MONITORIZARE SI DIAGNOZA IN SISTEME ELECTROMECANICE

TERMENI UZUALI:

situaţie de defect - **deteriorarea sau întreruperea capacităţii unui sistem de a asigura o funcţie cerută în condiţiile de funcţionare specificate**

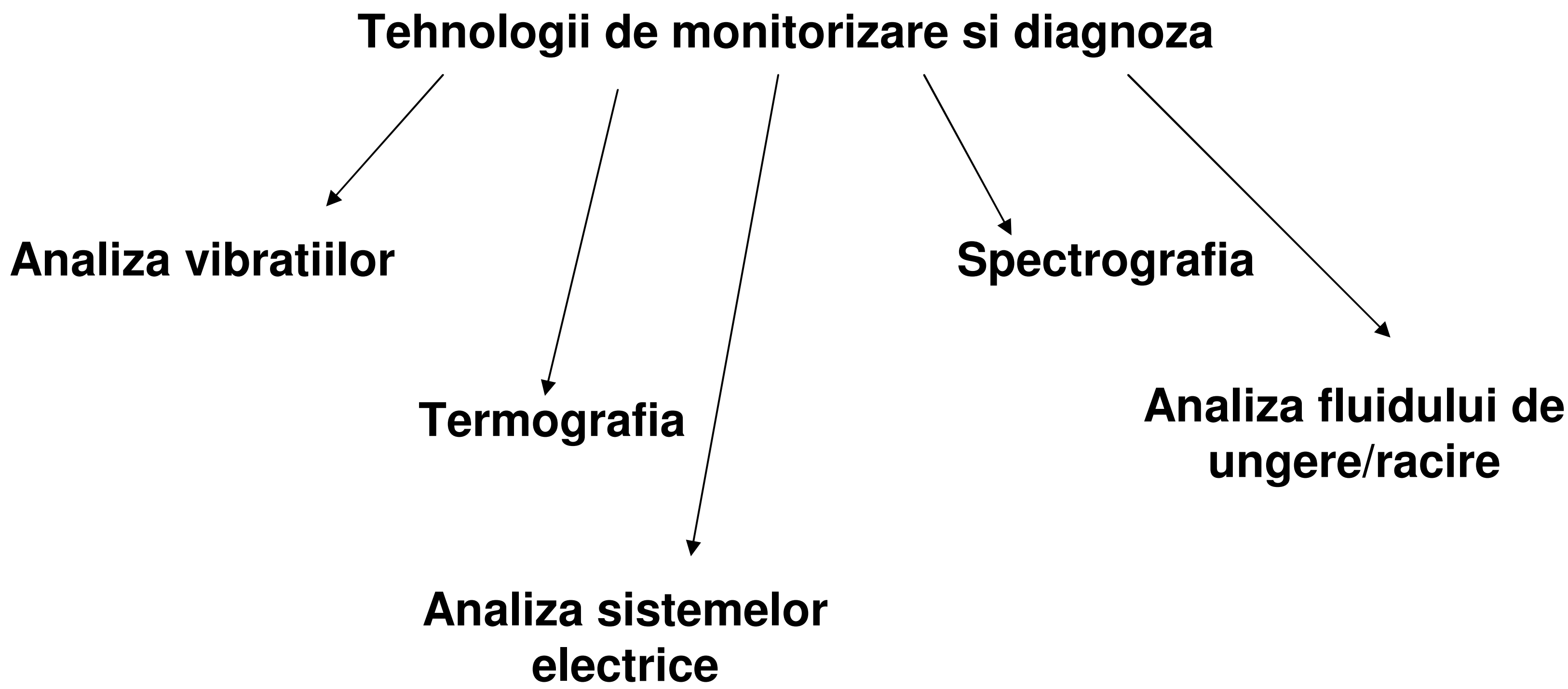
diagnoza - include etapele de izolare şi identificare a defectelor

determinarea tipului de defect, a locului de producere a defectului şi a momentului de detectare

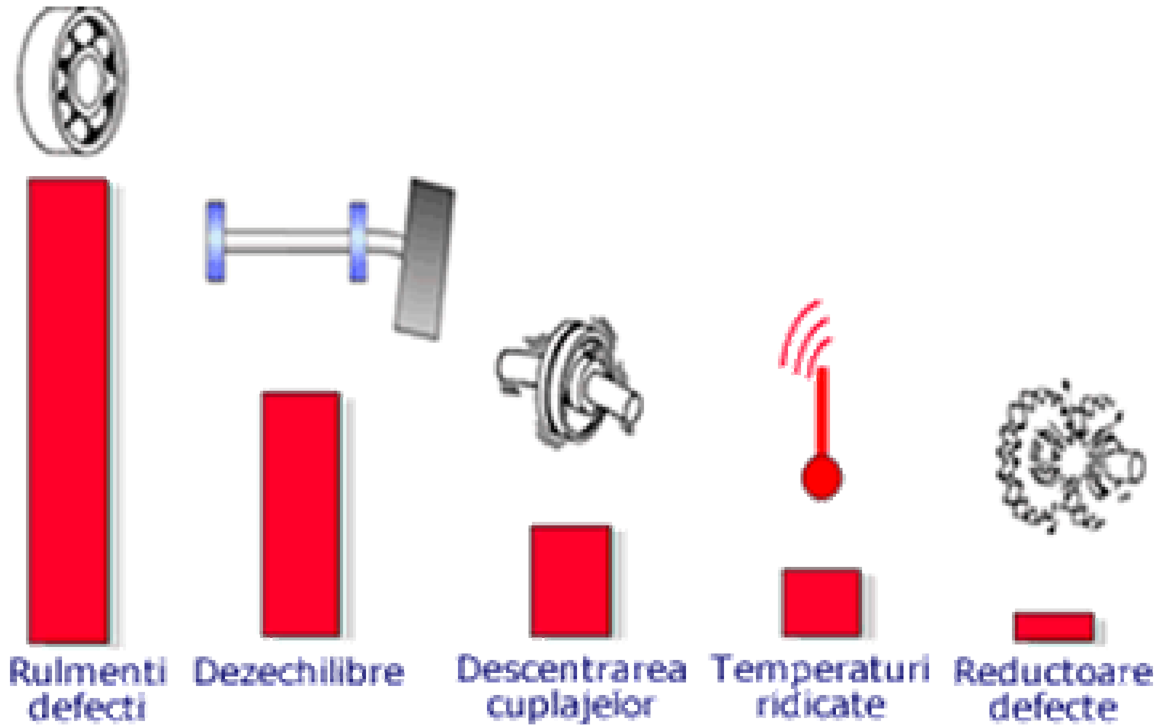
determinarea mărimii şi comportării în timp a defectului, respectiv a cauzei care a generat defectarea constatată.

Modul de monitorizare a stării sistemului **(condition monitoring module):**

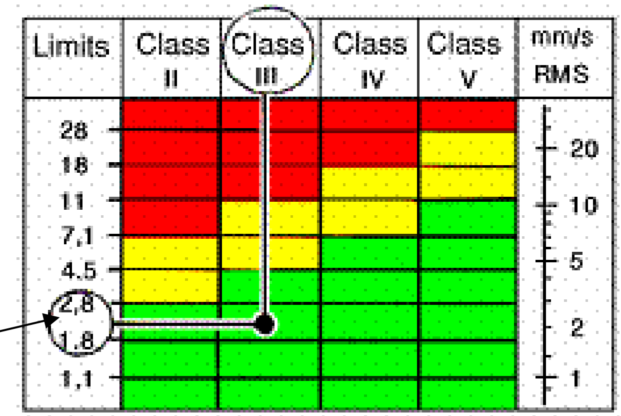
ansamblul tuturor echipamentelor care asigură preluarea şi analiza semnalelor din sistem, detecția şi diagnoza defectelor

