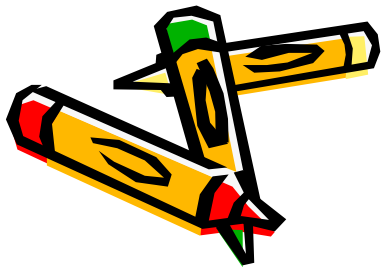
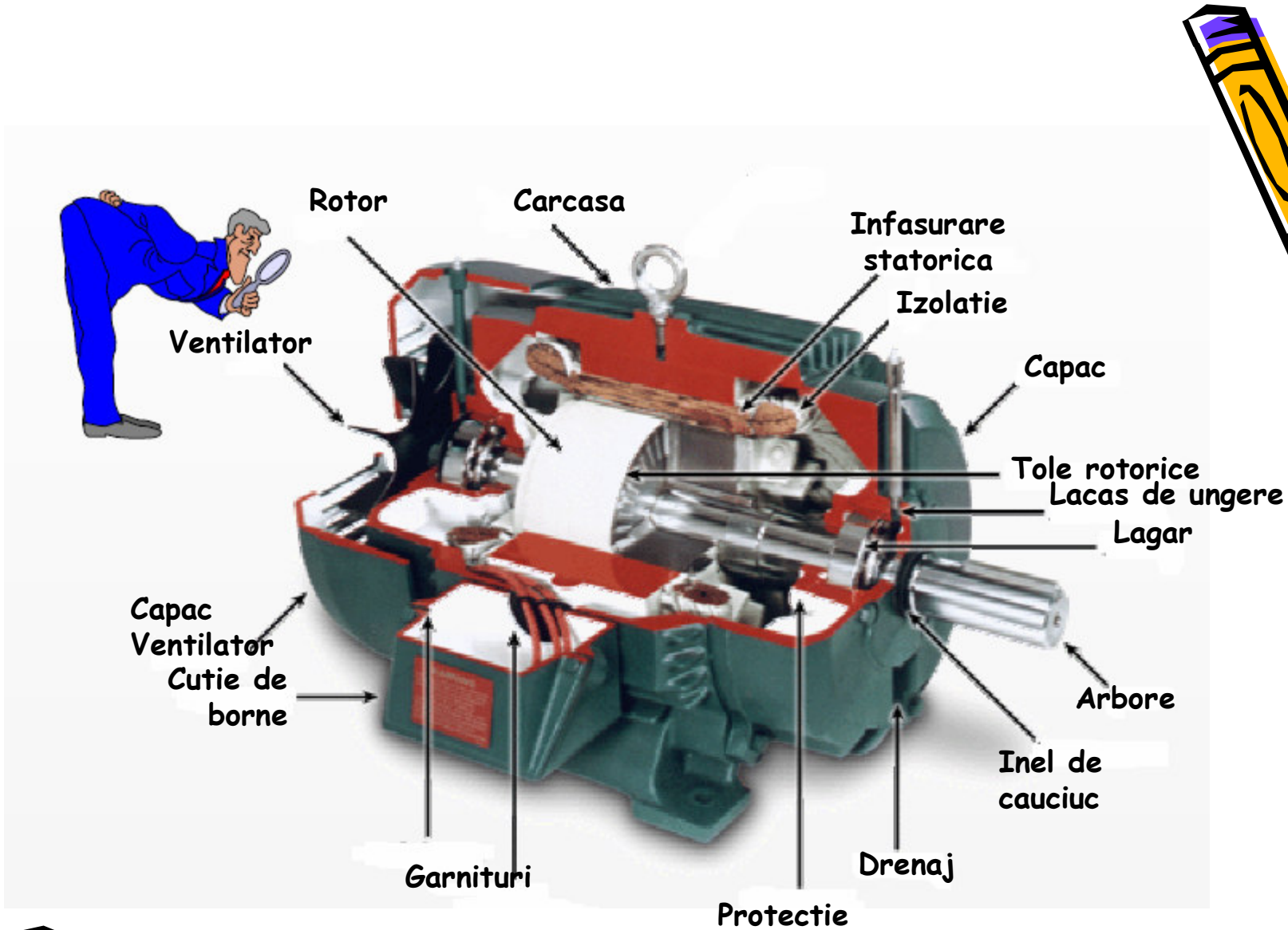




DEFECTE IN MASINI ELECTRICE



TIPURI DE DEFECTE

Defecte la nivelul sistemului mecanic:

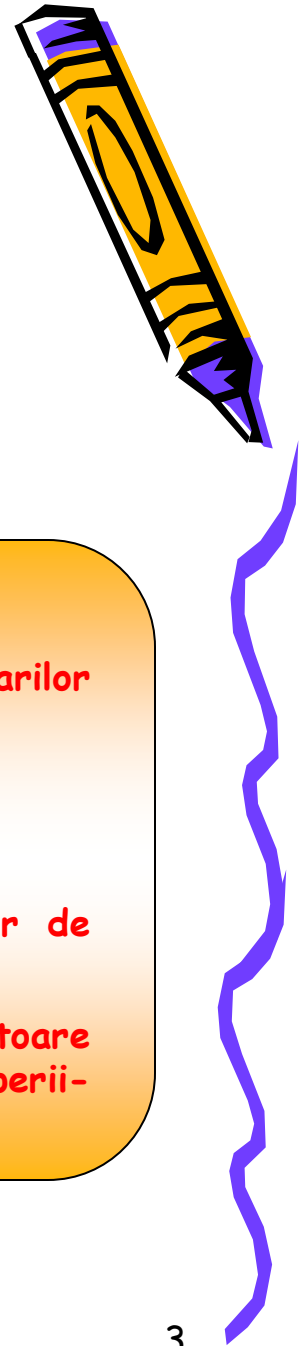
- La nivelul lagarelor
- La nivelul cuplajelor
- La nivelul arborelui

Defecte la nivelul sistemului magnetic:

- Excentricitati ale miezului rotoric
- Anizotropii
- Neomogenitati
- Fisuri ale miezului

Defecte la nivelul sistemului electric:

- Scurtcircuite la nivelul infasurarilor bobinate
- Inversari de cai de curent
- Intreruperi de bobinaj
- Fisuri ale barelor sau ale inelelor de scurtcircuitare
- Probleme la nivelul periiilor colectoare sau al sistemului perii-colector sau perii-inele colectoare.

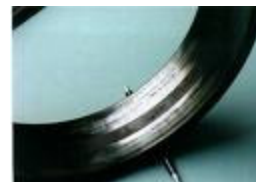
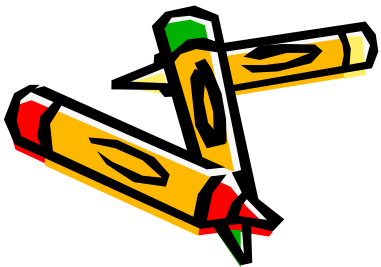


DEFECTE LA NIVELUL LAGARELOR

Defectele din lagăre reprezintă aproximativ 40÷50% din totalul defectelor care apar în mașinile electrice.

Cauze ale apariției defectelor la nivelul lagarelor:

- lubrifierea neadecvată sau insuficientă
- suprasolicitare axială și radială datorită deformării arborelui
- montare, centrare sau fundamentare necorespunzătoare
- acțiunea corosivă a apei, acizilor, etc.
- contaminarea datorată particulelor minuscule abrazive
- Probleme legate de circuitul electric al mașinii electrice

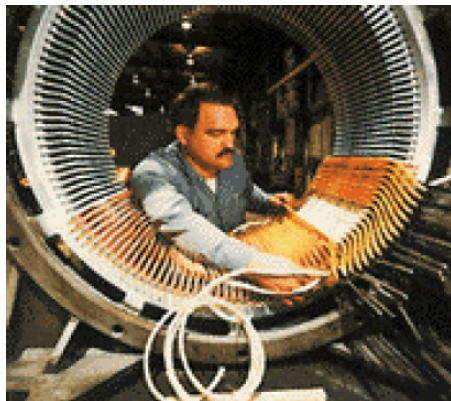


Mentenanța sistemelor
industriale - Curs 6

DEFECTE LA NIVELUL SISTEMULUI ELECTRIC

Tipuri de defecte:

- La nivelul infasurarilor bobinate
- La nivelul infasurarilor tip colivie
- La nivelul sistemului perii-colector sau perii-inele colectoare



Mentenanța sistemelor
industriale - Curs 6



Defecte la nivelul infasurarilor bobinate:

Acest tip de defecte reprezintă aproximativ 30÷40% din totalul defectelor care apar în mașinile electrice

Defecte tipice:

- întreruperea înfășurării unei faze;
- inversarea capetelor înfășurării unei faze;
- scurtcircuit între spirele conductoare elementare sau între bobinele aceleiași faze;
- scurtcircuit între înfășurările a două faze diferite;
- punerea la masă a înfășurării unei faze;
- inversarea unei căi de curent;

Defecte la nivelul infasurarilor tip colivie:

Aceste tipuri de defecte reprezintă aproximativ 5÷10% din totalul defectelor în mașinile electrice.

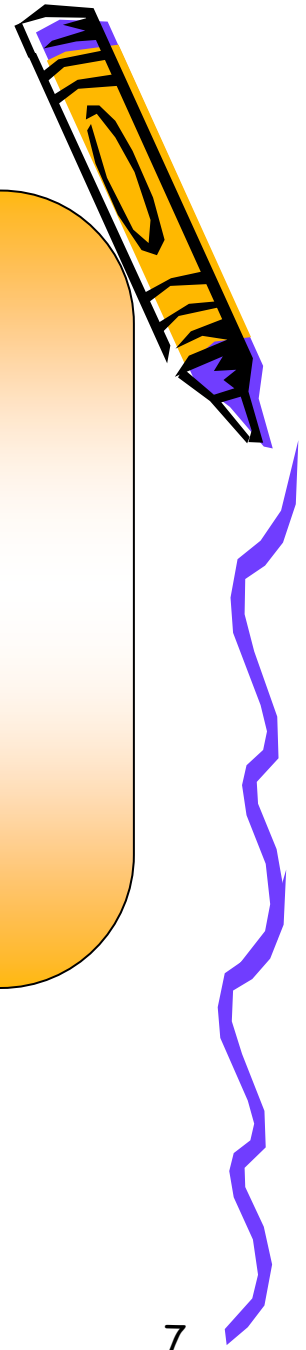
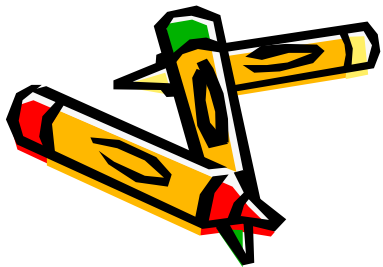
Tipuri de defecte:

- Fisuri sau intreruperi ale barelor
- Distrugerea îmbinării barelor cu inelele frontale de scurtcircuitare



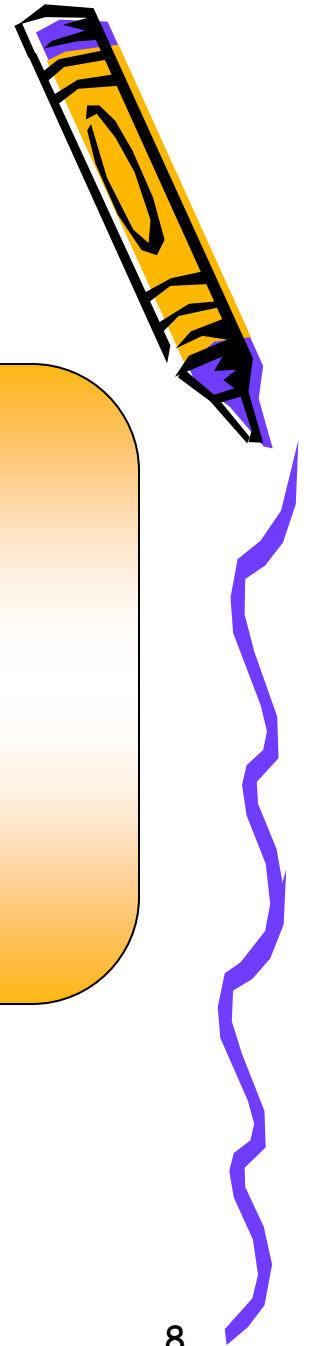
MODUL DE MANIFESTARE AL DEFECTELOR

- Supraîncălzirea mașinii de inducție.
- Imposibilitatea pornirii mașinii
- Rotorul se rotește cu o turație mai mică decât cea nominală.
- Vibratii
- Zgomote
- Dezechilibrul partilor rotative



