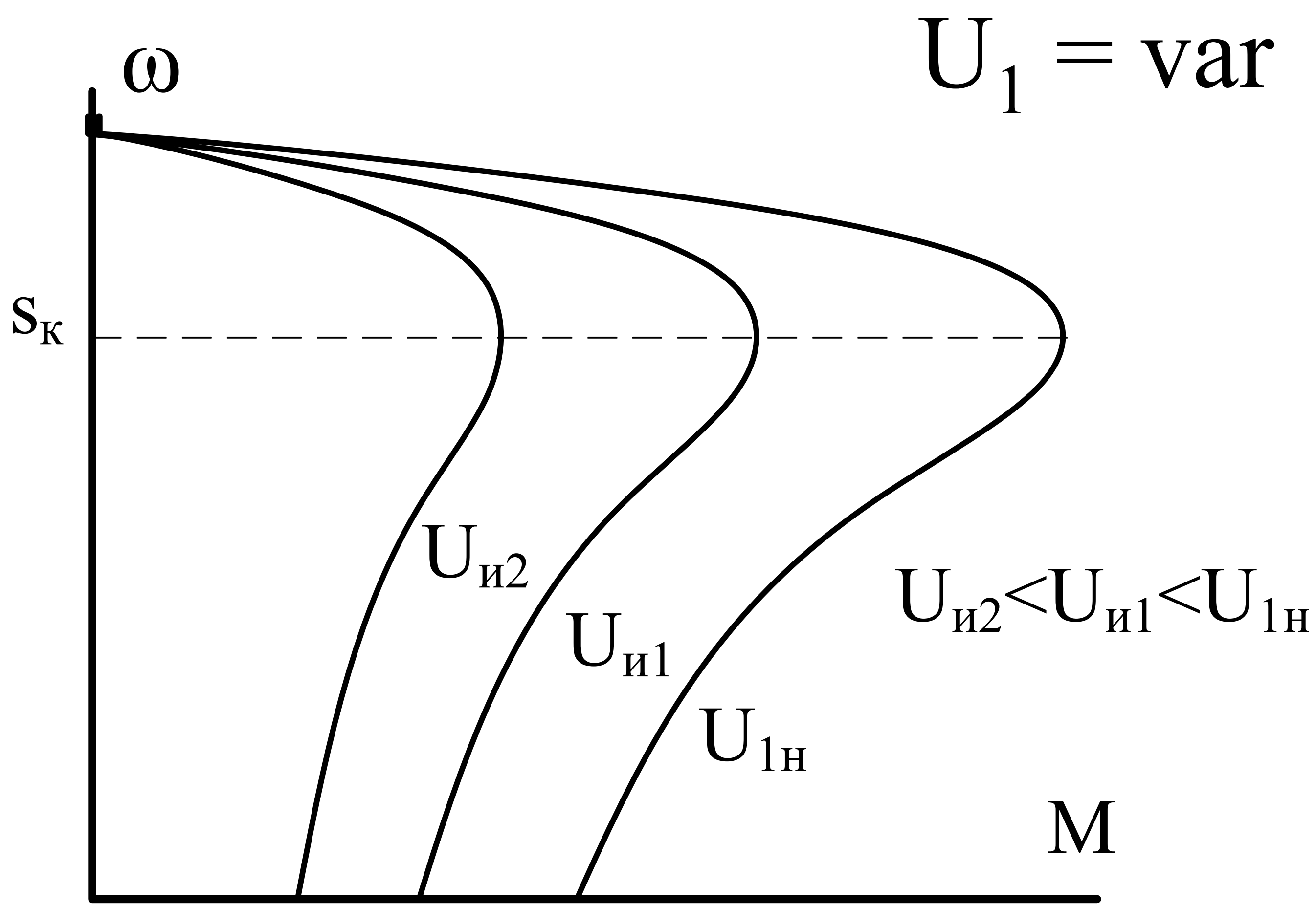
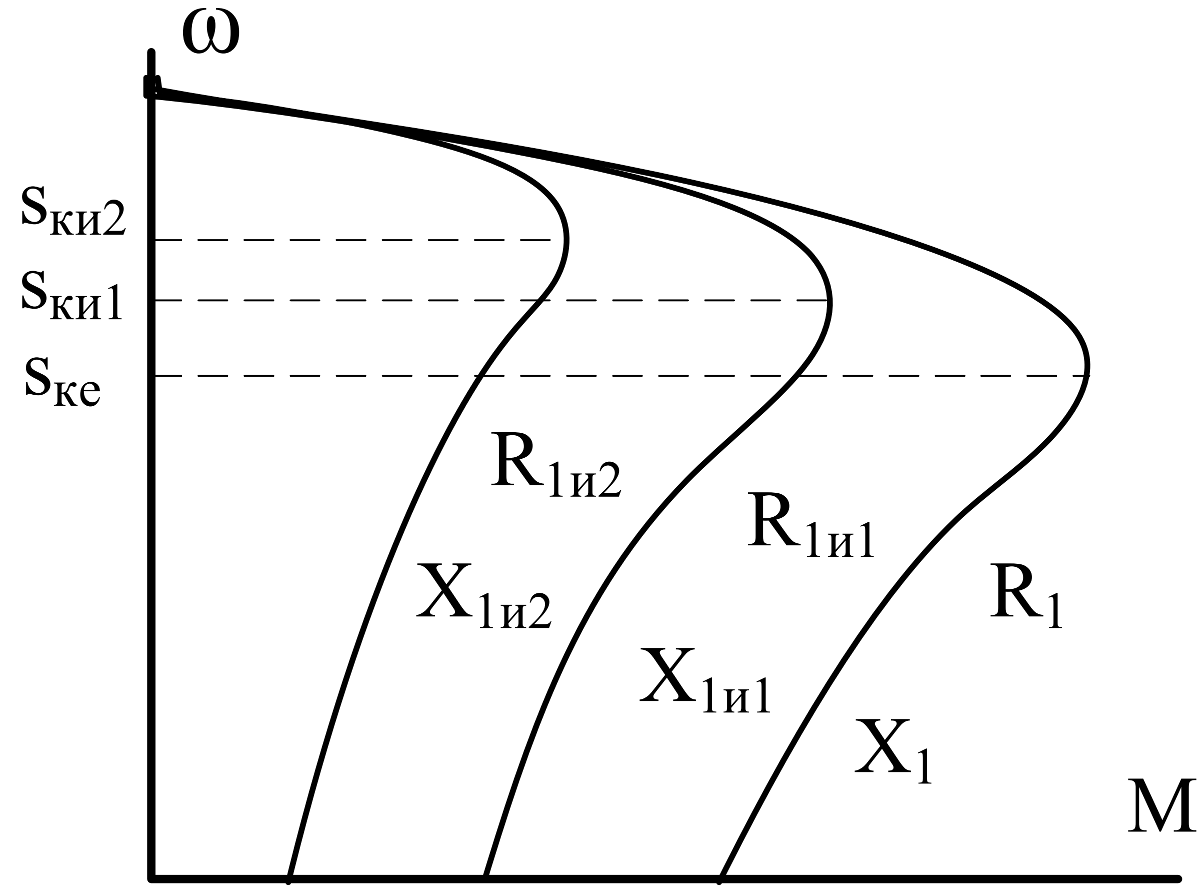
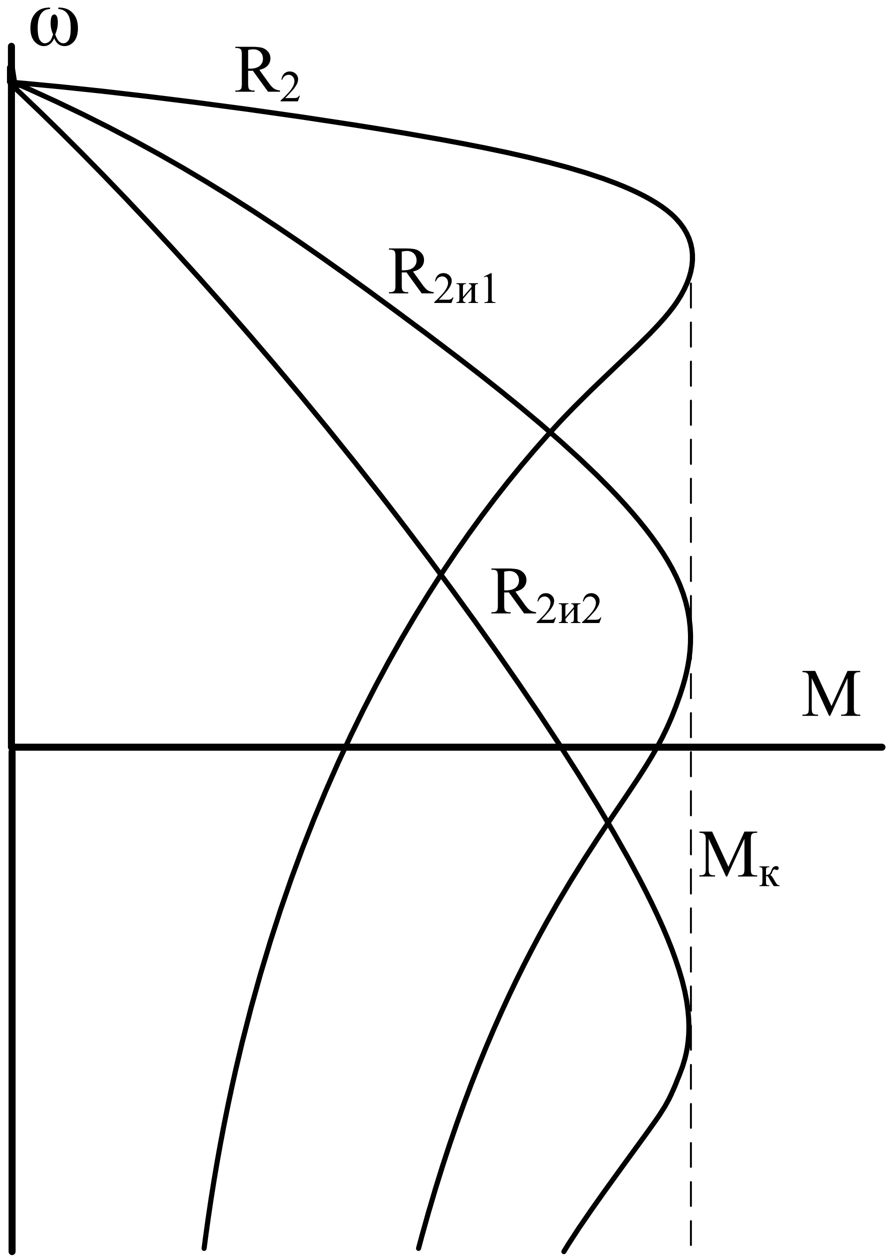
Регулирование частоты вращения вала АД



$R_1 = var, X_1 = var$



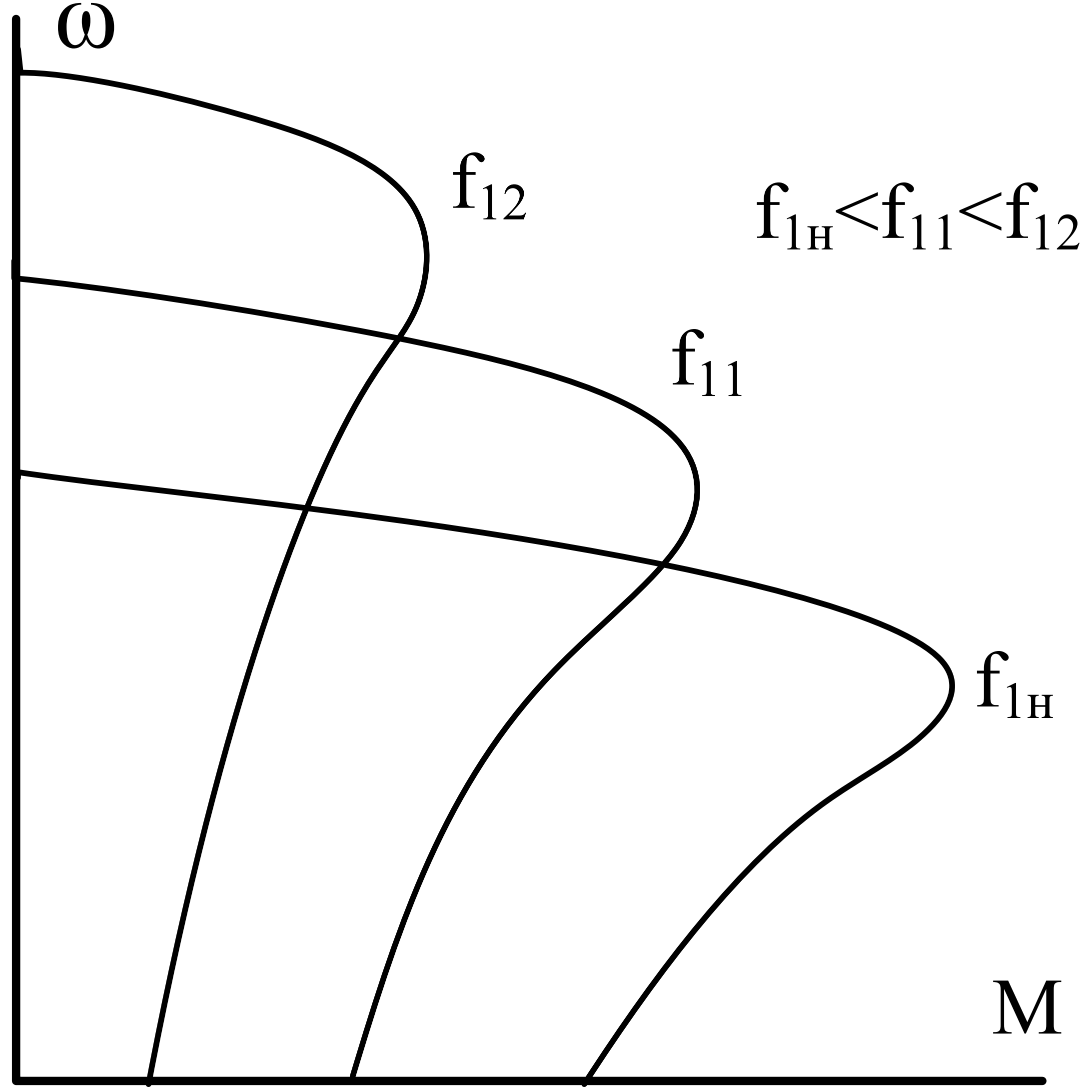
$R_{1и2} > R_{1и1} > R_1$ $X_{1и2} > X_{1и1} > X_1$



