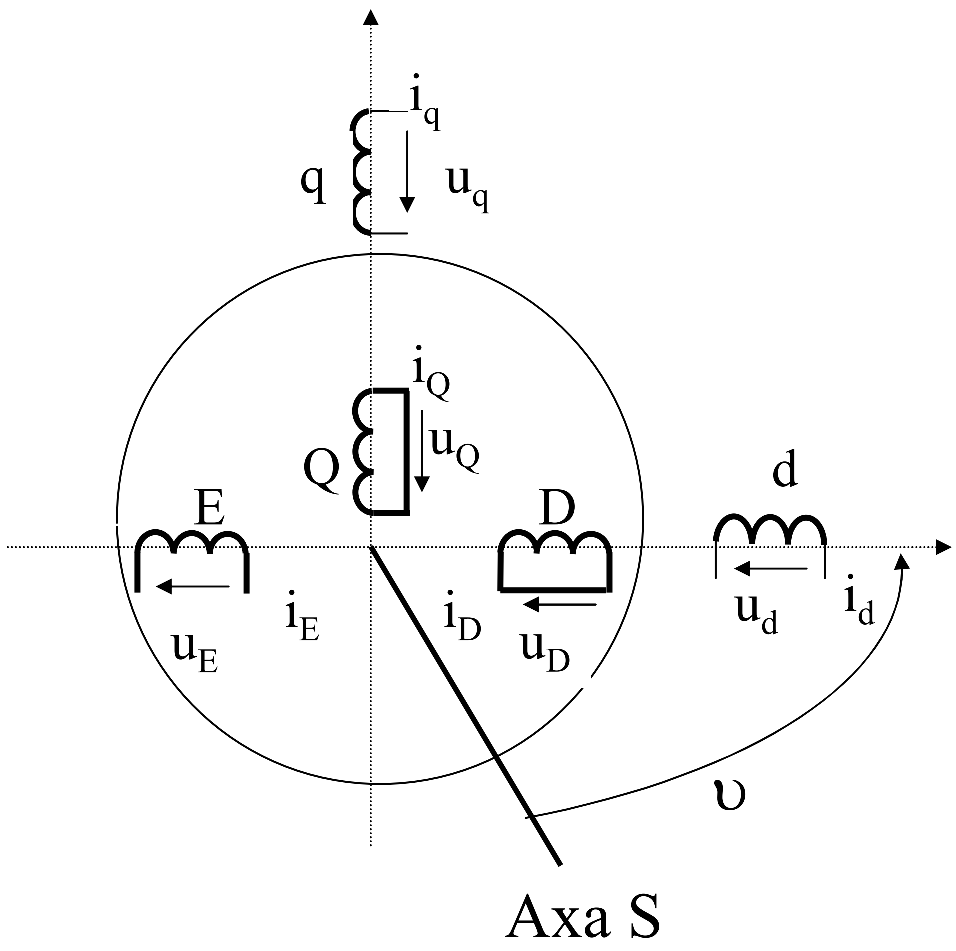
Regimurile tranzitorii ale maşinii sincrone

Regimuri cu variații reduse ale unghiului intern

Modelul bifazat al maşinii sincrone



Modelul bifazat al maşinii sincrone

$$u_d = R_S \cdot i_d + \frac{\partial \Psi_d}{\partial t} - \omega \cdot \Psi_q$$

$$u_q = R_S \cdot i_q + \frac{\partial \Psi_q}{\partial t} + \omega \cdot \Psi_d$$

$$u_E = R_E \cdot i_E + \frac{\partial \Psi_E}{\partial t}$$

$$0 = R_D \cdot i_D + \frac{\partial \Psi_D}{\partial t}$$

$$0 = R_Q \cdot i_Q + \frac{\partial \Psi_Q}{\partial t}$$

$$\Psi_d = L_{S\sigma} \cdot i_d + M_d \cdot \left(i_d + i_D + i_E\right)$$

$$\Psi_q = L_{S\sigma} \cdot i_q + M_q \cdot \left(i_q + i_Q\right)$$

$$\Psi_E = L_{E\sigma} \cdot i_E + +M_d \cdot \left(i_d + i_D + i_E\right)$$

$$\Psi_D = L_{D\sigma} \cdot i_D + M_d \cdot \left(i_d + i_D + i_E\right)$$

$$\Psi_Q = L_{Q\sigma} \cdot i_Q + M_q \cdot \left(i_q + i_Q\right)$$

$$\Psi_{dm} = M_d i_{dm}; i_{dm} = i_d + i_D + i_E$$

$$\Psi_{qm} = M_q i_{qm}; i_{qm} = i_q + i_Q$$

Parametrii operaționali ai maşinii sincrone

$$U_d = R_S \cdot I_d + p \cdot \left(\Psi_d - \frac{\Psi_{d0}}{p} \right) - \omega \cdot \Psi_q$$

$$U_q = R_S \cdot I_q + p \cdot \left(\Psi_q - \frac{\Psi_{q0}}{p} \right) + \omega \cdot \Psi_d$$

$$U_E = R_E \cdot I_E + p \cdot \left(\Psi_E - \frac{\Psi_{E0}}{p} \right)$$

$$0 = R_D \cdot I_D + p \cdot \left(\Psi_D - \frac{\Psi_{D0}}{p} \right)$$

$$0 = R_Q \cdot I_Q + p \cdot \left(\Psi_Q - \frac{\Psi_{Q0}}{p} \right)$$

$$\boxed{\begin{aligned}
\Psi_d &= \left(M_{md} + L_{S\sigma}\right) \cdot I_d + M_{md} \cdot \left(I_E + I_D\right) \\
\Psi_q &= \left(M_{mq} + L_{S\sigma}\right) \cdot I_q + M_{mq} \cdot I_Q \\
\Psi_E &= \left(M_{md} + L_{E\sigma}\right) \cdot I_E + M_{md} \cdot \left(I_d + I_D\right) \\
\Psi_D &= \left(M_{md} + L_{D\sigma}\right) \cdot I_D + M_{md} \cdot \left(I_E + I_d\right) \\
\Psi_Q &= \left(M_{mq} + L_{Q\sigma}\right) \cdot I_Q + M_{md} \cdot I_q
\end{aligned}}$$

Parametrii operaționali ai maşinii sincrone

Se calculează expresiile fluxurilor:

$$\Psi_d - \frac{\Psi_{d0}}{p} = L_d\left(i_d - \frac{I_d}{p}\right) + M_d\left(i_E - \frac{I_E}{p}\right) + M_d\left(i_D - \frac{I_D}{p}\right)$$

$$\Psi_E - \frac{\Psi_{E0}}{p} = M_d\left(i_d - \frac{I_d}{p}\right) + L_E\left(i_E - \frac{I_E}{p}\right) + M_d\left(i_D - \frac{I_D}{p}\right)$$

$$\Psi_D - \frac{\Psi_{D0}}{p} = M_d\left(i_d - \frac{I_d}{p}\right) + M_d\left(i_E - \frac{I_E}{p}\right) + L_D\left(i_D - \frac{I_D}{p}\right)$$

Ținând seama de regimul staționar $\quad I_{D0} = 0; \qquad I_{E0} = \dfrac{U_E}{R_E}$

Din ecuația de tensiune se exprimă:

$$i_D = -\frac{M_d}{\dfrac{R_D}{p} + L_D}\left[\left(i_d - \frac{I_{d0}}{p}\right) + \left(i_E - \frac{U_E}{p \cdot R_E}\right)\right]$$

Parametrii operaţionali ai maşinii sincrone

Definiind constanta de timp în gol a circuitului de amortizare longitudinal

$$T_{D0} = \frac{L_D}{R_D}$$

Rezultă:

$$i_D = -\frac{M_d}{L_D}\frac{p \cdot T_{D0}}{1 + p \cdot T_{D0}}\left[\left(i_d - \frac{I_{d0}}{p}\right) + \left(i_E - \frac{U_E}{p \cdot R_E}\right)\right]$$

Din ecuaţia de tensiune se exprimă

$$i_E - \frac{U_E}{p \cdot R_E} = f\left(i_d - \frac{I_{d0}}{p}, U_E - \frac{U_{E0}}{p}\right)$$

Definiind constanta de timp în gol a circuitului de excitaţie

$$T_{E0} = \frac{L_E}{R_E}$$

Parametrii operaționali ai mşsinii sincrone

$$\Psi_{Sd}-\frac{\Psi_{Sd0}}{p}=X_d(p)\cdot\left(i_d-\frac{I_{d0}}{p}\right)+G_E(p)\cdot\left(U_E-\frac{R_E\cdot I_{E0}}{p}\right)$$

$$\Psi_{Sq}-\frac{\Psi_{Sq0}}{p}=X_q(p)\cdot\left(i_q-\frac{I_{q0}}{p}\right)$$

Reactanțele operaționale $X_d(p)$ si $X_q(p)$

Inductanțele operaționale: $L_d(p)$ si $L_q(p)$

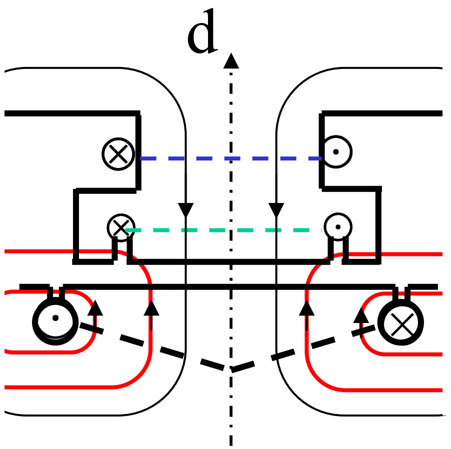
$$L_d(p)=\frac{L_d+p\cdot L_d\left[\left(1-\frac{M_d^2}{L_D\cdot L_d}\right)T_{D0}+\left(1-\frac{M_d^2}{L_E\cdot L_d}\right)T_{E0}\right]}{1+p\cdot(T_{D0}+T_{E0})+p^2\cdot T_{E0}\cdot T_{D0}\left(1-\frac{M_d^2}{L_E\cdot L_D}\right)}+$$

$$\frac{p^2\cdot T_{E0}\cdot T_{D0}\left(1-\frac{M_d^2}{L_E\cdot L_D}\right)\cdot\left(L_d-\frac{M_d^2\cdot L_E+M_d^2\cdot L_D-2\cdot M_d^3}{L_E\cdot L_D-M_d^2}\right)}{1+p\cdot(T_{D0}+T_{E0})+p^2\cdot T_{E0}\cdot T_{D0}\left(1-\frac{M_d^2}{L_E\cdot L_D}\right)}$$

Parametrii operaționali ai mașinii sincrone

La inceputul procesului tranzitorii $t = 0 \quad p \rightarrow \infty$

Reactanța (inductanța) supratranzitorie (subtranzitorie)



$$x_d'' = \lim_{p \to \infty} X_d(p)$$

$$L_d'' = L_d - \frac{M_d^2 \cdot L_E + M_d^2 \cdot L_D - 2 \cdot M_d^3}{L_E \cdot L_D - M_d^2}$$

Această inductivitate este mai mare dacât inductivitatea de scăpări a înfăşurării induse, din cauza scăpărilor din întrefier determinate de inductorul fără înfăşurare.

