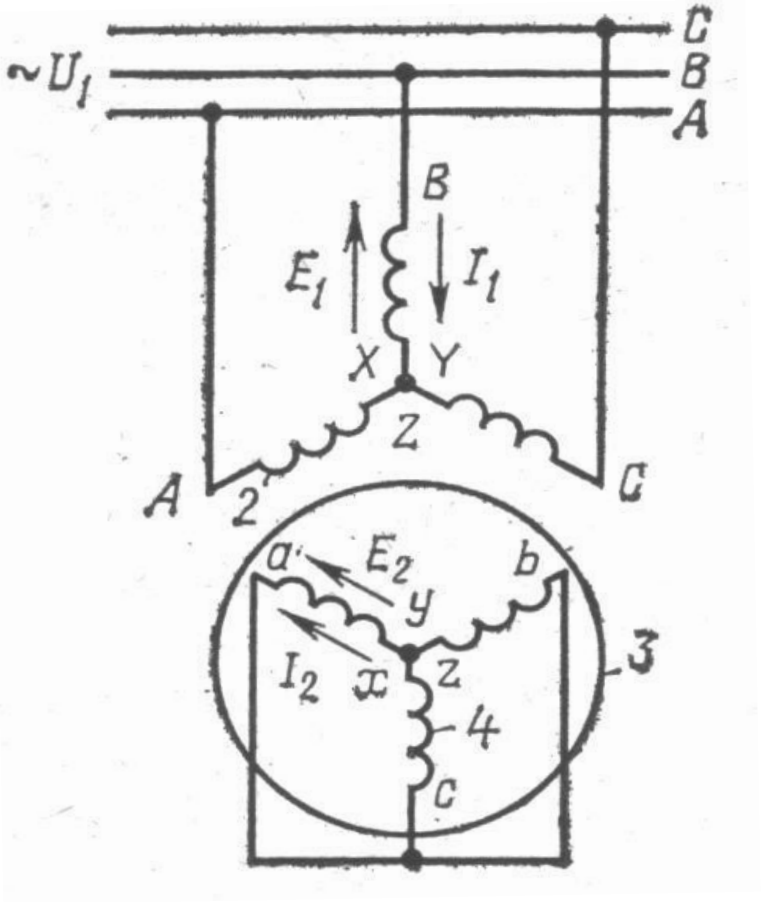
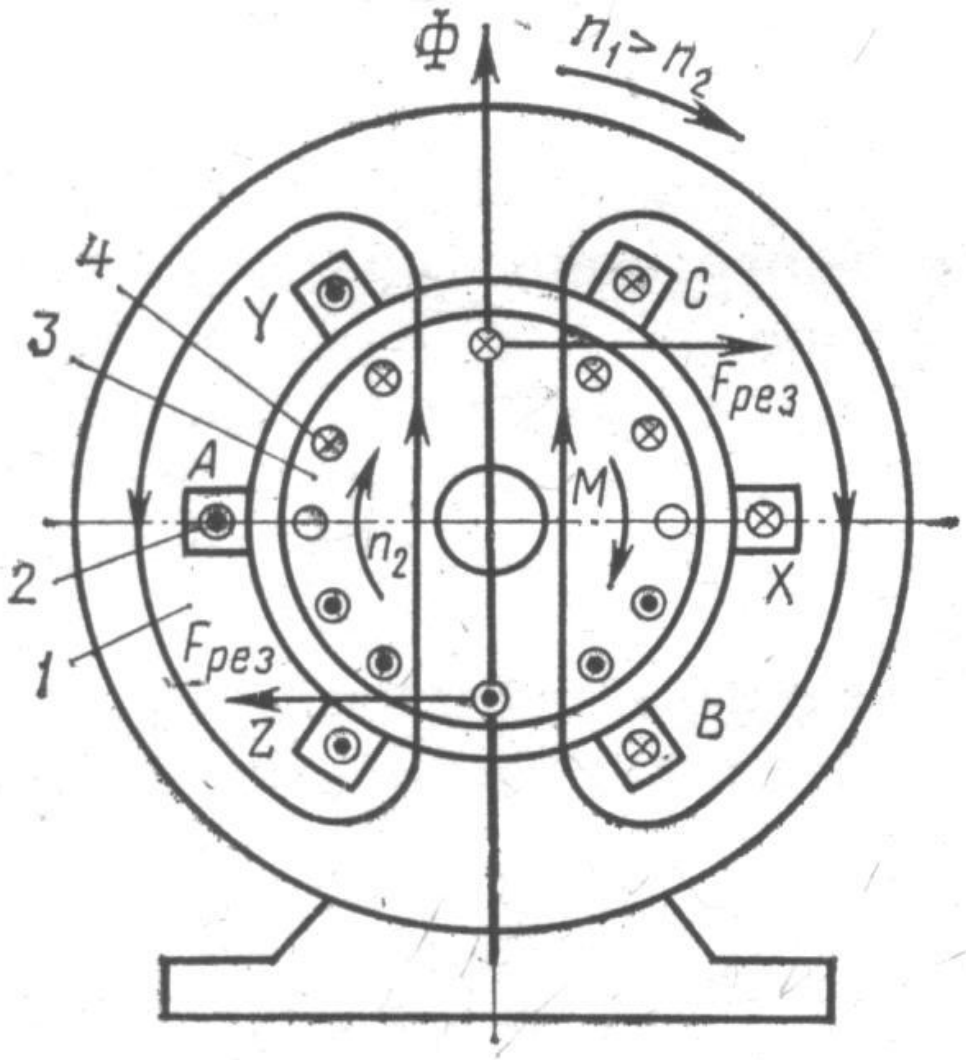
Асинхронные машины