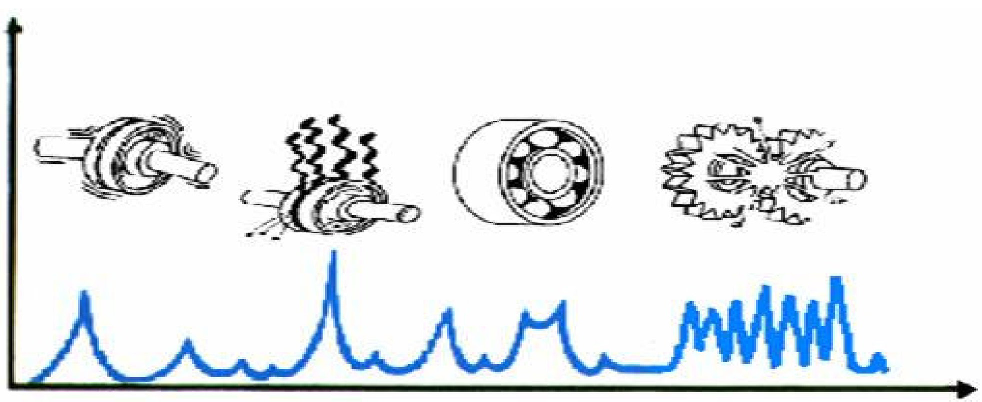


ANALIZA VIBRATIILOR



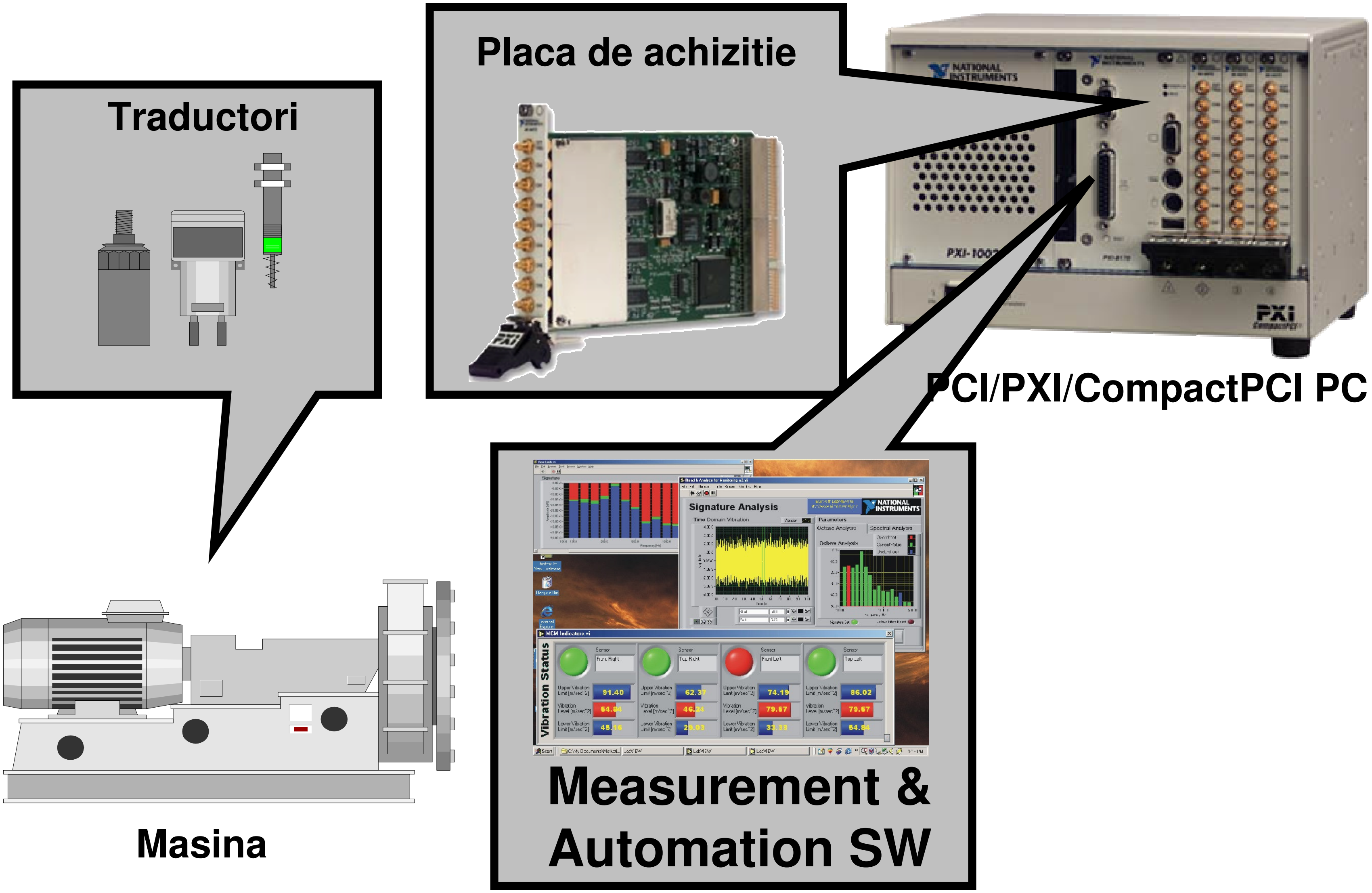
acccelerometru



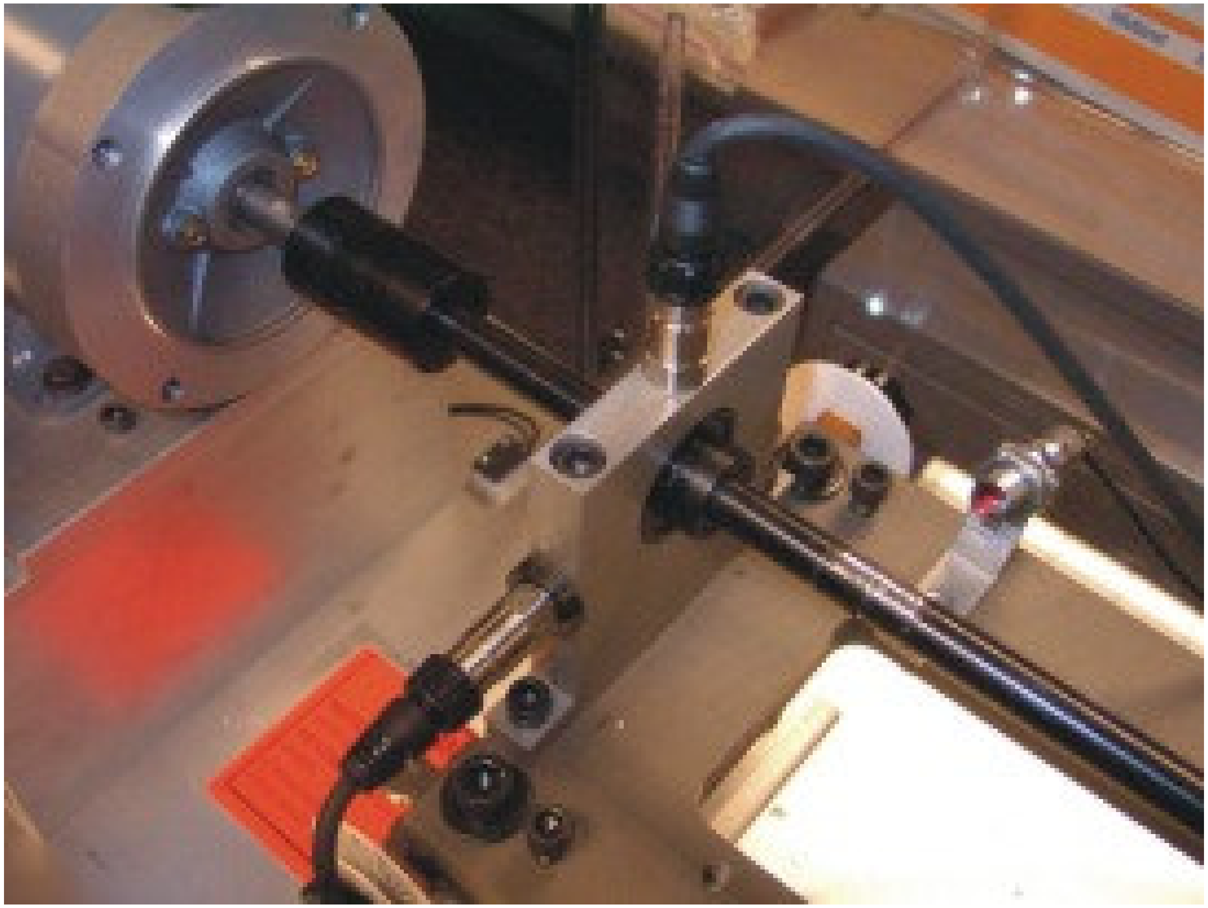


Fiecare tip de defect se regaseste in anumite frecvente in spectrum vibratiilor

Sistem de monitorizare si diagnoza



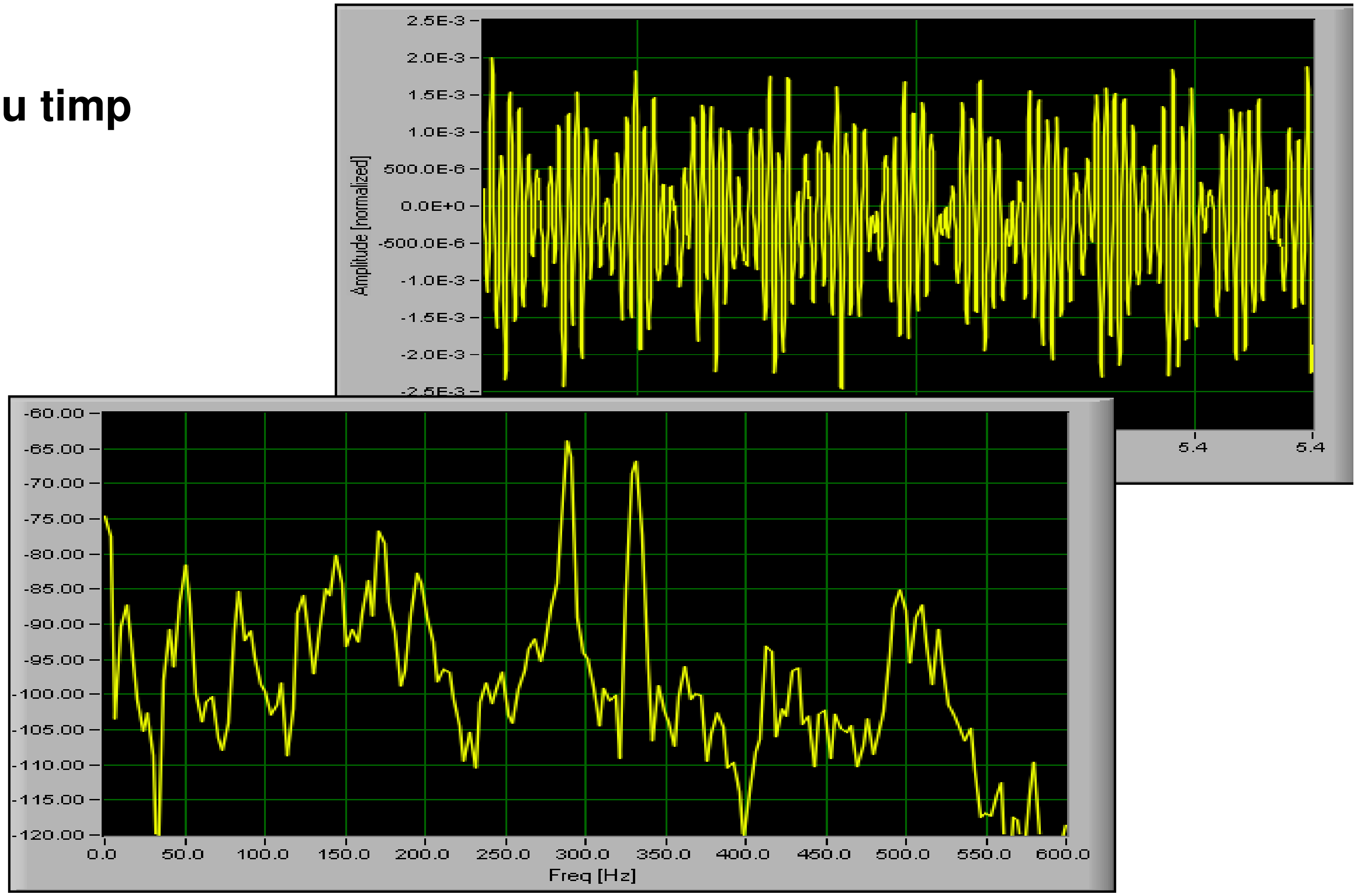
Pozitionarea accelerometrului



Procesarea semnalului

Domeniu timp

Domeniu frecventa



ANALIZA TEMPERATURII

Utilizand traductori de temperatura – termocuple, de exemplu

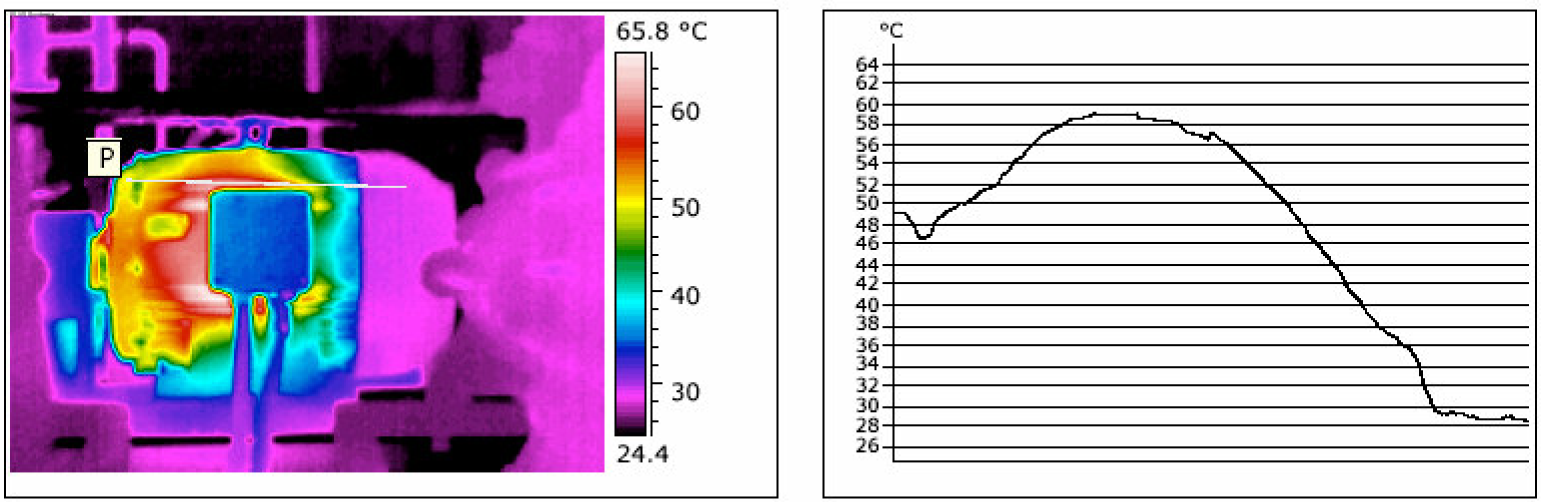
Utilizand camere cu infrarosu pentru vizualizarea si masurarea energiei termice

Termografia

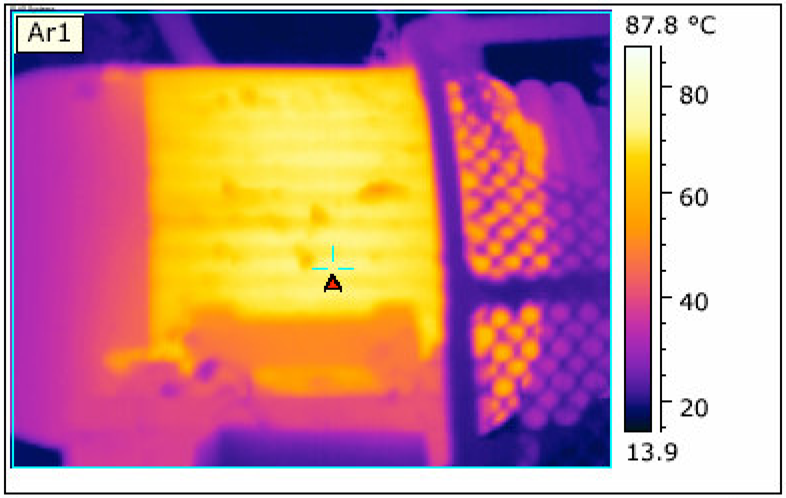
Se bazeaza pe faptul ca orice corp, cu temperatura peste sau sub 0℃ emite caldura.

Pentru motoarele electrice

- **Ventilatie blocata**
- **Suprasarcina**
- **Alimentare nesimetrica**

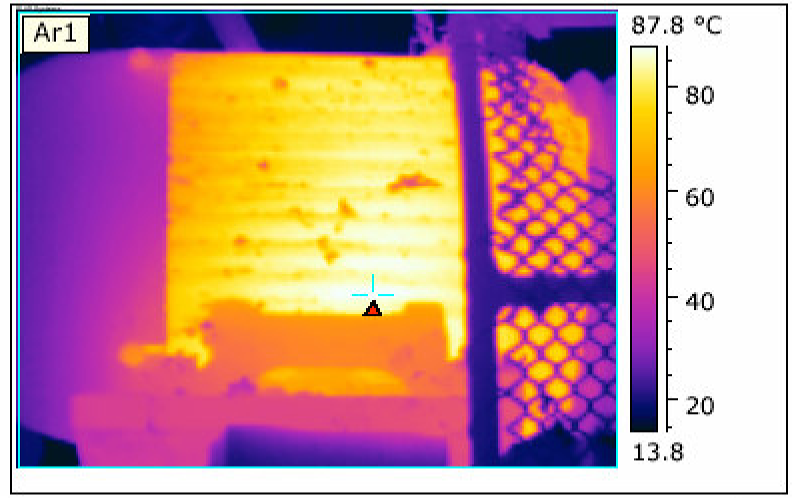


Termograma si profilul variatiei temperaturii la o ventilatie corespunzatoare



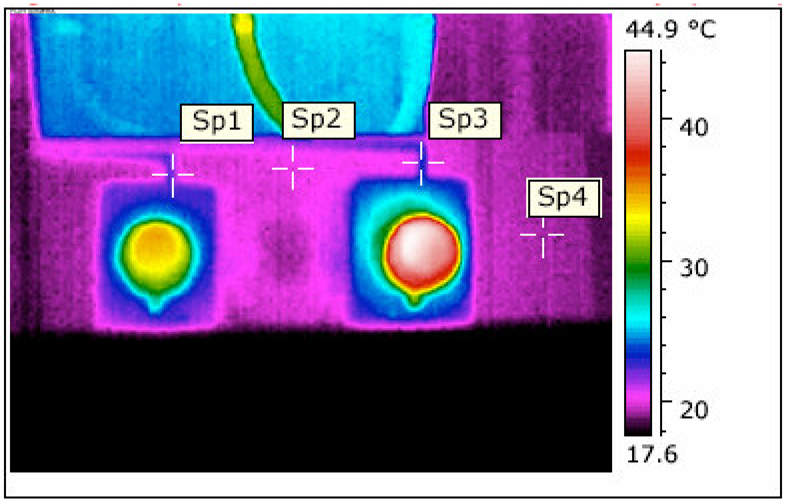
Label	Value
Ar1: Max	71.0 °C

Termograma la alimentare simetrica



Label	Value
Ar1: Max	82.3 °C

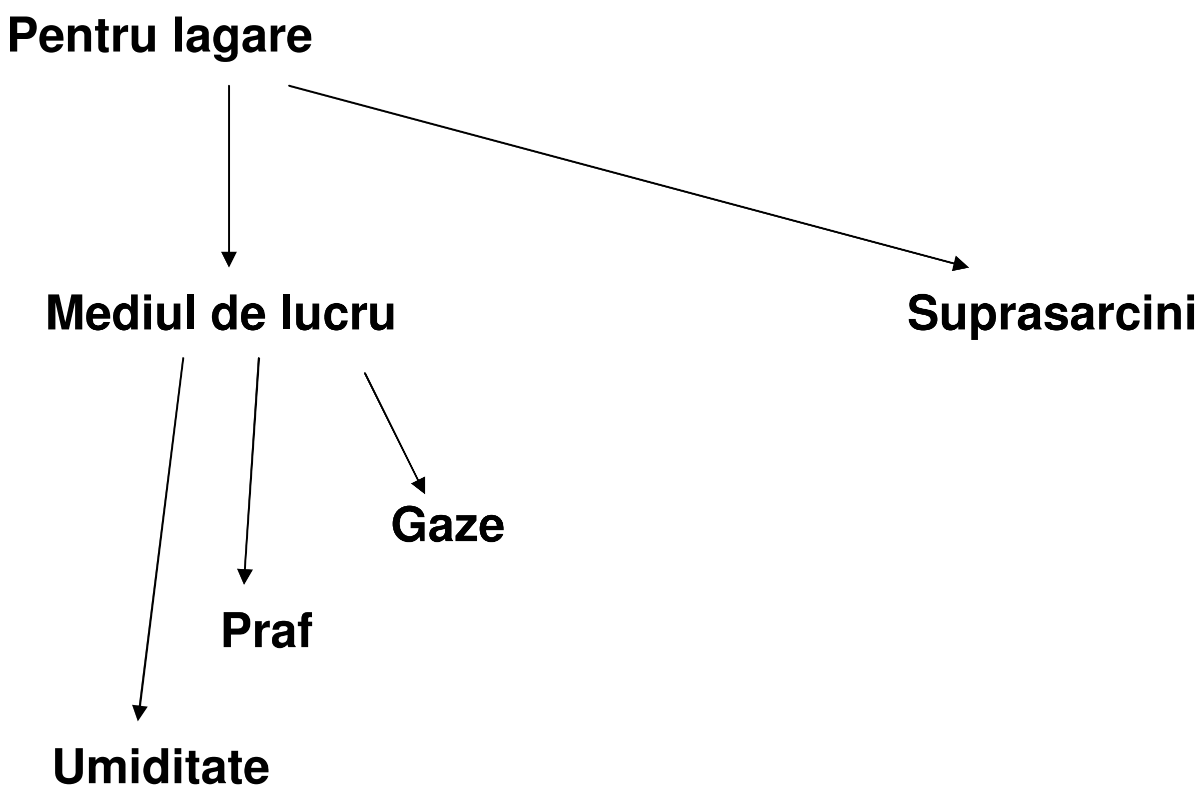
Termograma la alimentare nesimetrica – o faza nealimentata