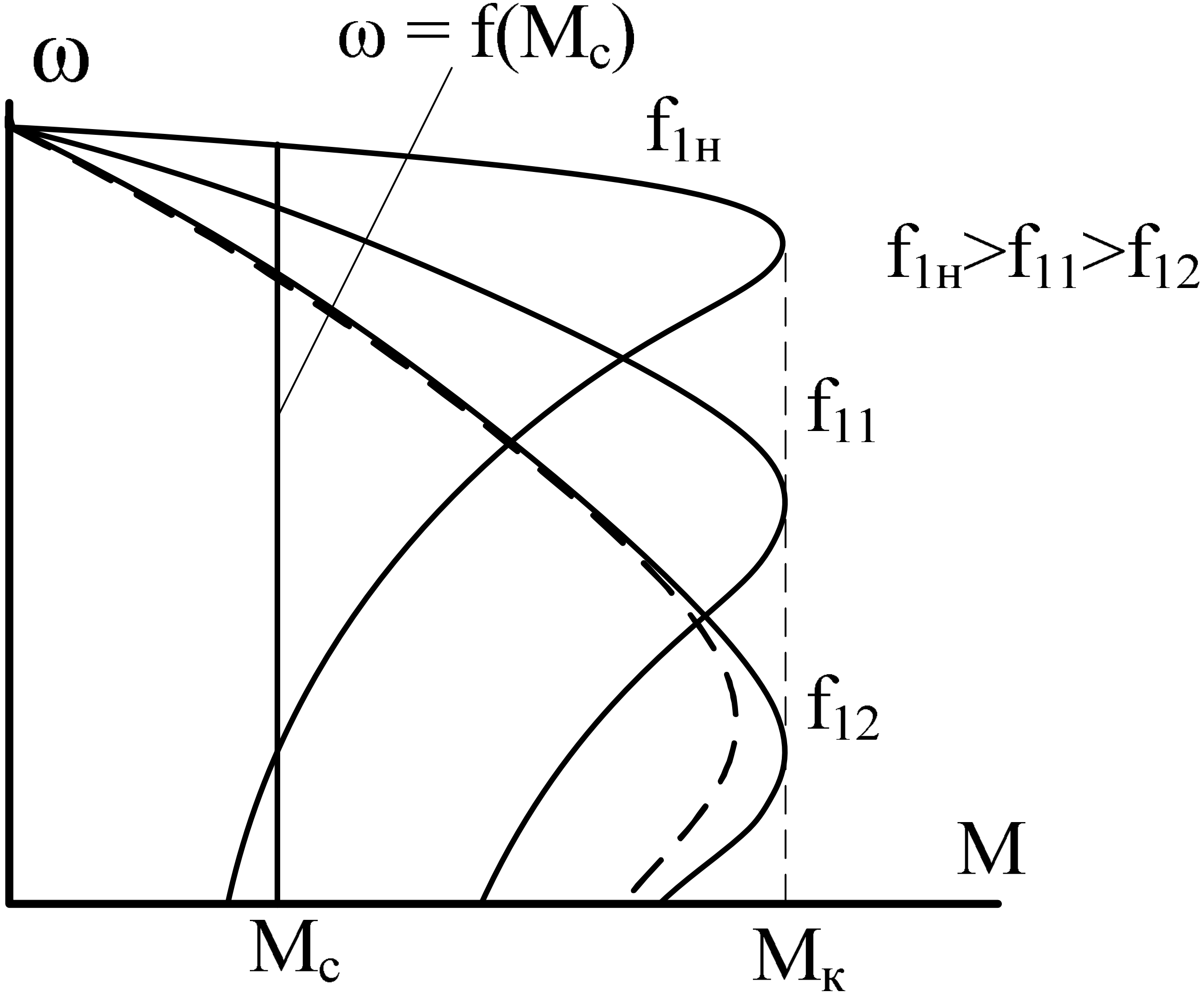
$R_2 = var$

$R_2 > R_{2и1} > R_{2и2}$

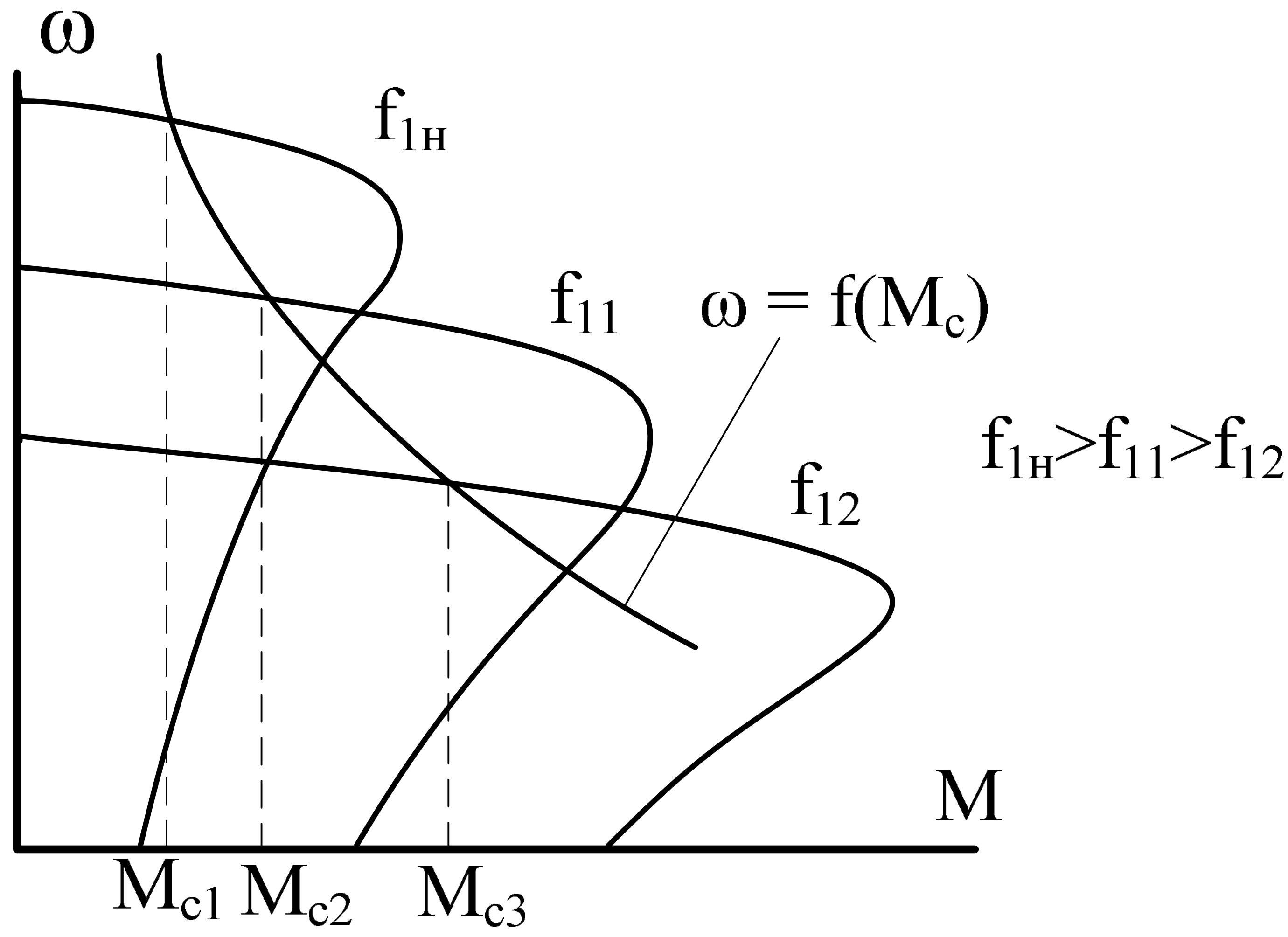
$f_1 = var$

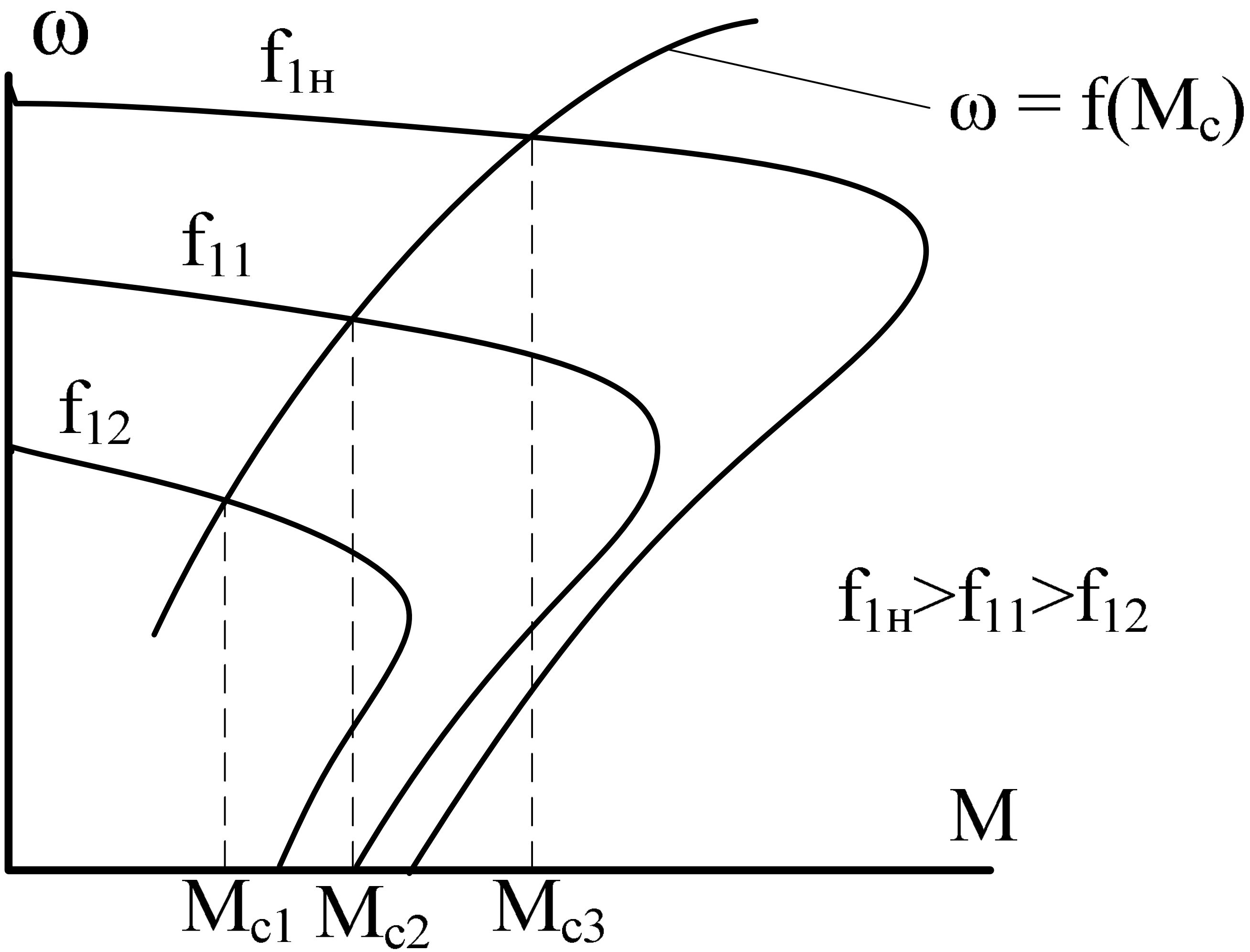


$$\frac{U_1}{f_1} = const \qquad M_c = const$$



$$\frac{U_1}{\sqrt{f_1}} = const \qquad P_c = const$$




ω
f1н
ω = f(Mc)
f11
f12
f1н>f11>f12
M
Mc1
Mc2
Mc3

$$\Delta P_2 = M\omega_0 S$$

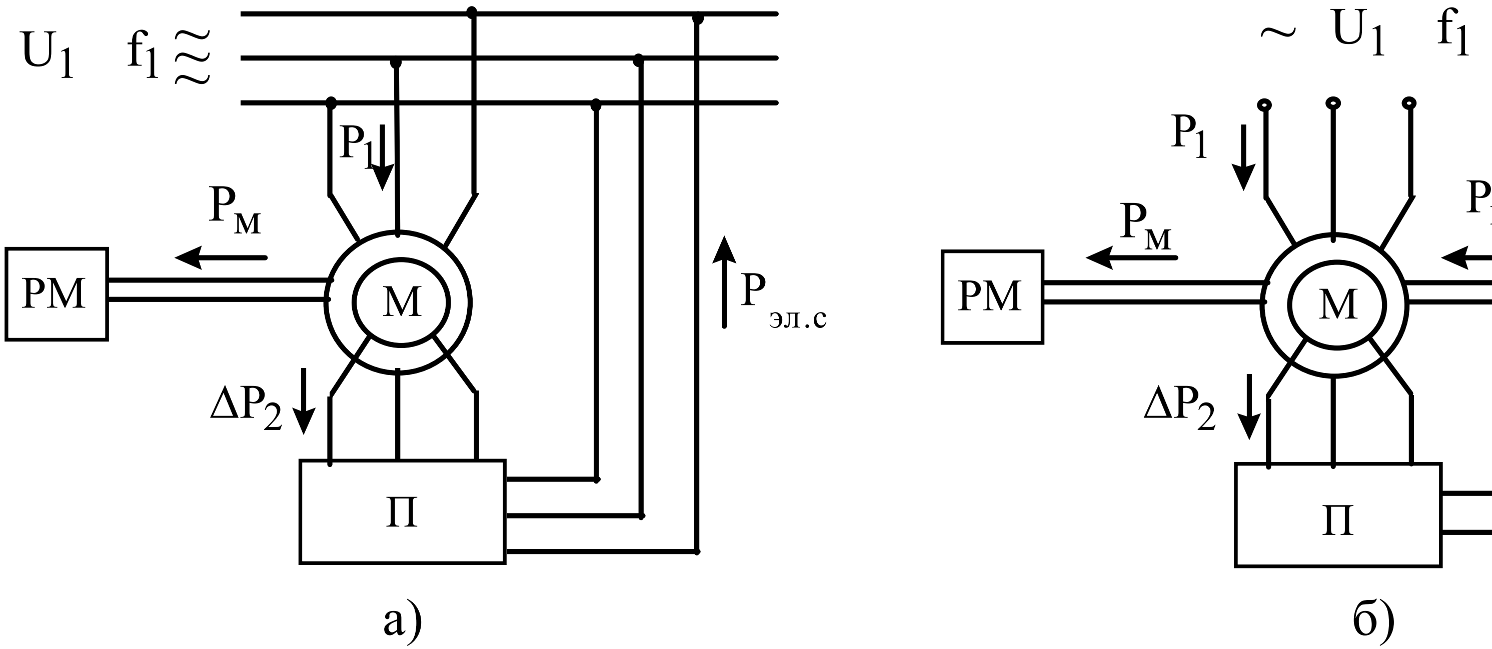


Рис. 3.42

$$P_{эл.с.} = \Delta P_2 - \Delta P_{2эл.} - \Delta P_n$$

$$P_{вм} = \Delta P_2 - \Delta P_n - \Delta P_{2эл.} - \Delta P_{вм}$$

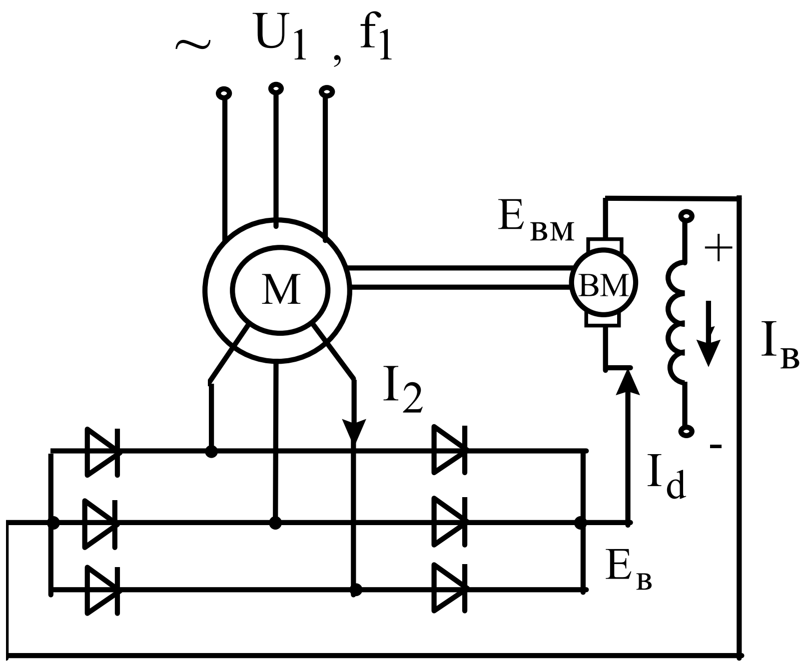


Рис. 3.43

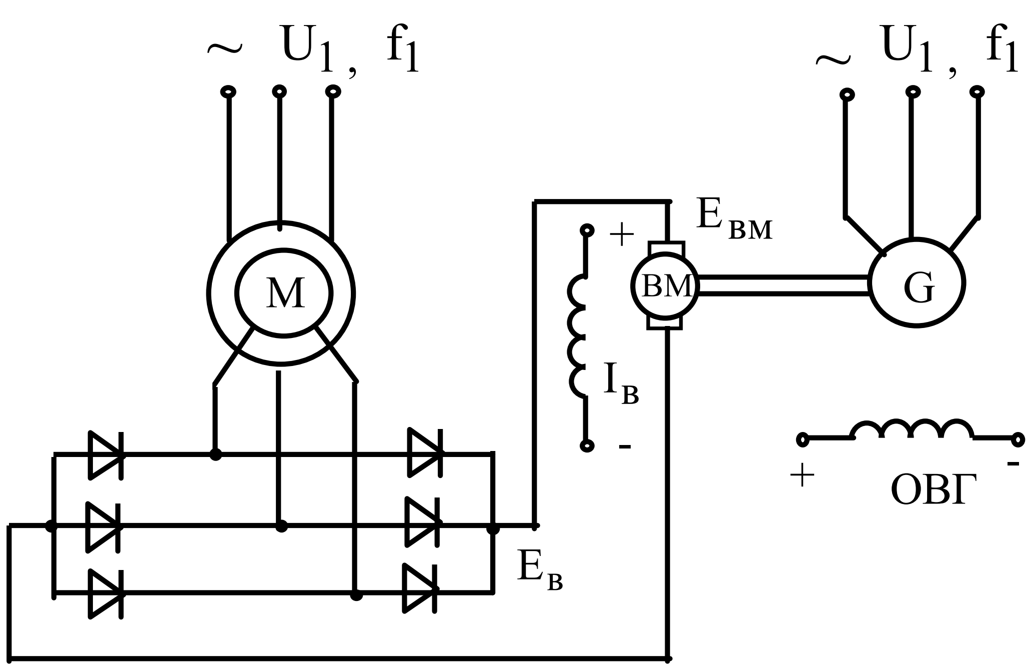
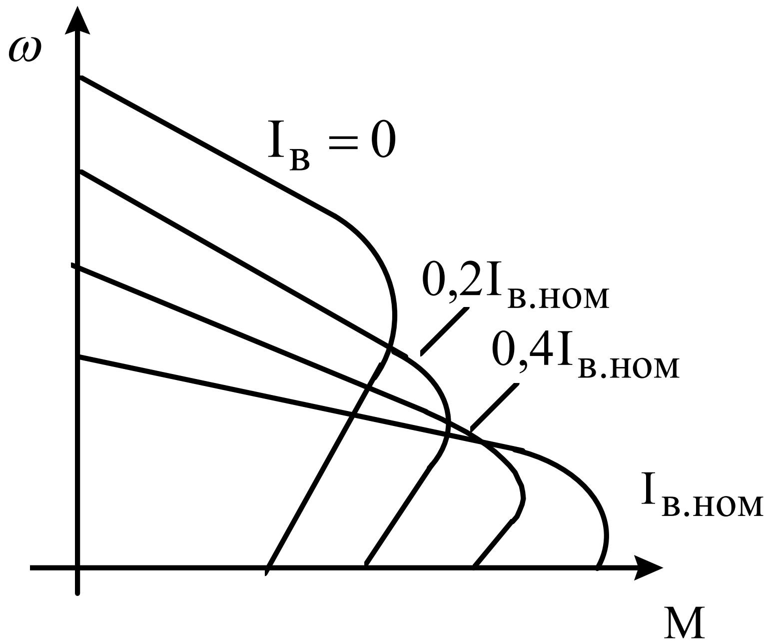