Назначение и принцип действия асинхронных машин



Двигательный режим



$$n_1 = \frac{60f}{p}$$

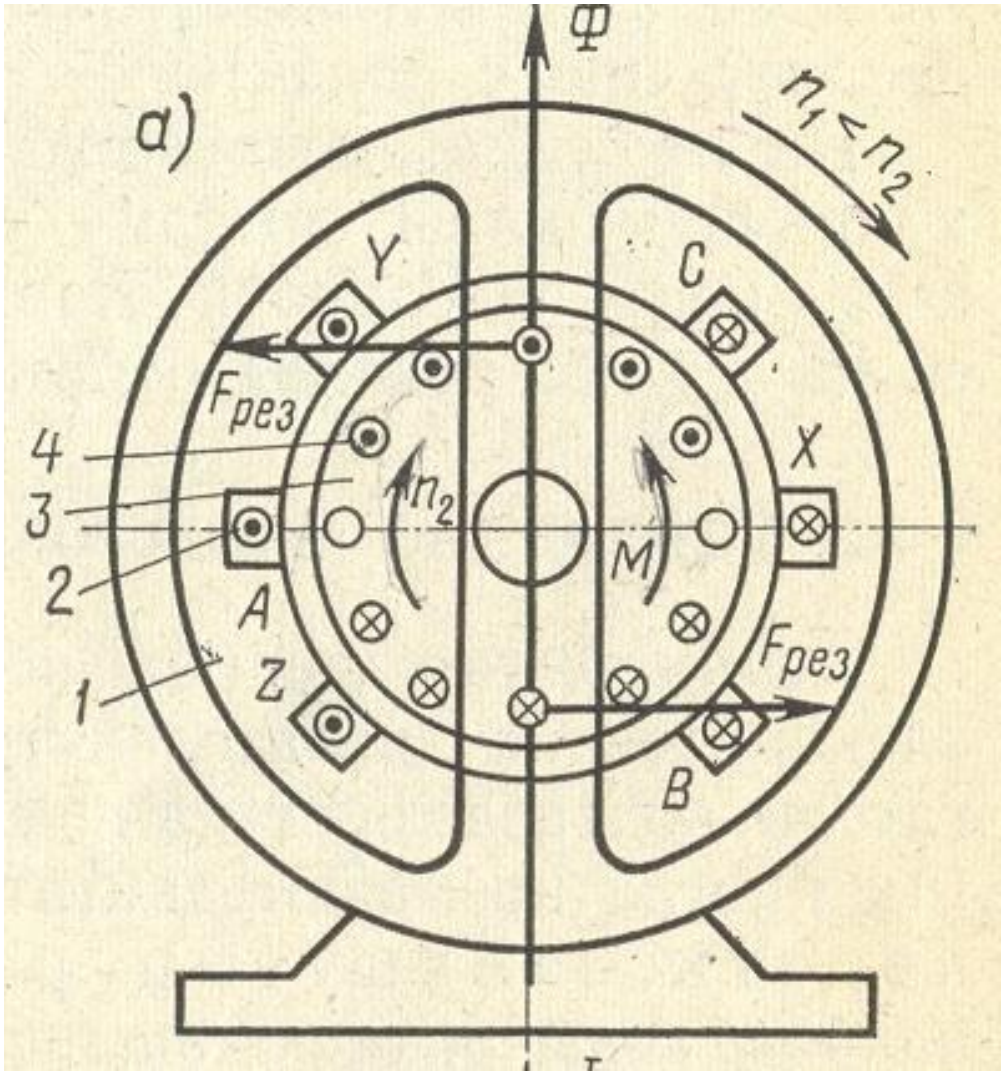
$$0 \le n_2 \le n_1$$

$$S = \frac{n_1 - n_2}{n_1} \cdot 100\%$$

$S_н$= 0,02-0,05

S>0 I_{a2} **>0** I_{r2}**>0**

Генераторный



$$n_2 > n_1$$

$S<0 \quad I_{r2}>0 \quad I_{a2}<0$

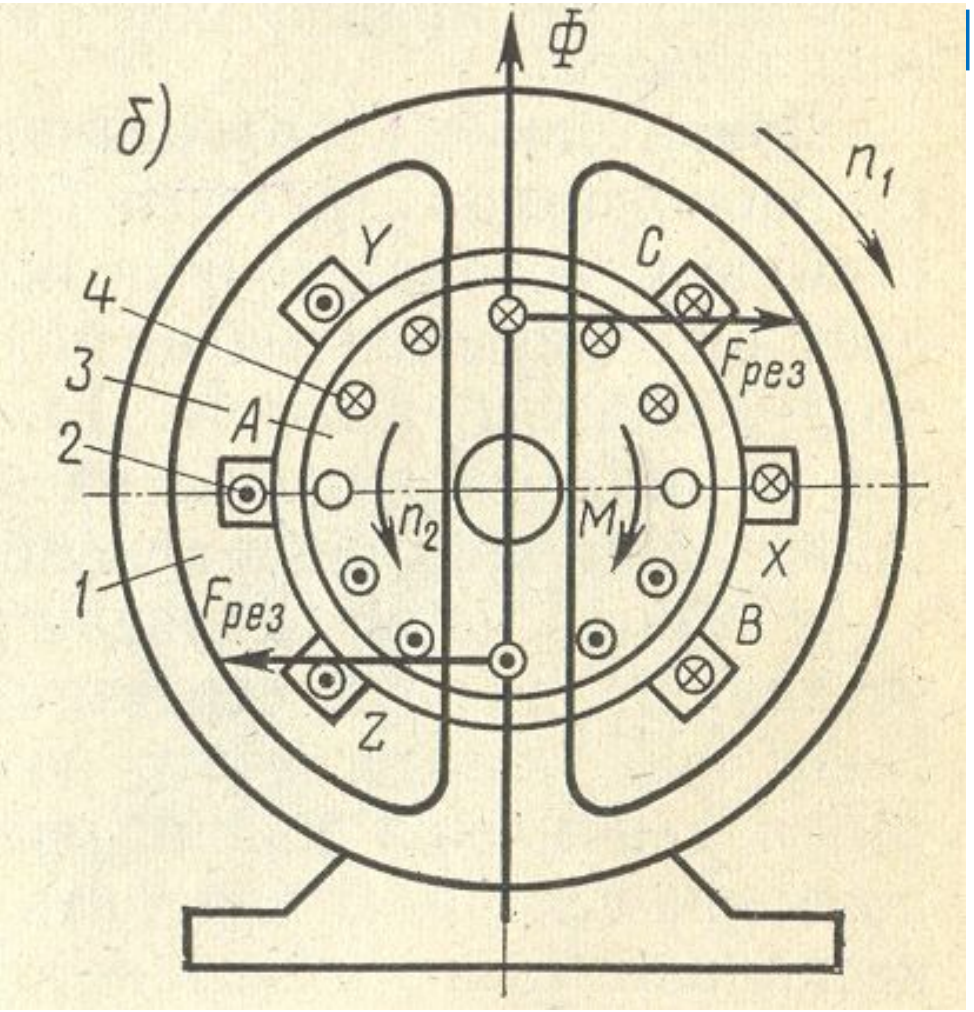
$I_{1a}=I_1 \cos\varphi_1<0$

$P_1=m_1 U_1 I_1 \cos\varphi_1<0$

$I_{1r}=I_1 \sin\varphi_1$

$Q_1= m_1 U_1 I_1 \sin\varphi_1$

Режим



ючения

$n_2 < 0$ $S > 1$

Режим короткого замыкания

$$Z_k = Z_1 + \frac{Z_2' \times Z_m}{Z_2' + Z_m}$$

s=1

$Z_m >> Z'_2$

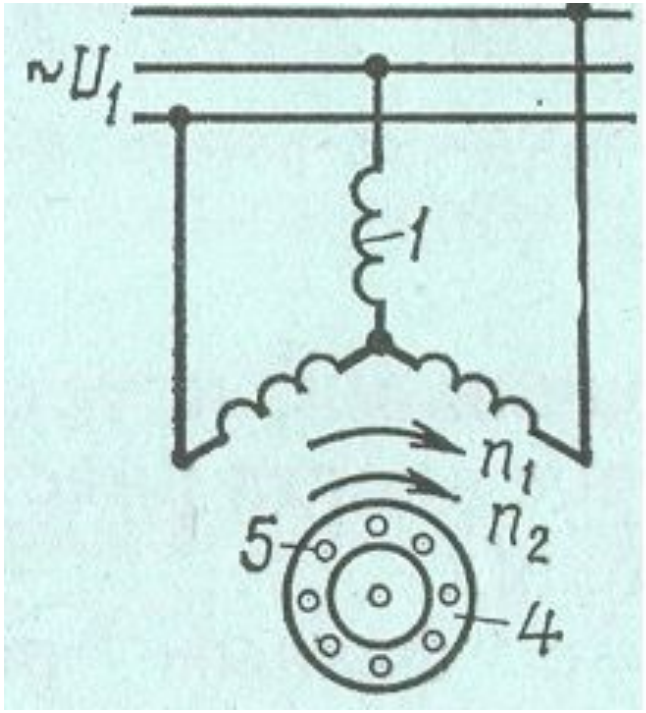
$Z_к \approx Z_1 + Z_2' = r_к + jx_к$

$Z_к^* = 0{,}14\text{-}0{,}20$

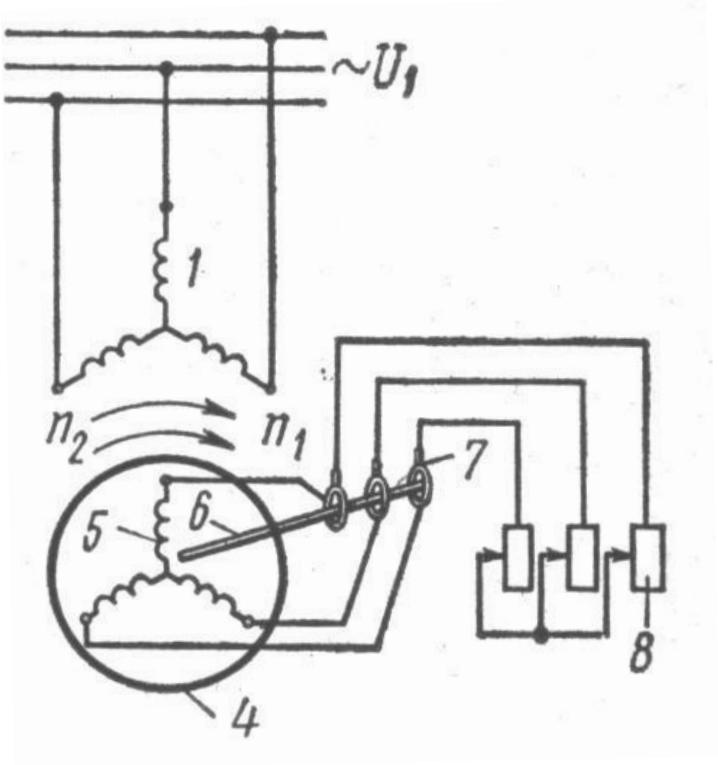
$I_{1к} = (5\text{-}7)\, I_{ном}$

Устройство и область применения асинхронных двигателей

Двигатели с короткозамкнутым ротором.



Двигатели с фазным ротором



Асинхронная машина при заторможенном роторе

$$\begin{bmatrix} E_1 = 4.44 f_1 w_1 K_{об1} \Phi_m \\ E_2 = 4.44 f_1 w_2 K_{об2} \Phi_m \end{bmatrix}$$

$$\frac{E_1}{E_2} = \frac{w_1 K_{об1}}{w_2 K_{об2}} = K_E$$

0,96 – 0,90

$$k_E = \frac{w_1}{w_2}$$

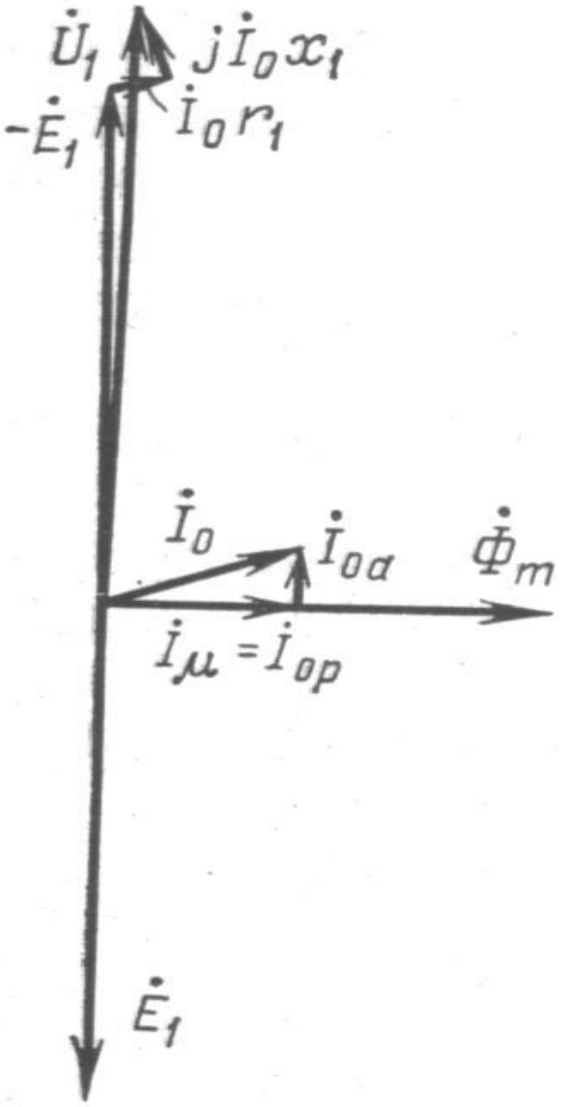
Холостой ход

$$\dot{U}_1 + \dot{E}_1 + \dot{E}_{\sigma 1} = \dot{I}_0 r_1$$

$$E_1 = 4.44 f_1 w_1 K_{об1} \Phi_m$$

$$E_{\sigma 1} = 4.44 f_1 w_1 K_{об1} \Phi_{\sigma 1}$$

$$x_1 = \frac{E_{\sigma 1}}{I_1} \qquad x_2 = \frac{E_{\sigma 2}}{I_2}$$



Работа машины под нагрузкой

$$\left.\begin{aligned}
&\dot{U}_1 + \dot{E}_1 = \dot{I}_1 r_1 + j\dot{I}_1 x_1 \\
&\dot{U}_2' = \dot{E}_2' - \dot{I}_2' r_2' - j\dot{I}_2' x_2' \\
&\dot{I}_1 = \dot{I}_0 + (-\dot{I}_2')
\end{aligned}\right\}$$

