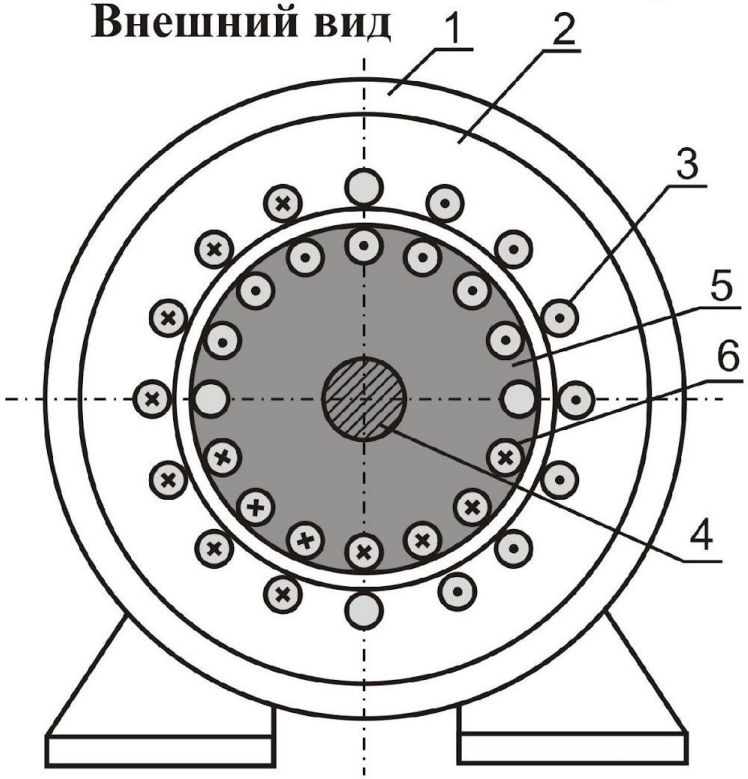
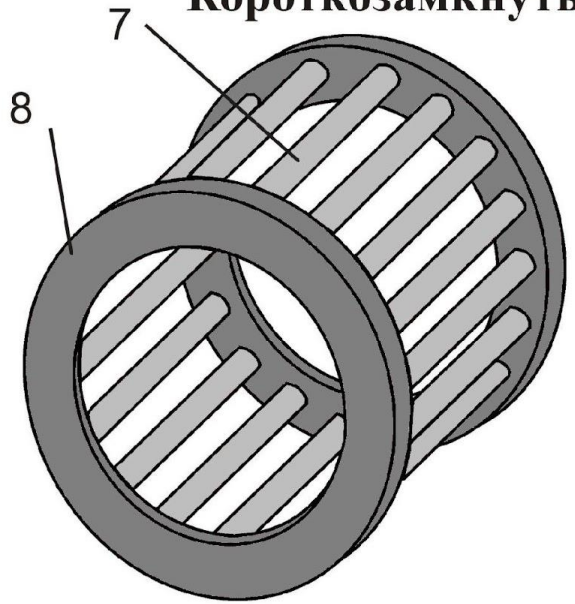
Асинхронные двигатели, устройство двигателя

Внешний вид



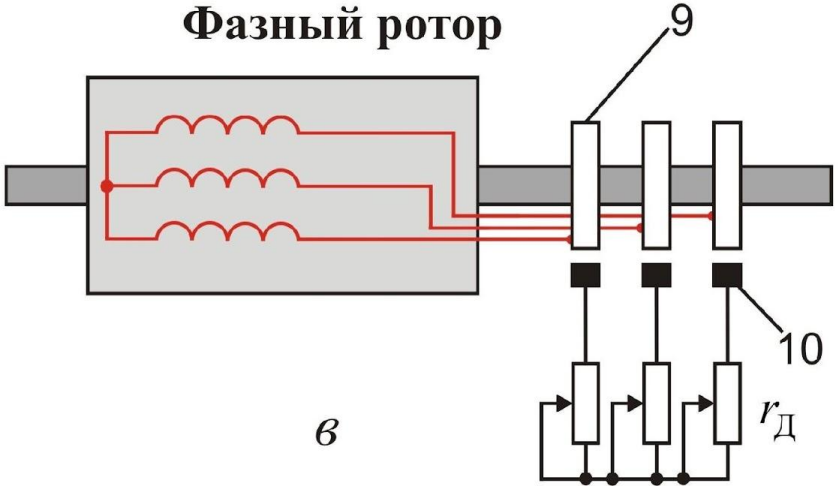
а

Короткозамкнутый ротор



б

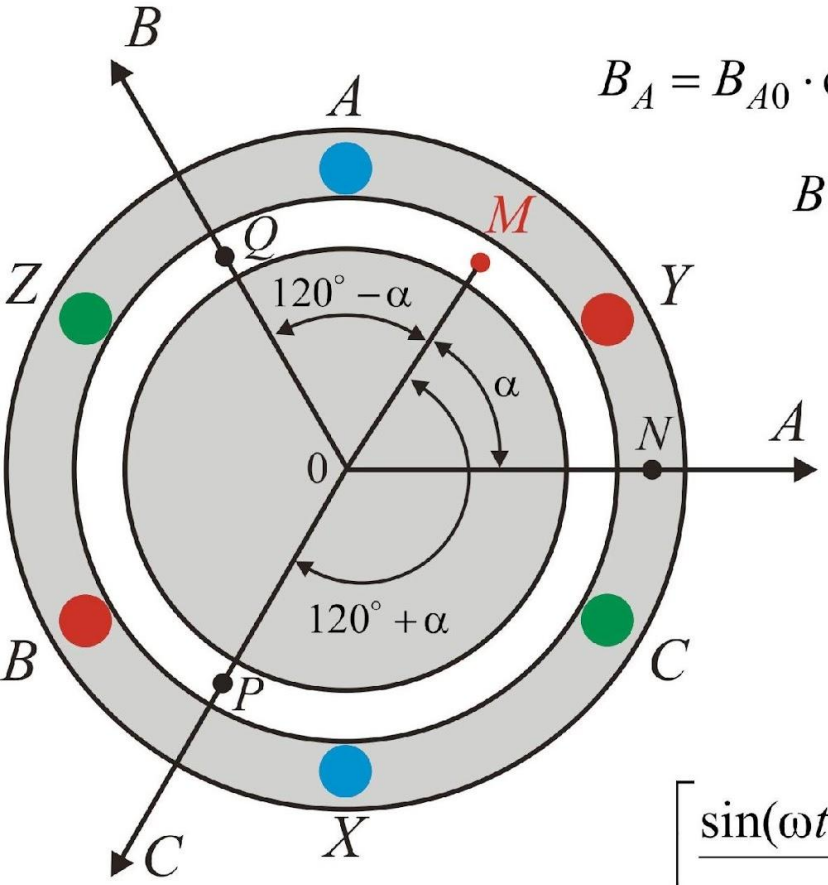
Фазный ротор



в

1 - корпус
2 - сердечник статора
3 - обмотка статора
4 - вал
5 - сердечник ротора
6 - обмотка ротора
7 - стержни
8 - замыкающие кольца
9 - контактные кольца
10 - щетки

Вращающееся магнитное поле и принцип действия двигателя



$$B_A = B_{A0}\cdot\cos\alpha,\quad B_B = B_{B0}\cdot\cos(120^\circ-\alpha),\quad B_C = B_{C0}\cdot\cos(120^\circ+\alpha),$$

$$B = B_{A0}\cdot\cos\alpha + B_{B0}\cdot\cos(120^\circ-\alpha) + B_{C0}\cdot\cos(120^\circ+\alpha).$$

$$B_{A0} = B_m\cdot\sin\omega t,\ B_{B0} = B_m\cdot\sin(\omega t-120^\circ),$$

$$B_{C0} = B_m\cdot\sin(\omega t+120^\circ).$$

$$B = B_m[\sin\omega t\cos\alpha + \sin(\omega t-120^\circ)\cos(120^\circ-\alpha) +$$

$$+\sin(\omega t+120^\circ)\cos(120^\circ+\alpha)].$$

$$\sin A\cdot\cos B = \frac{\sin(A+B)+\sin(A-B)}{2},$$

$$B = B_m\left[\frac{\sin(\omega t+\alpha)+\sin(\omega t-\alpha)}{2} + \frac{\sin(\omega t-\alpha)+\sin(\omega t+\alpha-240^\circ)}{2} + \right.$$

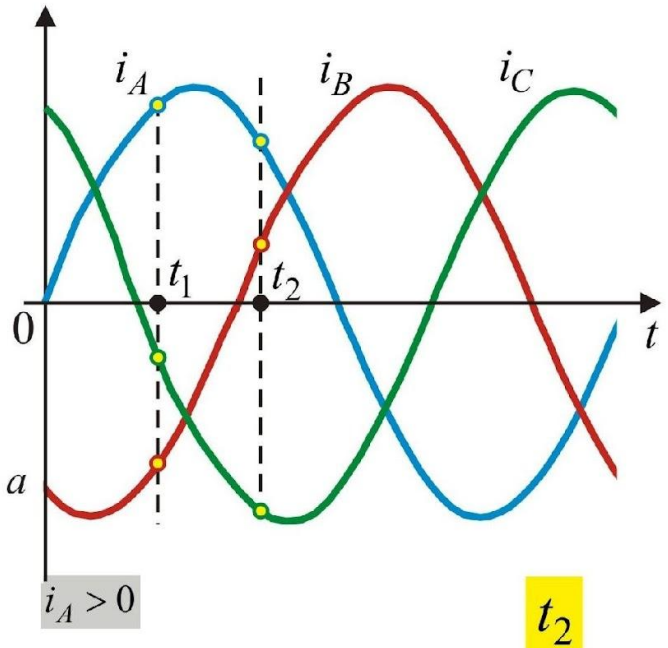
$$\left. + \frac{\sin(\omega t+\alpha+240^\circ)+\sin(\omega t-\alpha)}{2}\right].$$

$$\sin(\omega t+\alpha)+\sin(\omega t+\alpha-240^\circ)+\sin(\omega t+\alpha+240^\circ)=0$$

$$B = \frac{3}{2}B_m\sin(\omega t-\alpha).$$

$$\sin(\omega t-\alpha)=+1 \Rightarrow \omega t-\alpha=\frac{\pi}{}\Rightarrow \alpha=\omega t-\frac{\pi}{}.$$