Рис. 3.44

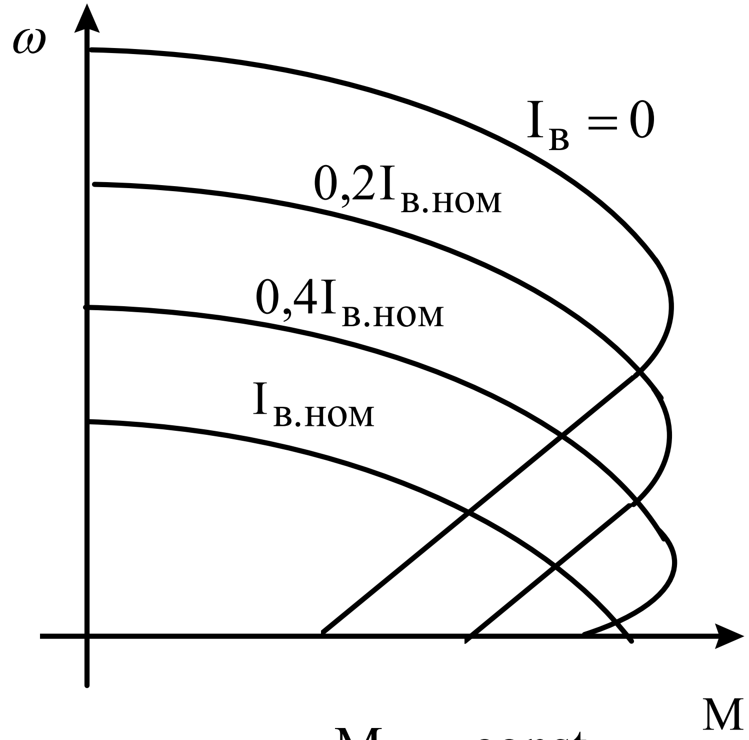
$$I_d = \frac{E_в - E_{вм}}{R_\Sigma}$$



$P_м = M_к \cdot \omega = const$

Каскад постоянной мощности

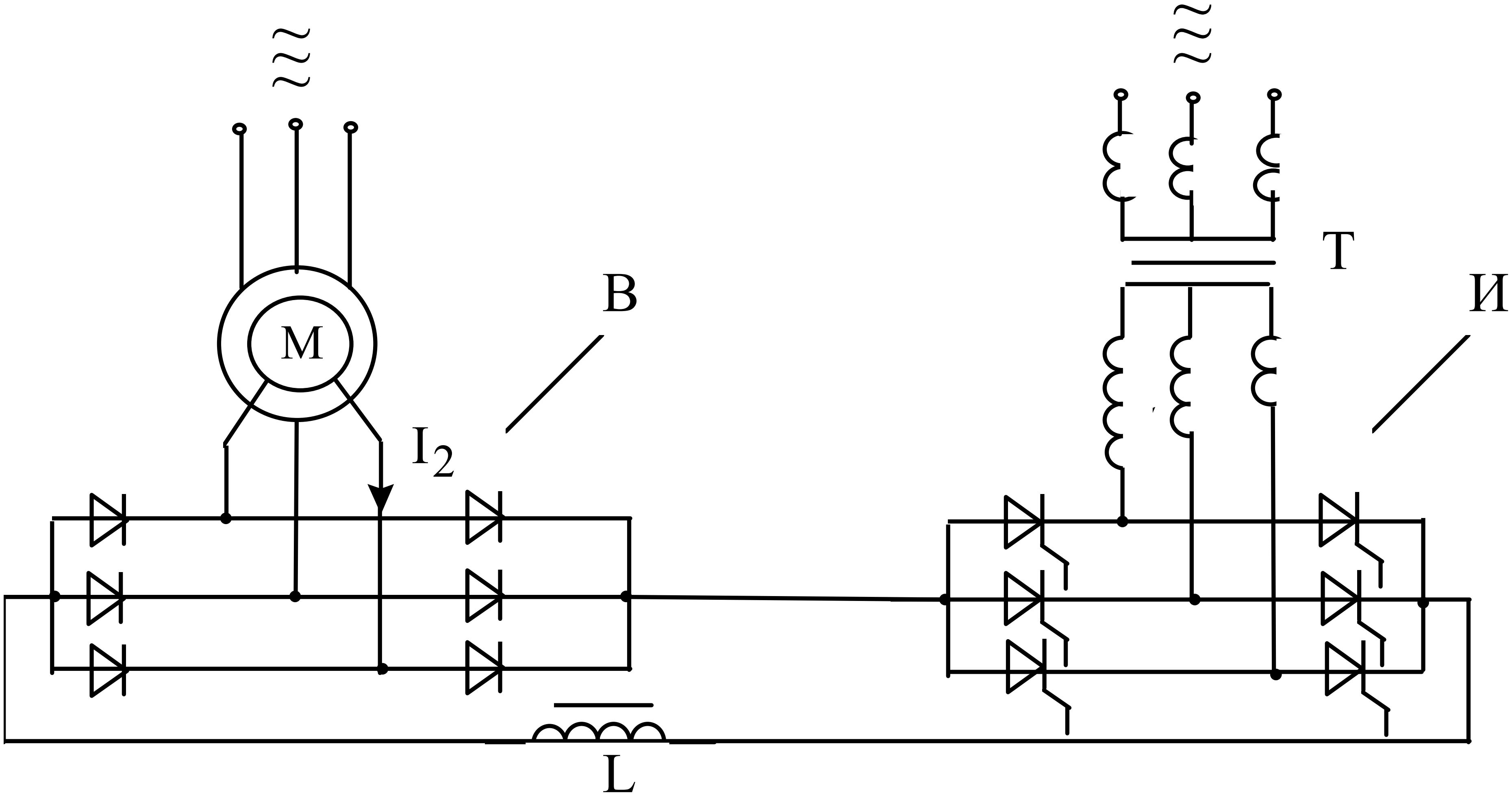
Рис. 3.45



$M_к = const$

Каскад постояного момента

Рис. 3.46



Асинхронно-вентильный каскад

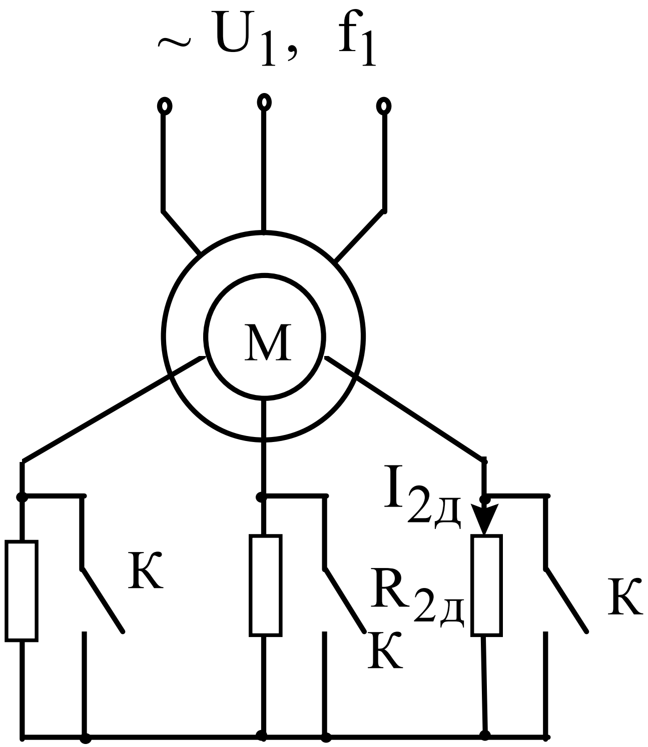


Рис. 3.48

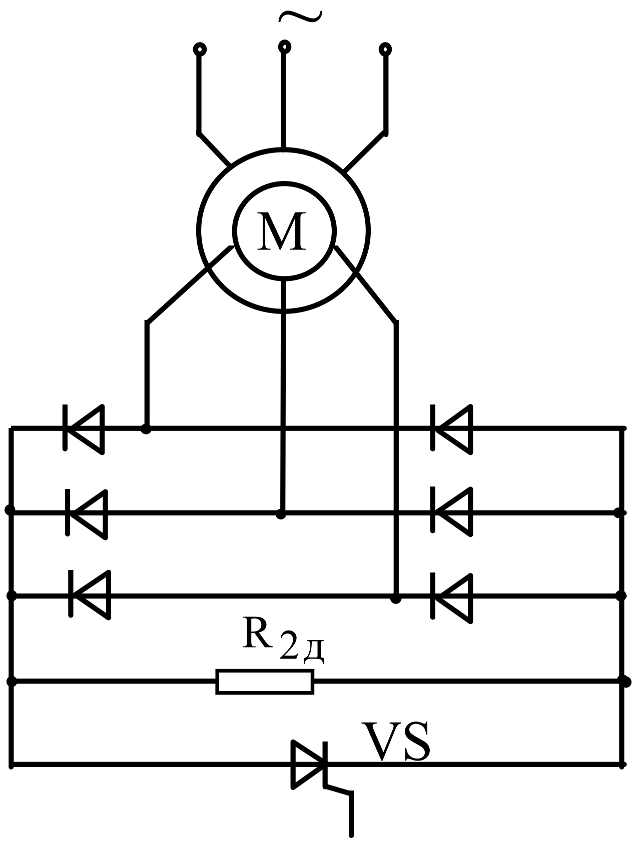
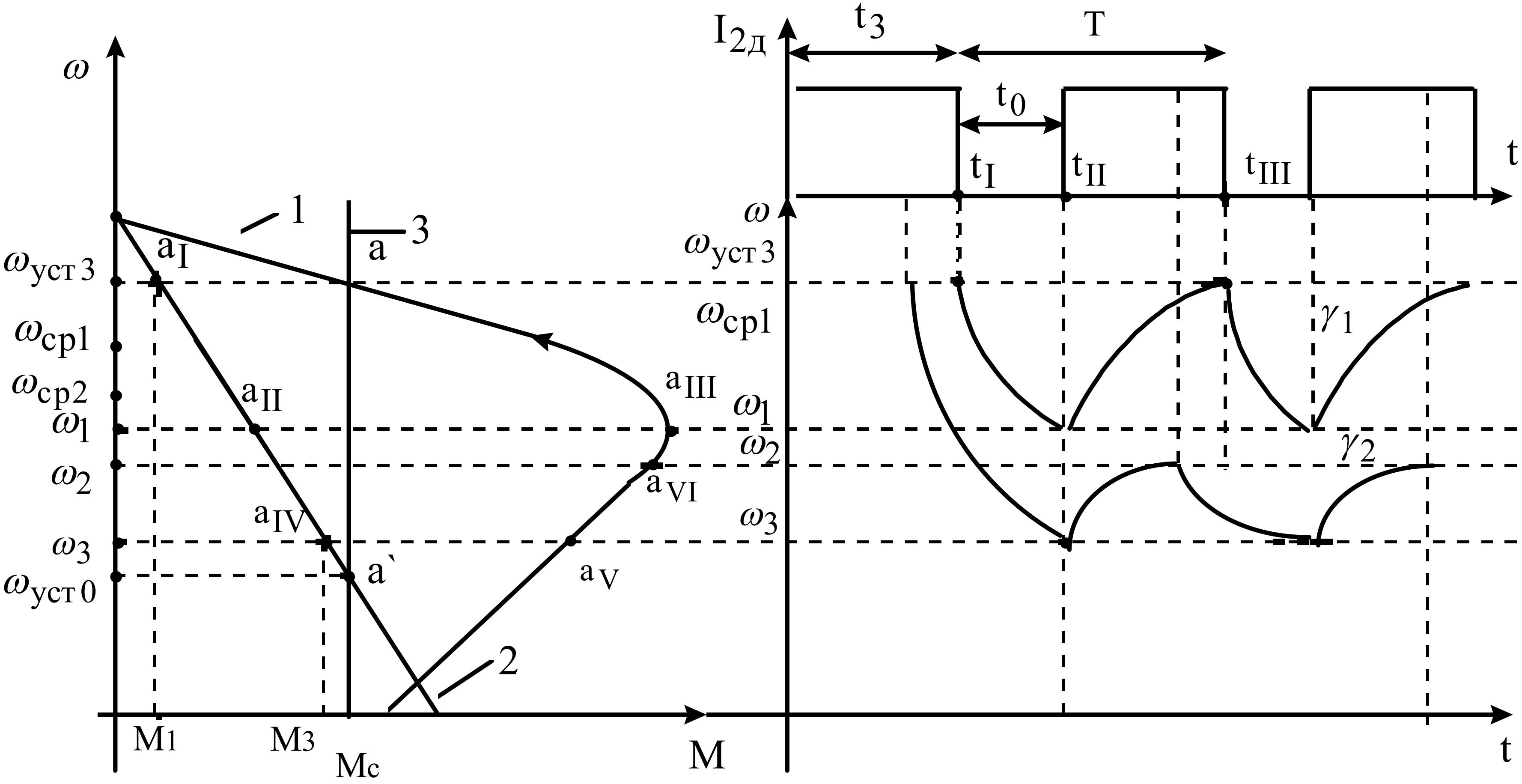


Рис. 3.50



ω
ω_уст 3
ω_ср1
ω_ср2
ω_1
ω_2
ω_3
ω_уст 0
1
3
a
a_I
a_II
a_III
a_IV
a_V
a_VI
a`
2
M1
M3
Mс
M
I_2д
t_3
T
t_0
t_I
t_II
t_III
t
γ_1
γ_2

Рис. 3.49

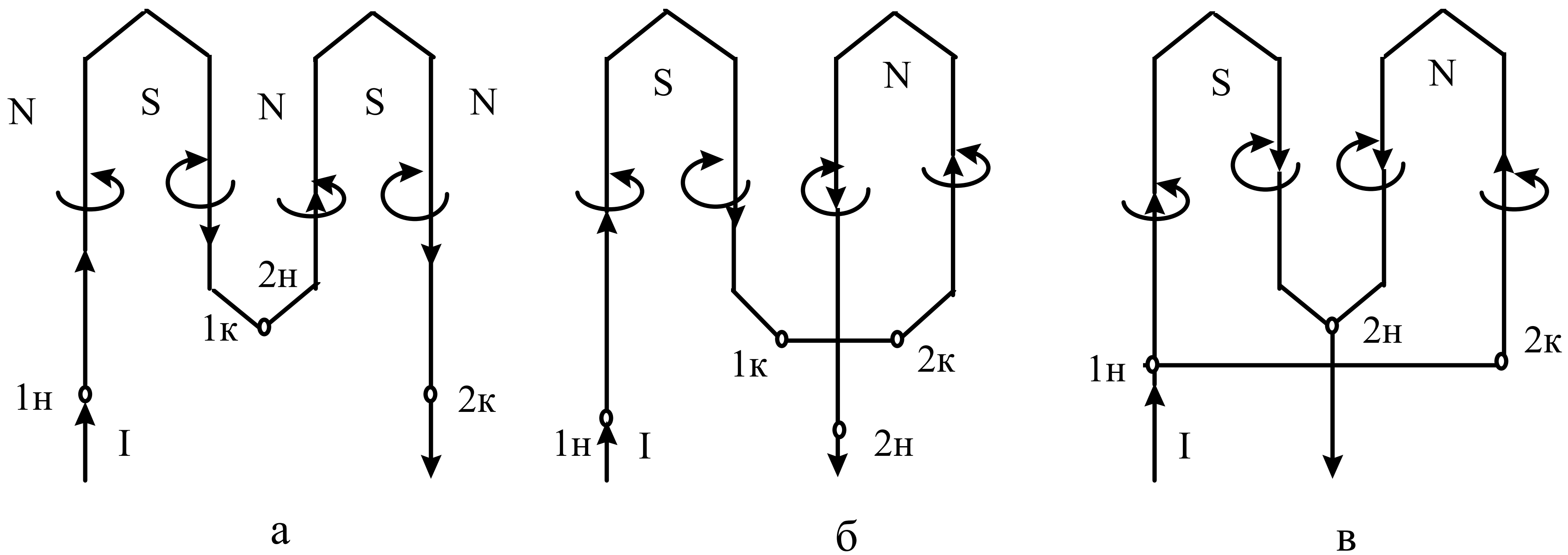
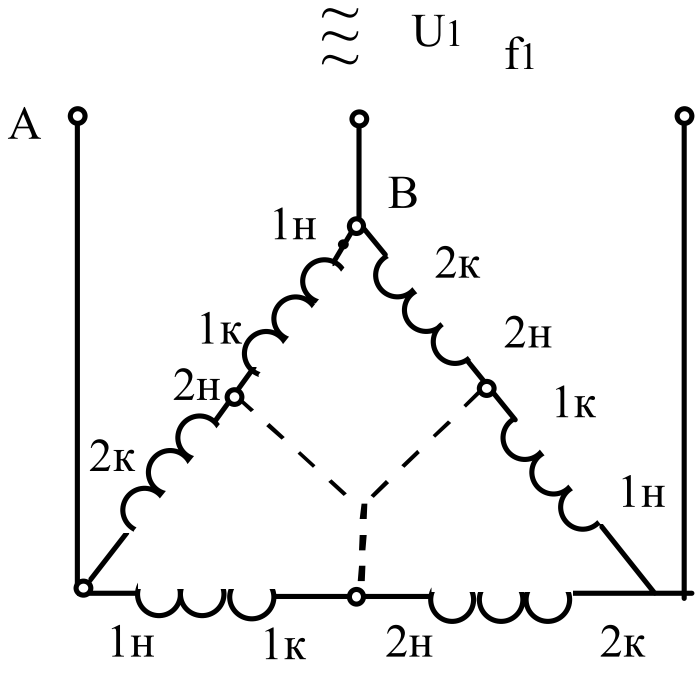
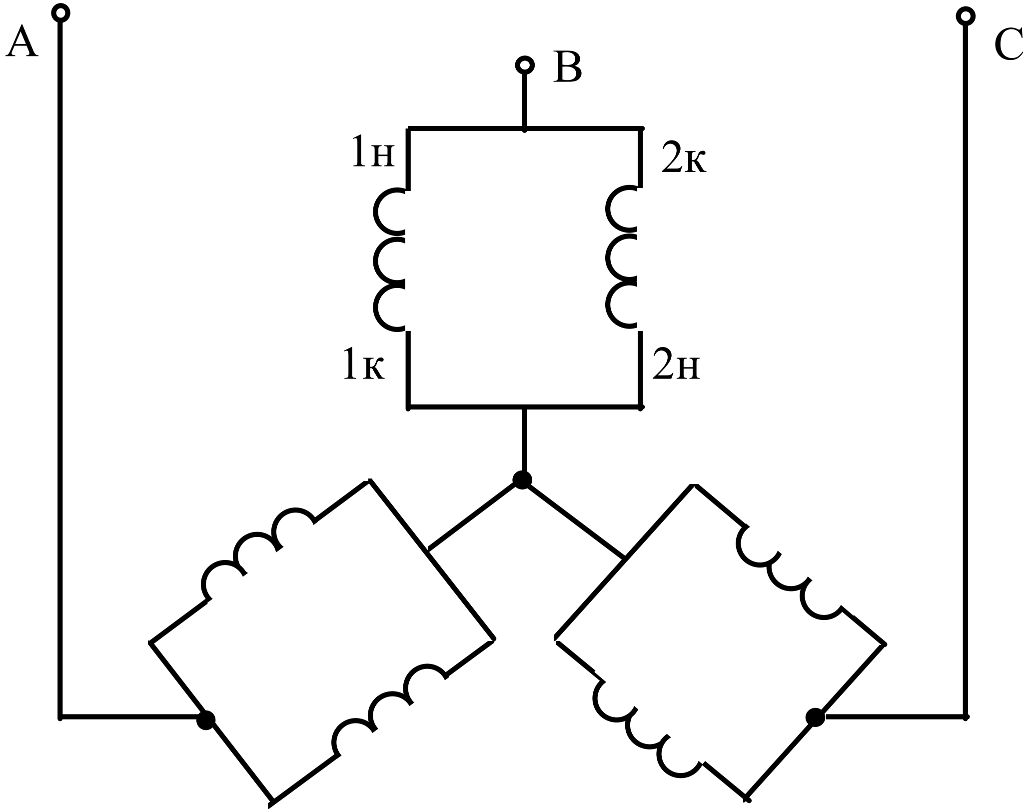
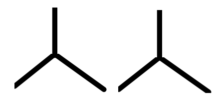