METODE DE DETECTIE A DEFECTELOR

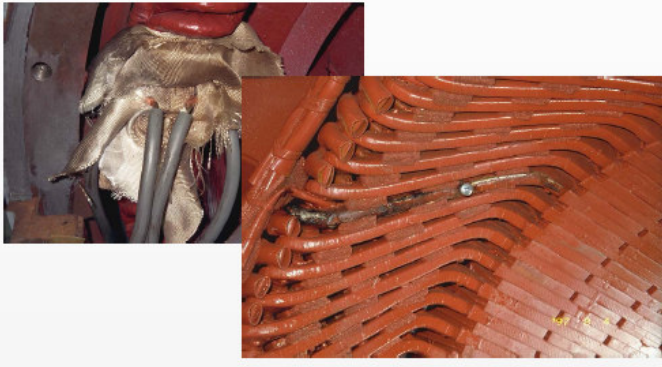
- Analiza spectrala a curentilor statorici/rotorici
- Analiza fluxului axial
- Analiza spectrala a vibratiilor
- Analiza zgomotelor masinii
- Analiza termografica



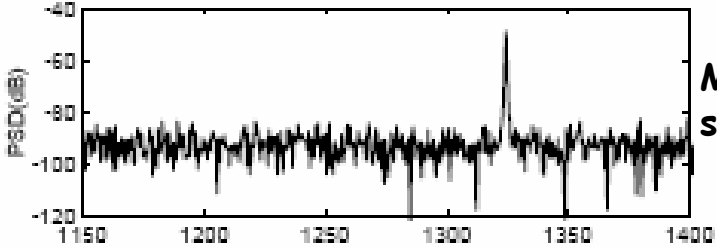


Analiza spectrala a curenților statorici/rotorici

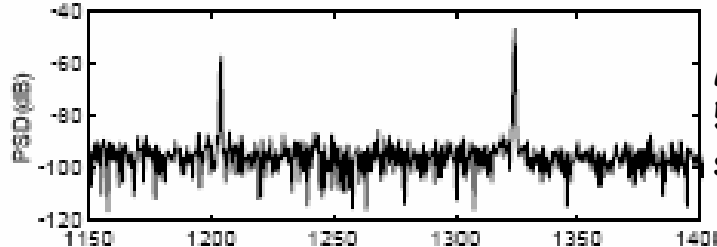
Scurtcircuit statoric



Spectrul curentului statoric



Masina sanatoasa



**Masina defecta
5 spire din 324
scurtcircuitate**

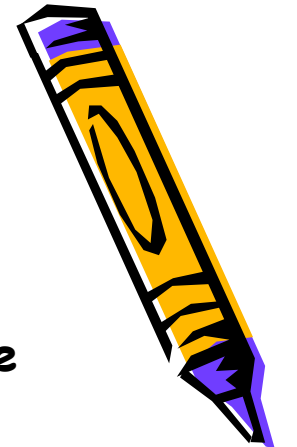
Frequency (Hz)



BAZE TEORETICE ALE ANALIZEI SPECTRULUI CURENTILOR STATORICI/ROTORICI

Ecuatia de tensiuni a unei faze statorice/rotorice:

$$\begin{array}{l} \text{Tensiunea la borne} \rightarrow u = Ri + \frac{d\Psi}{dt} \leftarrow \text{Fluxul ce inlantuie faza respectiva} \\ \underbrace{\hspace{15em}} \\ \begin{array}{lll} \text{Fluxul propriu al fazei} & \text{Fluxul determinat de celelalte faze statorice/rotorice} & \text{Fluxul determinat de infasurarile rotorice/statorice} \end{array} \end{array}$$



Armonicile induse de curenții statorici în înfășurările rotorice

Solenatia statorică în
întrefier

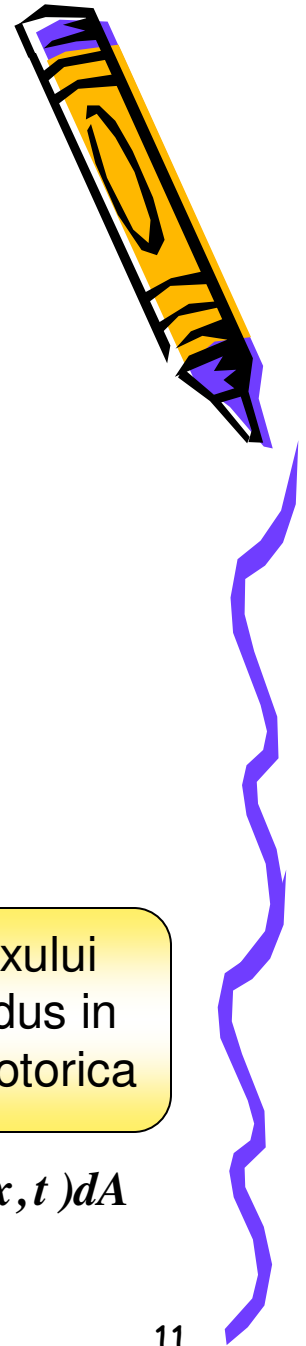
$$\Theta_b = Ni(t)$$

Calculul inducției
magnetice

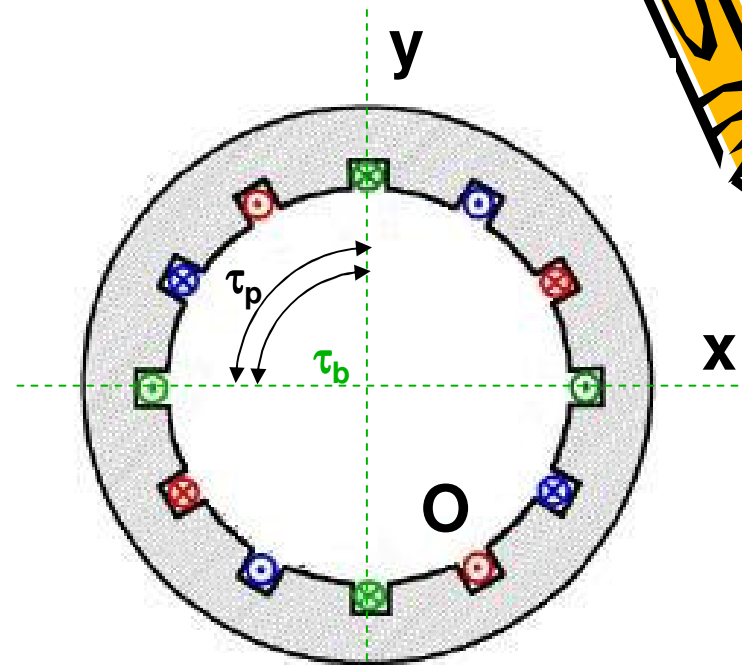
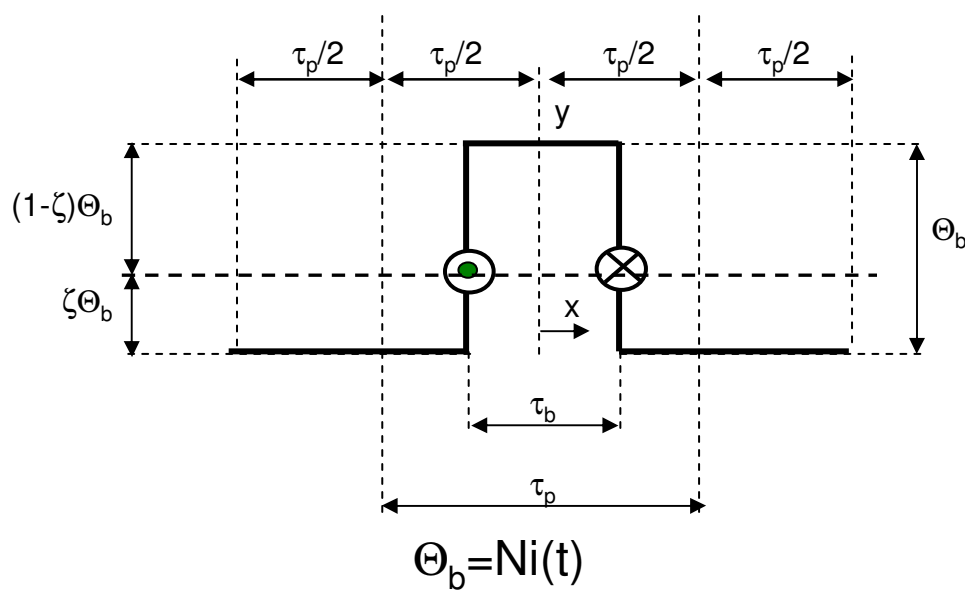
$$B(x, t) = \frac{\mu_0 \Theta_b(x, t)}{2\delta_c}$$

Calculul fluxului
magnetic indus în
înfășurarea rotorică

$$\Psi = \int_{\text{Suprafața}} B(x, t) dA$$



Distributia solenatiei unei bobine (pentru un pol)



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

Dezvoltare in serie Fourier

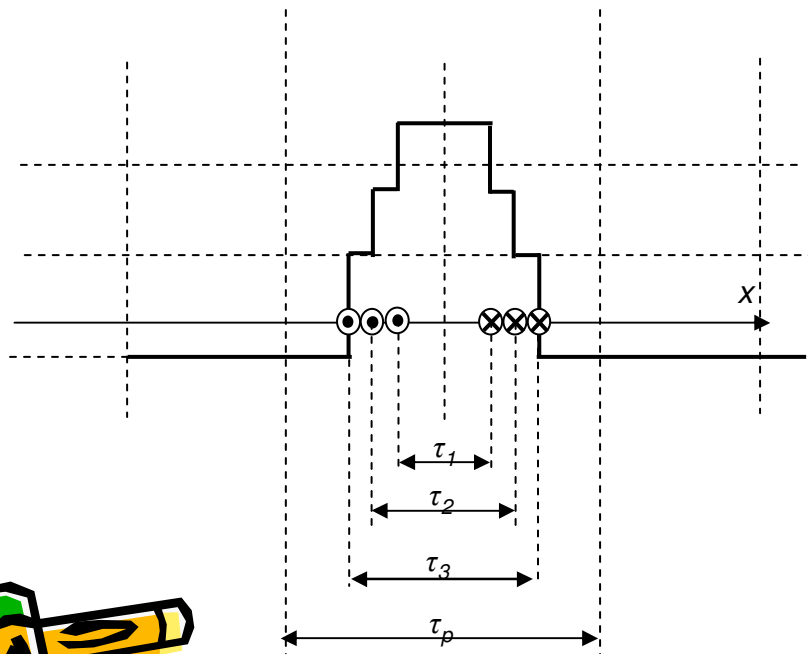
$$\Theta_b(x) = \sum_{v=1}^{\infty} \Theta_{bv} \cos\left(v \frac{x}{\tau_p} \pi\right)$$

Bobina

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

Grup de n_b bobine

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



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

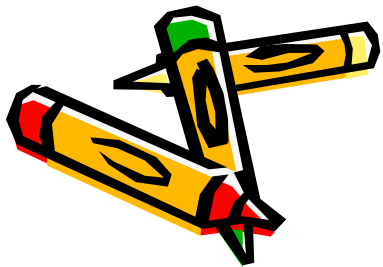
$$\Theta_{total}(x, t) = \frac{2}{\pi} N \sum_{g=1}^{mp} n_b I_g \sum_{v=1}^{\infty} \frac{1}{v} k_{gv} [\sin(\alpha - v\beta) + \sin(\alpha + v\beta)]$$

