RR. 5.

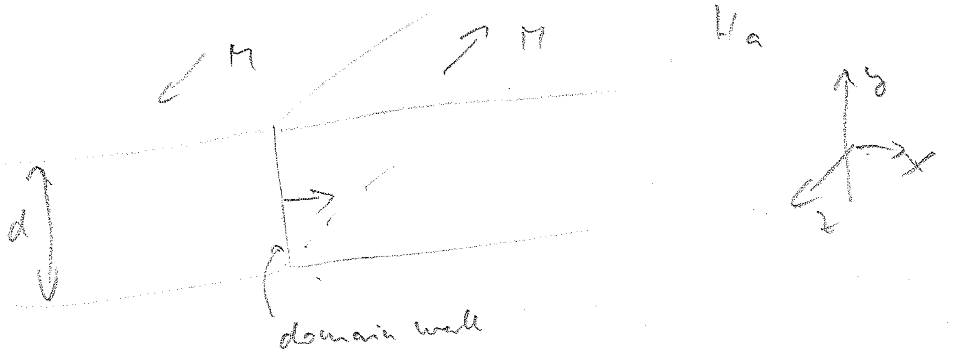
Barkhausen effect

- single domain wall movement
- eddy - current damping
- stochastic domain wall dynamics
- random pinning fields
- Langevin
- Fokker - Planck

magnetic flux ϕ ... magnetization ... field ... space average of H

$$\frac{d\phi}{dt} = f\left[M(\ldots), H(\ldots) \right] = g(\phi, H(\ldots))$$

Single domain wall



$$\frac{d\phi}{dt} = 2 I_s d \cdot v_w = 2 \mu_0 M_s d \frac{dx_w}{dt}$$

→ eddy currents → Joule heat, small v_w limit

$\nabla \times j = 0$

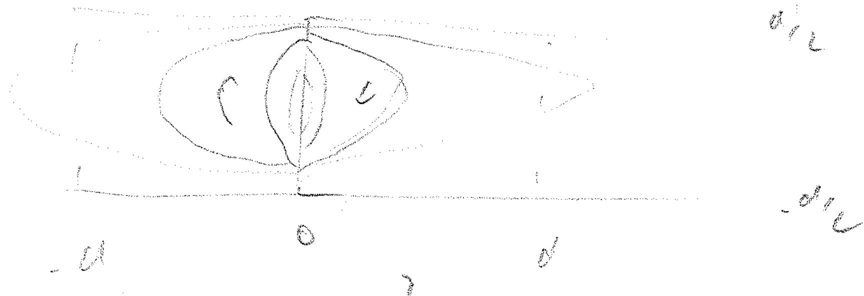
$\nabla j = 0$

$j_x(x)$ even, $j_y(x)$ odd $\qquad j_y(y = \pm d/2) = 0$

$$j_y(x = 0^-) = -j_y(x = 0^+) = \sigma I_s v_w = \frac{\sigma}{2d} \frac{d\phi}{dt}$$

$$j_x = \frac{2\sigma}{d} \frac{d\phi}{dt} \sum_{\text{odd } n} \frac{(-1)^{(n-1)/2}}{n\pi} \sin \frac{n\pi y}{d} \exp\left(\frac{n\pi |x|}{d}\right)$$

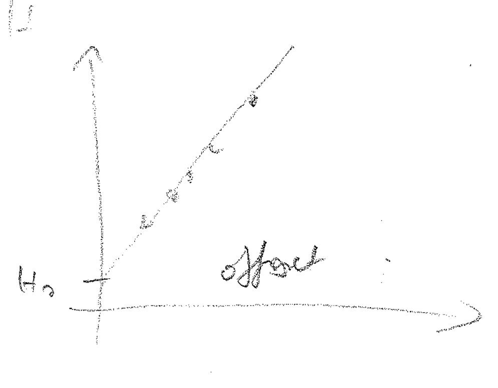
$j_y = \ldots \qquad \cos$



$$P_w = \sigma G \left(\frac{d\phi}{dt}\right)^2 \qquad G = \frac{4}{\pi}\sum_{odd}\frac{1}{n^3} \approx 0{,}136\ldots$$