$$n_{2F} = \frac{60 f_2}{p_2}$$

$$f_2 = f_1 \qquad n_{2F} = \frac{60 f_1}{p_2}$$

$$p_1 = p_2 = p$$

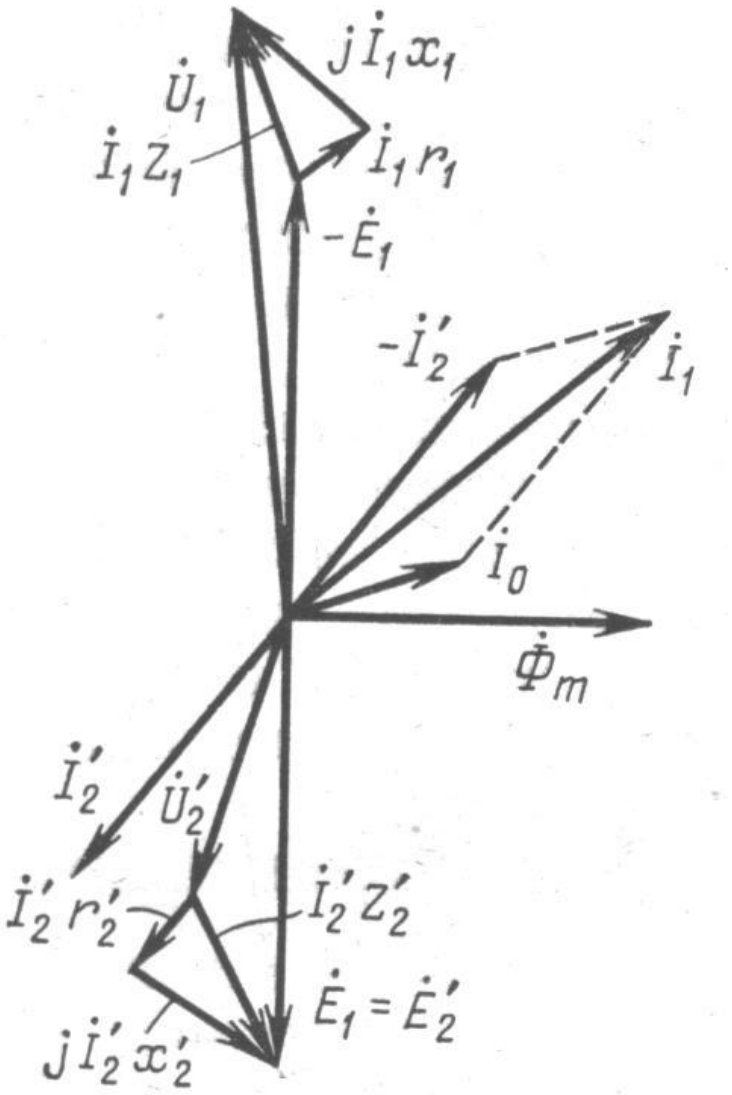
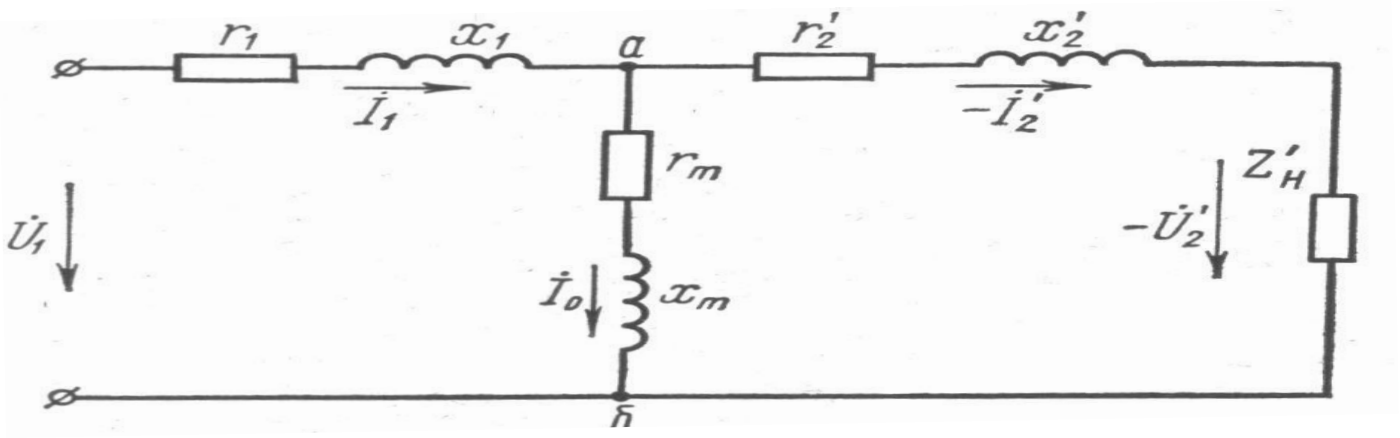


Схема замещения



$$K_E = \frac{w_1 k_{об1}}{w_2 k_{об2}} = \frac{E_1}{E_2}$$

$$E_2^{'} = E_1 = K_E E_2$$

$$m_2 E_2 I_2 = m_1 E_2^{'} I_2^{'}$$

$$I_2^{'} = \frac{m_2}{m_1}\frac{E_2}{E_2^{'}} I_2 = \frac{m_2 w_2 k_{об2}}{m_1 w_1 k_{об1}} = \frac{I_2}{k_i}$$

$$k_j = \frac{m_1 w_1 k_{об1}}{m_2 w_2 k_{об2}}$$

$$m_2 I_2^2 R_2 = m_1 I_2'^2 R_2$$

$$R_2' = k_i k_E R_2$$

$$\frac{I_2 X_2}{E_2} = \frac{I_2' X_2'}{E_2'}$$

$$X_2' = k_i k_E X_2$$

$$k_i k_E$$

Работа АМ при вращающемся роторе

ЭДС и ток в обмотках ротора

$$n_S = n_1 - n_2 \qquad f_2 = \frac{pn_S}{60} = \frac{p(n_1 - n_2)}{60}$$

$$\frac{pn_1}{60} = f_1 \qquad \frac{n_1 - n_2}{n_1} = S \qquad f_2 = f_1 S$$

$$E_{2S} = 4.44 f_2 w_2 k_{об2} \Phi_m = 4.44 f_1 S w_2 k_{об2} \Phi_m$$

$$E_2 = 4.44 f_1 w_2 k_{об2} \Phi_m \qquad E_{2S} = S \cdot E_2$$

$$n_{F2} = \frac{60 f_2}{p} = \frac{60 f_1 S}{p} = n_1 S = n_1 - n_2$$

$$n_2 + n_{F2} = n_1$$

В асинхронной машине магнитное поле, вращающееся с частотой n_1

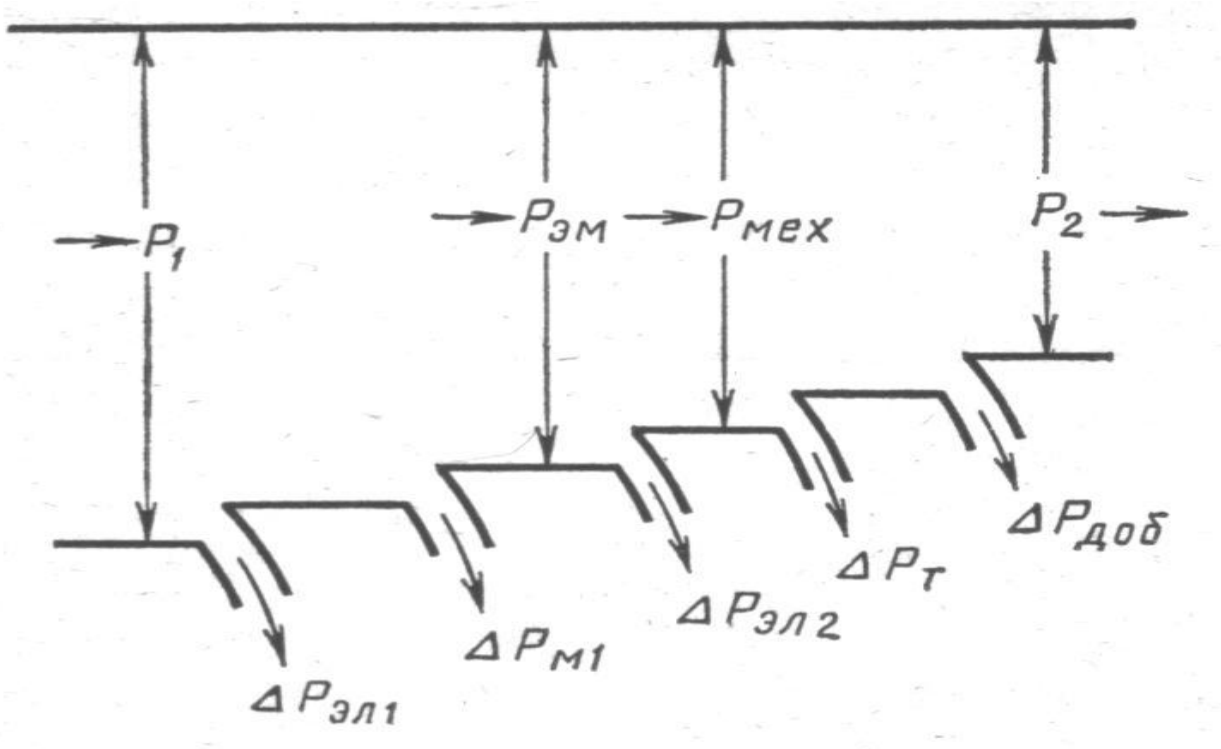
возникает в результате совместного действия бегущих волн МДС статора и ротора.

Энергетическая диаграмма

$$P_1 = m_1 U_1 I_1 Cos\varphi_1$$

$$P_{ЭМ} = P_1 - \Delta P_{ЭЛ1} - \Delta P_{М1}$$

$$P_{МЕХ} = P_{ЭМ} - \Delta P_{ЭЛ1} \qquad P_2 = P_{МЕХ} - \Delta P_{Т} - \Delta P_{ДОБ}$$



$$P_{ЭМ} = M\Omega_1 \qquad P_{МЕХ} = M\Omega_2$$

$$\Omega_1 = \frac{2\pi n_1}{60} \qquad \Omega_2 = \frac{2\pi n_2}{60}$$

$$\Delta P_{ЭЛ2} = P_{ЭМ} - P_{МЕХ} = M\Omega_1 - M\Omega_2 = M(\Omega_1 - \Omega_2)\frac{\Omega_1}{\Omega_1} = M\Omega_1 S$$

$$M = \frac{\Delta P_{ЭЛ2}}{\Omega_1 S} \qquad S = \frac{\Delta P_{ЭЛ2}}{M\Omega_1} = \frac{\Delta P_{ЭЛ2}}{P_{ЭМ}}$$

Связь между скольжением и КПД двигателя

$$\eta = \frac{P_2}{P_1} = \frac{P_{ЭМ}}{P_1}\frac{P_2}{P_{ЭМ}} = \eta_1\eta_2$$

$$\eta_2 = \frac{P_2}{P_{ЭМ}} = \frac{P_{ЭМ} - \Delta P_{ЭЛ2} - \Delta P_T - \Delta P_{ДОБ}}{P_{ЭМ}}$$

$$\eta_2 < \frac{P_{ЭМ} - \Delta P_{ЭЛ2}}{P_{ЭМ}} = 1 - \frac{\Delta P_{ЭЛ2}}{P_{ЭМ}} = 1 - S$$

$$\eta < \eta_2 < 1 - S \qquad n_{2НОМ} = n_1(1 - S) \approx 0.97 n_1$$

Электромагнитный момент

$$M = \frac{\Delta P_{ЭЛ2}}{\Omega_1 S}$$

$$\Omega_1 = \frac{2\pi n_1}{60} = \frac{2\pi f_1}{p}$$

$$\Delta P_{ЭЛ2} = m_2 I_2 E_{2S} Cos\psi_2$$

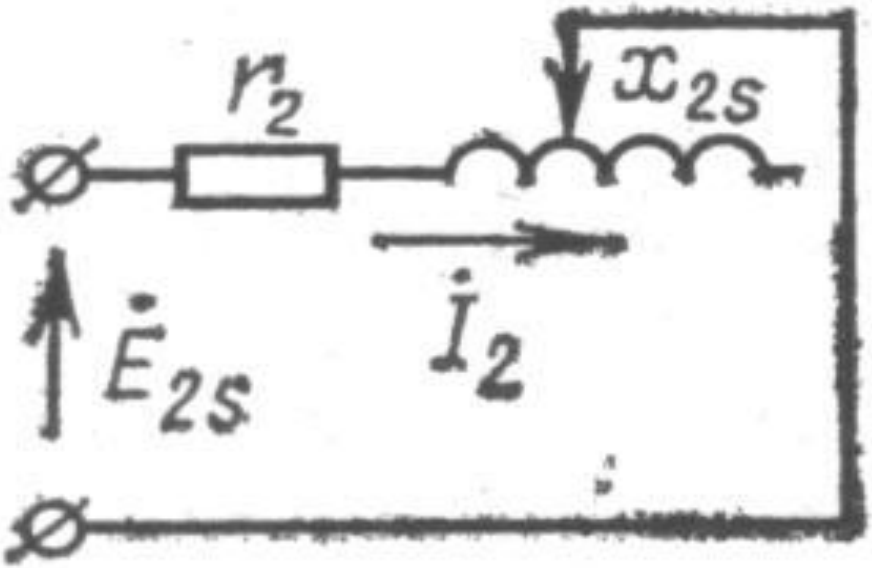
$$E_{2S} = S \cdot E_2$$

$$M = (\frac{p m_2 k_{ОБ2}}{\sqrt{2}})\Phi_m I_2 Cos\psi_2 = C_m \Phi_m I_2 Cos\psi_2$$

