



Predmet:
Električni stroji

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Vrsta gradiva:
Zapiski avditornih vaj

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Študijsko leto:
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EL STROJI - avditorne

Fišer, <http://es.fe.uni-lj.si>

lab. vaje (nad robotiko → Katedra za mehatroniko)

↳ začetek 23.3.

delovni zvezek (kupi)

Razumevanje !

snov močnostne elektrotehnike (elektromehanski pretvorniki)



el. energ. pretvarja v mehansko

$$\begin{array}{l} W_{el} \rightarrow W_{meh} \\ W_{meh} \rightarrow W_{el} \end{array}$$

motorsko obratovanje

generatorsko

Obliki obratovanja:

- el. motor
- el. generator

(lahko delajo v obe smeri !)

30-40%

izkoristki 80 → 95%

rotacijski stroji

- ① transformator $W_{el} \rightarrow W_{el}$, izkoristek okoli 99 %
(ni mehanskih izgub, magnetenje skoraj idealno)

omejuje nas zaloga energije, ki jo moramo
s sabo voziti

$$\eta = \frac{P_{oddana}}{P_{sprejeta}} = \frac{P_{izh}}{P_{vh}} < 1$$

Rotac. stroje delimo na:

- ② - sinhronski
- ③ - asinhronski
- ④ - enosmerni

Posrednik je magnetno polje, izkoriščamo mag. indukcijo (spr. mag. polja po času/kraju !)

Trans. (vzb. z izmeničnim tokom → indukcija)

$$\mathcal{E} = -N \frac{d\Phi}{dt}$$

Faraday ind. zakon

Transformatorji (lahko zelo majhni ali ogromni), statični

Sinhr. stroji (generira el. energ.)

Asinhr. (ogromne moči, ali zelo majhne, tipičen predstavnik motorskega obratovanja)

Enosmerni (oboje - generatorji in motorji)

- Določite magn. tok dušilke, navite na toroid. jedro iz feromag. materiala!

↳ induktivni element (ne more bit skokne spremembe) → prehodni pojav

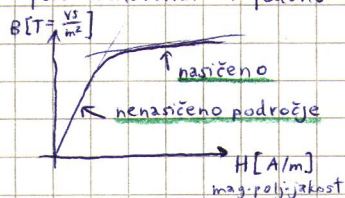
ferom. material → podano v obliki magnetilne krivulje

$$U = 230 \text{ V}$$

$$f = 50 \text{ Hz}$$

$$N = 1200$$

$$R_{sr} = 0,4 \text{ m}$$



začetek: linearen del (strm)

naprej: spet lin. del (vodoraven)

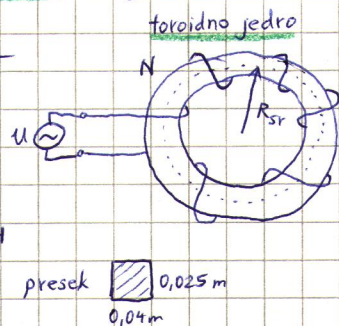
vmes: koleno

nasičeno p. (že polno izkoriščeno), silnice v jedru se bodo stresale v okolico

delovne točke postavljamo v koleno magnetilnice

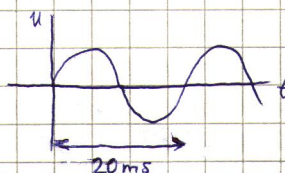


podana od proizvajalca

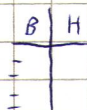


(mag. polje vstopa in izstopa)

jedra so lamelirana (da ni vrtilnih tokov - izgub)



U - kazalci



zanemarimo izgube v navitju

$$P_{cu} = 0, \text{ (upornost žic = 0, ni jouslskih izgub)}$$

$$P_{cu} = I^2 \cdot R$$

$$P_{Fe} = 0 \text{ (izgube v železu)}$$

$$\sum u = 0$$

$$u + e = 0$$

$$u = -e \text{ (po abs. vred. enaki)}$$

$$u = U_{max} \cdot \sin(\omega t) = \sqrt{2} U \cdot \sin(\omega t)$$

$$e = - \frac{d\psi(t)}{dt} = - N \frac{d\phi(t)}{dt}$$

mag. sklop

$$\psi = N \cdot \phi$$

$$\sqrt{2} U \cdot \sin(\omega t) - N \frac{d\phi(t)}{dt} = 0$$

$$\frac{d\phi(t)}{dt} = \frac{\sqrt{2}}{N} U \sin(\omega t)$$

$$\phi(t) = \int \frac{\sqrt{2}}{N} U \sin(\omega t) dt = - \frac{\sqrt{2} \cdot U}{N \omega} \cos(\omega t)$$

$$\phi_{max} = \frac{\sqrt{2} U}{N \cdot \omega}, \text{ } \omega \dots \text{ krožna frekv. } \rightarrow \omega = 2\pi f$$

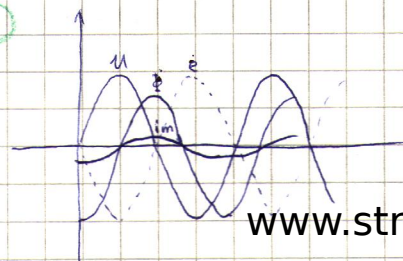
$$\phi_{max} = \frac{\sqrt{2} U}{N \cdot 2\pi f}$$

$$U = E = \frac{2\pi}{\sqrt{2}} \cdot f \cdot N \cdot \phi_{max} \cdot \frac{1}{2}$$

$$E = 4 \cdot \frac{\pi}{2\sqrt{2}} \cdot f \cdot N \cdot \phi_{max} = 4 \cdot \frac{\pi}{2\sqrt{2}} \cdot f \cdot N \cdot \phi_{max} = 4,44 \cdot f \cdot N \cdot \phi_{max} = 4,44 \cdot f \cdot N \cdot B_{max} \cdot S$$

(kvocient med ef. in sred. vred.)

$$\phi = B \cdot S_{Fe}$$

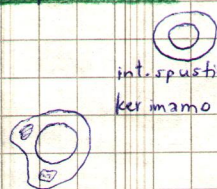


Amperov zakon

$$\oint \vec{H} \cdot d\vec{s} = \sum i_{\mu}$$

vsota vseh magnetnih vzbujanj

govori o povečevalcu mag. polja



$$H_{\max} \cdot l_{sr} = I_{\max} \cdot N$$

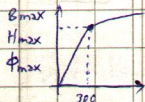
mag. količine

el. količine

$$H_{\max} \cdot l_{sr} = \sqrt{2} I_{\mu} \cdot N$$

$$I_{\mu} = \frac{H_{\max} l_{sr}}{\sqrt{2} N} = \frac{B_{\max} l_{sr}}{\mu \sqrt{2}}$$

$\cdot N ? \checkmark$



opreka imamo z
MAKSIMALNIMI
vrednostmi

$B_{\max}, H_{\max}, \Phi_{\max}$

$$B = \mu \cdot H$$

$$B = \mu_r \mu_0 H$$

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

podaja lastnost materiala (paramagnetni, dia-, fero-)

$$\mu_r \approx 1$$

↳ nekaj 1000 x več

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

$$\mu = \mu_r \cdot \mu_0$$

$$\mu_r = \frac{\mu}{\mu_0} = \frac{1}{300} \cdot \frac{10^{-7}}{4\pi} = 2653$$

$$B_{\max} = \frac{\Phi_{\max}}{S_{Fe}} = 0,86 T$$

$$\Phi_{\max} = \frac{U}{4,44 \cdot f \cdot N} = \frac{230}{4,44 \cdot 50 \cdot 1200} = 0,00086 Vs$$

$$S_{Fe} = 0,04 \cdot 0,025 = 0,001 m^2$$

$$l_{sr} = 2\pi R_{sr} = 0,8\pi m$$

$$\mu = \frac{1}{300} \cdot \text{odčitek}$$

$$I_{\mu} = \frac{B_{\max} \cdot l_{sr}}{\sqrt{2} \mu \cdot N} = \frac{0,86 \cdot 0,8\pi \cdot 300}{\sqrt{2} \cdot 1200 \cdot 1} = 0,382 A$$

ne ferom. material → navijemo na les

$$I_{\mu_0} = \frac{B_{\max} \cdot l_{sr}}{\mu_0 \sqrt{2} \cdot N} = \frac{0,86 \cdot 0,8\pi}{4\pi \cdot 10^{-7} \cdot \sqrt{2} \cdot 1200} = 10,14 A$$

mag. sklop z drugo tuljavo bo bistveno slabši

(tok bo uhajal vsepovsod)

↳ slab mag. sklop

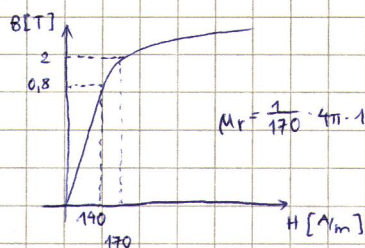
če imamo ferom. jedro

bo ves pretok notri → zaobjame vse silnice

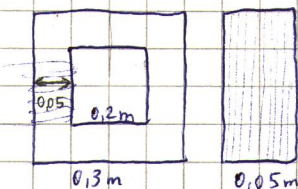
(le stresano mag. polje)

stroji postanejo učinkoviti, se bo dobro magnetil

- Enofazni transf. brez zr. reže ima jedro v obliki kvadratnega okvirja. Faktor polnjenja želez. jedra je 0,85. Magnetilna karakteristika:



$$\mu_r = \frac{1}{170} \cdot 4\pi \cdot 10^{-7} = 4680$$



$$0,3 - 0,2 = 0,1 \rightarrow S = 0,05 \cdot 0,05 = 0,0025$$

μ_{Fe}
ni le ferom. tudi plast oksida (zaradi lamel.)
kolikšen delež je ferom. koliko izolacija lameliramo $\perp$
bliže 1 $\rightarrow$ boljše izol.



