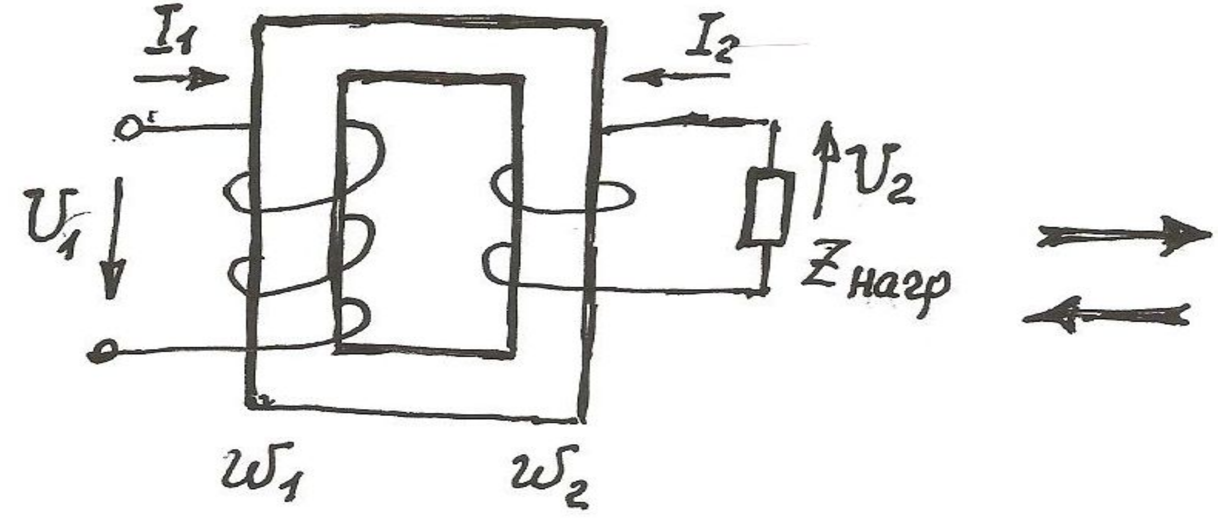
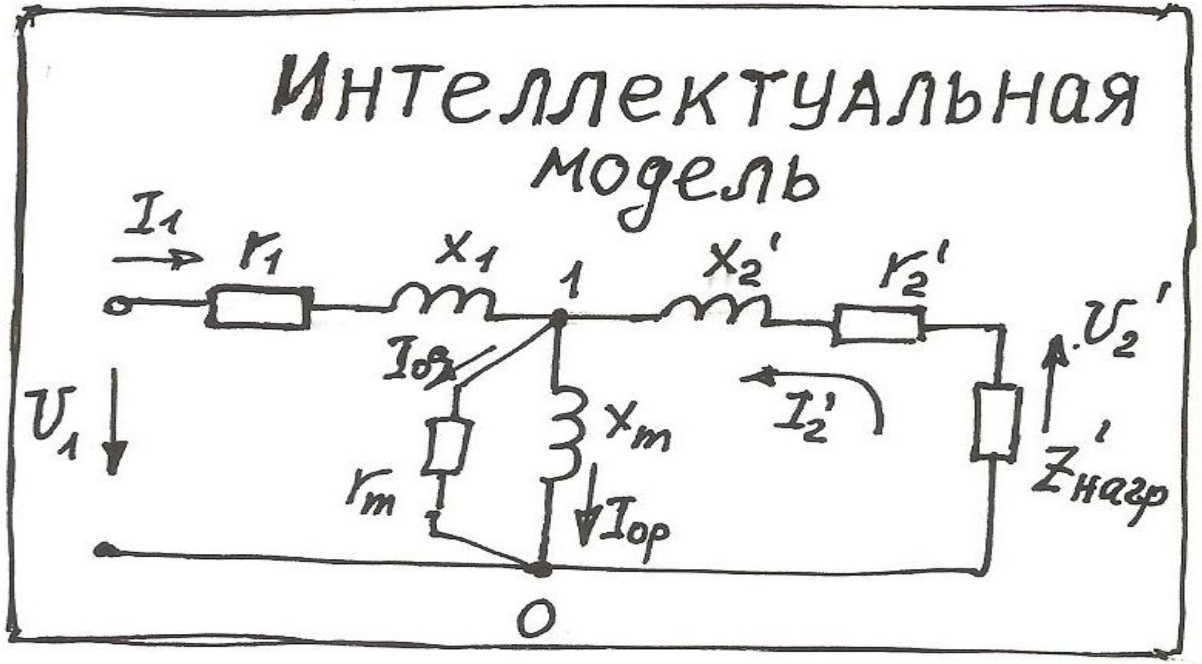
1

① Трансформатор



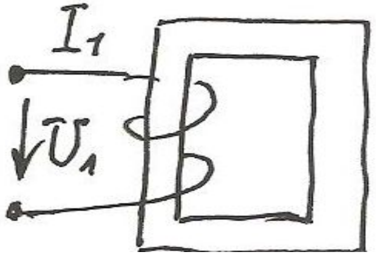


r_1, r_2' и r_m — ?

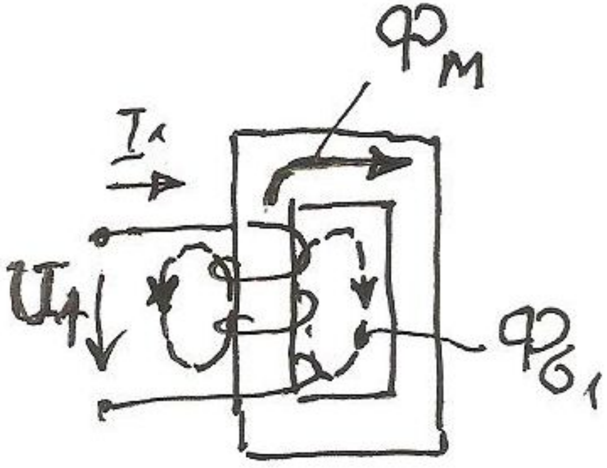
$P_{магн} = r_m \cdot I_{0a}^2$

X_1, X_2' и X_m — ?

Холостой ход (режим):

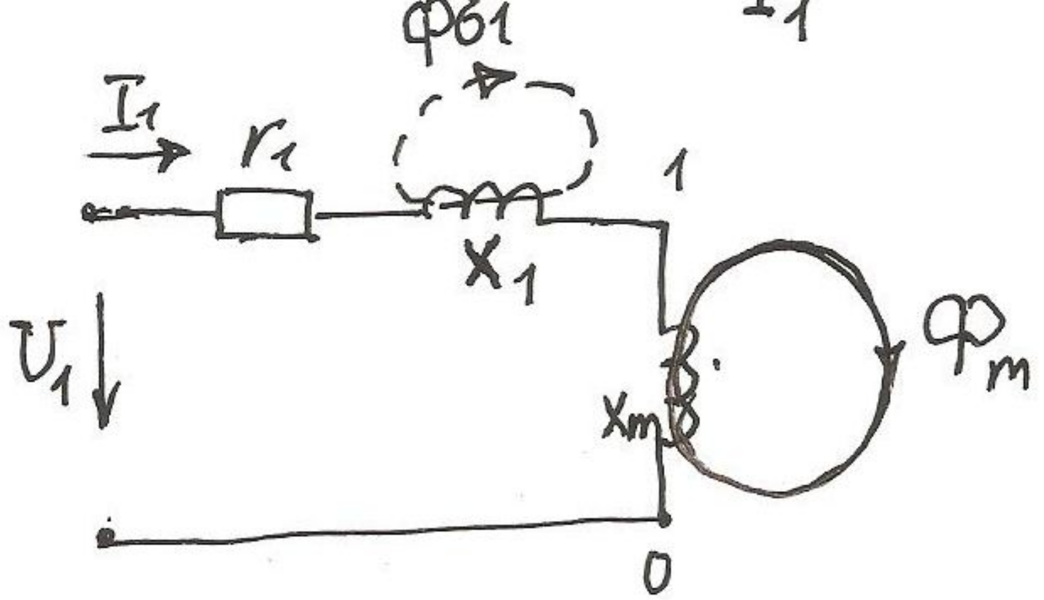


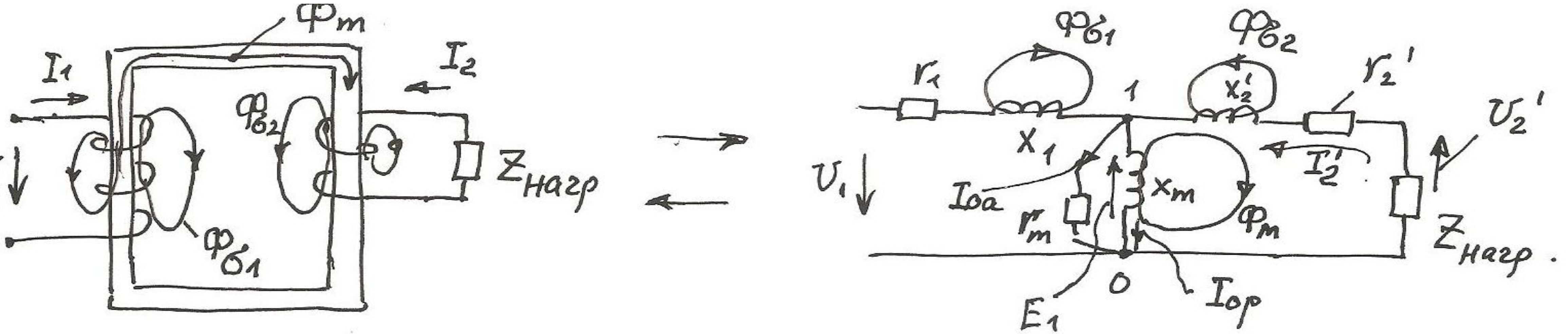
$$L = \frac{\Phi}{I_1} = \frac{\overbrace{\Phi + \Phi}^{?}}{I_1}$$



$$\frac{\Phi_m}{I_1} = L_m \equiv L_m \cdot \omega = X_m$$

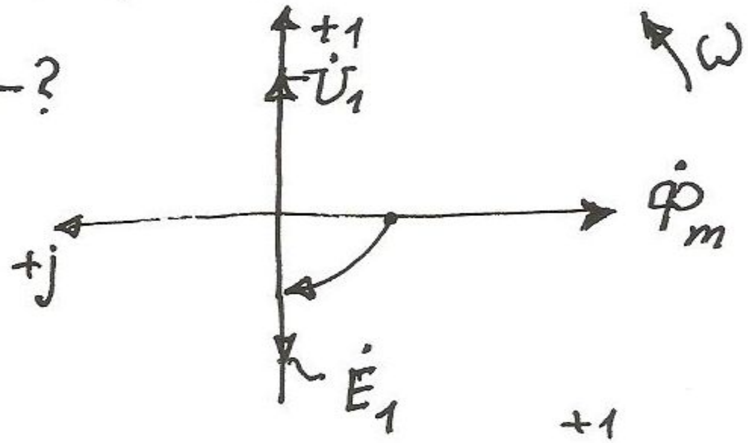
$$\frac{\Phi_{\sigma 1}}{I_1} = L_{\sigma 1} \equiv L_{\sigma 1} \cdot \omega = X_1$$





$\Phi_{\sigma 1}$, $\Phi_{\sigma 2}$ и Φ_m — ?

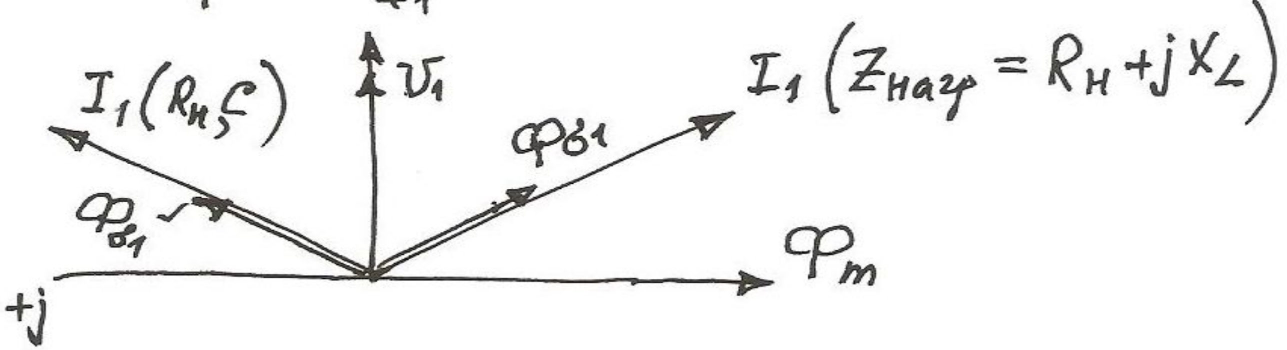
1. $\boxed{\Phi_m}$ — ?



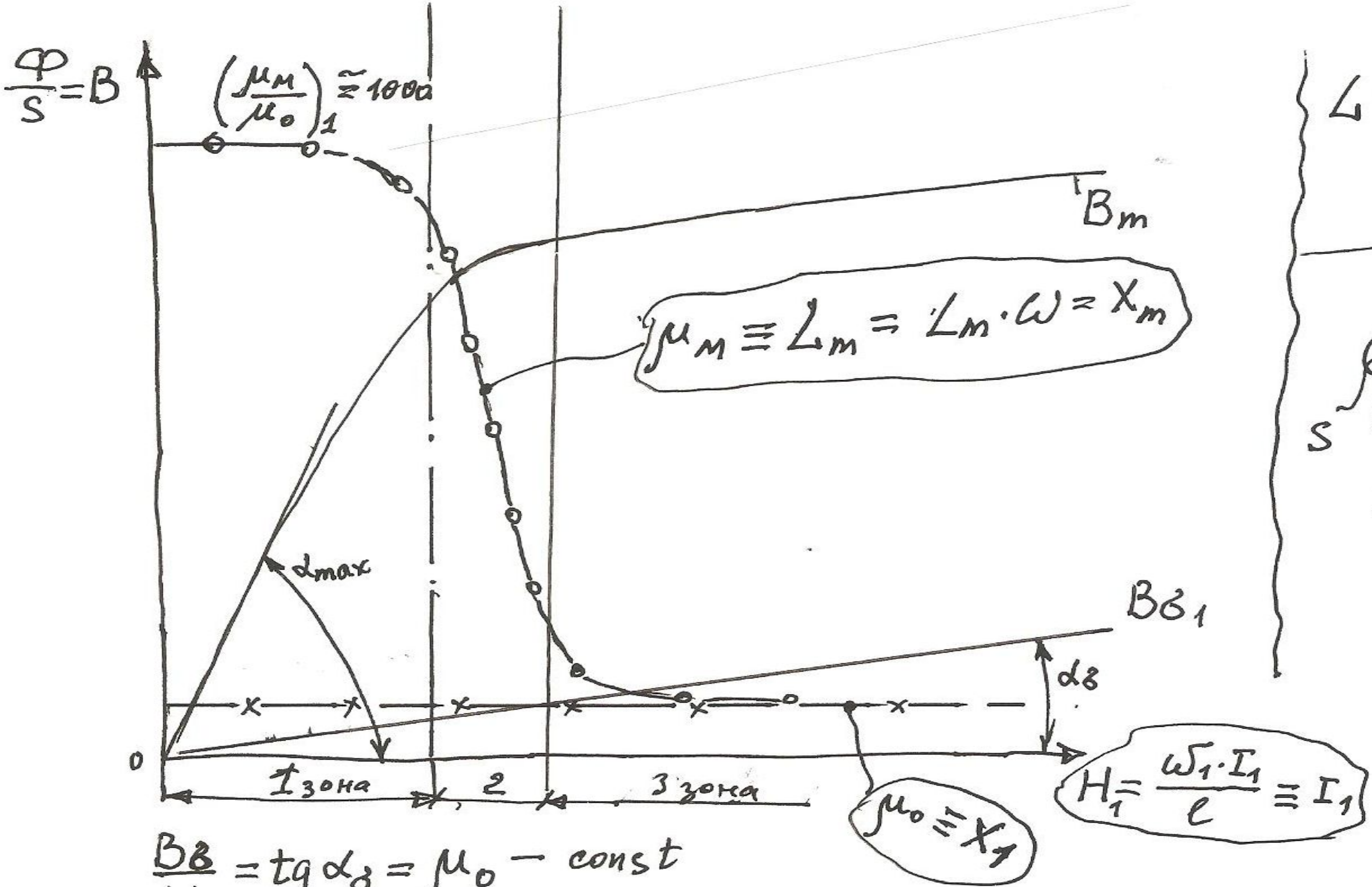
$$U_1 \approx E_1 = 4{,}44 \cdot f_1 \cdot w_1 \cdot \Phi_m$$

$$\boxed{\Phi_m \equiv U_1}$$

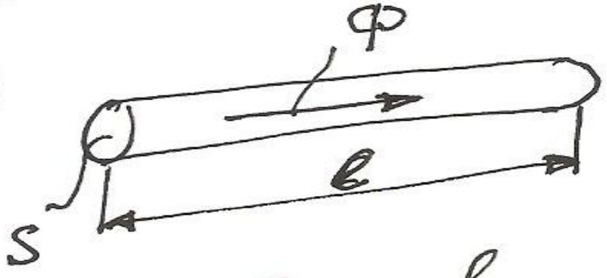
$\Phi_{\sigma 1}$ — ?