Рис. 3.10



Δ





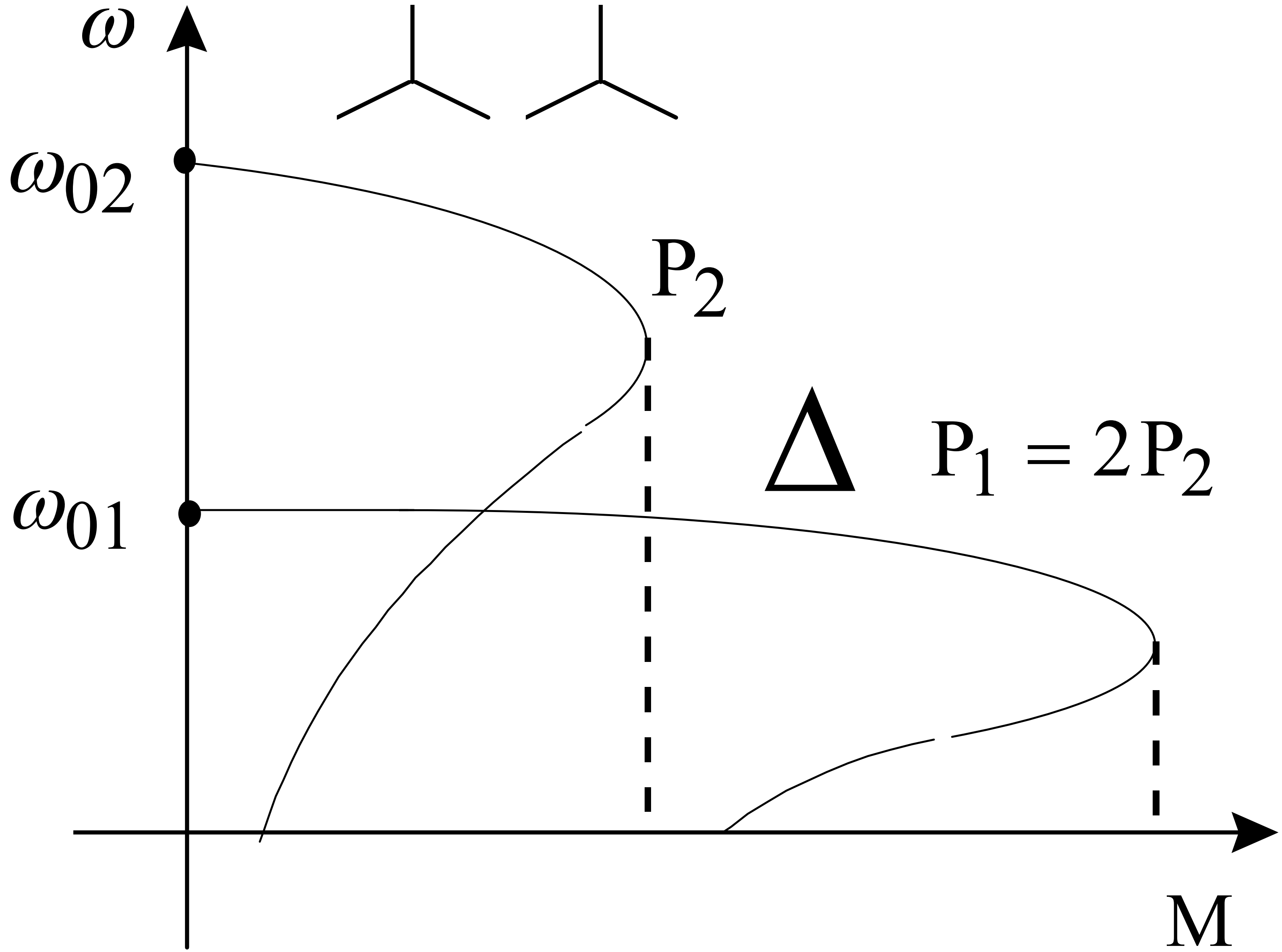


Рис. 3.12

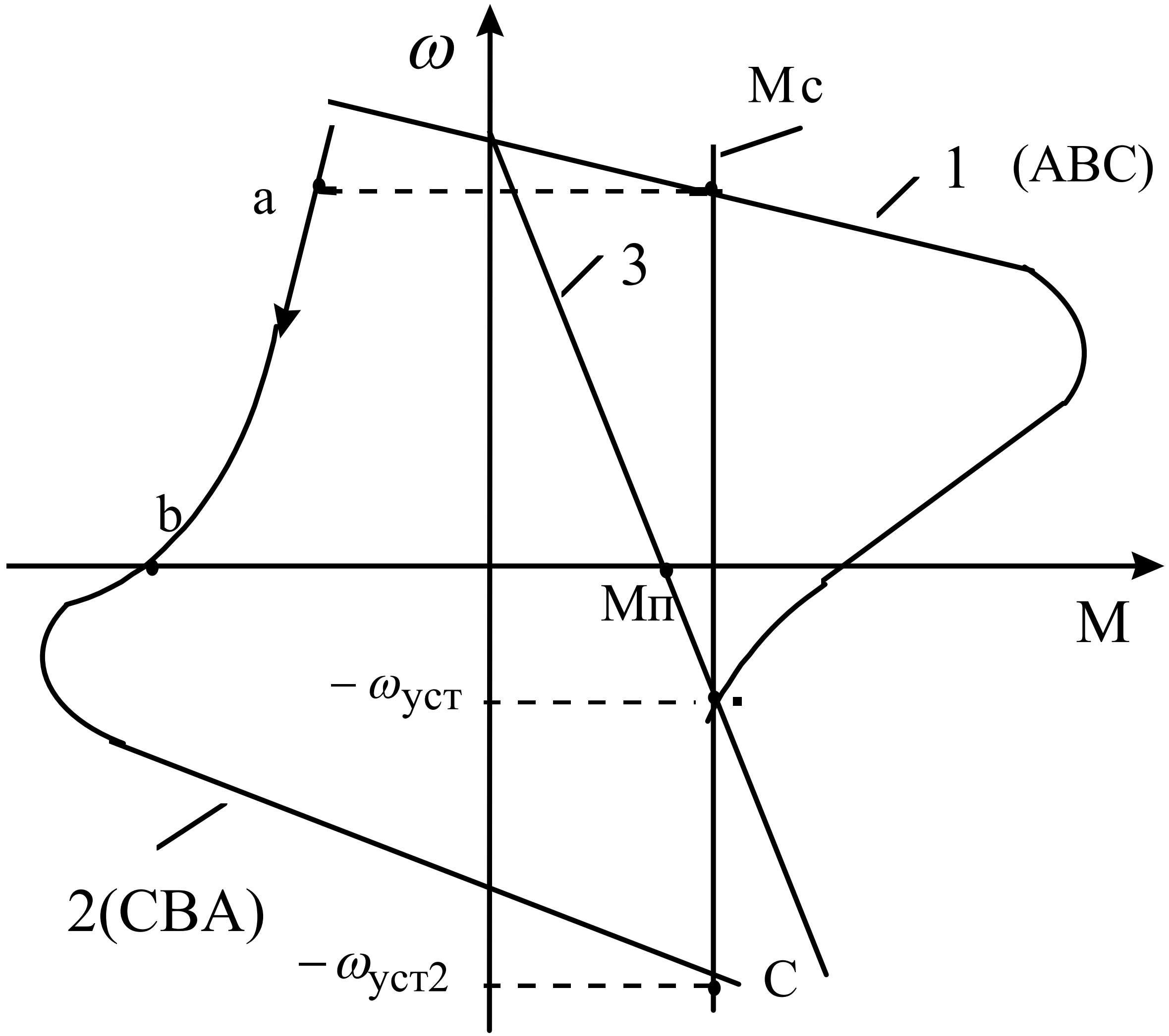


Рис. 3.51

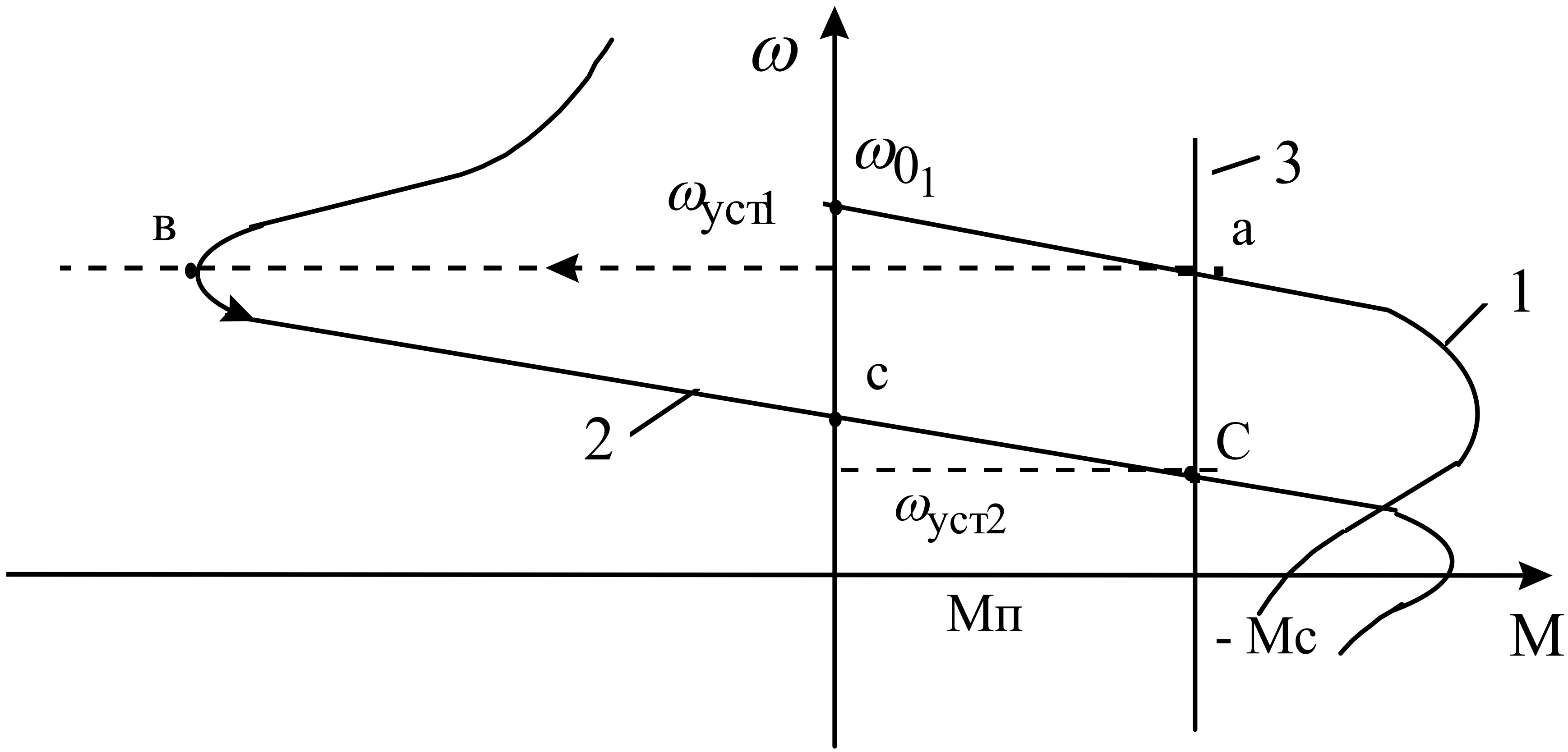


Рис. 3.52

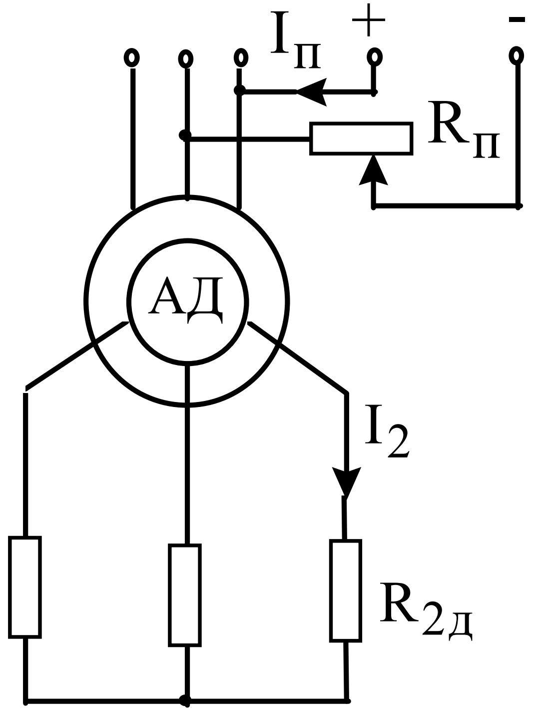


Рис. 3.53

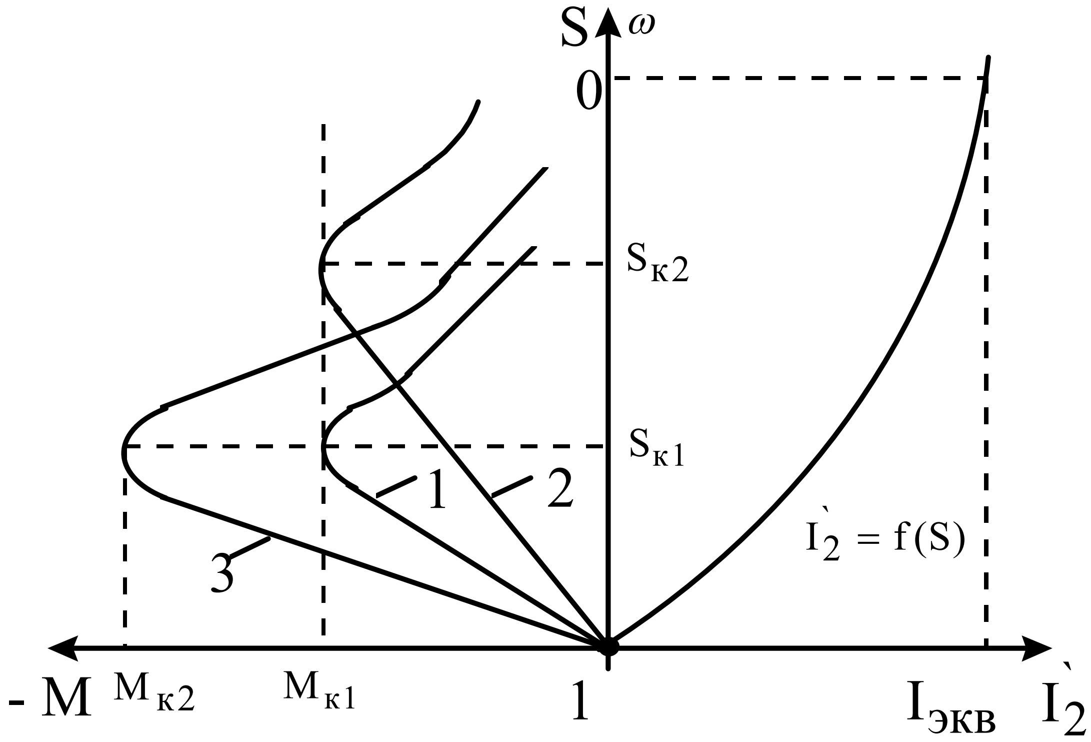


Рис. 3.55

Синхронный двигатель

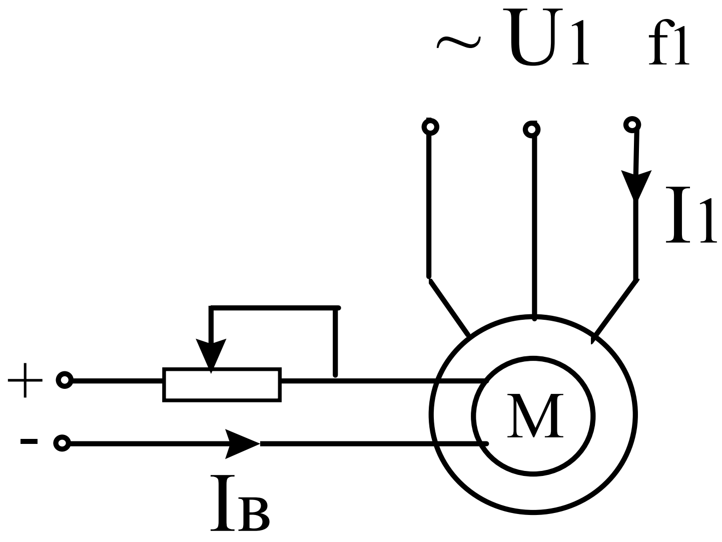


Рис. 4.1

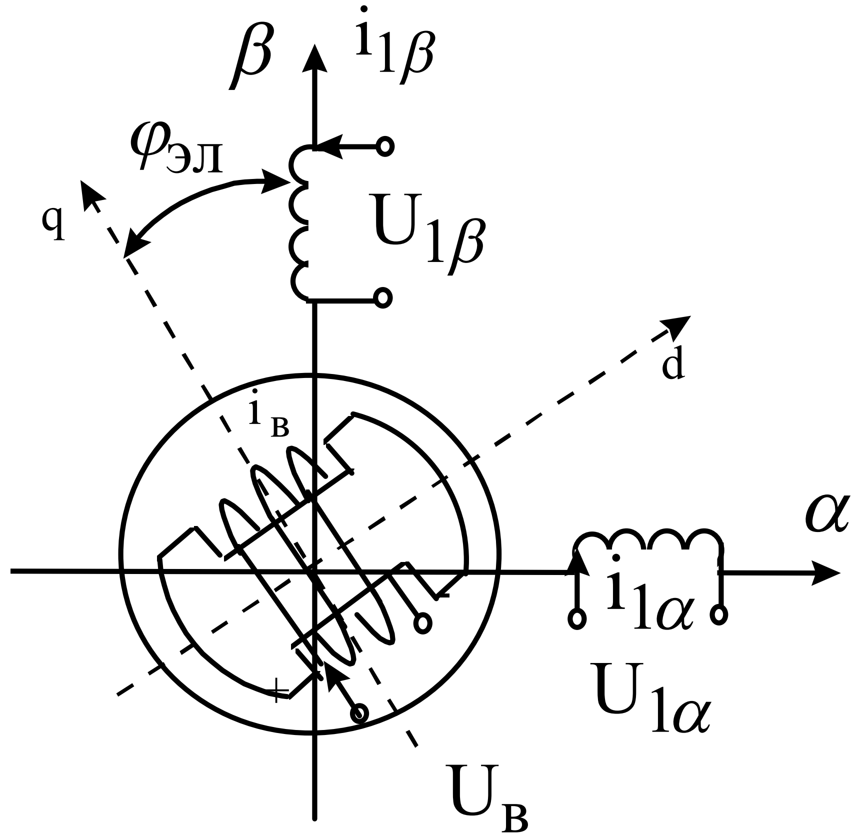


Рис. 4.2

$$
\begin{aligned}
U_{1\alpha} &= U_{1\max} \cdot \sin(\omega_{0\,эл} t), \\
U_{1\beta} &= U_{1\max} \cdot \sin(\omega_{0\,эл} t - \pi / 2),
\end{aligned}
\qquad (1)
$$

$$
\begin{cases}
\mathrm{U}_{1\alpha} = \mathrm{R}_1 \mathrm{i}_{1\alpha} + \mathrm{d}\Psi_{1\alpha} / \mathrm{dt}, \\
\mathrm{U}_{1\beta} = \mathrm{R}_1 \mathrm{i}_{1\beta} + \mathrm{d}\Psi_{1\beta} / \mathrm{dt}, \\
\mathrm{U}_{\text{в}} = \mathrm{R}_{\text{в}} \mathrm{i}_{\text{в}} + \mathrm{d}\Psi_{\text{в}} / \mathrm{dt}.
\end{cases}
\qquad (2)
$$