$$L_d'' = L_{s\sigma} + L_{scapari}$$

Parametrii operaţionali ai maşinii sincrone

Notând:

$$\sigma_{xy} = 1 - \frac{M_d^2}{L_x \cdot L_y}$$

$$L_d(p) = L_d \frac{1 + p \cdot (\sigma_{Dd} \cdot T_{D0} + \sigma_{Ed} \cdot T_{E0}) + p^2 \cdot \sigma_{DE} \cdot \frac{L_d^{''}}{L_d} T_{D0} \cdot T_{E0}}{1 + p(T_{E0} + T_{D0}) + p^2 \cdot \sigma_{DE} \cdot T_{E0} \cdot T_{D0}} = \frac{Y(p)}{N(p)}$$

corespunzător reactanţelor (inductivităţilor) subtranzitorii şi tranzitorii se definesc constantele de timp în gol subtranzitorie T''_{do} şi tranzitorie T'_{do}. Definite :

$$N(p) = (1 + p \cdot T_{d0}^{'})(1 + p \cdot T_{d0}^{''})$$

Rezultă:

$$T_{d0}^{'} + T_{d0}^{''} = T_{E0} + T_{D0}$$

$$T_{d0}^{'} \cdot T_{d0}^{''} = \sigma_{ED} \cdot T_{E0} \cdot T_{D0}$$

Constantele de timp

Rezolvând ecuația caracteristică : $N(p) = 0 \quad cu \quad p = -\frac{1}{T}$

$$T = \frac{T_{D0} + T_{E0}}{2}\left\{1 \pm \sqrt{1 - 4 \cdot \sigma_{ED} \frac{T_{E0} \cdot T_{D0}}{(T_{E0} + T_{D0})^2}}\right\}$$

$$T'_{d0} \approx T_{E0} + T_{D0}$$

$$T''_{d0} \approx \sigma_{ED} \frac{T_{E0} \cdot T_{D0}}{T_{E0} + T_{D0}} \approx \sigma_{ED} \cdot T_{D0}$$

Dacă este amortizare obişnuită

$$T_{D0} << T_{E0}$$

$$T'_{d0} \approx T_{E0}$$

$$T''_{d0} \approx \sigma_{ED} \cdot T_{D0}$$

Analog cu constantele de timp în gol se definesc şi constantele de timp în scurtcircuit subtranzitorii şi tranzitorii longitudinale.

$$Y(p) = \left(1 + p \cdot T'_d\right)\left(1 + p \cdot T''_d\right)$$

Constantele de timp

Rezulta din $L_d(p)$:

$$T_d' \approx \sigma_{Ed} \cdot T_{E0} + \sigma_{Dd} \cdot T_{D0}$$

$$T_d'' \approx \sigma_{ED} \frac{T_{E0} \cdot T_{D0}}{\sigma_{Ed} \cdot T_{E0} + \sigma_{Dd} \cdot T_{D0}} \frac{L_d''}{L_d}$$

Rezolvând ecuația caracteristică : $Y(p) = 0 \quad cu \quad p = -\frac{1}{T}$

$$T = \frac{\sigma_{Dd} \cdot T_{D0} + \sigma_{Ed} \cdot T_{E0}}{2} \left\{ 1 \pm \sqrt{1 - 4 \cdot \sigma_{ED} \frac{T_{E0} \cdot T_{D0}}{\left(\sigma_{Ed} \cdot T_{E0} + \sigma_{Dd} \cdot T_{D0}\right)^2} \frac{L_d''}{L_d}} \right\}$$

$$T_d' + T_d'' = \sigma_{Ed} \cdot T_{E0} + \sigma_{Dd} \cdot T_{D0}$$

$$T_d' \cdot T_d'' = \sigma_{ED} \cdot T_{E0} \cdot T_{D0} \cdot \frac{L_d''}{L_d}$$

Dacă este amortizare obişnuită

$$T_{D0} << T_{E0}$$

$$T_d' \approx \sigma_{Ed} \cdot T_{E0}$$

$$T_d'' \approx \frac{T_{d0}''}{\sigma_{Ed}} \frac{L_d''}{L_d}$$

Parametrii operaționali ai maşinii sincrone

Expresia reactantei operationala devine:

$$\frac{1}{X_d(p)} = \frac{1}{X_d}\frac{\left(1+p\cdot T_{d0}^{''}\right)\cdot\left(1+p\cdot T_{d0}^{'}\right)}{\left(1+p\cdot T_d^{''}\right)\cdot\left(1+p\cdot T_d^{'}\right)}$$

Dacă se descompune în fracții simple şi se notează:

$$X_d^{'} = X_d \frac{T_d^{'} - T_d^{''}}{T_{d0}^{'} + T_{d0}^{''} - T_d^{''}\left(1+\frac{X_d}{X_d^{''}}\right)}$$

Rezultă expresia :

$$\frac{1}{pX_d(p)} = \frac{1}{pX_d} + \left(\frac{1}{X_d^{'}} - \frac{1}{X_d}\right)\frac{1}{p+\frac{1}{T_d^{'}}} + \left(\frac{1}{X_d^{''}} - \frac{1}{X_d^{'}}\right)\frac{1}{p+\frac{1}{T_d^{''}}}$$

Parametrii operaționali ai maşinii sincrone

Pentru circuitul transversal, procedând similar rezultă :

$$X_q(p) = X_q \frac{1 + p \cdot T_{Q0}\left(1 - \frac{M_q^2}{L_Q \cdot L_q}\right)}{1 + p \cdot T_{Q0}}$$

Unde constanta de timp în gol a circuitului de amortizare transversal

$$T_{Q0} = \frac{L_Q}{R_Q}$$

Valoarea reactanței subtranzitorii transversale

$$x_q^{"} = \lim_{p \to \infty} X_q(p) \qquad X_q^{"} = X_q\left(1 - \frac{M_q^2}{L_Q \cdot L_q}\right)$$

Constantele de timp subtranzitorii de mers in gol si scurtcircuit

$$T_{q0}^{"} = T_{Q0}$$

$$T_q^{"} = \frac{X_q^{"}}{X_q} T_{Q0}$$

reactanța subtranzitorie transversala

$$\frac{1}{X_q(p)} = \frac{1}{X_q} \frac{\left(1 + p \cdot T_{q0}^{"}\right)}{\left(1 + p \cdot T_q^{"}\right)}$$

Parametrii operaționali ai mașinii sincrone

Expresia reactanței operationale subtranzitorii transversale

$$\frac{1}{pX_q(p)} = \frac{1}{pX_q} + \left(\frac{1}{X_q''} - \frac{1}{X_q}\right)\frac{1}{p + \frac{1}{T_q''}}$$

<u>Variația în timp a parametrilor</u>

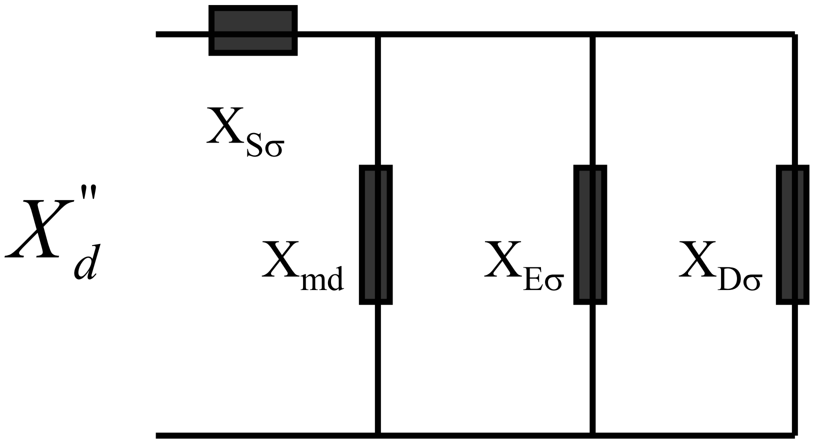
Reactanta longitudinala

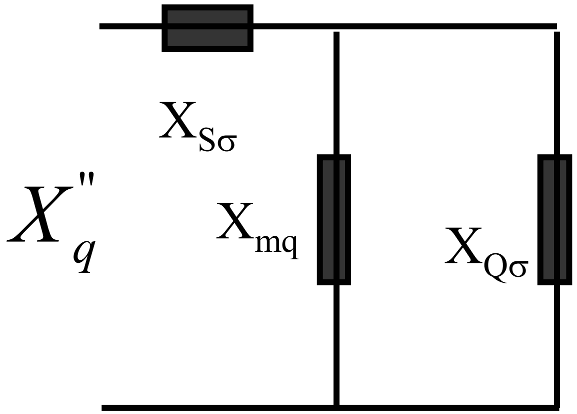
$$\frac{1}{X_d(t)} = \frac{1}{X_d} + \left(\frac{1}{X_d'} - \frac{1}{X_d}\right)\cdot e^{-\frac{t}{T_d'}} + \left(\frac{1}{X_d''} - \frac{1}{X_d'}\right)\cdot e^{-\frac{t}{T_d''}}$$

Reactanta transversala

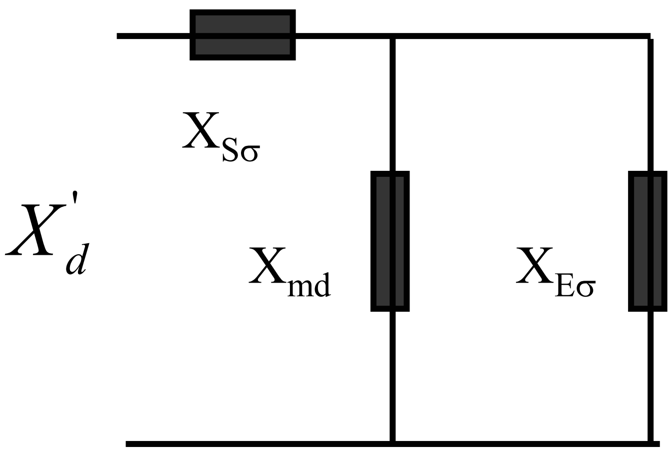
$$\frac{1}{X_q(t)} = \frac{1}{X_q} + \left(\frac{1}{X_q'} - \frac{1}{X_q}\right)\cdot e^{-\frac{t}{T_q''}}$$

Schemele echivalente





$$X_q^{''} = X_q\left(1 - \frac{M_q^2}{L_Q \cdot L_q}\right)$$



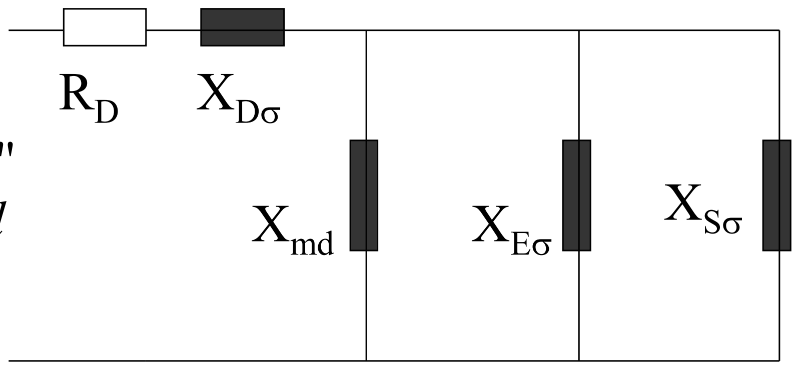
$$X_q = X_{S\sigma} + X_{mq}$$

$$X_Q = X_{Q\sigma} + X_{mq}$$

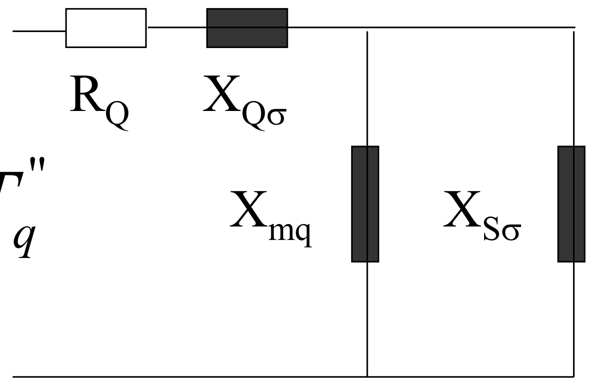
$$X_q^{''} = X_{S\sigma} + \frac{X_{mq} \cdot X_{Q\sigma}}{X_{mq} + X_{Q\sigma}}$$