$$\boxed{\Phi_{\sigma 1} \equiv I_1}$$



$$L = \frac{\Phi}{I_1} \equiv \frac{B}{H} = tg\alpha \equiv \mu$$

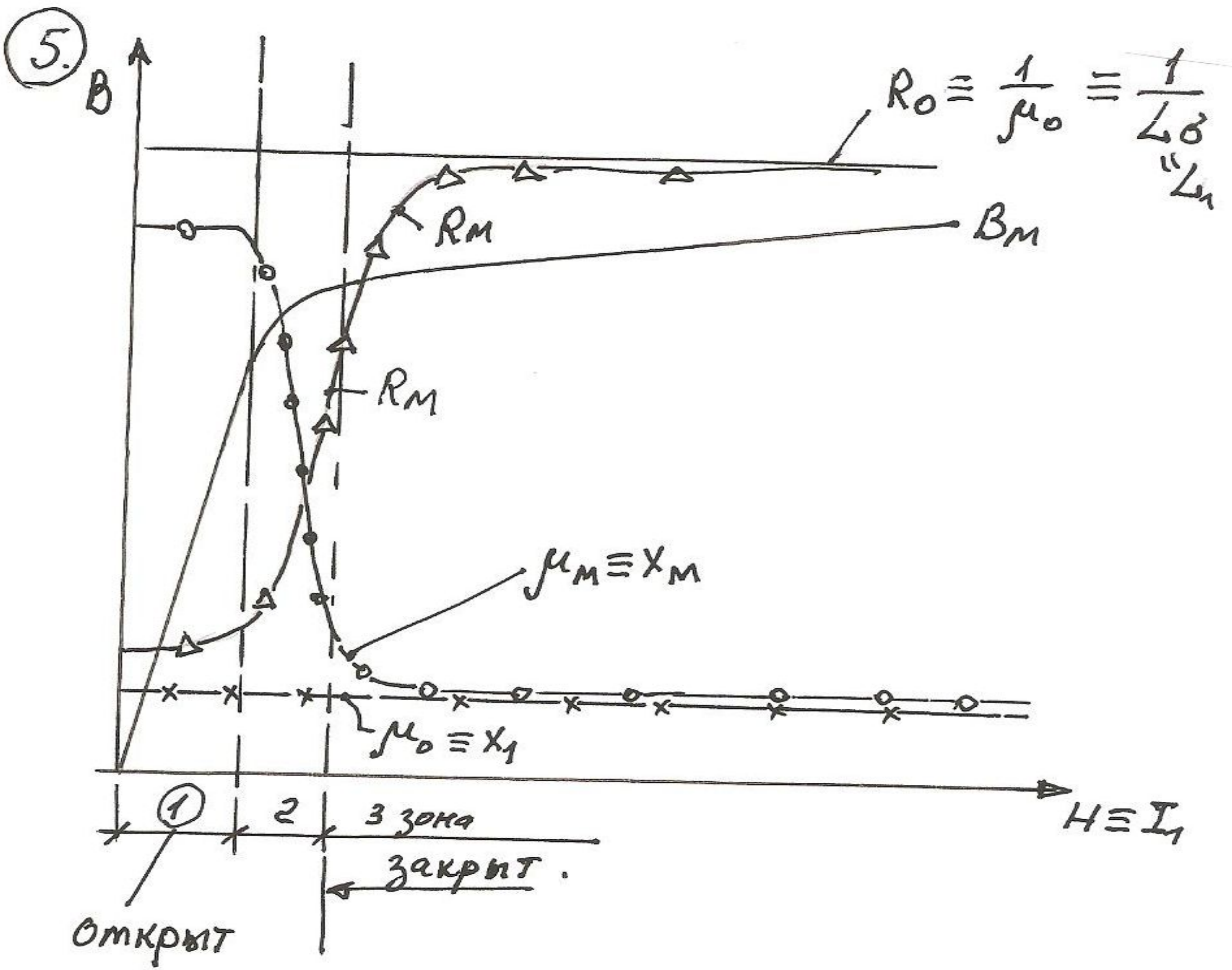


$$R_M = \frac{l}{\mu_M \cdot S}$$

$$\boxed{R_M \equiv \frac{1}{\mu_M}}$$

$$\frac{B\delta}{H} = tg\,\alpha_\delta = \mu_0 - const$$

$$\frac{dB_m}{dH} = tg\,\alpha_m$$

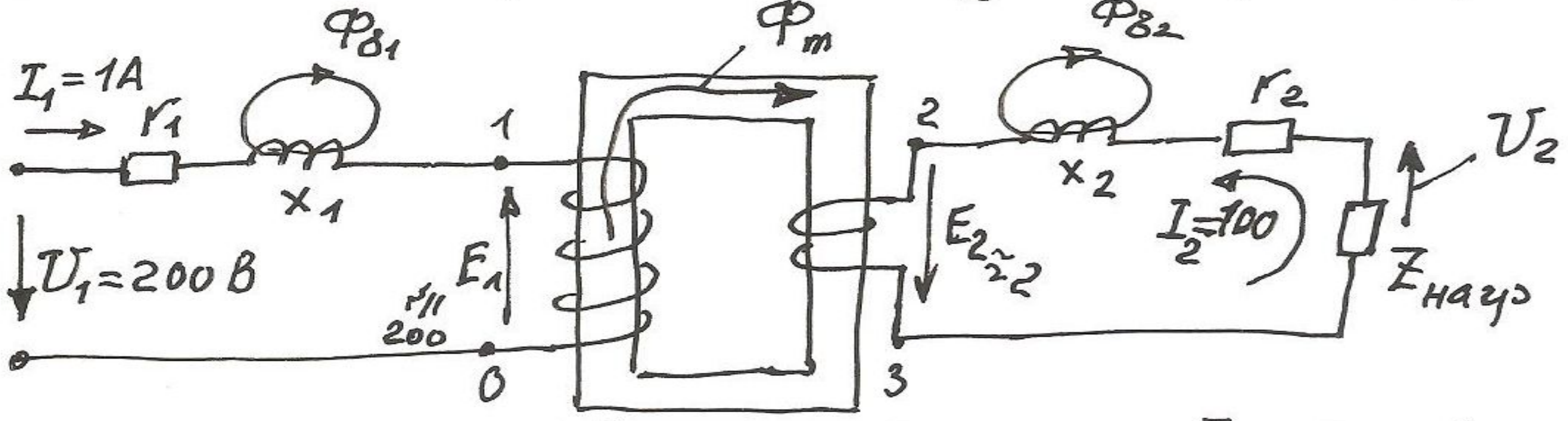


$$R_M \equiv \frac{1}{\mu_M} \equiv \frac{1}{L_M}$$

$$\boxed{L_M = \frac{\omega_1^2}{R_M}}$$

⑥ Процесс построения модели трансформатора

1)



$w_1 = 1000; \quad w_2 = 10$

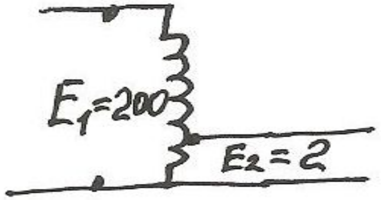
$$\boxed{K = \frac{w_1}{w_2} = 100}$$

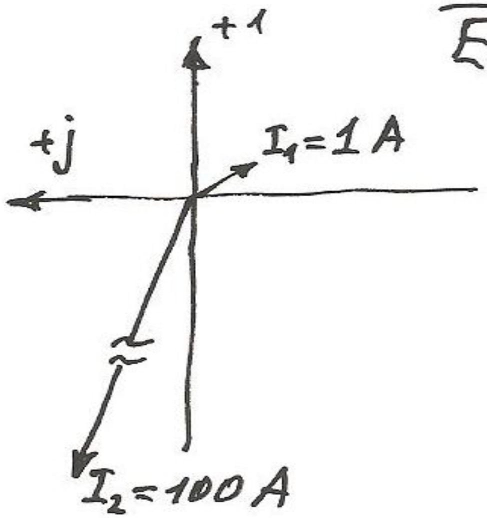
$$E_1 = 4{,}44 \cdot f_1 \cdot w_1 \cdot \Phi_m$$

$$E_2 = 4{,}44 \cdot f_1 \cdot w_2\, \Phi_m$$

$$\frac{E_1}{E_2} = \frac{w_1}{w_2} = 100; \quad E_2 = \frac{200}{100} = 2\ B$$

<u>1. Вариант</u>





7 Второй вариант

Переход к приведенному тр-ру:

$w_2' = w_1 \longrightarrow E_2' = E_1$; $I_2' \approx I_1$

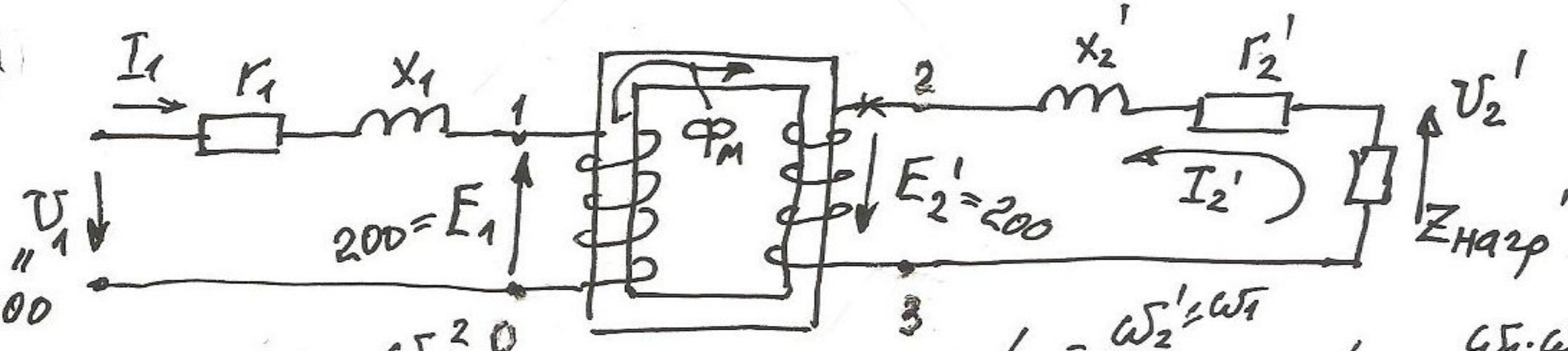
$$\underset{E_1 \cdot I_1}{\underset{\shortparallel}{S_1}} = \underset{E_2 \cdot I_2 = E_2' \cdot I_2'}{\underset{\shortparallel}{S_2}}$$

$I_2' = \frac{I_2}{k}$; $E_2' = E_2 \cdot k$

$$r_2' = \rho \frac{(l \cdot k)}{\left(\frac{S}{k}\right)} = \underbrace{\left(\rho \frac{l}{S}\right)}_{r_2 \text{ — до изменения}} \cdot k^2 = r_2 \cdot k^2 \quad ; \quad Z_2' = Z_2 \cdot k^2 ;$$

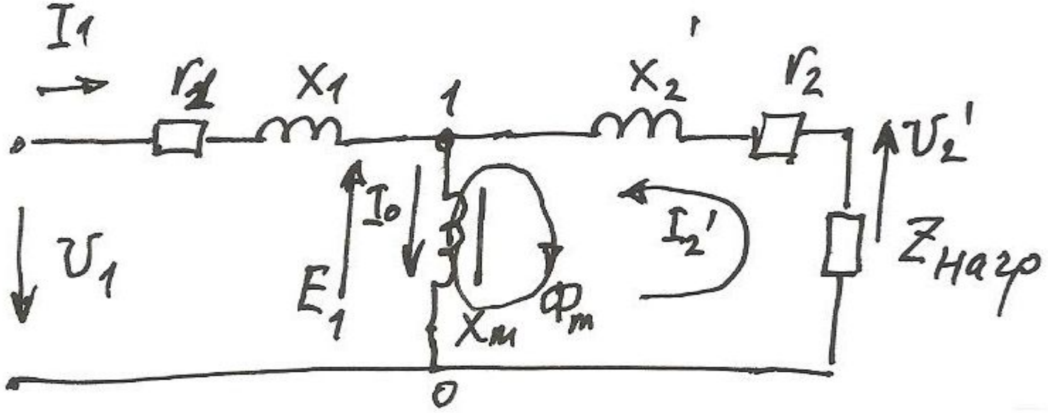
$x_2' = x_2 \cdot k^2$

$z_{нагр}' = z_{нагр} \cdot k^2$

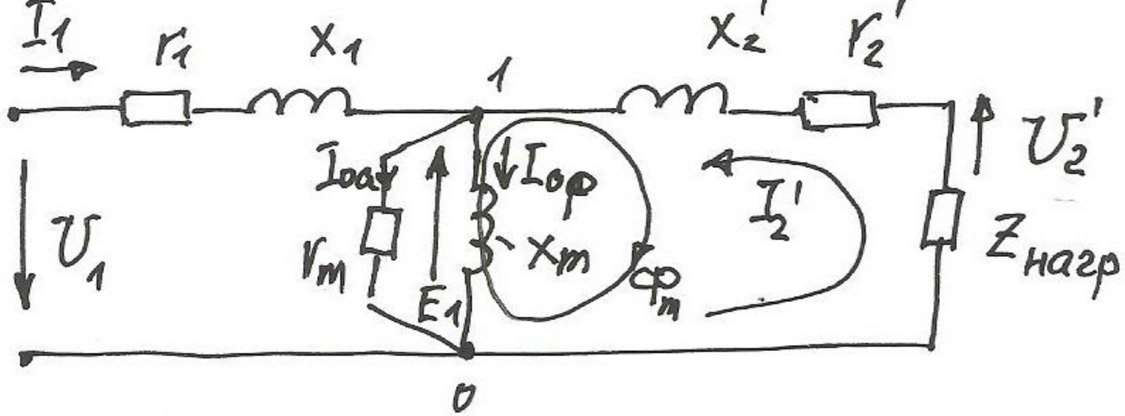
2) 