Inductia magnetica in intrefier

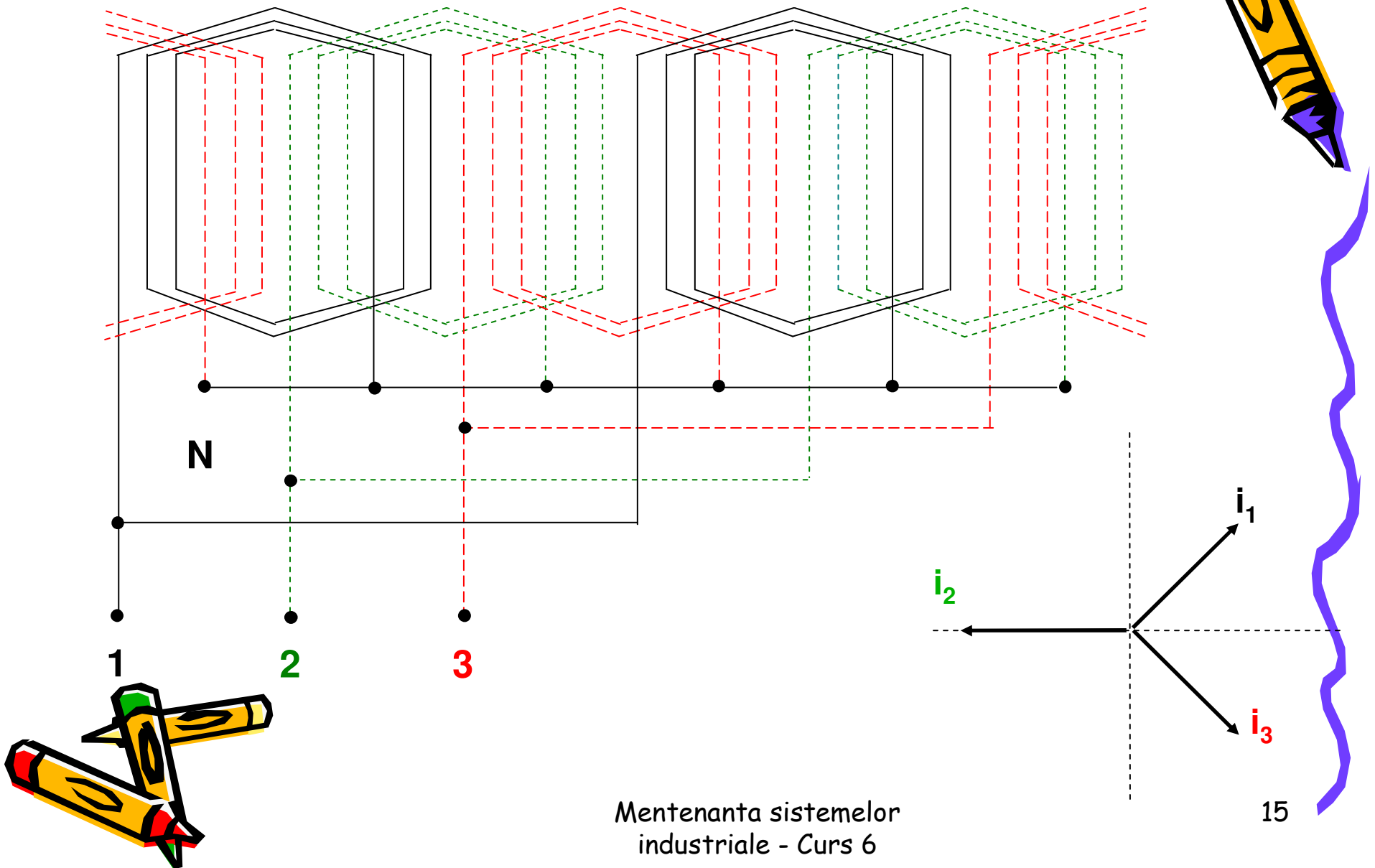
$$B(x, t) = \frac{\mu_0 \Theta_{total}(x, t)}{2\delta_c} = \frac{\mu_0}{\pi\delta_c} N \sum_{g=1}^{mp} n_b I_g \sum_{v=1}^{\infty} \frac{1}{v} k_{gv} [\sin(\alpha - v\beta) + \sin(\alpha + v\beta)]$$

Campul magnetic creat de infasurarile statorice

$$\Psi = \int_{Suprafata} B(x, t) dA$$



MASINA DE INDUCTIE – distributia infasurarilor in crestaturi



Curenti statorici

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



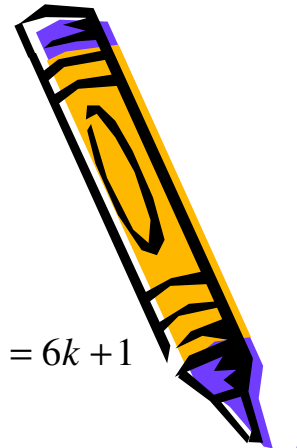
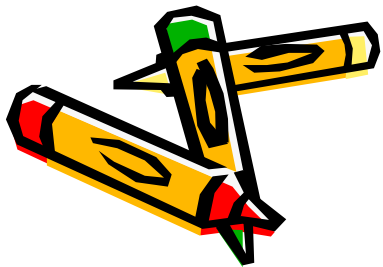
Solenatie statorica

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

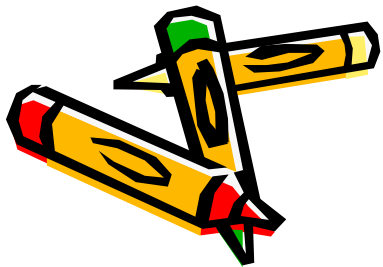
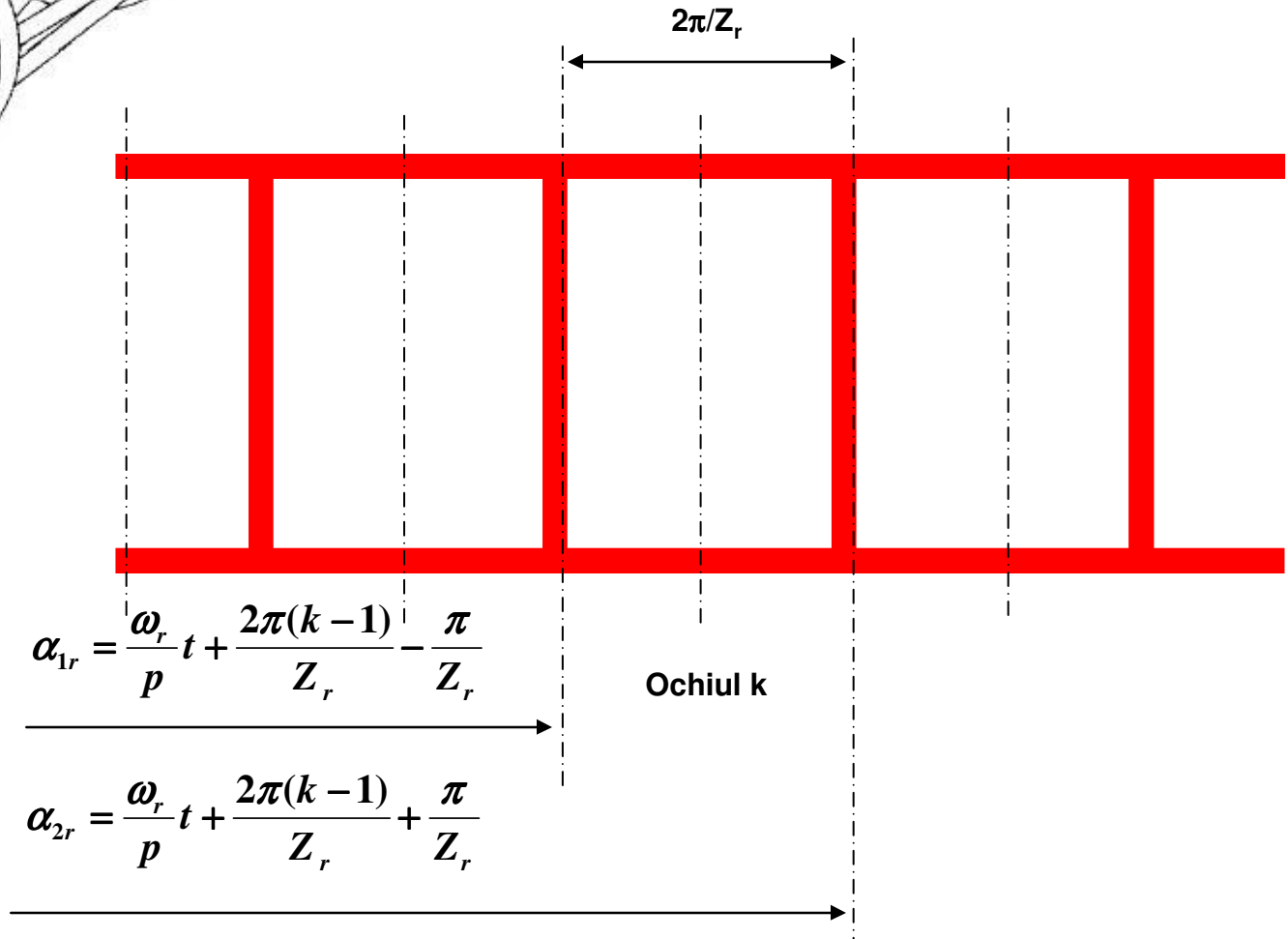
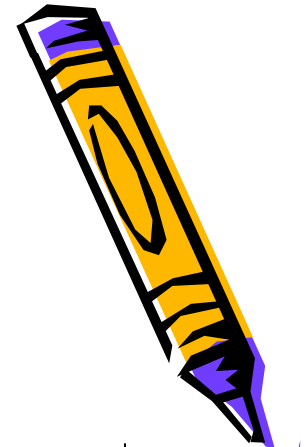
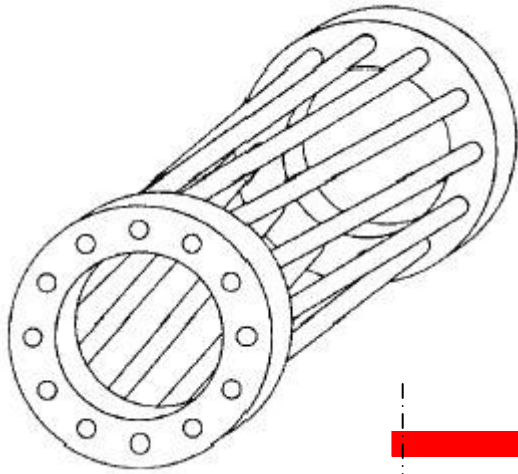


Flux indus de catre solenatia statorica intr-un ochi rotor

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



Rotorul in colivie: Z_r ochiuri rotorice

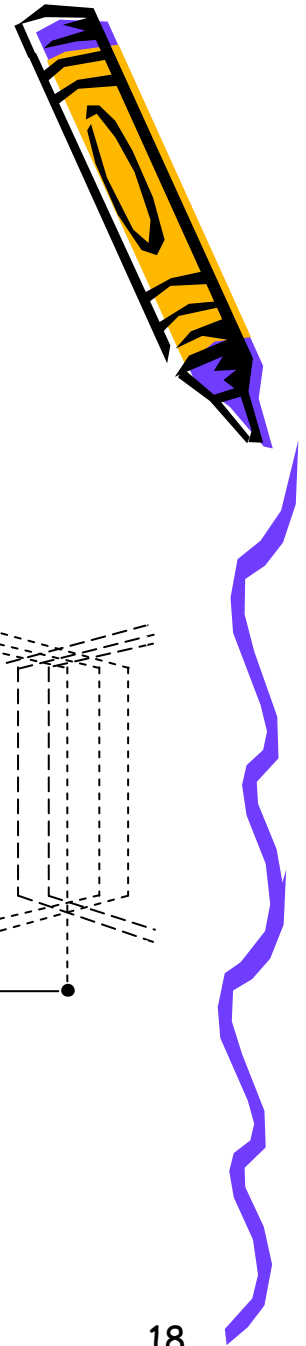
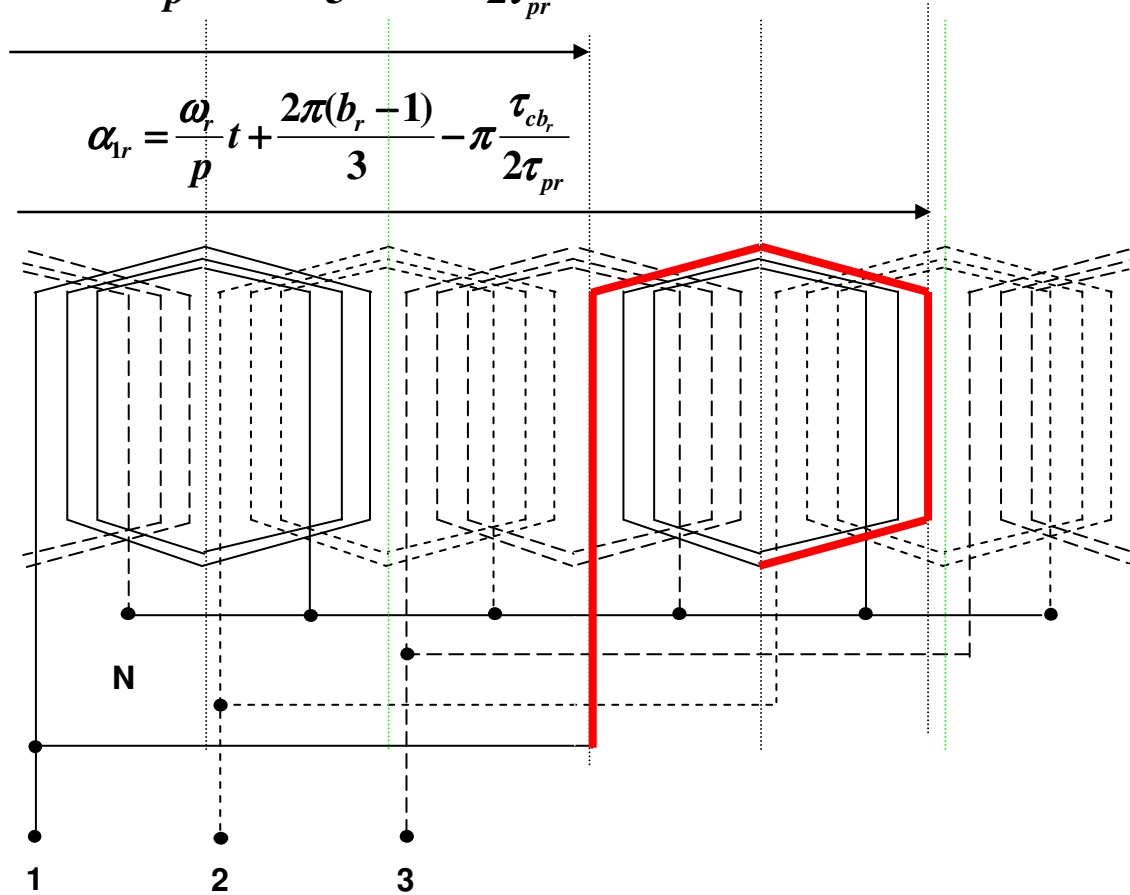