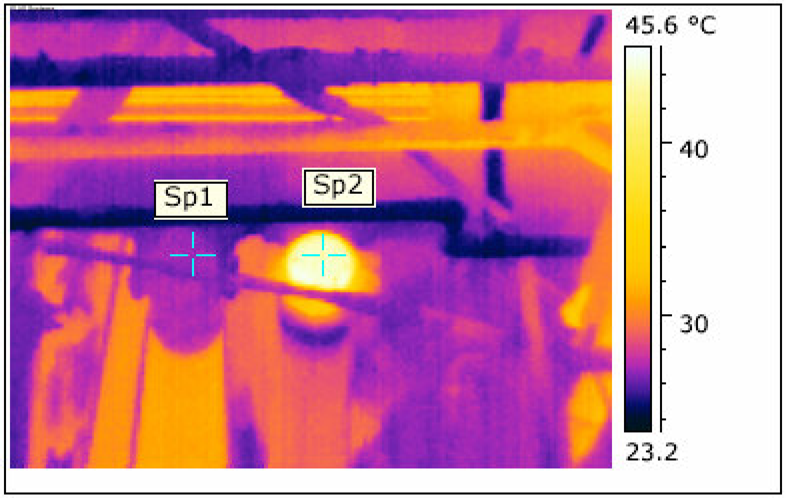


Label	Value
Sp1	22.0 °C
Sp2	19.8 °C
Sp3	23.0 °C
Sp4	19.3 °C

Cutia cu borne - termograma

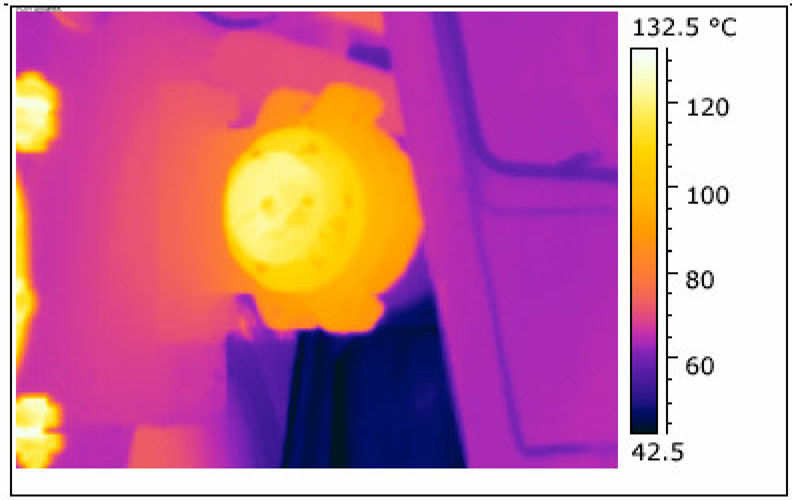
Observatie. Faza 2 este nealimentata.

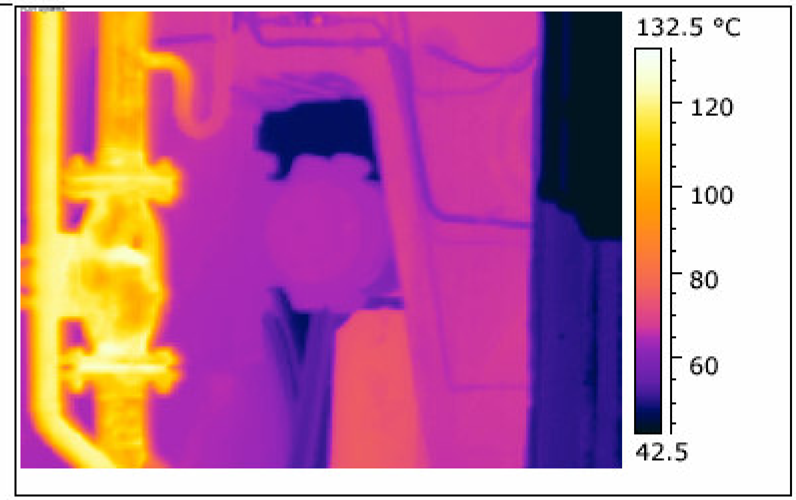

Pentru lagare
Mediul de lucru
Suprasarcini
Gaze
Praf
Umiditate



Label	Value
Sp1	26.7 °C
Sp2	43.3 °C

Termograma a doua lagare: unul deteriorat datorita umiditatii si unul fara probleme

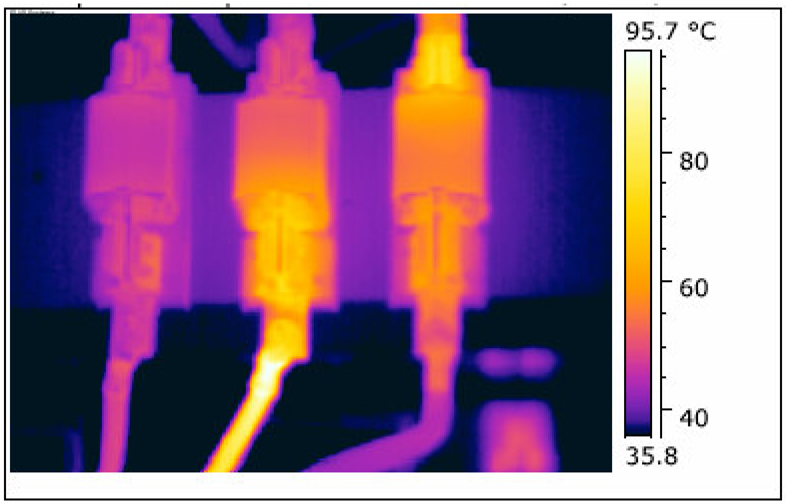


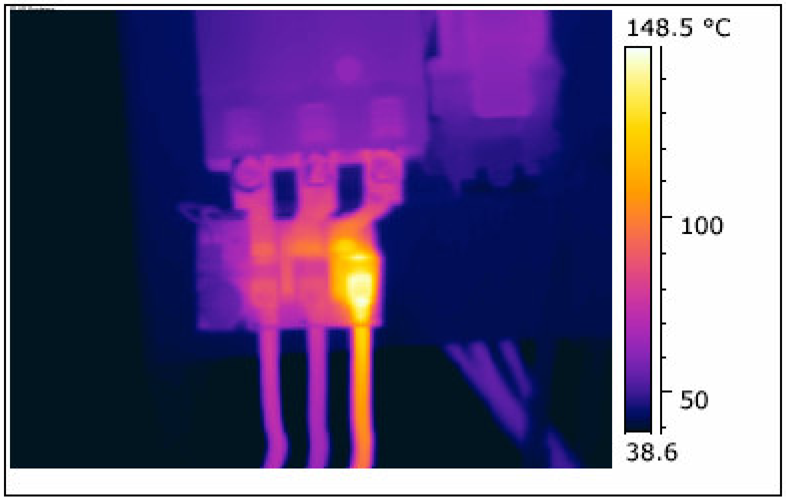


Lagar cu probleme

Lagar fara probleme

Echipament electric





Contactoare **Fuzibile**

ANALIZA FLUIDULUI DE UNGERE/RACIRE

Prezenta unor particule metalice: prin spectrometrie.

Indicator al unei uzuri

Aciditatea: oxidare datorita temperaturilor inalte, particule de apa, sau utilizarea indelungata

Vascozitatea: poate fi modificata la contaminarea cu funingine sau datorita oxidarii.

Diluarea: la motoarele termice poate reprezenta o problema la sistemul de injectie. Se masoara prin cromatografie.

ANALIZA SISTEMULUI DE ACTIONARE ELECTRICA

Exista o gama larga de metode pentru monitorizare si diagnoza in sisteme de actionare electrice, functie de tipul si localizarea defectelor.

Defecte

- **La nivelul circuitului de forta**
- **La nivelul convertorului electromecanic**
  - **Ale circuitului electric**
  - **Ale circuitului magnetic**
  - **Mecanice**

Metode de monitorizare si diagnoza in SAE

- **Pe baza unui model al sistemul de actionare**
- **Pe baza estimarii parametrilor sistemului**
- **Prin analiza unor marimi importante : curenti, tensiuni, cuplu, flux de scapari, etc**

ARMONICI IN MASINI ELECTRICE DE CURENT ALTERNATIV

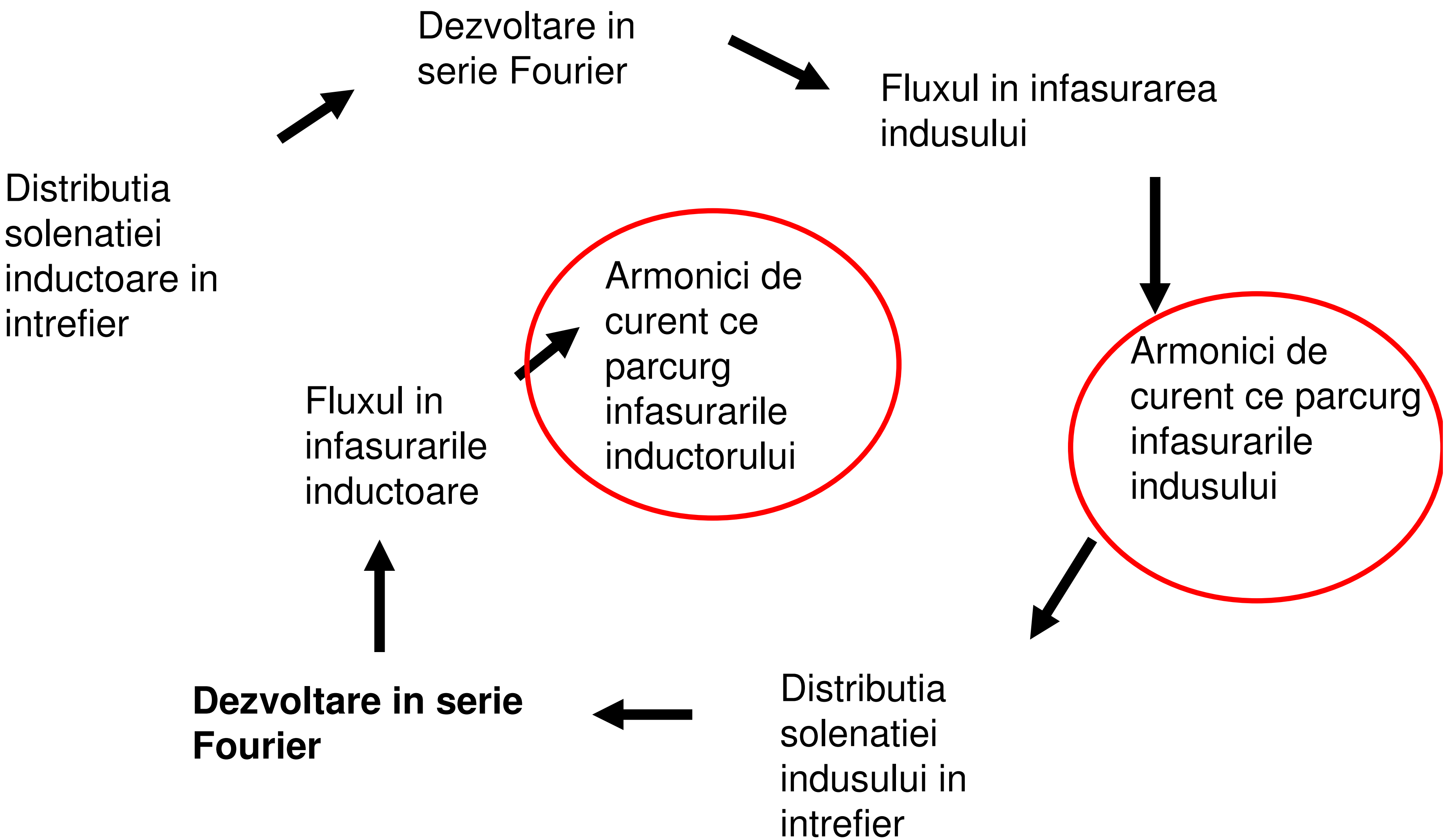
Armonici in masinile electrice

Armonici de spatiu: datorita distributiei solenatiei in intrefier

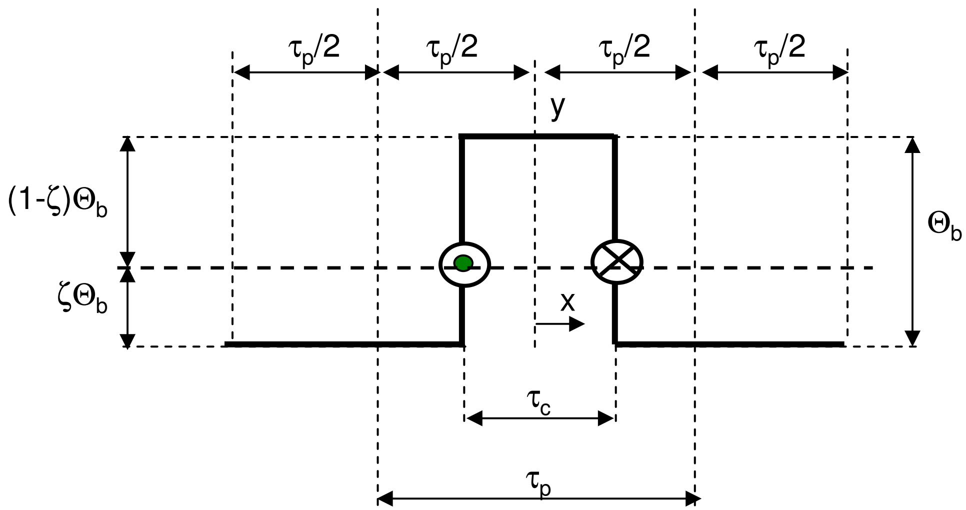
Armonici de timp: datorate armonicilor surselor de alimentare

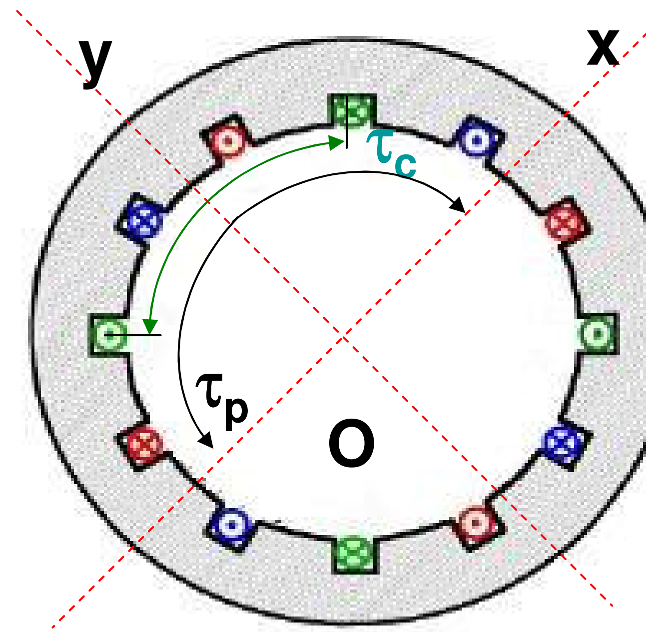
- **convertoare**
- **reteaua de alimentare**