$$\omega_0 = \frac{2\pi f_1}{P_n} = \text{const}$$

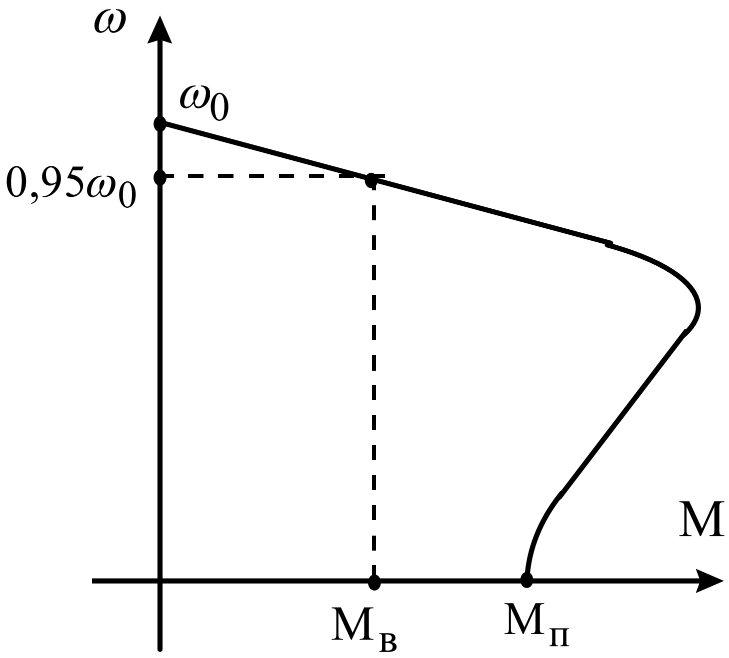


Рис. 4.3

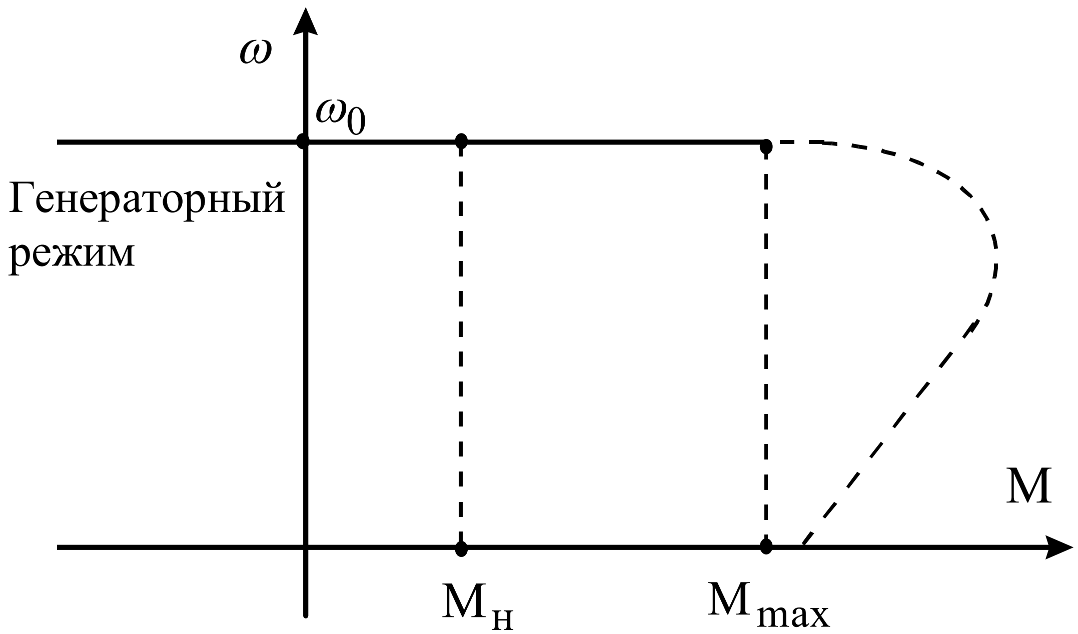
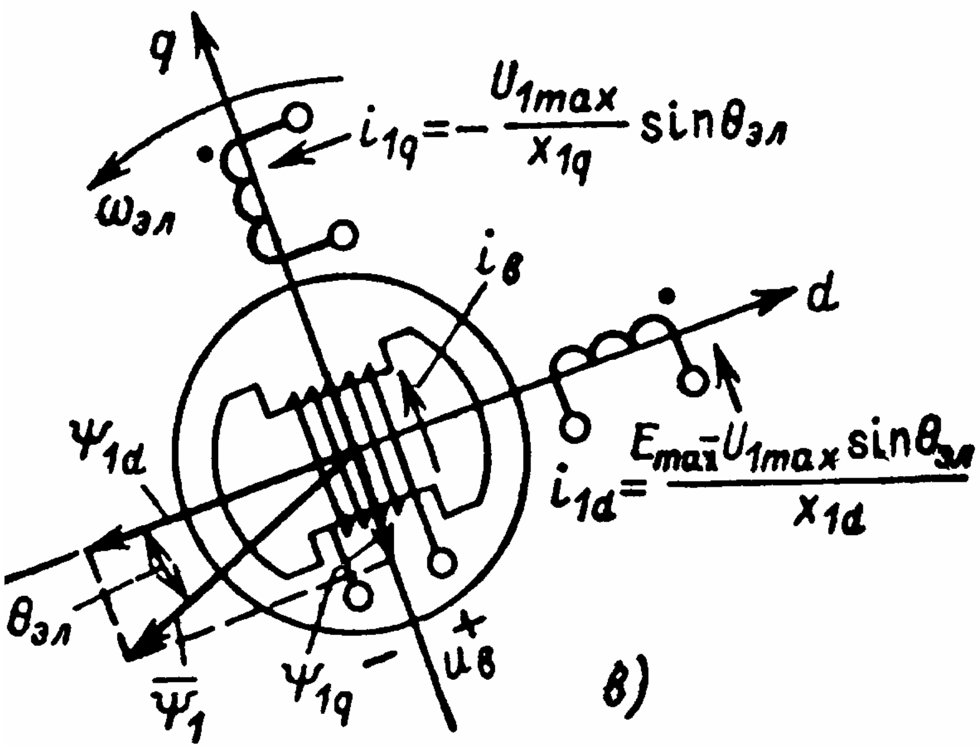


Рис. 4.4

$$\theta_{эл} = \varphi_{0эл} - \varphi_{эл} = \omega_{0эл} t - \varphi_{эл}$$

$$\begin{aligned} U_{1d} &= U_{1\alpha} \cdot \cos\varphi_{эл} + U_{1\beta} \cdot \sin\varphi_{эл} = U_{1\max} \sin\theta_{эл} \\ U_{1q} &= -U_{1\alpha} \cdot \sin\varphi_{эл} + U_{1\beta} \cdot \cos\varphi_{эл} = -U_{1\max} \cos\theta_{эл} \end{aligned} \quad (3)$$

$$\begin{cases} U_{1\max} Sin\theta_{эл} = R_1 i_{1d} + d\Psi_{1d} / dt - \omega_{эл} \Psi_{1q} \ ; \\ -U_{1\max} Cos\theta_{эл} = R_1 i_{1q} + d\Psi_{1q} / dt + \omega_{эл} \Psi_{1d} \ ; \\ U_{в} = R_{в} i_{в} + d\Psi_{в} / dt \ ; \\ M = P_n (\Psi_{1d} i_{1q} - \Psi_{1q} i_{1d}) \ . \end{cases} \quad (4)$$



$$L_{1d} \neq L_{1q} \quad \text{и} \quad L_{12d} \neq L_{12q} \;;$$

$$\begin{aligned} \Psi_{1d} &= L_{1d} \cdot i_{1d} + L_{12d} \cdot i_в; \\ \Psi_{1q} &= L_{1q} \cdot i_{1q}; \end{aligned} \qquad (5)$$

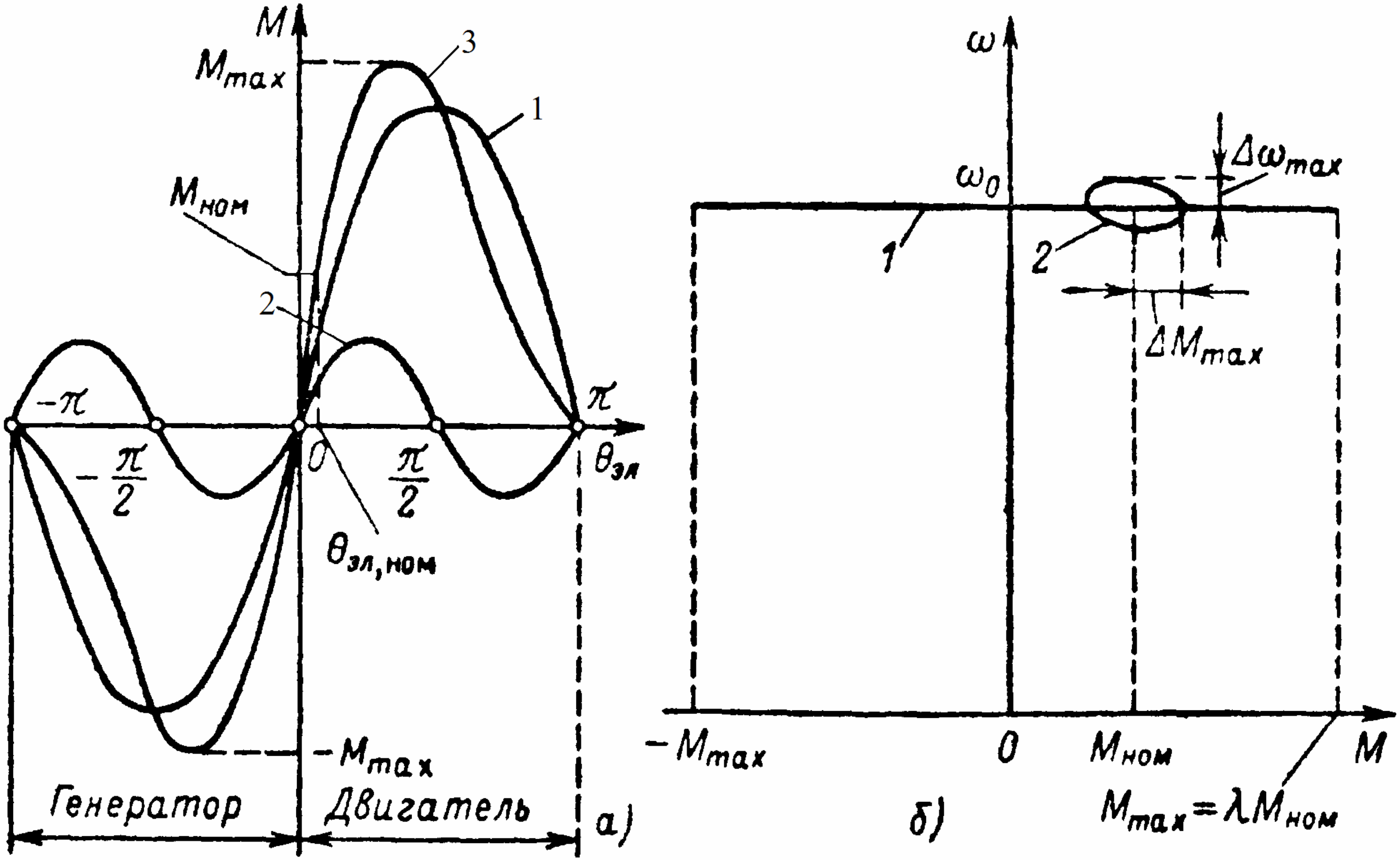
$$d/dt=0,\ \omega_{ЭЛ}=\omega_{0ЭЛ},\ R_1\approx 0,\ i_В=const$$

$$\begin{cases} U_{1\max} Sin\theta_{эл} = -\omega_{0эл} L_{1q} I_{1q} = -X_{1q} I_{1q} \ ; \\ -U_{1\max} Cos\theta_{эл} = \omega_{0эл} L_{1d} I_{1d} - \omega_{0эл} L_{12d} I_{в} = X_{1d} I_{1d} - E_{\max} ; \\ M = P_n \left[-L_{12d} I_{в} I_{1q} + \left(L_{1d} - L_{1q} \right) I_{1d} I_{1q} \right] . \end{cases} \qquad (6)$$

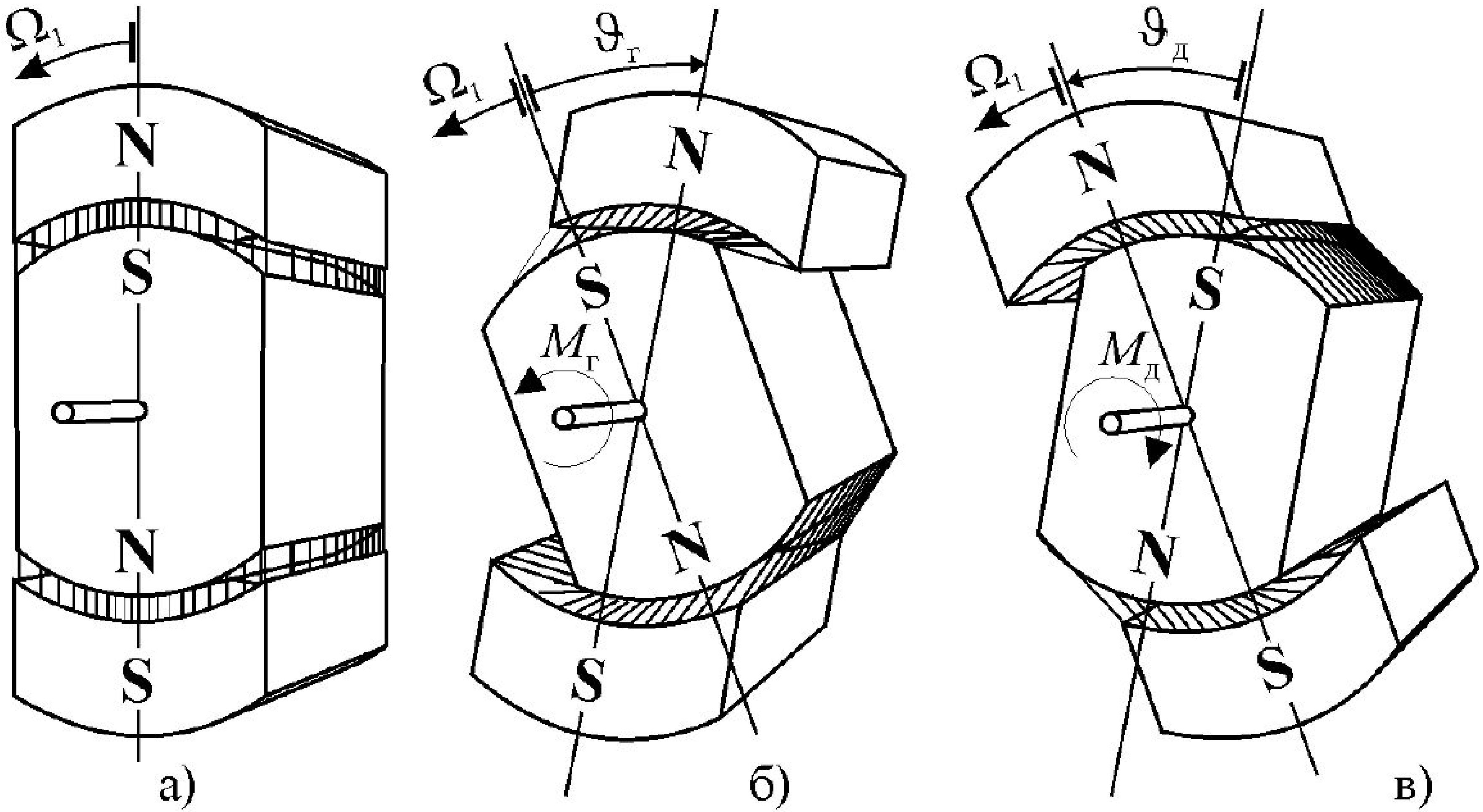
$$I_{1q} = -\frac{U_{1\max} Sin\theta_{эл}}{X_{1q}} \qquad I_{1d} = -\frac{E_{\max} - U_{1\max} Cos\theta_{эл}}{X_{1d}} \qquad (7)$$

$$L_{12d} I_{В} = E_{MAX} / \omega_{0ЭЛ}$$

$$M = \frac{2U_1 E \cdot Sin\theta_{эл}}{\omega_0 X_{1d}} + \frac{3U_1^2}{2\omega_0}\left(\frac{1}{X_{1q}} - \frac{1}{X_{1d}}\right) Sin2\theta_{эл} \qquad (8)$$



M
Mmax
3
1
Mном
2
−π
π
−π/2
0
π/2
θэл
θэл,ном
−Mmax
Генератор
Двигатель
а)
ω
ω0
Δωmax
1
2
ΔMmax
−Mmax
0
Mном
M
Mmax = λMном
б)


Ω1
N
S
N
S
а)
ϑг
Ω1
N
S
Mг
N
S
б)
ϑд
Ω1
N
S
Mд
N
S
в)

$$M = \mathrm{f}(\theta_{\text{эл}}) \qquad M = \mathrm{k} \cdot \theta_{\text{эл}},$$

$$M \approx \frac{M_{ном} \cdot \theta_{эл}}{\theta_{эл.ном}} = c_{эм} \cdot \theta$$

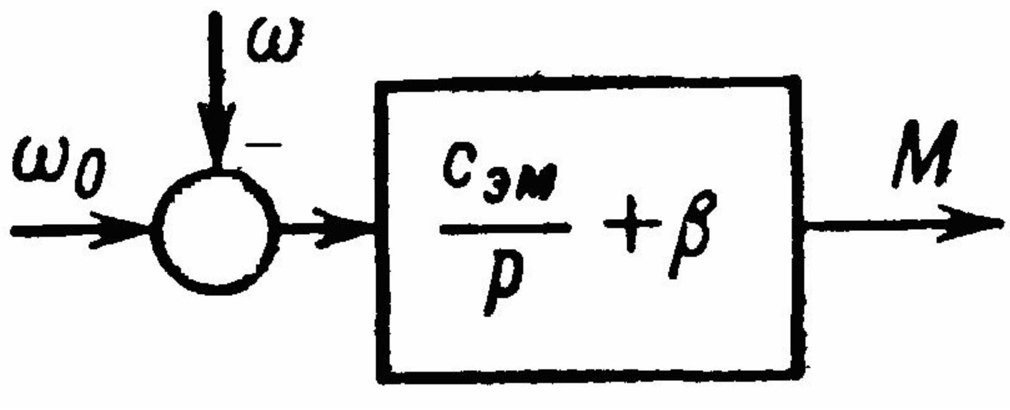
$$\frac{dM}{dt} = c_{эм} \cdot (\omega_0 - \omega) \qquad (9)$$

$$M_{12} = c_{12} \cdot (\varphi_1 - \varphi_2) \qquad \frac{dM_{12}}{dt} = c_{12} \cdot (\omega_1 - \omega_2) \qquad (10)$$

$$M = M_{син} + M_{ас} = c_{эм} \cdot \theta + \beta \cdot (\omega_0 - \omega)$$

$$c_{эм} = \frac{M_{ном}}{\theta_{ном}} \qquad \beta = \frac{2M_k}{\omega_0 \cdot s_k}$$

$$M = (c_{эм} / p + \beta) \cdot (\omega_0 - \omega)$$



Шаговый режим работы синхронного электромеханического преобразователя

$$i_{1\alpha}=I_{1П} \qquad i_{1\beta}=0$$

$$M = P_n(\Psi_{1d} i_{1q} - \Psi_{1q} i_{1d})$$

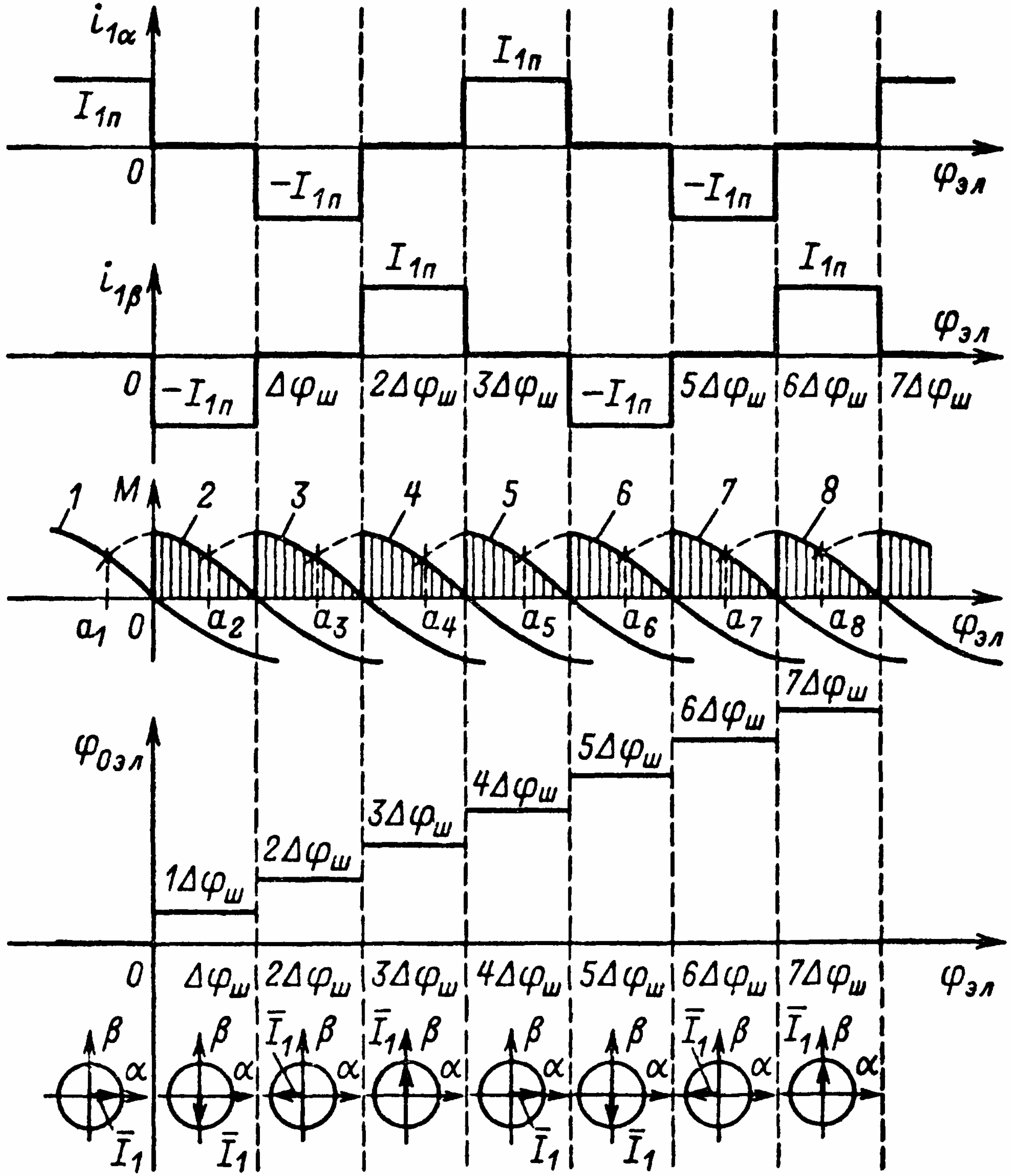
$$I_{1d} = I_{1П} \cdot \cos(\varphi_{эл})$$

$$I_{1q} = -I_{1П} \cdot \sin(\varphi_{эл})$$

$$\Psi_{1d} = L_{1d} \cdot I_{1П} \cdot \cos\varphi_{эл} + L_{12d} \cdot I_{в};$$