Scheme pentru constantele de timp

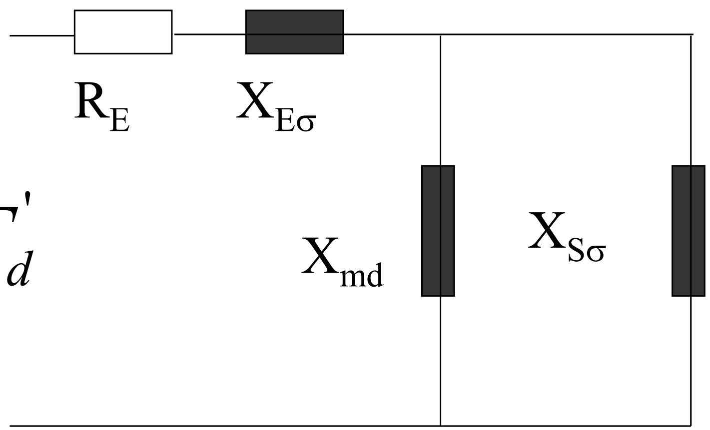
T''_d



T''_q



T'_d



$$T''_q = \frac{X''_q}{X_q}\frac{L_Q}{R_Q}$$

$$T''_q = \frac{X_{Q\sigma} + \dfrac{X_{S\sigma}\cdot X_{mq}}{X_{S\sigma}+X_{mq}}}{\omega\cdot R_Q}$$

Constantele de timp

De mers în gol:

excitatie

$$T_{E0} = \frac{L_E}{R_E}$$

Amortizare long.

$$T_{D0} = \frac{L_D}{R_D}$$

Amortizare transv.

$$T_{Q0} = \frac{L_Q}{R_Q}$$

tranzitorie longitudinal $T_{d0}^{'} \approx T_{E0}$

subtranzitorie longitudinal $T_{d0}^{''} \approx \sigma_{ED} \cdot T_{D0}$

Scurtcircuit

$$T_d^{'} \approx \sigma_{Ed} \cdot T_{E0}$$

tranzitorie longitudinal

$$T_d^{'} = \frac{X_d^{'}}{X_d} T_{d0}^{'}$$

$$T_d^{''} \approx \frac{T_{d0}^{''}}{\sigma_{Ed}} \frac{L_d^{''}}{L_d}$$

subtranzitorie longitudinal

$$T_d^{''} = \frac{X_d^{''}}{X_d^{'}} T_{d0}^{''}$$

$$T_q^{''} = \frac{X_q^{''}}{X_q} T_{q0}^{''}$$

subtranzitorie transversal

Constanta de timp a rotorului

$$T_a = \frac{2 \cdot X_d^{''} \cdot X_q^{''}}{\omega \cdot R_S \cdot \left(X_d^{''} + X_q^{''}\right)}$$

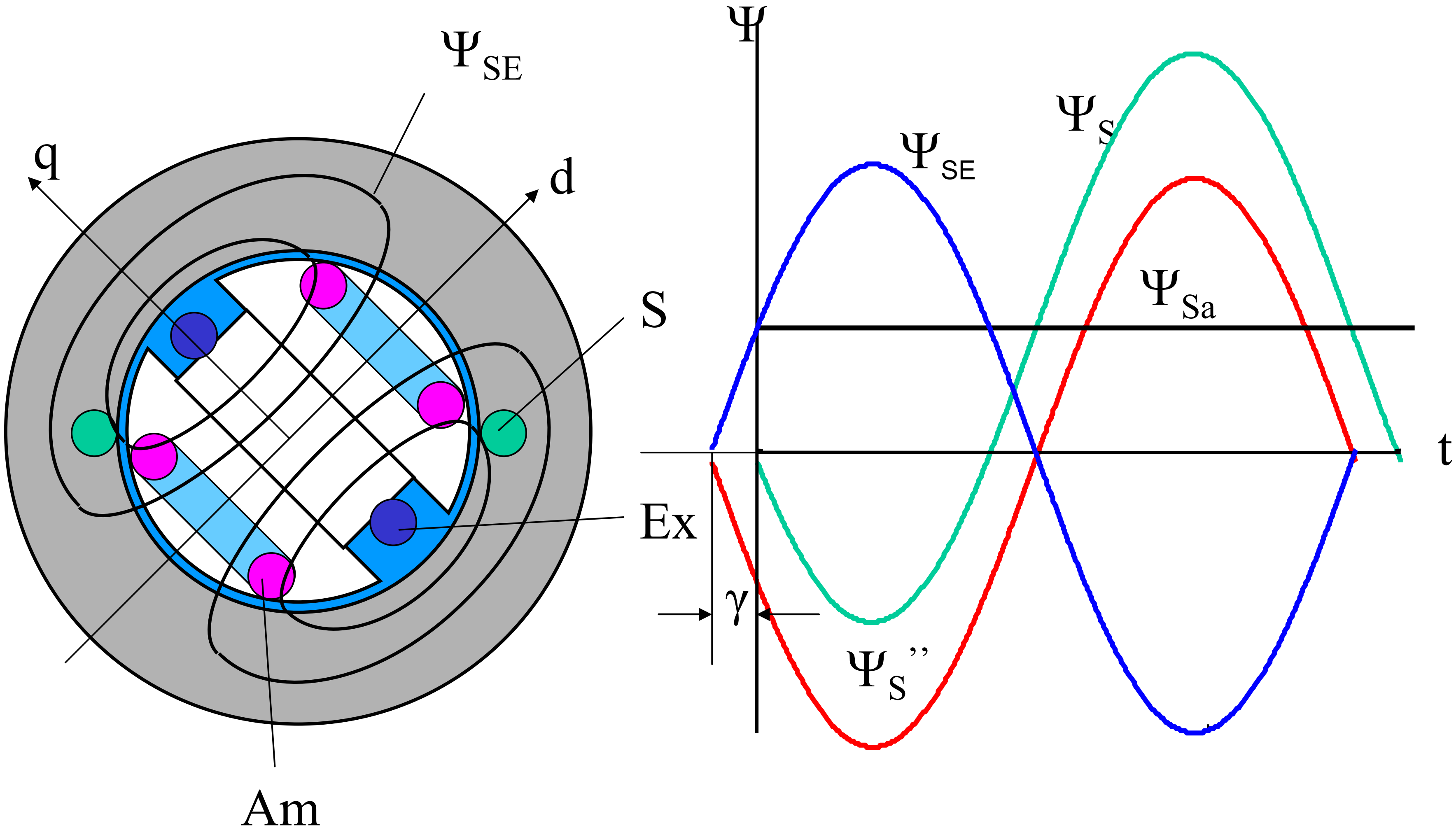
Parametrii operaționali ai mașinii sincrone

$$\Psi_{Sd} - \frac{\Psi_{Sd0}}{p} = X_d(p)\cdot\left(i_d - \frac{I_{d0}}{p}\right) + G_E(p)\cdot\left(U_E - \frac{R_E \cdot I_{E0}}{p}\right)$$

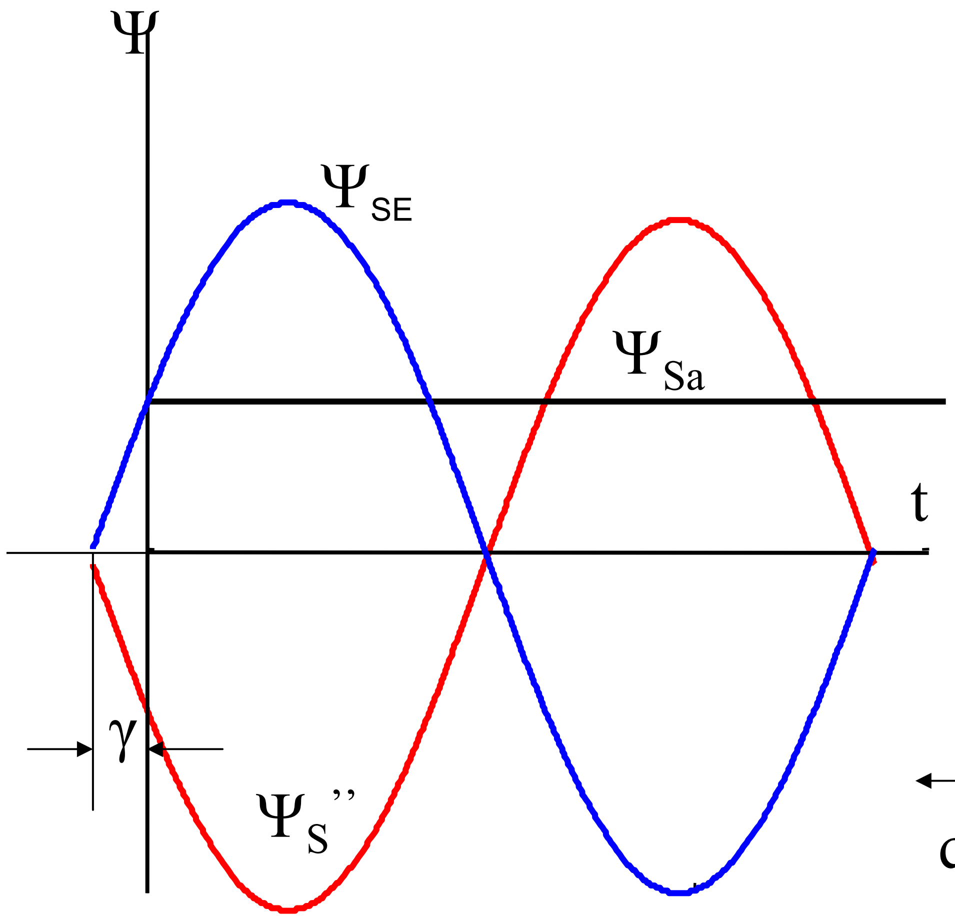
Coeficient operational

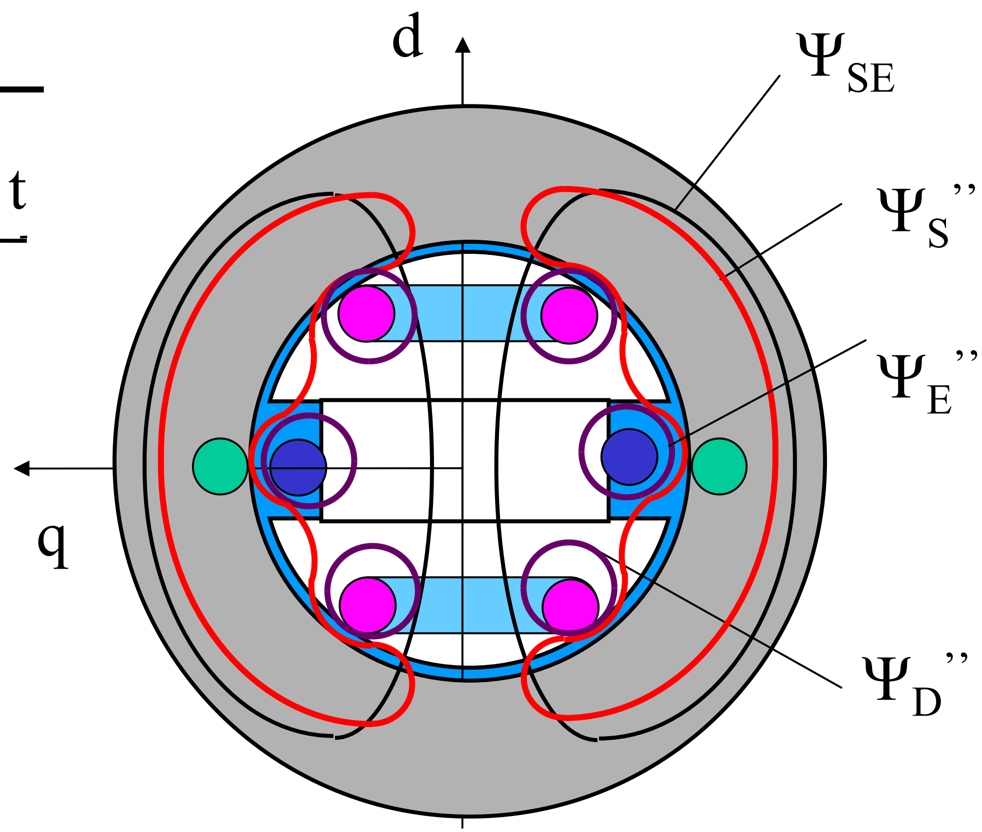
$$G_E(p) = \frac{X_{md}}{X_E} T_{E0} \frac{1 + p\cdot T_{D0}\left(1 - \frac{X_{md}^2}{X_D \cdot X_E}\right)}{\left(1 + p\cdot T_{d0}^{'}\right)\cdot\left(1 + p\cdot T_{d0}^{''}\right)}$$