Mod de lucru


Distributia solenatiei inductoare in intrefier
Dezvoltare in serie Fourier
Fluxul in infasurarea indusului
Armonici de curent ce parcurg infasurarile indusului
Distributia solenatiei indusului in intrefier
Dezvoltare in serie Fourier
Fluxul in infasurarile inductoare
Armonici de curent ce parcurg infasurarile inductorului

Distributia solenatiei unei bobine (pentru un pol)





$\Theta_b = Ni(t)$

$$\Theta_b(x) = \begin{cases} (1-\varsigma)\Theta_b & 0 < x < \frac{1}{2}\tau_b \\ -\varsigma\Theta_b & \frac{1}{2}\tau_b < x < 2\tau_p - \frac{1}{2}\tau_b \\ (1-\varsigma)\Theta_b & 2\tau_p - \frac{1}{2}\tau_b < x < 2\tau_p \end{cases}$$

$\Theta_b = Ni(t)$

Dezvoltare in serie Fourier

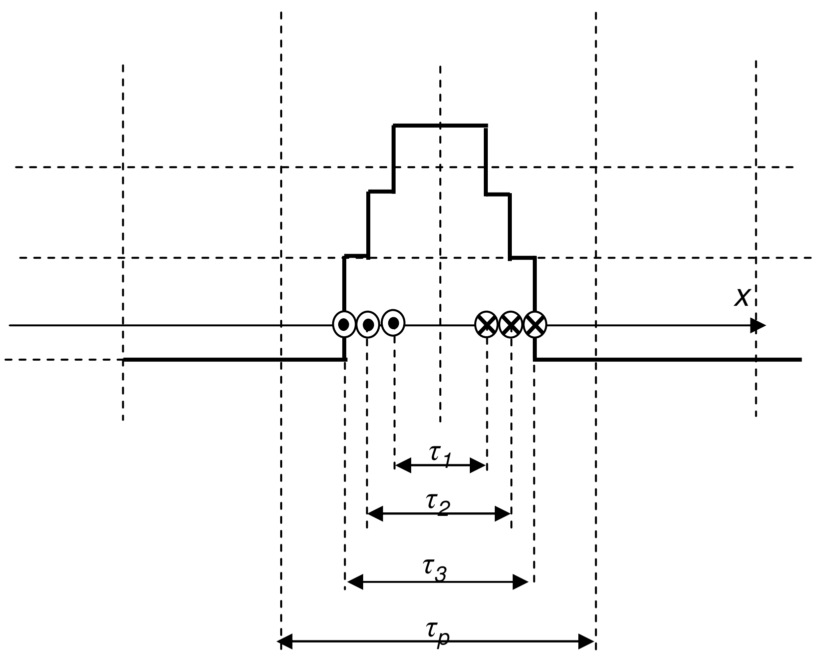
$$\Theta_b(x) = \sum_{\nu=1}^{\infty} \Theta_{b\nu} \cos(\nu \frac{x}{\tau_p} \pi)$$

Bobina

$$\Theta_b(x) = \frac{2}{\pi} N i(t) \sum_{\nu=1}^{\infty} \frac{1}{\nu} \sin\left(\nu \frac{\pi}{2} \frac{\tau_b}{\tau_p}\right) \cos(\nu \frac{x}{\tau_p} \pi)$$

Grup de n_b bobine

$$\Theta_{grup}(x) = \frac{2}{\pi} N i(t) \sum_{b=1}^{n_b} \sum_{\nu=1}^{\infty} \frac{1}{\nu} \sin\left(\nu \frac{\pi}{2} \frac{\tau_b}{\tau_p}\right) \cos(\nu \frac{x}{\tau_p} \pi)$$



Distributia solenatiei unui grup de 3 bobine concentrice, cu latimi diferite, inseriate.

Pentru o masina cu *p* poli si *m* faze, solenatia totala pe armatura

$$\Theta_{total}(x,t) = \frac{2}{\pi} N \sum_{g=1}^{mp} n_b I_g \sum_{\nu=1}^{\infty} \frac{1}{\nu} k_{g\nu} \left[\sin(\alpha - \nu\beta) + \sin(\alpha + \nu\beta) \right]$$

Inductia magnetica in intrefier

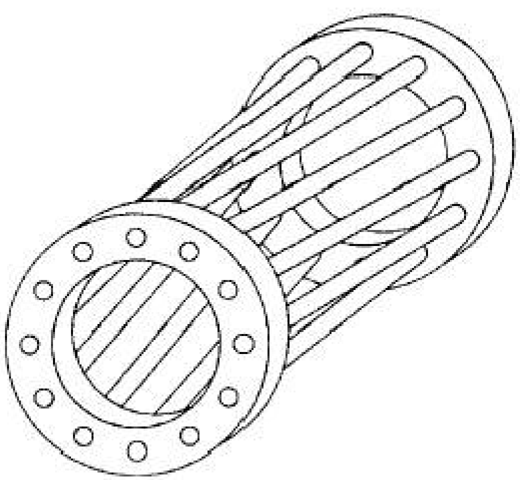
$$B(x,t) = \frac{\mu_0 \Theta_{total}(x,t)}{2\delta_c} = \frac{\mu_0}{\pi\delta_c} N \sum_{g=1}^{mp} n_b I_g \sum_{\nu=1}^{\infty} \frac{1}{\nu} k_{g\nu} \left[\sin(\alpha - \nu\beta) + \sin(\alpha + \nu\beta) \right]$$

MASINA DE INDUCTIE

Rotorul in colivie

! Fiecare crestatura contine un conductor de sectiune mare..

! Toate barele sunt legate in scurtcircuit.



Parametrii masinii de inductie:

- **m - numarul de faze**
- **2p – numarul de poli**
- **g – numarul de grupuri de bobine pe faza**
- **c – numarul de bobine pe grup**
- **Z_r – numarul de crestaturi rotorice**

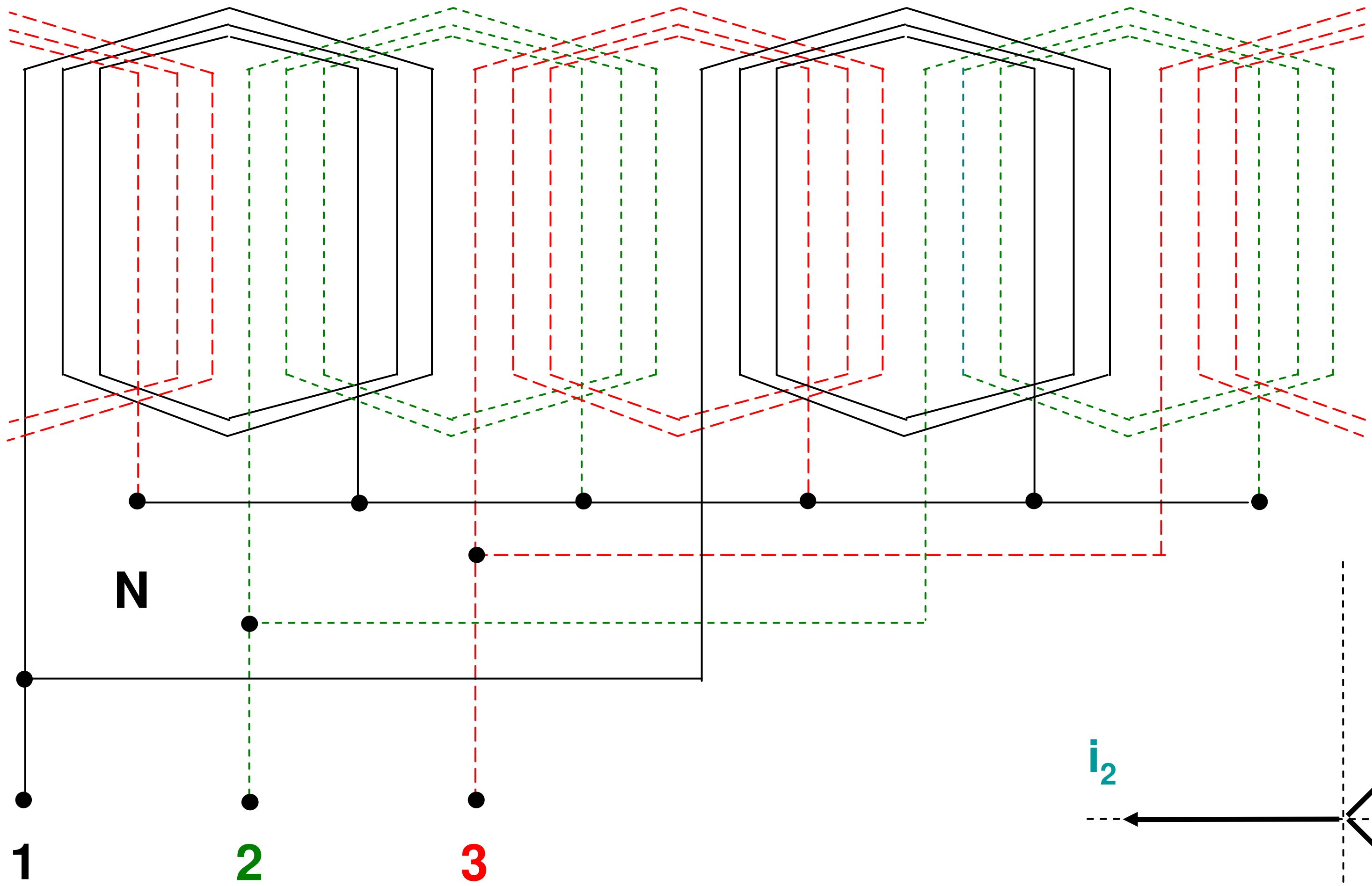
Rotor bobinat

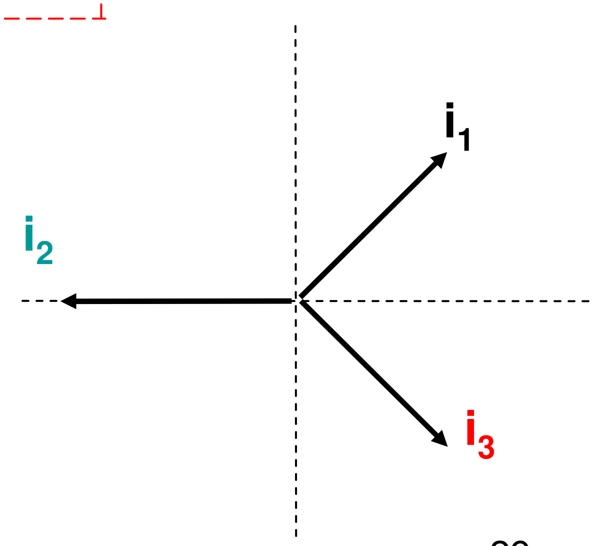
! Rotorul are un bobinaj asemanator cu cel statoric.

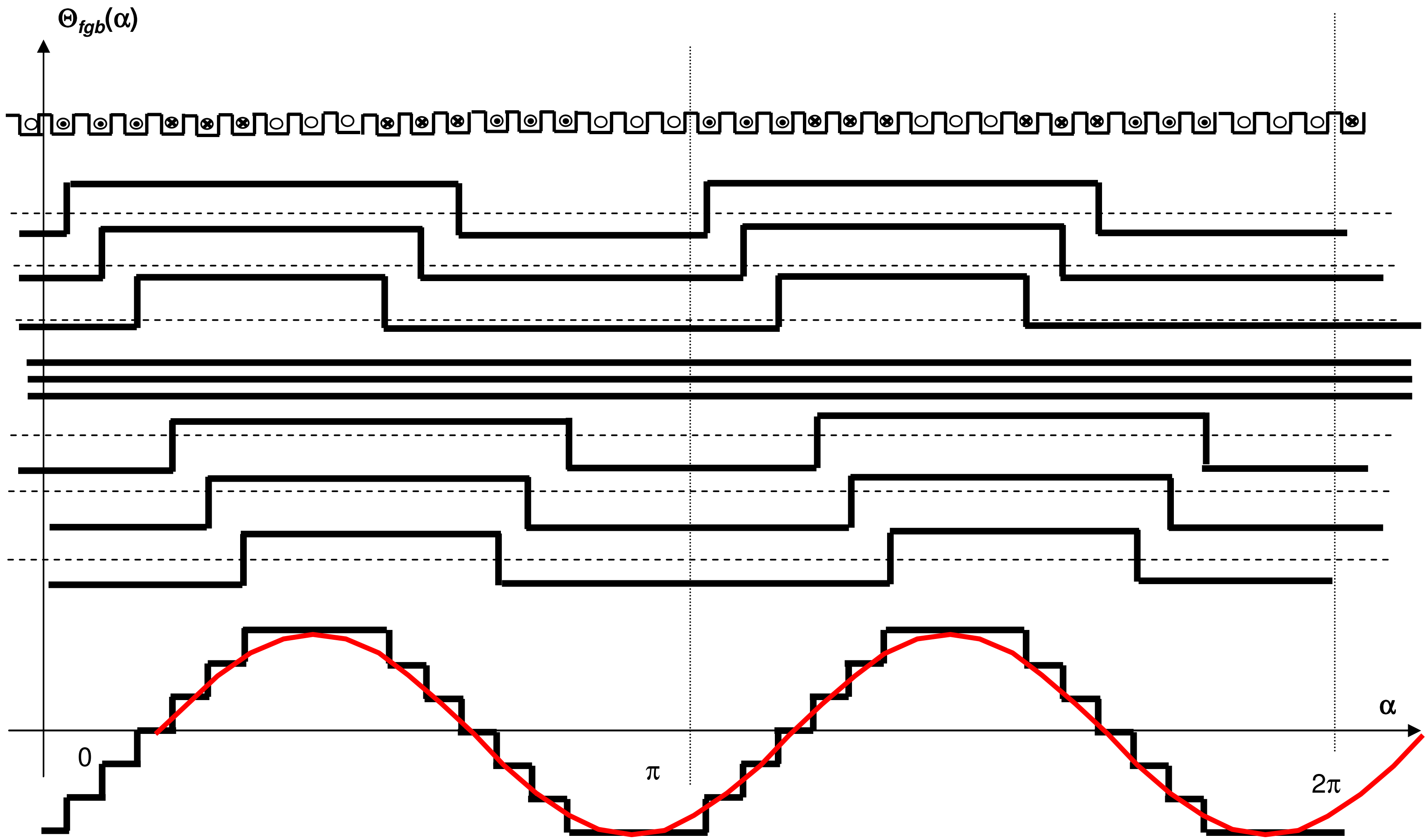
! Infasurarile sunt accesibile prin borne

Paramètres de la machine à induction:

m - numarul de faze
2p – numarul de poli
g_s – numarul de grupuri de bobine pe faza in stator
c_s – numarul de bobine pe grup in stator
g_r – numarul de grupuri de bobine pe faza in rotor
c_r – numarul de bobine pe grup in rotor


N
1
2
3


i1
i2
i3



Distribuția solenației statorice pentru maşina de inducție considerată

Curenti statorici

$$i_a(t) = \sqrt{2} I \sin(\omega t)$$
$$i_b(t) = \sqrt{2} I \sin\left(\omega t - \frac{2\pi}{3}\right)$$
$$i_c(t) = \sqrt{2} I \sin\left(\omega t + \frac{2\pi}{3}\right)$$