Rotorul bobinat: Z_r crestaturi rotorice

$$\alpha_{2r} = \frac{\omega_r}{p} t + \frac{2\pi(b_r - 1)}{3} + \pi \frac{\tau_{cb_r}}{2\tau_{pr}} \quad \text{Bobina } b_r \text{ a rotorului}$$

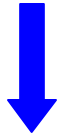
$$\alpha_{1r} = \frac{\omega_r}{p} t + \frac{2\pi(b_r - 1)}{3} - \pi \frac{\tau_{cb_r}}{2\tau_{pr}}$$





T.e.m. indusa de catre solenatia statorica intr-un ochi/bobina rotorica/rotorica

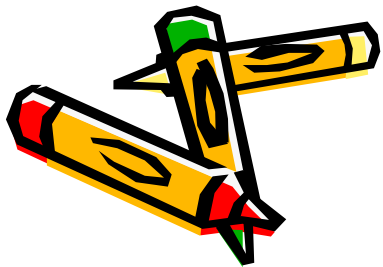
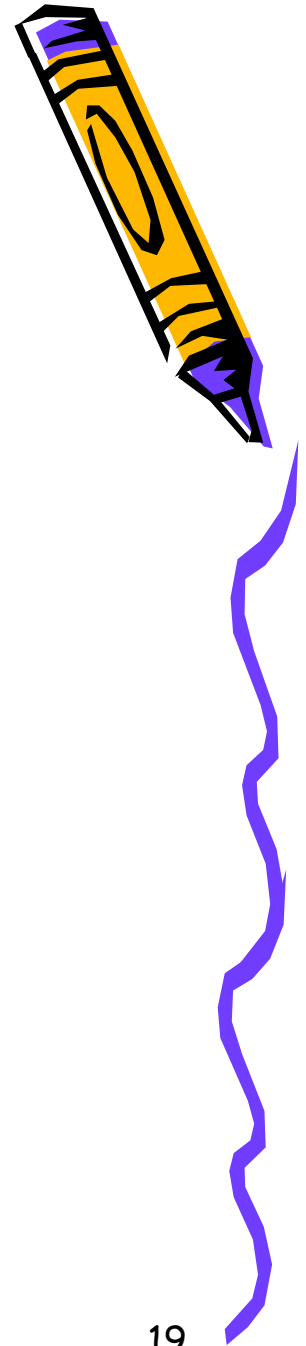
$$e_{k,v} = -\frac{d}{dt} \Phi_{kv}^s(t) = [1 \mp v(1-s)] \omega \Phi_{max v} \cos \left[\omega t \mp v \omega_r t \mp \frac{v\pi}{p} \frac{2\pi(k-1)}{Z_r} \right]$$



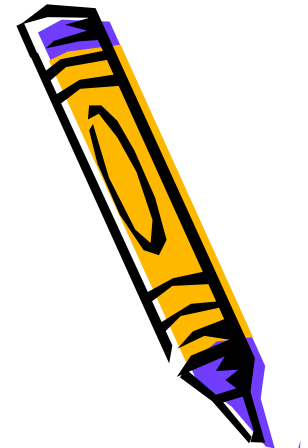
$$f_{rotor} = [1 - v(1-s)]f, v = 6k + 1$$

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

Frecventele componentelor spectrale ale curentilor rotorici



Armonicile induse de curenții rotorici în înfășurările statorice



Solenatia rotorica în
întrefier

$$\Theta_b = Ni(t)$$



Calculul inducției
magnetice

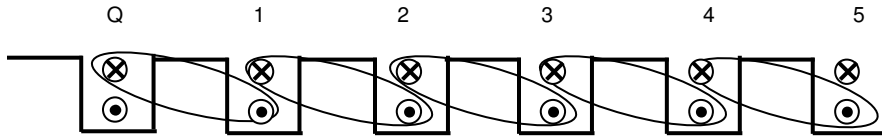
$$B(x, t) = \frac{\mu_0 \Theta_b(x, t)}{2\delta_c}$$



Calculul fluxului
magnetic indus în
înfășurarea statorică

$$\Psi = \int_{\text{Suprafața}} B(x, t) dA$$





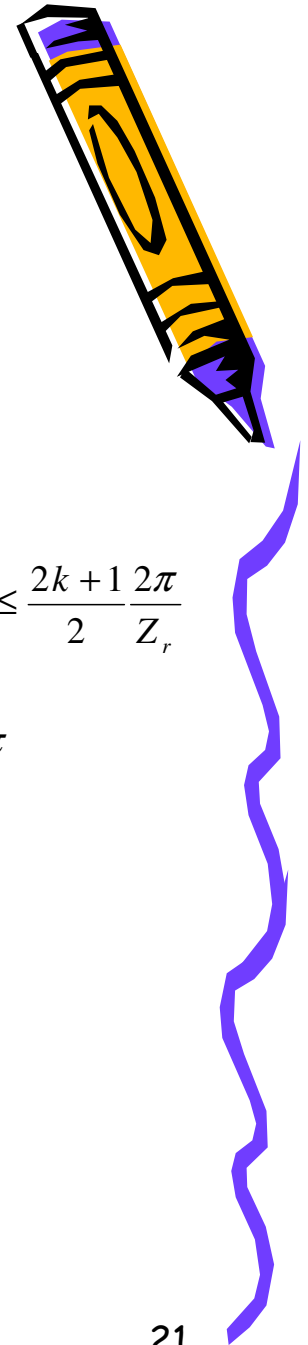
Infasurarea echivalenta a rotorului în colivie.

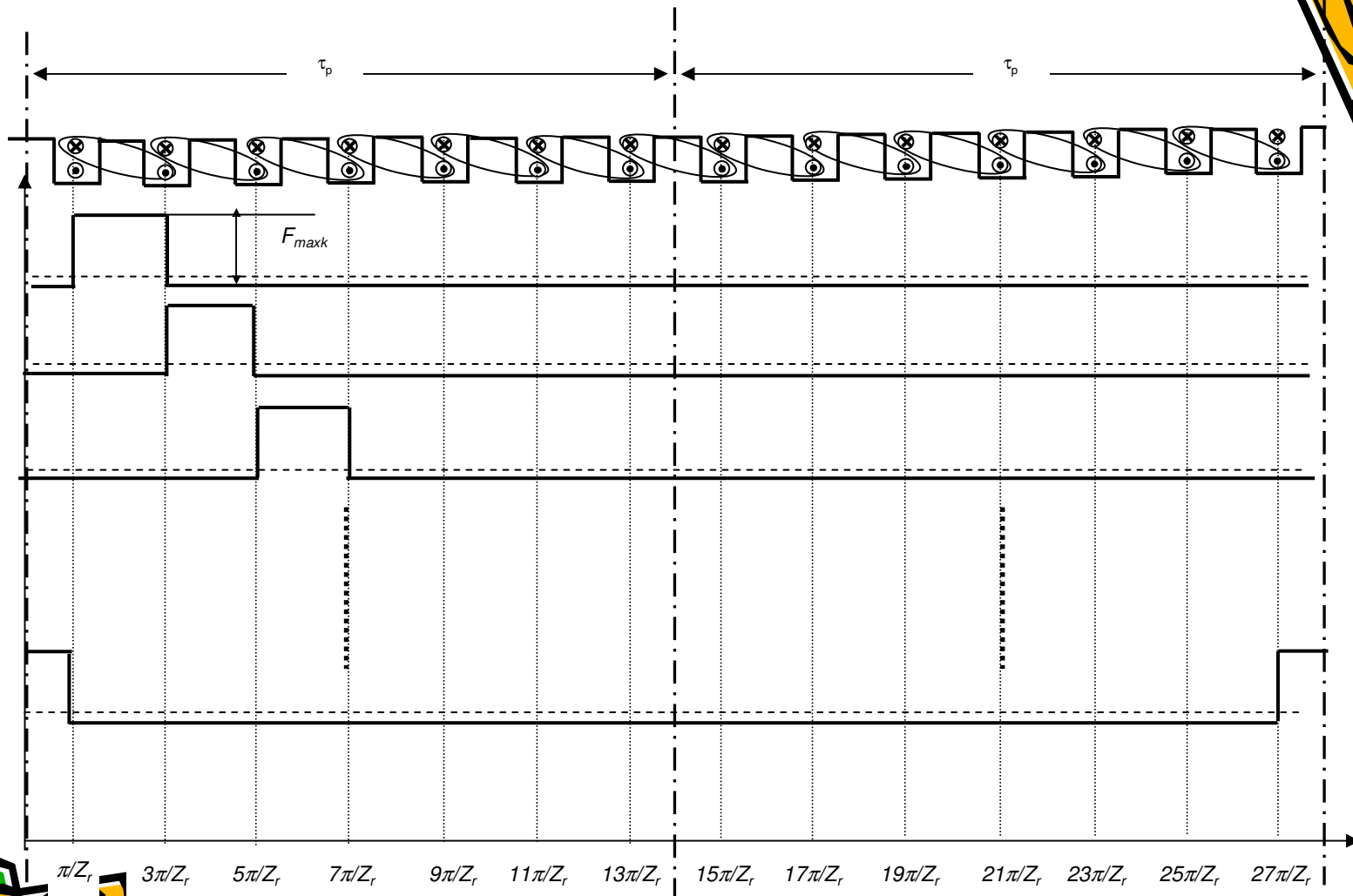
Solenajia corespunzatoare unei faze rotorice

$$\Theta_{kv}^r(\alpha) = \begin{cases} -\zeta_r \Theta_{\max k}^r, & 0 \leq \alpha < \frac{2k-1}{2} \frac{2\pi}{Z_r} \\ (1-\zeta_r) \Theta_{\max k}^r, & \frac{2k-1}{2} \frac{2\pi}{Z_r} \leq \alpha \leq \frac{2k+1}{2} \frac{2\pi}{Z_r} \\ -\zeta_r \Theta_{\max k}^r, & \frac{2k+1}{2} \frac{2\pi}{Z_r} < \alpha \leq 2\pi \end{cases}$$