- a) Določite št. primarnih ovijev N_1 , da bo pri pritisnjeni nap. $U_1 = 220V$, $f = 50Hz$ max. gostota v železu $B = 0,8T$.

$$E_1 = U_1 \text{ (idealni transf.)}$$

$$E_1 = 4,44 \cdot f \cdot N_1 \cdot \Phi = 4,44 \cdot f \cdot N_1 \cdot B \cdot S_{Fe}$$

$$S_{Fe} = S \cdot \mu_{Fe}$$

$$N_1 = \frac{U_1}{4,44 \cdot f \cdot B \cdot S \cdot \mu_{Fe}} = \frac{220}{4,44 \cdot 50 \cdot 0,8 \cdot 0,0025 \cdot 4680} = 583 \text{ (ovijev)}$$

zaokr. na nast. celo št.

transf. mora met jedro sklenjeno zr. reža $\rightarrow$ permeab. se spremeni iz 1000 na 1
(prinese veliko mag. upornost, magn. tok bo narastel)

motorji, gener. $\rightarrow$ nujna zr. reža

- b) Določite št. ovijev sekund. navitja tako, da bo v prostem toku sekund. induc. napetost $380V$! $E_2 = U_2 = 380V$ (prestava navzgor)

$$\frac{E_1}{E_2} = \frac{U_1}{U_2} = \frac{N_1}{N_2}$$

$$N_2 = N_1 \frac{E_2}{E_1} = 583 \frac{380}{220} = 1007$$

- c) Kolikšna je nazivna moč transf., če je μ_{Fe} transf. okna 0,3 pri navitju, ki je obremenjeno s specif. gostoto toka $j = 2 \cdot 10^6 A/m^2$? (2-5) A/mm^2 normalna gostota

$$S_{Cu} = \frac{S_{ok}}{2} \cdot \mu_{Cu}$$

$$S_{Cu1} = \frac{S_{ok}}{2} \cdot \mu_{Cu} \cdot \frac{1}{N} = \frac{0,2 \cdot 0,2}{2} \cdot 0,3 \cdot \frac{1}{583} = 10 \cdot 10^{-6} m^2 = 10 mm^2$$

$$I_{Cu} = j \cdot S_{Cu1} = 2 \cdot 10^6 \cdot 10 \cdot 10^{-6} = 20 A$$

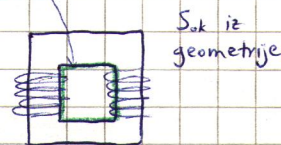
$$S_n = U_1 \cdot I_{Cu} = 220 \cdot 20 = 4,4 kVA$$

moč transf. večja, če bo večji tok

(z ne moremo vodit po žici poljubno toka $\rightarrow$ gostota toka;

fakt. polnjenja: koliko žice lahko damo v okno?

boljše polnjenje, če je tanjša žica



Suk iz geometrije

- d) Za koliko se spremeni magn. tok transf., če v jedru naredimo zr. režo 0,5mm?

$$d = 0,5 mm$$

$$B = \mu_r \mu_0 H$$

$$H_{max} \cdot l_{sr} = \sqrt{2} \cdot I_{\mu} \cdot N_1$$

$$I_{\mu} = \frac{H_{max} \cdot l_{sr}}{\sqrt{2} \cdot N_1} = \frac{140 \cdot 1}{\sqrt{2} \cdot 583} = 0,17 A$$

$$J_{\mu} = \frac{H \cdot d}{\sqrt{2} \cdot N_1} = \frac{B \cdot d}{\sqrt{2} \cdot \mu_0 \cdot N_1}$$

$$= \frac{B \cdot \mu_{Fe} \cdot d}{\sqrt{2} \cdot \mu_0 \cdot N_1} = \frac{0,8 \cdot 4680 \cdot 0,5 \cdot 10^{-3}}{\sqrt{2} \cdot 4\pi \cdot 10^{-7} \cdot 583} = 0,33 A$$

$$\text{skupni magn. tok } J = J_{\mu} + J_{\sigma} = 0,17 + 0,33 = 0,5 A$$

ko pridemo iz ferom. v zrak, se presek poveča, B zmanjša (materialno in geom. se spremeni)

$$B_{\sigma} = B \cdot \mu_{Fe}$$

veliko žic
izolacija ni zamenljiva debeline vmes zrak

$$\Phi = \int B \cdot S$$

Transf. ima podatke:

Določite razmerje izgub v bakru proti izg. v železu pri nazivnem obratovalnem stanju in nespremenjeni ef. vred. pri 50 Hz.

nazidezna moč $S_n = 50 \text{ kVA}$
 prestavno razm. $P = G = \frac{M}{N_2} = \frac{U_1}{U_2}$
 (med prim. in sek. napet. / oboji)
 $f = 42 \text{ Hz}$

izgube v prostem teku transf. $U_1 = 2400 \text{ V}$
 $P_0 = 300 \text{ W}$
 Upornost prim. navitja $R_1 = 0,76 \Omega$ (odvisna od T)
 $R_2 = 0,006 \Omega$

toplo stanje 75°C
 $R_t = R_{hl} (1 + \alpha \Delta T)$
 hladno temp. koef. upornosti
 $0,0041 \text{ AL}$
 $0,0033 \text{ Cu}$

$P_0 \approx P_{Fe}$, $P_{Cu} = I^2 R$
 $P_{cun} = P_{cu1} + P_{cu2} = I_{1n}^2 R_1 + I_{2n}^2 R_2 = 20,83^2 \cdot 0,76 + 125,00^2 \cdot 0,006 = 423,50 \text{ W}$
 nazivno obrat.

$I_{1n} = \frac{S_n}{U_1} = \frac{50 \cdot 10^3}{2400} = 20,83 \text{ A}$

$I_{2n} = P \cdot I_{1n} = 20,83 \cdot 6 = 125,00 \text{ A}$

$\frac{P_{cun}}{P_{Fen}} = \frac{423,50}{300} = 1,41$

(izgub v bakru je ponavadi več)

P_{Fen} - konst. pri isti U in f

histerezne

$P_H = k_H \cdot \frac{f}{50} \cdot B^x \cdot m_{Fe}$

vrt. tokovi $P_v = k_v \cdot \left(\frac{f}{50}\right)^2 \cdot B^2 \cdot m_{Fe}$

$x = (1,5 \div 3,0)$
 $P_v \propto (f, B)^2$

k_H, k_v - specif. izgube za ferom. material
 50 Hz, 1 T, 1 kg

$P_{Fe} = k_{Fe} \cdot \frac{f}{50} \cdot B^2 \cdot m_{Fe}$

$\left\{ \begin{array}{l} E = 4,44 \cdot f \cdot B \cdot N \cdot S_{Fe} \\ E' = 4,44 \cdot f' \cdot B' \cdot N \cdot S_{Fe} \end{array} \right\} \%$

$\frac{E}{E'} = \frac{f}{f'} \cdot \frac{B}{B'} = 1$, $E' = E$

$B' = B \cdot \frac{f}{f'}$

ne delaj na pamet!

$E \propto f \cdot B$
 $P_{Fe} \propto f \cdot B^2$

$B = \frac{E}{f}$

če razmerje ohranjamo konstantno

$\left\{ \begin{array}{l} P_{Fe} = k_{Fe} \cdot \frac{f}{50} \cdot B^2 \cdot m_{Fe} \\ P_{Fe}' = k_{Fe} \cdot \frac{f'}{50} \cdot B'^2 \cdot m_{Fe} \end{array} \right\}$

$\frac{P_{Fe}'}{P_{Fe}} = \frac{f'}{f} \cdot \frac{B'^2}{B^2} = \frac{f'}{f} \cdot \frac{B^2}{B^2} \left(\frac{f}{f'}\right)^2 = \frac{f'}{f} = \frac{42}{50} = 0,84$

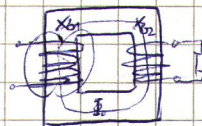
$P_{Fe}' = P_{Fe} \cdot 0,84 = 252 \text{ W}$

izgube so se znižale

$\frac{P_{cun}}{P_{Fe}'} = \frac{423,5}{252} = 1,68$

Enofazni transf.

$$X = \omega L_3$$



$$S_n = 50 \text{ kVA}$$

$$\frac{U_1}{U_2} = 2400/400 \text{ V}$$

$$f = 50 \text{ Hz}$$

$$R_1 = 0,72 \Omega$$

$$R_2 = 0,07 \Omega$$

induktivni upornost

$$X_{b1} = 0,92 \Omega$$

$$X_{b2} = 0,009 \Omega$$

avni mág. pretok

$$X_o = 4,5 \text{ k}\Omega$$

$$R_o = 34 \text{ k}\Omega$$

izgube v železu

ind. uporn. zaradi stresanja mag. polja

Nariši nadom. shemo transf. glede na prim. stran in izr. reducirane vrednosti!

Redukcijski faktorji:

$$\left. \begin{aligned} E_1 &= 4,44 \cdot f \cdot N_1 \cdot \Phi \\ E_2 &= 4,44 \cdot f \cdot N_2 \cdot \Phi \end{aligned} \right\} \frac{E_1}{E_2} = \frac{N_1}{N_2}$$

$$E_2 = 4,44 \cdot f \cdot N_2 \cdot \Phi$$

$$E_1' = 4,44 \cdot f \cdot N_1 \cdot \Phi$$

$\Phi = \text{konst.}$

$$\frac{E_2}{E_1'} = \frac{N_2}{N_1} \rightarrow \underline{E_1' = E_2 \cdot \frac{N_1}{N_2}}$$

$$I_2' N_1 = I_2 N_2 \rightarrow \underline{I_2' = I_2 \cdot \frac{N_2}{N_1}}$$

$$S_2' = E_2' \cdot I_2' = E_2 \cdot \frac{N_1}{N_2} \cdot I_2 \cdot \frac{N_2}{N_1} = E_2 \cdot I_2 = S_2$$

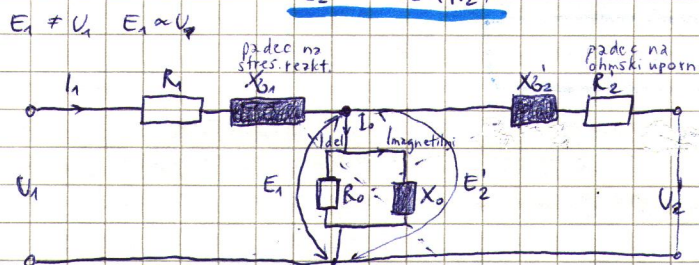
$$I_2'^2 R_2 = I_2^2 R_2' \rightarrow \underline{R_2' = R_2 \left(\frac{N_1}{N_2} \right)^2}$$

$$\underline{X_{b2}' = X_{b2} \left(\frac{N_1}{N_2} \right)^2}$$

$$\frac{N_1}{N_2} = 6$$

$$R_2' = 0,07 \cdot 6^2 = 2,52 \Omega$$

$$\underline{X_{b2}' = 0,324 \Omega}$$



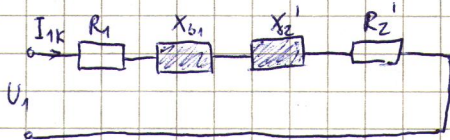
b) Izr. tok kratkega stika in kratkostično nap., če sta sekundarni sponki vezani kratko.

