$W_{elec} = W_{mag} + W_{term}$

$W_{elec} - W_{term} = W_{mag}$

$W_{mag} = W_{cin} + W_{hist} + W_{foul}$

$W_{cin} = W_{mag} - W_{hist} - W_{foul}$

$W_{potencial\ eléctrica} = \frac{C}{2}V^2$

$W_{magnética} = \frac{B(t)^2}{2\mu_0\mu_r}vol$

$W_{foucault} = \int_0^{t_{pulso}} [k_e(\frac{d}{dt}[B(t)])^2 vol]dt$

$w_{histéresis} = vol * A_{BH} * \eta(t)$

$w_{térmica} = \int_0^{t_{pulso}} I(t)^2 Rdt$

$\phi = arctan(-\frac{\alpha}{w_d})$

$$\eta(t) = 1 - \frac{A_{BH}B(t)\frac{dB(t)}{dt} + k_e[\frac{dB(t)}{dt}]^2}{\frac{B(t)}{\mu}\frac{dB(t)}{dt}}$$

si $\frac{dB(t)}{dt} \neq 0$

$$\eta(t) = 1 - \frac{\mu(A_{BH}B(t) + k_e\frac{dB(t)}{dt})}{B(t)}$$

$$\eta(t) = 1 - \mu A_{BH} + \frac{\mu k_e \frac{dB(t)}{dt}}{B(t)}$$

$\eta(t) = 1 - \mu A_{BH} + \mu k_e \frac{d}{dt}ln[B(t)]$

$t_{pulso} = \frac{3}{\zeta\omega_0}$

$\zeta = \frac{R}{2}\sqrt{\frac{C}{L}}$

$\omega_0 = \frac{1}{\sqrt{LC}}$

$A_{BH} = 5 - 20\ es\ empírico,\ se\ debe\ medir$

$k_e \sim \frac{d_n^{\ 2}}{\rho_n} del\ núcleo$

$R = \frac{\rho_c l_c}{A_c}\ del\ cobre$

$P_{foucault} = \frac{(\pi dB_{pico}f)^2}{6\rho}$

$f = \frac{1}{2\pi}\omega_d$

$\alpha = \frac{R}{2L}$

$\omega_d\sqrt{\omega_0^{\ 2} - \alpha^2}$

$I_0 = \frac{V_0}{L\omega_d}$

$B(t) = \mu_0\mu_r\frac{N}{l}I(t)$

$\Delta = (\frac{R}{2L})^2 - \frac{1}{LC}$

$\Delta < 0 \Rightarrow Subamortiguado\ (oscila)\ I(t) = I_0 e^{-\alpha t} sin(\omega_d t)$ y $V = \frac{V_0 e^{-\alpha t} cos(w_d t+\phi)]^2}{2}$

$\Delta = 0 \Rightarrow Críticamente\ amortiguado\ (vuelve\ a\ cero,\ drásticamente)\ I(t) = (A + Bt)e^{-\alpha t}$

$\Delta > 0 \Rightarrow Sobreamortiguado\ (vuelve\ a\ cero\ sin\ oscilar\ pero\ lento)$

$I(t) = Ae^{s_1 t} + Be^{s_2 t}$

$s =- \alpha \pm \sqrt{\alpha^2 - \omega_0}$

$A = \frac{-V_{max}}{L(s_1 - s_2)}$

$B = \frac{V_{max}}{L(s_1 - s_2)}$

$L\frac{d^2[I]}{dt^2} + R\frac{d[I]}{dt} + \frac{1}{C}I = 0$

$B(t) = Densidad\ de\ flujo\ magnético\ en\ función\ del\ tiempo\ [T]$

$\mu_0 = Permeabilidad\ magnética\ del\ vacío\ [H/m]$ ó$[\frac{mKg}{A^2 s^2}]$ Constante

$\mu_r = Permeabilidad\ relativa\ del\ material$ Constante 1,8T

$k_e = Constante\ de\ pérdidas\ por\ foucault\ [\Omega m^2]$ Constante

$t_{pulso} = duración\ efectiva\ del\ pulso\ [s]$

$A_{BH} = Área\ del\ bucle\ de\ histéresis\ [\frac{J}{m^3}]$ Constante

$\eta(t) = Eficiencia\ instantánea\ [0, 1]$

$B_{sat} = Campo\ de\ saturación\ del\ material\ [T]$ Constante

$\omega_0 = Frecuencia\ natural\ no\ amortiguada$

$\zeta = Coeficiente\ de\ amortiguamiento$

$L(t) = Inductancia\ dependiente\ del\ tiempo\ [H]$

$V = tensión,\ constante\ excepto\ en\ amortiguado\ [V]$

$I(t) = corriente,\ tres\ modelos\ posibles\ [A]$

$$W_{elec} - W_{term} = W_{mag}$$

$$W_{cin} = W_{mag} - W_{hist} - W_{foul}$$

$$\frac{C}{2}V^2 - \int_0^{t_{pulso}} I(t)^2 R dt = \frac{B(t)^2}{2\mu_0\mu_r} vol$$

$$w_{cin} = \frac{C}{2}V^2 - \int_0^{t_{pulso}} I(t)^2 R dt - \int_0^{t_{pulso}} [k_e(\frac{d}{dt}[B(t)])^2 vol]dt - vol * A_{BH} * \eta(t)$$

$$w_{cin} = \frac{C}{2}V^2 - R\int_0^{t_{pulso}} I(t)^2 dt - k_e vol \int_0^{t_{pulso}} (\frac{d}{dt}[B(t)])^2]dt - vol * A_{BH} * \eta(t)$$

$$w_{cin} = \frac{C}{2}V^2 - R\int_0^{t_{pulso}} I(t)^2 dt - k_e vol[B(t_{pulso})^2 - B(0)^2] - vol * A_{BH} * \eta(t)$$

$$w_{cin} = \frac{C}{2}V^2 - R\int_0^{t_{pulso}} I(t)^2 dt - vol[k_e B(t_{pulso})^2 + \eta(t)]$$