$$C_m = \frac{p m_2 k_{об2}}{\sqrt{2}} - const$$

Схема замещения АМ и векторная диаграмма ЭДС

Схема замещения



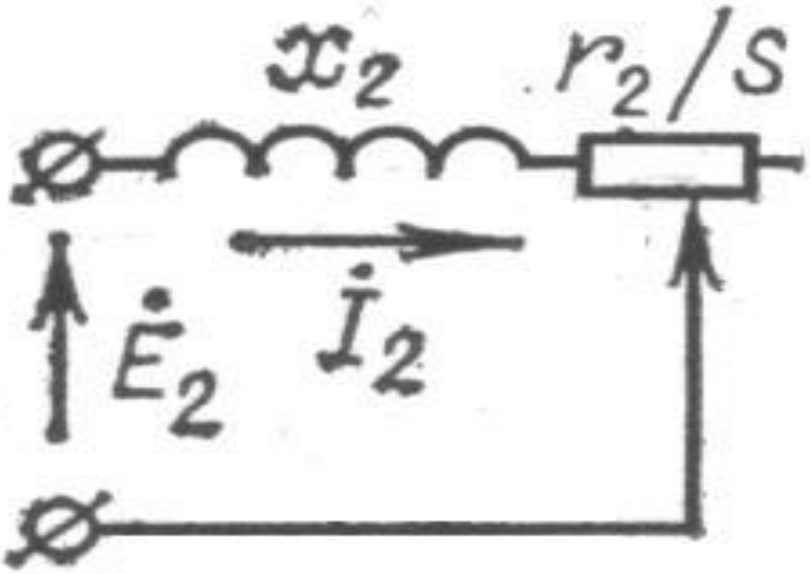
$$I_2 = \frac{E_{2S}}{Z_2} = \frac{E_{2S}}{\sqrt{R_2^2 + X_{2S}^2}}$$

$$f_2 = f_1 S$$

$$E_{2S} = S \cdot E_2$$

$$X_{2S} = 2\pi f_2 L_2 = 2\pi f_1 L_2 S = X_2 S$$

$$\left[I_2 = \frac{S \cdot E_2}{\sqrt{R_2^2 + (S \cdot X_2)^2}} = \frac{E_2}{\sqrt{(R_2/S)^2 + X_2^2}} \right]$$



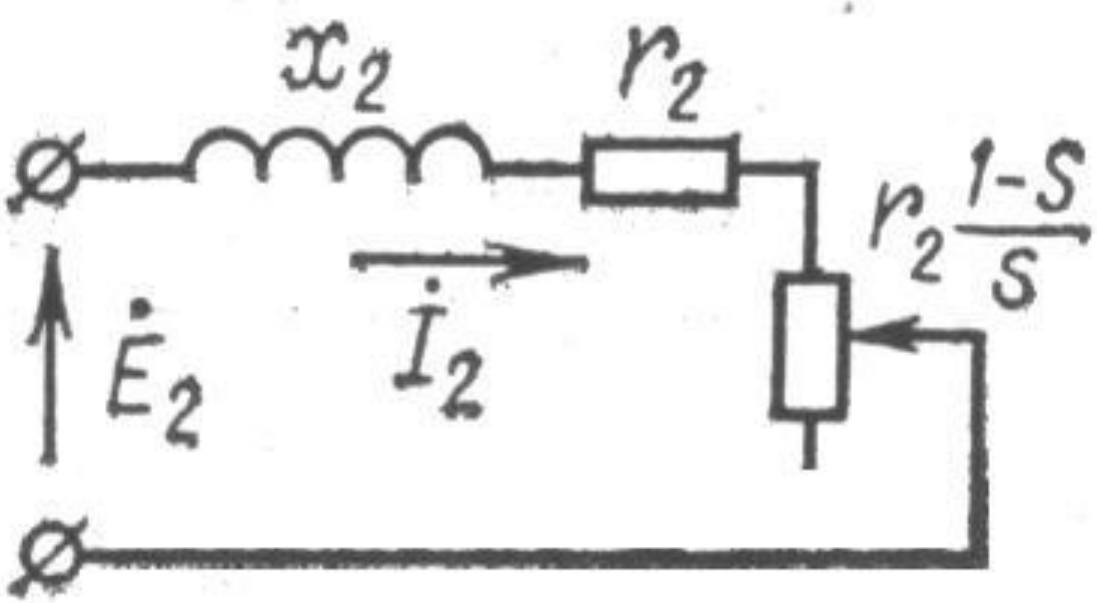
$$P_P = \Delta P_{ЭЛ2} = \mathrm{m}_2 I_2^2 R_2 \qquad P_P^{'} = \mathrm{m}_2 I_2^2 \frac{R_2}{S}$$

$$\frac{P_P}{P_P^{'}} = \frac{\Delta P_{ЭЛ}}{P_P^{'}} = \frac{\mathrm{m}_2 I_2^2 R_2}{\mathrm{m}_2 I_2^2 \dfrac{R_2}{S}} = S$$

$$S = \frac{\Delta P_{ЭЛ2}}{P_{ЭМ}}$$

$$P'_P = P_{ЭМ}$$

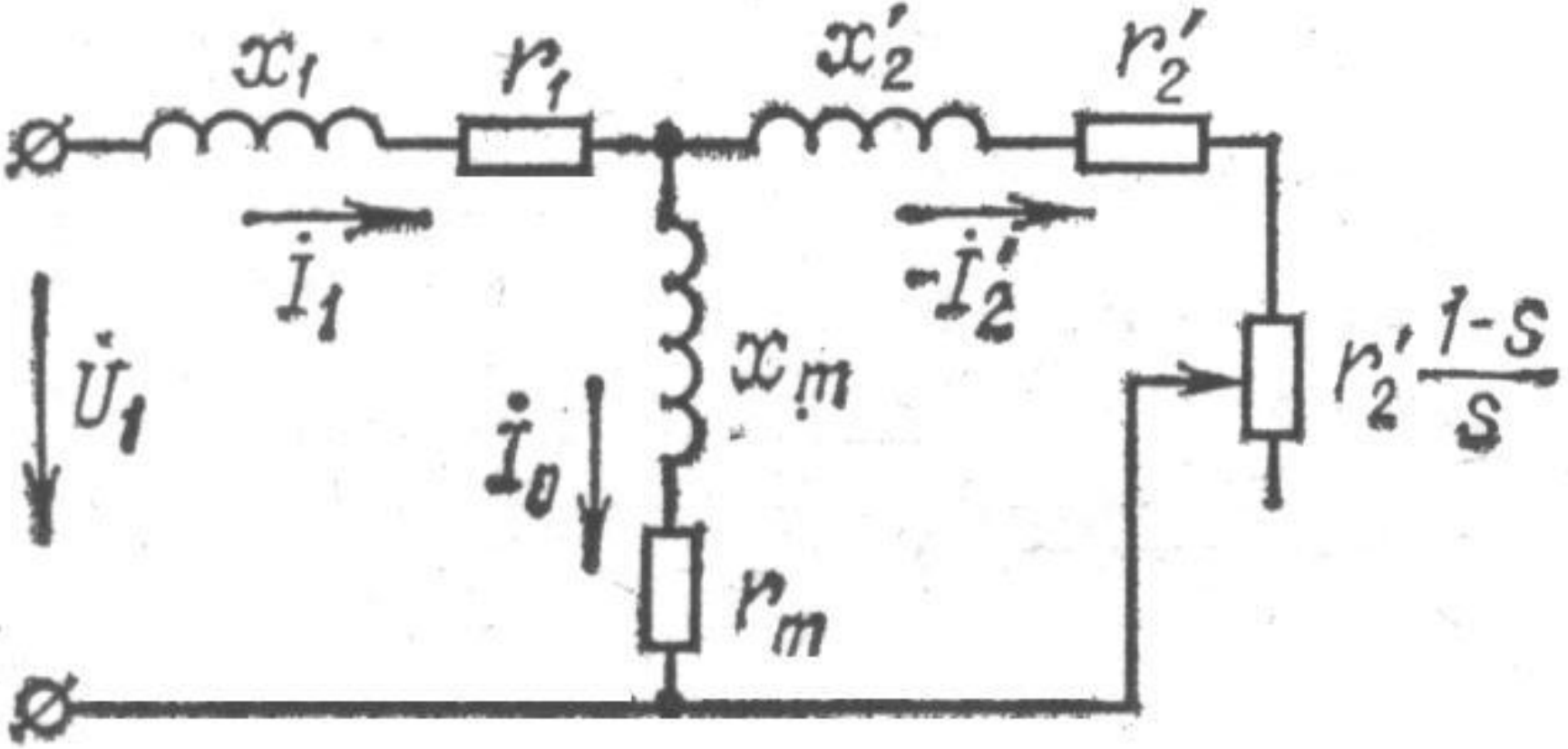
$$P_{МЕХ} = P_{ЭМ} - \Delta P_{ЭЛ2} = \mathrm{m}_2 I_2^2 \frac{R_2}{S} - \mathrm{m}_2 I_2^2 R_2 = \mathrm{m}_2 I_2^2 R_2 \frac{(1-S)}{S}$$