Solenatie statorica

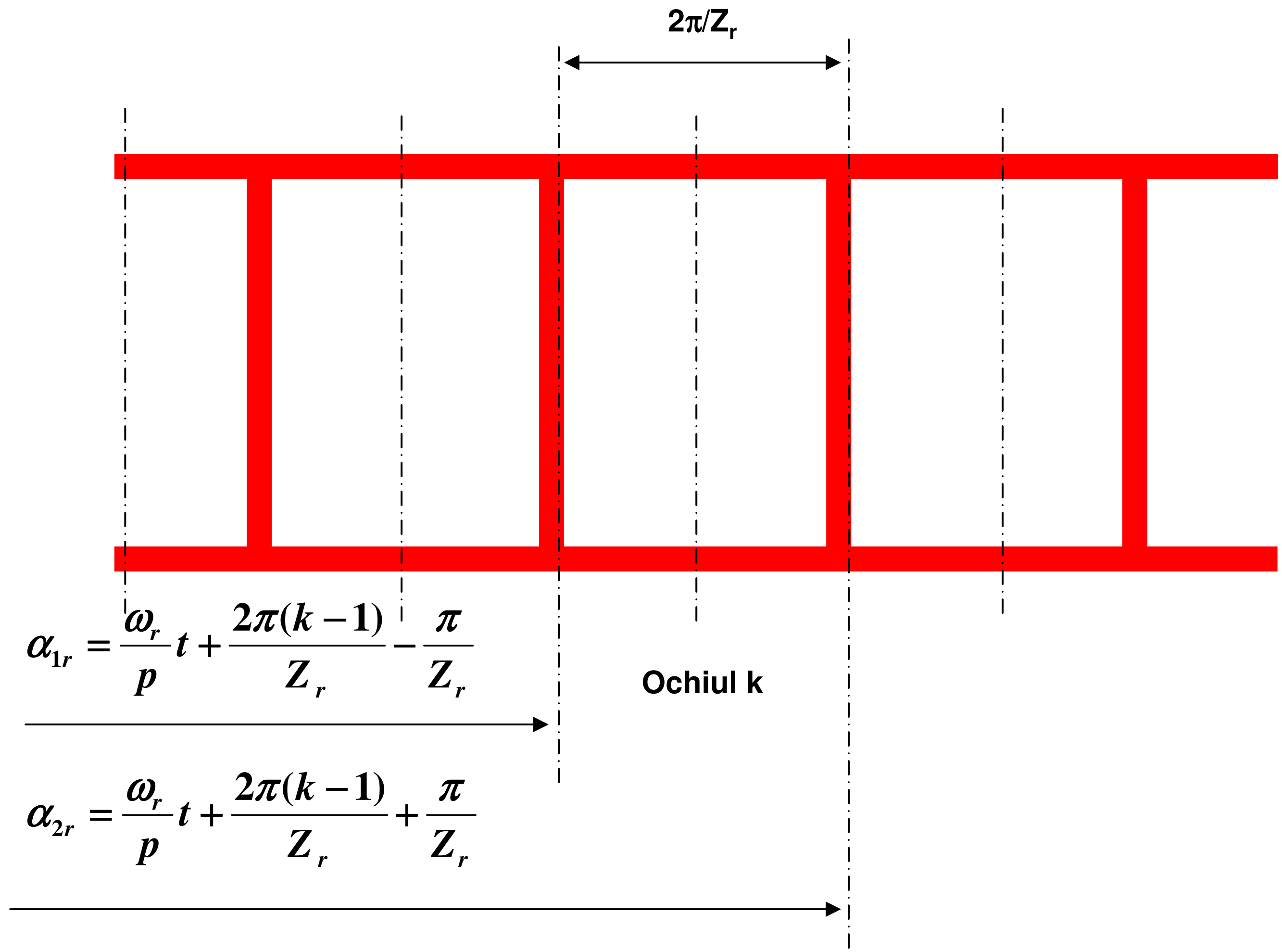
$$\Theta_\nu^s(t,x) = \frac{6 N_s I_a^s}{p\pi\nu}\left(\sum_{b=1}^{3} \sin\left(\nu \frac{\tau_{cb}}{\tau_p}\frac{\pi}{2}\right)\right)\sin\left[\omega t - \frac{\nu\pi}{\tau_p} x\right], \nu = 6k+1$$

$$\Theta_\nu^s(t,x) = \frac{6 N_s I_a^s}{p\pi\nu}\left(\sum_{b=1}^{3} \sin\left(\nu \frac{\tau_{cb}}{\tau_p}\frac{\pi}{2}\right)\right)\sin\left[\omega t + \frac{\nu\pi}{\tau_p} x\right], \nu = 6k-1$$

Flux indus de catre solenatia statorica intr-un ochi rotoric

$$\Phi_{k\nu}^s(t) = \begin{cases} \Phi_{\max\nu} \sin\left[\omega t - \nu\omega_r t - \frac{\nu\pi}{p}\frac{2\pi(k-1)}{Z_r}\right], \nu = 6k+1 \\ \Phi_{\max\nu} \sin\left[\omega t - +\nu\omega_r t + \frac{\nu\pi}{p}\frac{2\pi(k-1)}{Z_r}\right], \nu = 6k-1 \end{cases}$$

Rotorul in colivie: Z_r ochiuri rotorice

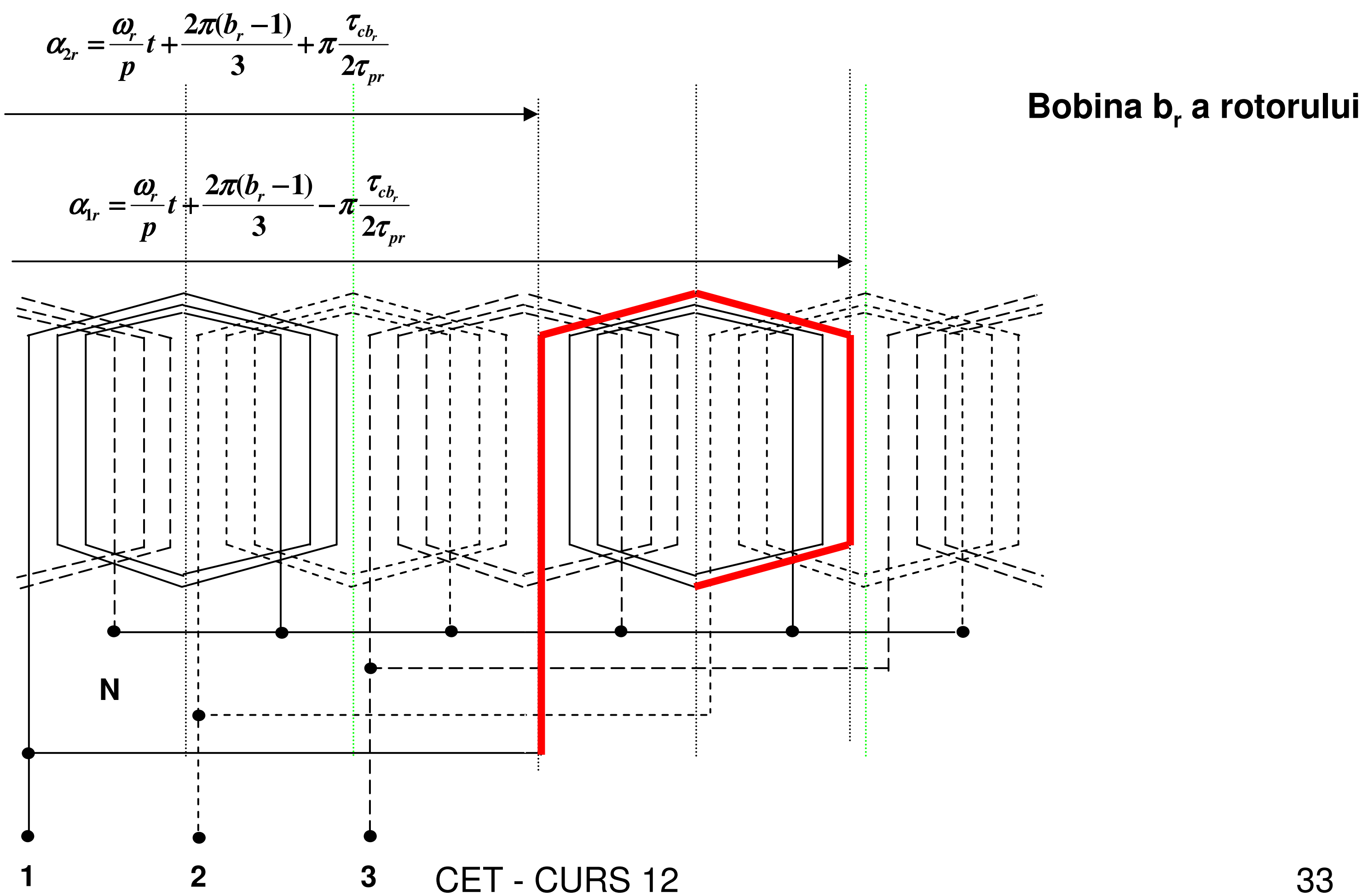


$$\alpha_{1r} = \frac{\omega_r}{p}t + \frac{2\pi(k-1)}{Z_r} - \frac{\pi}{Z_r}$$

$$\alpha_{2r} = \frac{\omega_r}{p}t + \frac{2\pi(k-1)}{Z_r} + \frac{\pi}{Z_r}$$

Rotorul bobinat: Z_r crestaturi rotorice

m_r faze rotorice



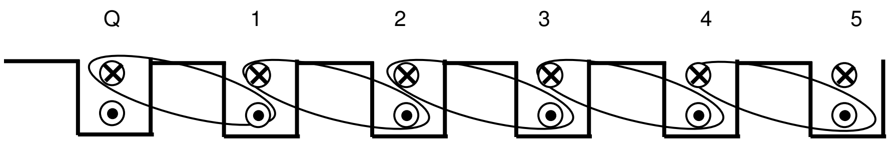
$$e_{k,\nu} = -\frac{d}{dt}\Phi^{s}_{k\nu}(t) = [1 \mp \nu(1-s)]\omega\Phi_{\max\nu}\cos\left[\omega t \mp \nu\omega_r t \mp \frac{\nu\pi}{p}\frac{2\pi(k-1)}{Z_r}\right]$$

T.e.m. indusa de catre solenatia statorica intr-un ochi rotoric

$$f_{rotor} = [1 - \nu(1-s)]f, \nu = 6k+1$$

$$f_{rotor} = [1 + \nu(1-s)]f, \nu = 6k-1$$

Frecventele componentelor spectrale ale curentilor rotorici



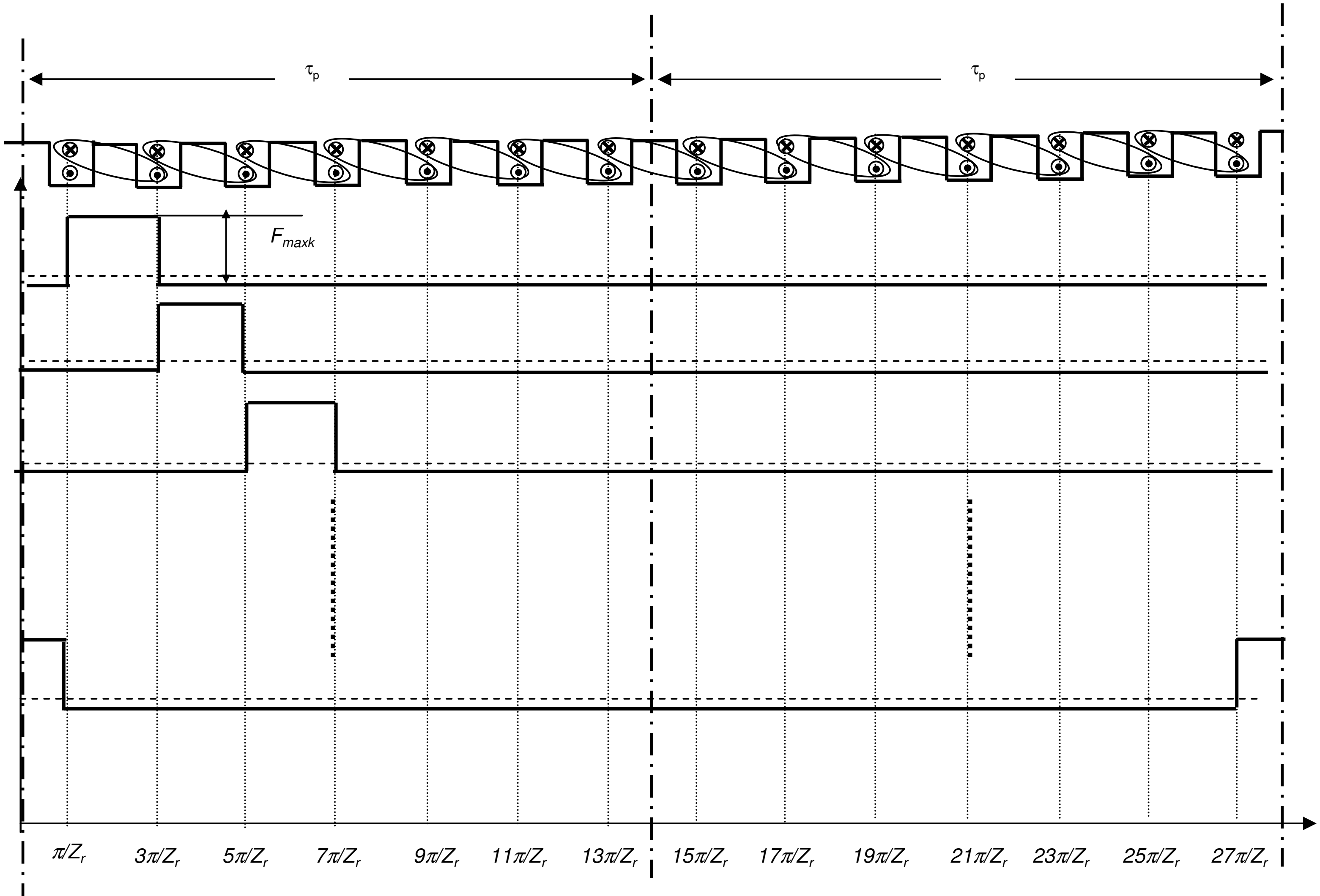
Infasurarea echivalenta a rotorului în colivie.