odprte sponke → noben tok na sekundarni

v kratkem stiku bo transf. najbolj omejen obremenjen

ker $R_o, X_o \gg R_1, R_2', X_{b1}, X_{b2}'$ prečno vejo zanemarimo

- kratkostični



kratkostična impedanca

$$\hat{Z}_k = R_1 + R_2' + j(X_{b1} + X_{b2}')$$

$$|\hat{Z}_k| = \sqrt{(R_1 + R_2')^2 + (X_{b1} + X_{b2}')^2} = \sqrt{3,24^2 + 1,24^2} = 3,47 \Omega$$

ponoviti, zelo velik

$$I_{1k} = \frac{U_1}{\hat{Z}_k} = \frac{2400}{3,47} = 692 \text{ A}$$

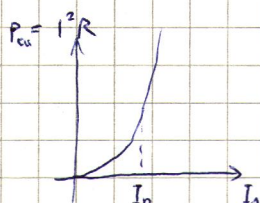
(zaradi meh. in termičnih vplivov je treba transf. zasčititi)

pri normalni obremenitvi

$$I_n = \frac{S_n}{U_1} = \frac{50 \cdot 10^3}{2400} = 20,83 \text{ A}$$

$$\frac{I_{1k}}{I_n} = \frac{692}{20,83} = 33,2$$

$$\boxed{I_k \gg I_n}$$



Kratkostična nap. je tista pritiskljiva napet., ki pri kratko sklenjenih sekund. sponkah, ki navitja ~~transf~~ požene nazivni tok.

$$U_k = Z_k \cdot I_n = 3,47 \cdot 20,83 = 72,3 \text{ V}$$

$$u_k = \frac{U_k}{U_n} \cdot 100\% = \frac{72,3}{2400} \cdot 100\% = 3\% \quad \text{Kolikšen delež } U_k \text{ že požene } U_n?$$

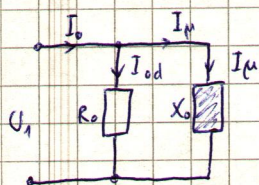
majhni
procenti

$$u_k = (3 \div 8)\%$$

c) Iz delovno in jalovo komponento toka prostega teka!

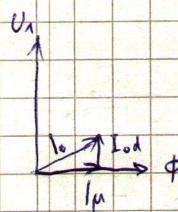
padca $R_1, X_{\sigma 1}$ zanemarimo
(tok ne teče)

ni bremena na izhodu - sponke so odprte (toka preko ni)



$$I_{od} = \frac{U_1}{R_0} = \frac{2400}{34 \cdot 10^{-3}} = 0,071 \text{ A}$$

$$I_{\mu} = \frac{U_1}{X_0} = \frac{2400}{4,5 \cdot 10^{-3}} = 0,533 \text{ A}$$



najmanj obremenjeno
stanje

$$I_0 = \sqrt{I_{od}^2 + I_{\mu}^2} = 0,538 \text{ A}$$

delovne komp.
so v fazi z napet.

$$I_0 (I_{\mu}) \ll I_n$$

$$\frac{I_0}{I_n} = \frac{0,538}{20,83} = 2,58\%$$

$$I_k \gg I_n \gg I_0$$

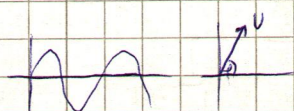
Razvoj kazalčnega diagrama transformator

$$u(t) = U \cdot \cos(\omega t + \varphi)$$

$$u(t) = U \cdot e^{j(\omega t + \varphi)} = U \cdot e^{j\omega t} \cdot e^{j\varphi}$$

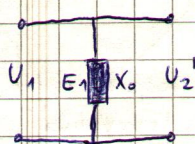
kazalec

$$U = U \cdot e^{j\varphi}$$



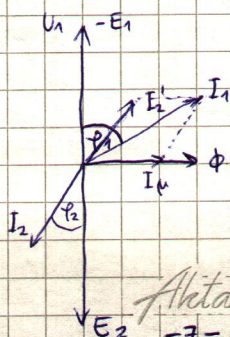
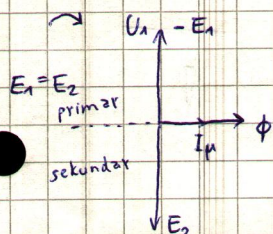
1.) Kazalčni diagram idealnega transformatorja

- ni izgub v železu $I_{od} = 0$
- ni izgub v bakru $R_1, R_2 = 0$
- ni stresanega mag. pretoka $\mu_r \rightarrow \infty, X_{\sigma 1}, X_{\sigma 2} = 0$



Prosti tek idealni transf.

Obremenitev idealnega transf. (prikjučimo Z_b)



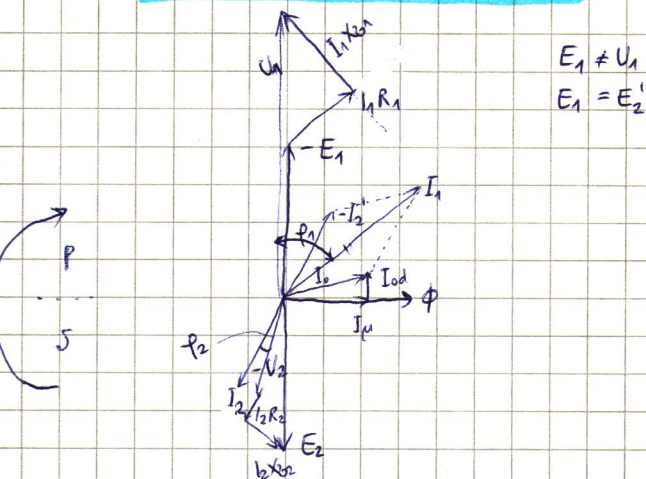
$$I_2 = \frac{E_2}{\sqrt{R_b^2 + X_b^2}}$$

$$\varphi_2 = \arctg \frac{X_b}{R_b}$$

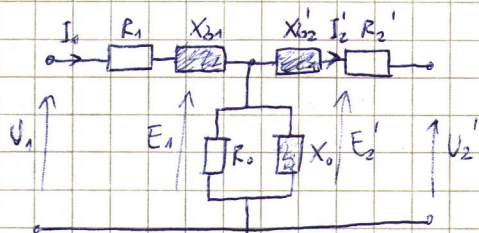
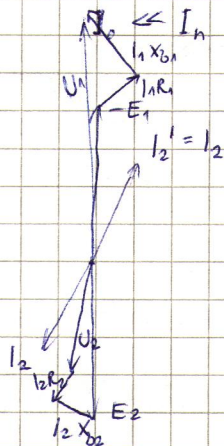
I_2 - posledica priklopite
bremena

v primerju imamo zdaj 2 toka

Obremenitev realnega transf. POPOLNI KAZALČNI DIAGRAM REALNEGA TR.



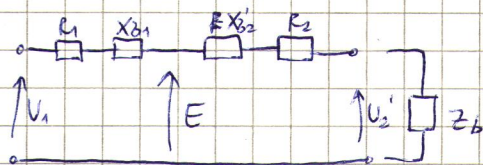
Poenostavljen kazalčni diagram realnega tr.



$$U_1 = E_1 + I_1 R_1 + I_1 X_{1\sigma}$$

$$E_2' = E_1 = U_2' + I_2' R_2' + I_2' X_{2\sigma}'$$

sekundar vržemo na prim stran (istoiznačne padce združimo)



$$I_1 = I_2' = I$$

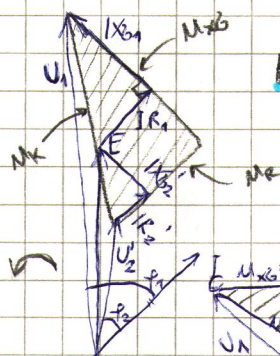
$$U_1 = U_2' + I \cdot Z_k$$

kratkostručna impedanca

$$|Z_k| = |R_k + jX_k| = \sqrt{R_k^2 + X_k^2}$$

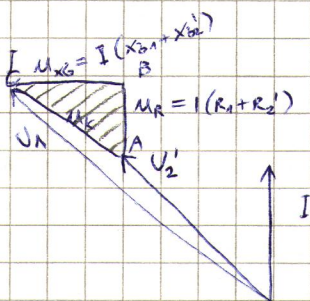
$$R_k = R_1 + R_2'$$

$$X_k = X_{1\sigma} + X_{2\sigma}'$$



KAPPOV TRIKOTNIK

(podaja konstrukcijsko značilnost transf.)



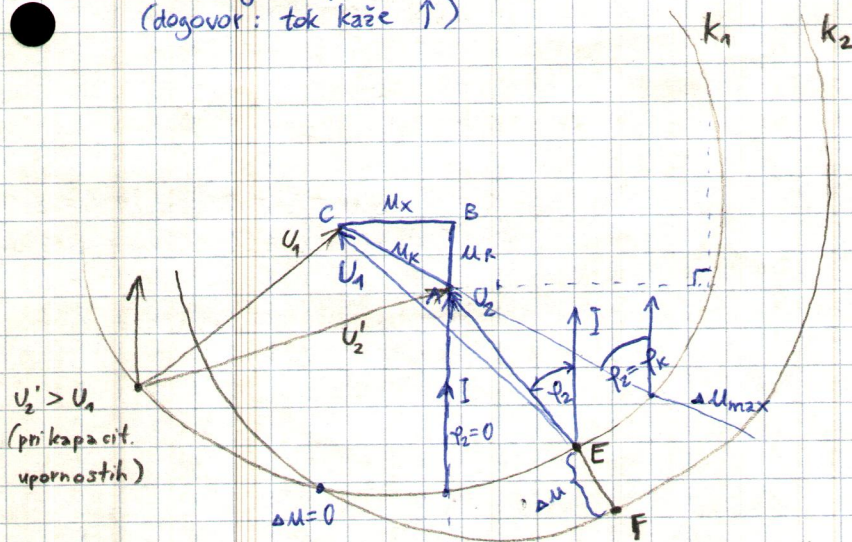
večji Δ , čim večja bo notr. upornost tr. in obremenitev vpliva

najpogostejša oblika

če je poudarjeno stresanje
če ga je zelo malo in
ohm upornost velika

KAPPOV DIAGRAM

osnova je Kappov trikotnik
(dogovor: tok kaže ↑)



iz C lok $k_1 = U_1$
iz A lok $k_2 = U_1$

$$\begin{aligned} \overline{EC} &= U_1 \\ \overline{FA} &= U_1 \\ \overline{EA} &= U_2' \\ \overline{EF} &= U_1 - U_2' = \Delta U \end{aligned}$$