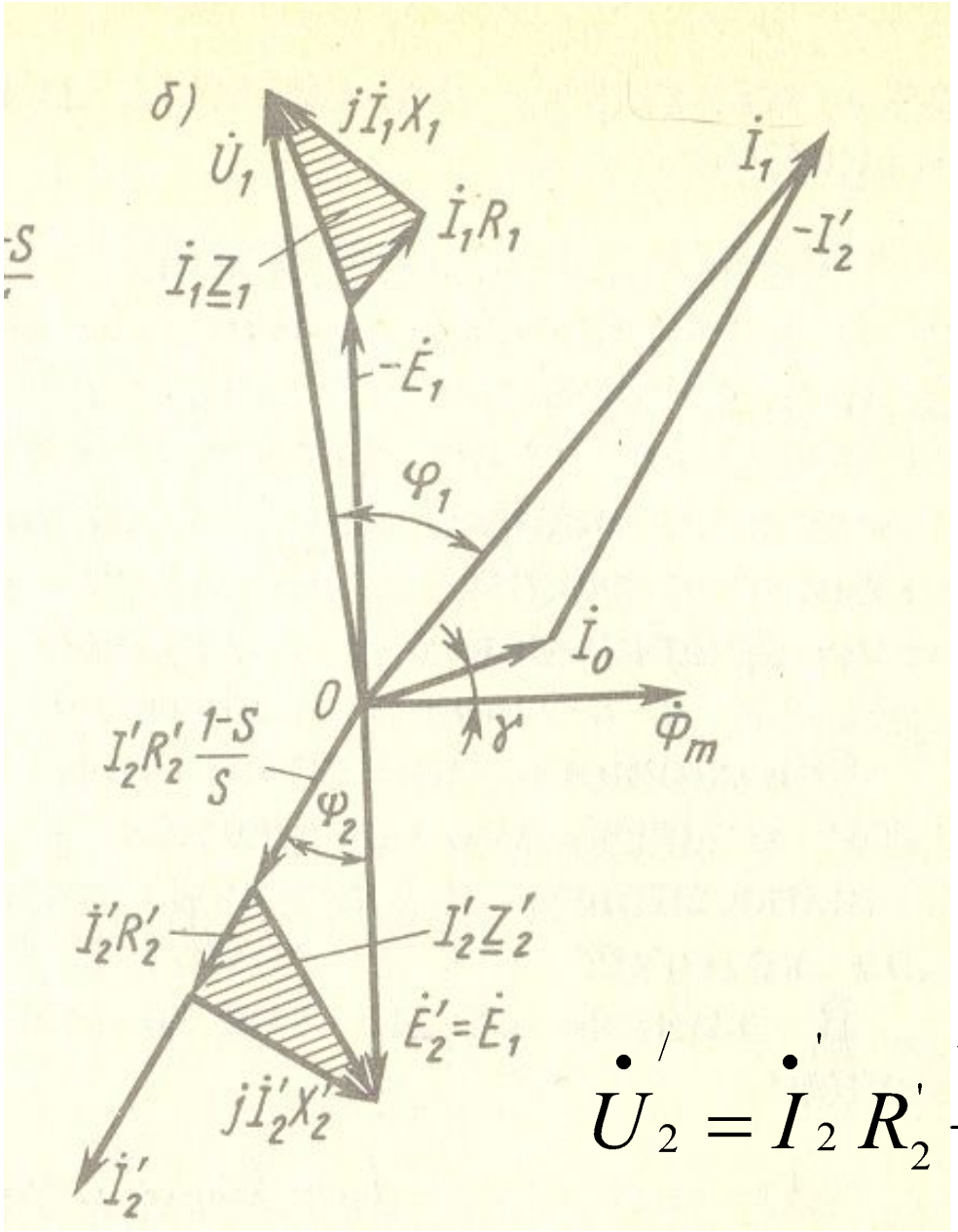


R_2

$R_2 \dfrac{1-S}{S}$

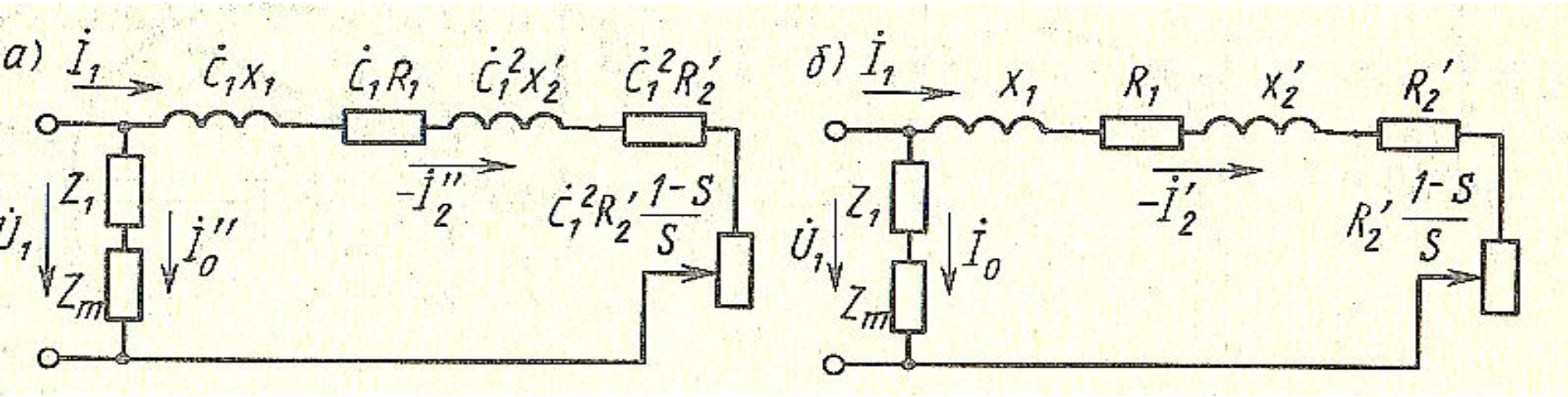
Т-образная схема замещения





$$\dot{U}_2' = \dot{I}_2' R_2' \frac{1-S}{S} = \dot{E}_2' - j\dot{I}_2' x_2' - \dot{I}_2' R_2'$$

Г-образная схема

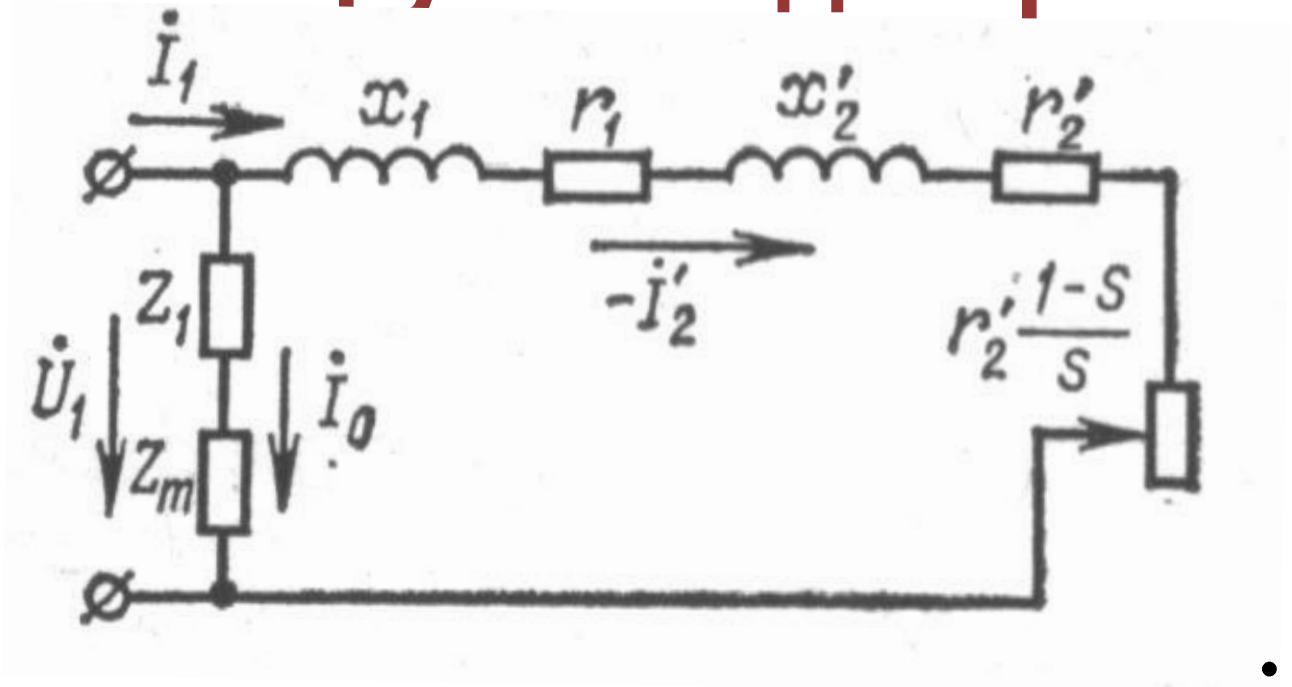


$$I_1 = I_0^{//} + (-I_2^{//})$$

$$I_2^{//} = I_2^{/} / C_1$$

$$C_1 = 1 + (r_1 + jx_1) / (r_m + jx_m)$$

Круговая диаграмма АМ



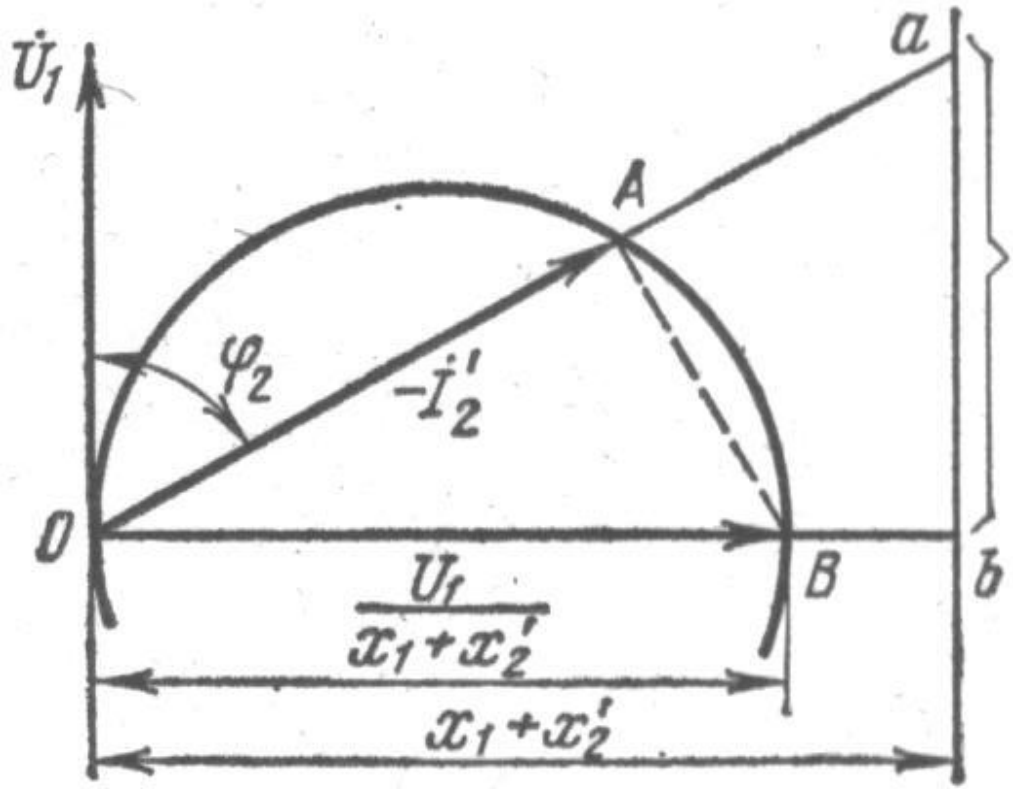
$$\dot{I}_1 = \dot{I}_0 + (-\dot{I}'_2)$$