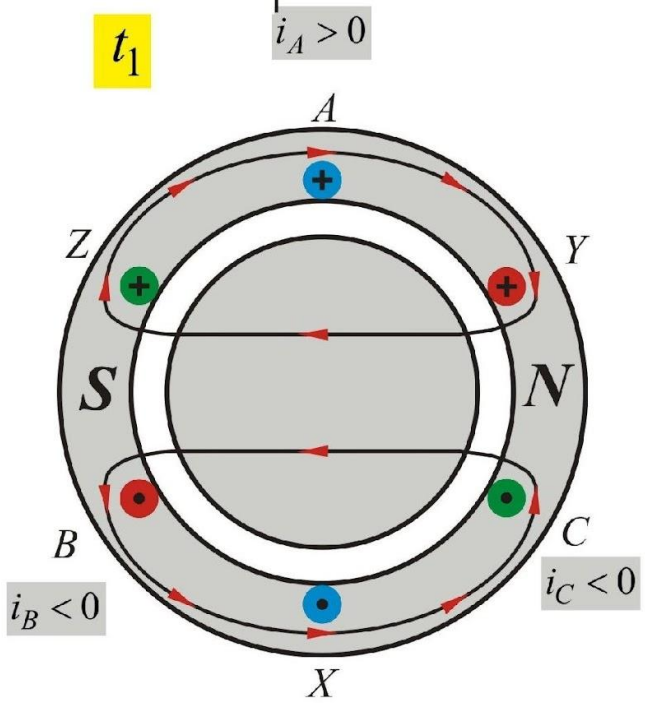
Вращающееся магнитное поле и принцип действия двигателя



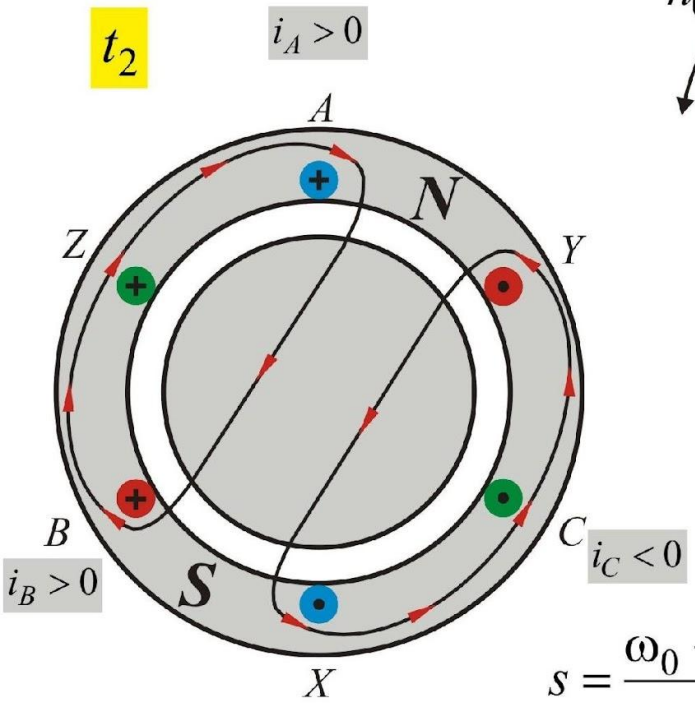
$$i_A(t_1) > 0, i_B(t_1) < 0, i_C(t_1) < 0.$$

$$i_A(t_2) > 0, i_B(t_2) > 0, i_C(t_2) < 0.$$

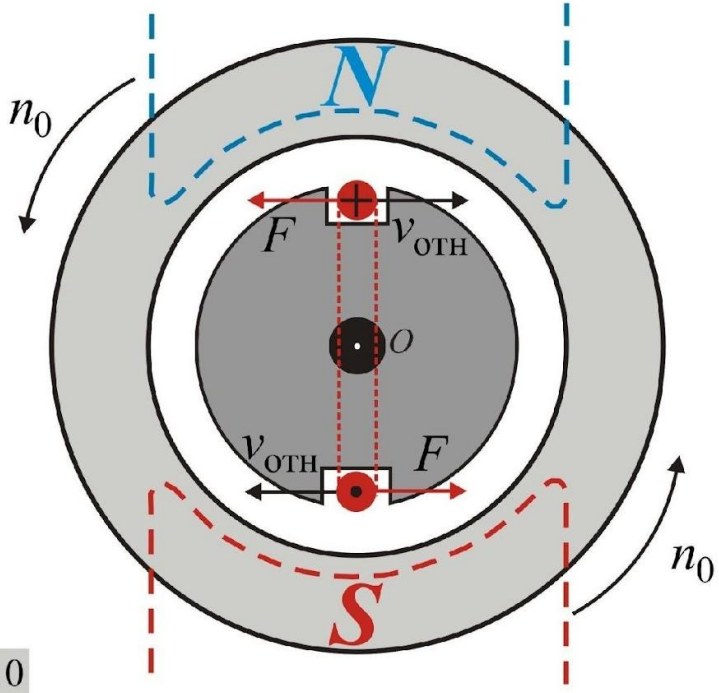
$$\omega_0 = \frac{\omega}{p} \qquad \omega = 2\pi f = \frac{\pi n}{30} \qquad n_0 = \frac{60 \cdot f}{p},$$



б



в



$$s = \frac{\omega_0 - \omega}{\omega_0} = \frac{n_0 - n}{n_0}. \qquad n = n_0 \cdot (1 - s).$$

Обмоточный коэффициент. ЭДС статора и ротора

$E < E' \cdot w \qquad k = 0{,}92 \div 0{,}96. \qquad E' = 4{,}44 \cdot f_1 \cdot \Phi. \qquad E_1 = E' \cdot k_1 \cdot w_1 = 4{,}44 \cdot f_1 \cdot k_1 \cdot w_1 \cdot \Phi.$

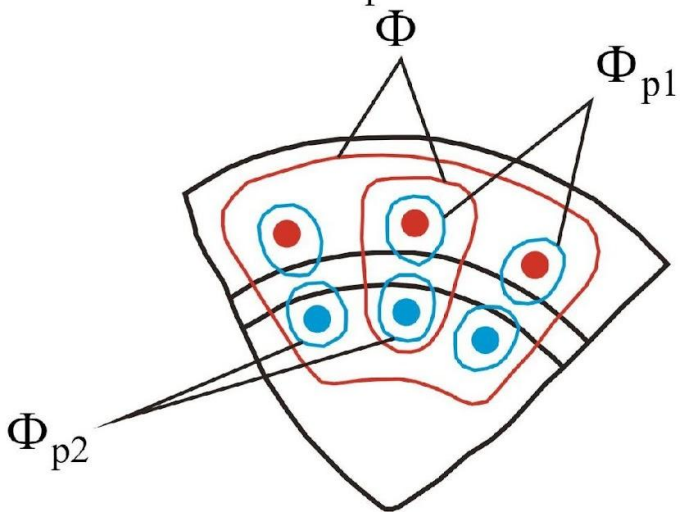
$f_1 = \frac{pn_0}{60}. \qquad E_{2н} = 4{,}44 \cdot f_1 \cdot k_2 \cdot w_2 \cdot \Phi. \qquad f_2 = \frac{p(n_0 - n)}{60}. \qquad f_2 = \frac{p(n_0 - n)}{60} \cdot \frac{n_0}{n_0} = \frac{pn_0}{60} \cdot \frac{(n_0 - n)}{n_0},$

$f_2 = f_1 \cdot s; \qquad E_2 = 4{,}44 \cdot f_2 \cdot k_2 \cdot w_2 \cdot \Phi = 4{,}44 \cdot f_1 \cdot s \cdot k_2 \cdot w_2 \cdot \Phi = E_{2н} \cdot s.$

Магнитные потоки асинхронной машины

$-\dot{E}_{p1} = \dot{I}_1 \cdot jx_{p1} = \dot{I}_1 \cdot j\omega \cdot L_{p1}; \; -\dot{E}_{p2} = \dot{I}_2 \cdot jx_{p2} = \dot{I}_1 \cdot j\omega_2 \cdot L_{p2} = \dot{I}_1 \cdot j\omega s \cdot L_{p2}.$

$\dot{I}_1 = \frac{\dot{U}_1 + \dot{E}_1 + \dot{E}_{p1}}{r_1}, \qquad \dot{I}_1 \cdot (r_1 + jx_{p1}) = \dot{I}_1 \cdot Z_1, \qquad Z_1 = r_1 + jx_{p1} \qquad \dot{U}_1 = \dot{I}_1 \cdot Z_1 + \left(-\dot{E}_1\right)$



$U_1 \approx E_1, \qquad E_1 = \text{const} \cdot \Phi, \qquad U_1 = \text{const} \cdot \Phi.$

$m_1 \cdot w_1 \cdot k_1 \cdot \dot{I}_1 + m_2 \cdot w_2 \cdot k_2 \cdot \dot{I}_2 = m_1 \cdot w_1 \cdot k_1 \cdot \dot{I}_0.$

$\dot{I}_1 = \dot{I}'_2 + \dot{I}_0. \qquad \dot{I}'_2 = -\dot{I}_2 \frac{m_2 \cdot w_2 \cdot k_2}{m_1 \cdot w_1 \cdot k_1}$

Ток ротора

$r_2 \qquad x_{p2} = \omega_2 \cdot L_{p2} = \omega s \cdot L_{p2}$

$$z_2 = \sqrt{r_2^2 + (\omega s L_{p2})^2}.$$

$$I_2 = \frac{E_2}{z_2} = \frac{E_2}{\sqrt{r_2^2 + (\omega s L_{p2})^2}} = \frac{E_{2н} \cdot s}{\sqrt{r_2^2 + (\omega s L_{p2})^2}} = \frac{E_{2н}}{\sqrt{\frac{r_2^2}{s^2} + (\omega L_{p2})^2}}.$$