↳ padec napet. na tr.
to tr. zase potroši, za križje
svojih padcev

C ← R čistoh. obremenitev → L

- Transf. nazivne moči $S_n = 100 \text{ kVA}$, $U_1 = 10 \text{ kV}$, $U_2 = 0,5 \text{ kV}$ ima izkoristek pri naziv. obrat. $\eta_n = 0,98$,
 $M_k = 4\%$, $\frac{P_{cun}}{P_{fen}} = 2$. Tr. obremenimo z $I' = 10 \cdot I_n$

$$\eta = \frac{S_{ed}}{S_{sp}} = \frac{S_n - \sum P_{izg}}{S_n} \Rightarrow \sum P_{izg} = (S_n - \eta_n S_n) = S_n (1 - \eta_n)$$

$$P_{izg,n} = P_{cun} + P_{fen} = S_n (1 - \eta_n) = 100 \cdot (1 - 0,98) = 2 \text{ kW}$$

$$P_{izg,n} = P_{cun} + \frac{P_{cun}}{2} = \frac{3}{2} P_{cun} \rightarrow P_{cun} = \frac{2}{3} P_{izg} = 1,33 \text{ kW}$$

$$P_{fen} = \frac{1}{3} P_{izg} = 0,67 \text{ kW}$$

$$P_{cun} \% = \frac{P_{cun}}{S_n} \cdot 100\% = \frac{I_n^2 \cdot R}{U_n \cdot I_n} \cdot 100\% = \frac{I_n R}{U_n} \cdot 100\% = u_R \%$$

$$u_R \% = \frac{1,33}{100} \cdot 100\% = 1,33\%$$

$$u_k \% = 4\%$$

$$u_x \% = \sqrt{u_k^2 - u_R^2} = \sqrt{4^2 - 1,33^2} = 3,8\%$$

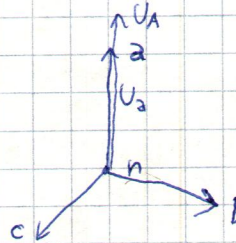
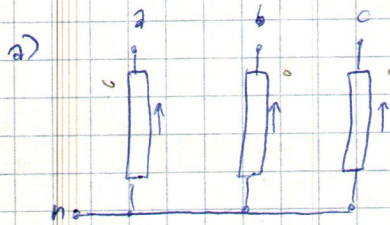
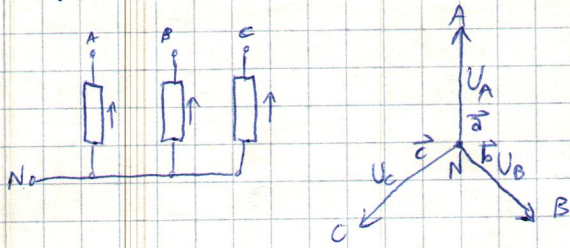
$$I_n: u_R \% = 1,33\%, u_x \% = 3,8\%, u_k \% = 4\%$$

$$I' = 10 I_n: u_R' \% = 13,3\%, u_x' \% = 38\%, u_k' \% = 40\%$$

$$U_1 = 10 \text{ kV} = 100\% = 1 = 10 \text{ cm}$$

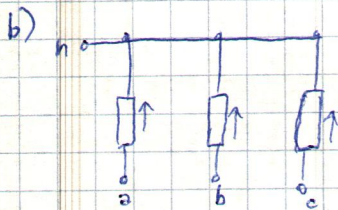
■ Določite oznako vezave trif. tr. ki imajo navijza vezana po nastl. shemah:

fazna št. tr. je kot, za katerega je sek. faz. nap. relativno premaknjena proti prim. f. nap. In je označujemo v smislu urinik št.

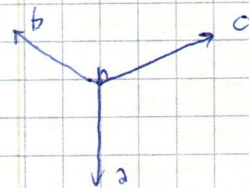


(Y_Ny_n)
Yy0

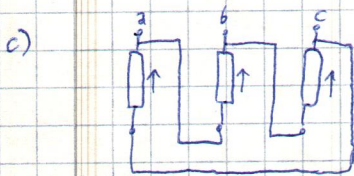
$$\frac{0^\circ}{30^\circ} = 0^\circ$$



$$\left(\frac{180^\circ}{30^\circ} = 6\right)$$

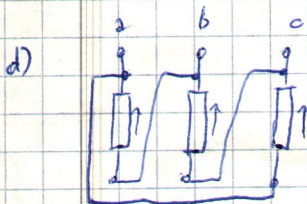


Yy6

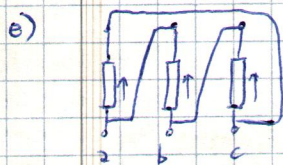
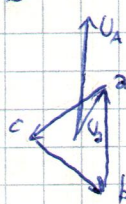


Yd11

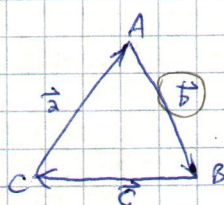
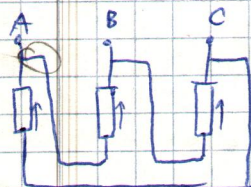
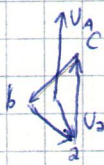
$$\frac{330^\circ}{30^\circ} = 11$$



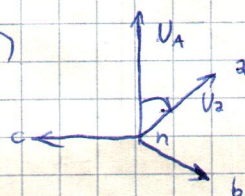
Yd1



Yd5

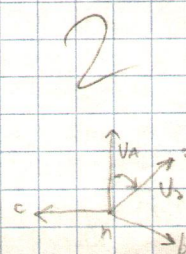


a) (stike enake)

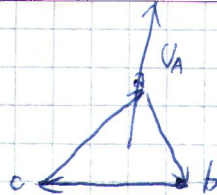


Dy1

Alketa
-11-

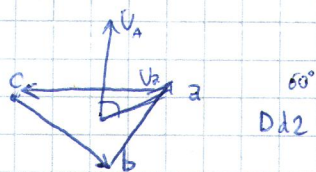


c)



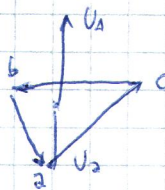
D.d Ø

2

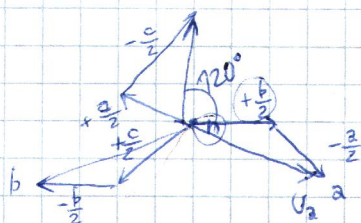
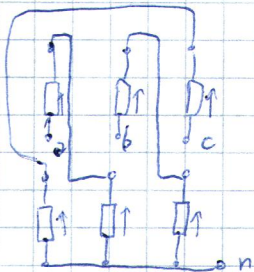
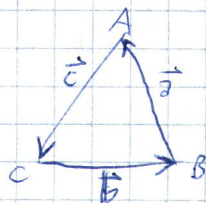
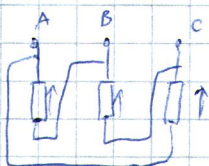
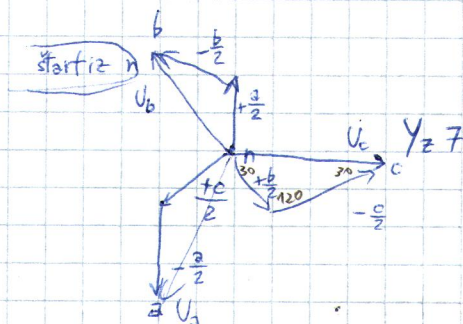
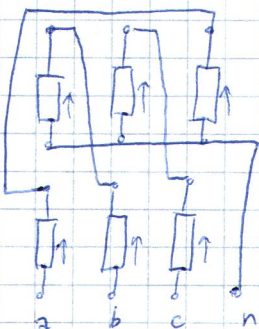
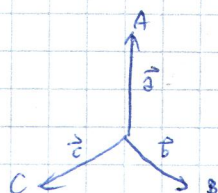
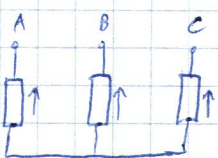
 $d)$ 

Dd2

e)



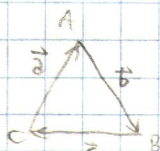
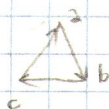
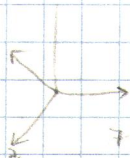
DAG



Dz 4

yz liha 57.

Dz sode st.

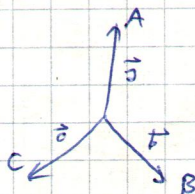
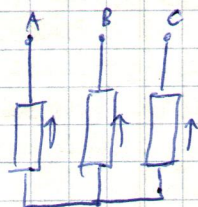


Trif. tr. je na sek. strani napačno spojen. a) kaj se zgodi v tr. pri kratki skl. sponkah a, b ?

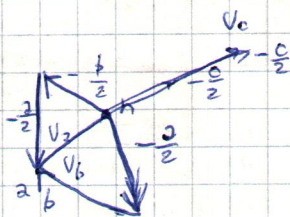
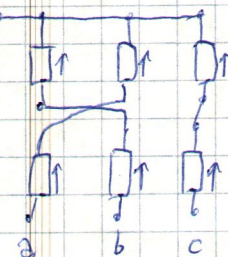
$$S_n = 100 \text{ kVA}$$

$$\text{prest. razm. } 10/0,6 \text{ kV}$$

$$Yz5$$



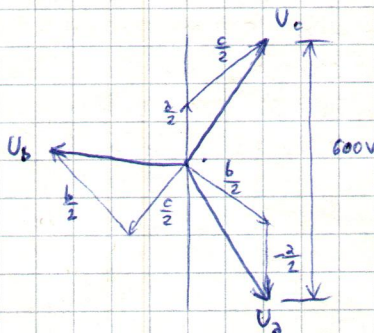
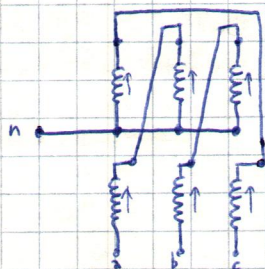
(izpaka)



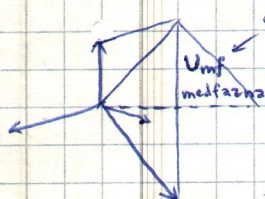
$$b) U_a, U_b, U_c = ? V$$

Kakšne so napetosti na sek. sponkah ?

Pravilna Yz5



Koliko da eno navitje ?



enakostraničen

$$N = \frac{2\sqrt{3}}{2}$$

$$\frac{U_{mf}}{2} = \frac{U_f \sqrt{3}}{2}$$

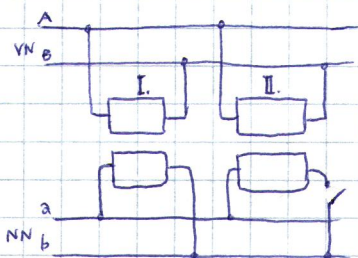
$$U_{mf} = \sqrt{3} U_f$$

$$U_{f/2} = \frac{U_{mf} \sqrt{3}}{2}$$

$$U_{f/2} = \frac{U_f}{\sqrt{3}} = \frac{U_{mf}}{\sqrt{3} \cdot \sqrt{3}} = \frac{600V}{3} = 200V$$

$$U_a = 200V, U_b = 200V, U_c = 400V$$

PARALELNO OBRATOVANJE



Iz primarne smeri se na ustreznih napetostnih nivojih prenaša na skupno omrežje. Ko vklopimo II. ne sme teč izenačevalni tok. Bile bi večje izgube! Če bi imeli enega samega...? Zakaj ne? Zaradi prevoza, varnost (če en odpove, ni groze), poraba ni skos enaka. $s \rightarrow m \rightarrow e$ el. energ. ne moremo ^{dobro} skladiščiti

Zahteve:

- 1) Napetostni prestavi morata biti enaki! $U_{nI} = U_{nII}$
- 2) Enaki fazni št. [pravilni f. zamik] Δ ali razlika za 4!
- 3) Zaporedje faz enako priključeno. [Ohraniti tudi desnosučni sistem.]