$$\dot{I}_0 = \frac{\dot{U}_1}{Z_m + Z_1} \approx const$$

$$tg\varphi_0 = \frac{X_m + x_1}{R_m + R_1}$$

$$X_m + x_1 > R_m + R_1$$

$$\varphi_0 \approx \frac{\pi}{2}$$



$$I'_{2\max} = \frac{U_1}{x_1 + x'_2}$$

$$\overline{Oa} = \sqrt{\overline{Oв}^2 + \overline{вa}^2}$$

$$\frac{\overline{Oв}}{\overline{Oa}} = \frac{OA}{OB}$$

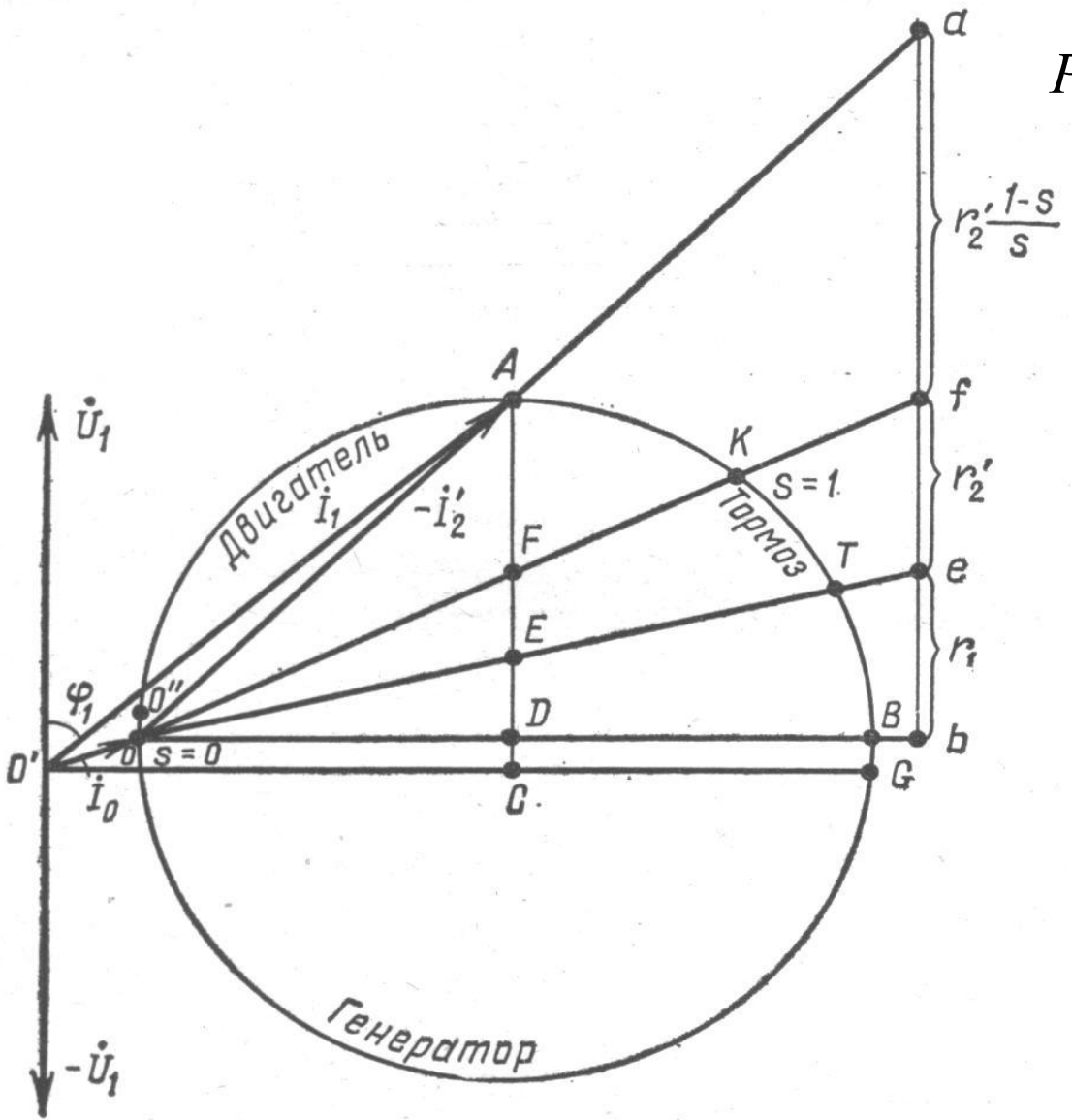
$$Z_{\text{РК}} = \sqrt{(x_1 + x'_2)^2 + (R_1 + \frac{R'_2}{S})^2}$$

$$OA = \frac{\overline{Oв} \bullet OB}{\overline{O\,a}} = \frac{I_{2\max} \bullet (x_1 + x'_2)}{Z_p} = \frac{U_1}{Z_p} = I'_2$$

$$tg\varphi_2 = \frac{\overline{Oв}}{\overline{aв}} = \frac{x_1 + x'_2}{R_1 + \frac{R'_2}{S}}$$

$$D = \frac{U_1}{x_1 + x'_2}$$

Определение мощностей и вращающе момента по круговой диаграмме



$$P_{PK} = m_1 \dot{I}_2^{'2} [R_1 + R_2^{'} + R_2^{'} \frac{1-S}{S}]$$

$$m_1 \dot{I}_2^{'2} R_1$$

$$m_1 \dot{I}_2^{'2} R_2^{'}$$

$$P_{MEX} = m_1 \dot{I}_2^{'2} R_2^{'} \frac{1-S}{S}$$

$$S = \frac{\Delta P_{Э Л 2}}{P_{ЭМ}} = \frac{EF}{AE}$$

Механические характеристики АМ при вращающемся роторе

$$n_2 = f(M) \qquad M = f(n_2) \qquad M = f(S) \qquad M = f(V)$$

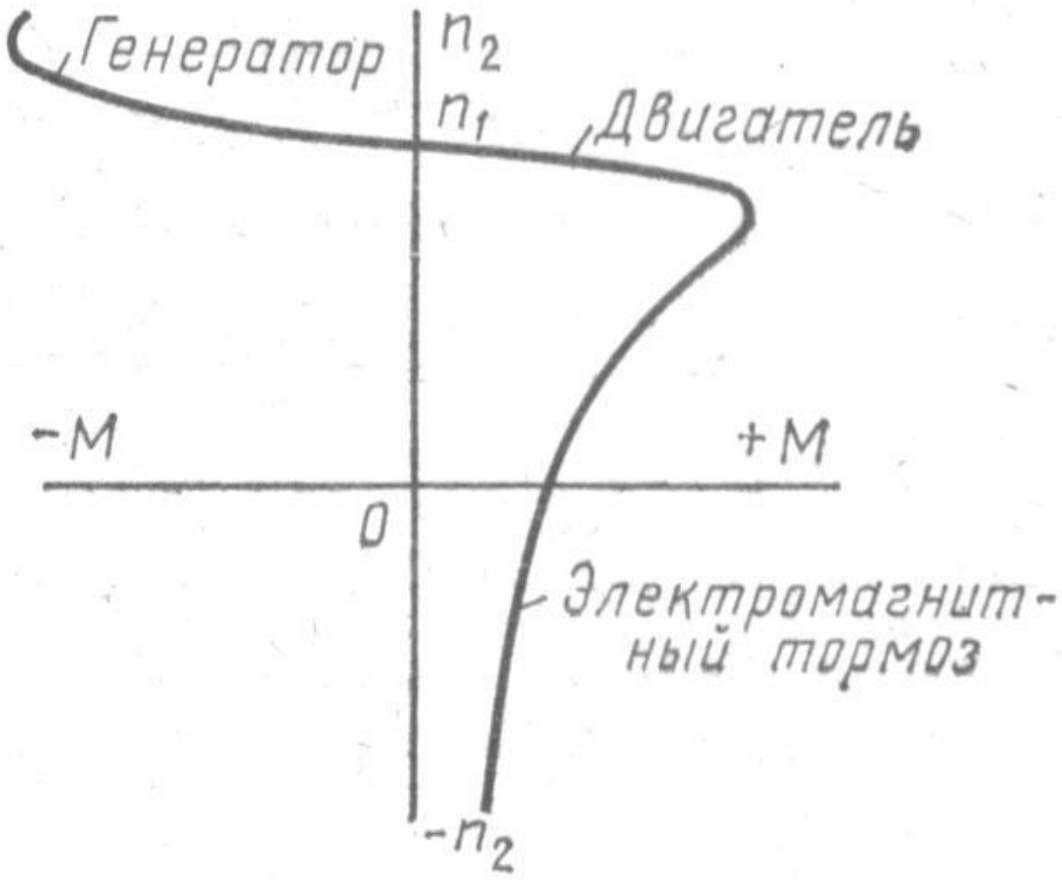
$$\left[S = \frac{n_1 - n_2}{n_1} = 1 - V \right] \qquad V = \frac{n_2}{n_1}$$

$$M = \frac{m_1 U_1^2 r_2^{'}}{\omega_1 S[(R_1 + \frac{C_1 R_2^{'}}{S})^2 + (x_1 + C_1 x_2^{'})^2]}$$

$$M = \frac{\Delta P_{Э Л 2}}{w_1 S} = \frac{m_1 I_2^{'2} R_2^{'}}{w_1 S}$$

$C_1 = 1 + (r_1 + jx_1) / (r_m + jx_m)$

$$M = \frac{m_1 U_1^2 r_2'}{\omega_1 S[(R_1 + \frac{R_2'}{S})^2 + (x_1 + x_2')^2]}$$