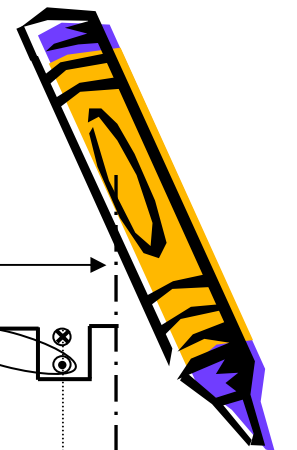
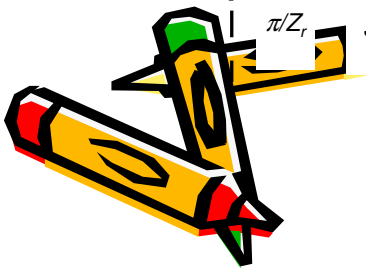
Dezvoltare in serie Fourier

$$\Theta_v(\alpha, t) = \sum_{k=1}^{Z_r} \frac{I_{rv, \max}}{\pi} \sum_{\gamma=1}^{\infty} \frac{1}{\gamma} \sin\left(\frac{\pi\gamma}{Z_r}\right) \sin\{\gamma\alpha \pm s_v \omega t + (\gamma \mp \nu p)\}$$





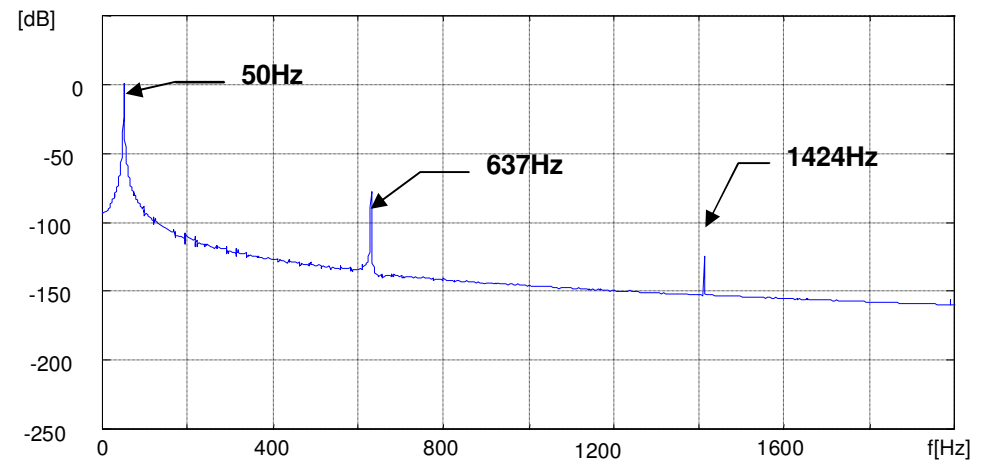
Distribuția solenației rotorice de-a lungul întrefierului.



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

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

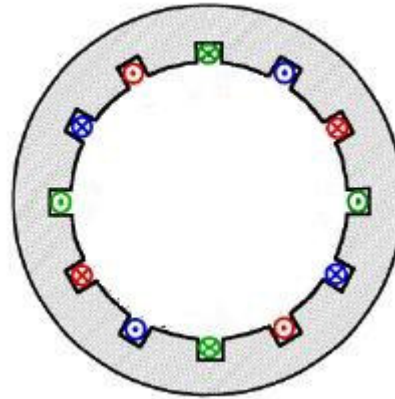
Ordinul armonicii (γ)	Frecvența armonicii [Hz]
1	637
2	1424
4	2698
5	3485
6	4171.5
8	5546
9	6133



Spectrul de frecvențe al curentului statoric



MASINA SINCRONA



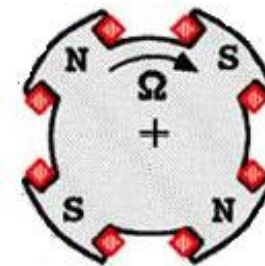
Stator(indusul)

Rotor(inductor)



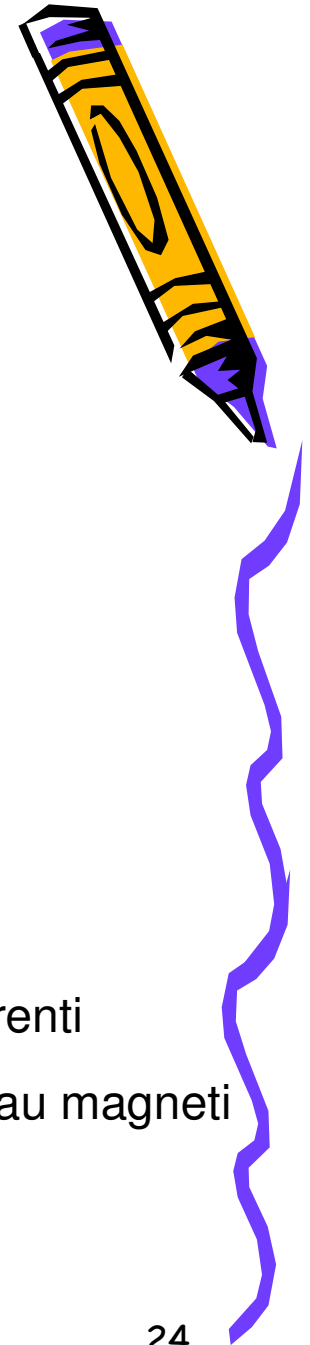
Rotor cu poli inecati

(infasurari distribuite in crestaturi rotorice)



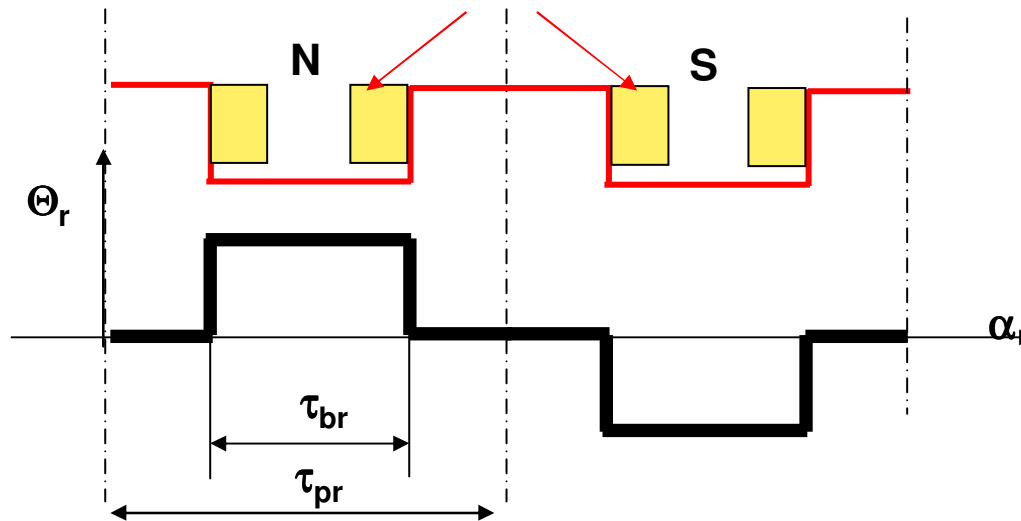
Rotor cu poli aparenti

(infasurari concentrate sau magneti permanenti)



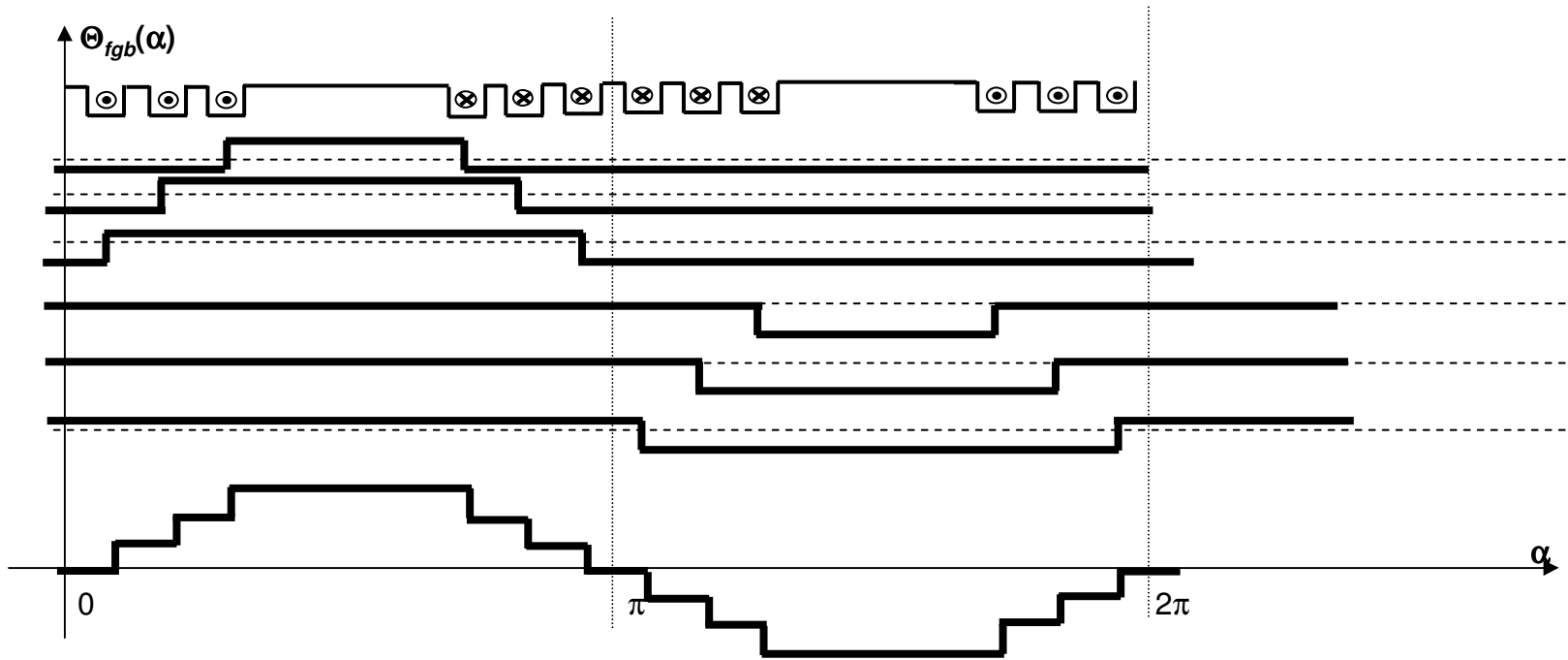
Rotor cu poli aparenti

**Bobine rotorice concentrate sau
magneti permanenti pe rotor**

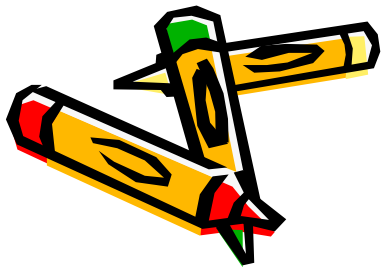


$$\Theta_r(\alpha, t) = \sum_{v=1}^{\infty} \Theta_{r,v,\max}(t) \cos p v \alpha$$
$$\Theta_{r,v,\max}(t) = \text{constant}$$