Priporočilo:

- 4) Kratkostični napetosti $U_{K1} \approx U_{K2}$ čim bolj enaki
- 5) Moč 1. se naj ne razlikuje več kot za faktor 3. $S_I \geq 3 S_{II}$

■ K transformatorju nazivne moči $S_n = 100 \text{ kVA}$, $u_k = 4\%$, $10/0,4 \text{ kV}$; vezava Yz5.

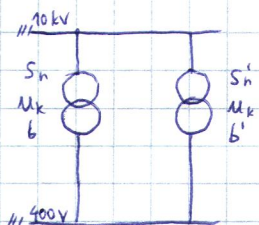
Paralelno priključimo $S'_n = 200 \text{ kVA}$, $u'_k = 8\%$, $10/0,4 \text{ kV}$, Dy1.

Tr. sta obremenjena z $S_b = 300 \text{ kVA}$. Določite, kako se razporedi moč na oba tr. in ugotovite, če je tako obratovanje dopustno.

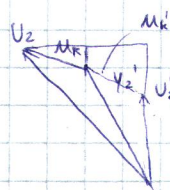
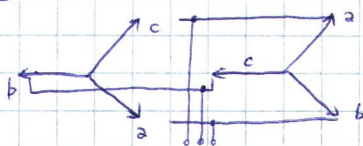
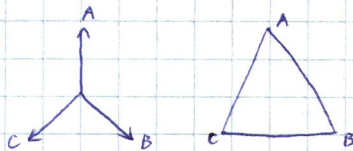
b - stopnja obremenitve

$$b = \frac{S}{S_n} \quad \text{koliko dela normirano na njegovo nazivno moč}$$

$$b' = \frac{S'}{S'_n}$$



Pogoji: 1) $\checkmark$ 2) razl. 4 3) $\checkmark$ 5) $\checkmark$



z večjim u_k

V obratnem sorazmerju je stopnja obr. z u_k

$$\frac{b}{b'} = \frac{u'_k}{u_k}$$

$$b = b' \frac{u'_k}{u_k}$$

$$b' = \frac{S_b}{\frac{u'_k}{u_k} \cdot S_n + S'_n}$$

$$0 + S' = S_b$$

$$b S_n + b' S'_n = S_b$$

$$\rightarrow b' \frac{u'_k}{u_k} S_n + b' S'_n = S_b$$

več dela močnejši

$$b' = \frac{300}{\frac{8}{4} \cdot 100 + 200} = \frac{3}{4} = 0,75$$

$$b = \frac{3}{4} \cdot \frac{8}{4} = \frac{3}{2} = 1,5$$

II. bo delal več kot lahko! preobremenjen

$$S = b \cdot S_n = 1,5 \cdot 100 = 150 \text{ kVA}$$

$$S' = b' \cdot S'_n = 0,75 \cdot 200 = 150 \text{ kVA}$$

Oba delata enako! S tem, da je 1. preveč obremenjen.

Razmerje izgub $\frac{P_{cun}}{P_{fen}} = 3 = \xi$

Segreje se pri nazivni obremenitvi $U_{max} = 60^\circ C$. Do katere nad temperature se bo segrel pri polovični obremenitvi $J' = \frac{J_n}{2}$

$P_{fe} = k_{fe} \cdot \frac{f}{50} \cdot B^2 \cdot U_{fe}$
 $P_{cu} = I^2 R$ → od bremenskega toka odvisne

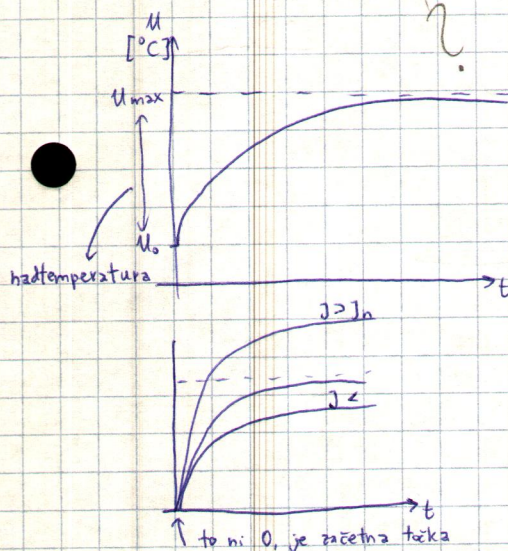
$P_{izg} = P_{fe} + P_{cu}$

$x = \frac{J'}{J_n} = \frac{J_n}{2J_n} = \frac{1}{2}$ splošne

$P_{izgn} = P_{fen} + P_{cun}$ → nazivne izgube

$P_{izg} = P_{fen} + x^2 P_{cun}$
 nove izg. pri novem obratovalnem

Razlika med toplim in hladnim stanjem je pogojena z izgubami.



[enaka, tudi če začnemo iz nižjega ali višjega]

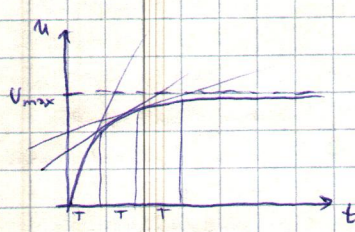
$\frac{U'_{max}}{U_{max}} = \frac{P_{fen} + P_{cun} x^2}{P_{fen} + P_{cun}} = \frac{1}{1 + \xi}$
 konst. člen odvisen od obremenitve
 $= \frac{1 + x^2 \frac{P_{cun}}{P_{fen}}}{1 + \frac{P_{cun}}{P_{fen}}} = \frac{1 + x^2 \xi}{1 + \xi}$

$U'_{max} = U_{max} \cdot \frac{1 + x^2 \xi}{1 + \xi} = 60^\circ C \cdot \frac{1 + \frac{1}{4} \cdot 3}{1 + 3} = 26,25^\circ C$

$J' = 2J_n$
 $x = \frac{2J_n}{J_n} = 2$

$U''_{max} = 60^\circ \cdot \frac{1 + 4 \cdot 3}{1 + 3} = 195^\circ C$
 pri dvakratnem nazivnem toku

Trans. je načrtovan tako, da se pri nazivni obremenitvi segreje na $U_{max} = 70^\circ C$. Pri bremenskem $I = 20A$ se segreje na $U_{max} = 50^\circ C$. Določite razmerje izgub $\frac{P_{cun}}{P_{fen}} = \xi = 3$



$U(t) = U_{max} (1 - e^{-\frac{t}{T}})$

$T \rightarrow$ toplotna čas. konst.

↳ odvisna od sestave

masa tr. specif. toplota materiala

$T = \frac{m \cdot c}{S \cdot h}$

ne vedno, včasih moras upoštevati koef. toplote, tok dobro prehaja

$\frac{P_{izg}}{P_{izgn}} = \frac{P_{fen} + P_{cu}}{P_{fen} + P_{cun}} = \frac{1 + \frac{P_{cu}}{P_{fen}}}{1 + \frac{P_{cun}}{P_{fen}}} = \frac{1 + x^2 \xi}{1 + \xi} = \frac{U_{max} (1 - e^{-t/T})}{U_{max} (1 - e^{-t'/T})}$

$x = \frac{1}{I_n}$
 $P_{cu} = I^2 \cdot R$

$\frac{50}{70} = \frac{1 + x^2 \cdot 3}{1 + 3}$

$x^2 = (\frac{5}{7} \cdot 4 - 1) \frac{1}{3} = 0,619$
 $x = 0,787$

nazivni tok

$J_n = \frac{I}{x} = \frac{20}{0,787} = 25,42A$

1T	→ 0,632
2T	→ 0,86
3T	→ 0,95
4T	→ 0,982
5T	→ 0,993 → stacionarno stanje

Večje izg. → višje se bo stroj segrel

nazivni podatki - tu ima stroj najboljši izkoristek, priporočeno pri čem naj obratuje

bolj obremenimo za krajši čas!

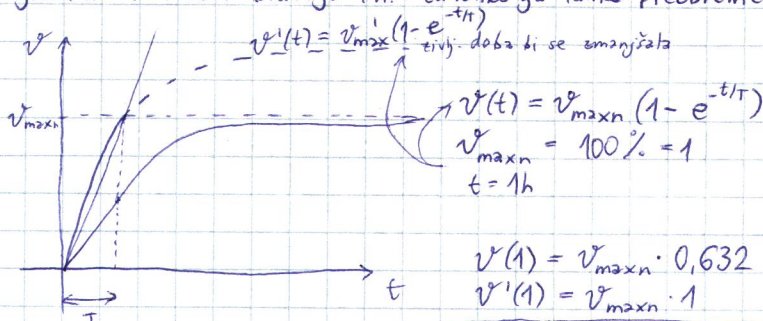
fen, sesalnik, mlinček za
rabo, gospodinjški aparati

- Tr. ima čas. konst. segr. 1 h. Vsak dan obratuje 1 h. Za koliko ga lahko preobremenimo v tej uri obratovanja?

$$T = 1h$$

$$t = 1h$$

$$\xi = \frac{P_{cun}}{P_{fen}} = 3$$



$$v(1) = v_{maxn} \cdot 0,632$$

$$v'(1) = v_{maxn} \cdot 1$$

$$\frac{v(1)}{v'(1)} = 0,632 = \frac{P_{iagn}}{P_{iag}} = \frac{1 + \xi}{1 + x^2 \xi} = \frac{1 + 3}{1 + x^2 \cdot 3}$$

$$x^2 = \frac{4}{0,632 - 1} = 1,776 \rightarrow x = 1,33$$

$$x = \frac{I'}{I_n}$$

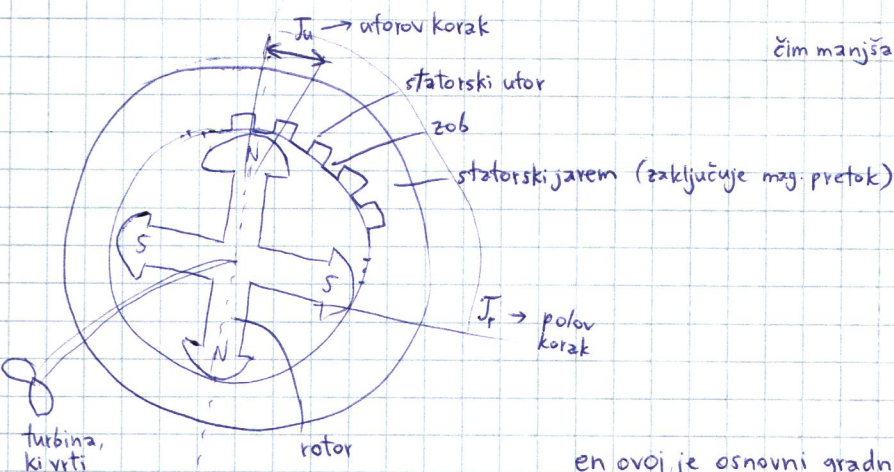
$$I' = x \cdot I_n = 1,33 \cdot I_n$$

SINHRONSKI STROJ

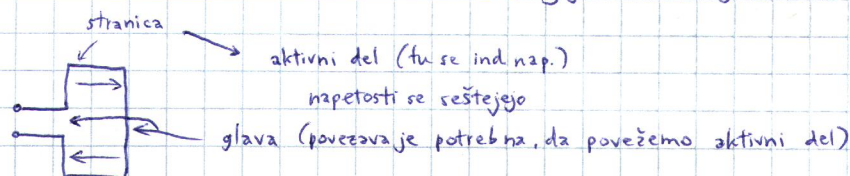
boljši v generatorskem obratovanju
stroji velikih moči (1000 MVA → ...)