$n_2 \approx (0{,}8...0{,}9)$

$n_2 = n_1$

M=0

$\frac{dM}{dS} = 0$

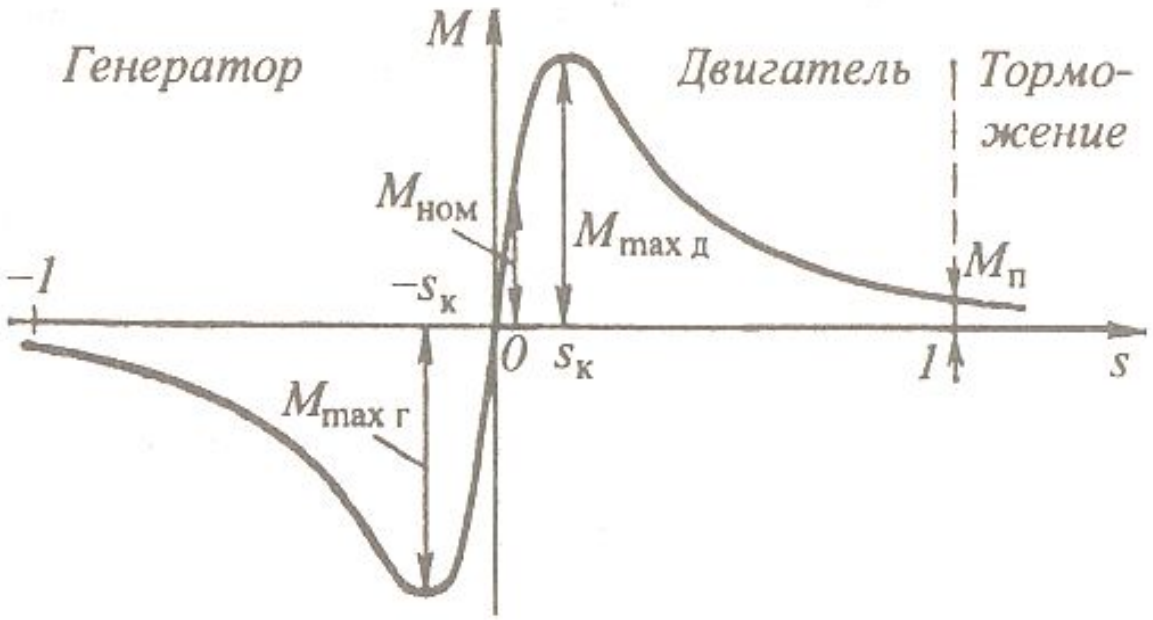
$n_2 = 0$

$M_П = (0{,}3...0{,}7)\mathrm{M}_{\max}$

$$S_{KP} = \pm \frac{R_2^{'}}{x_1 + x_2^{'}}$$

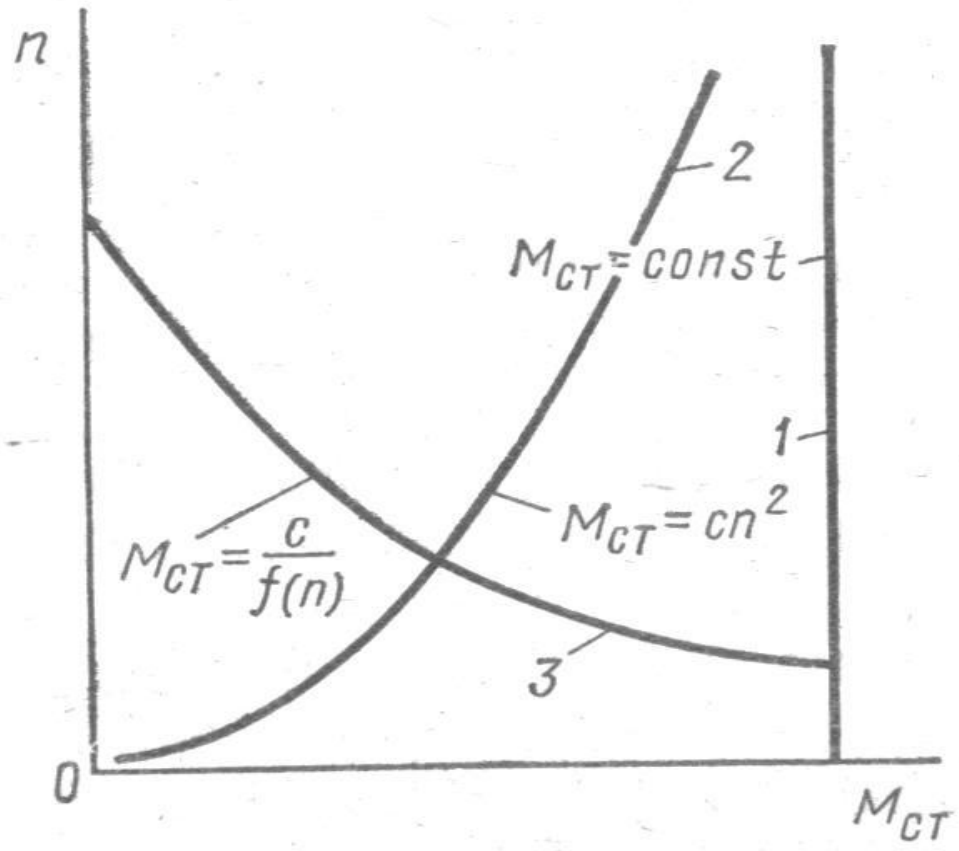
$$M_{\max} \approx \pm \frac{m_1 U_1^2}{2w_1(x_1 + x_2^{'})}$$