Solenația corespunzatoare unei faze rotorice

$$\Theta'^{r}_{k\nu}(\alpha) = \begin{cases} -\varsigma\Theta'^{r}_{\max k}, 0 \le \alpha < \frac{2k-1}{2}\frac{2\pi}{Z_r} \\ (1-\varsigma_r)\Theta'^{r}_{\max k}, \frac{2k-1}{2}\frac{2\pi}{Z_r} \le \alpha \le \frac{2k+1}{2}\frac{2\pi}{Z_r} \\ -\varsigma_r\Theta'^{r}_{\max k}, \frac{2k+1}{2}\frac{2\pi}{Z_r} < \alpha \le 2\pi \end{cases}$$

Dezvoltare in serie Fourier

$$\Theta_\nu(\alpha,t) = \sum_{k=1}^{Z_r}\frac{I_{r\nu,\max}}{\pi}\sum_{\gamma=1}^{\infty}\frac{1}{\gamma}\sin\left(\frac{\pi\gamma}{Z_r}\right)\sin\{\gamma\alpha \pm s_\nu\omega t + (\gamma\mu\nu p)\}$$

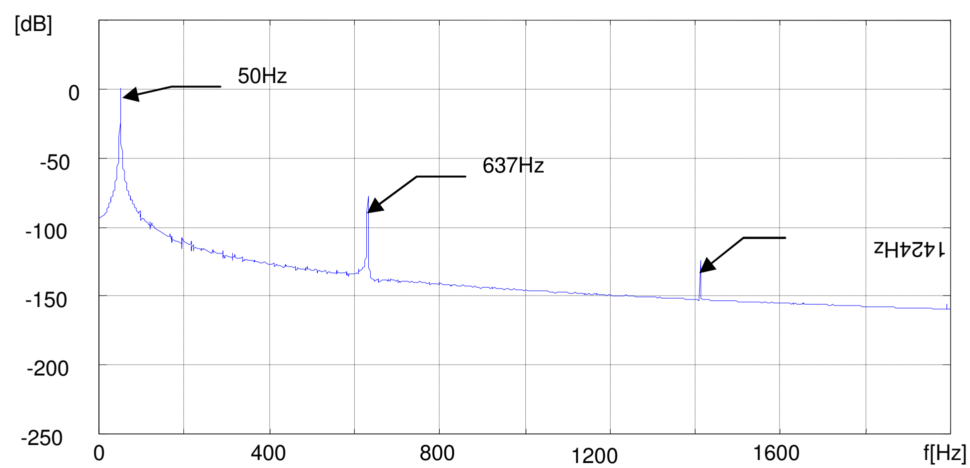


Distribuția solenației rotorice de-a lungul întrefierului.

Pentru tensiunea electromotoare indusă în bobina statorică rezulta armonici de curent de frecvență

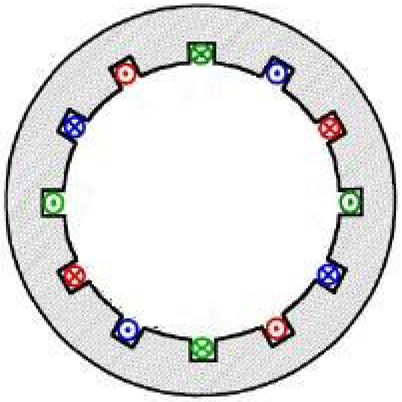
$$f_{stator} = \left[\gamma \frac{Z_r}{p}(1-s) \pm 1 \right] f$$

Ordinul armonicii (γ)	Frecvența armonicii [Hz]
1	637
2	1424
4	2698
5	3485
6	4171.5
8	5546
9	6133



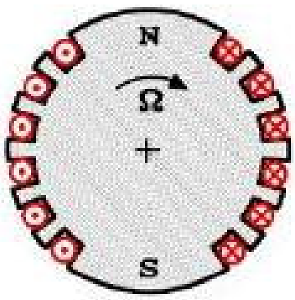
Spectrul de frecvențe al curentului statoric

MASINA SINCRONA



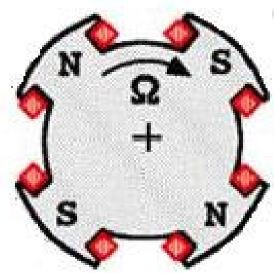
Stator(indusul)

Rotor(inductor)



Rotor cu poli inecati

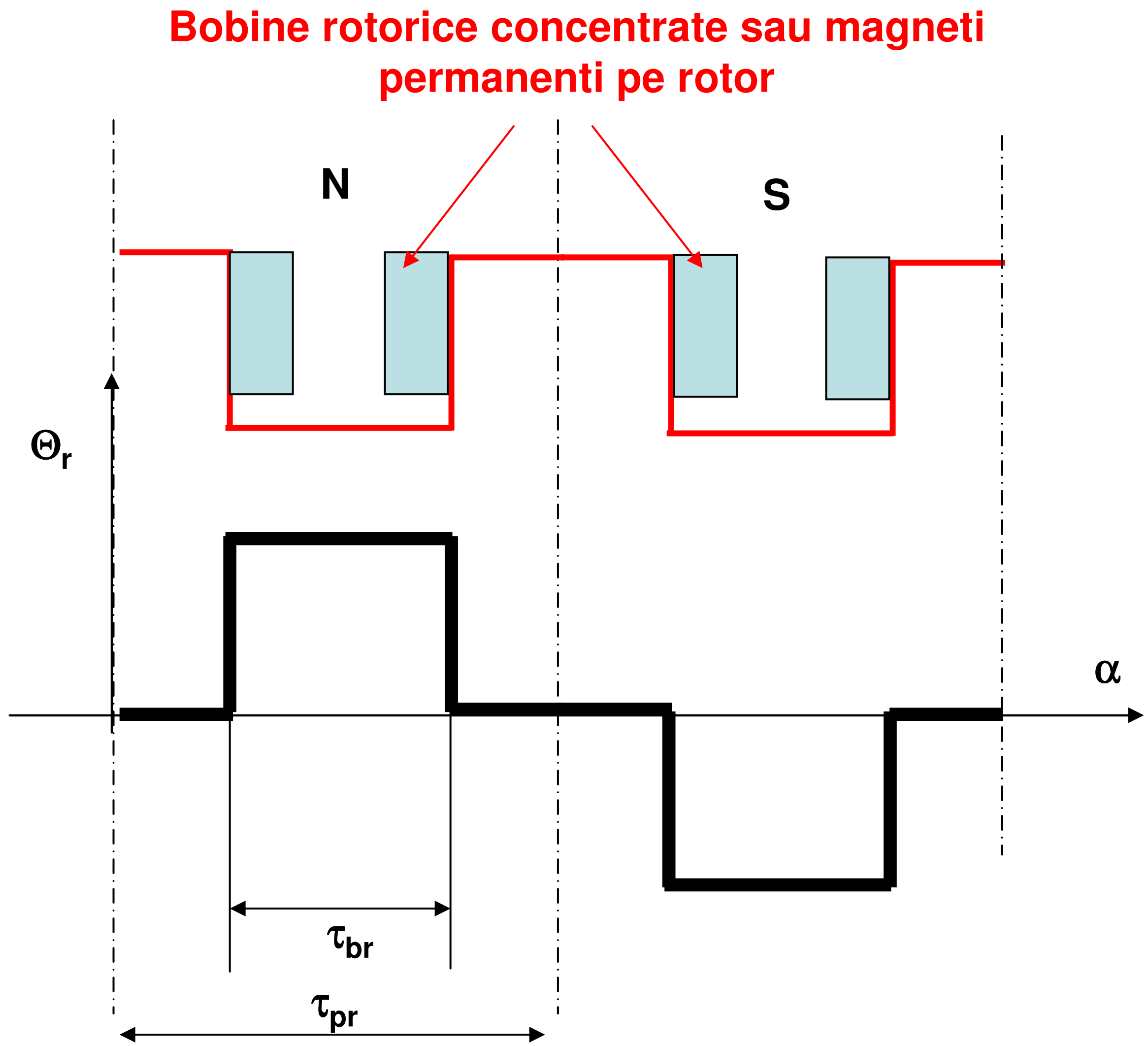
(infasurari distribuite in crestaturi rotorice)



Rotor cu poli aparenti

(infasurari concentrate sau magneti permanenti)

Rotor cu poli aparenti



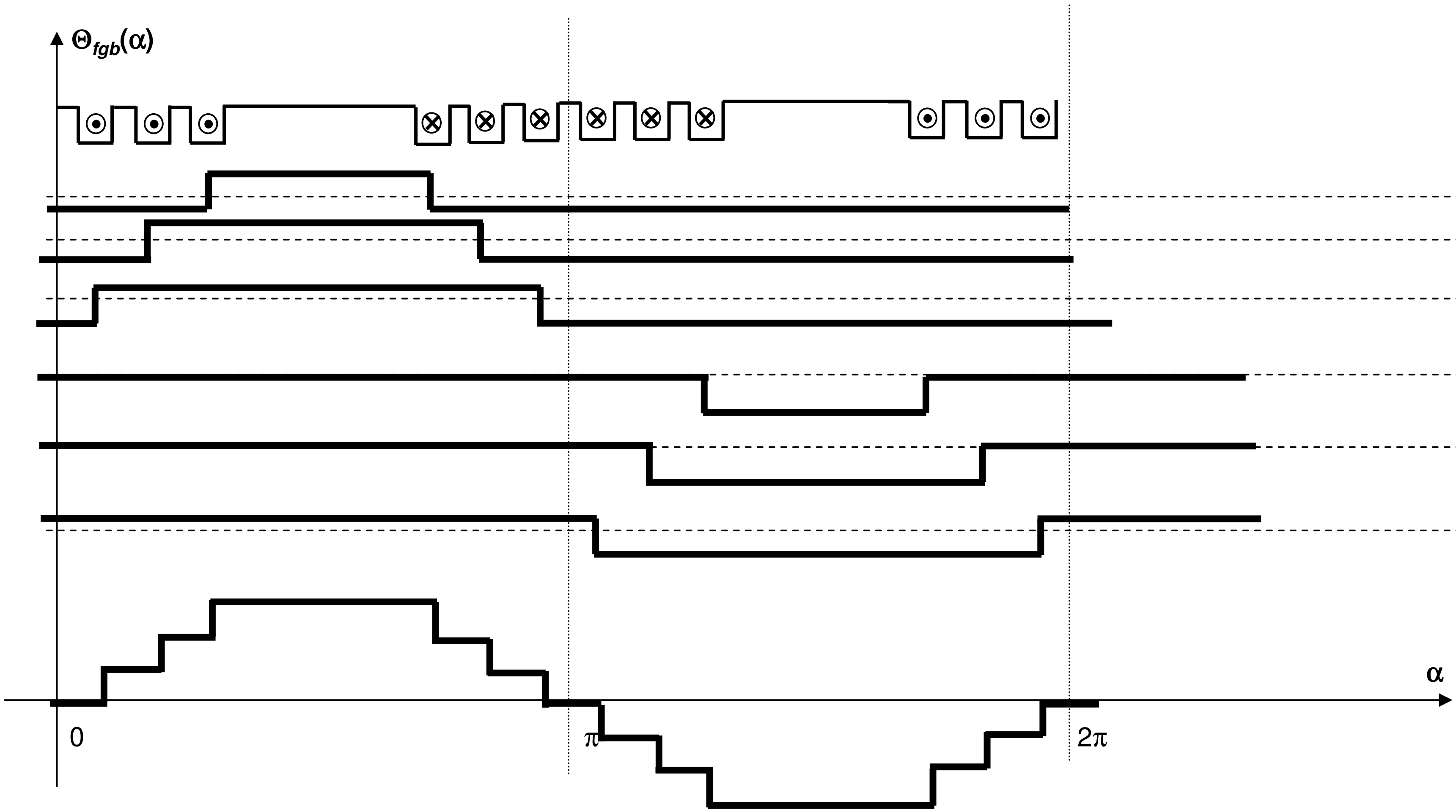
Solenatia dezvoltata de infasurarea/magnetul permanent rotoric:

$$\Theta_r(\alpha,t)=\sum_{\nu=1}^{\infty}\Theta_{r,\nu,\max}(t)\cos p\nu\alpha$$

cu

$$\Theta_{r,\nu,\max}(t)=constant$$

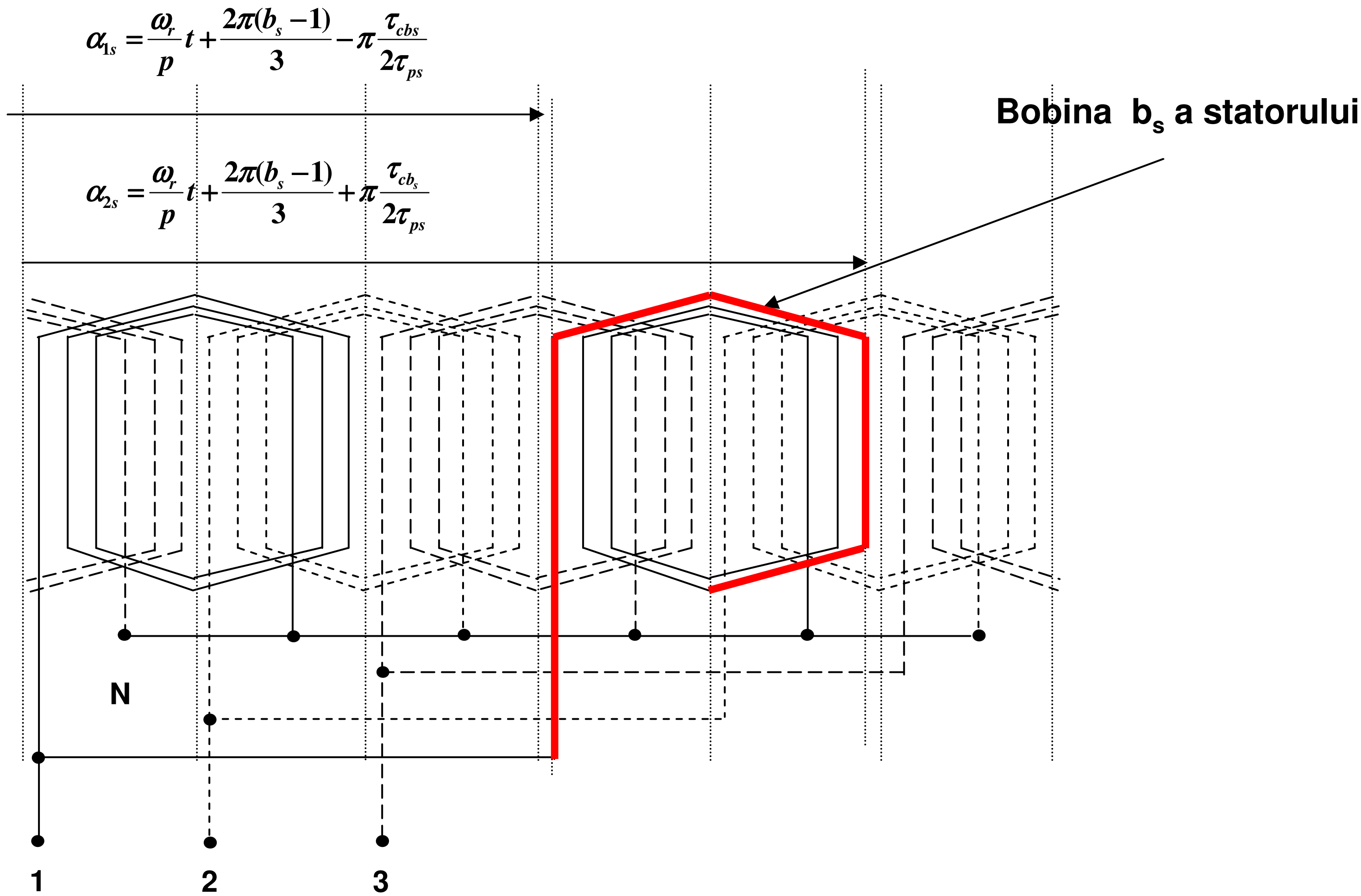
Rotor cu poli inecati



Solenatia dezvoltata de infasurarea rotorica:

$$\Theta_r(x) = \sum_{b_r=1}^{c} \Theta_{b_r}(x) = \frac{2}{\pi} cNi \sum_{\nu=1}^{\infty} \frac{1}{\nu} k_{c\nu} \cos\left[\nu\left(\frac{x}{\tau_p}\pi\right)\right]$$