$L_1 = \frac{w_1^2}{R_м}$ $\quad L_2 = \frac{w_2'^2}{R_м}$, $w_2' = w_1$ $\quad L_м = \frac{w_1 \cdot w_2'}{R_м}$, $w_2' = w_1$

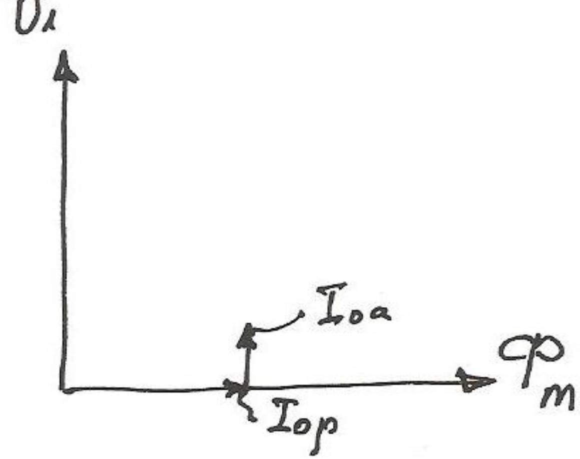
8



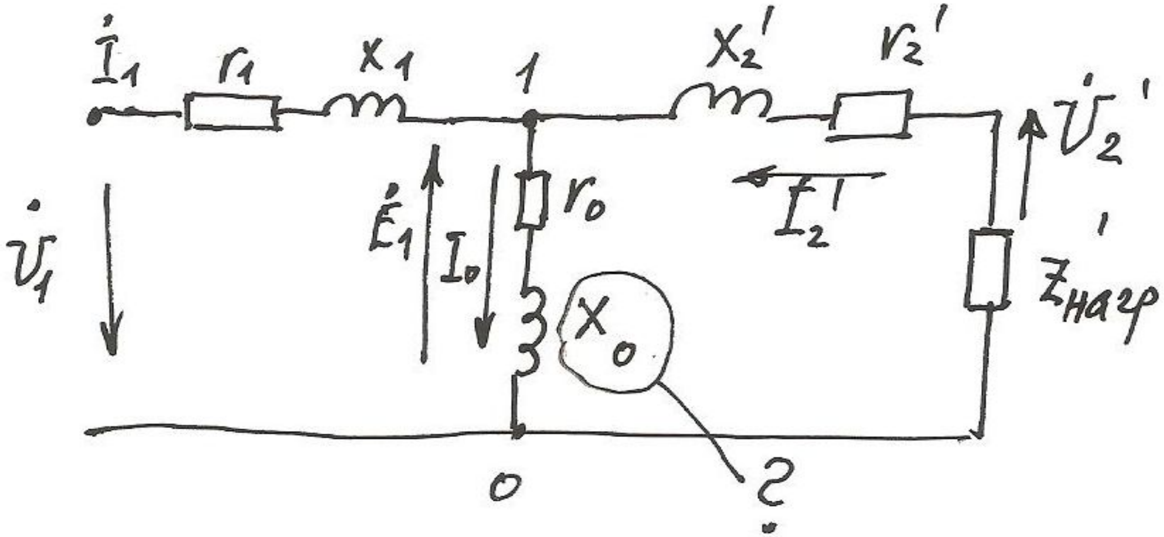
I1
r1
x1
1
x2'
r2
U2'
I0
E1
U1
I2'
Zнагр
xm
Фm
0



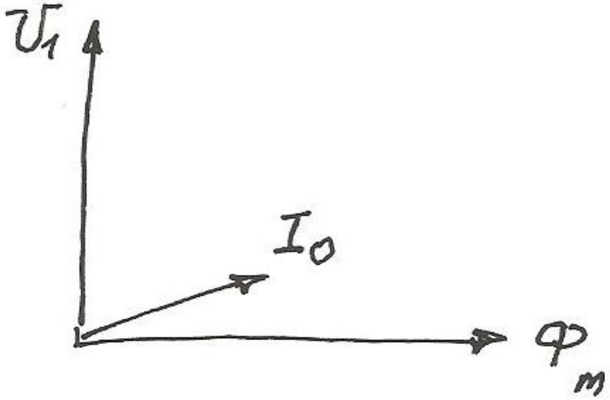
I1
r1
x1
1
x2'
r2'
U2'
I0a
I0p
rm
xm
E1
U1
I2'
Фm
Zнагр
0



U1
I0a
Фm
I0p

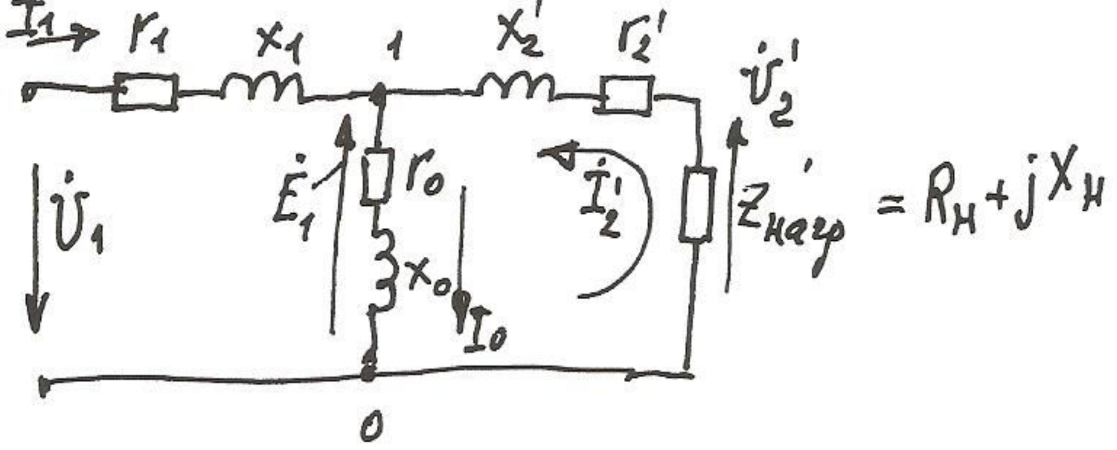


İ1
r1
x1
1
x2'
r2'
U̇2'
U̇1
Ė1
I0
r0
X0
I2'
Zнагр'
0
?



U1
I0
Фm

(9)



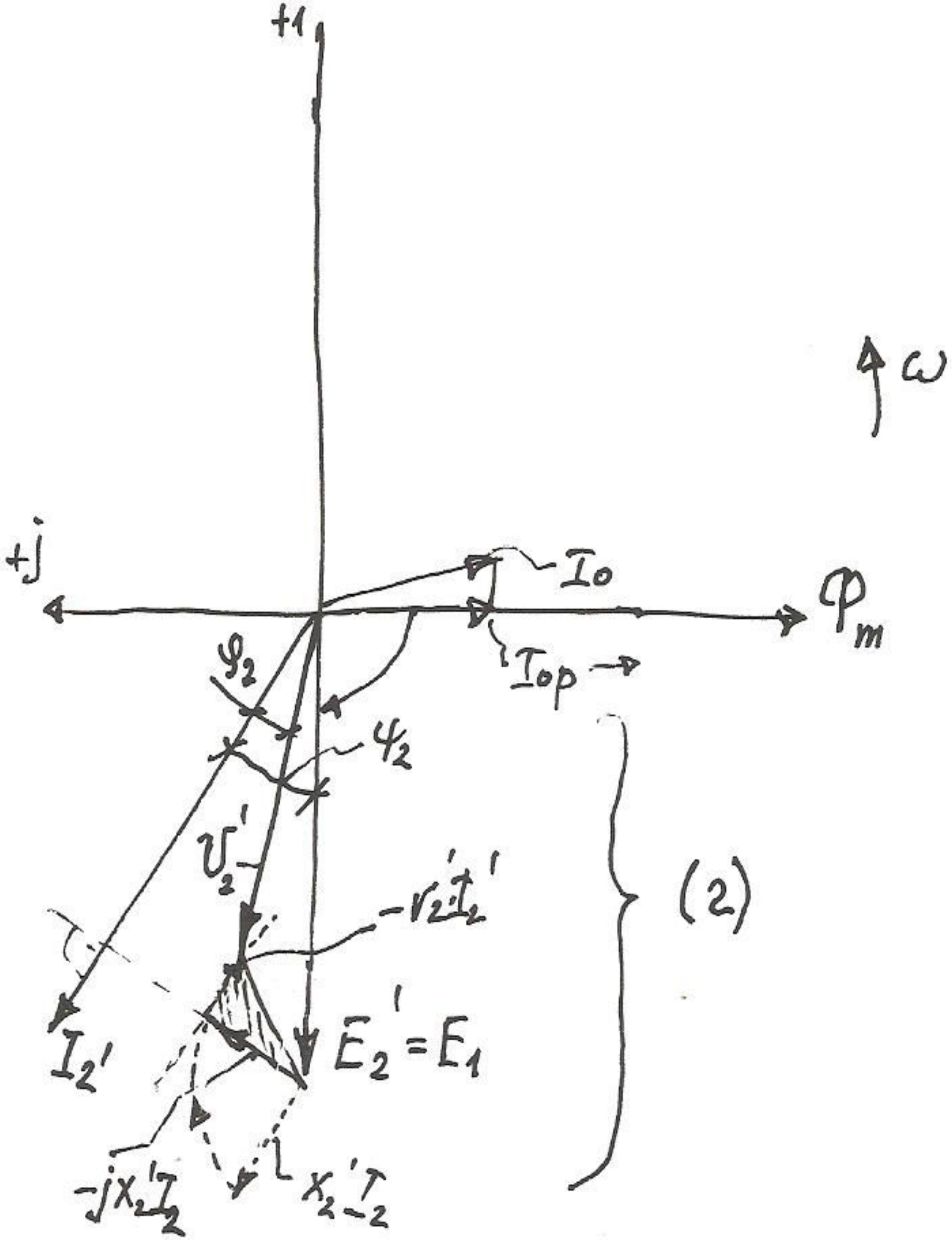
$$\dot U_1 = \left(-\dot E_1\right) + r_1 \cdot \dot I_1 + jx_1 \cdot I_1 \quad (1)$$

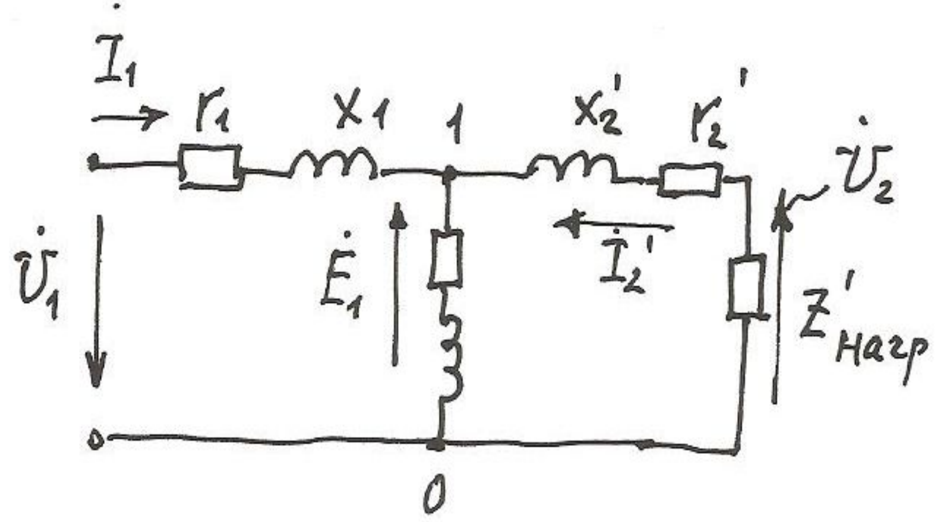
$$U_2' = \dot E_2' - jx_2' \dot I_2' - r_2' \cdot \dot I_2' \quad (2)$$