$\eta < 1 - S$



Устойчивость работы АД

$$M = M_{CT} + J\frac{d\omega_2}{dt}$$

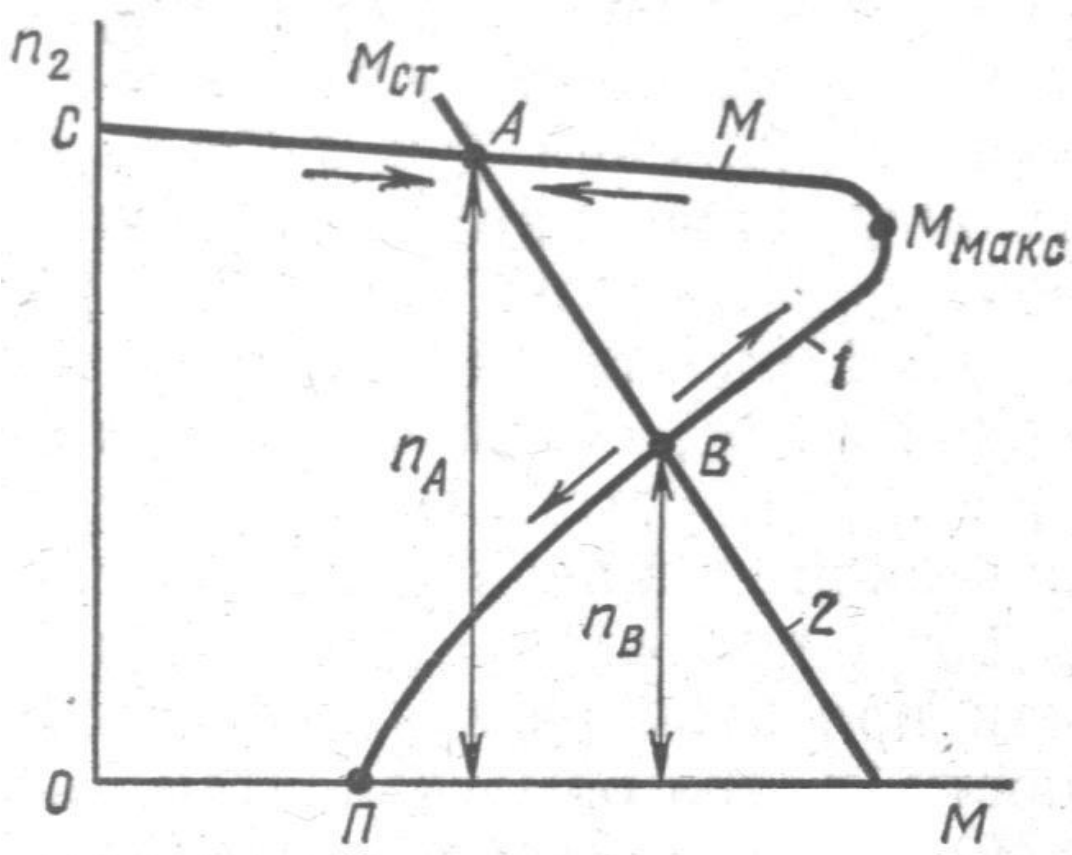


$$M_{CT} = f(n)$$

$$M = M_{CT}$$

$$M_{изб} = \pm(M\text{-}M_{CT})$$

$$\frac{dM}{dn_2} < \frac{dM_{CT}}{dn_2}$$



$$к_м = M_{макс}/M_{ном}$$

Рабочие характеристики АД

$$f_1 = const$$

$$U_1 = const$$

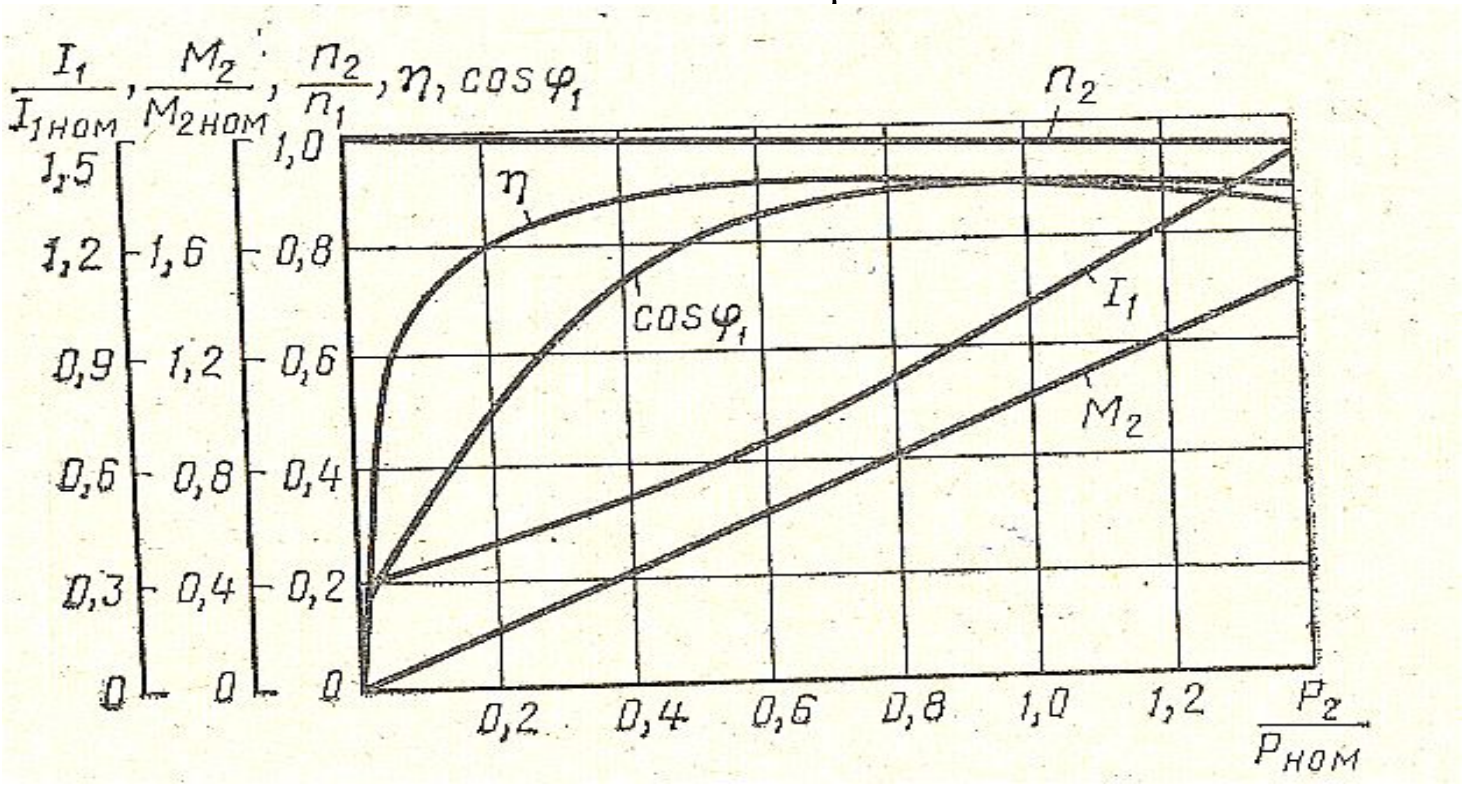
$$P_2 = 1.02 n_2 M_в$$

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

$$S = \frac{f_2}{f_1}$$

$$\mathrm{Cos}\varphi_1 = \frac{P_1}{m_1 V_1 I_1}$$

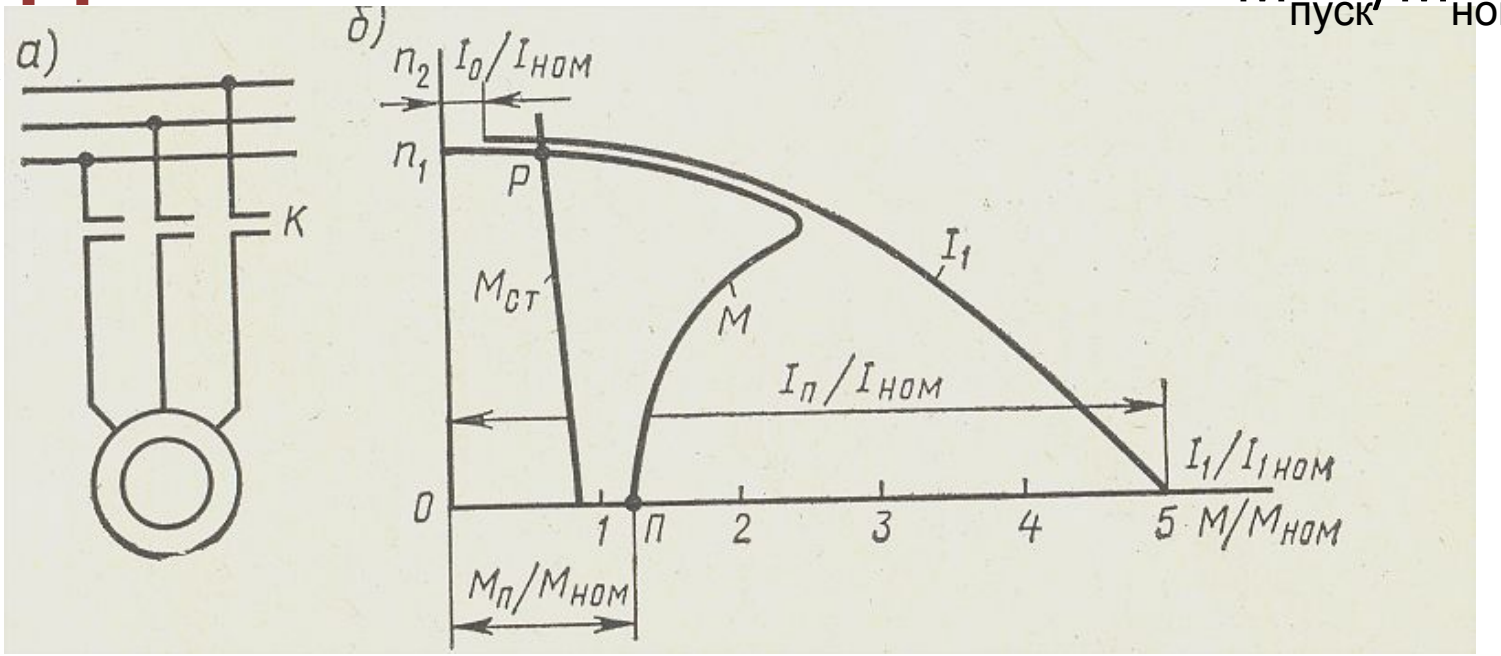
$$\eta = \frac{P_2}{P_1}$$



Пуск асинхронных двигателей

Прямой пуск

$M_{пуск}/M_{ном} = k_{п.м}$



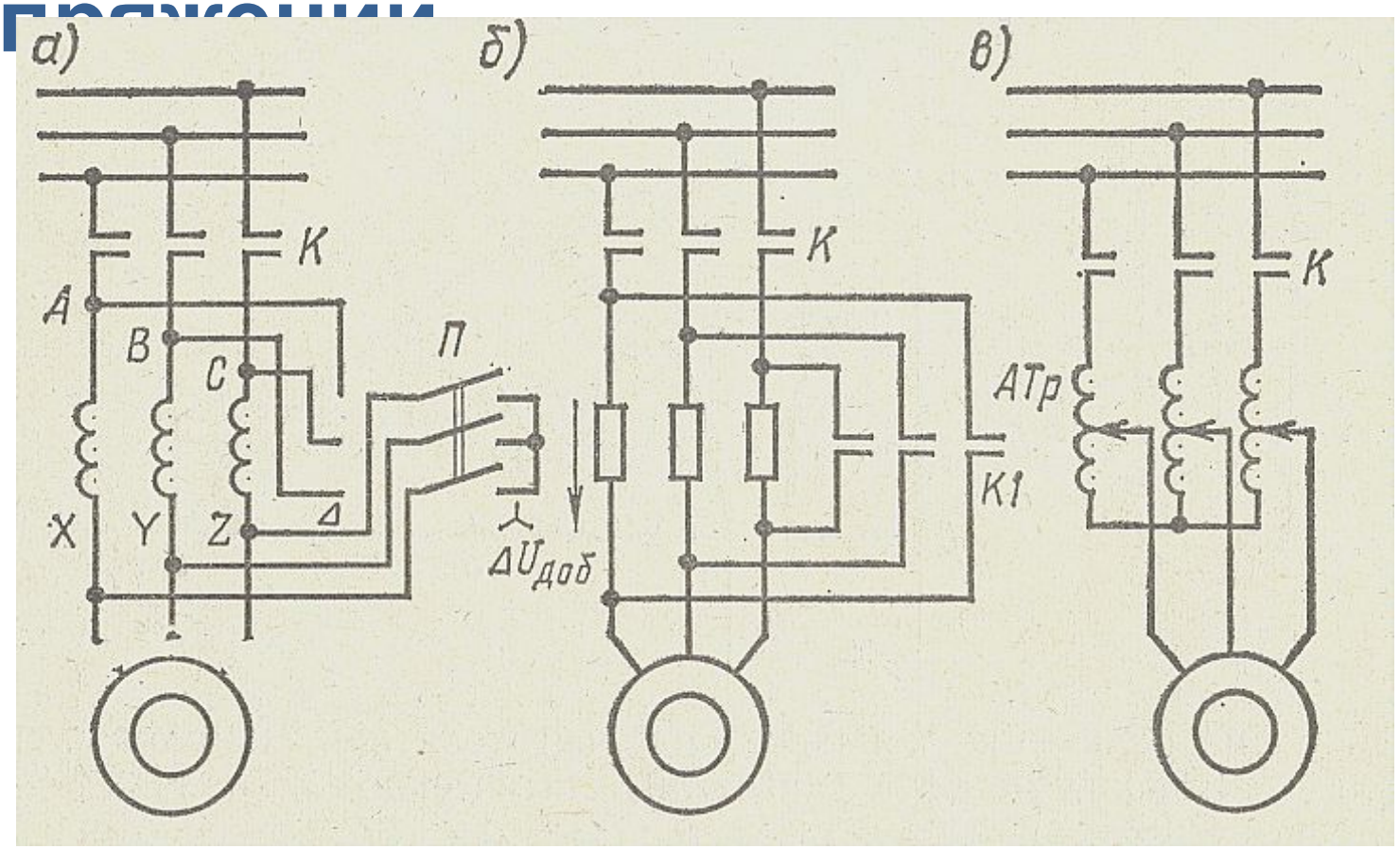
$$M = \frac{m_1 U_1^2 r_2'}{\omega_1 S[(R_1 + \frac{R_2'}{S})^2 + (x_1 + x_2')^2]}$$

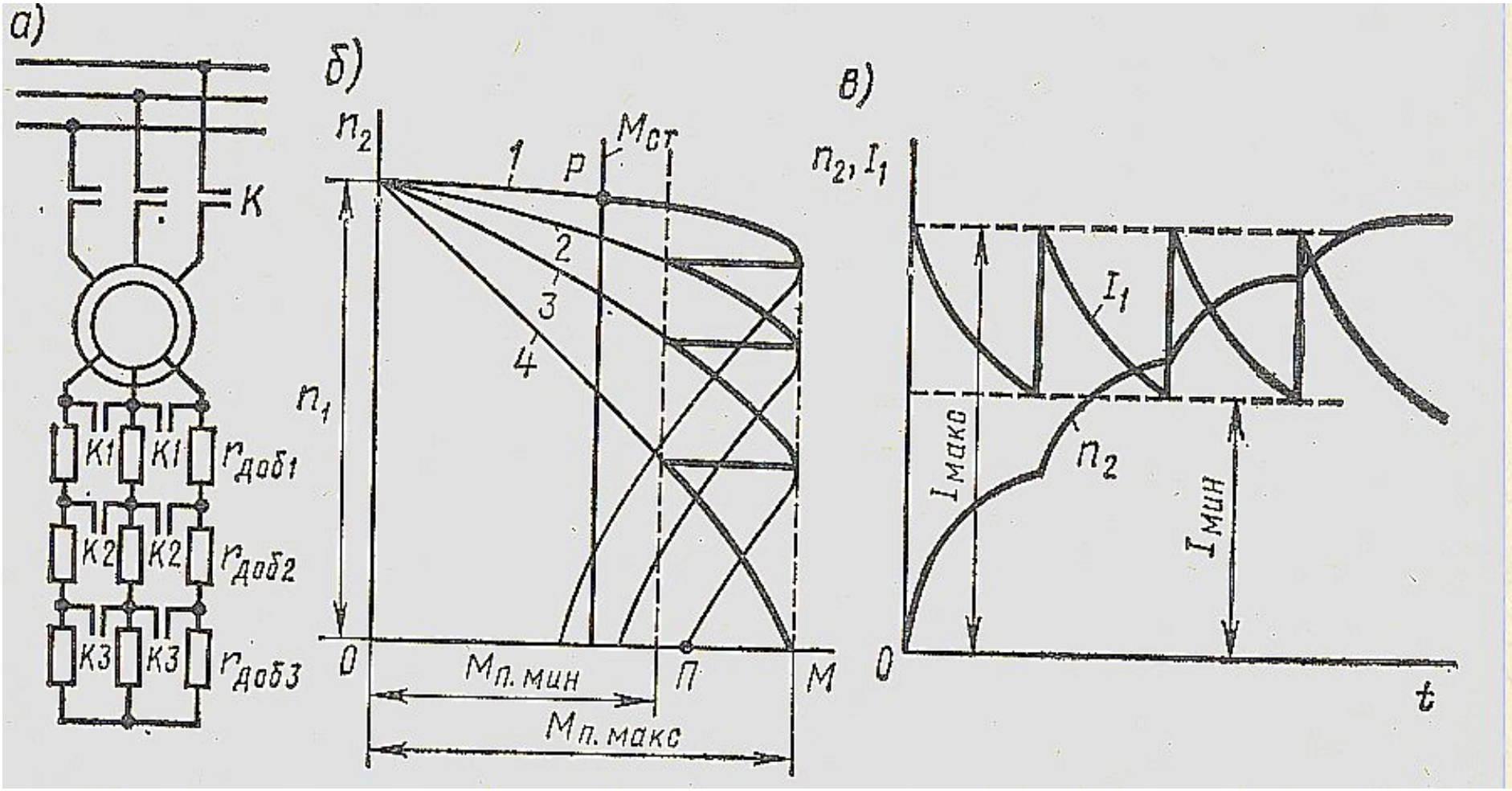
$$M_n = \frac{m_1 u_1^2 r_2'}{\omega_1[(R_1 + \frac{R_2'}{S})^2 + (x_1 + x_2')^2]}$$

0,6-100 кВт $k_{п.м}$=1,0 -2,0

100-1000кВт $k_{п.м}$ = 0,7-1,0.

Пуск при пониженном напряжении




а)
К
К1
К1
$r_{доб1}$
К2
К2
$r_{доб2}$
К3
К3
$r_{доб3}$
б)
n_2
$M_{ст}$
1
Р
2
3
4
n_1
0
$M_{п.мин}$
П
М
$M_{п.макс}$
в)
n_2, I_1
I_1
$I_{макс}$
n_2
$I_{мин}$
0
t