→ da je čim lepši sinus

čim manjša reza, da bo manjši magn. tok



en ovoj je osnovni gradnik



imamo več ovojov!



če je cel utor nafilan z eno stranico → enoplastno navitje

ena stranica pod
enim, druga pod drugim polom

↓
premerska tuljava

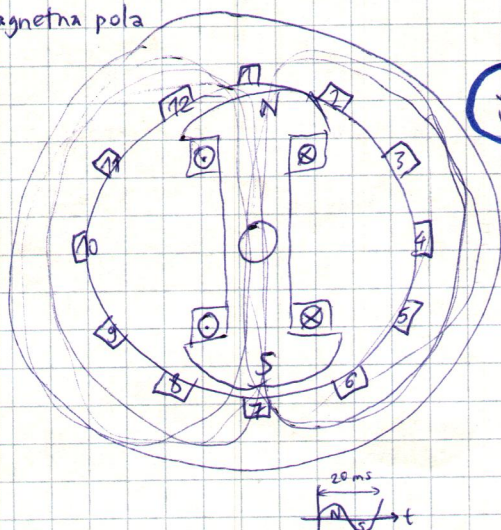
tetivljena tuljava

izr. faktor navitja in narišite shemo enoplastnega navitja dvopolnega trif. sinh. gener. ki ima na statorju 12 utorov.

Navitje na gener. je ★. V vsakem utoru je ena palica. Določite medf. nap., če se v eni palici inducira amplitudna vrednost 100V.

polov par = 2 magnetna pola

$p = 1$
 $2p = 1$
 frez $m = 3$
 $N = 12$
 $\wedge$
 št. poljev $z = 1$
 $E_{max} = 100V$



$$\alpha_g = \frac{360^\circ}{N} = \frac{360}{12} = 30^\circ$$

geometrijski

50Hz

$$n_s = \frac{60 \cdot f}{p} \quad [\text{min}^{-1}]$$

sinhronska

p	1	2	3	4	5	...
n_s	3000	1500	1000	750	600	

koliko utorov na en mag. pol

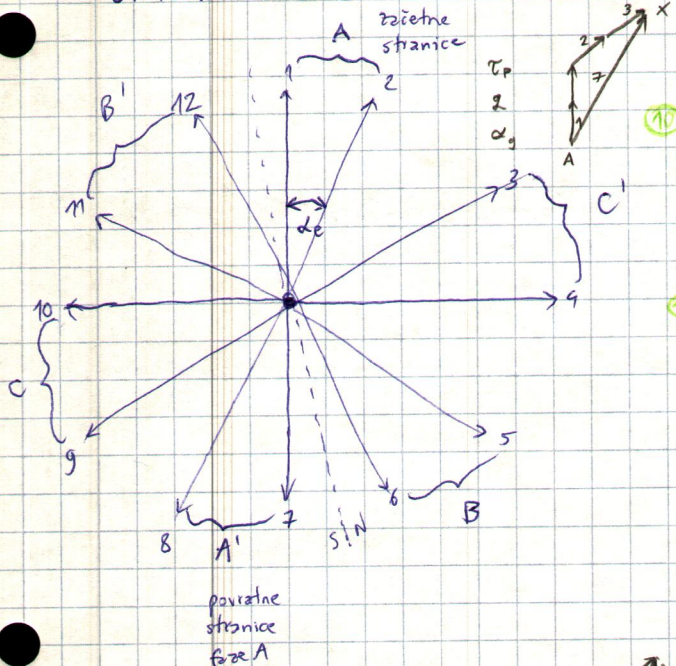
$$2) \tau_p = \frac{N}{2p} = \frac{12}{2 \cdot 1} = 6 \text{ utorov/pol}$$

$$3) \alpha_e = p \cdot \alpha_g = 1 \cdot 30^\circ = 30^\circ \text{ el}$$

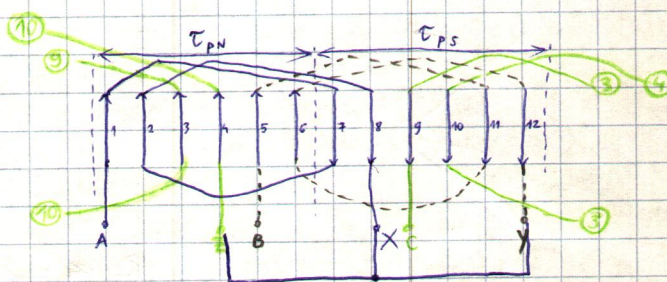
električni med kazalci sosednjih utorov ind. nap.

$$4) g = \frac{\tau_p}{m} = \frac{N}{2pm} = \frac{12}{2 \cdot 1 \cdot 3} = 2 \text{ ut/(pol+frez)}$$

UTOROVA ZVEZDA - zvezda kazalcev ind. nap. v utorih



vezalna shema



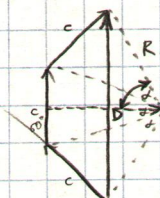
3 prispevki posameznih stranic

fz ena nap.

$$\star U_f = \frac{E_{max}}{\sqrt{2}} \cdot n \cdot \phi_n =$$

$$= \frac{E_{max}}{\sqrt{2}} \cdot \underbrace{z \cdot g \cdot 2 \cdot p \cdot f_n}_n = \frac{100}{\sqrt{2}} \cdot 1 \cdot 2 \cdot 2 \cdot 1 \cdot 0,966 = 273V$$

$$U_{mf} = \sqrt{3} U_f = 473V$$



aritmetična

$$\sum U_A = 3 \cdot c = 3 \cdot 2 \cdot R \cdot \sin \frac{\alpha_e}{2}$$

$$\sum U_e = D = 2 \cdot R \cdot \sin \frac{3\alpha_e}{2}$$

geometrijska

pasovni faktor $k_p = \frac{\sum U_e}{\sum U_A} = \frac{2R \sin \frac{3\alpha_e}{2}}{3 \cdot 2 \cdot R \cdot \sin \frac{\alpha_e}{2}} =$

$$= \frac{\sin \frac{3\alpha_e}{2}}{3 \sin \frac{\alpha_e}{2}}$$

$$k_p = \frac{\sin \frac{3\alpha_e}{2}}{2 \sin \frac{\alpha_e}{2}}$$

pasovni faktor

$$k_p = \frac{\sin \frac{2 \cdot 30}{2}}{2 \cdot \sin 15^\circ} = 0,966$$

$$k_s = \sin \left(\frac{\alpha}{\tau_r} \cdot \frac{\pi}{2} \right)$$

skrajšava tuljave

$$k_n = k_r \cdot k_s = 0,966 \cdot 1 = 0,966$$

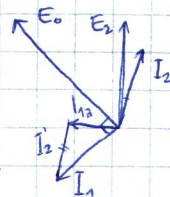
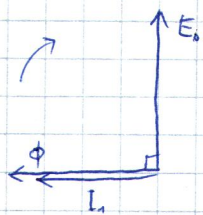
primar - rotor ①
sekundar - stator ②

$$E = 4,44 \cdot f \cdot N \cdot \Phi \cdot k_n$$

↳ faktor navitja

✱ Prosti tek sinh. gen. vez. z I_1 (to vez. mag. pretok Φ_1), v sekund. se ind. nap.

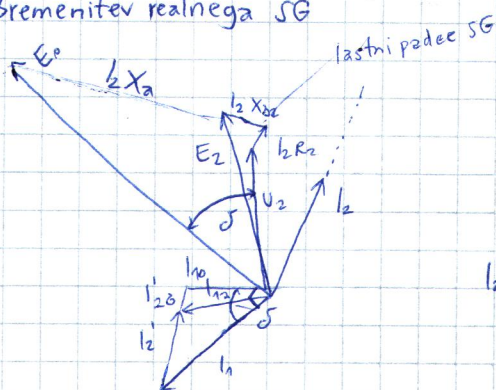
Ga obremenimo...



$I_{1a} \perp E_0$
 $I_{2a} \perp E_2$
↳ armature (= indukt)

Obremenitev SG
Reakcija indukta

Obremenitev realnega SG



$I_{1a} \perp U_2$

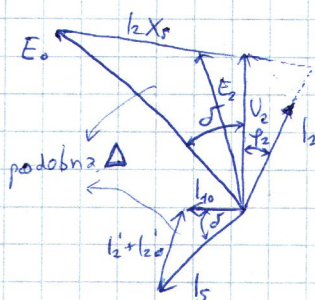
E_0 ... fiktivna ind. nap.

$I_2 X_a$... pozorimo reakcijo indukta

δ -kolesnik (med E_0 in U_2)

$R_2 \ll X_{b2}$ Upornost majhna napram stesani reaktanci

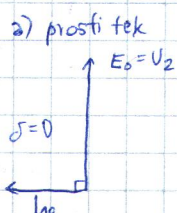
Kaz. diagram, ki se uporablja v praksi



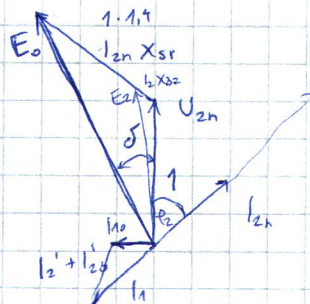
$X_s = X_a + X_{2b}$ sinh. reakt.