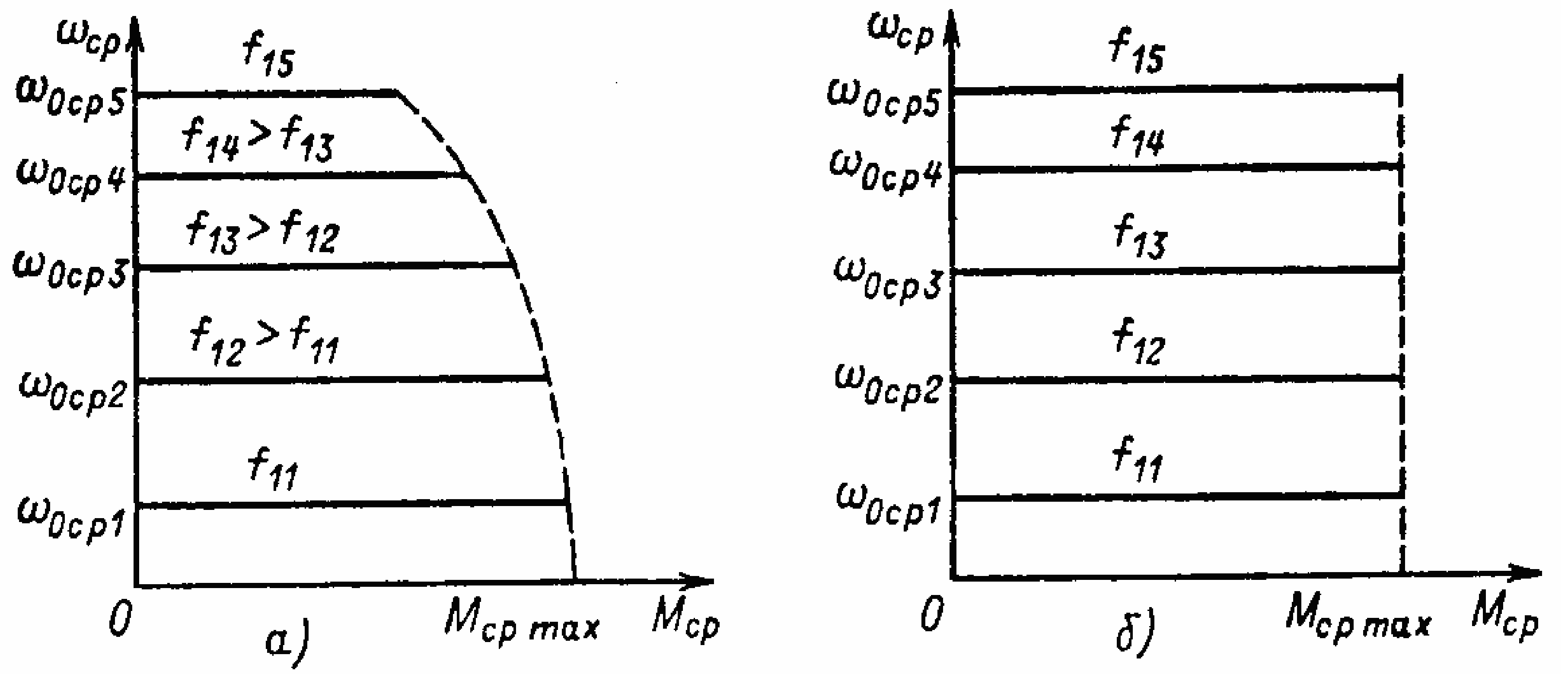
$$\Psi_{1q} = -L_{1q} \cdot I_{1П} \cdot \sin\varphi_{эл};$$

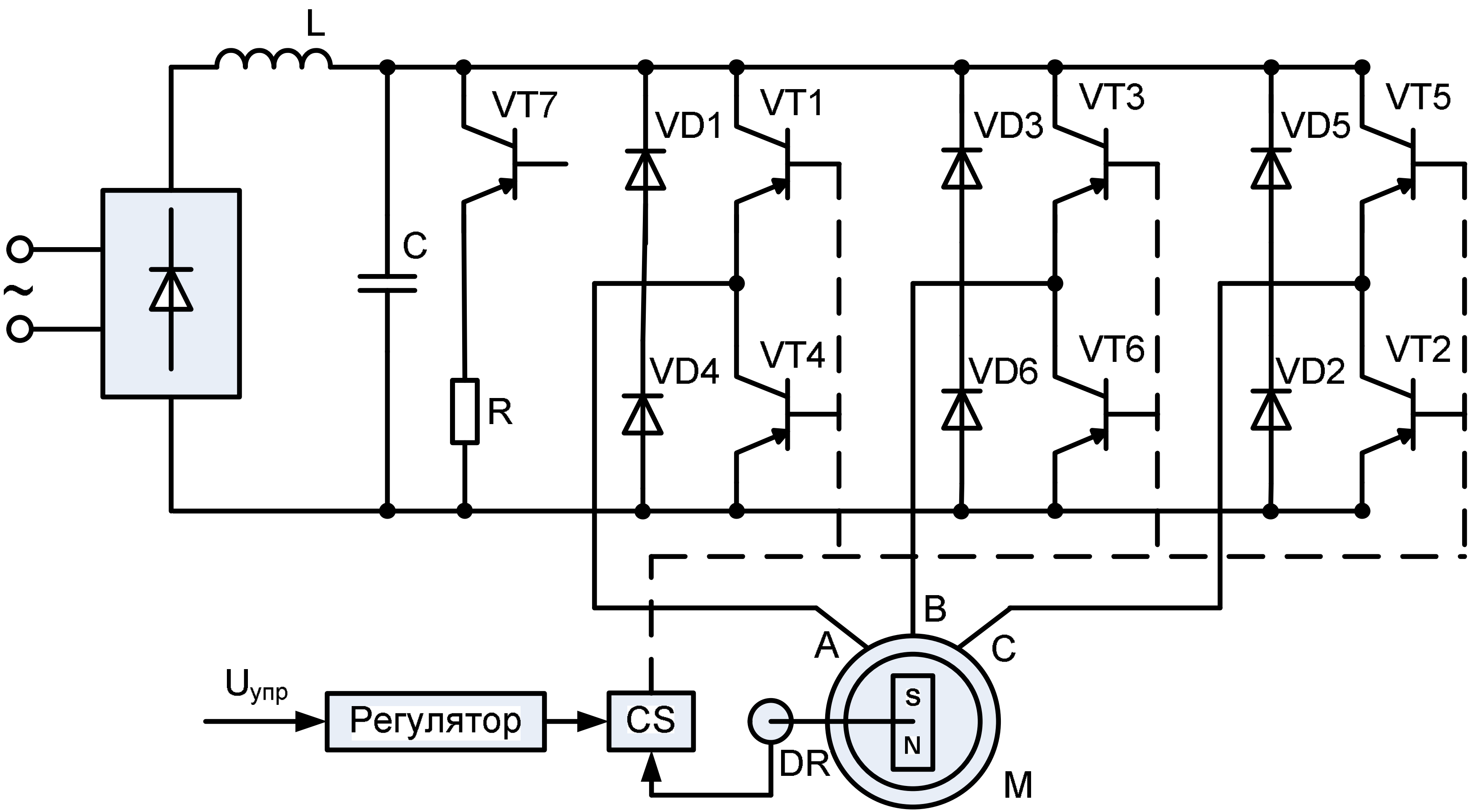
$$M = p_{п} \cdot \left[-L_{12} \cdot I_{в} \cdot I_{1П} \cdot \sin\varphi_{эл} - 0.5 \cdot I_{1П}{}^{2} \cdot (L_{1d} - L_{1q}) \cdot \sin2\varphi_{эл} \right]$$



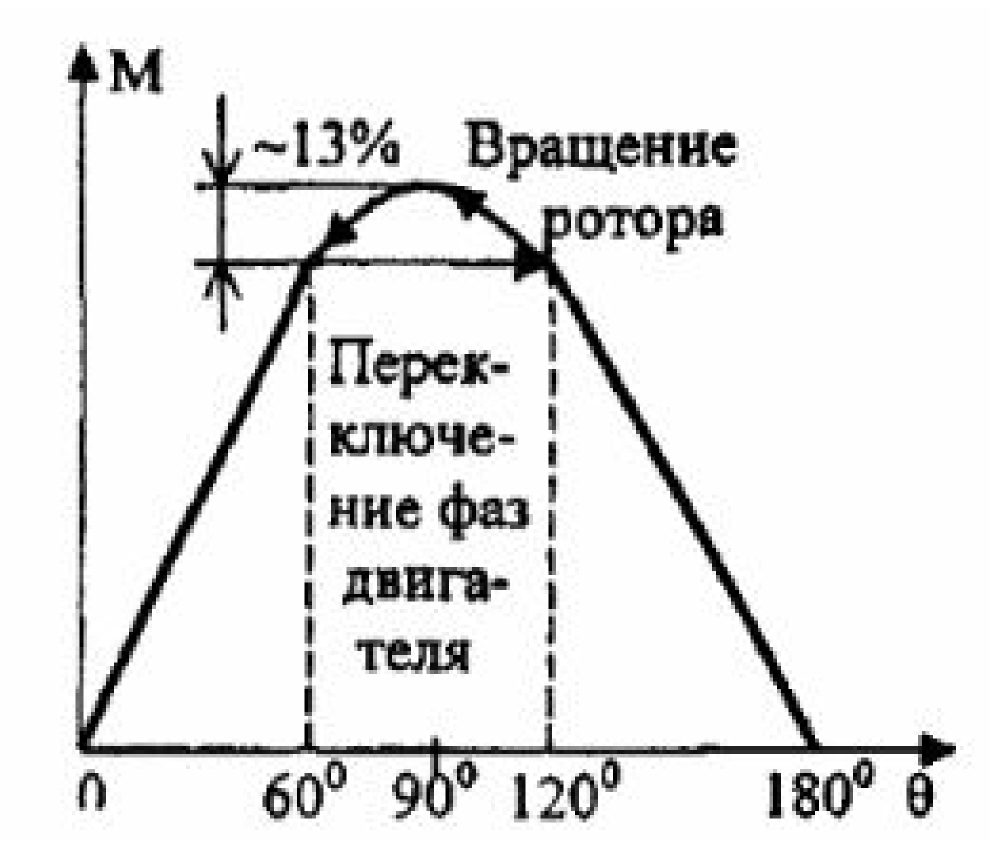
$i_{1\alpha}$
$I_{1п}$
$-I_{1п}$
$\varphi_{эл}$
$i_{1\beta}$
$\Delta\varphi_ш$
$2\Delta\varphi_ш$
$3\Delta\varphi_ш$
$5\Delta\varphi_ш$
$6\Delta\varphi_ш$
$7\Delta\varphi_ш$
M
1 2 3 4 5 6 7 8
a_1 a_2 a_3 a_4 a_5 a_6 a_7 a_8
$\varphi_{0эл}$
$1\Delta\varphi_ш$
$4\Delta\varphi_ш$
0
α
β
$\bar{I}_1$

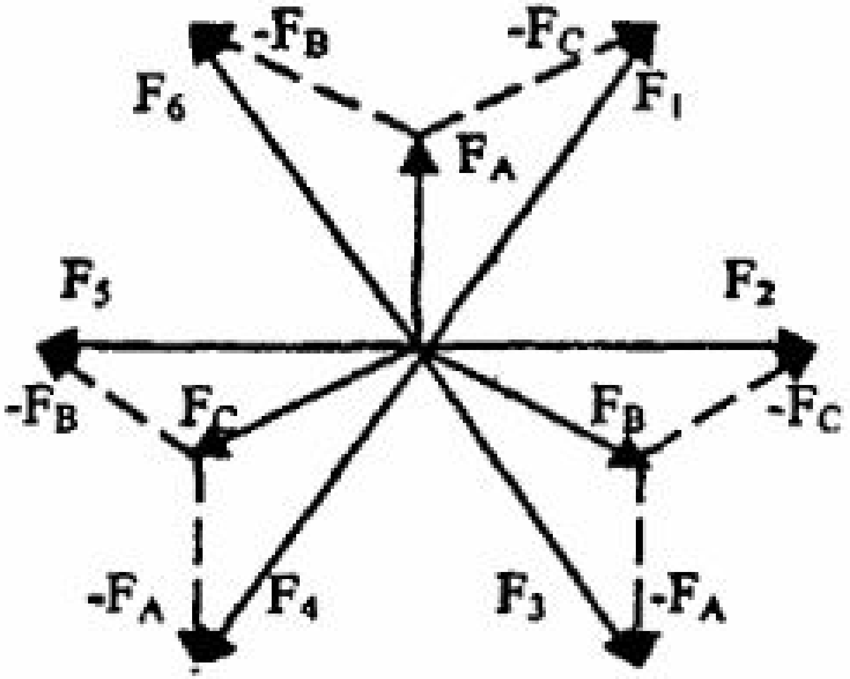
$$M_{cp\max} = \frac{2M_{\max} \cdot m}{\pi} \cdot \sin\left(\frac{\pi}{2m}\right)$$



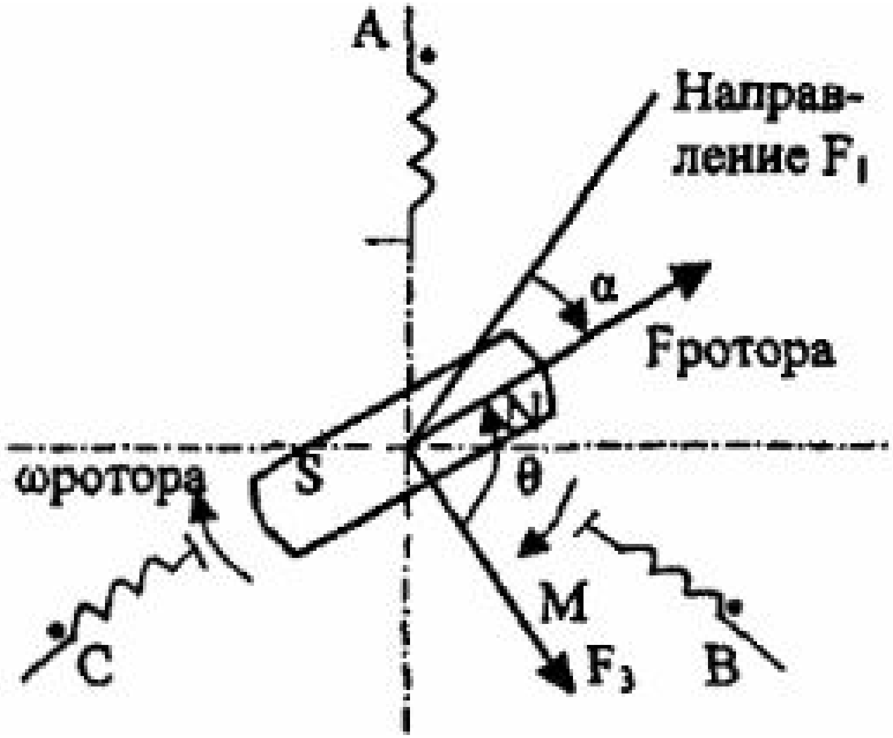

L
VT7
VD1
VT1
VD3
VT3
VD5
VT5
C
~
VD4
VT4
VD6
VT6
VD2
VT2
R
B
A
C
$U_{упр}$
Регулятор
CS
S
N
DR
M