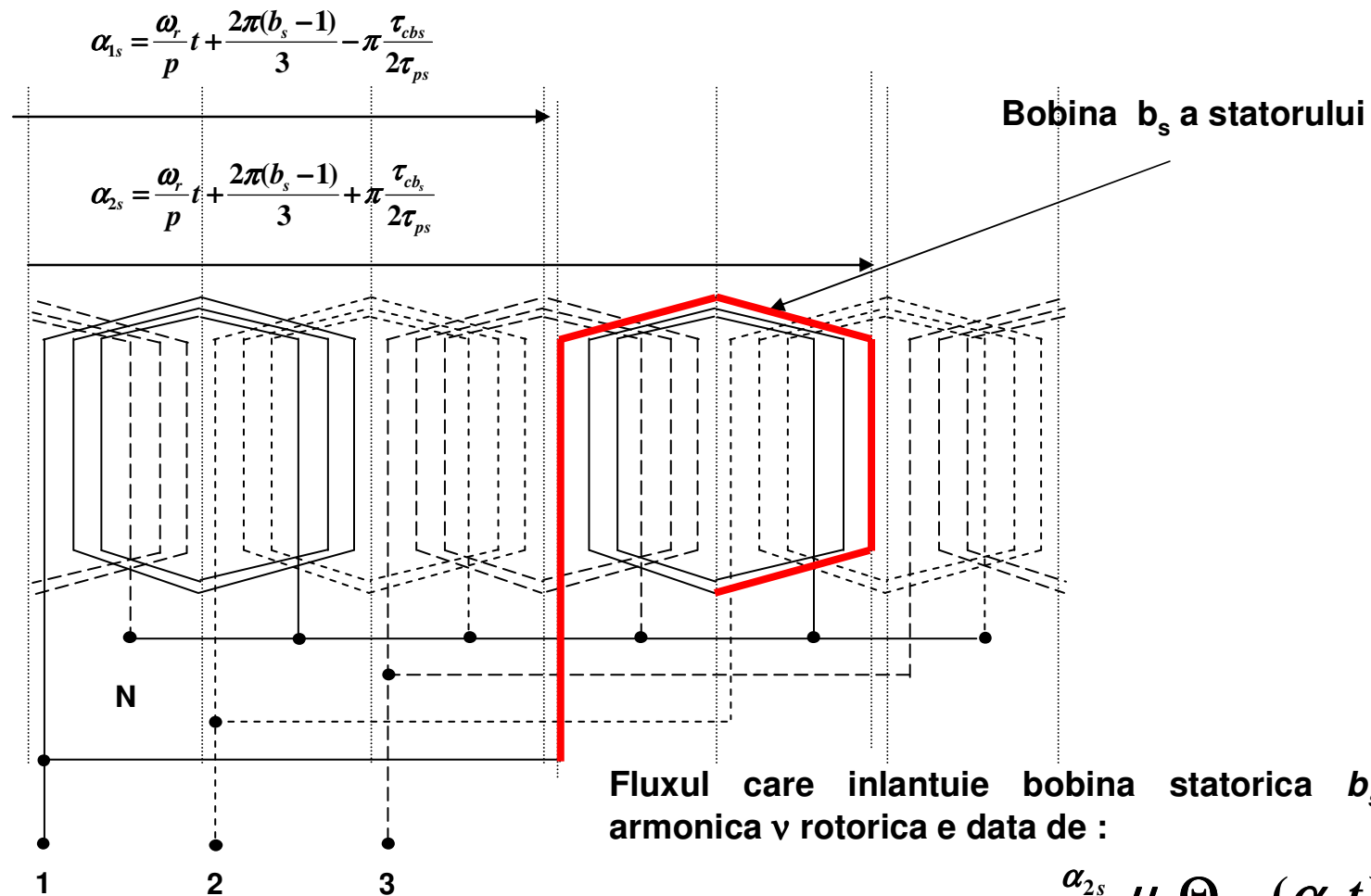
Rotor cu poli inecati



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

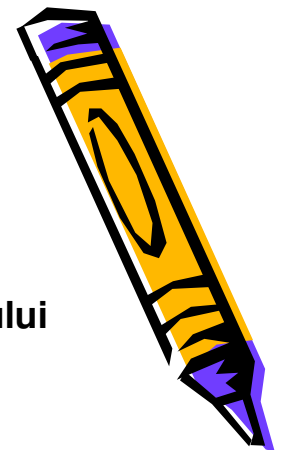
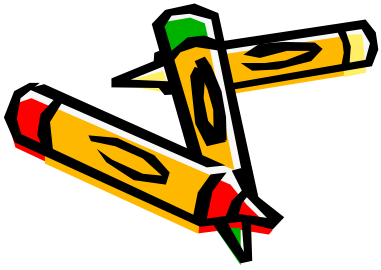


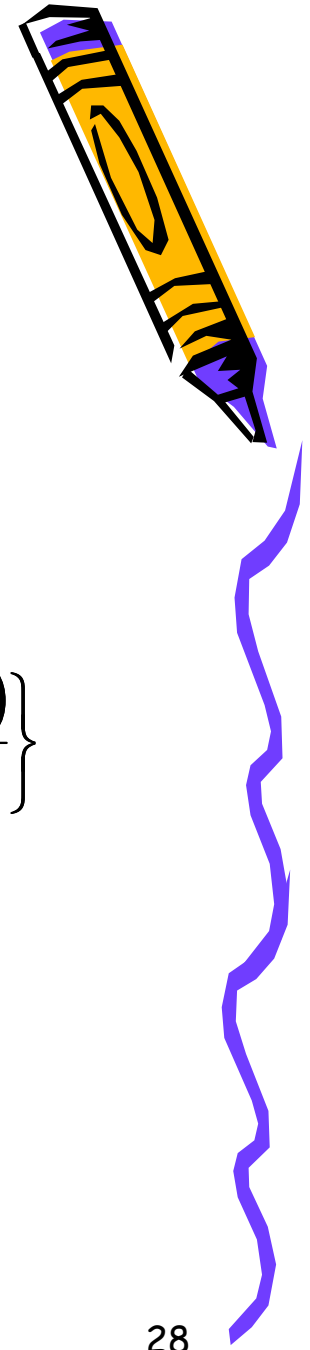
Conexiunile infasurarii statorice



Fluxul care inlantuie bobina statorica b_s prin armonica v rotorica e data de :

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





Fluxul total in bobina b_s :

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

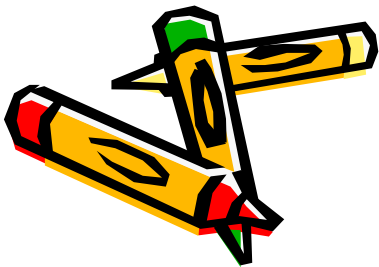
Tensiunea electromotoare indusa in bobina b_s :

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

Frecventele ce vor apare in curentul statoric:

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

Mentenananta sistemelor
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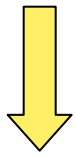




Diagnoza in masini de inductie



Defecte electrice

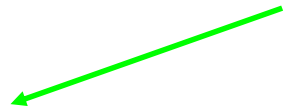


Bare sau inele rupte

Scurtcircuite statorice sau rotorice



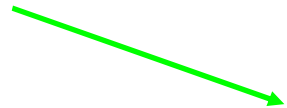
Dezechilibru



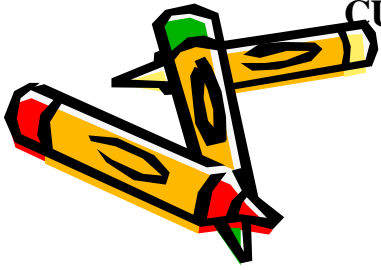
CURRENT



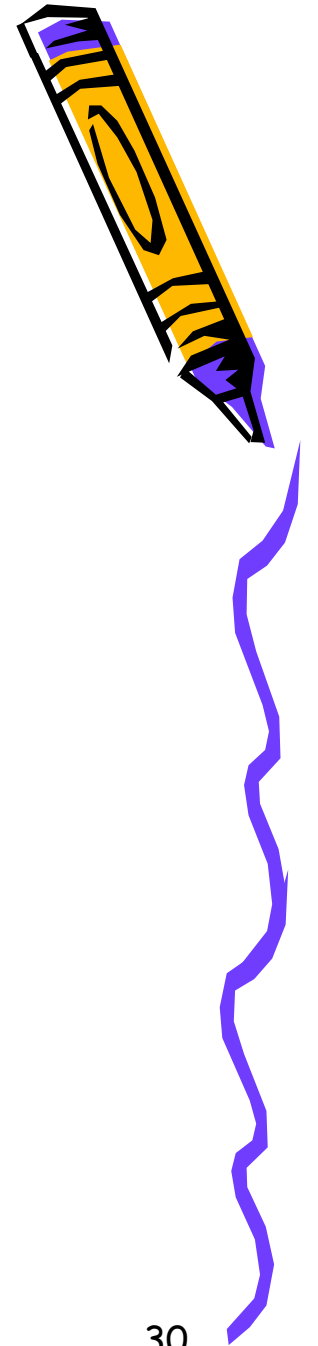
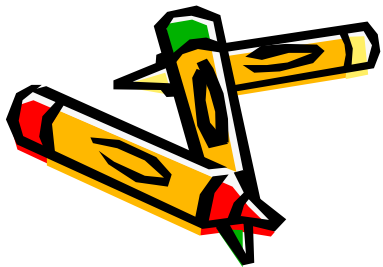
FLUX



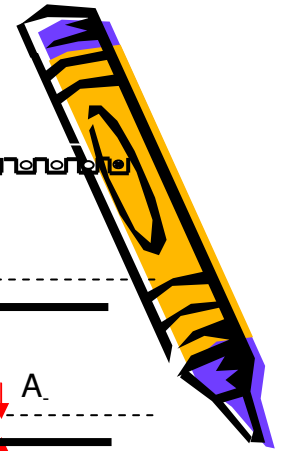
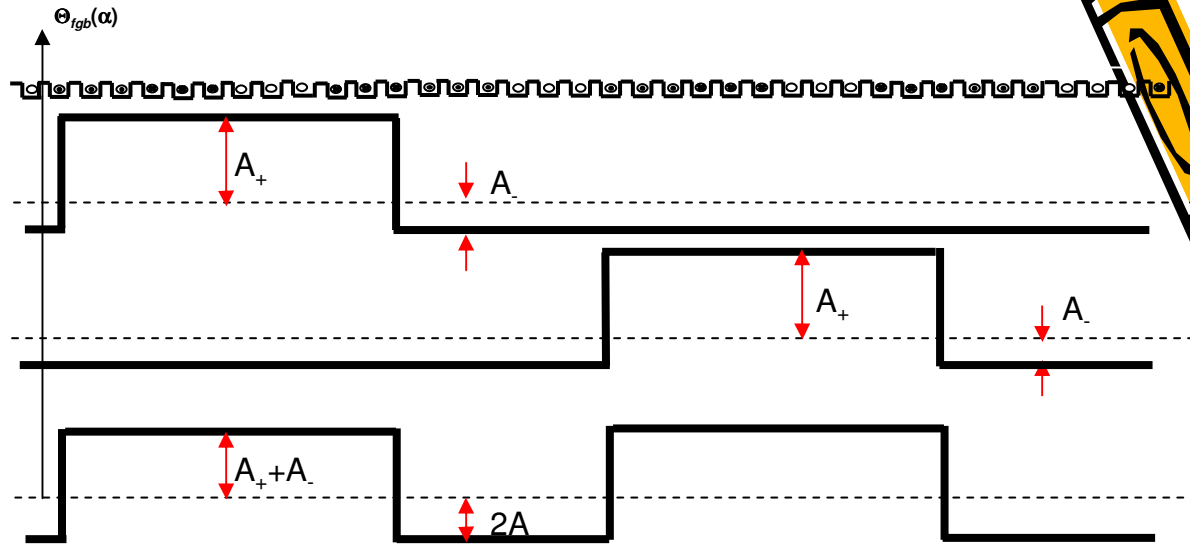
CUPLU



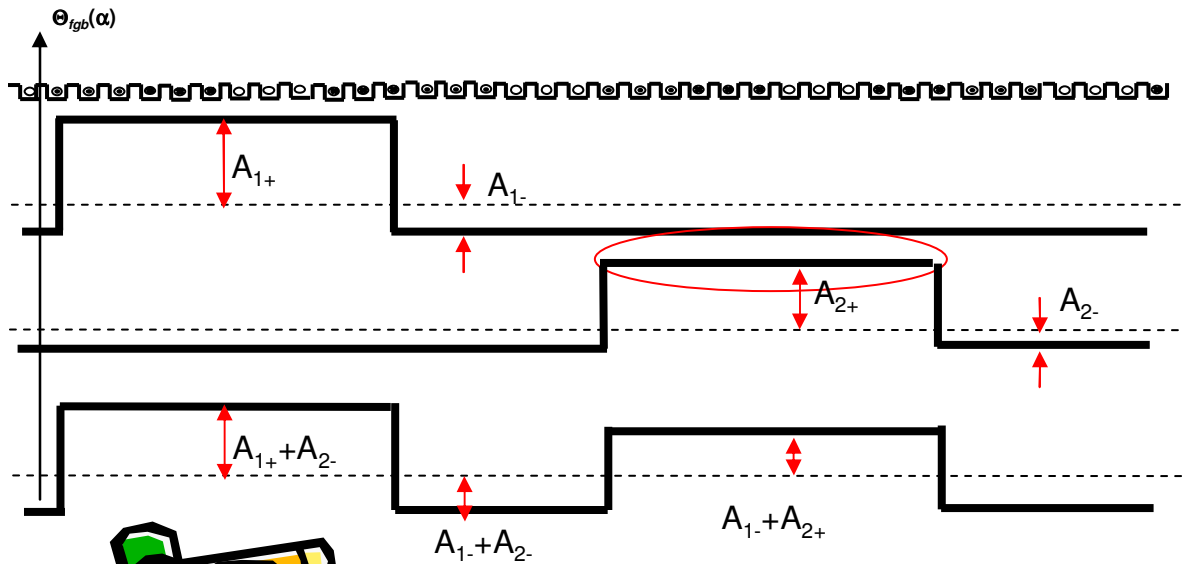
DEFECTE ELECTRICE STATORICE



Masina de inductie
fara defecte



Masina de inductie
cu scurtcircuit in faza
1 grupul 2



Solenatia statorului fara defecte

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

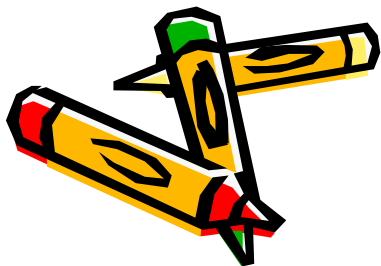
$$\nu = 6k \pm 1, \quad k = 0, 1, 2, \dots$$