$$\shortparallel$$

$$\dot E_1$$

$$\dot I_1 = \dot I_0 + \left(-\dot I_2\right) \quad (3)$$

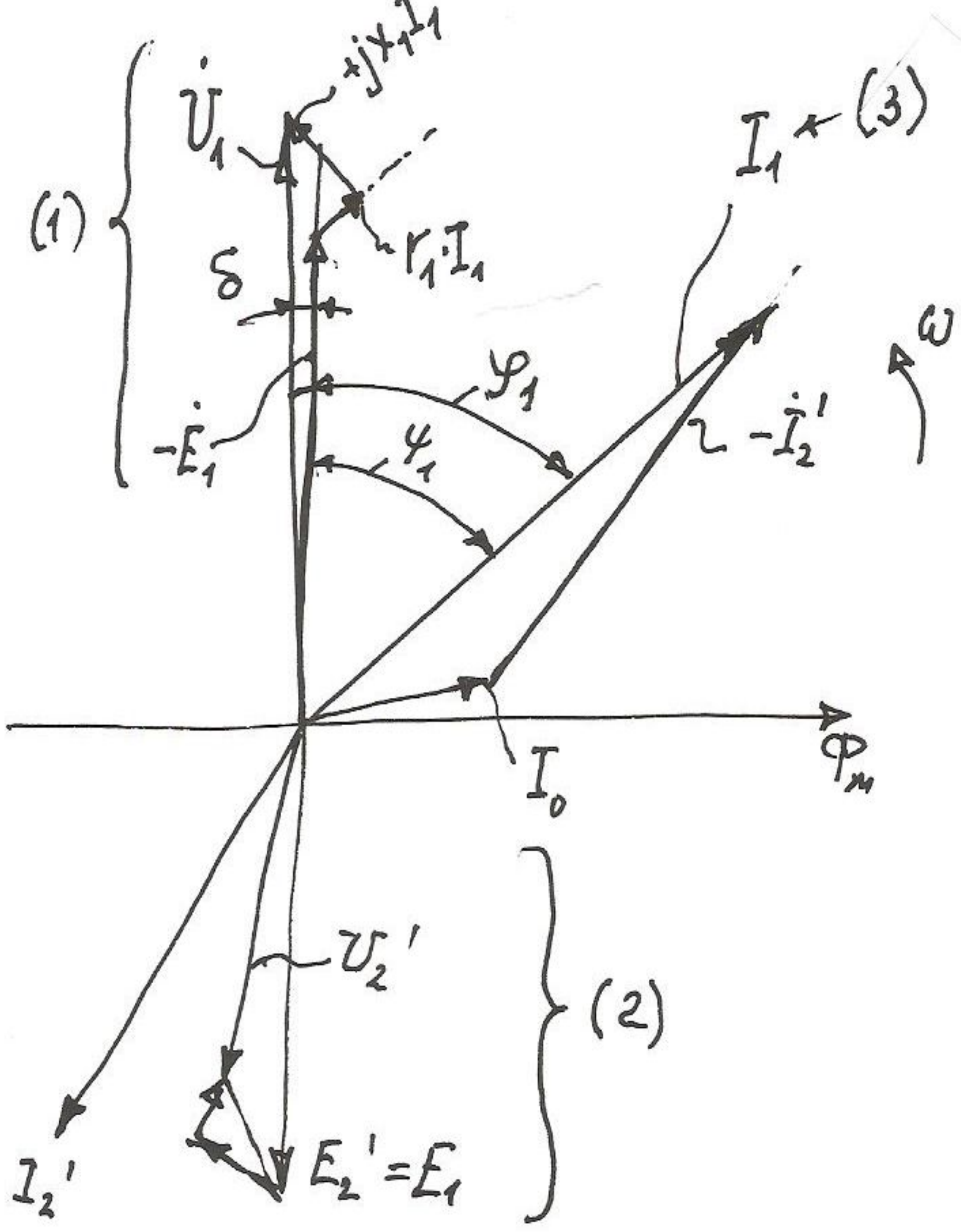




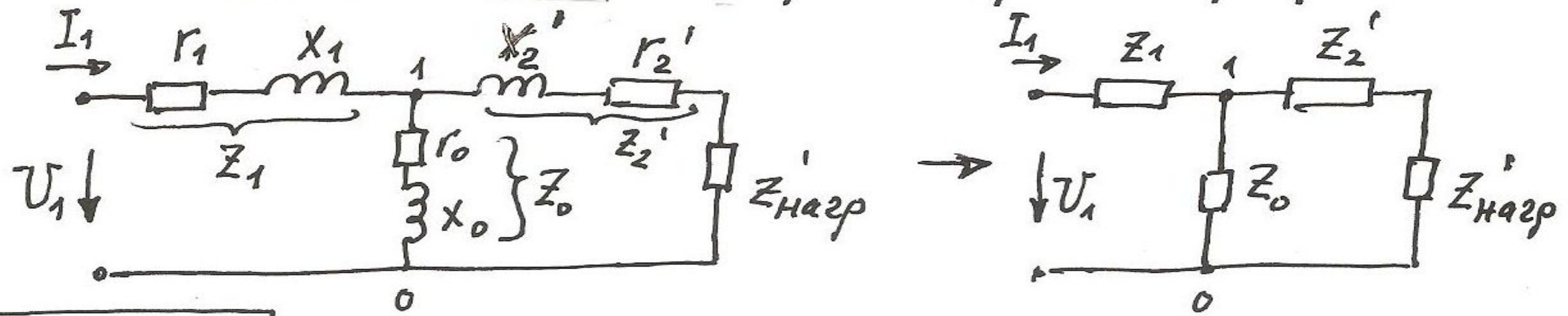
$$\dot{U}_1 = (-\dot{E}_1) + r_1\dot{I}_1 + jx_1\cdot\dot{I}_1 \quad (1)$$

$$\dot{U}_2' = E_2' - jx_2'\cdot I_2' - r_2' I_2' \quad (2)$$

$$\dot{I}_1 = \dot{I}_0 + (-\dot{I}_2') \quad (3)$$



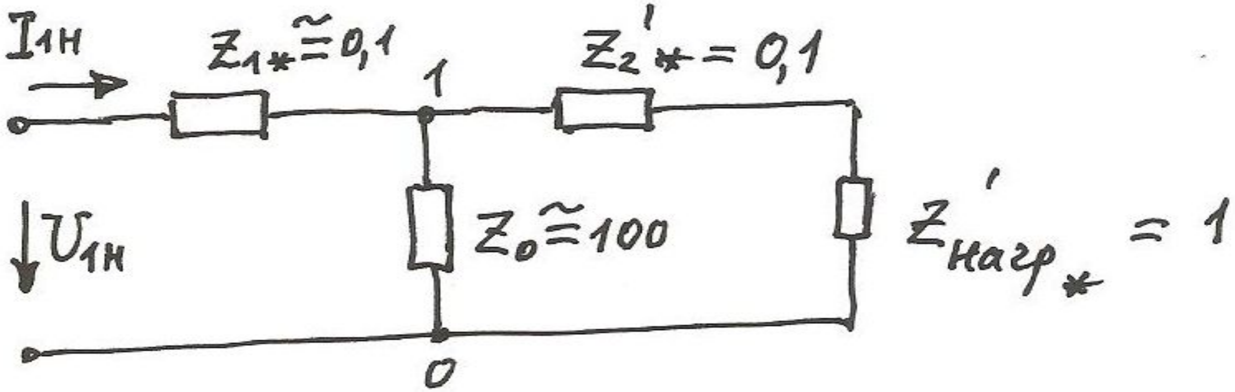
Соотношение параметров тр-ра



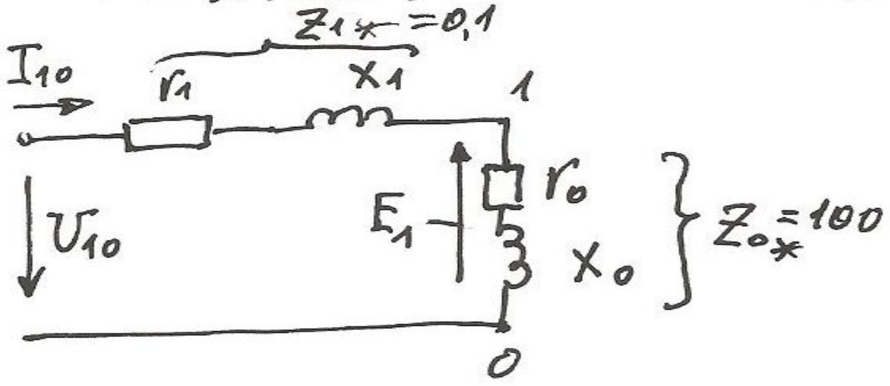
$$\boxed{Z_{ном} = \frac{U_{1н}}{I_{1н}}}$$

$$Z_{1*} = \frac{Z_1}{Z_{ном}} \cong 0{,}1 \quad ; \quad Z'_{2*} = \frac{Z'_2}{Z_{ном}} = 0{,}1 \quad ;$$

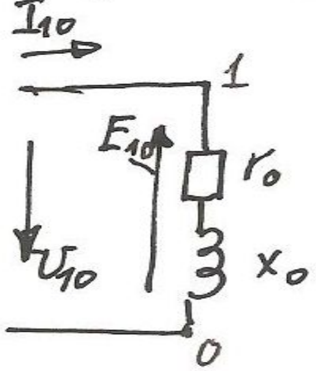
$$Z_{0*} = \frac{Z_0}{Z_{ном}} = 25 \ldots 200 \ (100) \quad ; \quad Z'_{нагр*} = \frac{Z'_{нагр}}{Z_{ном}} = 1 \qquad (Z'_{нагр} = Z_{ном})$$



Режим холостого хода (х.х.)



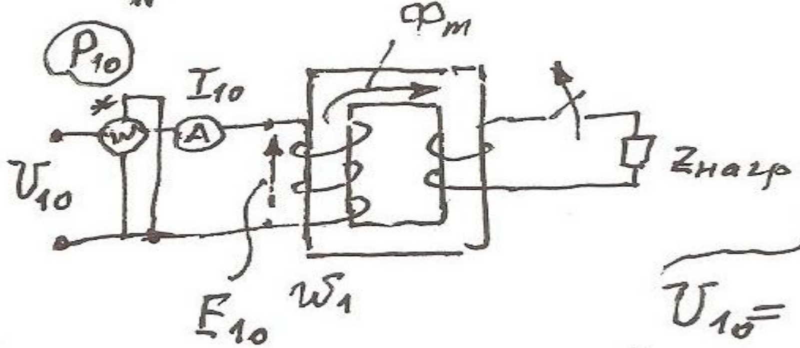
$\boxed{Z_0 >> Z_1}$ $\longrightarrow$



$\boxed{\text{При} \quad U_1 = U_{1н} \quad \text{и} \quad Z'_{нагр} = Z_{ном} \quad \underline{I_1} = I_{1н}}$

$\Downarrow$ в х.х. $U_1 = U_{1н}$ Ток протекает по $Z_0 \cong 100 \cdot Z_{нагр}$, поэтому $I_{10} = \frac{I_{1н}}{100}$

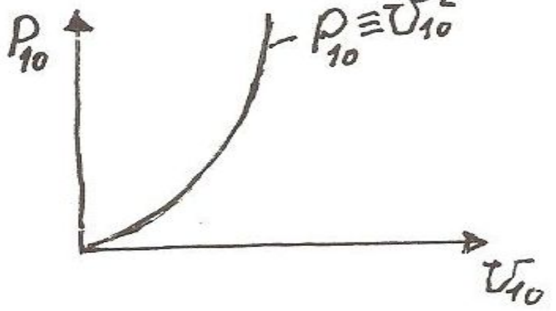
т.е. составляет 1% от номинального тока.

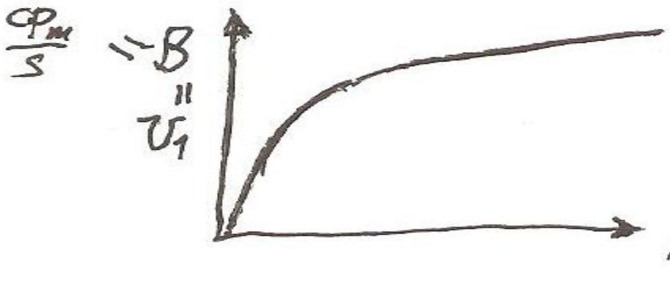


$P_{10} = P_{мг} = \Phi_m^2 \cdot R_{мг}$ — реальн. тр-р

$\cong r_0 \cdot I_{10}^2$ — схема замещения

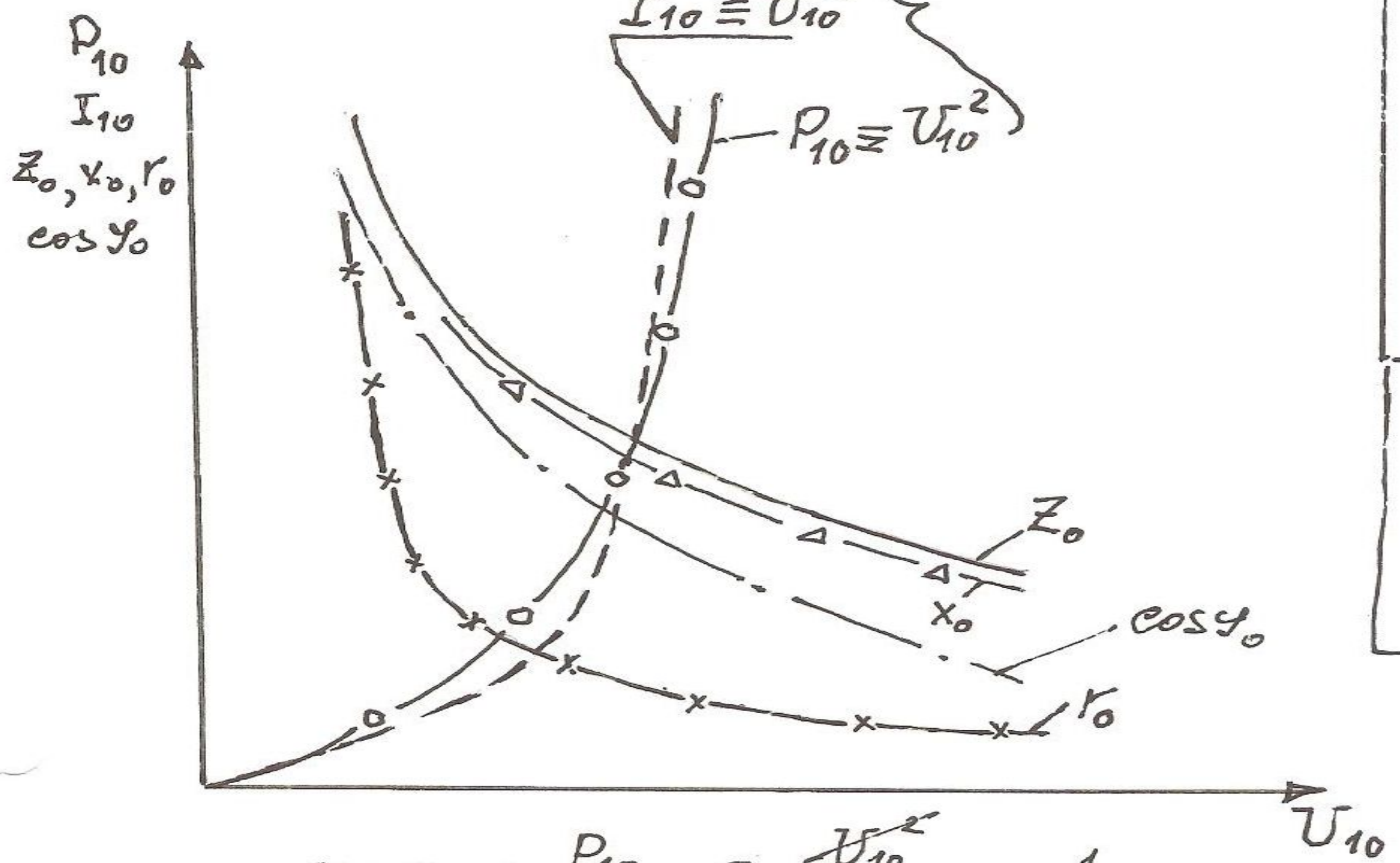
$\overbrace{U_{10} = E_{10}}^{х.х.} = 4{,}44 \cdot f_1 \cdot w_1 \cdot \Phi_m \rightarrow \Phi_m \equiv U_1 \rightarrow P_{10} \equiv U_{10}^2$ — реальн. трансф.