Векторная диаграмма при неподвижном роторе

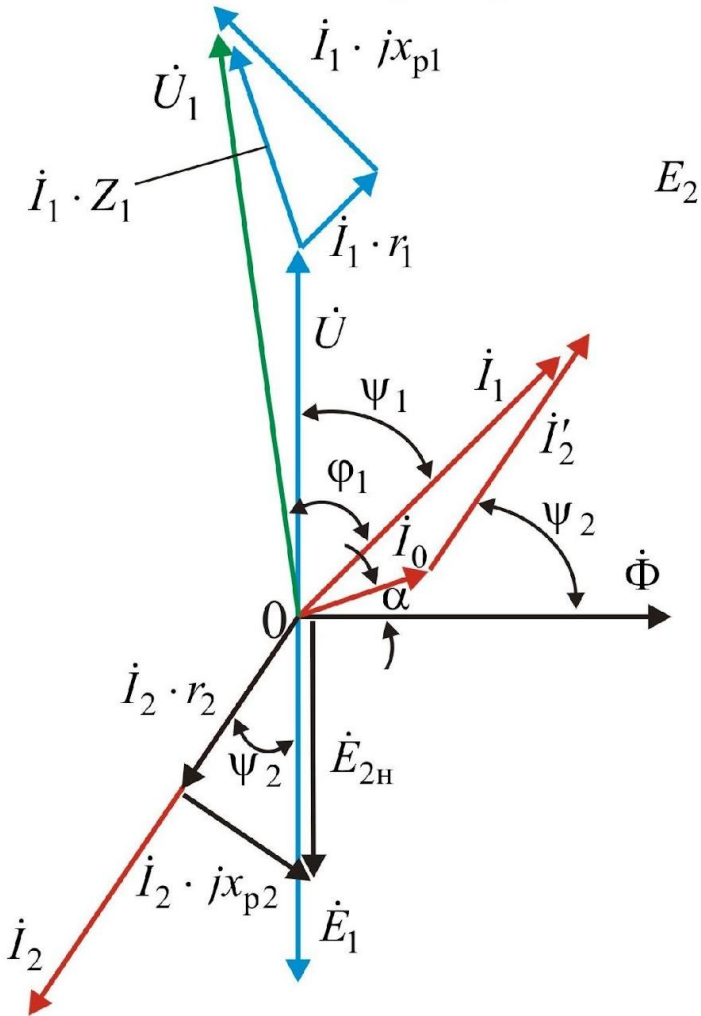
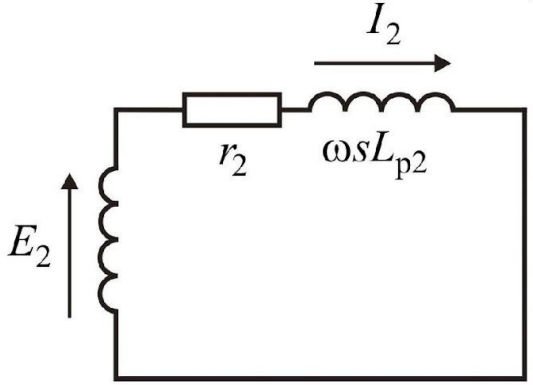
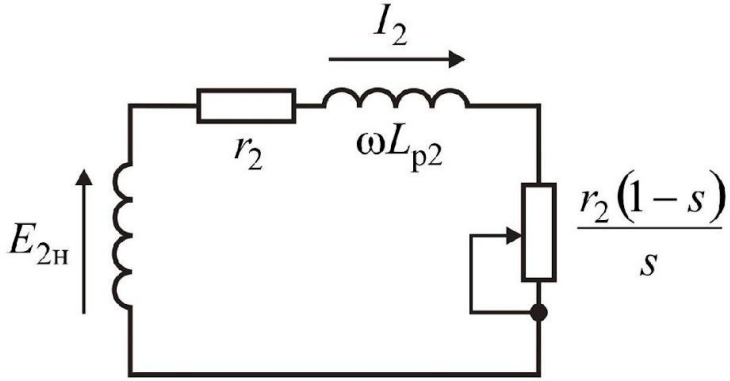


Схема замещения фазы вращающегося ротора



а - реальная



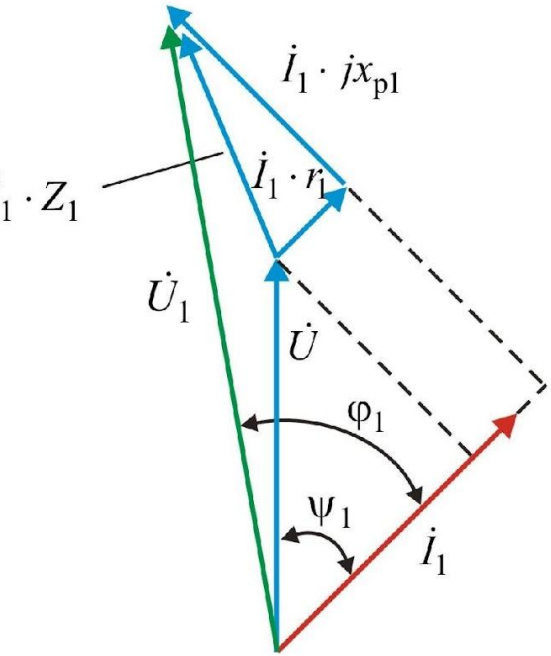
б - эквивалентная

$$\psi_2 = \arccos \frac{r_2}{\sqrt{r_2^2 + (\omega L_{p2})^2}}. \qquad \dot{I}_1 = \dot{I}'_2 + \dot{I}_0.$$

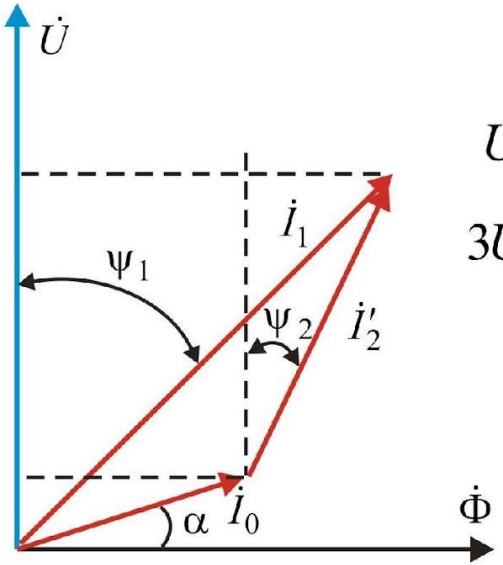
$$\dot{U}_1 = (-\dot{E}_1) + \dot{I}_1 \cdot Z_1 \qquad \frac{r_2}{s} = r_2 + r \Rightarrow r = \frac{r_2(1-s)}{s}.$$

$\dot{E}_{2н} \qquad \dot{I}_2 j\omega L_{p2} \qquad \dot{I}_2 \frac{r_2}{s}.$

Энергетический баланс в асинхронном двигателе



а



б

$$U_1\cos\varphi_1 = I_1 r_1 + U\cos\psi_1. \qquad U_1 I_1\cos\varphi_1 = I_1^2 r_1 + U I_1\cos\psi_1.$$

$$I_1\cos\psi_1 = I_0\sin\alpha + I'_2\cos\psi_2,$$

$$U_1 I_1\cos\varphi_1 = I_1^2 r_1 + U I_0\sin\alpha + U I'_2\cos\psi_2.$$

$$3U_1 I_1\cos\varphi_1 = 3I_1^2 r_1 + 3U I_0\sin\alpha + 3U I'_2\cos\psi_2.$$

$$P_1 = 3U_1 I_1\cos\varphi_1 \qquad P_{м1} = 3I_1^2 r_1$$

$$P_{СТ1} = 3U I_0\sin\alpha \qquad P_{ЭМ} = 3U I'_2\cos\psi_2$$

$$P_1 = P_{м1} + P_{СТ1} + P_{ЭМ}. \qquad I'_2 = -I_2\frac{m_2\cdot w_2\cdot k_2}{3\cdot w_1\cdot k_1}, \qquad U = -E_1 = -E_{2н}\frac{w_1\cdot k_1}{w_2\cdot k_2},$$

$$P_{ЭМ} = 3U I'_2\cos\psi_2 = 3\cdot\left(-E_{2н}\frac{w_1\cdot k_1}{w_2\cdot k_2}\right)\cdot\left(-I_2\frac{m_2\cdot w_2\cdot k_2}{3\cdot w_1\cdot k_1}\right)\cdot\cos\psi_2 = m_2 E_{2н} I_2\cos\psi_2.$$

$$E_{2н} = \frac{E_2}{s}, \qquad E_2\cos\psi_2 = I_2 r_2 \qquad 3U_1 I_1\cos\varphi_1 = 3I_1^2 r_1 + 3U I_0\sin\alpha + \frac{m_2}{s} I_2^2 r_2. \qquad P_{ЭМ} = \frac{m_2}{s} I_2^2 r_2$$

$$P_{ЭМ} = \Delta P_2 + P_{МЕХ}. \qquad \Delta P_2 = P_{СТ2} + P_{м2} \approx P_{м2} = m_2 I_2^2 r_2. \qquad f_2 = f\cdot s$$

$$P_{МЕХ} = P_{ЭМ} - \Delta P_2 \approx P_{ЭМ} - P_{м2} = \frac{m_2}{s} I_2^2 r_2 - m_2 I_2^2 r_2 = m_2 I_2^2\frac{r_2(1-s)}{s} \qquad r = \frac{r_2(1-s)}{s} \qquad P_{МЕХ} = m_2 I_2^2 r,$$