Conexiunile infasurarii statorice



Expresia fluxului care inlantuie bobina statorica b_s prin armonica ν rotorica e data de :

$$\Phi_{b_s,\nu}(t) = \int_{S_k} B_\nu dA = \int_{\alpha_{1s}}^{\alpha_{2s}} \frac{\mu_0 \Theta_{r,\nu}(\alpha,t)}{\delta_c} l_c d\alpha$$

Fluxul total in bobina b_s:

$$\Phi_{b_s}(t) = \sum_{\nu=1}^{\infty} \Phi_{b_s,\nu} \cos\left\{\nu\omega t + p\nu \frac{2\pi(b_s - 1)}{3}\right\}$$

Tensiunea electromotoare indusa in bobina b_s :

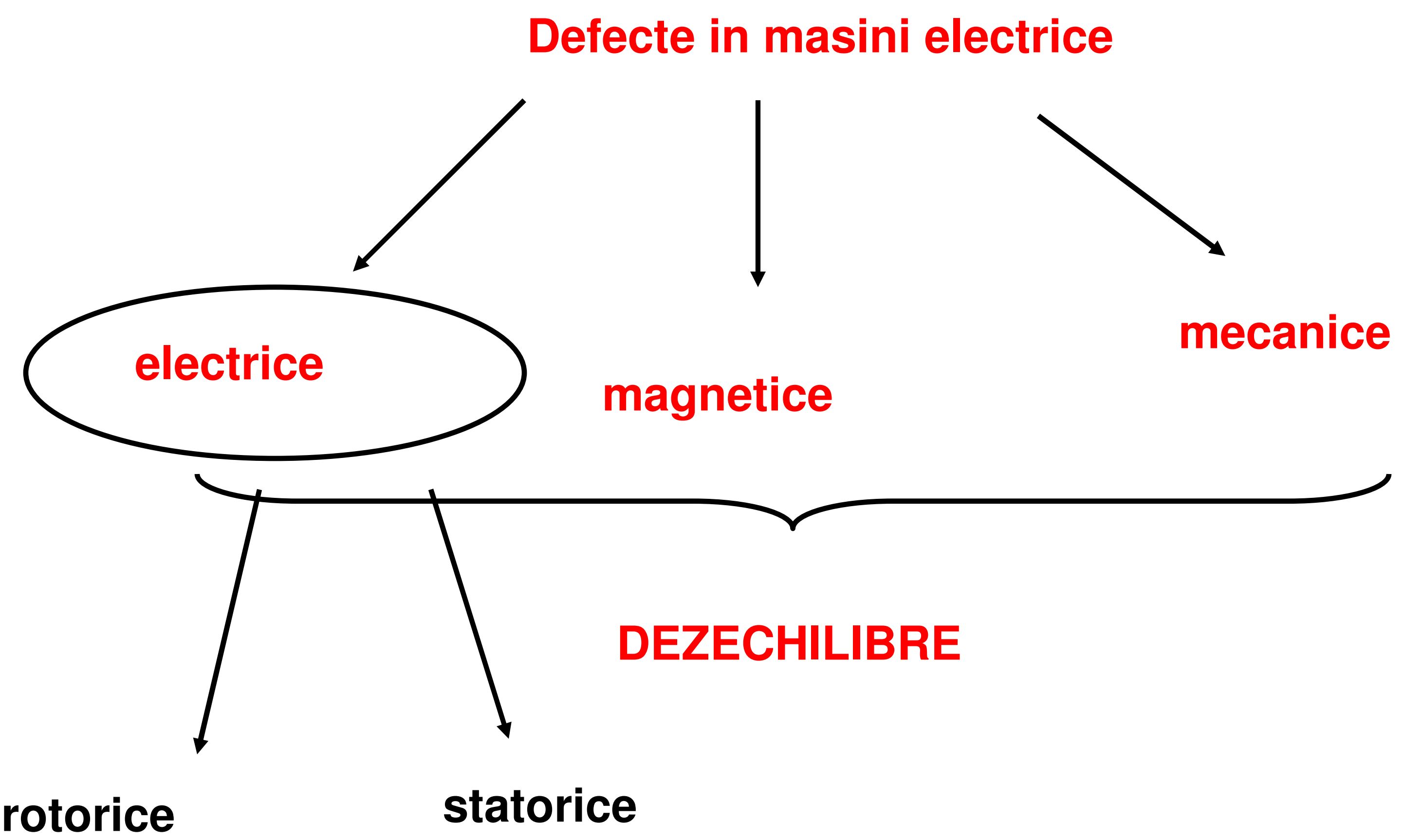
$$e_{b_s} = -\frac{d}{dt}\Phi_{b_s}(t) = \sum_{\nu=1}^{\infty} E_{b_s,\nu,\max} \cos\left\{\nu\omega t + p\nu \frac{2\pi(b_s - 1)}{3}\right\}$$

Frecventele ce vor apare in curentul statoric:

$$f_{stator} = \nu f_{source}$$

APLICATII

Diagnoza in masini electrice



Diagnoza in masini de inductie

Defecte electrice

Bare sau inele rupte

Scurtcircuite statorice sau rotorice

Dezechilibru

CURENT

FLUX

CUPLU

Expresia cuplului electromagnetic dezvoltat de o masina de inductie

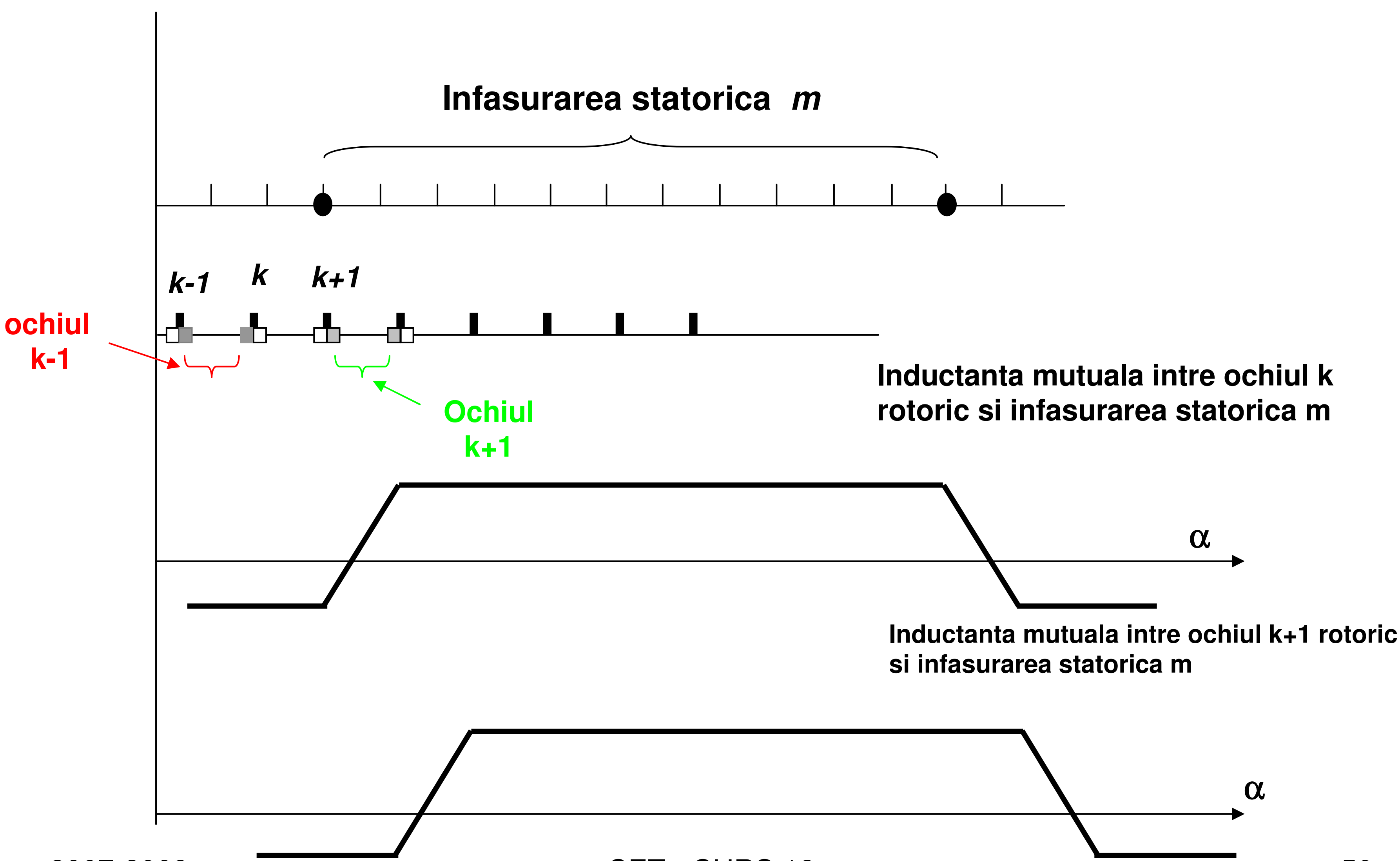
$$T = \frac{1}{2} \sum_{h=1}^{j} \sum_{k=1}^{N_r} i_h^s i_k^r \frac{dL_{h,k}^{sr}}{d\theta}$$

i^s_h **–curentul ce parcurge bobina h a infasurarii statorice**

i^r_k **– curentul ce parcurge ochiul h rotoric**

$L^{sr}_{h,k}$ **– inductanta mutuala intre bobina h statorica si ochiul k rotoric**

Inductanta mutuala intre un ochi rotoric si o infasurare statorica



$$f_{1torque} = [\alpha + \beta + \nu(1 - s)] f_{\sup ply}$$
$$f_{1torque} = [\alpha + \beta - \nu(1 - s)] f_{\sup ply}$$
$$f_{1torque} = [\alpha - \beta + \nu(1 - s)] f_{\sup ply}$$
$$f_{1torque} = [\alpha - \beta - \nu(1 - s)] f_{\sup ply}$$

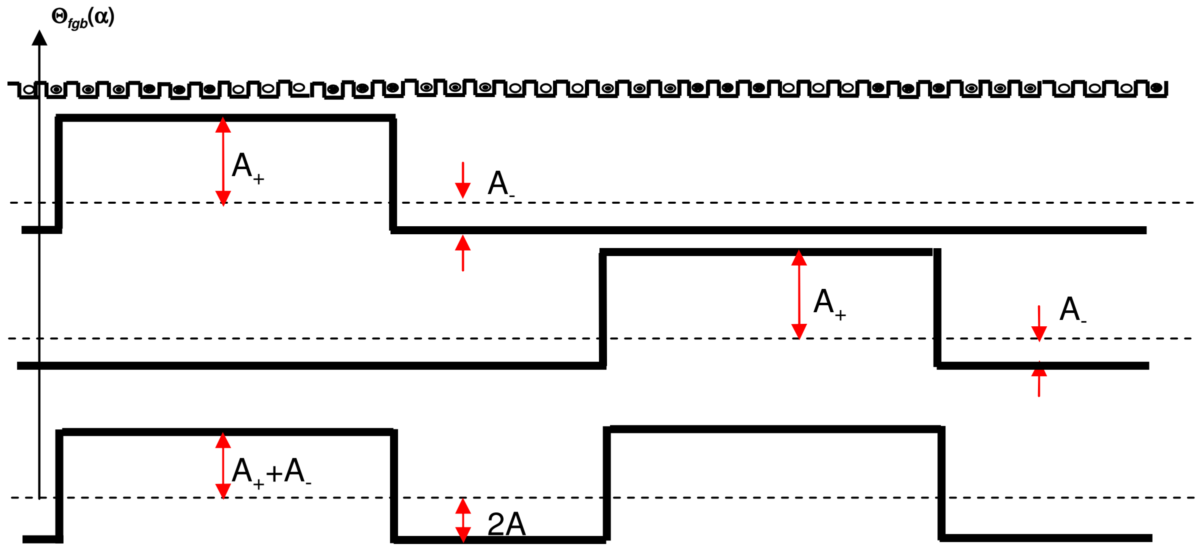
$$\alpha = q \frac{Z_r}{p}(1 - s) \pm 1$$

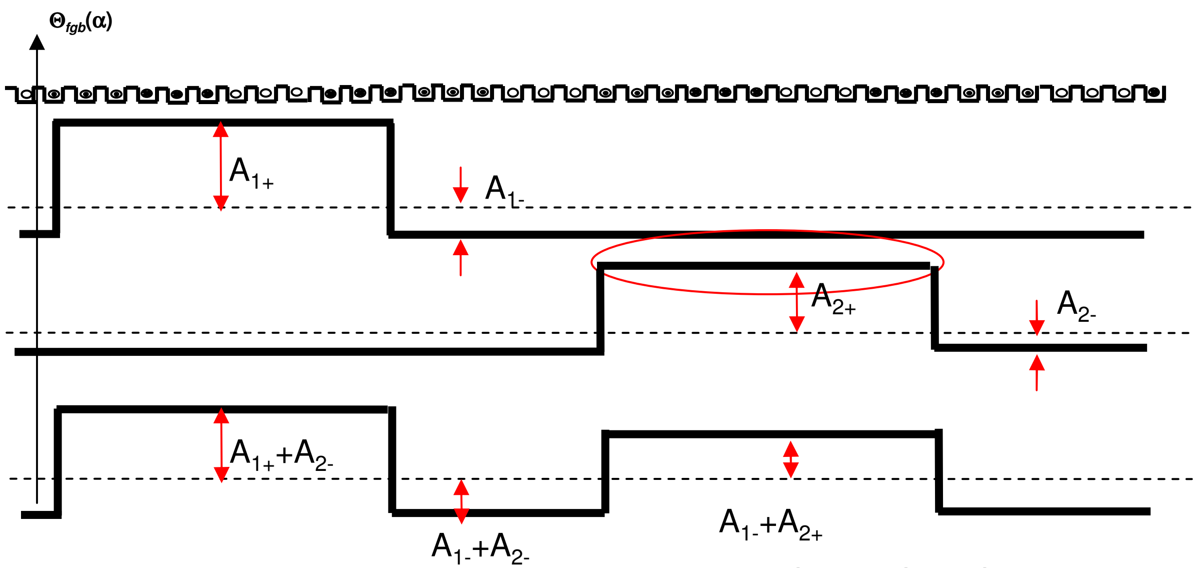
$$\beta = 1 \mu (1 - s)\nu$$

Un spectru foarte bogat in armonici

DEFECTE ELECTRICE STATORICE

Masina de inductie fara defecte





Masina de inductie cu scurtcircuit in faza 1 grupul 2

Solenatia statorului fara defecte

$$\Theta_s(t,x) = \sum_{\nu=1} \frac{3NI}{\pi\nu}\left(\sum_{b=1}^{3}\sin\left(\nu\frac{\tau_{cb}}{\tau_p}\frac{\pi}{2}\right)\right)\sin[\omega t \, \mu \, \nu p\alpha]$$

ν=6k±1,   k=0,1,2,...