- considerando $\eta(t) = 1 - \mu A_{BH} + \mu k_e \frac{d}{dt} ln[B(t)]$

$$w_{cin} = \frac{C}{2}V^2 - R\int_0^{t_{pulso}} I(t)^2 dt - vol[k_e[B(t_{pulso})^2 + \mu\frac{d}{dt} ln(B(t))] + 1 - \mu A_{BH}]$$

$$w_{cin} = \frac{C}{2}V^2 - R\int_0^{t_{pulso}} I(t)^2 dt - vol[k_e[(\mu_0\mu_r \frac{N}{l} I(t_{pulso}))^2 + \mu_0\mu_r \frac{d}{dt} ln(\mu_0\mu_r \frac{N}{l} I(t))] + 1 - \mu_0\mu_r A_{BH}]$$

- considerando $t_{pulso} = \frac{3}{\zeta\omega_0} = \frac{3}{\frac{R}{2}\sqrt{\frac{C}{L}}\frac{1}{\sqrt{LC}}} = \frac{6\sqrt{LC}}{R\sqrt{\frac{C}{L}}} = \frac{6}{R}\sqrt{\frac{L^2C}{C}} = \frac{6L}{R}$

$$w_{cin} = \frac{C}{2}V^2 - R\int_0^{\frac{6L}{R}} I(t)^2 dt - vol[\frac{d_n^{\ 2}}{\rho_n}\mu_0\mu_r[(\frac{N}{l} I(\frac{6L}{R}))^2 + \frac{d}{dt} ln(\mu_0\mu_r \frac{N}{l} I(t))] + 1 - \mu_0\mu_r A_{BH}]$$

$$\frac{m}{2}v^2 = \frac{C}{2}V^2 - R\int_0^{\frac{6L}{R}} I(t)^2 dt - vol[\mu_0\mu_r(\frac{d_n^{\ 2}}{\rho_n}[(\frac{N}{l} I(\frac{6L}{R}))^2 + \frac{d}{dt} ln(\mu_0\mu_r \frac{N}{l} I(t))] - A_{BH}) + 1]$$

$$v = \sqrt{\frac{2}{m}[\frac{C}{2}V^2 - R\int_0^{\frac{6L}{R}} I(t)^2 dt - vol[\mu_0\mu_r(\frac{d_n^{\ 2}}{\rho_n}[(\frac{N}{l} I(\frac{6L}{R}))^2 + \frac{d}{dt} ln(\mu_0\mu_r \frac{N}{l} I(t))] - A_{BH}) + 1]]}$$

$$max \frac{2}{m}[\frac{C}{2}V^2 - R\int_0^{\frac{6L}{R}} I(t)^2 dt - vol[\mu_0\mu_r(\frac{d_n^{\ 2}}{\rho_n}[(\frac{N}{l} I(\frac{6L}{R}))^2 + \frac{d}{dt} ln(\mu_0\mu_r \frac{N}{l} I(t))] - A_{BH}) + 1]]$$

$$L(t) = \frac{N^2\mu_0 A}{l - x(t) + \frac{x(t)}{\mu_r}}$$

$$R = \frac{\rho_c l_c}{A_c}$$

$$B(t) = \mu_0\mu_r \frac{N}{l} I(t)$$

$$t_p = \frac{6L}{R}$$

simplificada para simulación

$$w_{cin} = \frac{C}{2}V^2 - vol[\mu_0\mu_r(\frac{d_n^{\ 2}}{\rho_n}[(B(t_p)^2 + \frac{d}{dt} lnB(t)] - A_{BH}) + 1] - R\int_0^{t_p} I(t)^2 dt$$

$\Delta = (\frac{R}{2L_0})^2 - \frac{1}{L_0 C}$

$L_0 = \frac{\mu_0 \mu_R N^2 A}{l_b}$

$\Delta < 0 \Rightarrow Subamortiguado\ (oscila)\ I(t) = I_0 e^{-\alpha t} sin(\omega_d t)$ y $V = \frac{V_0 e^{-\alpha t} cos(w_d t + \phi)]^2}{2}$

$\Delta = 0 \Rightarrow Críticamente\ amortiguado\ (vuelve\ a\ cero,\ drásticamente)\ I(t) = (A + Bt)e^{-\alpha t}$

$\Delta > 0 \Rightarrow Sobreamortiguado\ (vuelve\ a\ cero\ sin\ oscilar\ pero\ lento)$

$I(t) = Ae^{s_1 t} + Be^{s_2 t}$

$s = -\alpha \pm \sqrt{\alpha^2 - \omega_0}$

$A = \frac{-V_{max}}{L(s_1 - s_2)}$

$B = \frac{V_{max}}{L(s_1 - s_2)}$

$\phi = arctan(-\frac{\alpha}{w_d})$

$\alpha = \frac{R}{2L}$

$\omega_d = \sqrt{\omega_0^2 - \alpha^2}$

$\omega_0 = \frac{1}{\sqrt{LC}}$

$\oint_{\partial S} B \cdot dl = \mu_0 I_{enc}$

$F(x) = IdL(B(x) \times v(x))$

$F_{total} = \int_0^L F(x)dx$

$a(t) = \frac{masa}{F_{total}}$

$masa * \frac{d^2 r}{dt^2} = F_{total}$