Scurtcircuit brusc

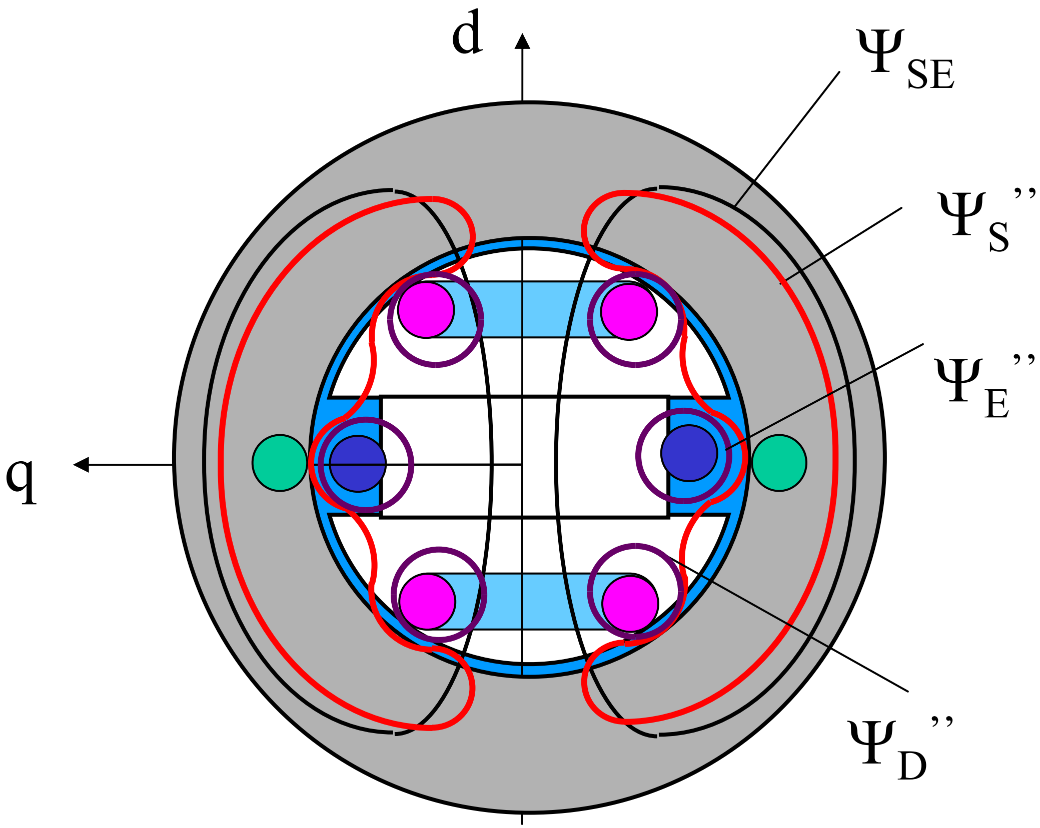


Scurtcircuit brusc

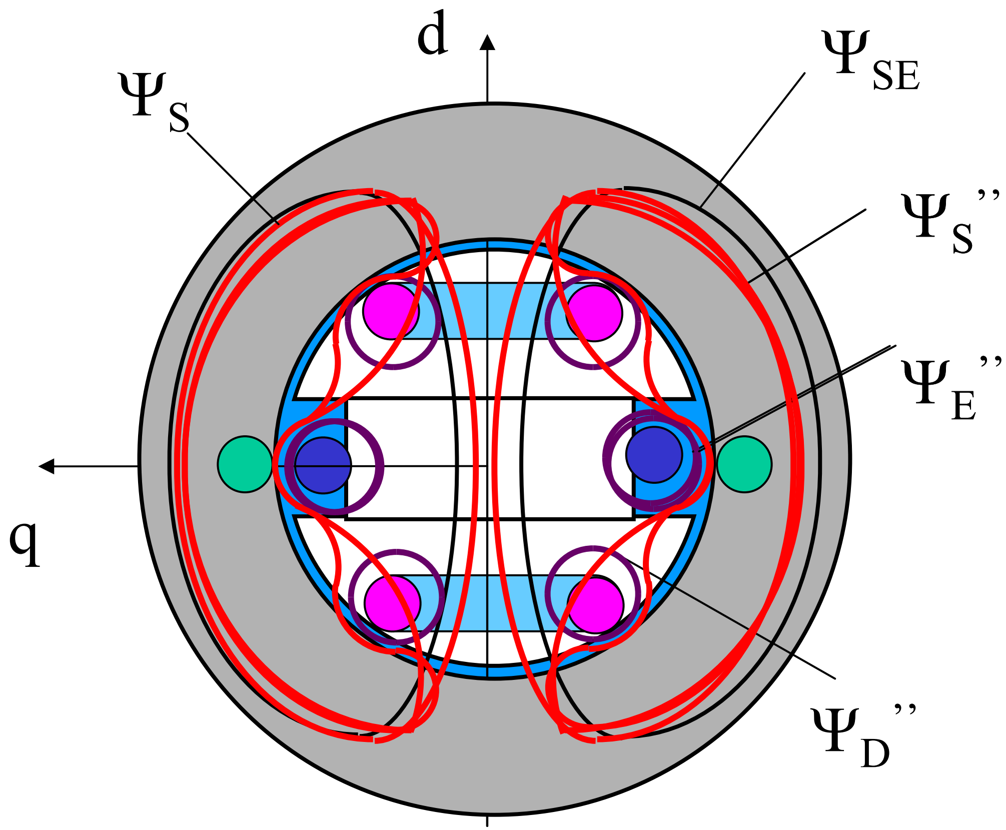




Scurtcircuit brusc



Scurtcircuit brusc



Scurtcircuit trifazat brusc

$$u_d = R_S \cdot i_d + \frac{\partial \Psi_d}{\partial t} - \omega \cdot \Psi_q$$

$$u_q = R_S \cdot i_q + \frac{\partial \Psi_q}{\partial t} + \omega \cdot \Psi_d$$

$$u_E = R_E \cdot i_E + \frac{\partial \Psi_E}{\partial t}$$

$$0 = R_D \cdot i_D + \frac{\partial \Psi_D}{\partial t}$$

$$0 = R_Q \cdot i_Q + \frac{\partial \Psi_Q}{\partial t}$$

$$\Rightarrow$$

$$0 = R_S \cdot i_d + \frac{\partial \Psi_d}{\partial t} - \omega \cdot \Psi_q$$

$$0 = R_S \cdot i_q + \frac{\partial \Psi_q}{\partial t} + \omega \cdot \Psi_d$$

$$u_E = R_E \cdot i_E + \frac{\partial \Psi_E}{\partial t}$$

$$0 = R_D \cdot i_D + \frac{\partial \Psi_D}{\partial t}$$

$$0 = R_Q \cdot i_Q + \frac{\partial \Psi_Q}{\partial t}$$

$$\Psi_{dm} = M_d \cdot i_{dm}; \quad i_{dm} = i_d + i_E$$

$$\Psi_{qm} = M_q \cdot i_{qm}; \quad i_{qm} = i_q$$

$$i_d = 0; \quad i_q = 0$$

$$\Psi_{dm} = M_d \cdot i_{dm}; \quad i_{dm} = i_E$$

$$\Psi_{qm} = 0; \quad i_{qm} = 0$$

$$u_q = \omega \cdot \Psi_d$$

Scurtcircuit trifazat brusc

$$0 = R_S \cdot I_d + p \cdot \left(\Psi_d - \frac{\Psi_{d0}}{p} \right) - \omega \cdot \Psi_q$$

$$0 = R_S \cdot I_q + p \cdot \left(\Psi_q - \frac{\Psi_{q0}}{p} \right) + \omega \cdot \Psi_d$$

$$U_E = R_E \cdot I_E + p \cdot \left(\Psi_E - \frac{\Psi_{E0}}{p} \right)$$

$$0 = R_D \cdot I_D + p \cdot \left(\Psi_D - \frac{\Psi_{D0}}{p} \right)$$

$$0 = R_Q \cdot I_Q + p \cdot \left(\Psi_Q - \frac{\Psi_{Q0}}{p} \right)$$

Dacă $i_S = 0$

$$i_d = 0\,; \quad i_q = 0$$

$$\Psi_{dm} = M_d \cdot i_{dm}\,; \quad i_{dm} = i_E$$

$$\Psi_{qm} = 0\,; \quad i_{qm} = 0$$

$$0 = R_S \cdot I_d + p \cdot \left(\Psi_d - \frac{\Psi_{d0}}{p} \right) - \omega \cdot \Psi_q$$

$$0 = R_S \cdot I_q + p \cdot \Psi_q + \omega \cdot \Psi_d$$

$$I_E - \frac{U_E}{p \cdot R_E} = -p \cdot G_E(p) \cdot I_d$$

$$\left(\Psi_d - \frac{\Psi_{d0}}{p} \right) = X_d(p) \cdot I_d$$

$$\Psi_q = X_q(p) \cdot I_q$$

Scurtcircuit trifazat brusc

Eliminând fluxurile, ținând seama de $\Psi_{d0} = \frac{U_q}{\omega}$

Ecuațiile devin:

$$\left[R_S + X_d(p)\right] \cdot I_d - \omega \cdot X_q(p) \cdot I_q = 0$$

$$\omega \cdot X_d(p) \cdot I_d + \left[R_S + X_q(p)\right] \cdot I_q = -\frac{U_{q0}}{p}$$

Soluția:

$$I_d(p) = -\frac{U_{q0}}{p} \frac{\omega \cdot X_q(p)}{N(p)}$$

$$I_q(p) = -\frac{U_{q0}}{p} \frac{R_S + p \cdot X_d(p)}{N(p)}$$

$$N(p) = \left[p \cdot X_d(p) + R_S\right] \cdot \left[p \cdot X_q(p) + R_S\right] + X_d(p) \cdot X_q(p)$$