Вращающий момент асинхронного двигателя

$$\omega_{\text{п}} = \frac{\omega}{p}. \quad \omega_{\text{р}} = \omega_{\text{п}}(1-s) = \frac{\omega(1-s)}{p}. \quad P_{\text{МЕХ}} = \frac{\omega(1-s)}{p} M = m_2 I_2^2 \frac{r_2(1-s)}{s} \Rightarrow M = \frac{m_2 p}{\omega s} I_2^2 r_2$$

$$I_2 r_2 = E_2 \cos\psi_2 = E_{2\text{н}} s \cos\psi_2,$$

$$M = \frac{m_2 p}{\omega s} I_2^2 r_2 = \frac{m_2 p}{\omega s} I_2 \cdot (I_2 r_2) = \frac{m_2 p}{2\pi f s} I_2 \cdot E_{2\text{н}} s \cos\psi_2 =$$

$$E_{2\text{н}} = 4{,}44\, f w_2 k_2 \Phi,$$

$$= \frac{m_2 p}{2\pi f} I_2 \cdot E_{2\text{н}} \cos\psi_2 = const \cdot \frac{I_2 \cdot E_{2\text{н}} \cos\psi_2}{f}.$$

$$M = const \cdot \Phi \cdot I_2 \cdot \cos\psi_2.$$

Схема замещения асинхронного двигателя

$$\dot{U}_1 = \dot{I}_1 \cdot Z_1 + \dot{I}_2' \cdot Z_2' + \dot{I}_2' \cdot Z_{\text{н}}';$$

$$\dot{U}_1 = \dot{I}_1 \cdot Z_1 + \dot{I}_0 \cdot Z_{12};$$

$$\dot{I}_1 = \dot{I}_0 + \dot{I}_2'.$$

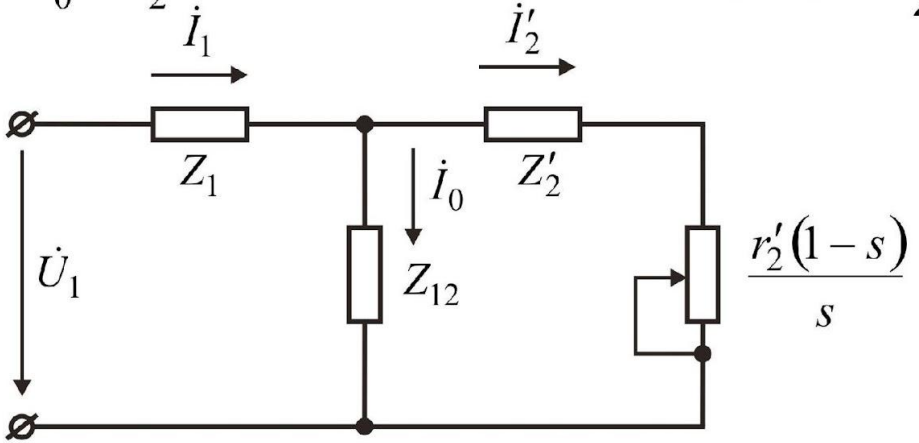
$$Z_{\text{н}} = r = \frac{r_2(1-s)}{s}$$

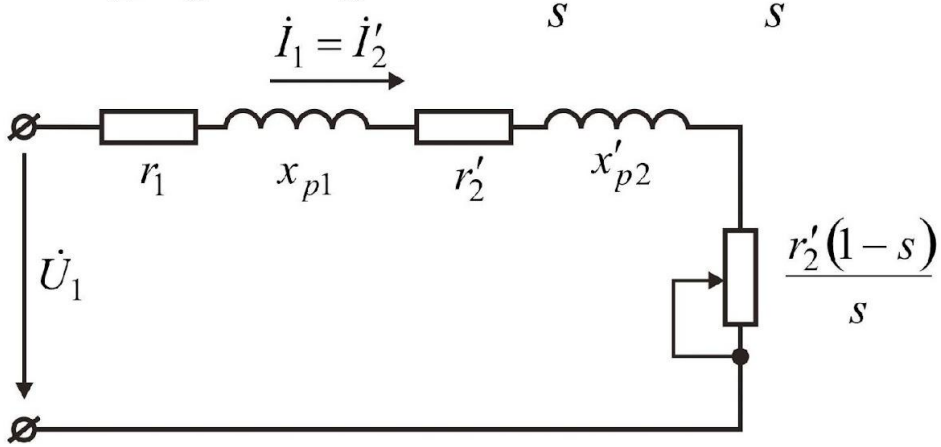
$$n = \frac{w_1 \cdot k_1}{w_2 \cdot k_2}$$

$$Z_1 = r_1 + j\omega L_{p1} = r_1 + jx_{p1}$$

$$Z_2 = r_2 + j\omega L_{p2} = r_2 + jx_{p2}$$

$$Z_2' = n^2 Z_2; Z_{\text{н}}' = n^2 Z_{\text{н}} = n^2 \frac{r_2(1-s)}{s} = \frac{r_2'(1-s)}{s} = r'$$





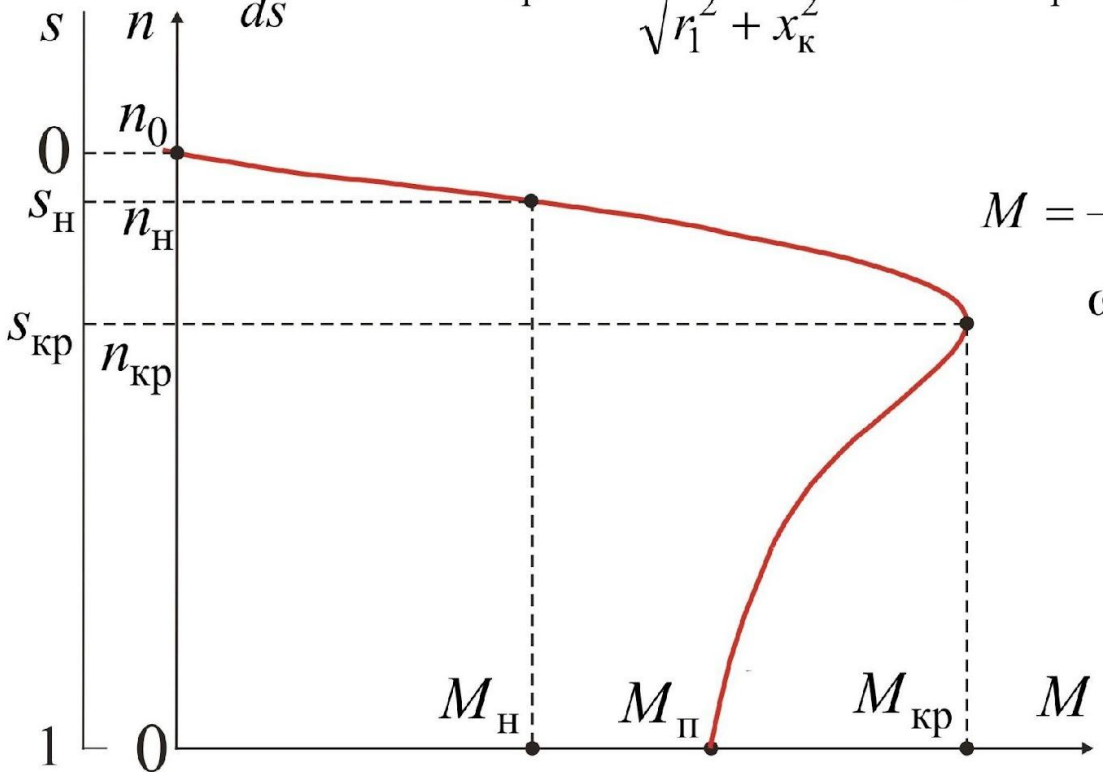
Механическая характеристика асинхронного двигателя

$n = f(M)$ $\quad s = f(M).$ $\quad M = \dfrac{m_2 p}{\omega s} I_2^2 r_2$ $\quad m_2 = 3$ $\quad \dfrac{\omega}{p} = \omega_0$ $\quad M = \dfrac{3 I_2^2 r_2}{\omega_0 s}.$ $\quad \dfrac{r_2'}{s} = r_2' + \dfrac{r_2'(1-s)}{s}.$

$$I_2' = \frac{U_1}{\sqrt{\left(r_1 + \dfrac{r_2'}{s} x_{p1}\right)^2 + \left(x_{p1} + x_{p2}'\right)^2}},$$

$$M = \frac{3 I_2^2 r_2}{\omega_0 s} = \frac{3 I_2'^2 r_2'}{\omega_0 s} = \frac{3 U_1^2 r_2'}{\omega_0 s\left[\left(r_1 + \dfrac{r_2'}{s}\right)^2 + \left(x_{p1} + x_{p2}'\right)^2\right]}.$$

$$\frac{dM}{ds} = 0 \Rightarrow s_{кр} = \pm \frac{r_2'}{\sqrt{r_1^2 + x_к^2}}, \qquad x_к = x_{p1} + x_{p2}' \qquad M_{кр} = \frac{3 U_1^2}{2\omega_0\left(r_1 \pm \sqrt{r_1^2 + x_к^2}\right)}$$



$$M = \frac{3 U_1^2 r_2'}{\omega_0 s\left[\left(\dfrac{r_2'}{s}\right)^2 + x_к^2\right]}; \qquad M_{кр} = \frac{3 U_1^2}{2\omega_0 x_к}.$$

$$s_{кр} = \pm \frac{r_2'}{x_к}, \qquad M = \frac{2 M_{кр}}{\dfrac{s}{s_{кр}} + \dfrac{s_{кр}}{s}}.$$

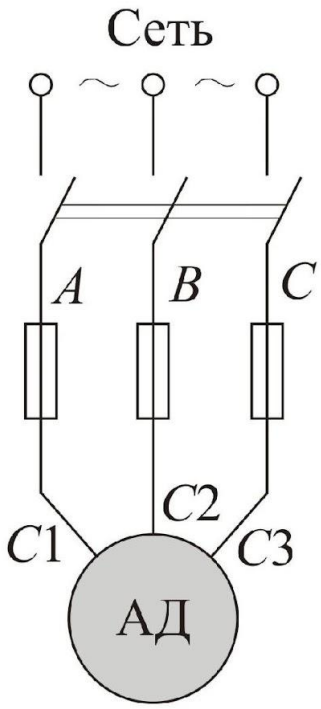
$M_{кр} / M_н = \lambda$ $\qquad s_{кр} = s_н\left(\lambda \pm \sqrt{\lambda^2 - 1}\right)$