Solenatia statorica cu defecte statorice (scurt circuit)

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

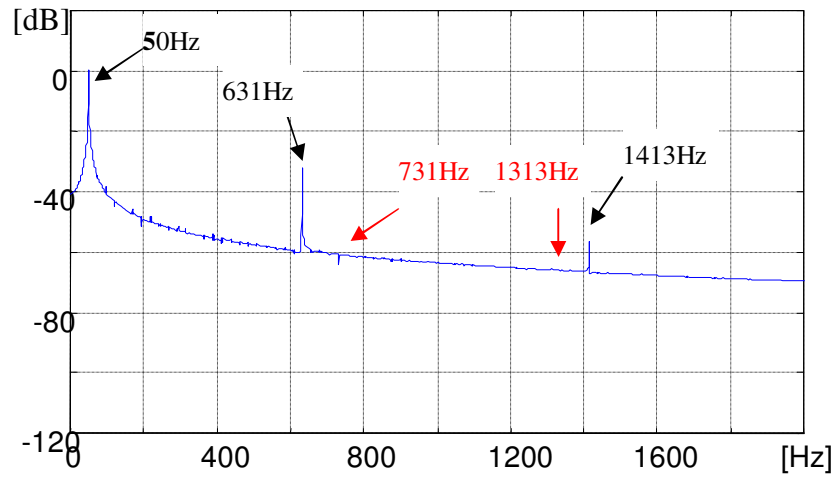
$$\nu = 6k \pm 1, \quad k = 0, 1, 2, \dots$$

$$\nu_{sc} = 1, 3, 5, \dots$$

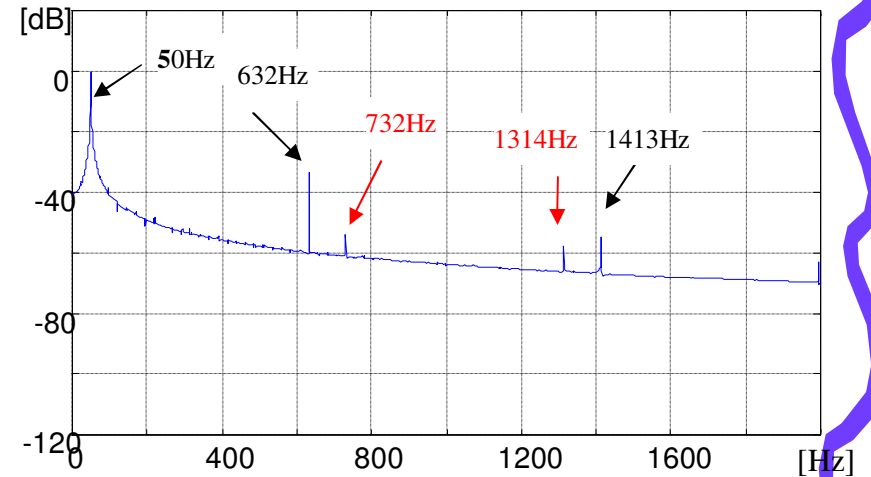




Masina de inductie fara defecte



Masina de inductie cu 6 spire in scurt-circuit



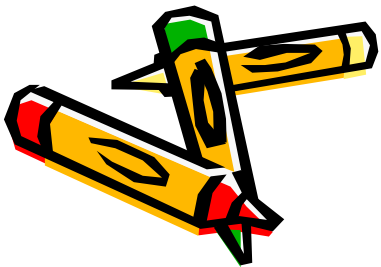
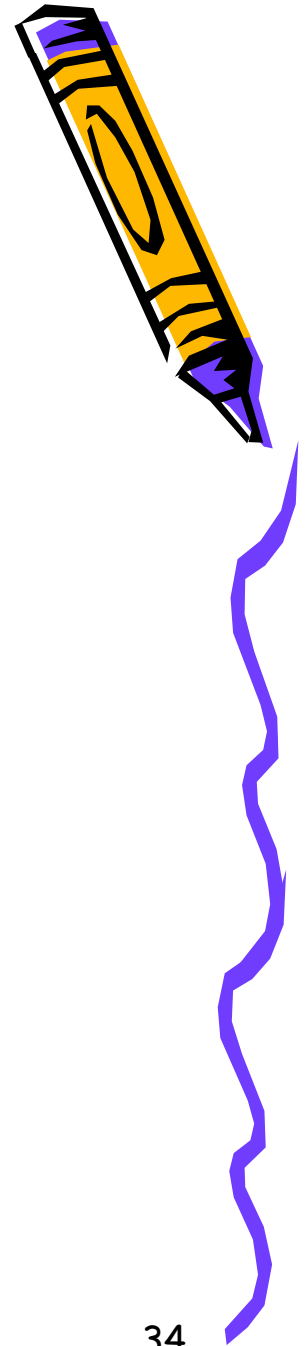
Curent statoric



DEFECTE ELECTRICE ROTORICE

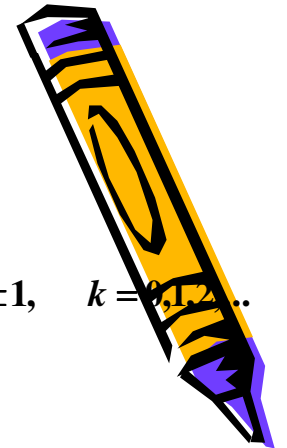


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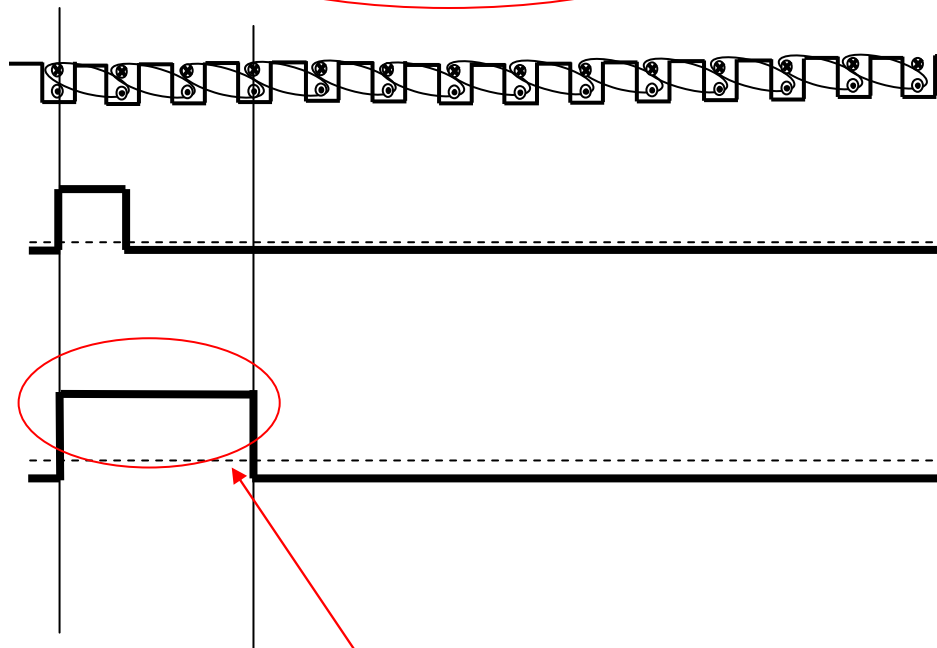
Solenatia rotorului fara defecte

$$\Theta_{r,v}(\alpha,t) = \frac{Z_r I_{rv,\max}}{\pi} \sum_{\gamma=1}^{\infty} \frac{1}{\gamma} \sin\left(\frac{\pi\gamma}{Z_r}\right) \sin\{\gamma\alpha \pm s_v \omega t\} \quad \gamma = qZ_r \pm v p, \quad q = 0,1,2,\dots \quad v = 6k \pm 1, \quad k = 0,1,2,\dots$$



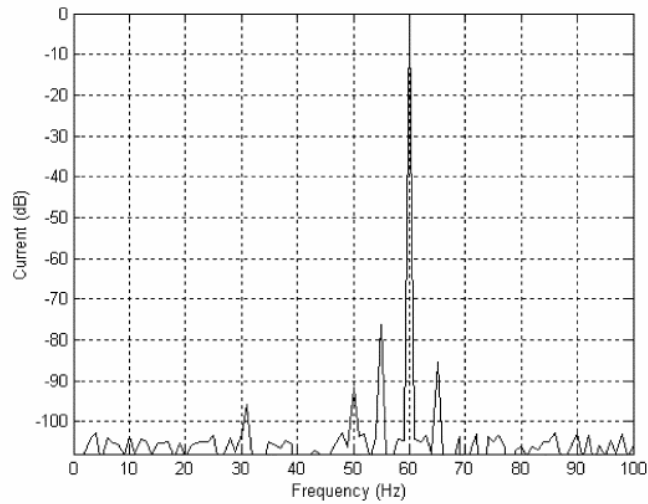
Solenatia rotorului cu defecte rotorice

$$\Theta_v(\alpha,t) = \sum_{k=1}^{N_r} \frac{I_{rv,\max}}{\pi} \sum_{\gamma=1}^{\infty} \frac{1}{\gamma} \sin\left(\frac{\pi\gamma}{Z_r}\right) \sin\left\{ \gamma\alpha \pm s_v \omega t + (\gamma \mp v p) \frac{2\pi}{Z_r} k \right\} \quad \gamma = 0,1,2,\dots \quad \gamma \neq 2pi, \quad i \in N$$

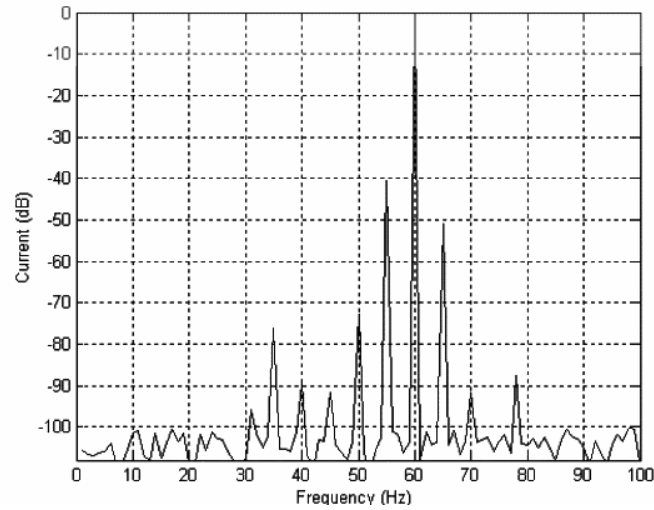


Ruptura a doua bare
 Mentenanta sistemelor
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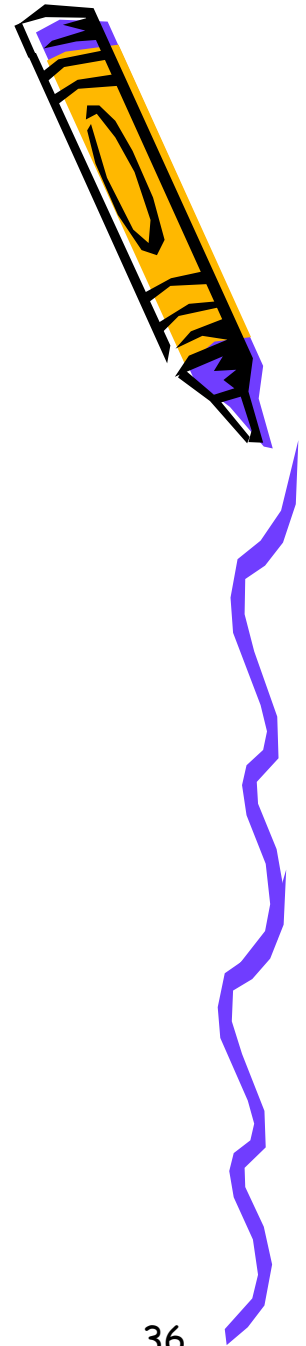
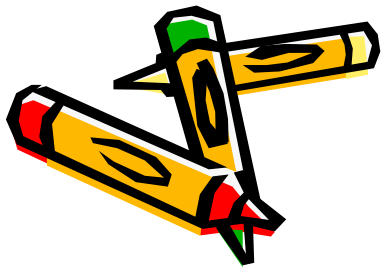