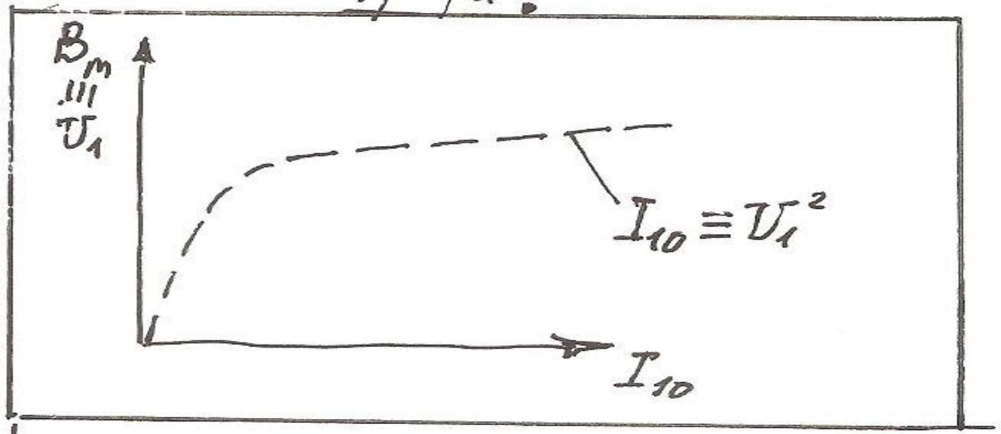




$H = \frac{w_1 \cdot I_{10}}{l} \equiv I_{10}$

эти х-ки снимаются из опыта х.х реального тр-ра!





$$Z_0 = \frac{U_{10}}{I_{10}} \equiv \frac{\cancel{U_{10}}}{U_{10}^{\cancel{2}}} = \frac{1}{U_{10}}$$

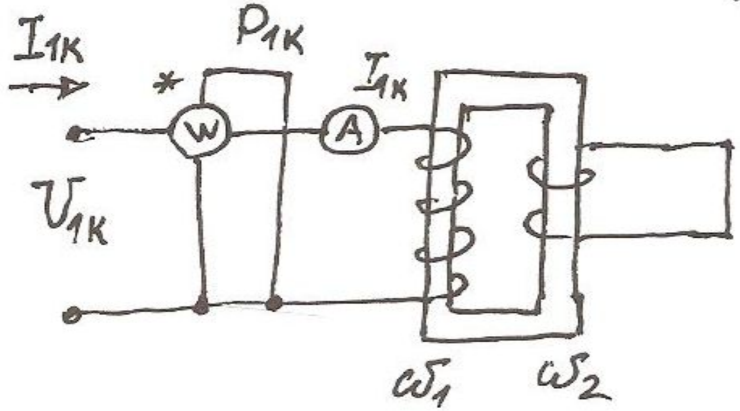
$$r_0 = \frac{P_{10}}{I_{10}^2} = \frac{U_{10}^{\cancel{2}}}{U_{10}^{\cancel{4}\,2}} = \frac{1}{U_{10}^2}$$

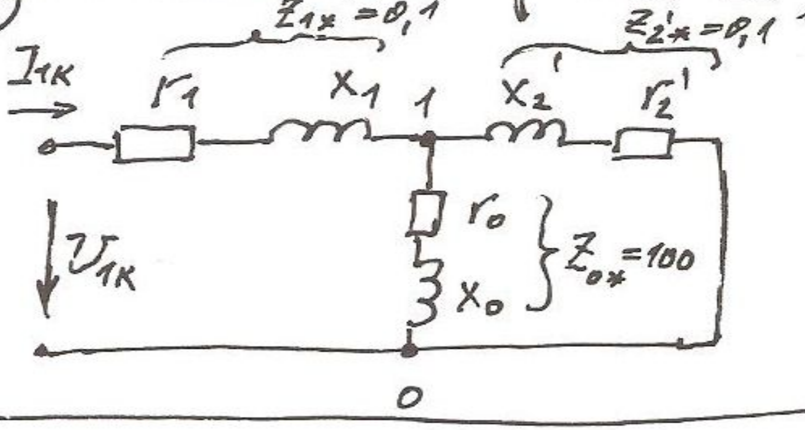
$$\underbrace{x_0 = \sqrt{z_0^2 - r_0^2} = \sqrt{\frac{U_{10}^2 - 1}{U_{10}^4}} \approx \frac{1}{U_{10}}}_{\text{(из реального тр-ра)}}$$

$$\cos\varphi_0 = \frac{P_{10}}{U_{10} \cdot I_{10}} \equiv \frac{\cancel{U_{10}^2}}{U_{10} \cdot \cancel{U_{10}^2}} = \frac{1}{U_{10}}$$

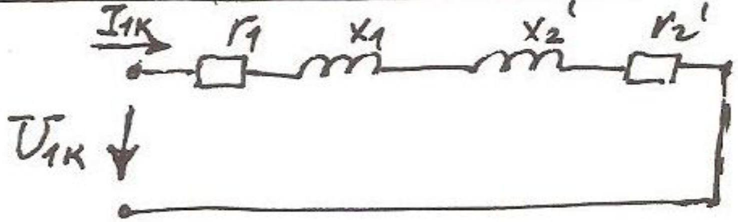
Вывод: Опыт х.х в реальном тр-ре определяется для того, чтобы определить переменные параметры и электрические величины для вертикальной ветви схемы замещения (!) (или параметров цепи намагничивания).

Режим короткого замыкания (К.З.)





При ‖ соединении в схеме замещения $\frac{Z_{0*}}{Z'_{2*}}=1000$, то пренебрегаем сопротивления цепи намагничивания



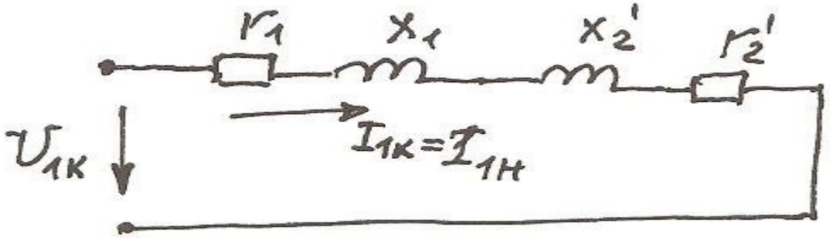
Прогноз:

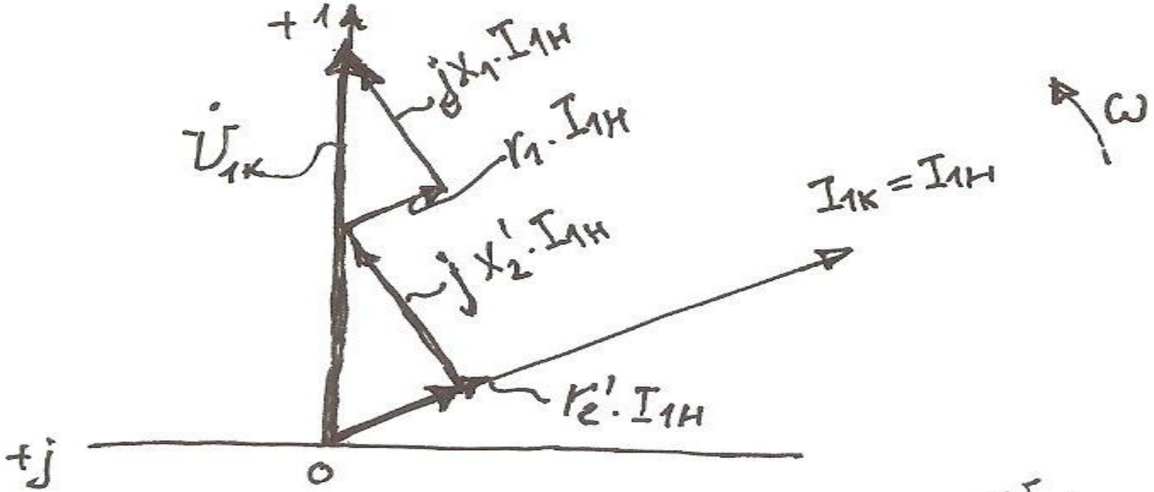
В режиме К.З. $Z_{нагр*}=0$, поэтому ток ограничивается параметрами обмоток:

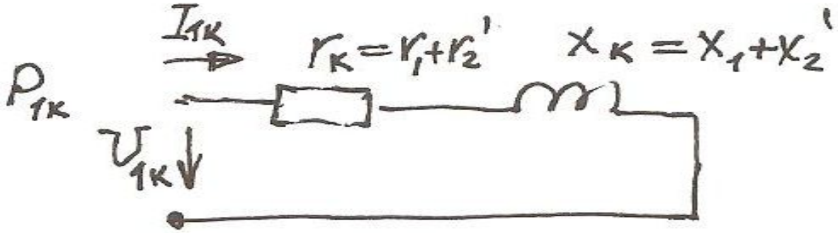
$Z_{к*}=Z_{1*}+Z'_{2*}=0,2$

Поэтому необходимо ограничить напряжение $U_{1к}$

$I_{1к}=I_{1н}$ при $\boxed{U_{1к}=0,2\cdot U_{1н}}$





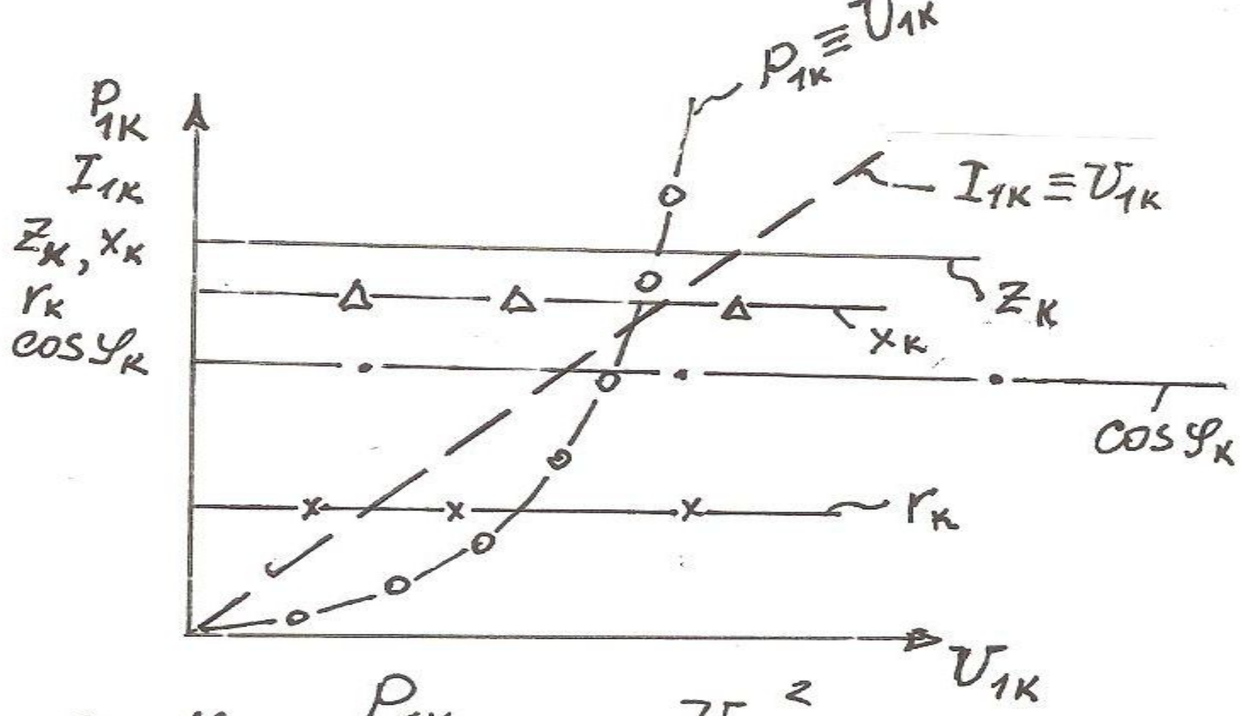


$$Z_K = \frac{U_{1K}}{I_{1K}} \text{ — const } \left(r_K, x_K \text{ — const}\right)$$

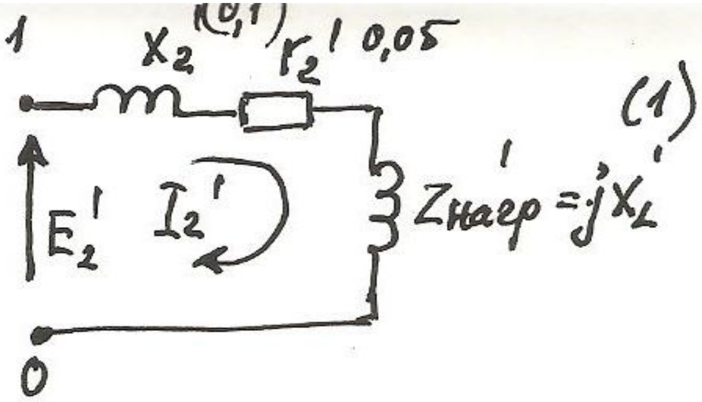
$$I_{1K} = \frac{U_{1K}}{Z_K} \equiv U_{1K}$$

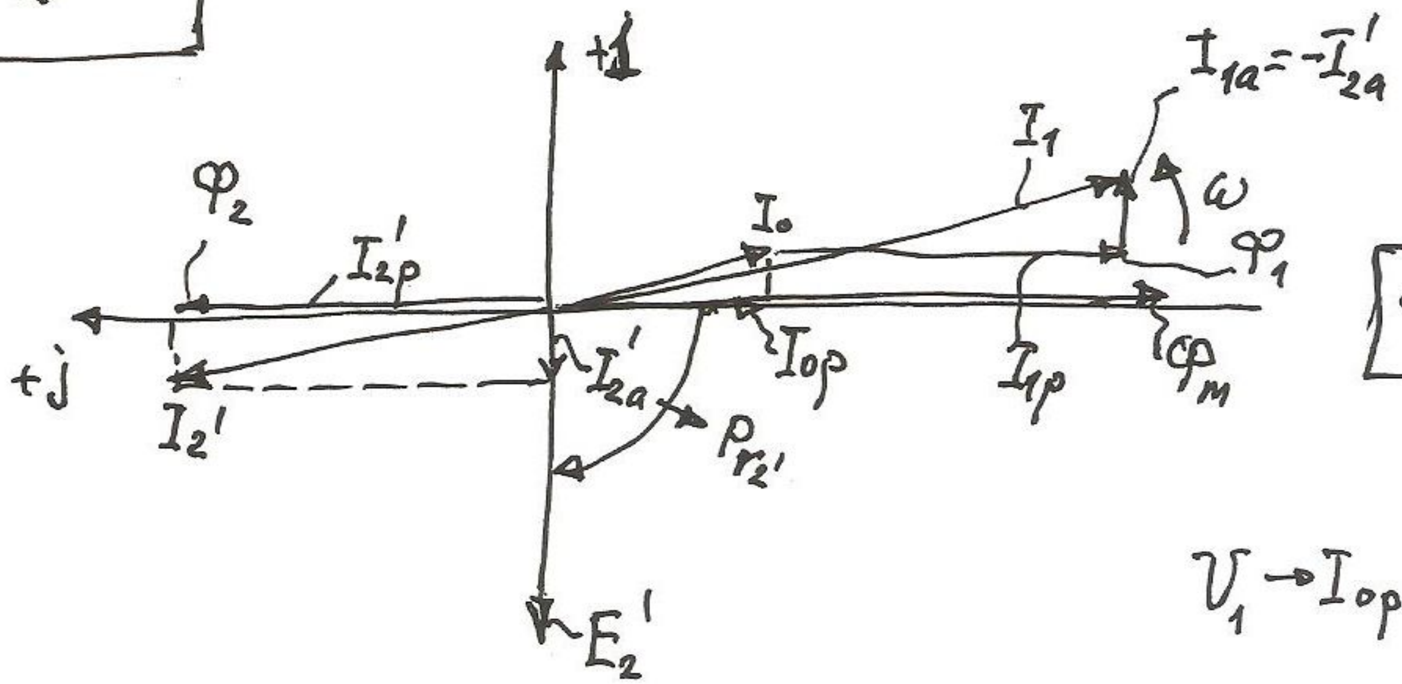
$$P_{1K} = r_K \cdot I_{1K}^2 \equiv U_{1K}^2$$