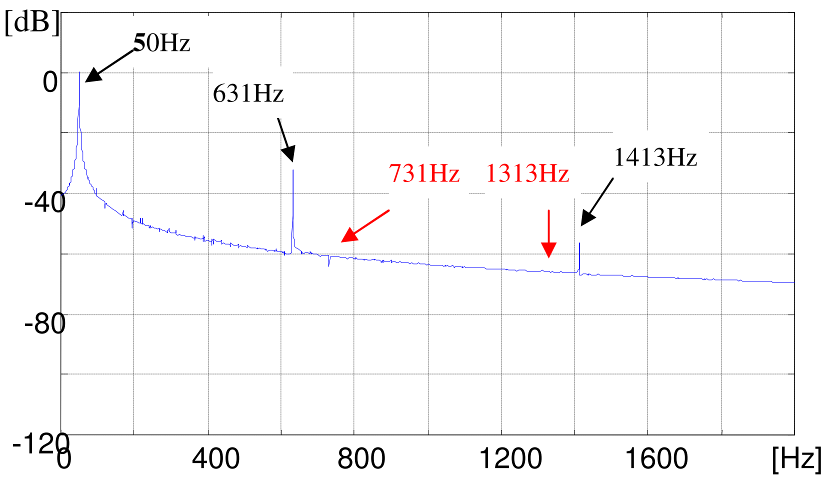
Solenatia statorica cu defecte statorice (scurt circuit)

$$\Theta_s(\alpha,t) = \sum_{\nu=1}^{\infty}\Theta_{\nu\max}\sin(\omega t \, \mu \, \nu p\alpha) + + \sum_{\nu_{sc}=1}^{\infty}\Theta_{\nu_{sc}\max}\sin(\omega t \, \mu \, \nu_{sc}\alpha)$$

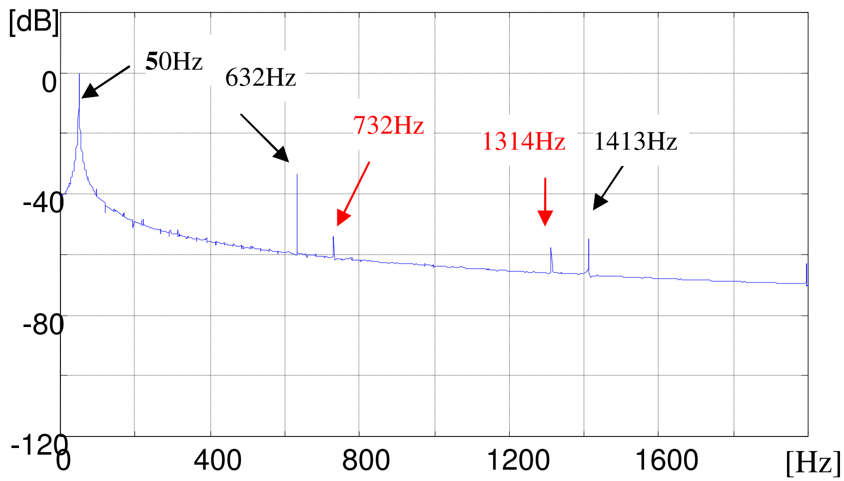
ν=6k±1,   k=0,1,2,...

ν_{sc}=1,3,5,...

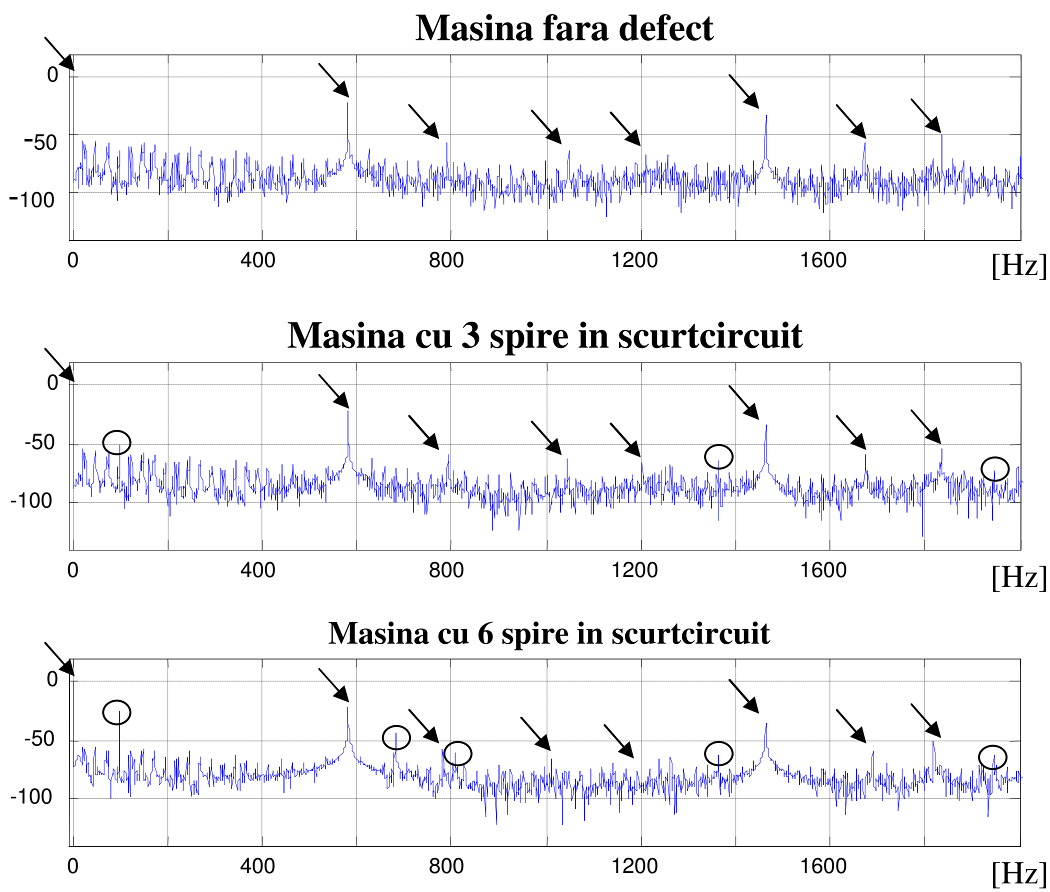
Masina de inductie fara defecte



Masina de inductie cu 6 spire in scurt-circuit



Curent statoric



CUPLU ELECTROMAGNETIC

Concluzii

Vom regasi armonici in plus in spectrele curentului statoric si al cuplului in cazul in care sunt defecte in masina

DEFECTE ELECTRICE ROTORICE

Solenatia rotorului fara defecte

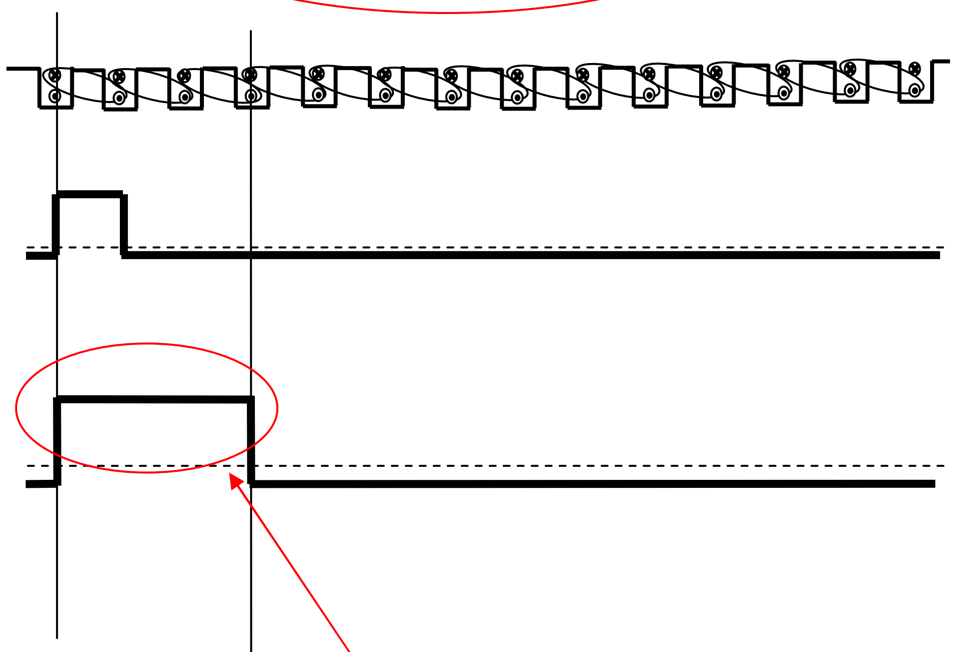
$$\Theta_{r,\nu}(\alpha,t)=\frac{Z_r I_{r\nu,\max}}{\pi}\sum_{\gamma=1}^{\infty}\frac{1}{\gamma}\sin\left(\frac{\pi\gamma}{Z_r}\right)\sin\{\gamma\alpha\pm s_\nu\omega t\}$$

$\gamma=qZ_r\pm\nu p,\quad q=0,1,2...\qquad \nu=6k\pm1,\quad k=0,1,2,...$

Solenatia rotorului cu defecte rotorice

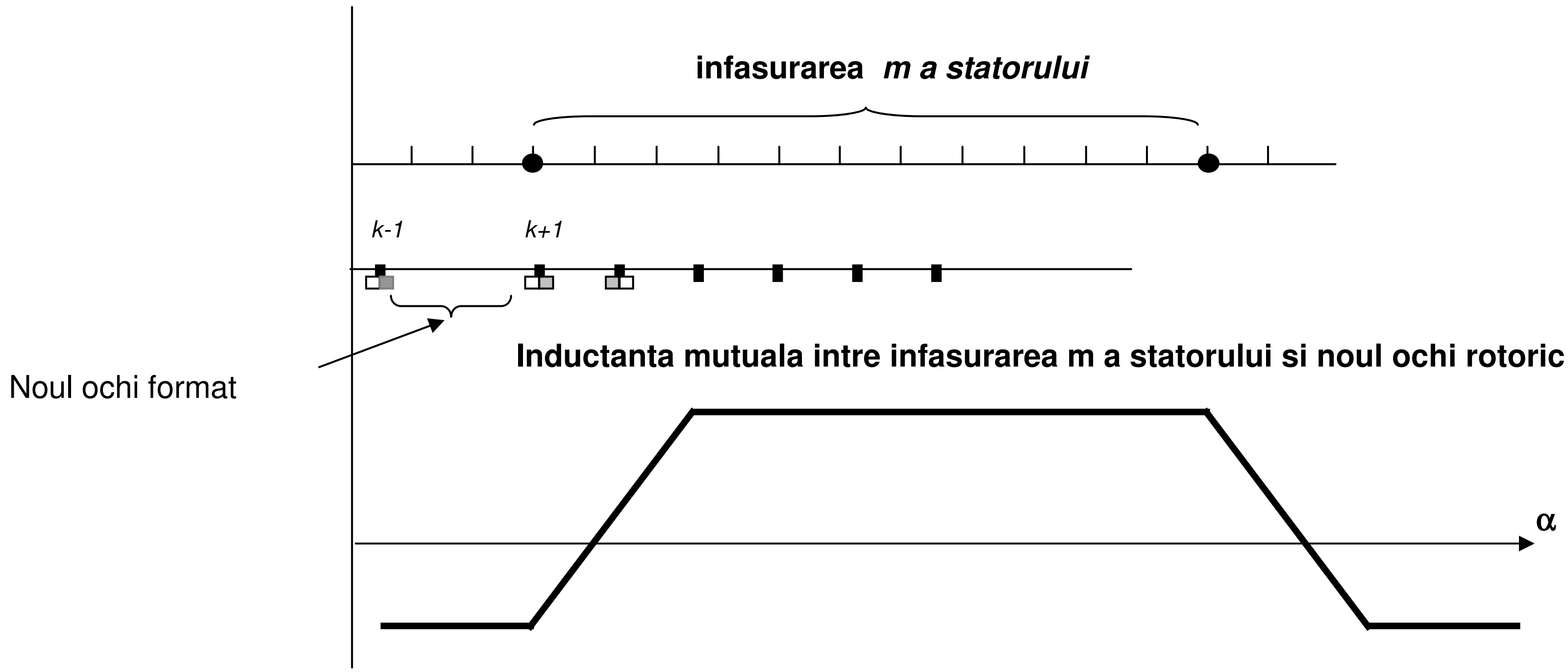
$$\Theta_\nu(\alpha,t)\;=\;\sum_{k=1}^{Nr}\frac{I_{r\nu,\max}}{\pi}\sum_{\gamma=1}^{\infty}\frac{1}{\gamma}\sin\left(\frac{\pi\gamma}{Z_r}\right)\sin\left\{\gamma\alpha\pm s_\nu\omega t+(\gamma\,\mu\,\nu p)\;\frac{2\pi}{Z_r}k\right\}$$

$\gamma=0,1,2,...\qquad \gamma\neq 2pi,\quad i\in N$



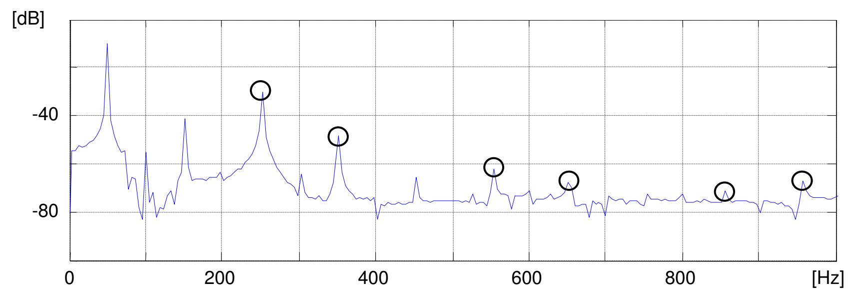
Ruptura a doua bare

Inductanta mutuala intre infasurarea m a statorului si noul ochi rotoric format

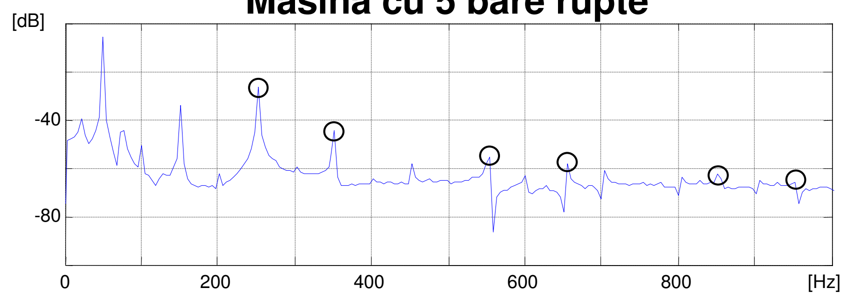


Vom regasi armonici in plus in spectrele curentului statoric si al cuplului in cazul in care sunt defecte in masina

Masina sanatoasa



Masina cu 5 bare rupte



$$f_{stator} = \left[\left(\frac{\mu}{p} \mu \nu \right) (1 - s) \pm 1 \right] f_{sursa}$$