Datele maşinii sincrone

$$X_d = 12{,}08 \quad \Omega$$

$$X_d'' = 2{,}064 \quad \Omega$$

$$X_d' = 2{,}658 \quad \Omega$$

$$X_q = 8{,}0 \quad \Omega$$

$$X_q'' = 2{,}847 \quad \Omega$$

$$T_d'' = 0{,}033 \quad s$$

$$T_d' = 0{,}1 \quad s$$

$$T_q'' = 0{,}040 \quad s$$

$$T_a = 0{,}022 \quad s$$

$$E_0 = U_q = 286{,}4\,V$$

$$I_N = 7{,}5 \quad A$$

Scurtcircuit brusc

Curentul de scurtcircuit în coordonate sincrone (legat de câmp)

staționar

tranzitoriu

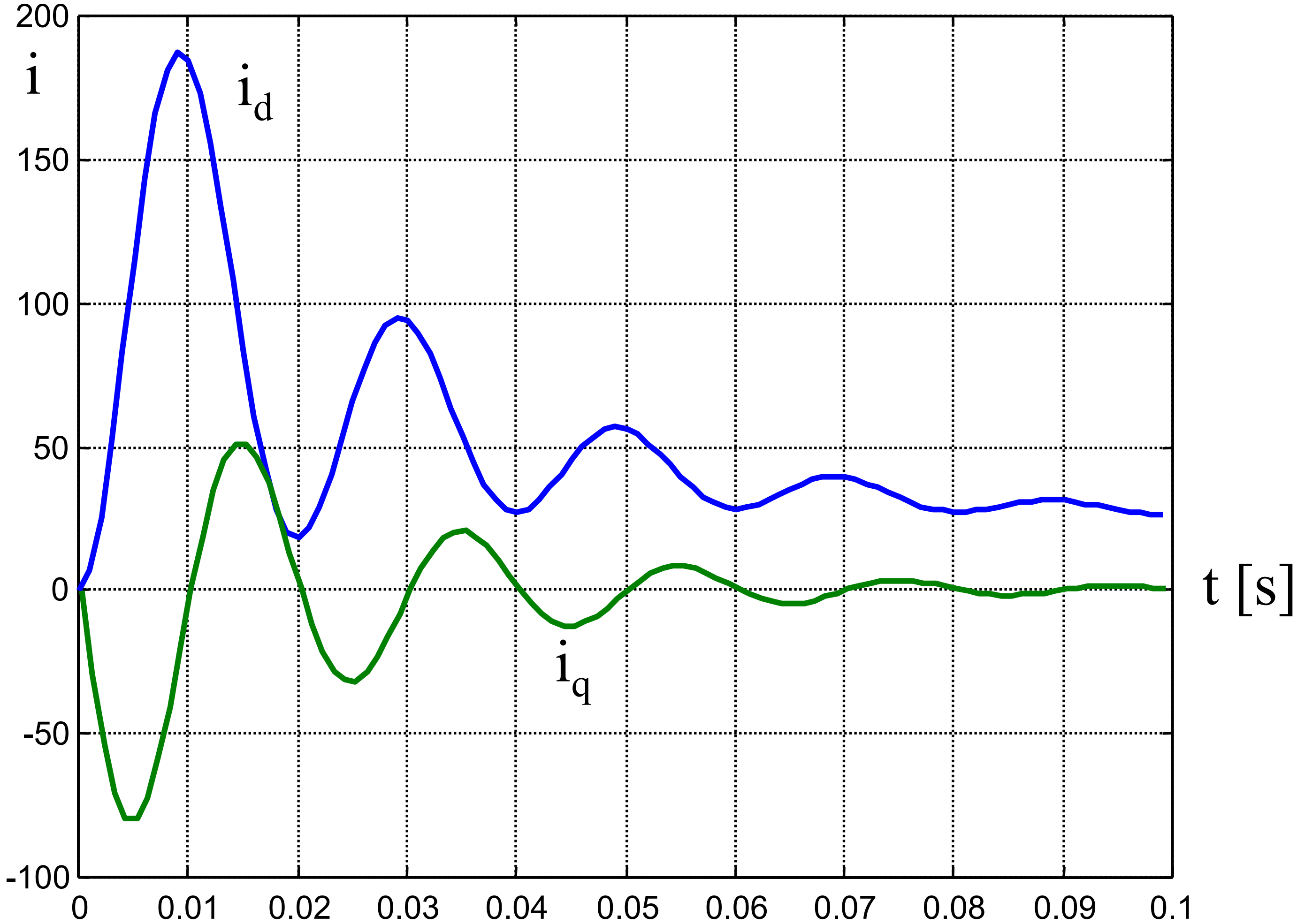
subtranzitoriu

$$i_d(t) = -u_{q0}\left\{\frac{1}{X_d} + \left(\frac{1}{X_d^{'}} - \frac{1}{X_d}\right)\cdot e^{-\frac{t}{T_d^{'}}} + \left(\frac{1}{X_d^{''}} - \frac{1}{X_d^{'}}\right)\cdot e^{-\frac{t}{T_d^{''}}} - \frac{1}{X_d^{''}} e^{-\frac{t}{T_a}} \cdot \sin(\omega \cdot t)\right\}$$

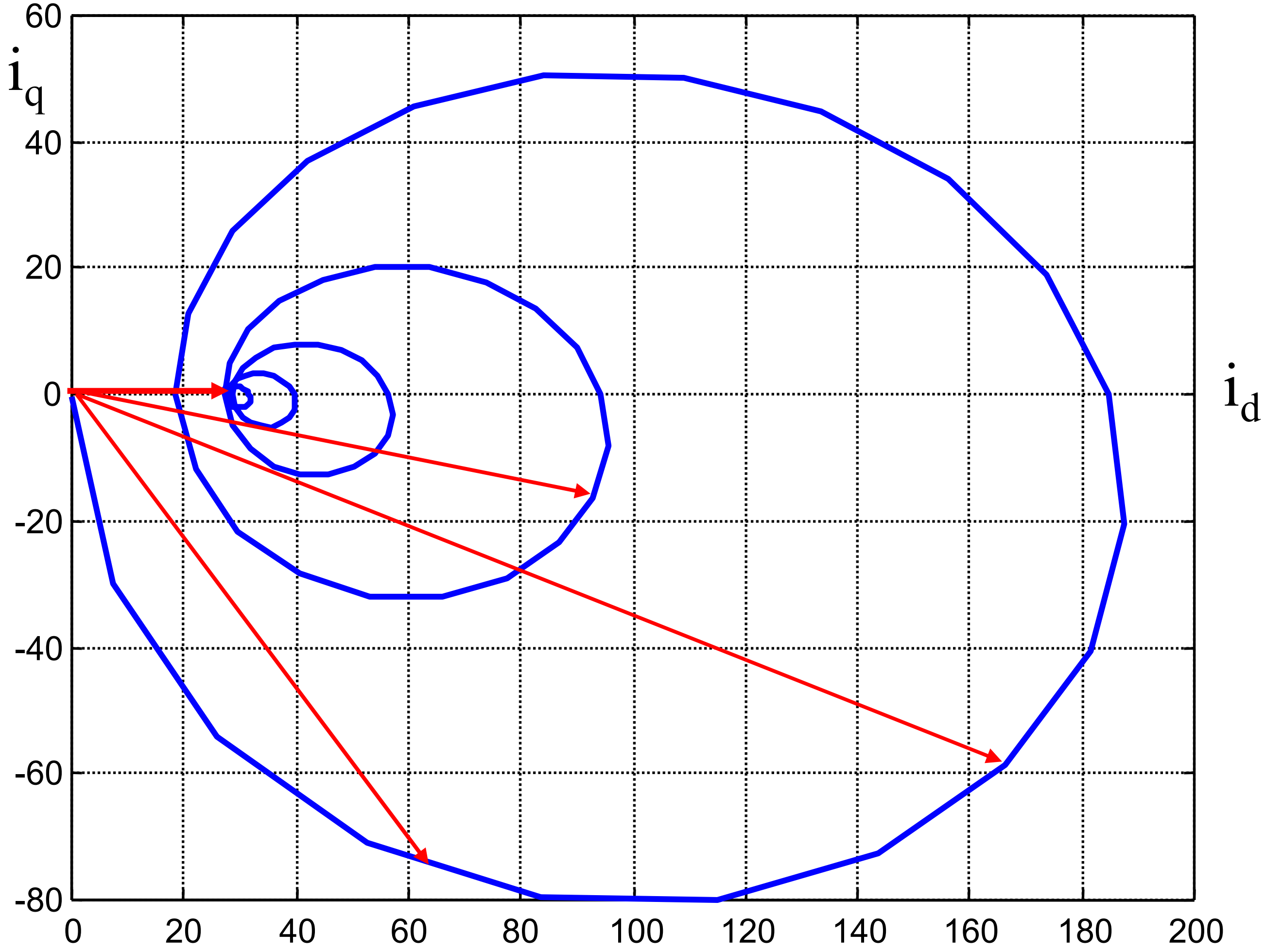
Asimetric(aperiodic)

$$i_q(t) \cong -u_q \frac{1}{X_q^{''}} e^{-\frac{t}{T_a}} \cdot \sin(\omega \cdot t)$$

Curenții i_d si i_q la scurtcircuit brusc



Fazorul curentului la scurtcircuit brusc



Scurtcircuit trifazat brusc

staționar

tranzitoriu

subtranzitoriu

$$i_a = -u_{q0}\left\{\left[\frac{1}{X_d} + \left(\frac{1}{X_d^{'}} - \frac{1}{X_d}\right)\cdot e^{-\frac{t}{T_d^{'}}} + \left(\frac{1}{X_d^{''}} - \frac{1}{X_d^{'}}\right)\cdot e^{-\frac{t}{T_d^{''}}}\right]\cdot \cos(\omega\cdot t + \gamma)\right.$$

$$-\frac{1}{2}\left(\frac{1}{X_d^{''}} - \frac{1}{X_q^{''}}\right)\cdot e^{-\frac{t}{T_a}}\cdot \cos\gamma$$

Asimetric(aperiodic)

$$\left.-\frac{1}{2}\left(\frac{1}{X_d^{''}} - \frac{1}{X_q^{''}}\right)\cdot e^{-\frac{t}{T_a}}\cdot \cos(2\cdot\omega\cdot t + \gamma)\right\}$$

Dublă frecvență

Curentul de scurtcircuit în sistemul de coordonate fix.

Scurtcircuit brusc

Valori inițiale:

$$I_{sc}^{''} = \sqrt{2} \cdot \frac{E_0}{X_d^{''}} \cos\gamma$$

subtranzitorie

$$I^{''} = 138{,}76 \quad A$$

$$I^{'} = 107{,}67 \quad A$$

$$I_a = -119{,}67 \; A$$

$$I_{2f} = -19{,}09 \; A$$

$$I = 23{,}71 \quad A$$

$$I_a = -\frac{\sqrt{2}}{2} E_0 \cdot \left(\frac{1}{X_q^{''}} + \frac{1}{X_d^{''}} \right) \cdot \cos\gamma$$