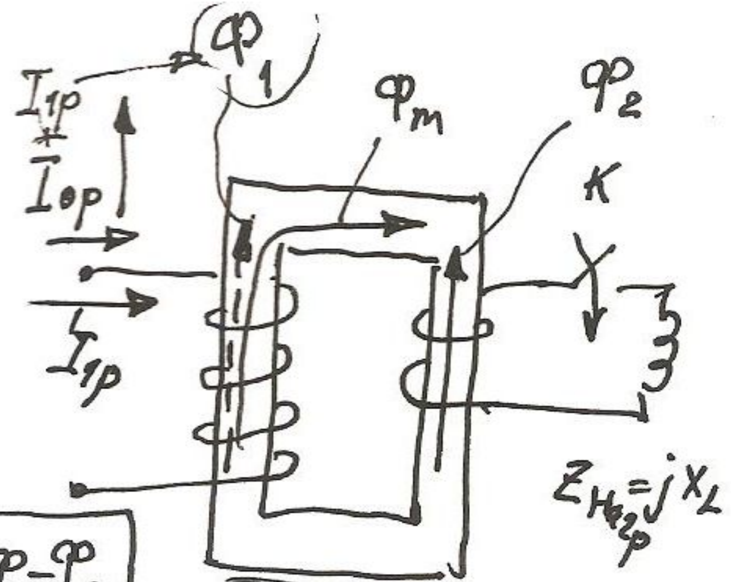
$$r_K = \frac{P_{1K}}{I_{1K}^2} = \frac{U_{1K}^2}{U_{1K}^2} \text{ — const}$$



$$\cos\varphi_K = \frac{P_{1K}}{U_{1K} \cdot I_{1K}} \equiv \frac{U_{1K}^2}{U_{1K} \cdot U_{1K}} \text{ — const}$$







$$\boxed{\Phi_\Sigma = \Phi_m - \Phi_2}$$

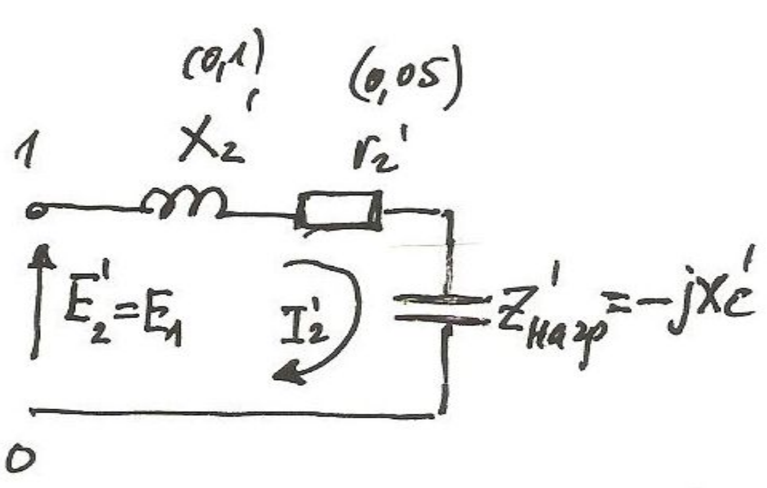
$$\Phi_1 = \Phi_2$$

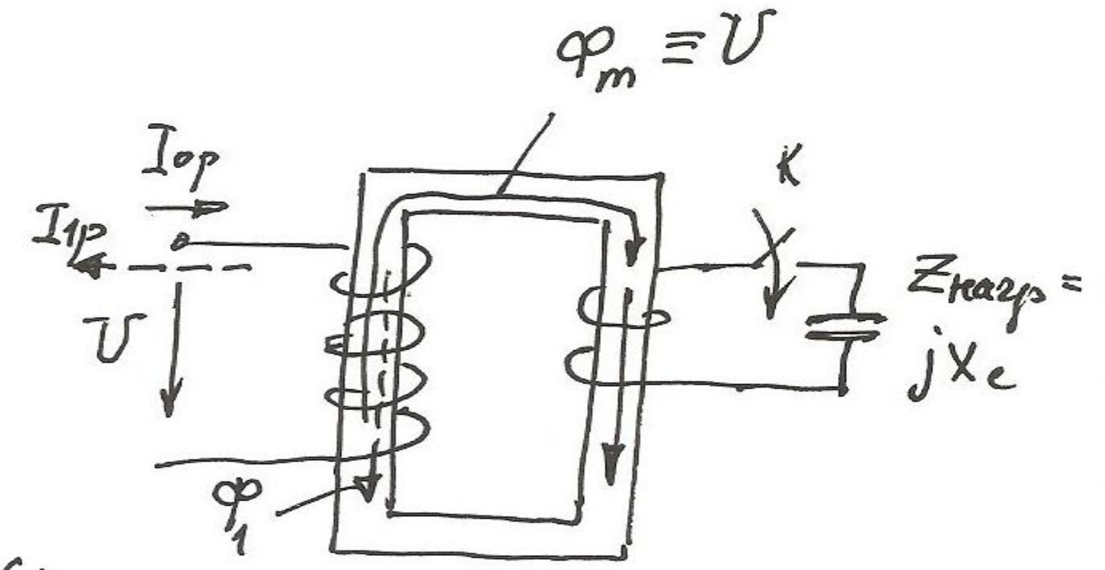
$$U_1 \to I_{0p} \to \Phi_m \to E_2' = E_1 \to \quad \to$$

$$\to I_2' \to I_{2p}' \to \Phi_2 \uparrow \downarrow \Phi_m$$

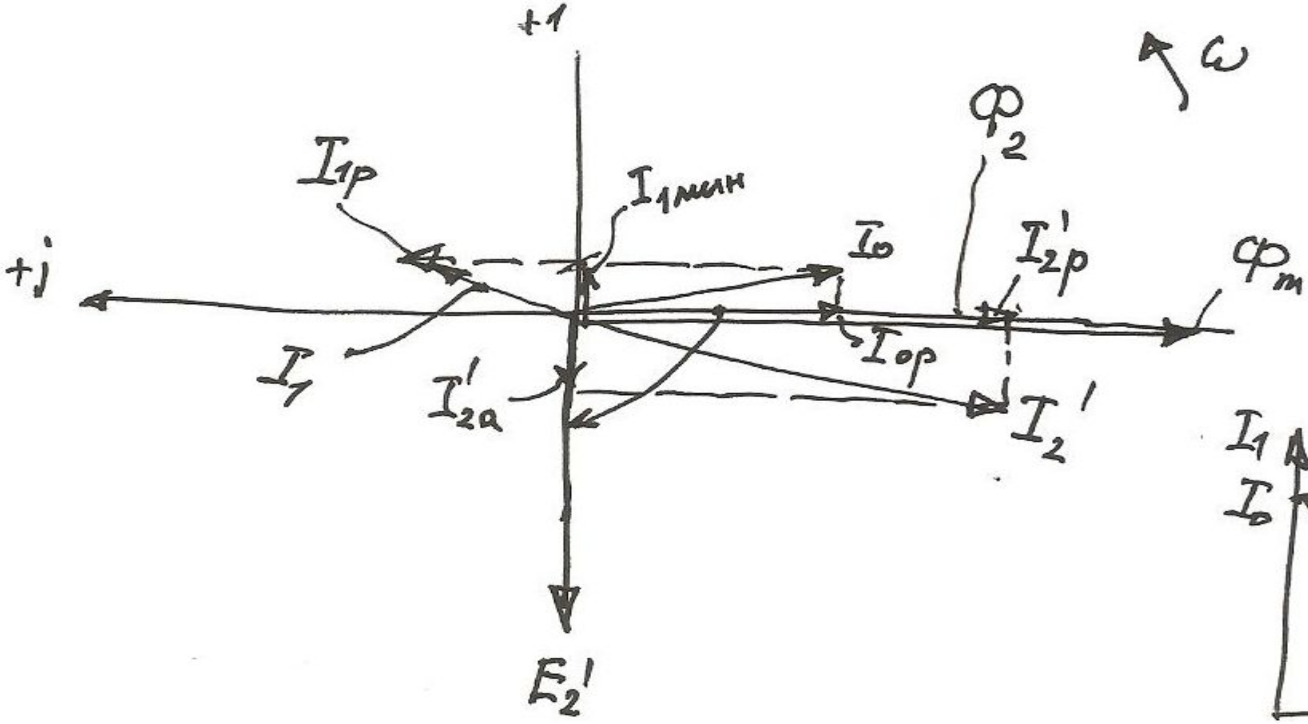
$$\to I_{2a}' \equiv P_{r_2'}$$

$$\underset{\text{const}}{U} = (\underset{\Phi_\Sigma \downarrow}{-E_1})\downarrow + (r_1 + jX_1)\cdot I_{1p}\uparrow$$

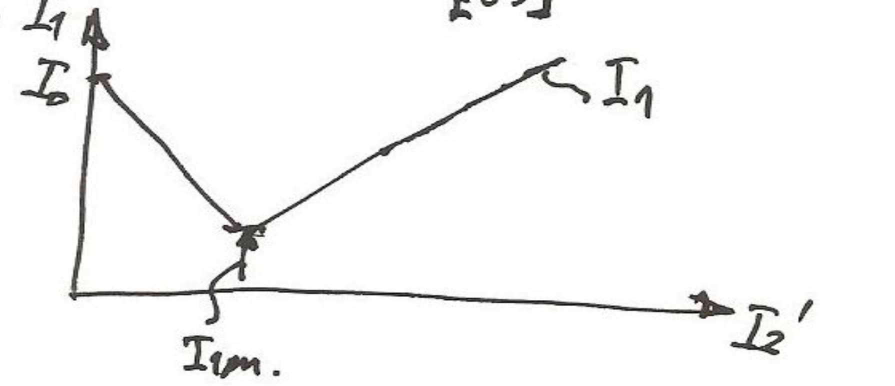




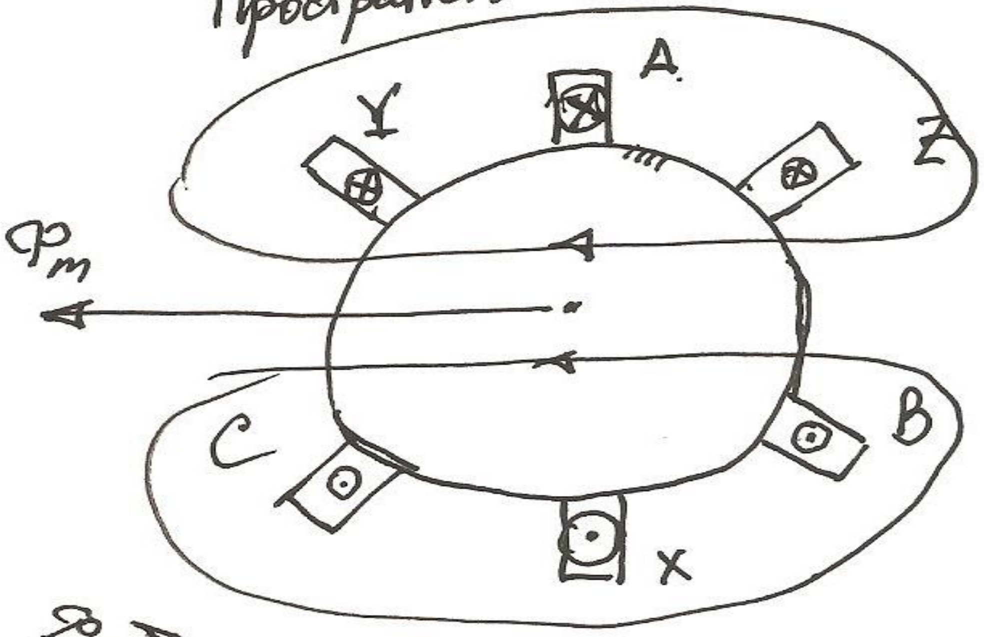
$$\Phi_\Sigma = \Phi_m + \Phi_2$$

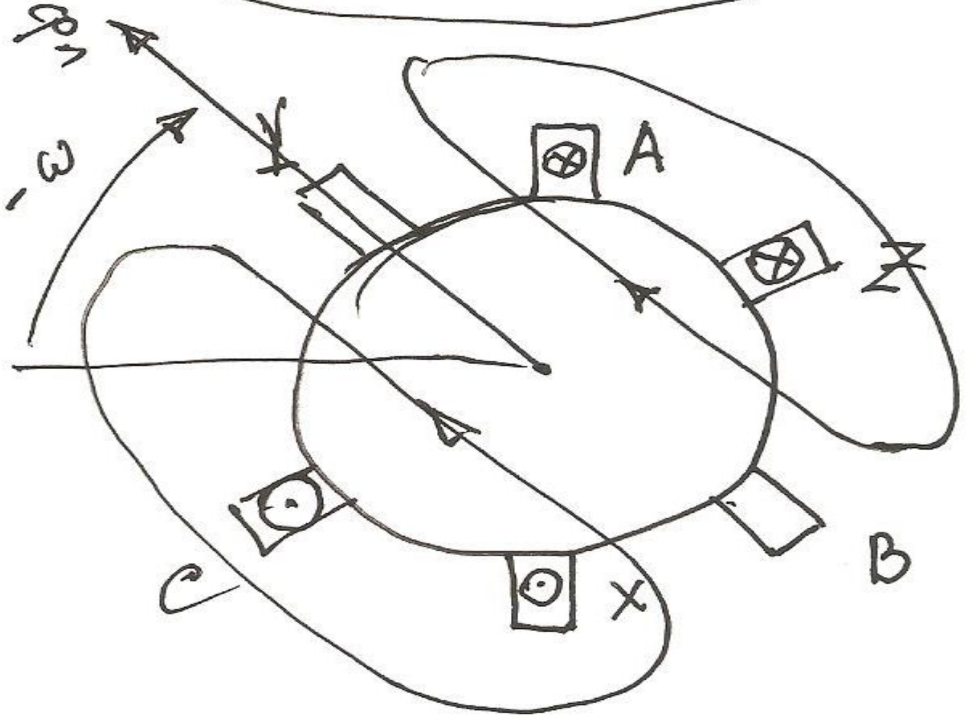


"V"-образная х-ка [вэ]