Паспортные данные асинхронных двигателей

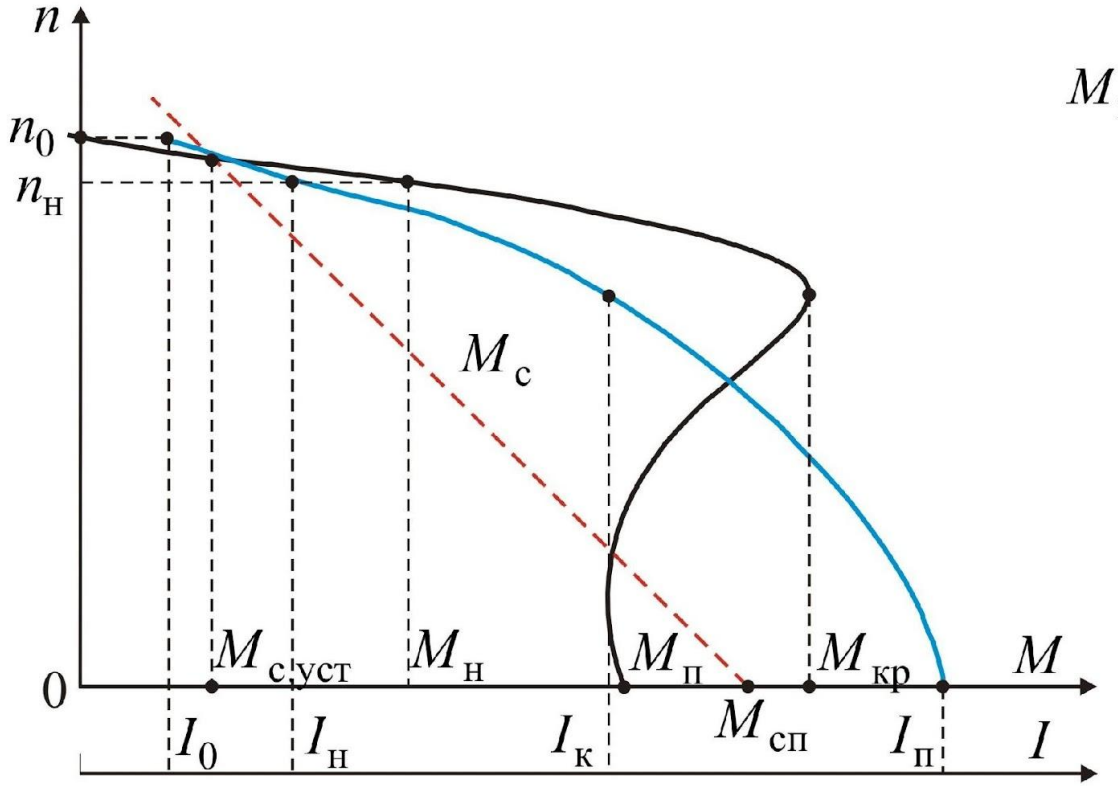
$U_н$ $P_н$ $n_н$ $I_н$ $\eta_н$ $\cos\varphi_н$ $M_{кр}/M_н = \lambda$ $M_п/M_н$ $I_п/I_н$.

$$P_1 = \sqrt{3}\cdot U \cdot I \cdot \cos\varphi; \qquad P_2 = \frac{M \cdot n}{9{,}55} = M \cdot \omega, \qquad \eta = \frac{P_2}{P_1}.$$

Пуск асинхронных двигателей



а



б

$M_п = (1{,}2 \div 1{,}6) M_н$

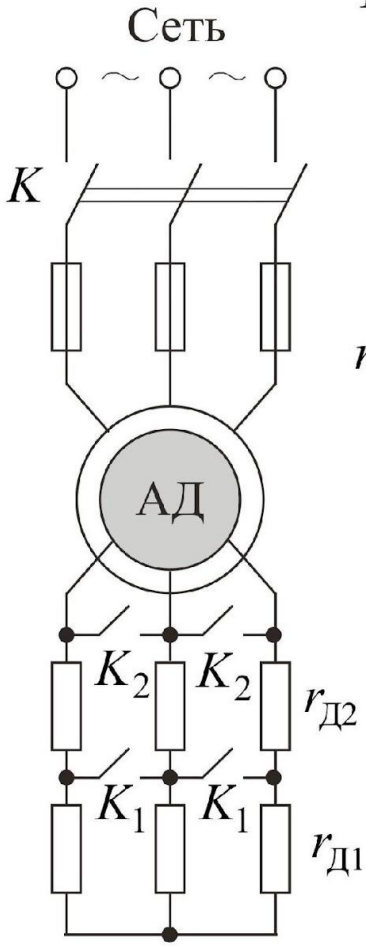
$I_п = (5 \div 7) I_н.$

$M_{сп} > M_п$

$M_{кр} > M_с$

$M_{с.уст} < M_н.$

Пуск асинхронных двигателей с фазным ротором



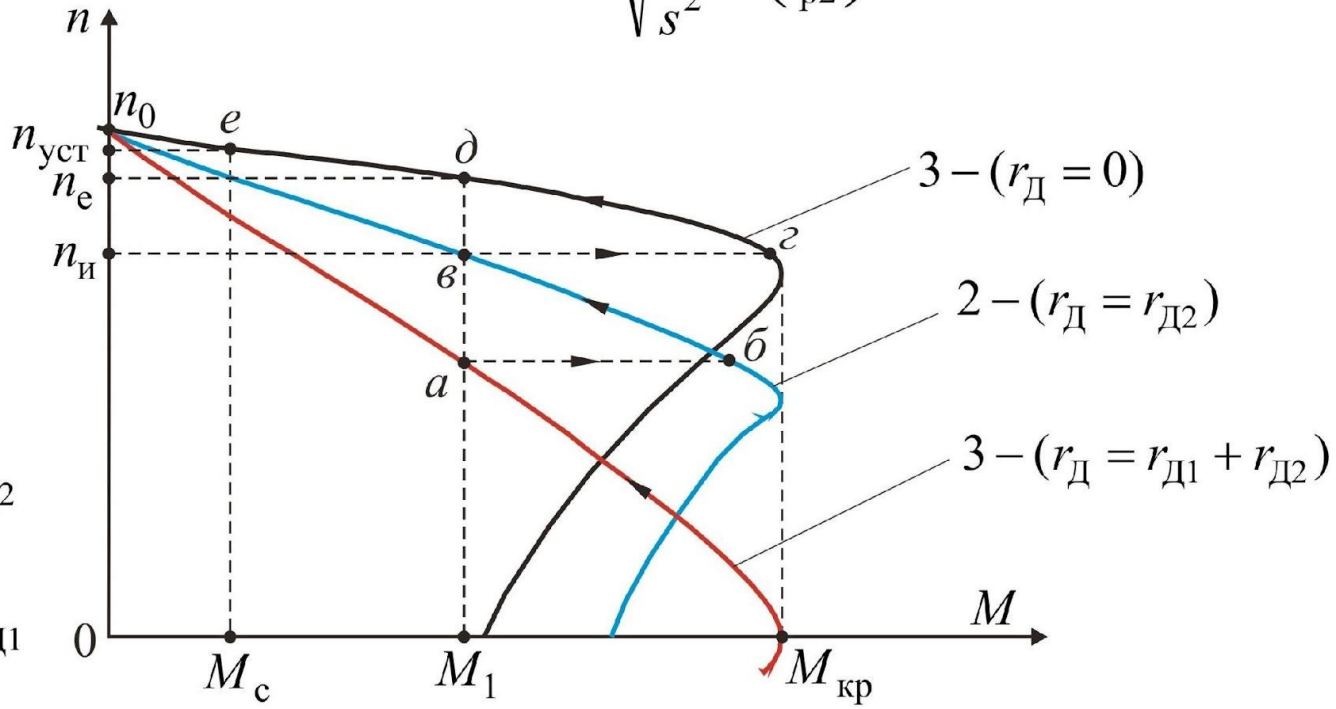
а

$r_{Д1} + r_{Д2}$,

$$I_2 = = \frac{E_{2н}}{\sqrt{\frac{r_2^2}{s^2} + (x_{р2})^2}},$$

$s = 1$: $r_Д$

$$I_{2п} = = \frac{E_{2н}}{\sqrt{(r_2 + r_Д)^2 + (x_{р2})^2}}.$$



б

$$M_п = \frac{3U_1^2 (r_2' + r_Д')}{\omega_0 \left[(r_2' + r_Д')^2 + x_к^2 \right]}$$

$r_2' + r' = x_к$:

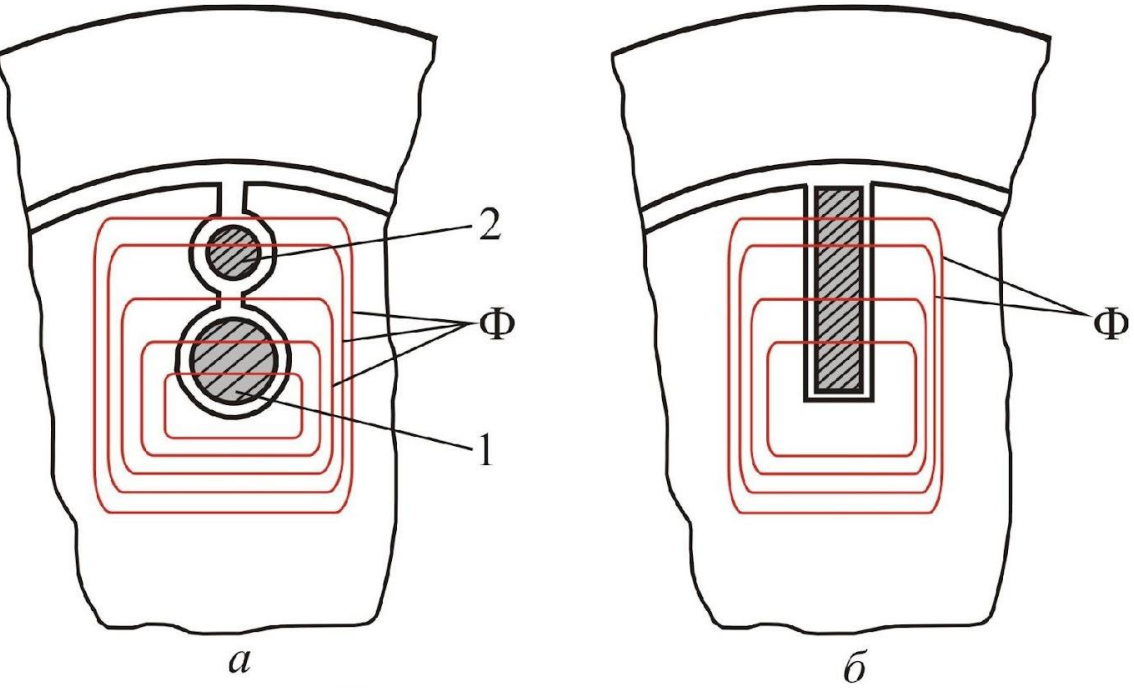
$$M_п = M_{кр} = \frac{3U_1^2}{2\omega_0 x_к}.$$

$$r_Д = r_2 \left(\frac{s_и}{s_е} - 1 \right),$$

$$s_и = \frac{n_0 - n_и}{n_0}$$

$$s_е = \frac{n_0 - n_е}{n_0}$$

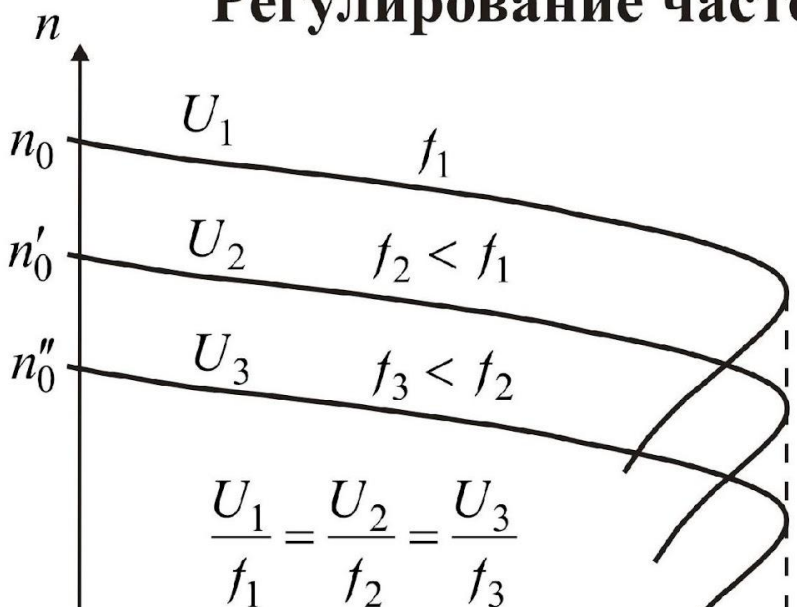
Двигатели с улучшенными пусковыми свойствами



$$s = 1$$

$$x_{p2} = 2\pi f_2 L_{p2} = 2\pi f s L_{p2} = 2\pi f L_{p2},$$

Регулирование частоты вращения асинхронных двигателей



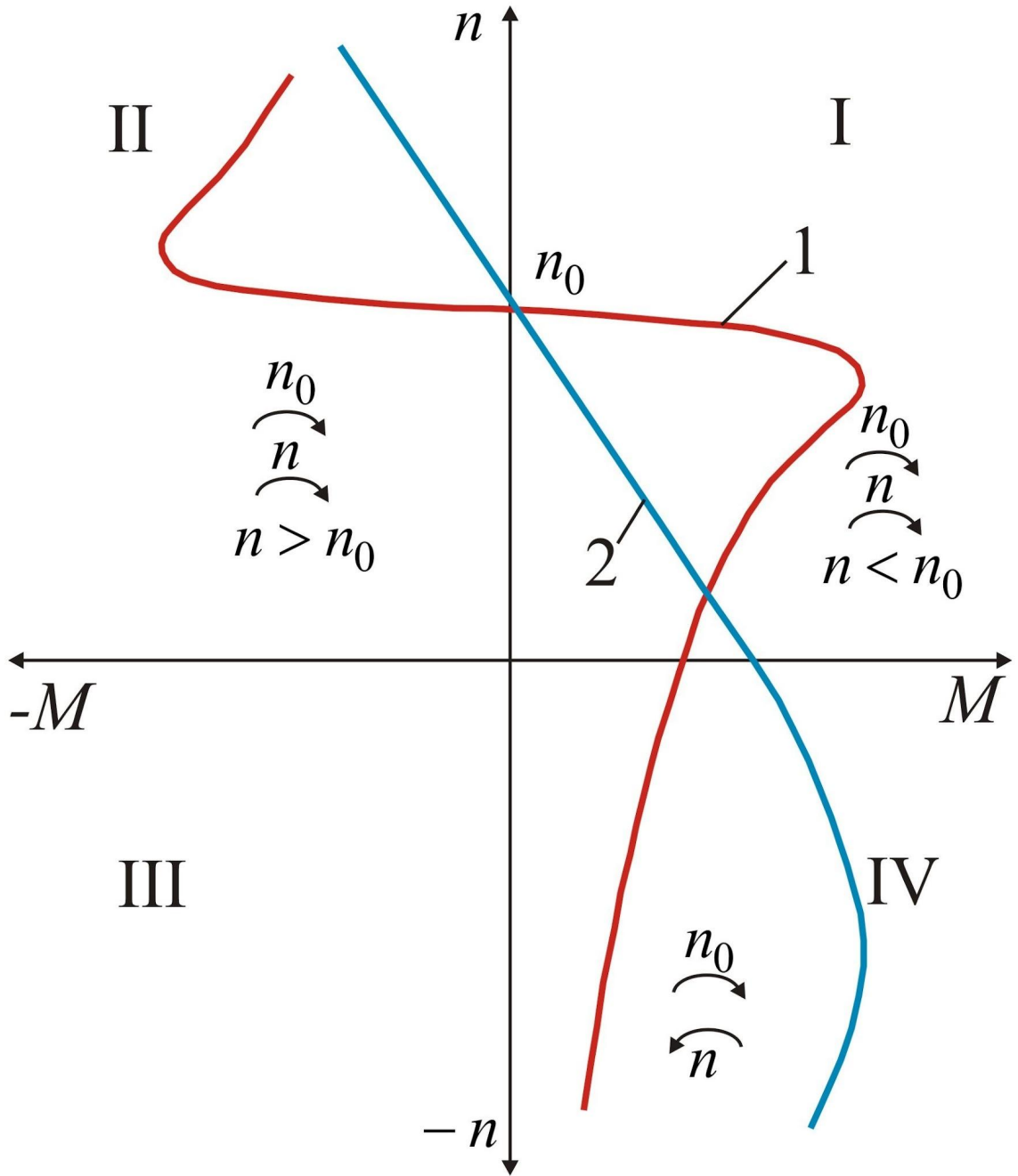
$$n = n_0 \cdot (1 - s) = n_0 \cdot \frac{60 f_1}{p}.$$

$$M = const \cdot \Phi \cdot I_2 \cdot \cos\psi_2,$$

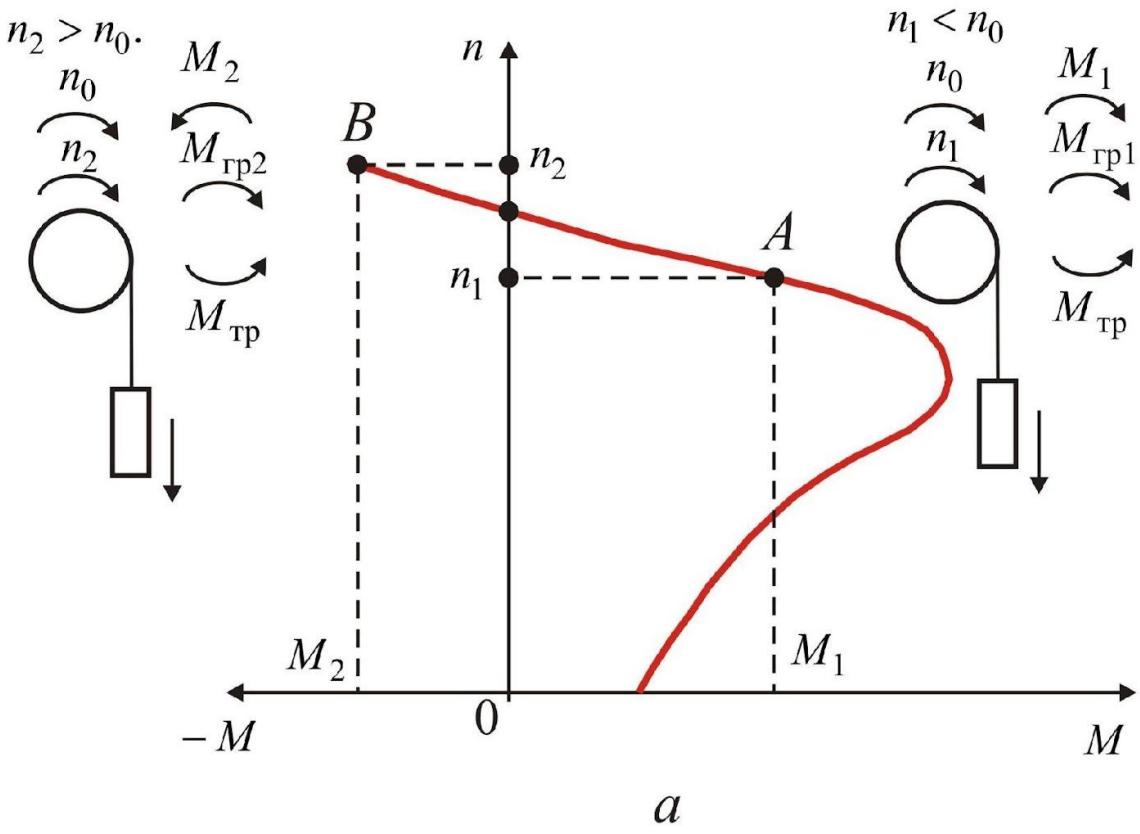
$$U_1 \approx E_1 = 4{,}44 \cdot w_1 \cdot k_1 \cdot f_1 \cdot \Phi,$$