aperiodic

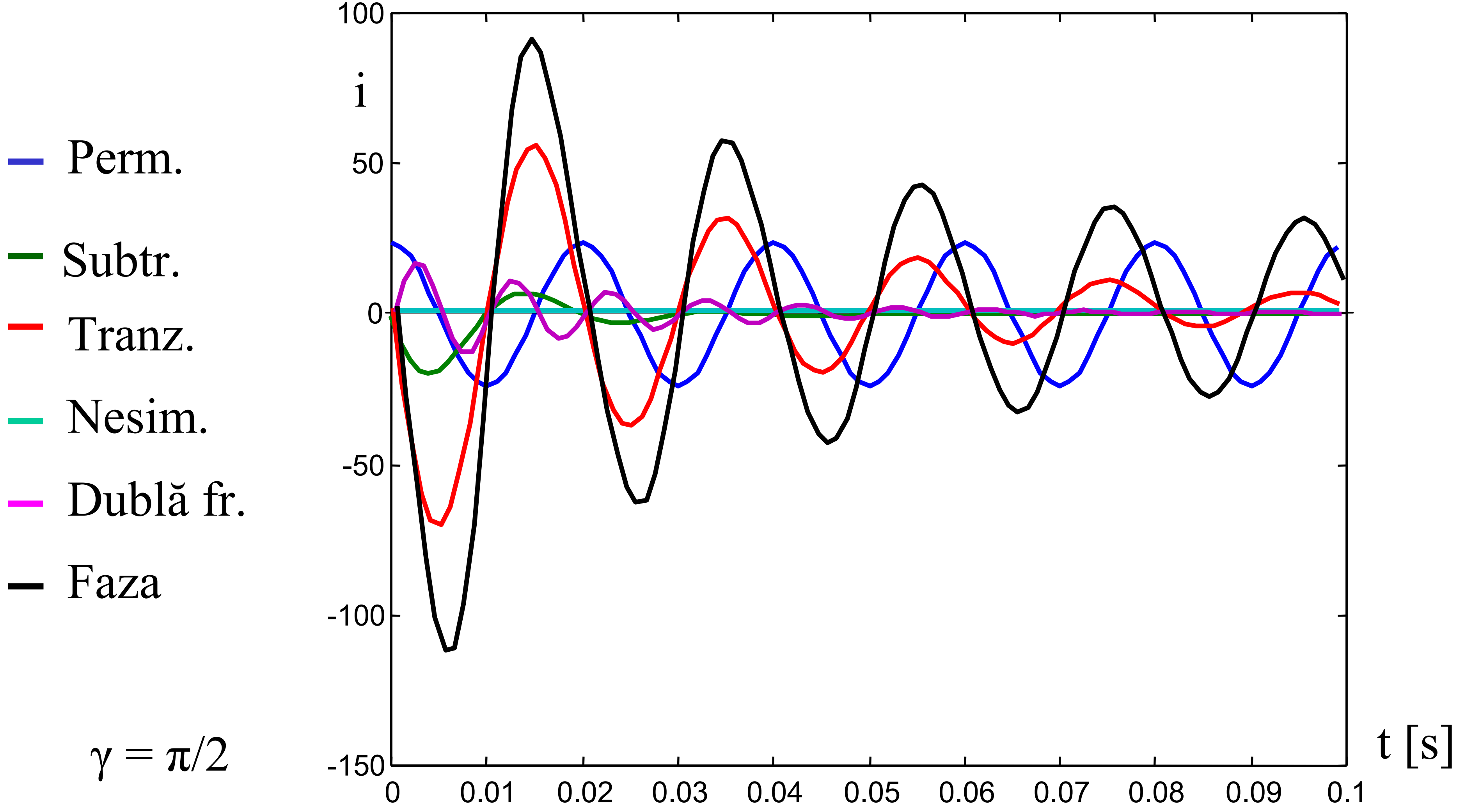
$$I_{2f} = \frac{\sqrt{2}}{2} E_0 \cdot \left(\frac{1}{X_q^{''}} - \frac{1}{X_d^{''}} \right) \cdot \cos\gamma$$

frecvență dublă

$$I_{sc}^{'} = \sqrt{2} \frac{E_0}{X_d^{'}} \cos\gamma$$

tranzitorie

Curentul de scurtcircuit brusc

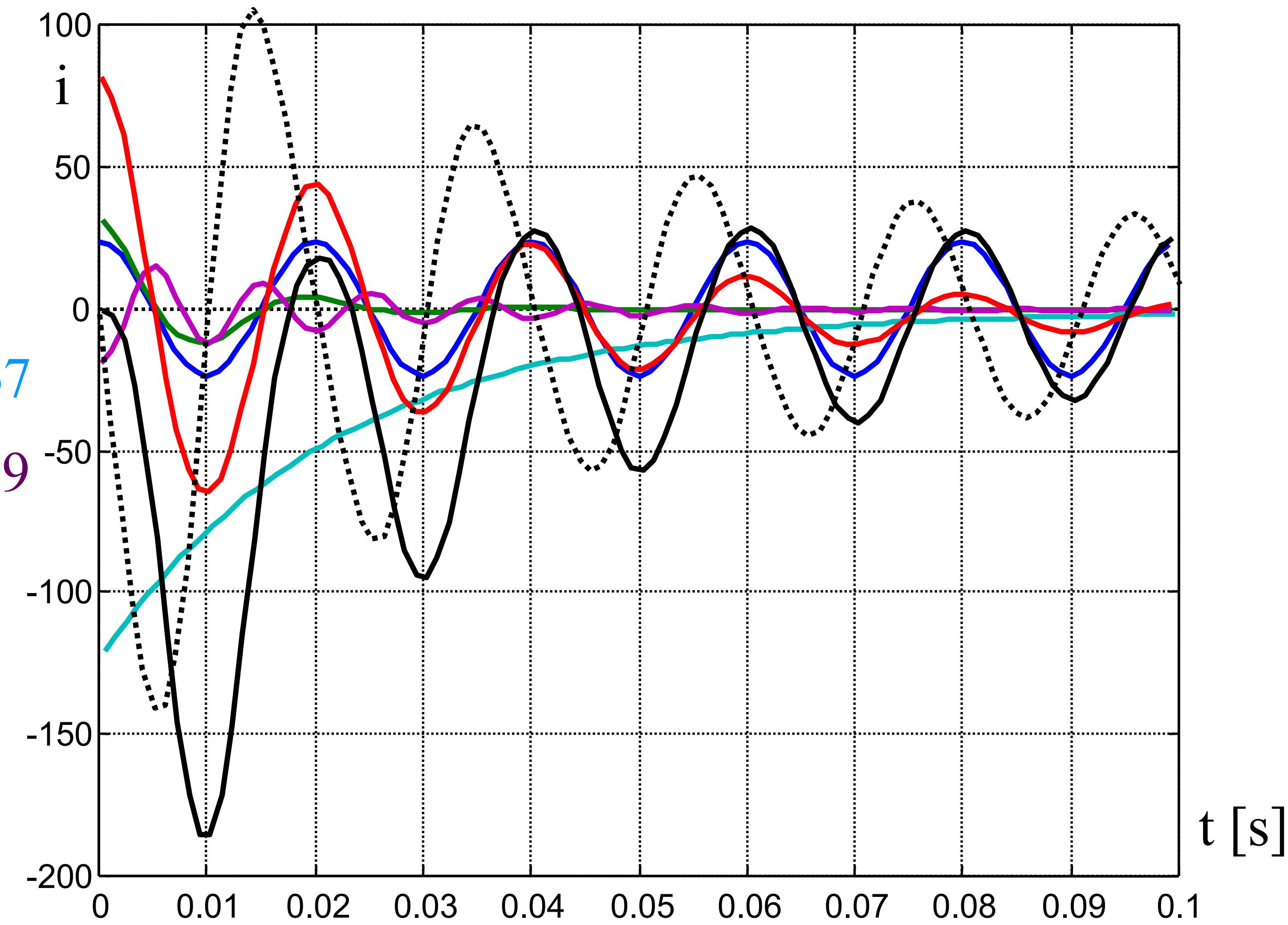


Curentul de scurtcircuit brusc

Valori inițiale:

- Perm. 23,71
- Subtr. 31,09
- Tranz. 83,96
- Nesim. -119,67
- Dublă fr.-19,09
- Faza

$\gamma = 0$



Scurtcircuit brusc

Curentul de excitație,

dacă nu se schimbă tensiunea, atunci

$$I_E - \frac{I_{E0}}{p} = -p\cdot G_E(p)\cdot I_d(p)$$

$$I_E - \frac{I_{E0}}{p} = I_{E0}\left(\frac{X_d}{X_d^{'}}-1\right)\frac{1}{p+\frac{1}{T_d^{'}}}\frac{1}{p^2+p\frac{2}{T_a}+1}$$

staționar

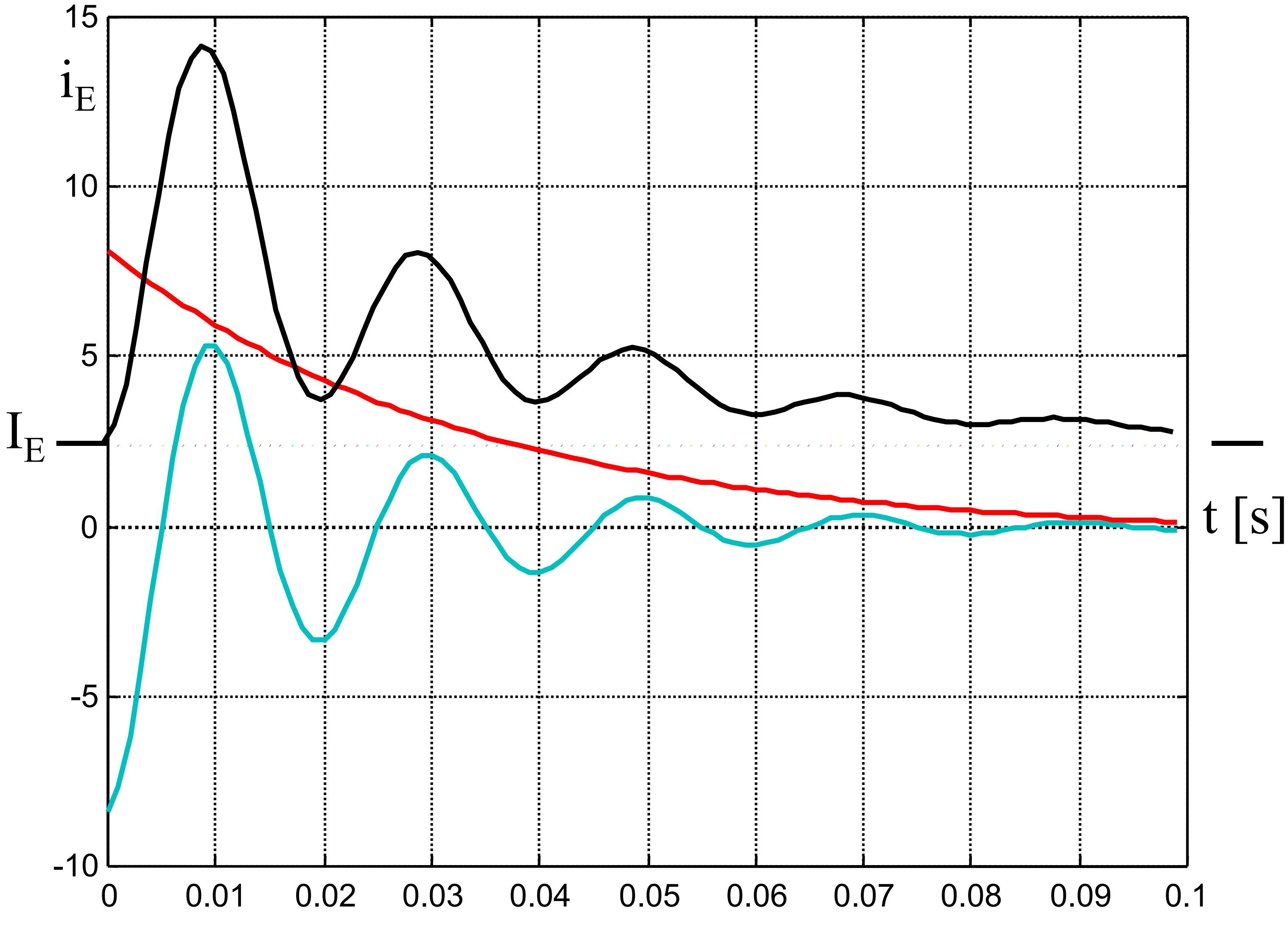
$$i_E = I_{E0}\left\{1+\left(\frac{X_d}{X_d^{'}}-1\right)\cdot e^{-\frac{t}{T_d^{'}}} - \left(\frac{X_d}{X_d^{'}}-1\right)\cdot e^{-\frac{t}{T_a}}\cdot\cos(\omega\cdot t)\right\}$$