■ $n = 3000 \text{ min}^{-1}$
 $f = 50 \text{ Hz}$
 $X_{sr} = 1,4$
 $X_{br} = 0,25$
 $U_{2n} = 1 = 100\%$

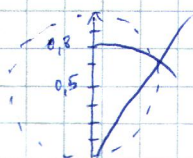
Za SG skic. v merilu kaz. diagr. za nast. obratovalna stanja



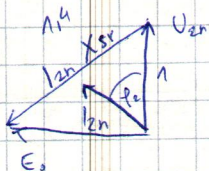
b) $U_{2n}, I_{2n}, \cos \varphi_2 = 0,8 \text{ ind}$
induktivno



padec na sinh.
reaktanci je
merilo za...

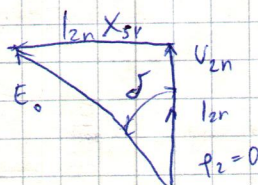


c) $U_{2n}, I_{2n}, \cos \varphi_2 = 0,8 \text{ cap}$



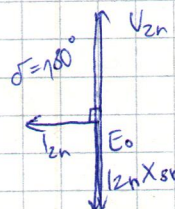
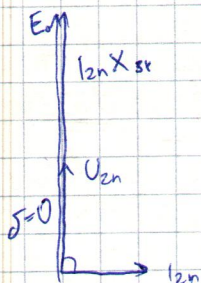
d) $U_{2n}, I_{2n}, \cos \varphi_2 = 1$

isto ohmsko breme



e) $U_{2n}, I_{2n}, \cos \varphi_2 = 0 \text{ ind}$

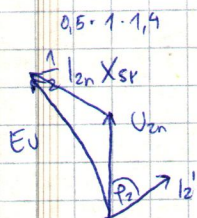
f) $U_{2n}, I_{2n}, \cos \varphi_2 = 0 \text{ cap}$



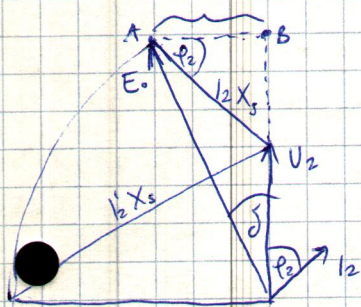
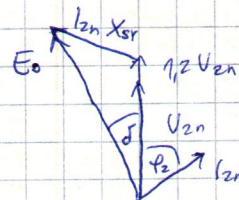
g) $U_{2n}, 0,5 I_{2n}, \cos \varphi_2 = 0,8 \text{ ind}$

(če ne piše, je ind)

0,5 · 1,4



i) $1,2 U_{2n}, I_{2n}, \cos \varphi_2 = 0,8$



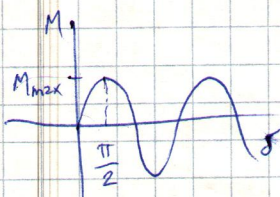
$I_2 X_s \propto$ navidezna moči $[VA]$
 $I_2 X_s \cos \varphi \propto$ delovni $[W]$
 $I_2 X_s \sin \varphi \propto$ jalovi $[Var]$

$P_u = m \cdot U_2 \cdot I_2 \cdot \cos \varphi_2$ delovna el. moč generatorja
 $AB = I_2 \cdot X_s \cdot \cos \varphi_2 = E_0 \sin \delta$

$I_2 \cos \varphi_2 = \frac{E_0}{X_s} \cdot \sin \delta$

$P_{el} = m \cdot \frac{E_0 \cdot U_2}{X_s} \cdot \sin \delta$

$P_{el} = P_m = M \cdot \omega_s \rightarrow M = \frac{P_{el}}{\omega_s} = \frac{m}{\omega_s} \cdot \frac{E_0 \cdot U_2}{X_s} \cdot \sin \delta$



☐ $S_n = 6,3 \text{ MVA}$

$$U_{2n} = 10 \text{ kV}$$

$\varphi = 50 \text{ Hz}$

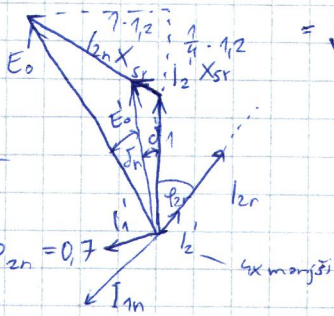
$$I_m = 50 \text{ A}$$

$$\cos \varphi_{2n} = 0,7$$

$$\dot{X}_{sr} = 1,2$$

$$s' = \frac{1}{4} s_n$$

$\cos \phi_2' = \cos \phi_{2n} = 0.7$ ← I_2 — 4x merişi



$$E_0 = \sqrt{(V_{2n} + I_{2n} X_{sr} \cdot \sin \varphi_{2n})^2 + (I_{2n} X_{sr} \cdot \cos \varphi_{2n})^2} =$$

$$= \sqrt{(1 + 1 \cdot 1,2 \cdot 0,71)^2 + (1 \cdot 1,2 \cdot 0,7)^2} = 2,03$$

$$\underline{E'} = \sqrt{(V_{zn} + I_z' \cdot X_{sr} \cdot \sin \theta_{zn})^2 + (I_z' X_{sr} \cos \theta_{zn})^2} =$$

$$= \sqrt{\left(1 + \frac{1}{4} \cdot 1,2 \cdot 0,71\right)^2 + \left(\frac{1}{4} \cdot 1,2 \cdot 0,7\right)^2} = 1,23$$

$$\frac{I_1'}{I_{1n}} = \frac{E_0'}{E_0}$$

$$I_1' = I_n \cdot \frac{E_0'}{E_0} = 50 \cdot \frac{1,23}{2,03} = \underline{\underline{30,17 \text{ A}}}$$

$$\tan \delta_n = \frac{b_n X_{sr} \cdot \cos \varphi_z}{U_{zn} + b_n X_{sr} \cdot \sin \varphi_{zn}} =$$

$$= \frac{1 \cdot 1,2 \cdot 0,7}{1 + 1 \cdot 1,2 \cdot 0,71} = 0,452 \Rightarrow \sigma_n = 24,34^\circ$$

$$f_g \sigma' = \frac{\frac{1}{2}}{1 + \frac{1}{2}} = \frac{\frac{1}{4} \cdot 1,2 \cdot 0,7}{1 + \frac{1}{4} \cdot 1,2 \cdot 0,71} \Rightarrow \sigma' = 9,81^\circ$$

ASINHRONSKI STROJI

- motorsko obratovanje

statorja sta enaka, rotor pa je v obliki kratkostične kletke

- trije tipi: z drsnimi obroči
 kratkostična kletka aluminij
 ↳ manj vpliva na delovanje imamo
 stator ① rotor, indukt ②

$$E_1 = 4,44 \cdot f_1 \cdot N_1 \cdot \Phi \cdot k_{m1} \quad \text{stator}$$

$$E_2 = 4,44 \cdot f_2 \cdot N_2 \cdot \Phi \cdot k_{m2} \quad \text{rotor}$$

$$f_1 = 50 \text{ Hz}$$

f_2 odvisna od relativnega

$$f_2 = s \cdot f_1$$

↳ karakteristični podatek

$$\text{slip } s = \frac{\omega_s - \omega_{mek}}{\omega_s}$$

$$s = \frac{n_s - n_{mek}}{n_s}$$

$$E_2 = s \cdot E_{20}$$

$$n_s = \frac{60 \cdot f}{p}$$

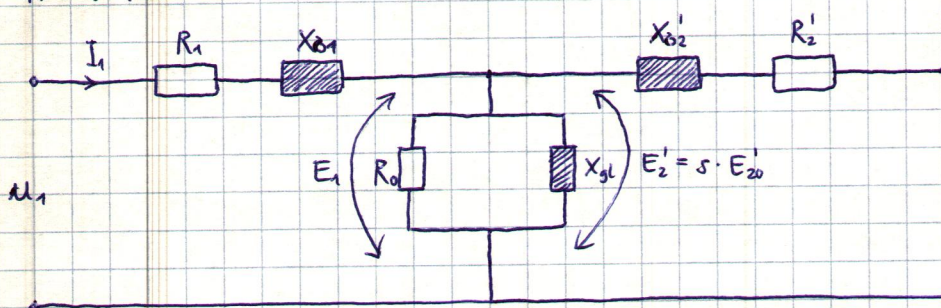
50 Hz
 3000, 1500 ...

$$n_m = 1456 \text{ min}^{-1} \rightarrow 15000$$

$$735 \rightarrow 750$$

$$972 \rightarrow 1000$$

NADOMESTNA SHEMA



$$X_{\sigma 2} = \omega_2 L_{\sigma 2} = 2\pi f_2 L_{\sigma 2} = 2\pi f_1 \cdot s \cdot L_{\sigma 2}$$

stresanje na rotorju se spreminja s frekvenco

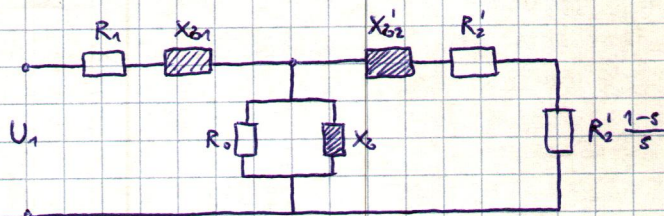
$$I_2 = \frac{E_2}{Z_2} = \frac{s \cdot E_{20}}{\sqrt{R_2^2 + (s X_{\sigma 2})^2} \cdot \sqrt{3}} = \frac{s \cdot E_{20}}{\sqrt{3} \sqrt{\left(\frac{R_2}{s}\right)^2 + X_{\sigma 2}^2} \cdot s} = \frac{E_{20}}{\sqrt{3} \sqrt{\left(\frac{R_2}{s}\right)^2 + X_{\sigma 2}^2}}$$

dejanska upornost rot. navijača da bo fazna

$$\frac{R_2}{s} = R_2 + R_2 \frac{1-s}{s}$$

mehansko vrtenje (realna moč) in dejanska upornost

↳ mehansko vrtenje



kratek stik

- zavrti rotor
- ob trenutku zagona je rotor v kratkem stiku

$s=1$: rotor stoji $n=0$

$M=M_2$ zagonski navor

$$R_2' \frac{1-s}{s} = 0$$

$P_m = M \cdot \omega = 0$ → mehanska moč je 0 ob zagonu

Alta

prosti tek

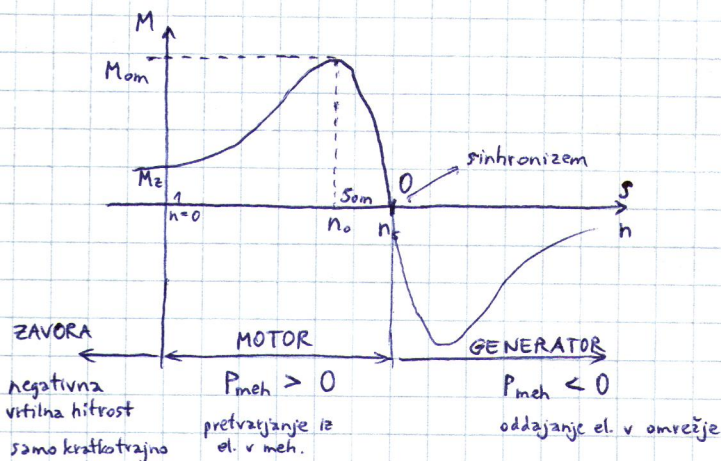
$$s=0$$

$$h=n_s$$

$$P_{meh} = M \cdot \omega = 0$$

$$0 \cdot \omega_{sinh.}$$

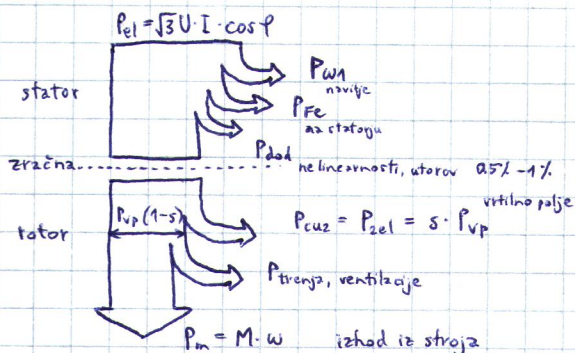
v sinhronizmu; ampak tam motor itak ne more trajno delovati