$$U/f = \text{const}$$

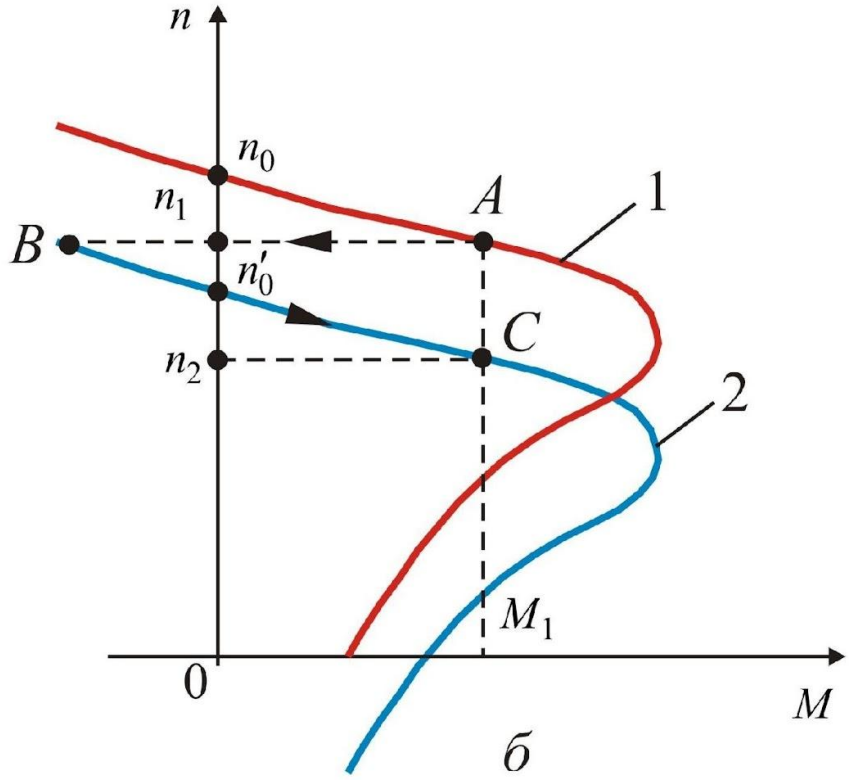
Тормозные режимы работы двигателей



Режим генераторного торможения



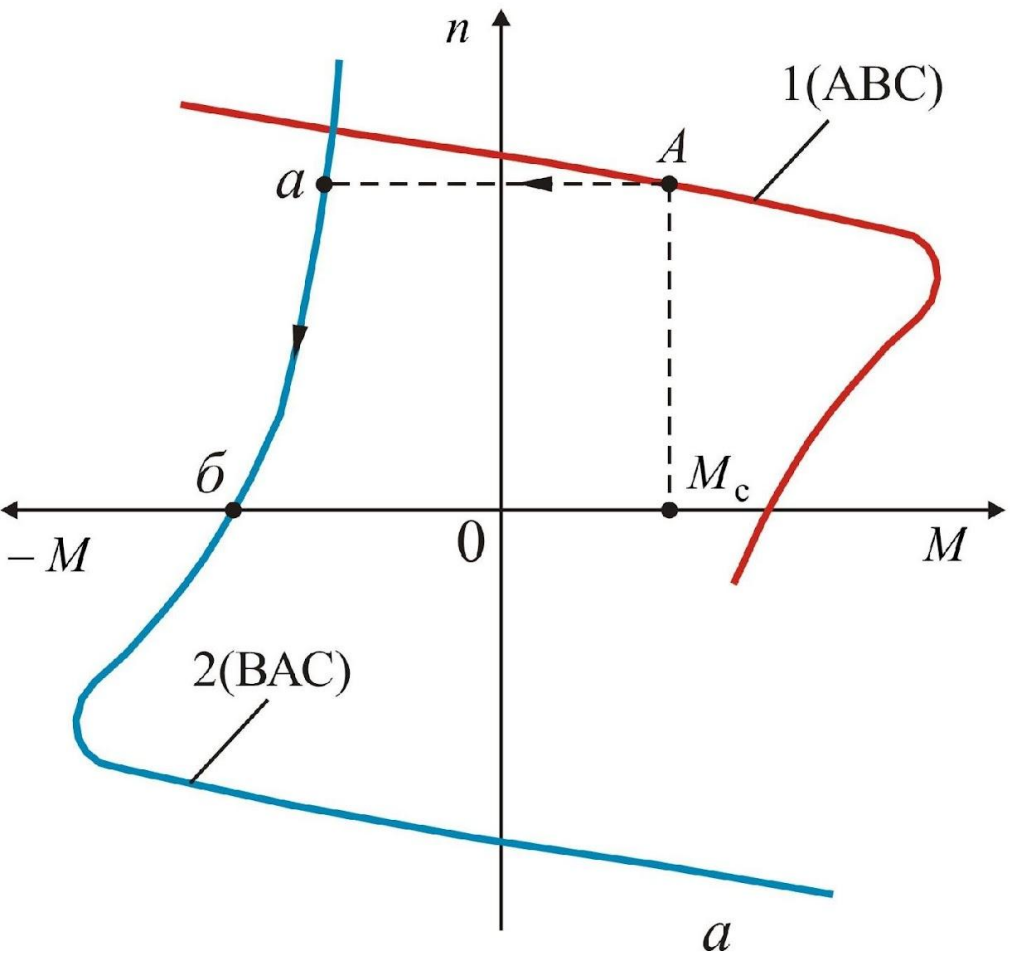
а

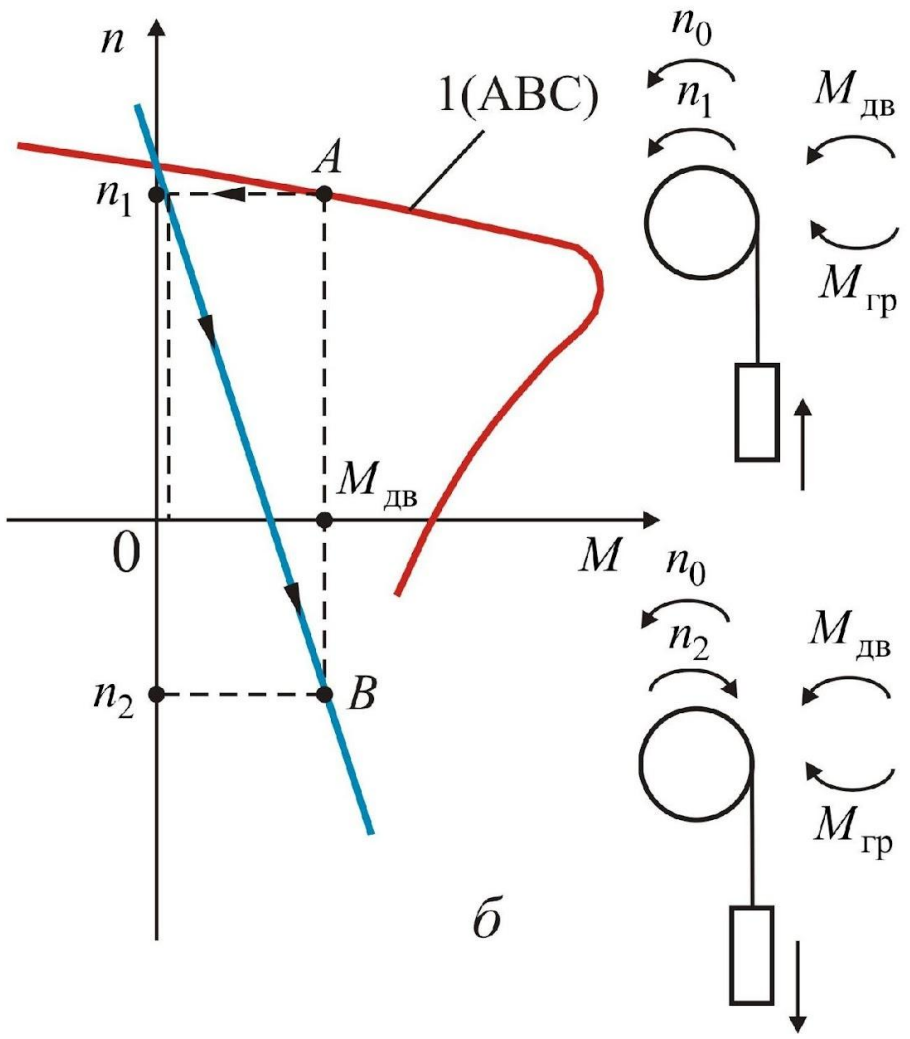


б

$$M_{тр} = M_{гр1} + M_1. \qquad M_{тр} = \text{const}. \qquad M_{гр2} > M_{гр1}. \qquad M_2 = (M_{тр} - M_{гр2}) < 0$$

Торможение противовключением





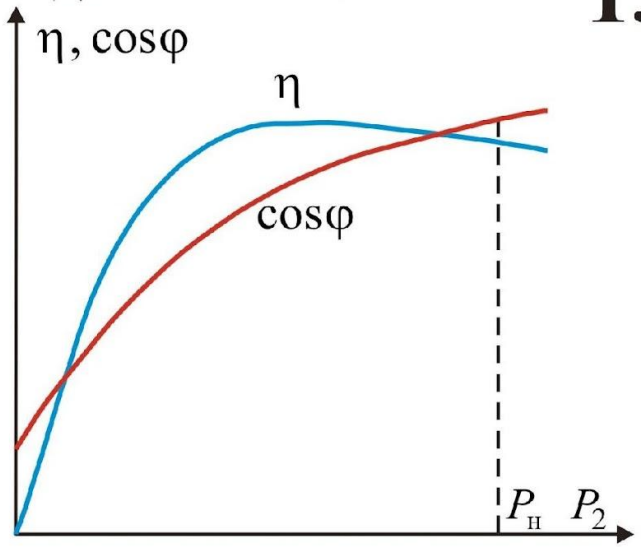
Энергетические показатели асинхронных двигателей