aperiodic

tranzient

periodic

Curentul de excitație la scurtcircuit brusc



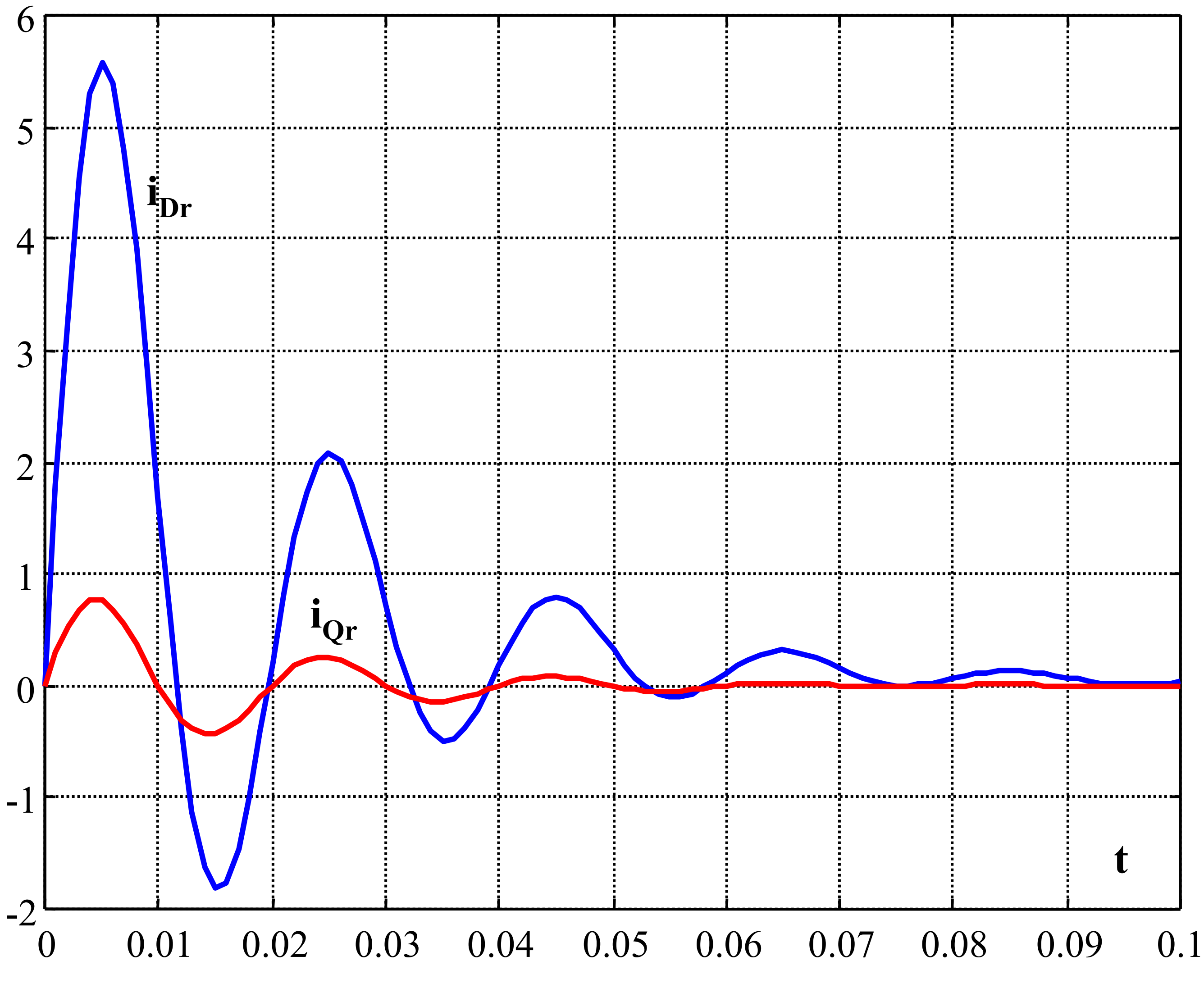
Scurtcircuit brusc

Curenții din înfășurările de amortizare

$$I_D = -\frac{M_d}{L_D}\frac{p\cdot T_{D0}}{1+p\cdot T_{D0}}\left[\left(i_d - \frac{I_{d0}}{p}\right)+\left(i_E - \frac{U_E}{p\cdot R_E}\right)\right]$$

$$I_Q = -\frac{X_{mq}}{X_Q}\frac{p\cdot T_{Q0}}{1+p\cdot T_{Q0}}\left(I_q - \frac{I_{q0}}{p}\right)$$

Curenții din înfășurările de amortizare



Scurtcircuit brusc nesimetric

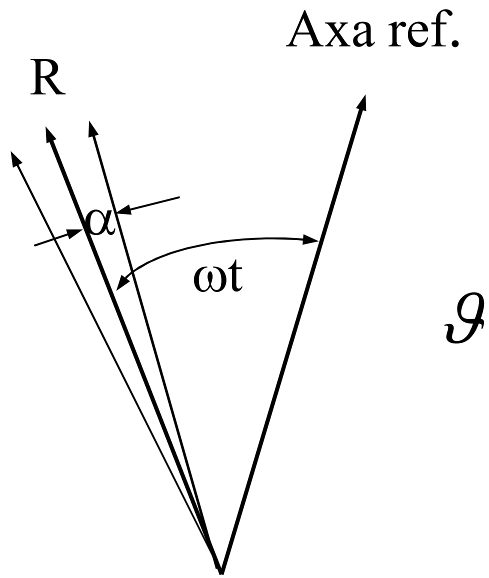
Scurtcircuit nesimetric

$$I''_{sc2} = \sqrt{2}\,\frac{\sqrt{3}\cdot E_0}{X''_d + X_i} \qquad I''_{sc1} = \sqrt{2}\,\frac{3\cdot E_0}{X''_d + X_i + X_h}$$

$$T'_{d2} = \frac{X'_d + X_i}{X_d + X_i} T'_{d0} \qquad T'_{d1} = \frac{X'_d + X_i + X_h}{X_d + X_i + X_h} T'_{d0}$$

$$T_{a2} \approx T_a \qquad T_{a1} \cong \frac{2\cdot X_i + X_h}{3\cdot \omega \cdot R_S}$$

Oscilațiile mașinii sincrone



Ecuația mișcării:

$$\frac{J}{p}\frac{d^2\vartheta_s}{dt^2} = C - C_s$$

$$\vartheta = \omega \cdot t + \vartheta_0 + \alpha$$

Cuplul de sarcină

$$C_s = C_0 + C_r + \Delta C_r$$

$$\Delta C_r = \sum_{\nu=1} C_{\nu\max} \cdot \cos\left(\nu \cdot \Omega_S \cdot t - \varphi_\nu\right)$$

Cuplul electromagnetic

$$C = p \cdot \left(\Psi_d \cdot i_q - \Psi_q \cdot i_d\right)$$

Oscilațiile mașinii sincrone

Cuplul asincron

$$s = \frac{\omega_S - \frac{d\vartheta}{dt}}{\omega_S} = -\frac{1}{\omega_S}\frac{d\alpha}{dt}$$

$$C_{as} \cong 2 \cdot C_k \frac{s}{s_k} = -k_a \cdot \frac{d\alpha}{dt}$$

Cuplul sincron

$$C_s = C_{sm} + \frac{dC_s}{d\vartheta} \cdot \alpha + ...$$

Ecuația oscilațiilor

$$\frac{J}{p}\frac{d^2\alpha}{dt^2} = -C_{si} \cdot \alpha - k_a \cdot \frac{d\alpha}{dt} - \Delta C_r$$

$$\frac{J}{p}\frac{d^2\alpha}{dt^2} + k_a \cdot \frac{d\alpha}{dt} + C_{si} \cdot \alpha = -\Delta C_r$$

Oscilațiile mașinii sincrone

Oscilații (pendulări) libere.

- Mașina cuplată la rețea
- perturbația s-a terminat

$$\frac{J}{p}\frac{d^2\alpha}{dt^2}+k_a\cdot\frac{d\alpha}{dt}+C_{si}\cdot\alpha=0$$

Soluția

$$\alpha = A\cdot e^{\lambda\cdot t}$$

$$\lambda=-\frac{p\cdot k_a}{2\cdot J}\pm\sqrt{\left(\frac{p\cdot k_a}{2\cdot J}\right)^2-\frac{p\cdot C_{si}}{J}}=-\frac{1}{T_D}\pm j\cdot\omega_0$$

Frecvența oscilațiilor proprii

$$f_0=\frac{\omega_0}{2\cdot\pi}=\frac{1}{2\cdot\pi}\sqrt{\frac{p\cdot C_{si}}{J}}$$

Oscilațiile mașinii sincrone

<u>Oscilații forțate</u> - perturbația se menține

Mașina este cuplată la rețea

$$\frac{J}{p}\frac{d^2\alpha}{dt^2}+k_a\cdot\frac{d\alpha}{dt}+C_{si}\cdot\alpha=-\Delta C_r$$

Soluția:

$$\alpha_\nu=\alpha_{\nu m}\sin\left(\nu\cdot\Omega\cdot t-\varphi_\nu-\gamma_\nu\right)$$

Amplitudinea

$$\alpha_{\nu m}=\frac{\dfrac{C_{\nu m}}{\nu\cdot\Omega_s}}{\sqrt{k_a^2+\left(\dfrac{J}{p}\nu\cdot\Omega_s-\dfrac{C_{si}}{\nu\cdot\Omega_S}\right)^2}}$$

Faza

$$\gamma_\nu=arctg\,\frac{\dfrac{J}{p}\nu\cdot\Omega_s-\dfrac{C_{si}}{\nu\cdot\Omega_s}}{k_a}$$

Oscilațiile mașinii sincrone

Mașina nu este cuplată la rețea

$$\frac{J}{p}\frac{d^2\vartheta}{dt^2} = \Delta C_s$$

Oscilația:

$$\alpha_{\nu 0} = -\frac{C_{\nu m}}{J\cdot\left(\nu\cdot\Omega_s\right)^2}\cos\left(\nu\cdot\Omega_s\cdot t-\varphi_\nu\right)$$

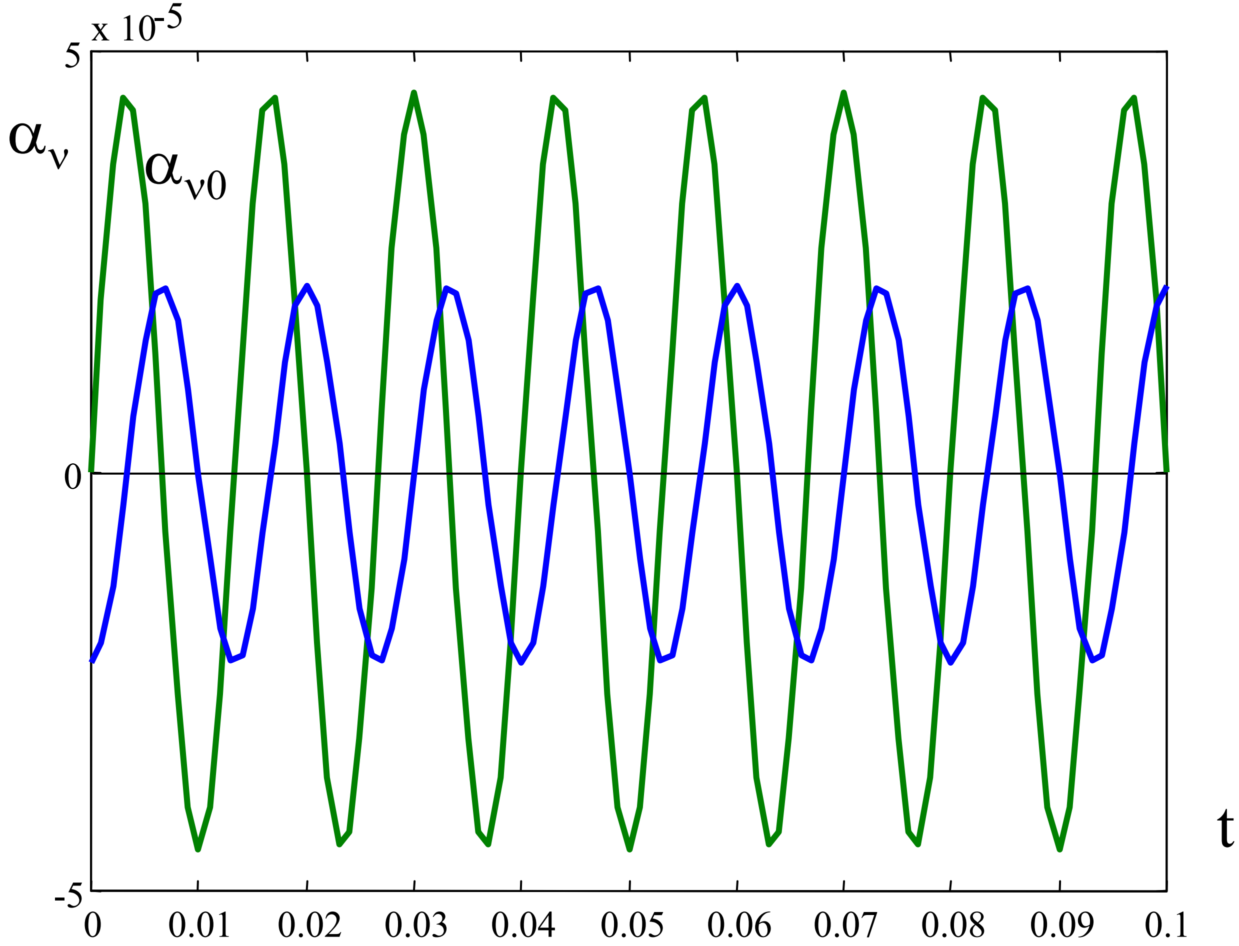
Viteza de rotație

$$\Omega_\nu = \Omega_s + \frac{1}{p}\frac{d\alpha_{\nu 0}}{dt} = \Omega_s + \frac{C_{\nu m}}{J\cdot\nu\cdot\Omega_s}\sin\left(\nu\cdot\Omega_s\cdot t-\varphi_\nu\right)$$