Klosova enačba:

$$\frac{M}{M_{om}} = \frac{2}{\frac{s}{s_{om}} + \frac{s_{om}}{s}}$$

$$P_{meh} = M \cdot \omega$$



$$E_2 = s \cdot E_{20}$$

$$f_2 = s \cdot f_1$$

$$P_{Fe} = f \cdot B^2$$

$$\eta = \frac{P_m}{P_{stet}}$$

P_m - nazivna moč

■ Trifazni štiripolni AM z drsnimi obroči:

$$S_n = 25 \text{ kW}$$

$$U_{ln} = 380 \text{ V}$$

$$f = 50 \text{ Hz}$$

$$n_n = 1440 \text{ min}^{-1}$$

$$I_{ln} = 49 \text{ A}$$

$$\cos \phi_{ln} = 0,87$$

$$E_{20} = 335 \text{ V}$$

$$I_{2n} = 46 \text{ A}$$

$$R_1 = 0,14 \Omega$$

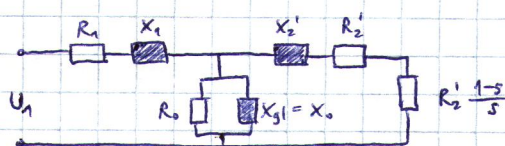
S preizkusom prostega teka in kr. stika dobimo:

$$I_{10} = 18,9 \text{ A}$$

$$P_{10} = 1,14 \text{ kW}$$

$$I_{1k} = 318 \text{ A}$$

$$P_{1k} = 135 \text{ kW}$$



Izr. elemente nadom. sheme, reducirano na statorsko stran. Predpostavka $Y_2' = Y_1$

prosti tek

$$s=0 \quad R_2' \frac{1-s}{s} \rightarrow \infty \quad I \rightarrow 0 \quad M \rightarrow 0$$

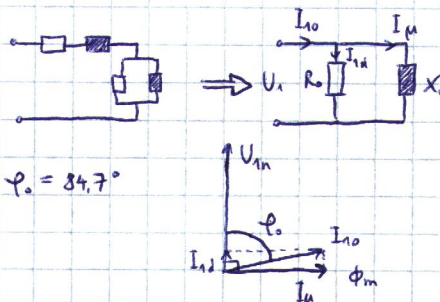
$$\cos \phi_0 = \frac{P_{10}}{\sqrt{3} U_{ln} I_{10}} = \frac{1,14 \cdot 10^3}{\sqrt{3} \cdot 380 \cdot 18,9} = 0,0916 \Rightarrow \phi_0 = 84,7^\circ$$

$$\sin \phi_0 = 0,9958$$

$$I_\mu \rightarrow X_0 = \frac{U_{ln}}{\sqrt{3} I_{10} \sin \phi_0} = \frac{380}{\sqrt{3} \cdot 18,9 \cdot 0,9958} = 11,6 \Omega$$

$$I_{od} \rightarrow R_0 = \frac{U_{ln}}{\sqrt{3} I_{10} \cos \phi_0} = 12,7 \Omega$$

$$\frac{I_\mu}{I_{ln}} = \frac{18,9 \cdot \sin \phi_0}{49} = 38,4\% \quad \text{ni zanemarljivo}$$

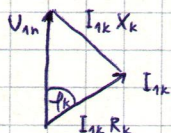
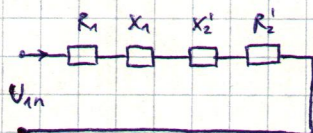


kratek stik

$$R_2' \frac{1-s}{s} \rightarrow 0$$

$$R_k = R_1 + R_2'$$

$$X_k = X_1 + X_2'$$



$$\cos \varphi_k = \frac{P_{1k}}{\sqrt{3} U_{1n} I_{1k}} = \frac{135 \cdot 10^3}{\sqrt{3} \cdot 380 \cdot 318} = 0,695 \Rightarrow \varphi_k = 50^\circ$$

$$\sin \varphi_k = 0,764$$

$$U_{1n} \sin \varphi_k = \sqrt{3} I_{1k} (X_1 + X_2') \rightarrow X_1 + X_2' = \frac{U_{1n}}{\sqrt{3} I_{1k}} \sin \varphi_k = 0,527 \Omega$$

$$X_1 = X_2' = 0,264 \Omega$$

$$U_{1n} \cos \varphi_k = \sqrt{3} I_{1k} (R_1 + R_2') \rightarrow R_k = \frac{U_{1n}}{\sqrt{3} I_{1k}} \cos \varphi_k = 0,445 \Omega$$

$$R_2' = R_k - R_1 = 0,305 \Omega$$

- Določite energijsko bilanco AM s kratkostično kletko. Narišite diagram pretoka moči, izgube v rotorju, moč, kijo jemlje iz omrežja, izkoristek stroja?

$$f = 50 \text{ Hz}$$

$$U_{1n} = 380 \text{ V}$$

$$M_b = 100 \text{ Nm}$$

$$n_p = 1410 \text{ min}^{-1}$$

$$P_{cu1} + P_{Fe1} = 300 \text{ W}$$

$$P_{tr,vent} \rightarrow 0$$

$$P_b = M_b \cdot \omega_b = M_b \cdot \frac{2\pi n_b}{60} = 100 \cdot \frac{2\pi \cdot 1410}{60} = 14,765 \text{ kW}$$

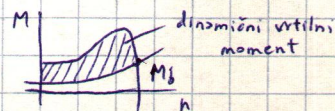
$$s_b = \frac{n_s - n_b}{n_s} = \frac{1500 - 1410}{1500} = 0,06$$

$$P_{vp} = \frac{P_b}{1-s} = \frac{14,765}{1-0,06} = 15,707 \text{ kW}$$

$$P_{zel} = P_{vp} - P_b = s \cdot P_{vp} = \dots = 0,942 \text{ kW}$$

$$P_{el} = P_{vp} + P_{cu1} + P_{Fe} = 15,707 + 0,300 = 16,007 \text{ kW}$$

$$\eta = \frac{P_b}{P_{el}} = \frac{14,765}{16,007} = 92,2 \%$$



PROBLEM ZAGONA

3-fazni AM s kratkostično, vezava trikot. Pri zagonu mora razviti $M_{min} = 34 \text{ Nm}$. Določite min. napetost omrežja ob zagonu, če je statorsko navitje v $\star$ vezavi, in zagonski tok!

$$P_n = 22 \text{ kW}$$

$$U_n = 380 \text{ V}$$

$$f = 50 \text{ Hz}$$

$$n_n = 2935 \text{ min}^{-1}$$

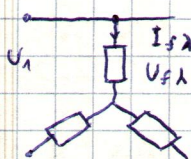
$$I_n = 42 \text{ A}$$

$$\cos \varphi_n = 0,88$$

$$\frac{I_2}{I_n} = 5,5$$

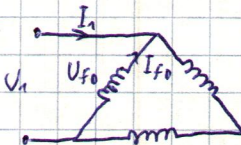
$$\frac{M_2}{M_n} = 1,7$$

$$\frac{M_{om}}{M_n} = 2,6$$



$$U_{f\lambda} = \frac{U_1}{\sqrt{3}}$$

$$I_{f\lambda} = I_n$$



$$U_{fa} = U_1$$

$$I_{f1} = \frac{I_n}{\sqrt{3}}$$

$$P = 3 U_f I_f = 3 \cdot \frac{U_1}{\sqrt{3}} I_n = 3 \cdot U_1 \cdot \frac{I_n}{\sqrt{3}} = \sqrt{3} U_1 I_n$$

$$M \propto U^2$$

$$M = k \Phi I$$

$$M_\lambda / M_n = \left(\frac{U_{f\lambda}}{U_{fa}} \right)^2 = \left(\frac{U_1}{\sqrt{3} U_1} \right)^2 = \frac{1}{3}$$

$$M_\lambda = \frac{1}{3} M_n$$

$$I_\lambda = \frac{I_n}{\sqrt{3}} \cdot \frac{1}{\sqrt{3}} = \frac{1}{3} I_n$$

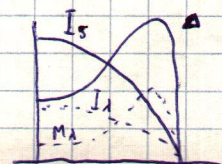
$$\text{vezava } \Delta: M_n = \frac{P_n}{\omega_n} = \frac{22 \cdot 10^3 \cdot 60}{2\pi \cdot 2935} = 71,6 \text{ Nm}$$

$$M_2 = 1,7 \cdot M_n = 122 \text{ Nm}$$

$$I_2 = 5,5 \cdot I_n = 231 \text{ A}$$

$$\text{vezava } \lambda: M_2 = \frac{1}{3} M_n = 122 \cdot \frac{1}{3} = 40,6 \text{ Nm}$$

$$I_{2\lambda} = \frac{1}{3} I_{2\Delta} = 77 \text{ A}$$



$$\frac{M_{z\lambda}}{M_{z\lambda\min}} = \left(\frac{U_{\lambda}}{U_{\lambda\min}} \right)^2$$

$$U_{\lambda\min} = U_{\lambda} \sqrt{\frac{M_{z\lambda\min}}{M_{z\lambda}}} = 380 \sqrt{\frac{34}{40,6}} = \underline{348 \text{ V}}$$

$$\frac{I_{z\lambda}}{I_{z\lambda\min}} = \frac{U_{\lambda}}{U_{\lambda\min}}$$

$$I_{z\lambda\min} = I_{z\lambda} \frac{U_{\lambda\min}}{U_{\lambda}} = 77 \cdot \frac{348}{380} = \underline{\underline{70,5 \text{ A}}}$$