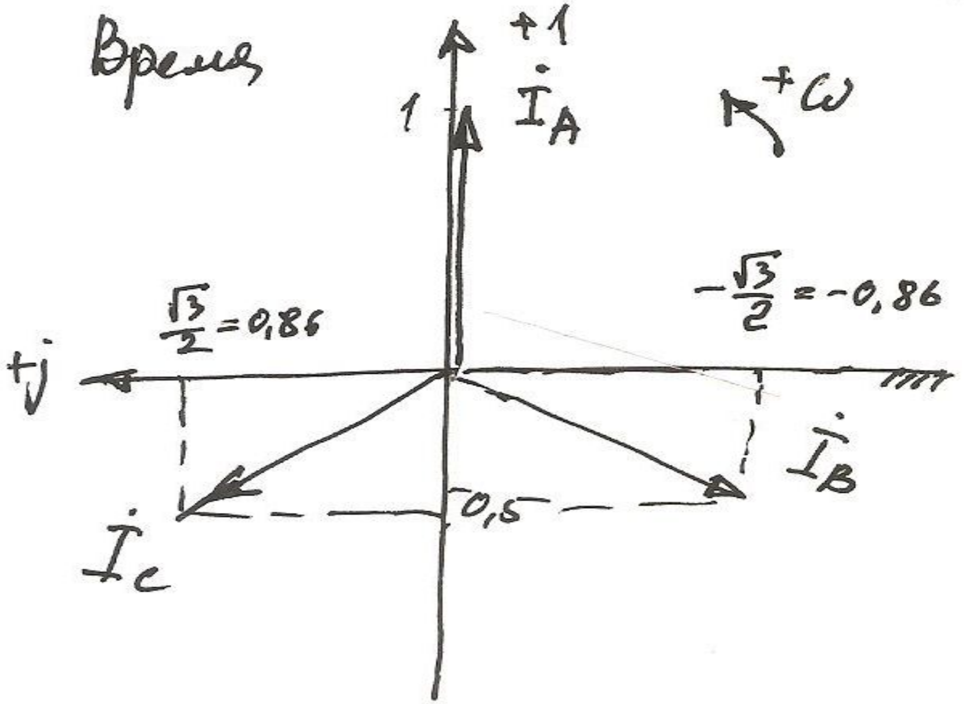


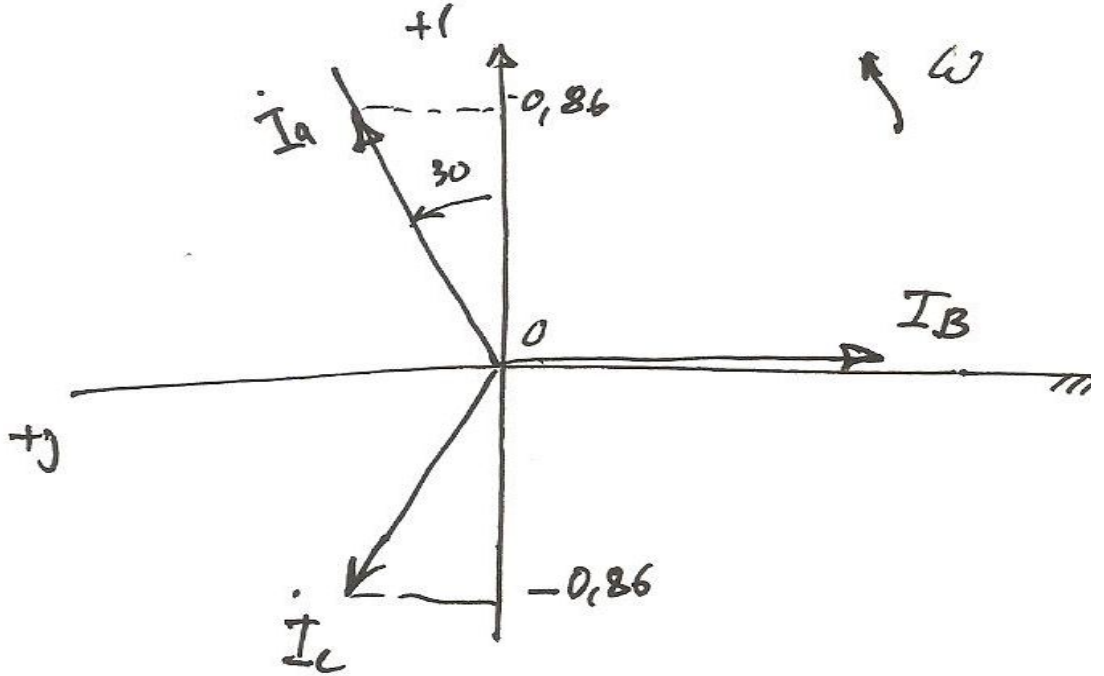
Пространство

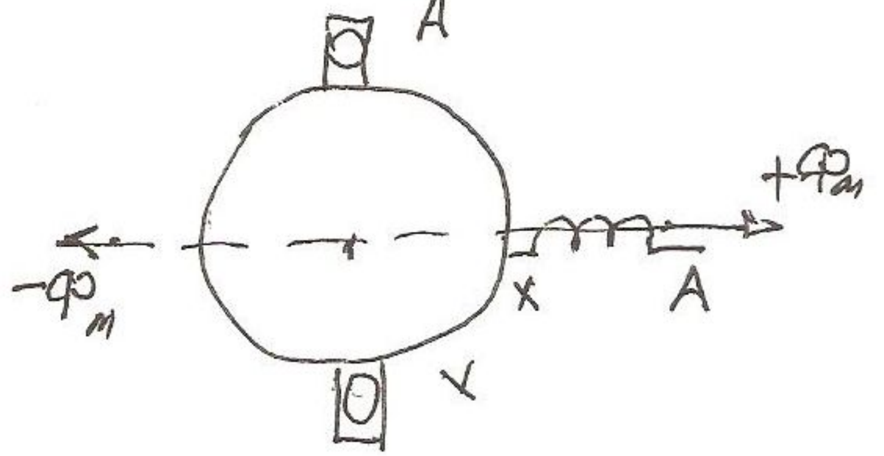


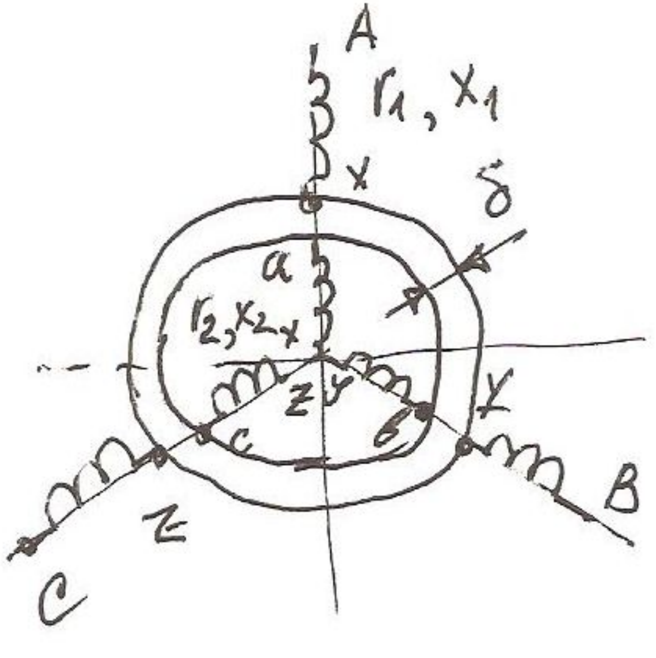


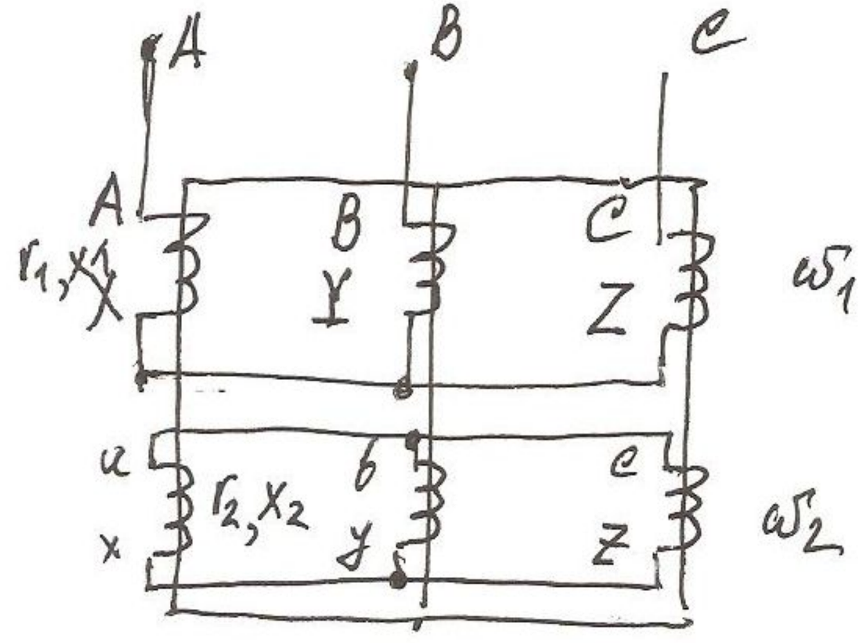
Время

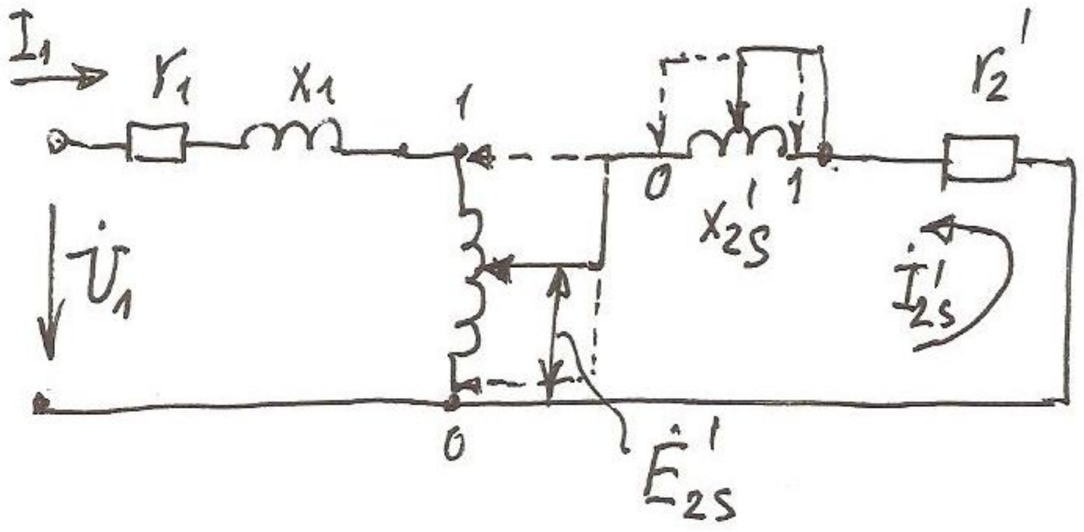












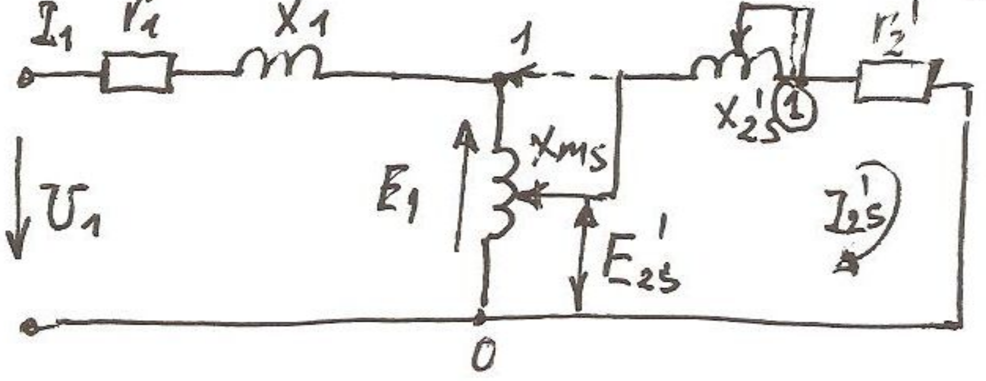
$\boxed{S = \frac{n_1 - n_2}{n_1}}$ – скольжение

Если $n_2 = n_1 \rightarrow S = 0$ – И.Х.Х.

$n_2 = 0 \rightarrow$ К.З. (неподв. ротор)

$S = 1$

Схема замещения АД с вращающимся ротором

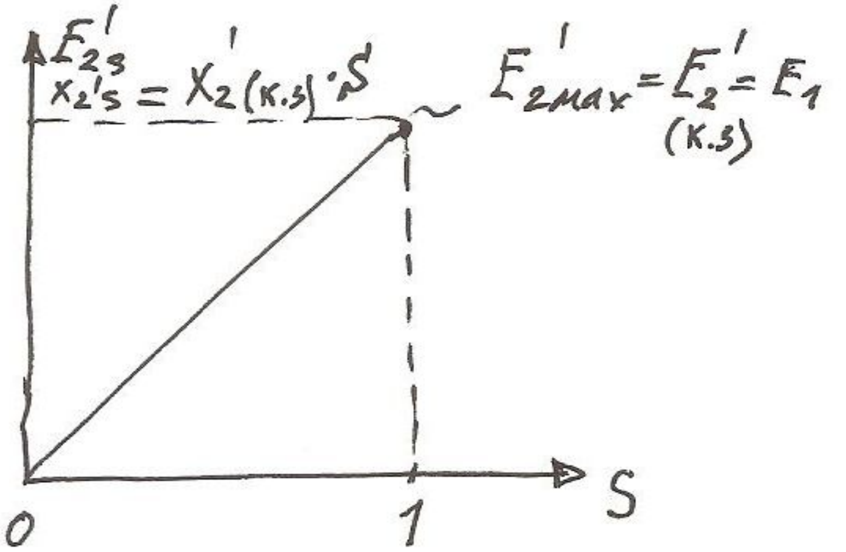


$$S = \frac{n_2 - n_1}{n_1}$$

n_1 – синхронная скорость вращения поля

n_2 – скорость ротора.

$$\begin{cases} E_{2s}' = 4{,}44 \cdot f_2 \cdot w_1 \cdot k_{об} \cdot \Phi_m \equiv \underset{(к.з)}{E_2'} \cdot S, \quad E_2' = E_1 \\ x_{2s}' = \underset{(к.з.)}{x_2'} \cdot S \end{cases}$$



$$\begin{cases} U_1 = (-E_1) + r_1 \cdot I_1 + j x_1 \cdot I_1 & (1) \\ E_{2s}' - j x_{2s}' \cdot I_2' - r_2' \cdot I_2' = 0 & (2) \\ I_1 = I_0 + (-I_2') & (3) \end{cases}$$

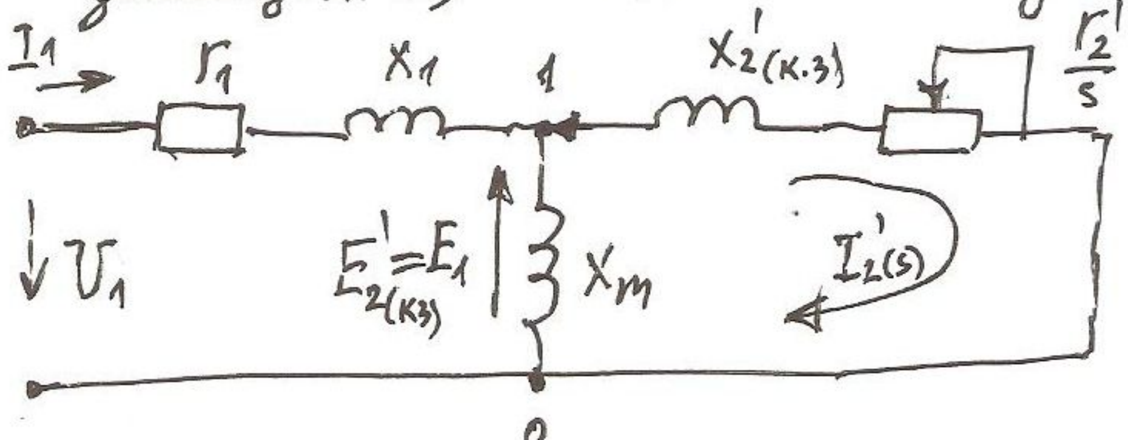
Из уравнения (2):

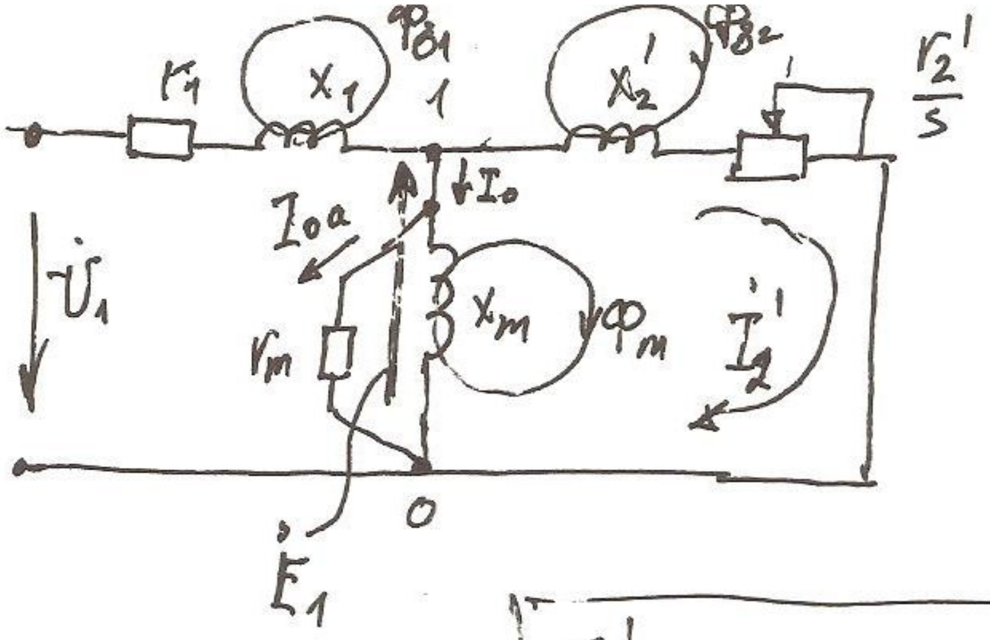
$$\dot{E}'_{2s} - j x'_{2s}\cdot \dot{I}'_2 - r'_2\cdot \dot{I}'_2 = 0$$

$$\dot{I}'_2 = \frac{\dot{E}'_{2s}}{r'_2 + j x'_{2s}} = \frac{\overset{E_1}{\overset{\parallel}{E'_{2(к.з)}}}\, S}{r'_2 + j X'_{2(к.з)}\cdot S} =$$ — уравнение с вращающимся ротором.