Masina sanatoasa



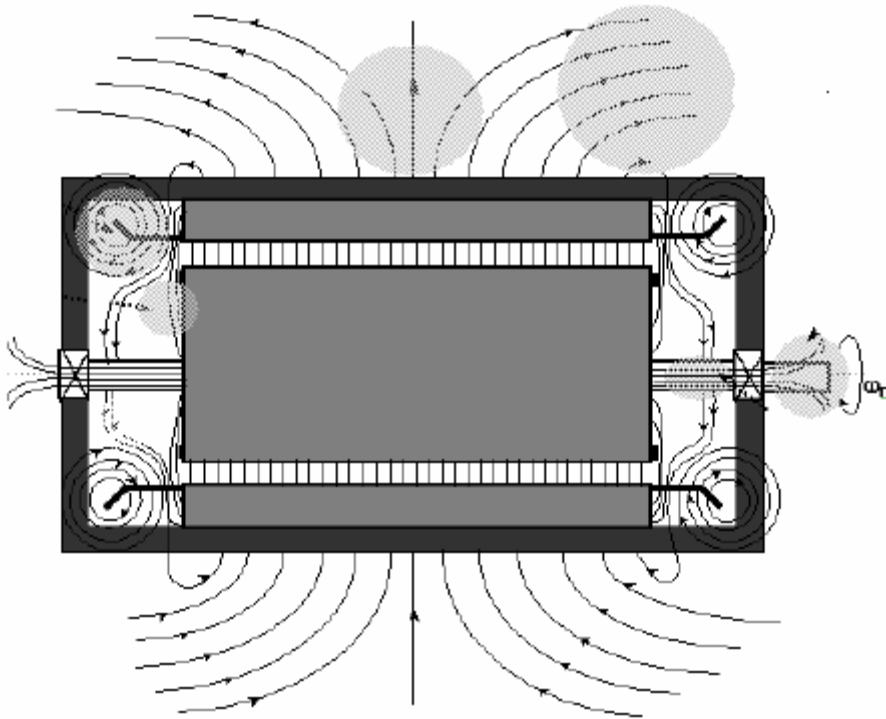
**Masina cu bare
intrerupte**

$$f_b = (1 \pm 2ks)f_1, \quad k = 1, 2, 3 \dots$$

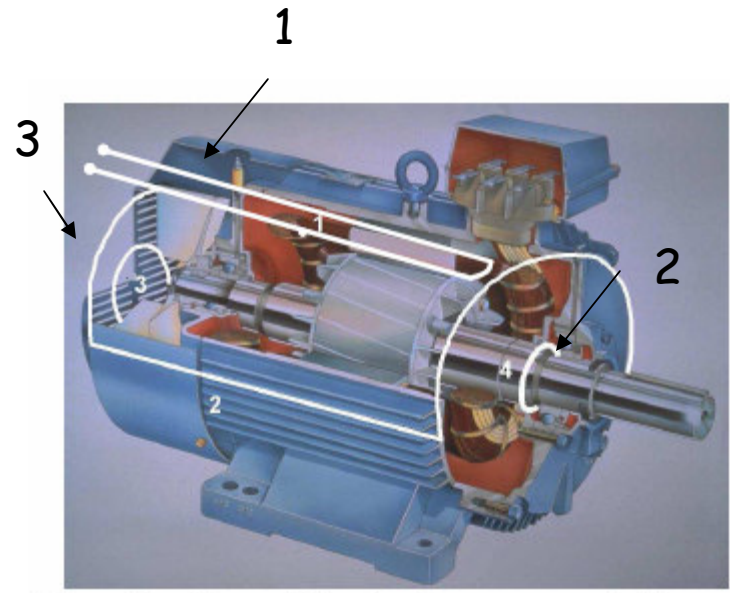




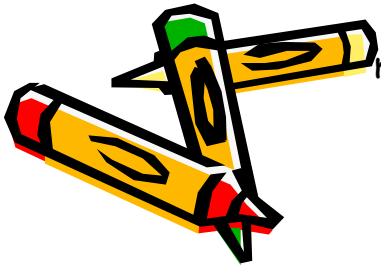
❑ Analiza spectrala a fluxului de scapari



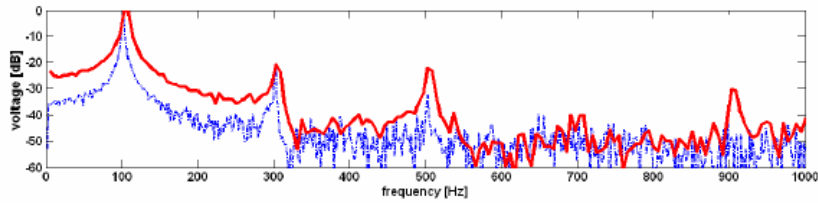
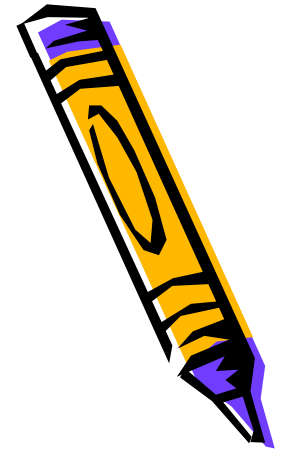
Fluxuri de scapari intr-o masina electrica



Posibile locatii ale bobinelor spion

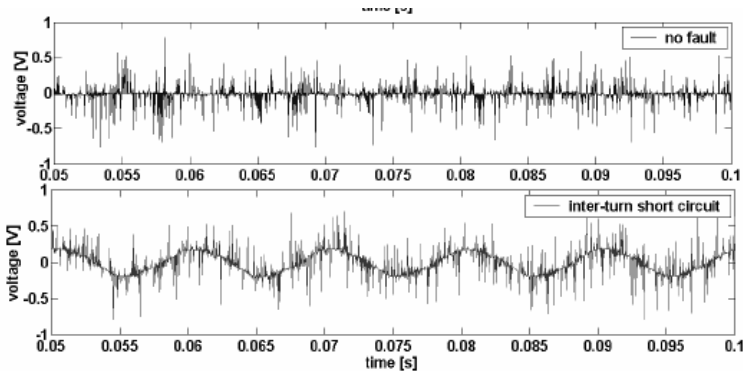


SCURTCIRCUIT STATORIC



— Fara defect
— Cu defect

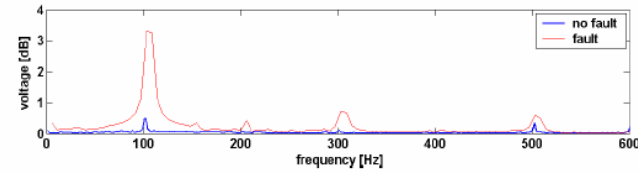
Spectrul tensiunii induse in bobina spion (1) instalata pe un dinte statoric



Fara defect

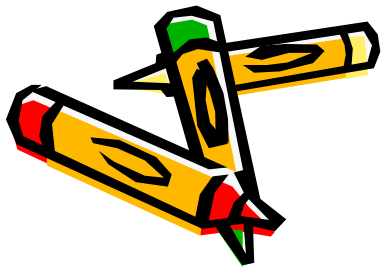
Cu defect

Tensiunea indusa in bobina spion (2) instalata pe capatul axului



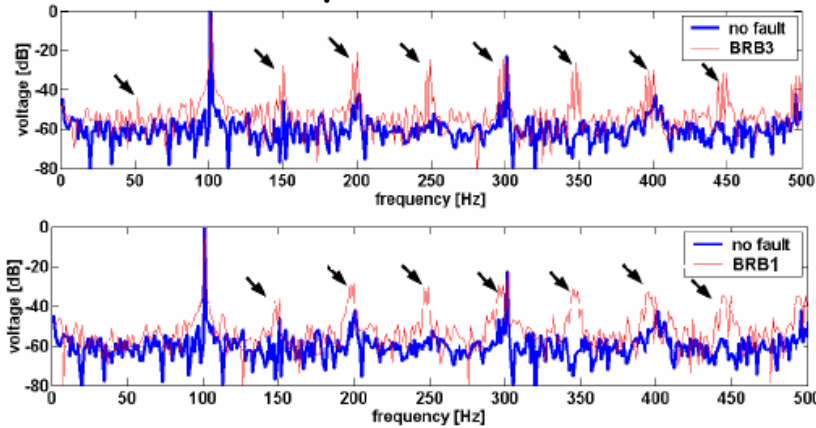
— Fara defect
— Cu defect

Spectrul tensiunii induse in bobina spion (2) instalata pe capatul axului



BARE RUPTE

Spectrul tensiunii induse in bobina spion (1) instalata pe un dinte statoric



3 BARE intrerupte

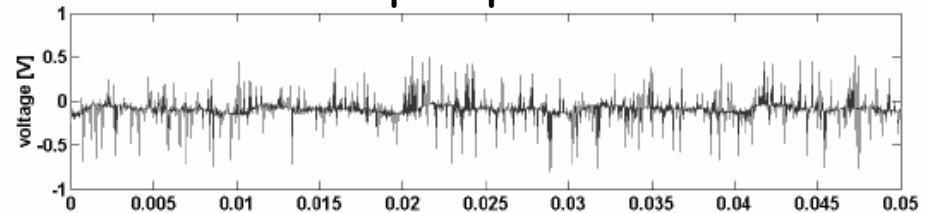
1 Bara intrerupta

— Fara defect

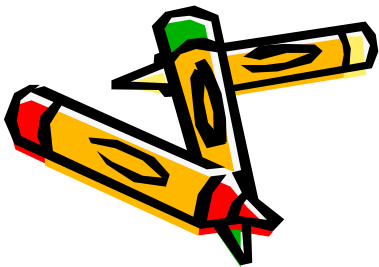
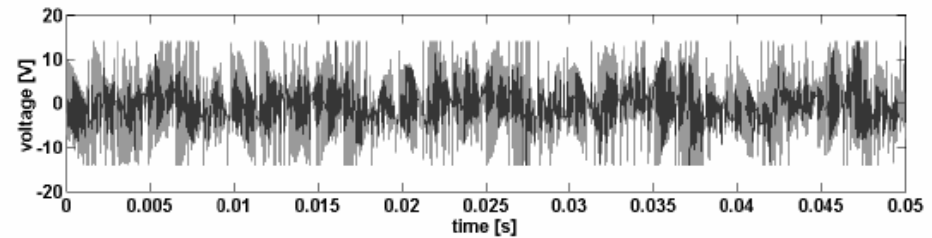
— Cu defect

Tensiunea indusa in bobinele spion (2 si 3) instalate pe capatele axului

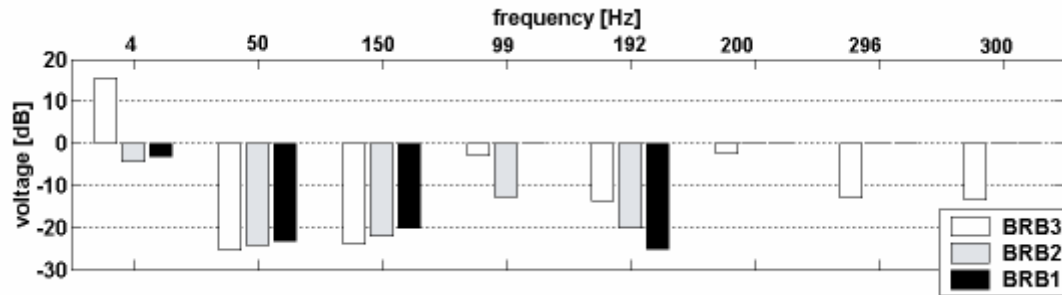
Capatul de pe partea ventilatorului (3)



Capatul liber (2)



Side-band-urile din spectrul tensiunii induse in bobina spion (3) instalata pe capatul axului



- BRB3- 3 bare intrerupte
- BRB2 - 2 bare intrerupte
- BRB1 - 1 bara intrerupta

Side-band-urile din spectrul tensiunii induse in bobina spion (2) instalata pe capatul axului