This work per unit slab and unit time by $H_a \frac{d\phi}{dt}$

$$H_a = \sigma G \frac{d\phi}{dt} = \beta \frac{dX_w}{dt} \qquad \beta = 2\sigma G / sd$$



linear dependence

$$\sigma G \frac{d\phi}{dt} = H_a - H_0$$

$$P_w = \left|H_0 \frac{d\phi}{dt}\right| + \sigma G \left(\frac{\partial\phi}{\partial t}\right)^2$$

independent of the wall velocity
rate independent hysteresis

rate dependent

loss separation

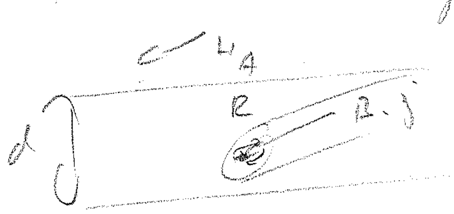
↳ internal degrees of freedom

↳ structural disorder

RR 5

Internal degrees of freedom

Barkhausen jump



$$\frac{d\phi}{dt} = \nu\,\Delta\phi$$

flux change (inside R)

average number of jumps per unit time

Dissipation $j(x, t, \underbrace{x_i, t_i}_{\text{coordinates of the jump}})$

$j = \sum_i j_i$ $\qquad$ ν number of jumps in T

$$|j|^2 = \sum_i |j_i|^2 + \sum_{i \neq j} j_i \cdot j_j = \nu\left(T\langle |j_i|^2\rangle\right) + \nu^2\left(T\langle j\rangle\right)^2$$

$$\nu \sim \frac{d\phi}{dt}$$

$$P_R = \left| H_0 \frac{d\phi}{dt} \right| + \sigma G' \left(\frac{d\phi}{dt}\right)^2$$

H_0, G' const $\quad$ funct of $\Delta\phi, j, \rho(x)$

Same structure as before

Stochastic domain wall dynamics

$$\left(\gamma \frac{dX}{dt} = H(t) - \frac{\partial F}{\partial X} = H(t) - H_F(X) \right)$$

$$(1) \quad \sigma G \frac{d\phi}{dt} = H_a(t) - H_F(\phi)$$

$$(2) \quad H_F(\phi) = \frac{\phi}{S\mu} + H_p(\phi)$$

random pinning field

large scale stability
macroscopic magnetization const slope

correlation length ξ — correlations destroyed beyond ξ by randomness

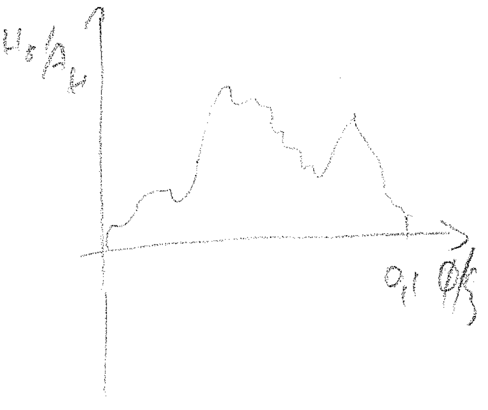
Ornstein–Uhlenbeck process

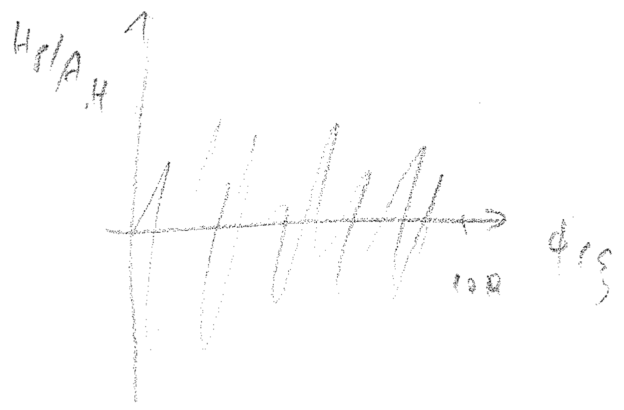
$$(3) \quad \frac{dH_p}{d\phi} + \frac{H_p}{\xi} = \frac{dW}{d\phi} \qquad \langle dW \rangle = 0, \quad \langle |dW|^2 \rangle = \frac{2A_H^2}{\xi} d\phi$$

Gaussian white noise

dW Wiener process

$$P_0(H_p) = \frac{1}{\sqrt{2\pi A_H^2}} \exp\left(- \frac{H_p^2}{2 A_H^2} \right) \quad \text{eq. distr.}$$





