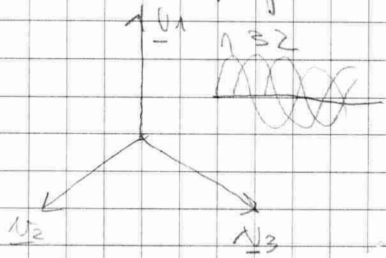
Negativni sistem / Pozitivni sistem

Pozitivno in negativno fazno zaporedje

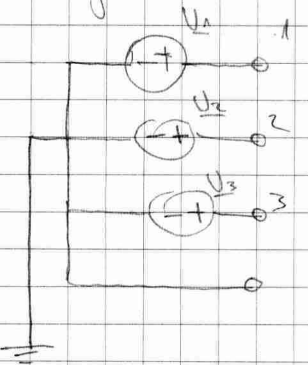
(+) Fazno zaporedje



(−) Negativno fazno zaporedje



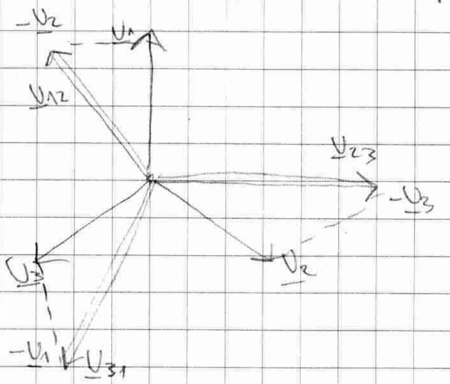
Vezava v skupno točko.
Na generatorski strani točka ozemljena (Spremenjena na zvezdo)

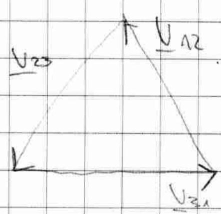


Fazne in medfazne napetosti

$v_{10}, v_{20}, v_{30} \to v_1, v_2, v_3 \to \underline{U}_1, \underline{U}_2, \underline{U}_3$

$v_{12}, v_{23}, v_{31} \to \underline{U}_{12}, \underline{U}_{23}, \underline{U}_{31}$





$\underline{U}_1 + \underline{U}_2 + \underline{U}_3 = 0$
$\underline{U}_{12} + \underline{U}_{23} + \underline{U}_{31} = 0$

Amplituda medfazne napetosti je $\sqrt{3}$ večja od fazne napetosti Npr 400kV daljnovod → 230kV

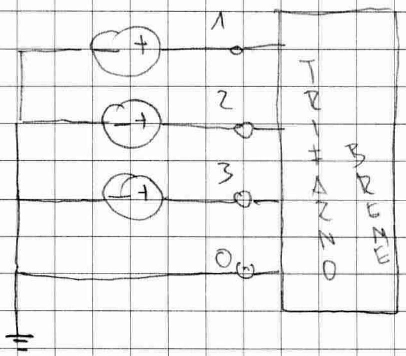
Nivoji: 400kV, 200kV, 110kV, ...

$230 U_{ef} \cdot \sqrt{3} \simeq 400 U_{ef}$

Amplitudni kazalec: $\underline{U}$, $v = Re(\underline{U} e^{j\omega t})$, $\underline{U} = U_m e^{j\vartheta_u}$ ← $\underline{S} = \frac{1}{2}\underline{U}\,\underline{I}^*$

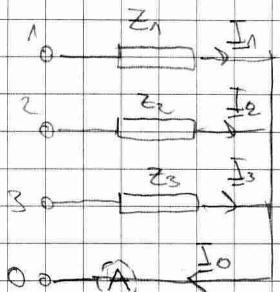
Efektivni kazalec: $\underline{U}$, $v = Re(\sqrt{2}\,\underline{U} e^{j\omega t})$, $\underline{U} = \frac{U_m}{\sqrt{2}} e^{j\vartheta_u} = U_{ef} e^{j\vartheta_u}$ ← $\boxed{\underline{S} = \underline{U}\,\underline{I}^*}$!

TRIFAZNO BREME IN OSNOVNI NAČINI PRIKLJUČEVANJA



zvezda in trikot osnovna načina

1) ZVEZDNA VEZAVA Z NIČLOVODOM



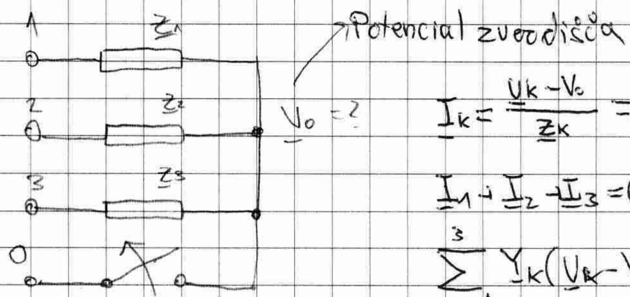
$$\underline{I}_k = \frac{\underline{U}_k}{\underline{Z}_k}$$