η
cosφ

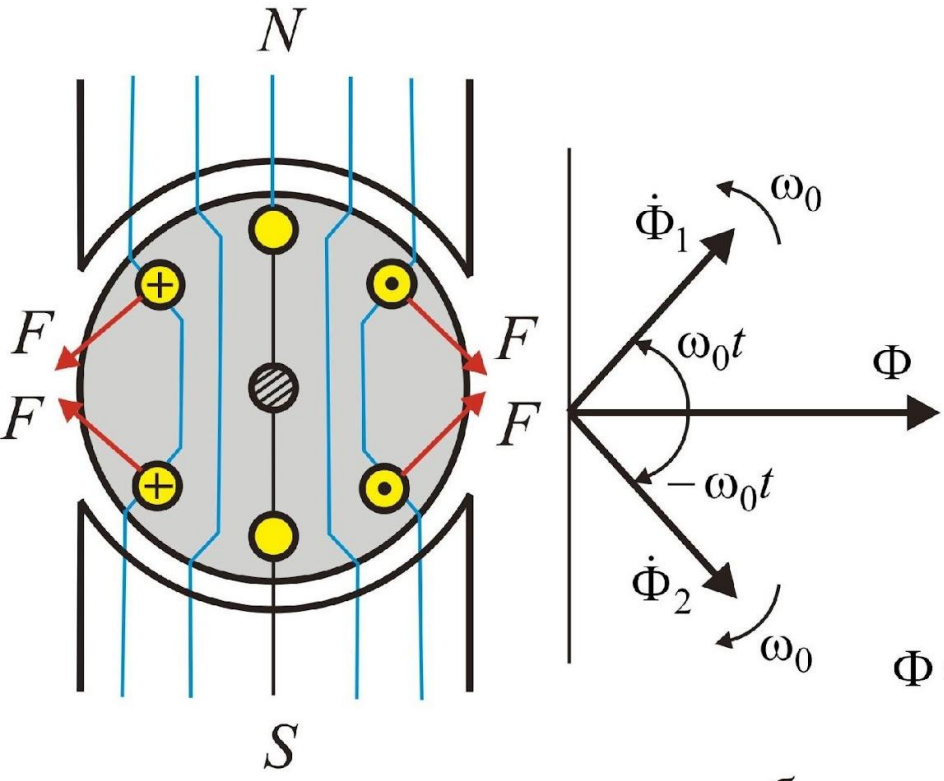
$$\eta(P_2) = \frac{P_2}{P_1} = \frac{P_2}{P_2 + \Delta P_c + \Delta P_{обм}};$$

$$\cos\varphi(P_2) = \frac{P_1}{S_1} = \frac{P_1}{\sqrt{P_1^2 + Q_1^2}} = \frac{P_2 + \Delta P_c + \Delta P_{обм}}{\sqrt{(P_2 + \Delta P_c + \Delta P_{обм})^2 + Q_1^2}}.$$

$$\Delta P_{обм} = 3I_1^2 r_1 + 3I_2^2 r_2$$



Однофазные асинхронные двигатели



$$\Phi = \Phi_m \cdot \cos\omega_0 t.$$

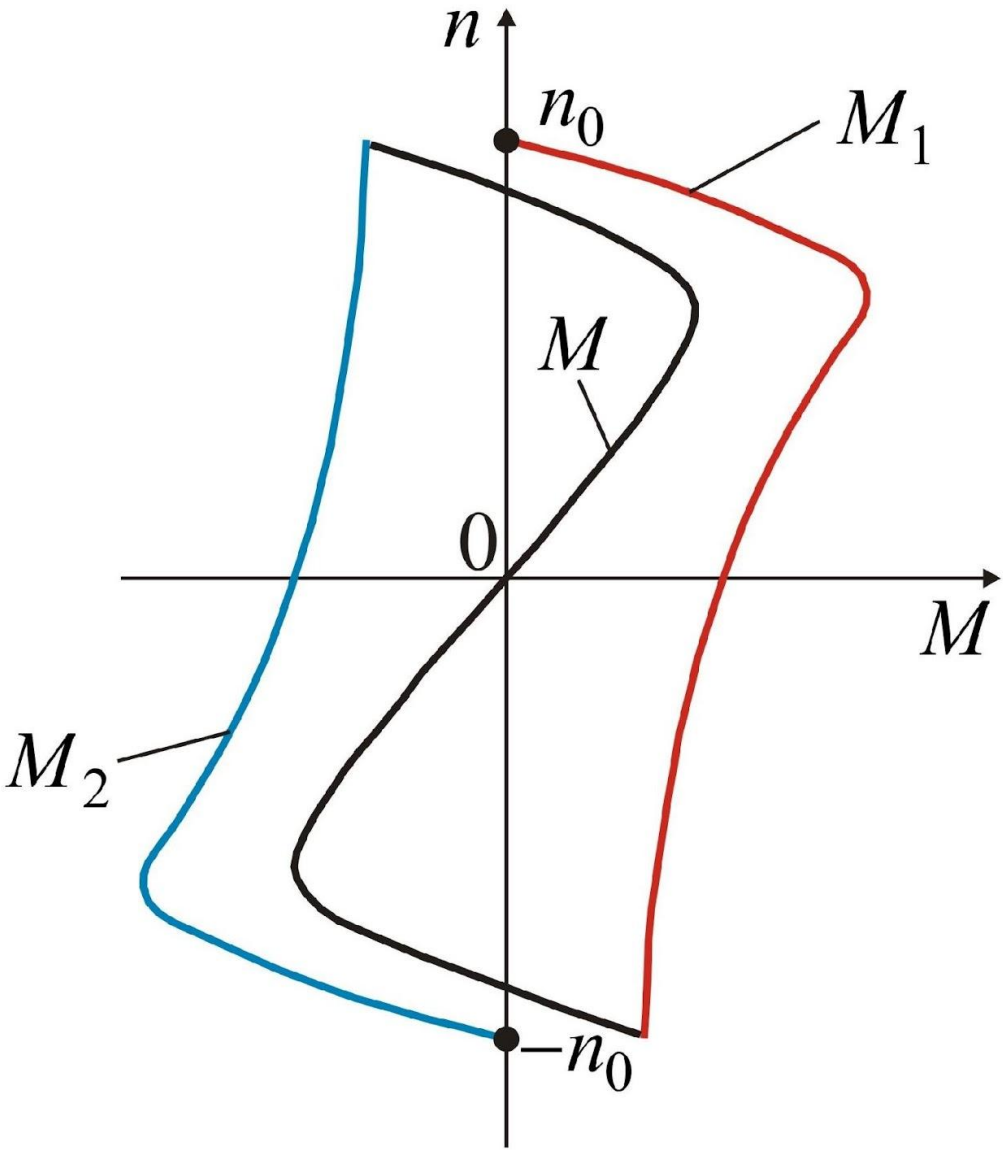
$$e^{j\omega t} = \cos\omega t + j\sin\omega t;\ e^{-j\omega t} = \cos\omega t - j\sin\omega t \Rightarrow$$

$$\Rightarrow \cos\omega t = \frac{e^{j\omega t} + e^{-j\omega t}}{2}.$$

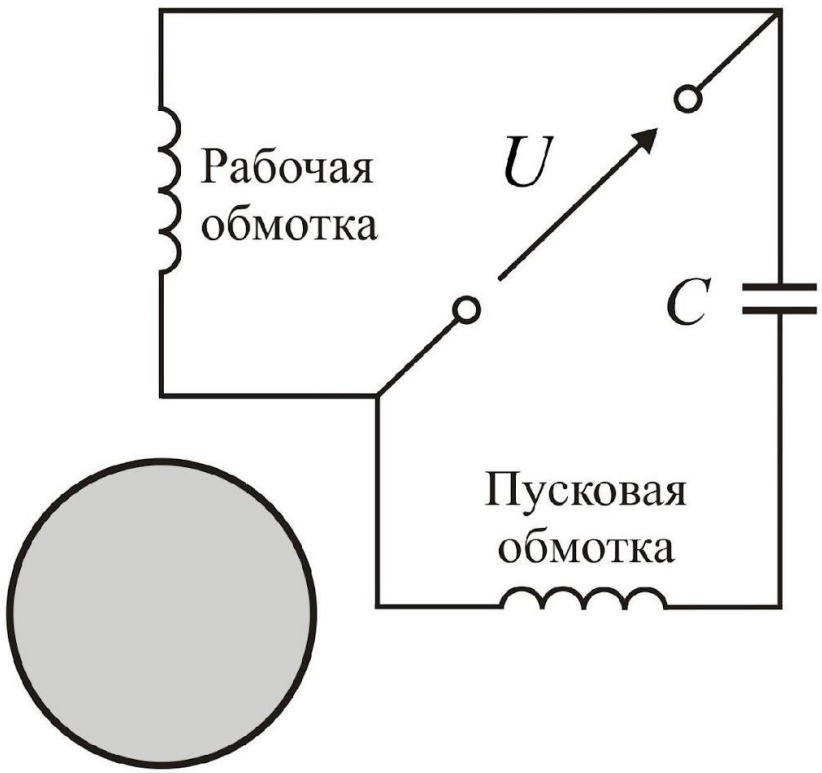
$$\Phi = \Phi_m \cdot \cos\omega_0 t = \frac{\Phi_m}{2} \cdot e^{j\omega_0 t} + \frac{\Phi_m}{2} \cdot e^{-j\omega_0 t} = \dot{\Phi}_1 + \dot{\Phi}_2,$$

б

Механическая характеристика однофазного двигателя



а



б