(1) + (2) + (3) dynamics of domain wall
time space

→ too complicated → approx

$\xi \to \infty$ limit

$\xi \to \infty \quad A = \frac{A_H^2}{\xi}$

$\frac{H}{\xi} \to 0 \quad \Rightarrow H_p$ Wiener process with $\langle |dH_p|^2 \rangle = 2A d\phi$

$$\Rightarrow \sigma G \frac{d\phi}{dt} = H_a(t) - \frac{\phi}{S\mu} - H_p(\phi)$$

$$\langle dH_p \rangle = 0 \qquad \langle |dH_p|^2 \rangle = 2A\, d\phi$$

Dedimensionalization

<u>const.</u> $\tau = \sigma G S \mu \qquad \Phi_0 = A S^2 \mu^2 \qquad H_0 = A S \mu$

$c = \frac{\tau}{H_0} \frac{dH_a}{dt} \quad \to$ dimensionless parameter

$u = \frac{t}{\tau} \qquad x = \frac{\phi}{\Phi_0} \qquad v = \frac{dx}{du} \qquad h_p = \frac{H_p}{H_0}$

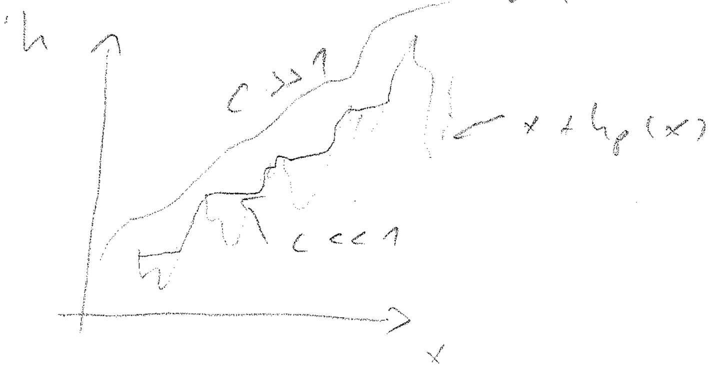
$$\frac{dx}{du} = h_a - x - h_p(x)$$

$$\frac{dh_a}{du} = c \qquad \langle dh_p \rangle = 0 \qquad \langle |dh_p|^2 \rangle = 2dx$$

Langevin approach

$$\frac{dv}{du} + (v - c) = -\frac{dh_p}{du} \qquad \langle dh_p \rangle = 0 \qquad \langle |dh_p|^2 \rangle = 2v du$$

?



$\langle v \rangle = c \Leftrightarrow \frac{1}{S}\frac{d\langle\phi\rangle}{dt} = \mu \frac{dH_a}{dt}$

macroscopic law of linear magnetization

<u>Noise term</u>

(Brownian fluctuation at thermal equilibrium)

Here zero temperature, random driving force
rate of change from disorder

$\frac{dh_r}{du} = ?$

dh_p vs. $dx \to \langle (dh_p)^2 \rangle = 2dx$

? variance for du

$dx = v \cdot du \Rightarrow \langle (dh_p)^2 \rangle = 2dx = 2v\,du$

$\Rightarrow \frac{dh_p}{du}$ white noise term of intensity from time to time in proportion to v

Ito stochastic diff. eq.

$dv + (v-c)\,du = \sqrt{2v}\,dw$ — Wiener process $\langle dw^2 \rangle = du$

Fokker - Planck equation

$$\frac{\partial P}{\partial u} + \frac{\partial}{\partial v}(c-v)P - \frac{\partial^2}{\partial v^2} vP = 0$$

$$\frac{\partial P}{\partial u} + \frac{\partial j_P}{\partial v} = 0 \qquad j_P = (c-v)P - \frac{\partial}{\partial v} vP$$

probability current

$P(v, u=0|v_0) = \delta(v - v_0)$ decays exponentially for $v \to \infty$

$j_r(v=0^+) = 0$ $v=0$ is a reflecting boundary

$P_\lambda(v,u) = C_\lambda e^{-\lambda u} e^{-v} f_\lambda(v)$ $\lambda > 0$

$P_0(v) = \frac{1}{\Gamma(c)} v^{c-1} e^{-v}$

Self similarity

$j_P = (c-1-v)P - v\frac{\partial P}{\partial v}$

$v \ll 1$ neglected

scale invariance : $u \to bu$, $v \to bv$

$P_0(v) \sim v^{c-1}$

$P_u(\Delta u) \sim (\Delta u)^{-\tau}$ $\tau = 2 - c$

$P_x(\Delta x) \sim (\Delta x)^{-\beta}$ $\beta = 3/2 - c/2$