$$\underline{I}_0 = \underline{I}_1 + \underline{I}_2 + \underline{I}_3$$

$$\underline{S}_k = \underline{U}_k \underline{I}_k^*$$

$$\underline{S} = \underline{S}_1 + \underline{S}_2 + \underline{S}_3$$

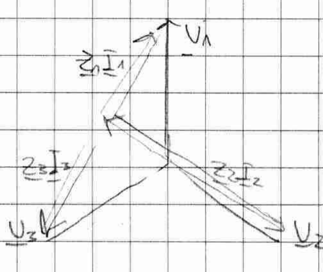
a) zvezdna vezava brez ničlovoda



$$\underline{I}_k = \frac{\underline{U}_k - \underline{V}_0}{\underline{Z}_k} = \underline{Y}_k(\underline{U}_k - \underline{V}_0)$$

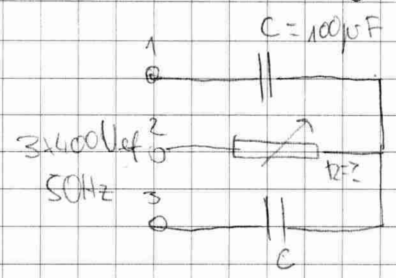
$$\underline{I}_1 + \underline{I}_2 + \underline{I}_3 = 0$$

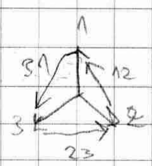
$$\sum_{k=1}^{3} \underline{Y}_k(\underline{U}_k - \underline{V}_0) = 0 \Rightarrow \underline{V}_0 = \frac{\underline{Y}_1\underline{U}_1 + \underline{Y}_2\underline{U}_2 + \underline{Y}_3\underline{U}_3}{\underline{Y}_1 + \underline{Y}_2 + \underline{Y}_3}$$

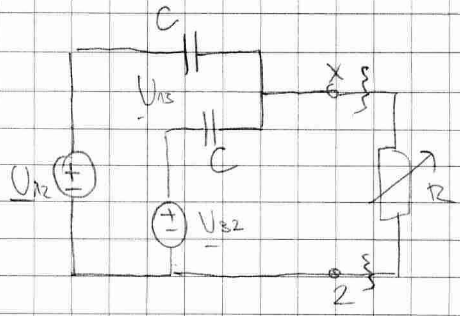


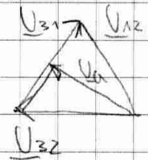
Na to temo naloga na kolokviju..

ZGLED: P.N. 6.69









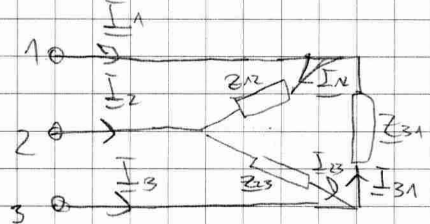
$$\underline{U}_0 = \frac{\underline{U}_{32} - \underline{U}_{12}}{2} + \underline{U}_{12} \qquad \frac{\underline{U}_{31}}{2}$$

$$|\underline{U}_0| = 400\sqrt{\frac{3}{2}}$$

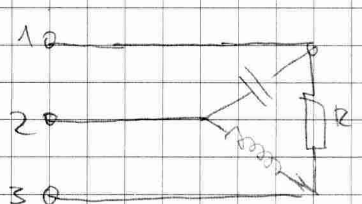
$$R = \frac{1}{2\omega C}$$

Največja moč ko bo polovica napetosti

2) TRIKOTNA VEZAVA BREMEN



Trikotna vezava pri motorjih.
Tudi za zagon asinhronskih motorjev.
Zagonski tok je veliko večji (10x) kot delovni. (trikot-zvezda-stikalo)
Stari uporabljajo ta stikala



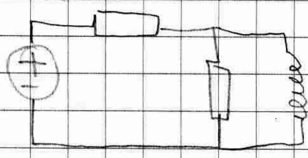
To breme proti omrežju zgleda kot trije upori.
Da lahko mirno enofazna bremena priključimo na omrežje

Kolokvij II

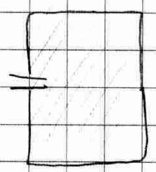
1. → RLC vezja z impedanco - zadnji namsel

2.) → Verava zvezda brez povratnega = ohm. potencial

3.) → vezje brez stikala



4.) →



Ovrednoti kroženje okoli tem vezju

5.) → Induktivnost - Trodelevna jedra z dvema navitjema - glej zgled v zapiskih