$$M = k \cdot \Phi_1 \cdot \Phi_2 \cdot \sin\left(\frac{\theta}{p_n}\right)$$





-F_B
-F_C
F_6
F_1
F_A
F_5
F_2
-F_B
F_C
F_B
-F_C
-F_A
F_4
F_3
-F_A



A
Направ-
ление F_1
α
Fротора
S
ωротора
θ
M
F_3
C
B

$$I_1 = \frac{U_1 - E}{2R_1}$$

$$U_1 = k \cdot \Phi_2 \cdot \omega + 2I_1R_1 + 2L_1 \frac{dI_1}{dt}$$

$$M = k \cdot \Phi_2 \cdot I_1$$

Переходные процессы и методы их анализа

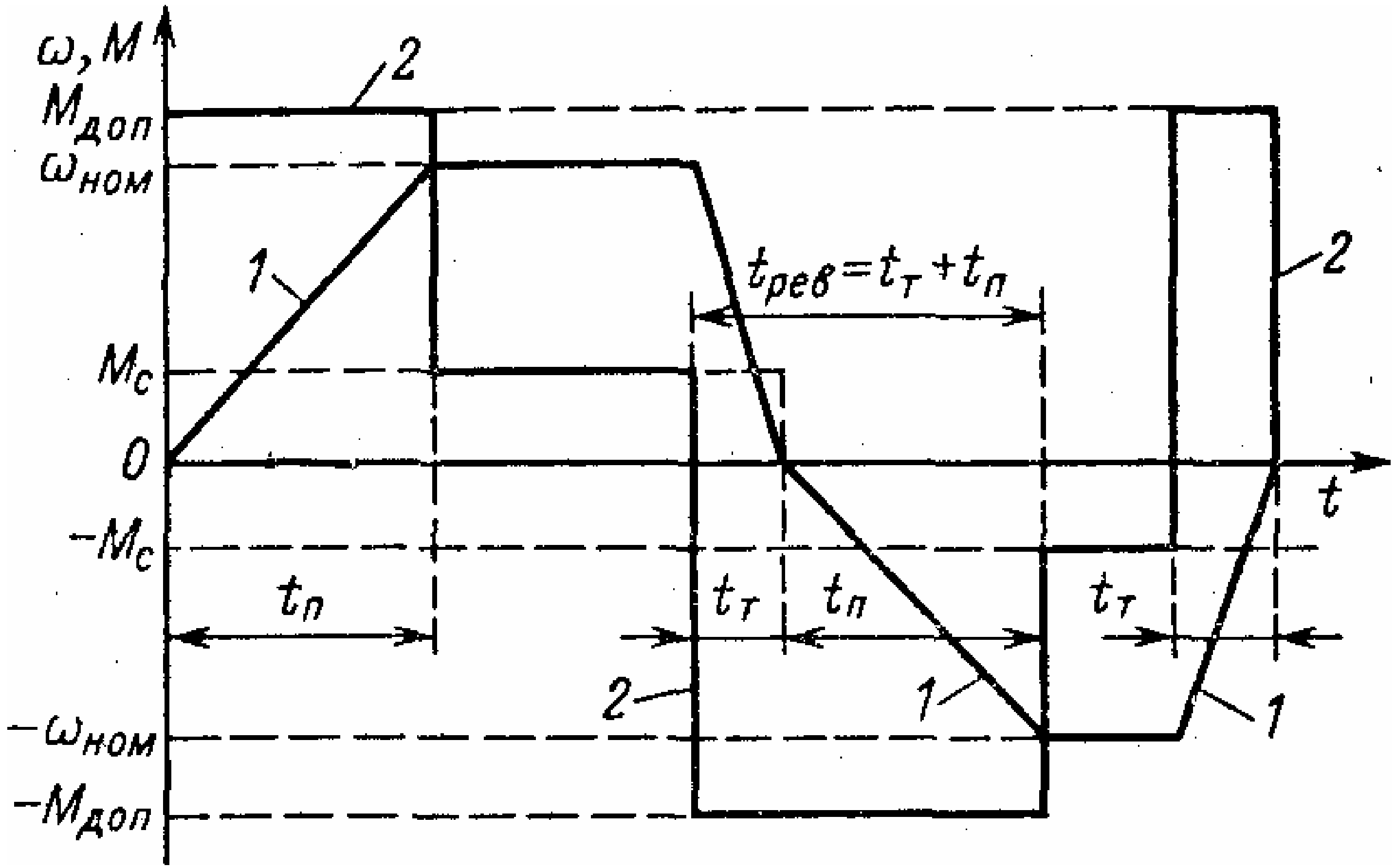


Рис. 1

$$\varepsilon = d\omega / dt = [M_{доп} - M_c(\omega)] / J_\Sigma$$

$$\varepsilon \leq \varepsilon_{доп}$$

$$a_{доп} = 1{,}5 \text{ м/с}^2$$

$$\varepsilon = \varepsilon_{доп} = const \qquad M = var$$

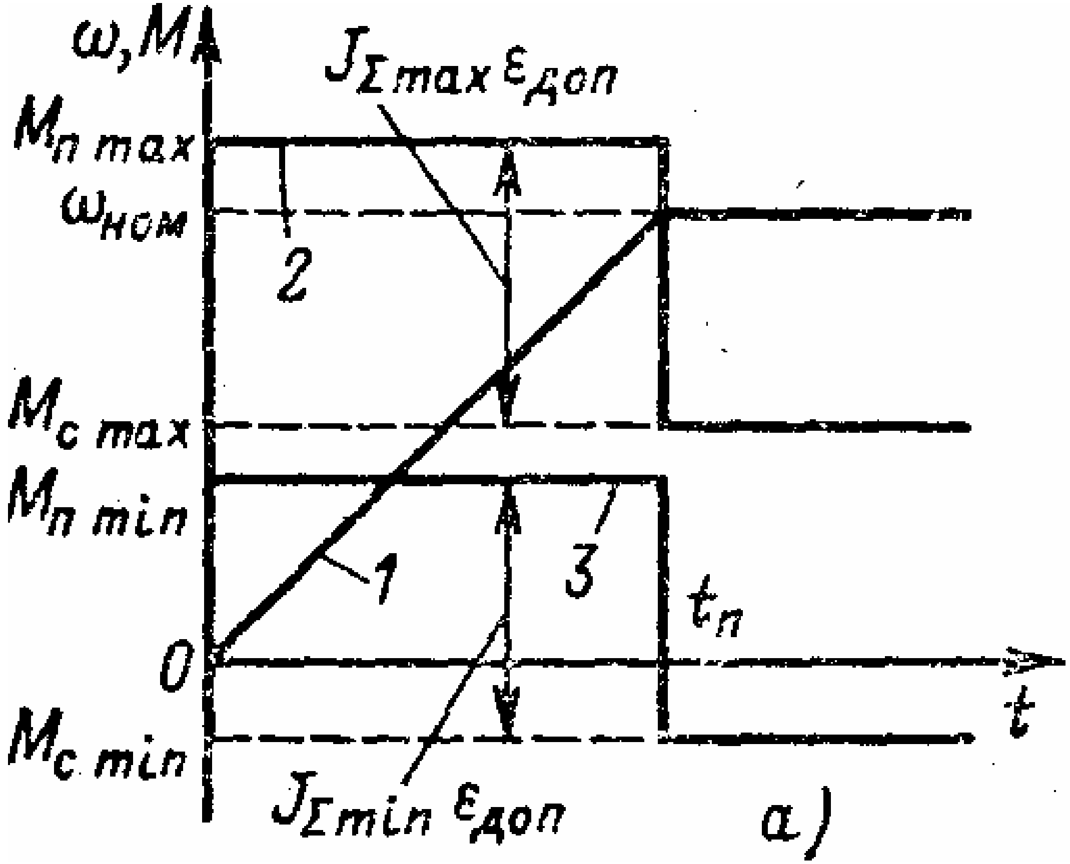


Рис. 2

$$M = J_{\Sigma} \cdot \varepsilon_{доп} + M_c$$

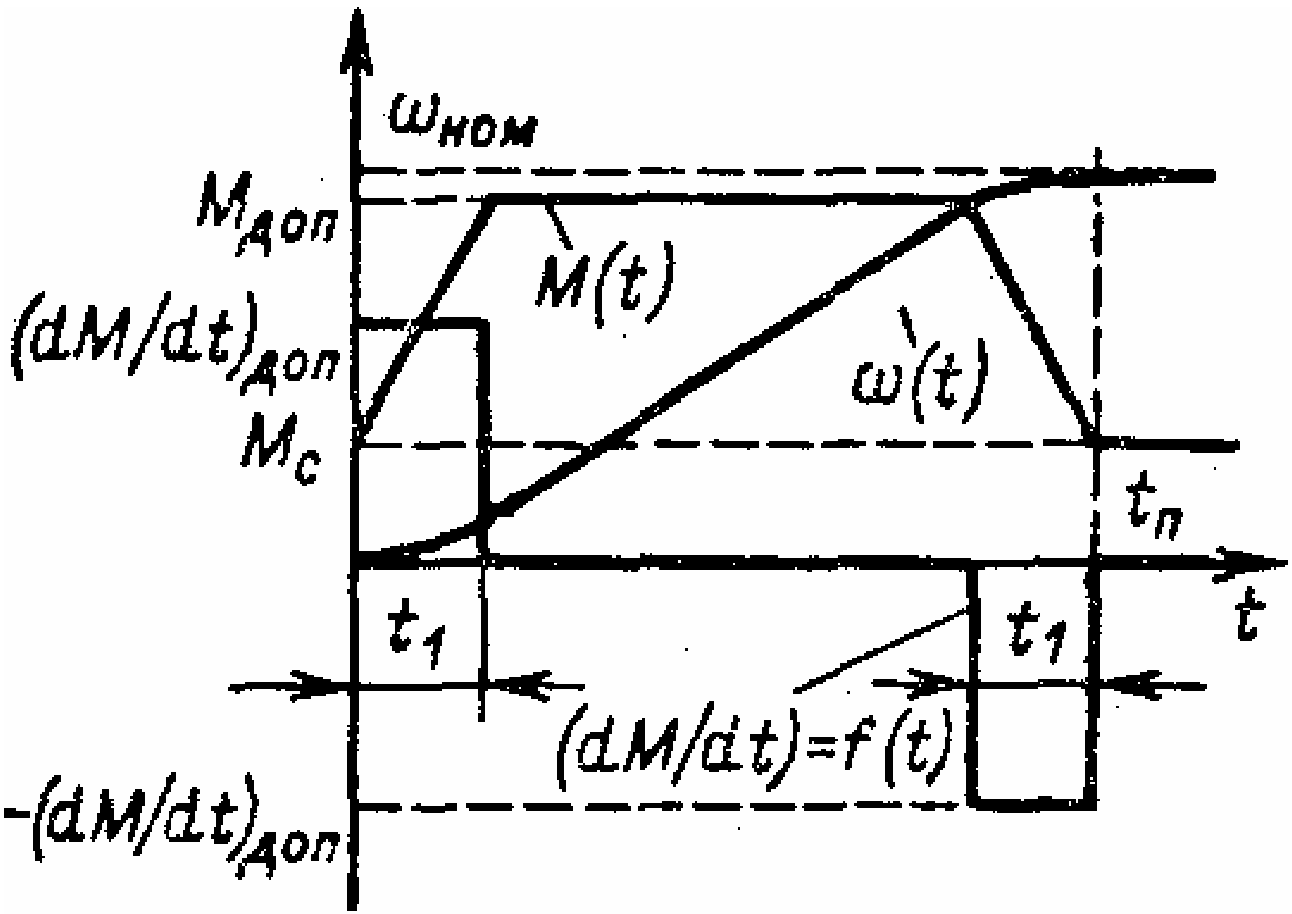
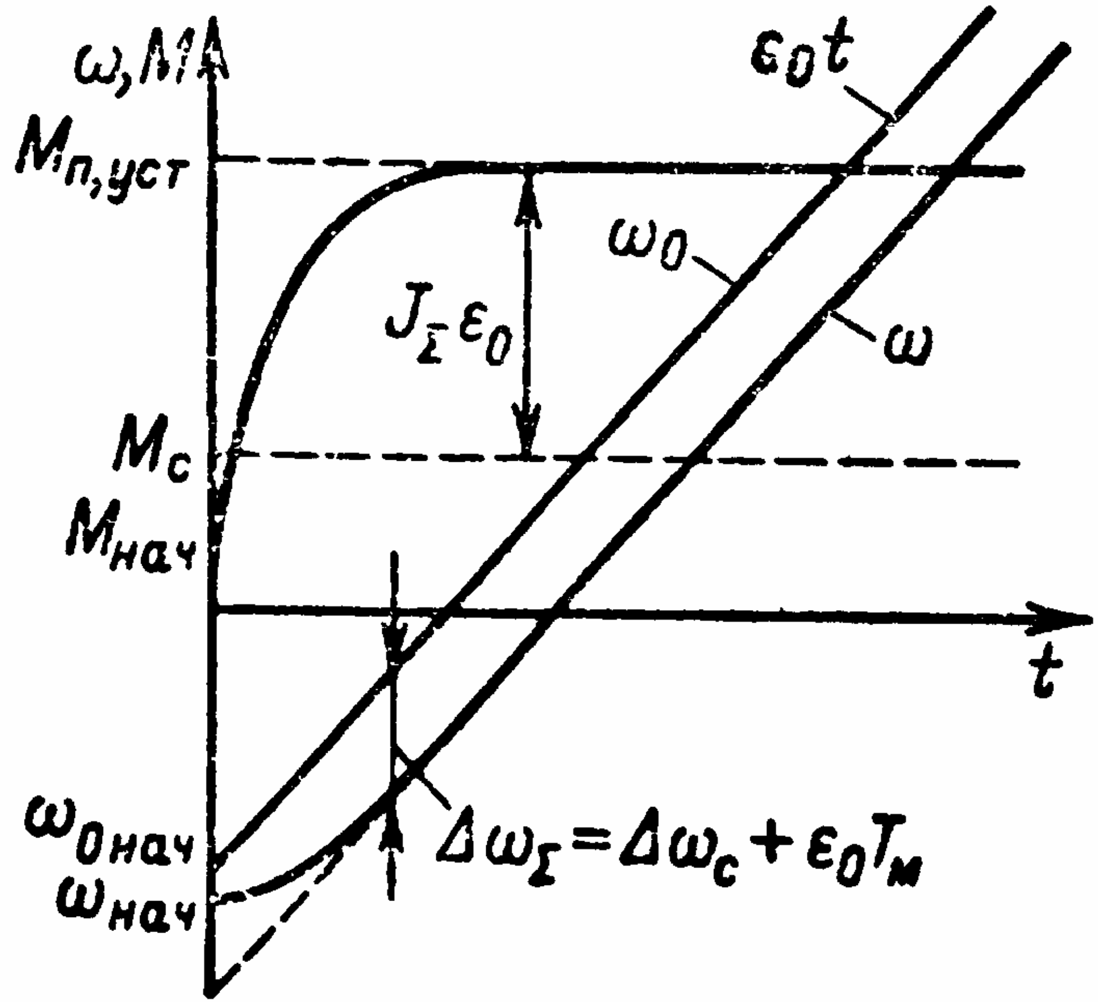


Рис. 3

$$\omega_0(t) = \omega_{0нач} + \varepsilon_0 t.$$



$$\Delta\omega_C = M_C/\beta$$

$$\Delta\omega_{ДИН} = J_\Sigma \cdot \varepsilon_0/\beta$$

Рис. 4

$$t_з = M_c/\beta\varepsilon_0 = \Delta\omega_c/\varepsilon_0.$$

$$\omega = \varepsilon_0 t - \varepsilon_0 T_м (1 - e^{-t/T_м});$$

$$M = (M_с + \beta\varepsilon_0 T_м)(1 - e^{-t/T_м}).$$

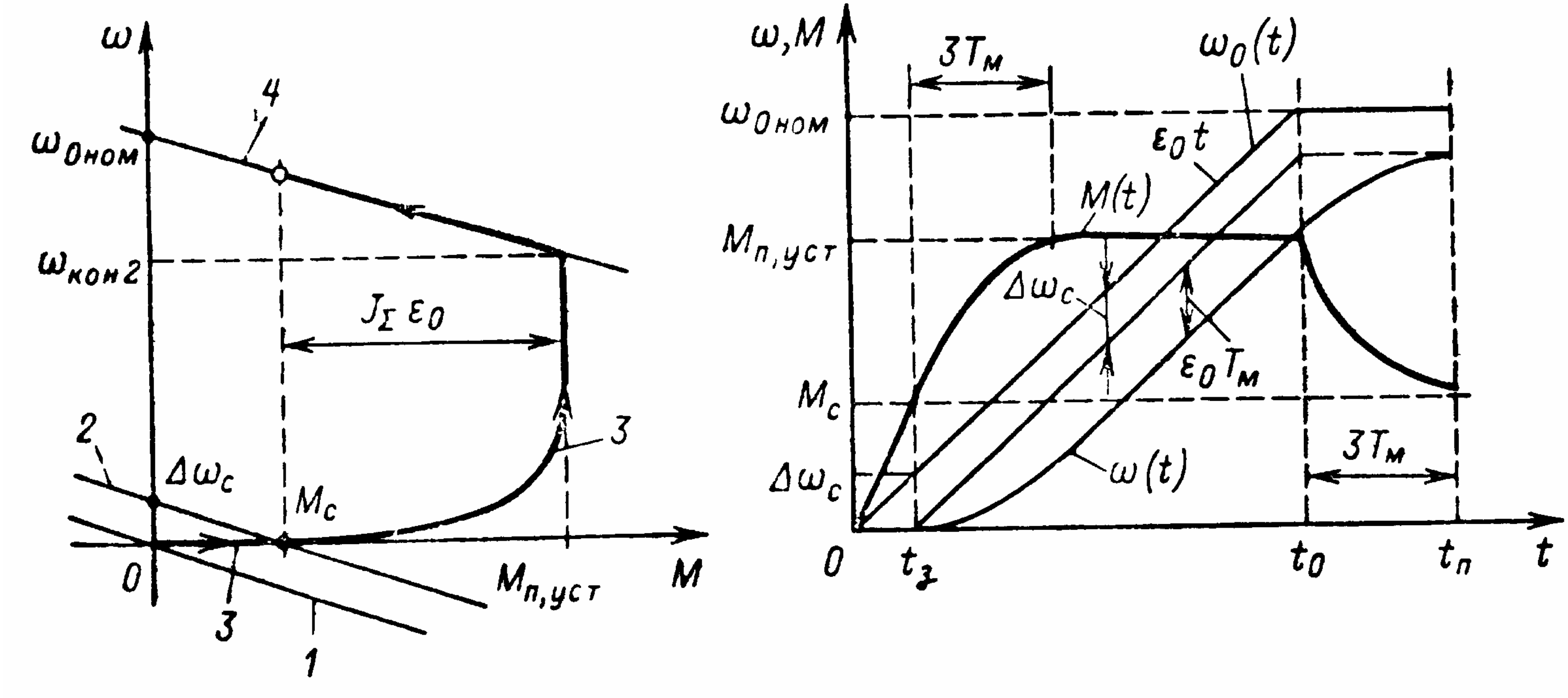


Рис. 5

$$t_{п,п} = t_0 + 3T_м.$$

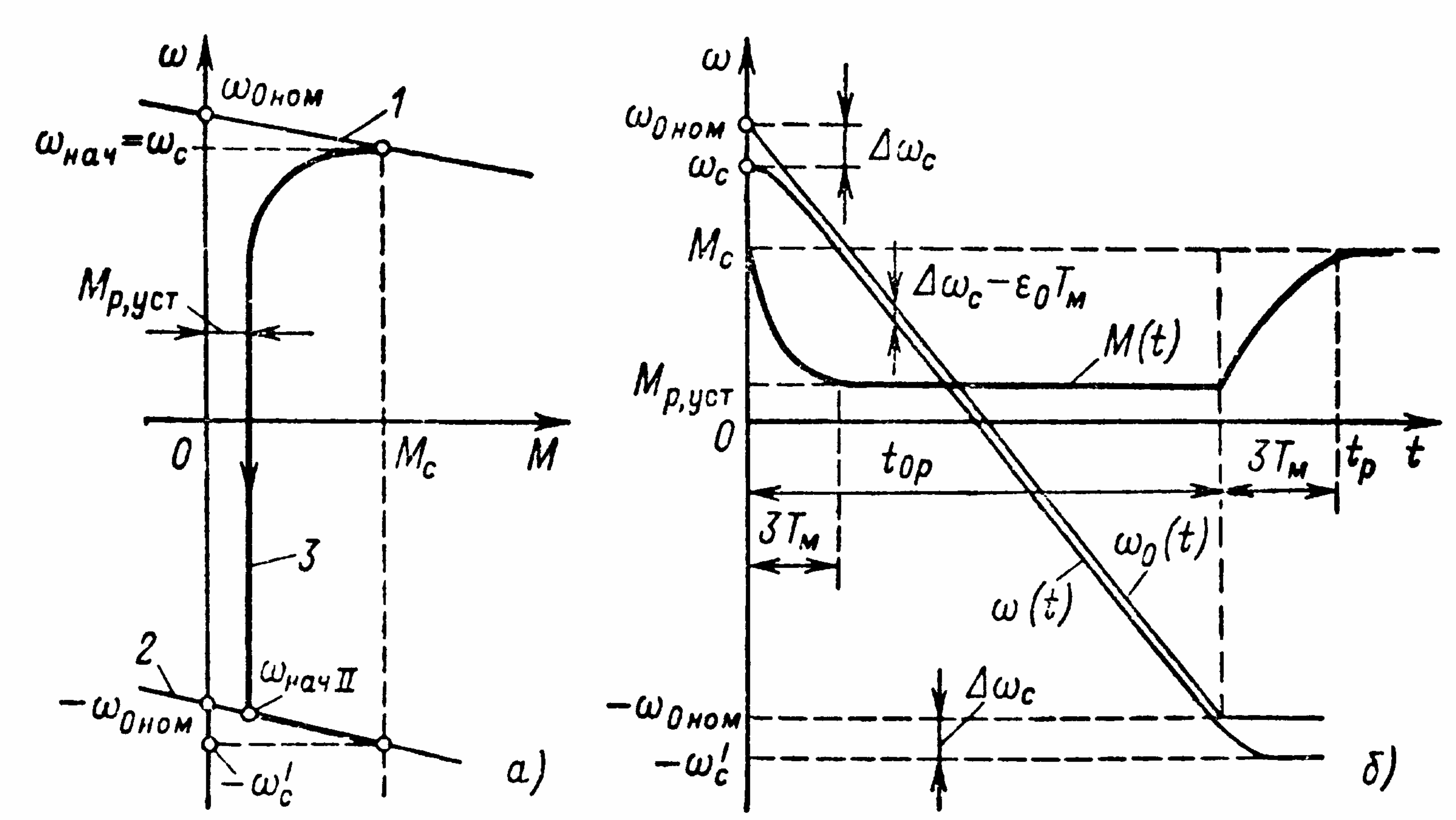

ω
ω0ном
1
ωнач=ωс
Mр,уст
0
Mс
M
3
2
ωначII
−ω0ном
−ω'с
а)
ω
ω0ном
ωс
Δωс
Mс
Δωс−ε0Tм
M(t)
Mр,уст
0
t0р
3Tм
tр
t
3Tм
ω0(t)
ω(t)
Δωс
−ω0ном
−ω'с
б)