Grad de neregularitate

$$0.0125 \geq \delta_\nu \geq 0.005 \qquad \delta_\nu = \frac{\Omega_{\nu\max}-\Omega_{\nu\min}}{\Omega_{\nu med}} = \frac{2\cdot C_{\nu m}}{J\cdot\nu\cdot\Omega_s^2}$$

Oscilatiile fortate



Oscilațiile mașinii sincrone

Constanta de amortizare
$$d_\nu = \frac{p \cdot k_a}{J \cdot \nu \cdot \Omega_s}$$

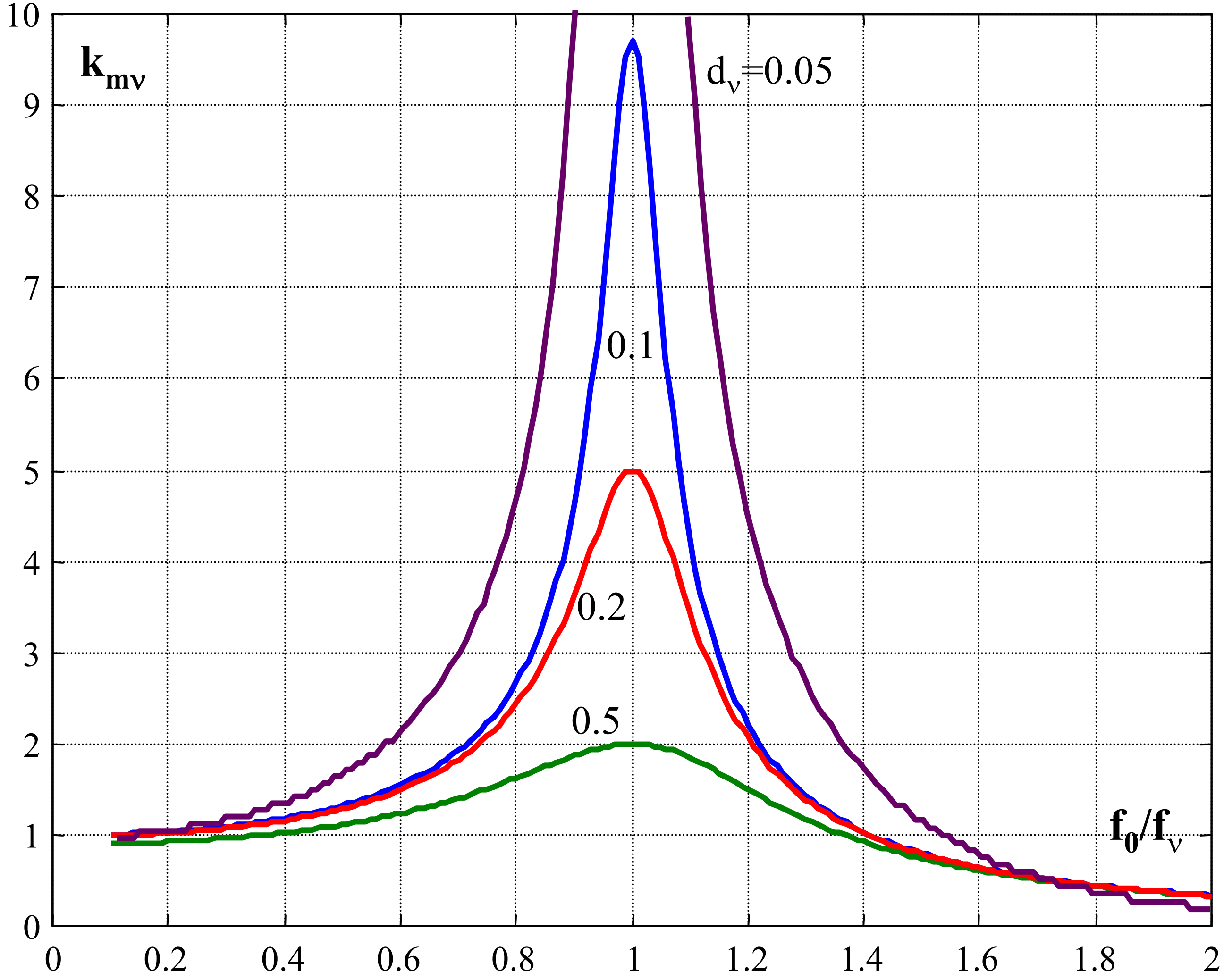
Frecvența oscilațiilor forțate
$$f_\nu = \frac{\nu \cdot \Omega_s}{2 \cdot \pi}$$

Modul de rezonanță mecanică

$$k_{m\nu} = \frac{\alpha_{\nu m}}{\alpha_{\nu 0m}} = \frac{1}{\sqrt{\left[1 - \left(\frac{f_0}{f_\nu}\right)^2\right]^2 + d_\nu^2}}$$

Rezonanța la $f_0 = f_\nu$

Modul de rezonanță mecanic



Funcționare sigură

$$0.8 \geq \frac{f_0}{f_\nu} \geq 1.25$$

Oscilațiile mașinii sincrone

Pendularea puterii electrice

$$\Delta P = \Omega_s \cdot \Delta C = \Omega_s \cdot \left(k_a \cdot \frac{d\alpha_\nu}{dt} + C_{si} \cdot \alpha_\nu \right)$$

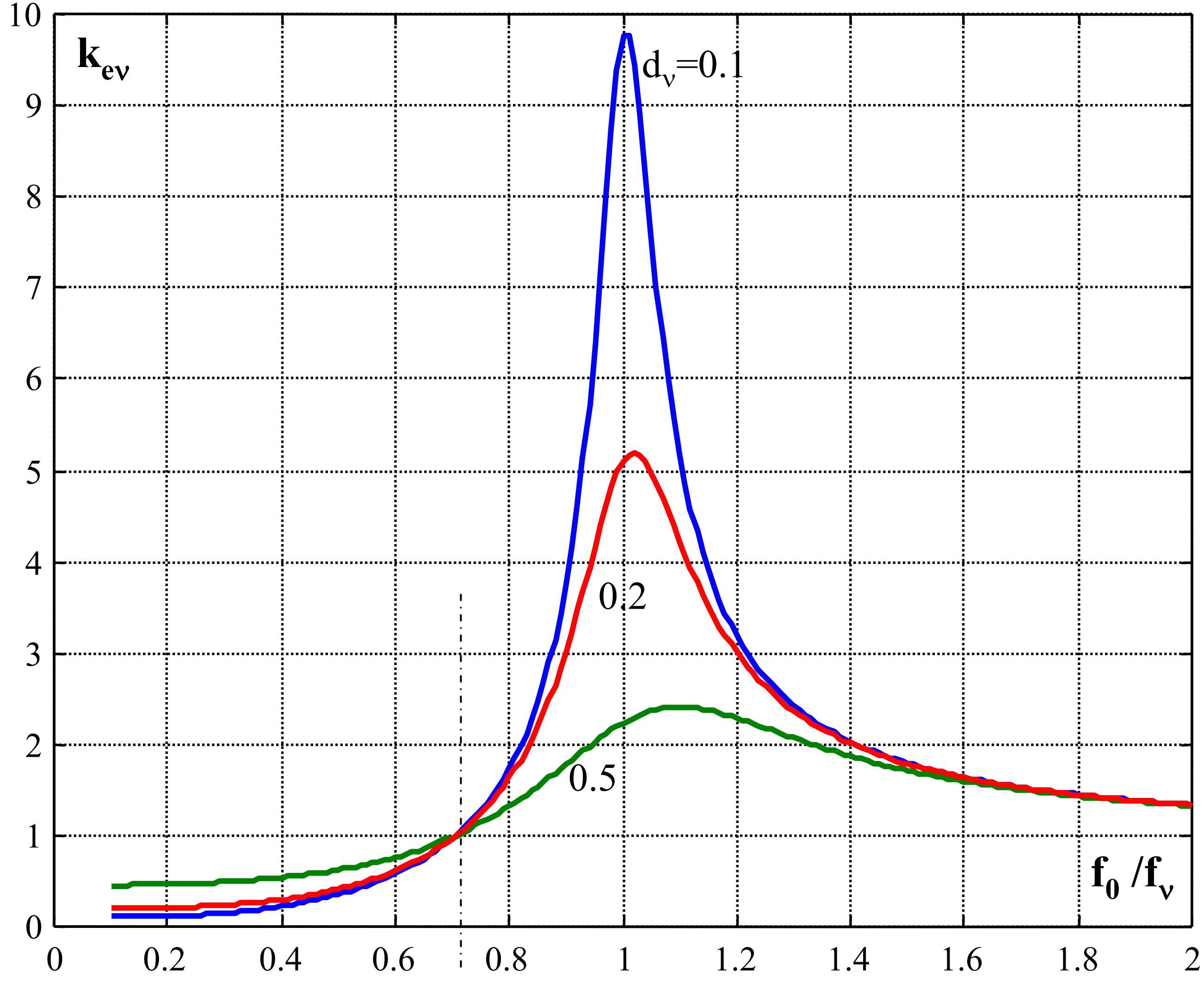
Pendularea puterii mecanice

$$\Delta P_m = \Omega_s \cdot \Delta C_r = \Omega_s \cdot C_{\nu m} \cdot \cos\left(\nu \cdot \Omega_s \cdot t - \varphi_\nu\right)$$

Modulul de rezonanță electrică

$$k_{e\nu} = \frac{\Delta P_{\max}}{\Delta P_{m\max}} = \sqrt{\frac{d_\nu^2 + \left(\frac{f_0}{f\nu}\right)^4}{d_\nu^2 + \left[1 - \left(\frac{f_0}{f_\nu}\right)^2\right]^2}}$$

Modul de rezonanță electrică



Oscilațiile mașinii sincrone

Pentru $\frac{f_0}{f_\nu} = \frac{1}{\sqrt{2}}$ $k_{e\nu} = 1$

Pentru $\frac{f_0}{f_\nu} > \frac{1}{\sqrt{2}}$ Puterea electrică pendulată este mai mare decât cea mecanică - este necesară amortizarea

Pentru $\frac{f_0}{f_\nu} < \frac{1}{\sqrt{2}}$ Puterea electrică este mai mică decât cea mecanică - nu este necesară amortizare, chiar dezavantajoasă.

Pentru $\frac{f_0}{f_\nu} < 0.3$ Funcționarea este acceptabilă