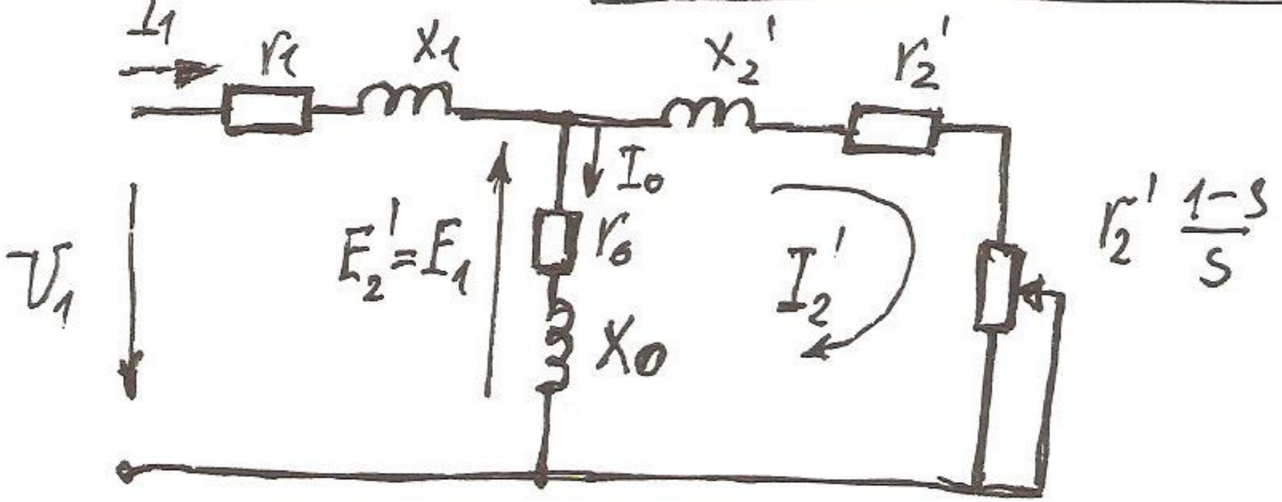
$$= \frac{E'_{2(к.з)}}{\frac{r'_2}{S} + j X'_{2(к.з)}}$$ — уравнение с неподвижным ротором.

Схема замещения АД с неподвижным ротором:



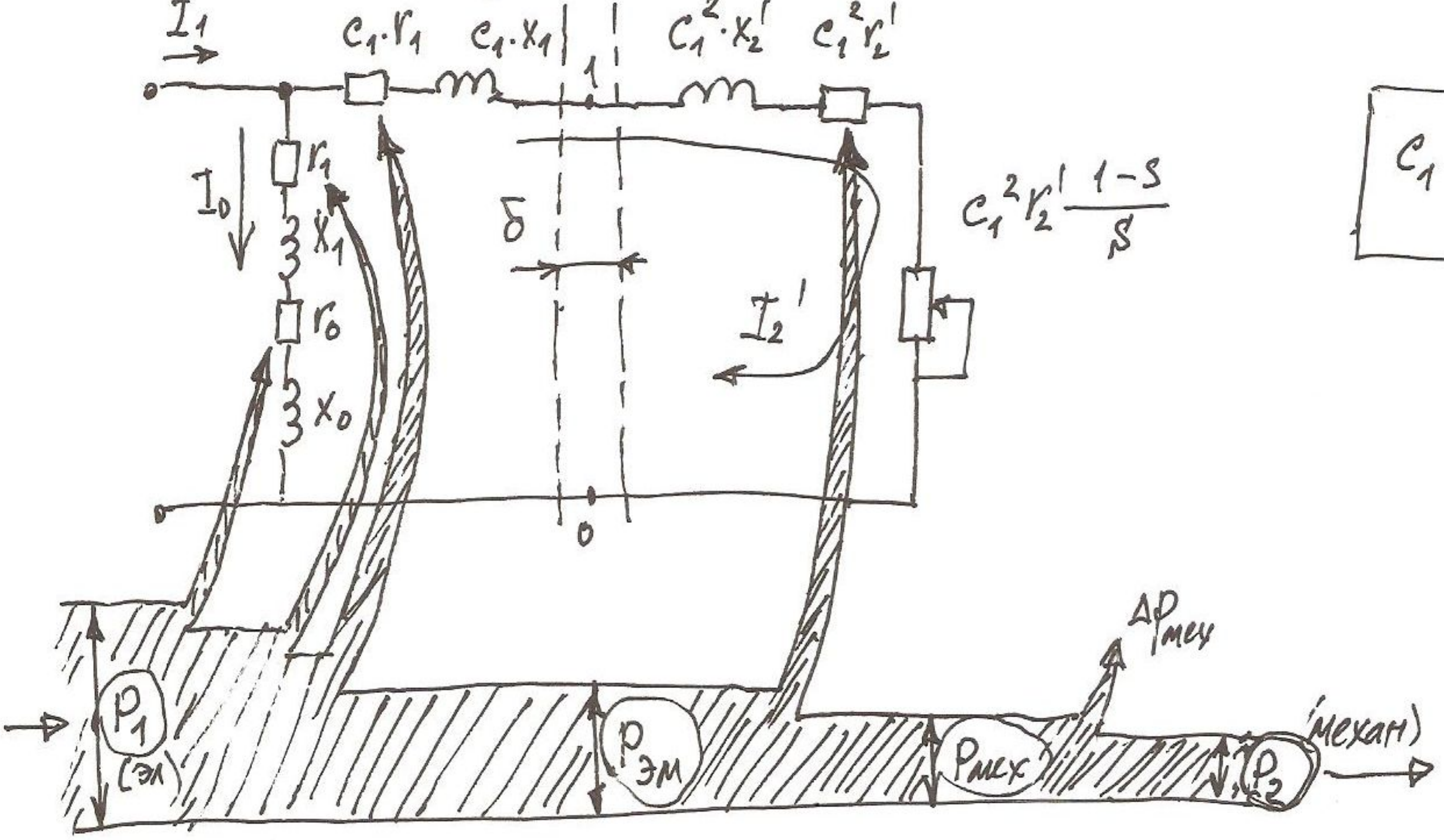


$$\boxed{\frac{r_2'}{s} - r_2' = r_2' \, \frac{1-s}{s}}$$



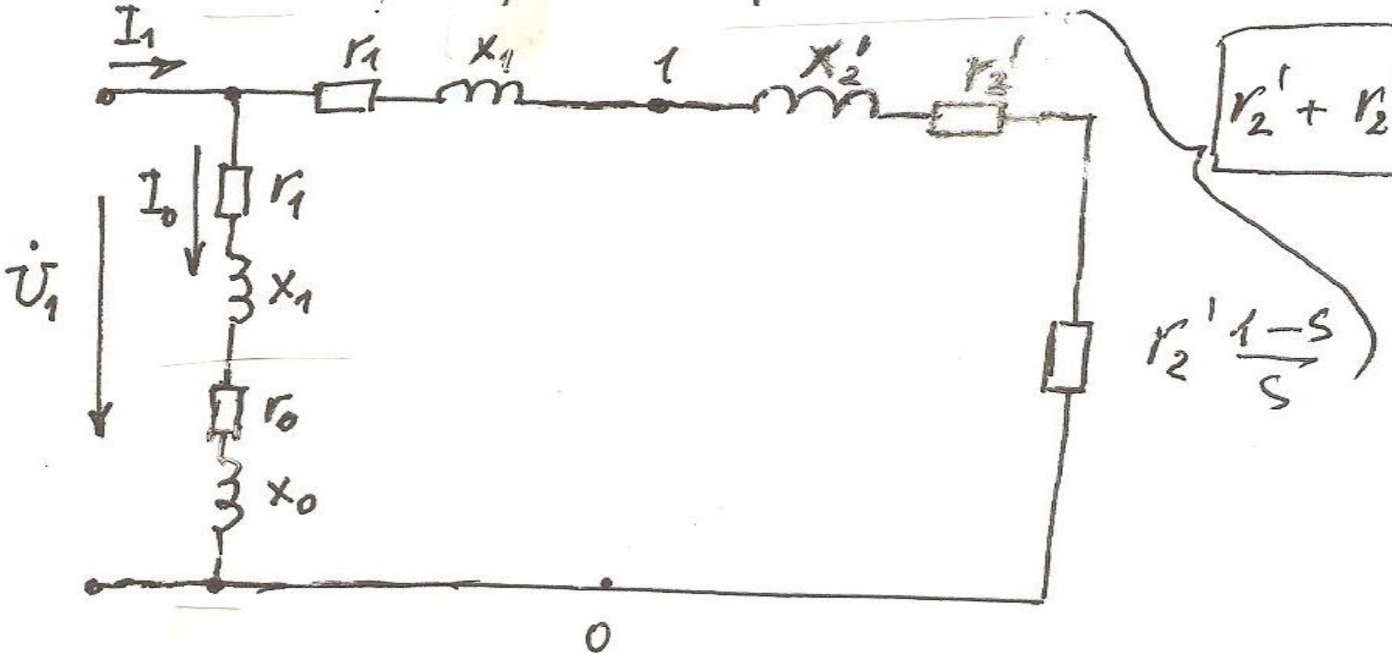
$$\begin{cases} \dot U_1 = (-\dot E_1) + r_1 \cdot \dot I_1 + j x_1 \cdot \dot I_1 & (1) \\ \dot E_2' - j x_2' \cdot \dot I_2' - r_2' \cdot I_2' = \underbrace{r_2' \, \frac{1-s}{s} \cdot I_2'}_{U_2'} & (2) \\ I_1 = I_0 + (-I_2') & (3) \end{cases}$$

Г-схема замещения АД и энергетическая диаграмма



$$\boxed{c_1 = \frac{U_1}{E_1}} = 1{,}02 \div 1{,}04$$

Пренебрегая $C_1 \approx 1$

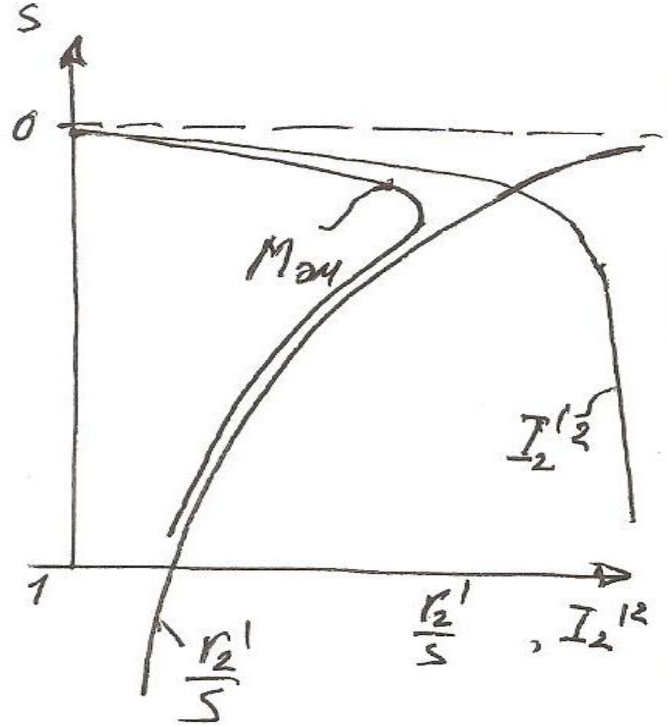


$$\boxed{r_2' + r_2' \cdot \frac{1-s}{s} = \frac{r_2'}{s}}$$

$$I_2' = \frac{U_1}{\sqrt{\underbrace{\left(r_1 + \frac{r_2'}{s}\right)^2}_{R} + \underbrace{(x_1 + x_2')^2}_{X}}}$$

$$P_{эм} = 3 \cdot I_2'^2 \cdot \frac{r_2'}{s} = \frac{3 \cdot U_1^2 \cdot \frac{r_2'}{s}}{\left(r_1 + \frac{r_2'}{s}\right)^2 + (x_1 + x_2')^2}$$

$$M_{эм} = \frac{P_{эм}}{\omega_0} = \frac{P_{эм}}{\frac{2\pi f}{p}}$$



$$\widehat{U\ I_2'} \rightarrow tg\beta = \frac{r_1 + \frac{r_2'}{s}}{\underbrace{x_1 + x_2'}_{x_к}} = \frac{r_1 + \frac{r_2'}{s}}{x_к}$$

К построению круговой диаграммы

Ось $P_{эм} = 0$ $\quad s = 0$ (х.х.х) и $s = \infty$

$$\boxed{tg\beta'\Big|_{s=\infty} = \frac{r_1}{x_к}}$$

Ось $P_{мех} = 0$ $\quad s = 0$ и $s = 1$ (к.з)

$$tg\beta''\Big|_{s=1} = \frac{r_1 + r_2'}{x_к}$$

Ось линии диаметра

$$tg\,2\gamma = \frac{2 \cdot r_1 \cdot I_0}{U_{1н}} \qquad P_{э10} = I_0^2 \cdot r_1$$

$$D \cdot m_I = I'_{2\,max} = \frac{U_1}{\sqrt{\underbrace{\left(r_1 + \frac{r_2'}{s}\right)^2}_{=0} + (x_1 + x_2')^2}} = \frac{U}{x_1 + x_2} \longrightarrow x_1 + x_2' = \frac{U}{I'_{2max}}.$$