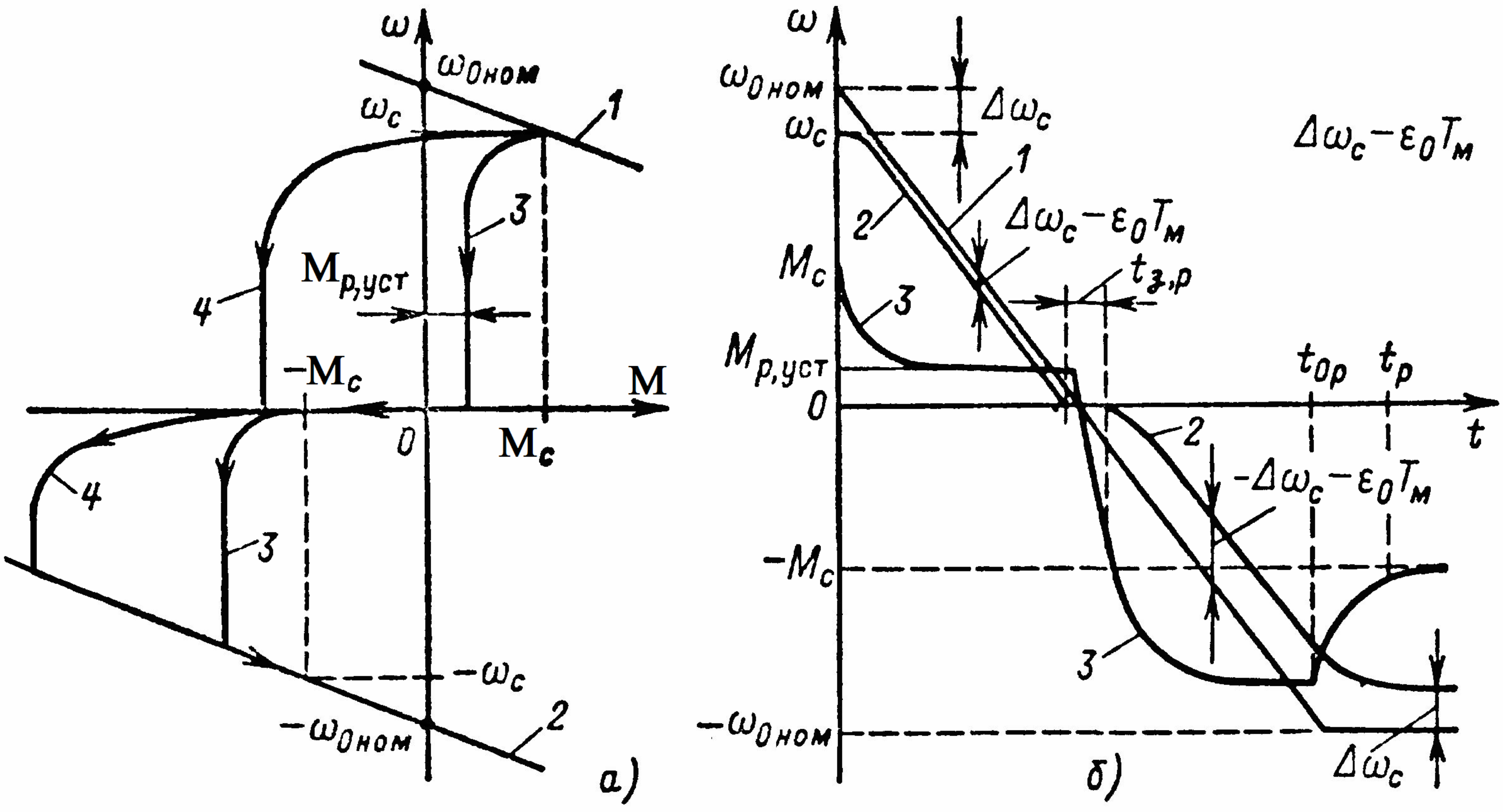
Рис. 6

$$\omega_0 = \omega_{0\,\text{ном}} - \varepsilon_0 t$$

$$M_{\text{р.уст}} = M_{\text{с}} - \beta \cdot \varepsilon_0 \cdot T_{\text{м}}$$

$$\Delta\omega_{\Sigma} = \Delta\omega_{\text{с}} - \varepsilon_0 \cdot T_{\text{м}}$$

$$t_{\text{р}} = t_{0\text{р}} + 3T_{\text{м}}$$



ω
ω0ном
ωc
1
3
Mр,уст
4
−Mc
M
0
Mc
4
3
−ωc
−ω0ном
2
а)
ω
ω0ном
ωc
Δωc
Δωc−ε0Tм
1
2
Δωc−ε0Tм
Mc
3
tз,р
Mр,уст
0
t0р
tр
t
2
−Δωc−ε0Tм
−Mc
3
−ω0ном
Δωc
б)

Рис. 7

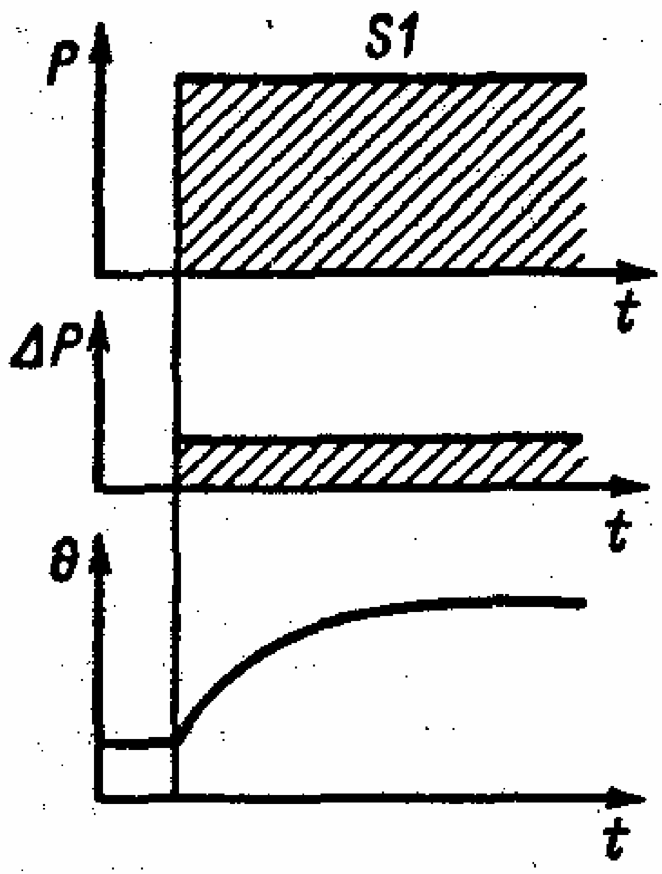


Рис. 9.21. Зависимости мощности на валу двигателя, потерь и температуры от времени, режим S1

$$\Delta P_{cp} = \frac{\Delta P_1 t_1 + \Delta P_2 t_2 + \Delta P_3 t_3}{t_1 + t_2 + t_3}$$

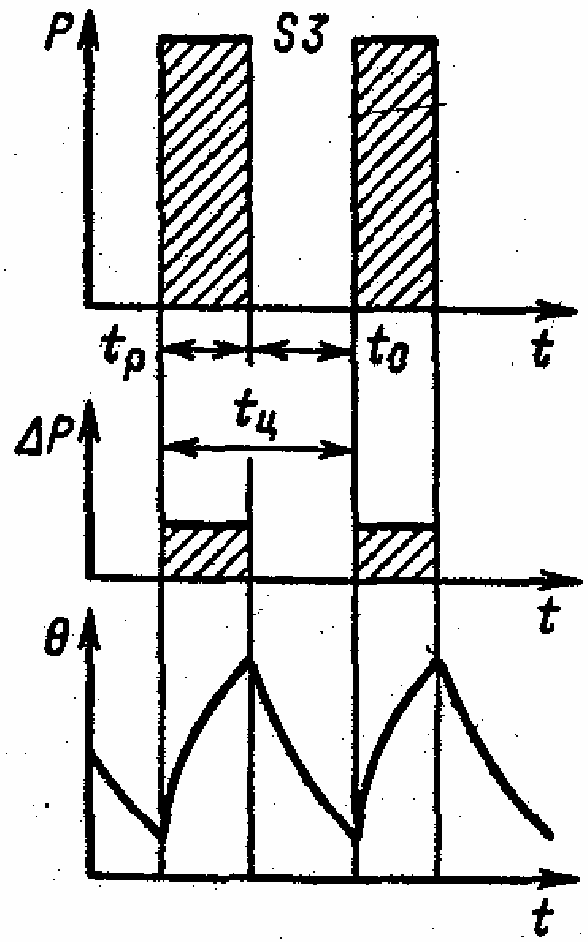


Рис. 9.23. Зависимости мощности на валу двигателя, потерь и температуры от времени, режим S3

$$\Delta P_{ср} = \frac{\Delta P_1 t_1 + \Delta P_2 t_2 + \Delta P_3 t_3}{t_1 + t_2 + t_3}$$

$$\Delta P_{н} = P_{н}(1 - \eta_{н}) / \eta_{н}$$

$$\Delta P_{ср} \leq \Delta P_{ном}$$

$$\Delta P_{т} = \Delta P_{с} + I^2 R$$

$$I_{Э} = \sqrt{\frac{1}{T_{ц}} \int_{0}^{T_{ц}} I^2(t)dt}$$

$$I_{Э} = \sqrt{\frac{1}{T_{ц}} \sum_{i=1}^{n} I_i^2 t_i} = \sqrt{\frac{I_1^2 t_1 + I_2^2 t_2 + I_3^2 t_3 + I_4^2 t_4 + I_5^2 t_5}{T_{ц}}}$$

$$I_{Э} \leq I_{ном}$$

$$M_Э = \sqrt{\frac{1}{T_ц}\int_0^{T_ц} M^2(t)dt}$$

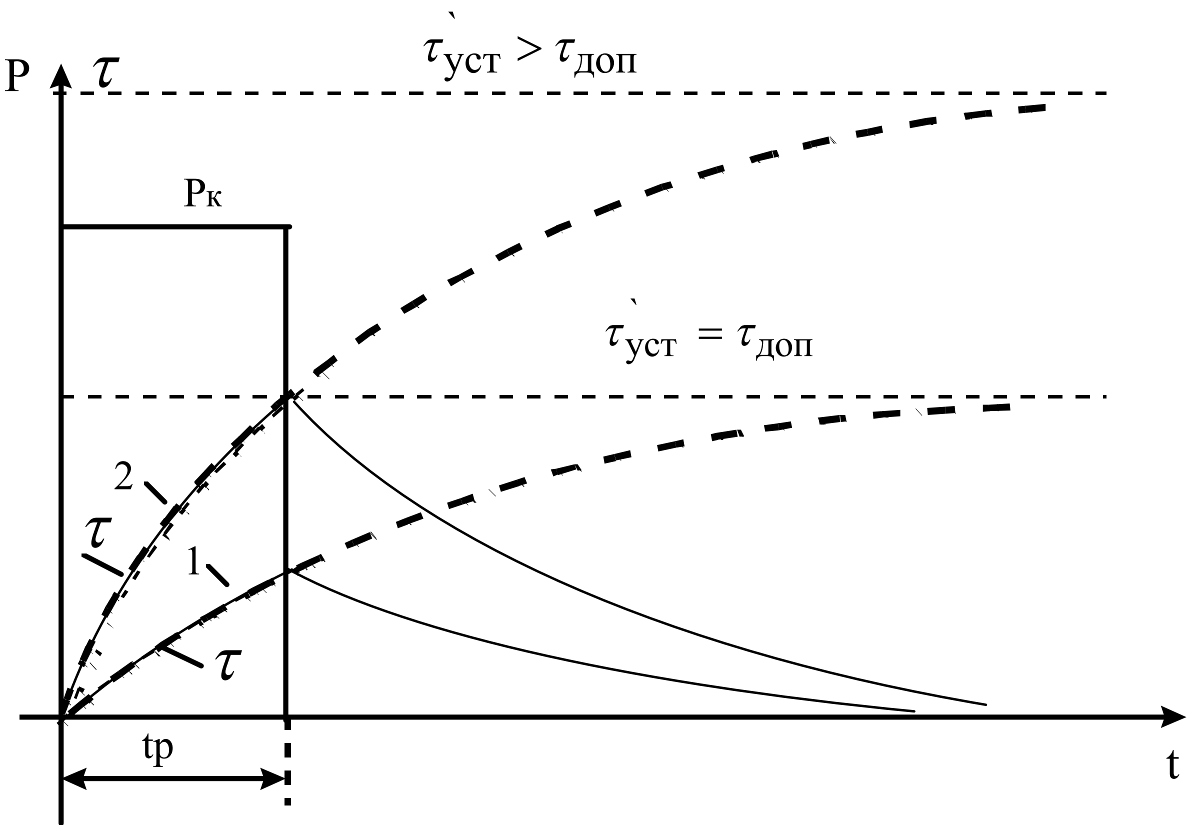
$$M_Э = \sqrt{\frac{1}{T_ц}\sum_{i=o}^{n} M_i t_i}$$

$$M_Э \le M_{ном}$$

$$P_{Э} = \sqrt{\frac{1}{T_{ц}} \int_{0}^{T_{ц}} P^{2}(t)dt}$$

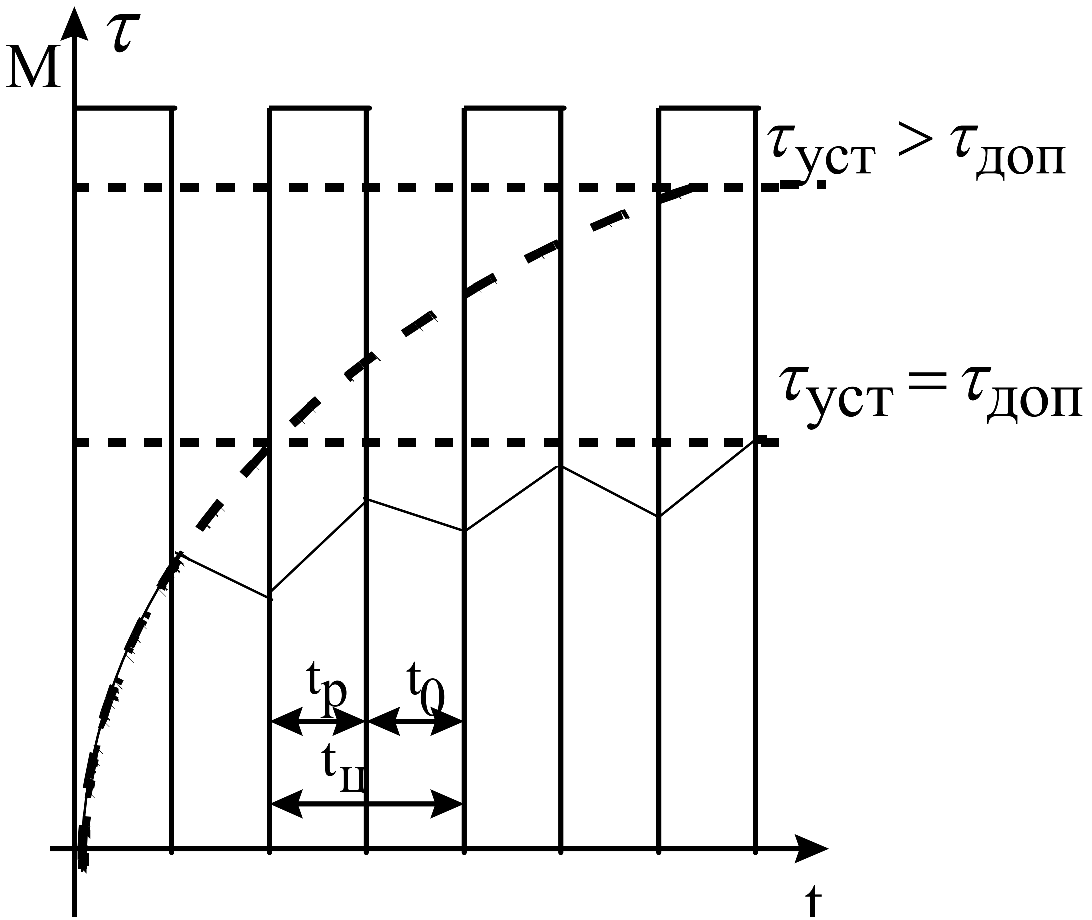
$$P_{Э} = \sqrt{\frac{1}{T_{ц}} \sum_{1}^{n} P_{i}^{2} t_{i}}$$

$$P_{Э} \leq P_{ном}$$



$$\tau_{доп} = \frac{\Delta P_{ном}}{A}\left(1 - e^{-\frac{t_p}{T_н}}\right)$$

$$ПВ\% = \frac{t_p}{t_p + t_0}100\% = \frac{t_p}{t_ц}100\%$$



$$I_{н} \geq I_1 \sqrt{\frac{ПВ_1}{ПВ_{н}}}$$

$$M_{н} \geq M_1 \sqrt{\frac{ПВ_1}{ПВ_{н}}}$$

$$P_{н} \geq P_1 \sqrt{\frac{ПВ_1}{ПВ_{н}}}$$