Preisach model for magnetic hysteresis

Xiaoshan Xu
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Levels of details for ferromagnets

- Atomic level:
  - Exchange interaction that aligns atomic moments $J_{ij} \mathbf{S}_i \cdot \mathbf{S}_j$

- Micromagnetic level
  - Smear the individual atoms into continuum, see magnetization as a function of position (domain wall)

- Domain level
  - Domains are separated by walls of zero thickness

- Nonlinear level
  - Average magnetization of the entire magnet
Why Perisach model

- We describe hysteresis using a few parameters $M_r, M_0, H_0$
- But, how to understand the shape analytically?

Hysteron

- A magnet is made of many hysterons.
- For a hysteron:
  - The saturation magnetization is always $m_0$
  - Can be described by two parameters, the coercive fields: $U, V$
  - The coercive fields are not necessarily asymmetric: $(U \neq -V)$. 
Hysteron distribution and mapping

By definition, the probability is zero if $U < V$.

$P(U, V)$

Probability of have a hysteron of two coercive fields $U$ and $V$. 

$U = -V$

$U > V$

$U < V$
Calculate magnetization from the hysteron map

Large negative field to full saturate the magnetic in the down position

Increase the field to $H_0$ to flip some of the hysteron up

$$M = -M_0 + \int_{-\infty}^{H_0} dU \int_{-\infty}^{U} P(U,V) dV$$
Calculate magnetization from the hysteron map

Large positive field to full saturate the magnetic in the up position

Decrease the field to $H_1$ to flip some of the hysteron down

$$M = M_0 - \int_{-\infty}^{H_0} dU \int_{-\infty}^{U} P(U,V) dV$$
A typical hysteron distribution

- \( P(U,V) = \frac{1}{4\pi \sigma_i \sigma_k} \exp\left( \frac{\sigma_i^2 (U-V-2h_k)^2 + \sigma_k^2 (U+V)^2}{8 \sigma_i^2 \sigma_k^2} \right) \)

- Most probably, the hysteron is symmetric, i.e. 
  \( U = -V \)
Full hysteresis and parameters

\[ P(U, V) = \frac{1}{4\pi\sigma_i\sigma_k} \exp\left(\frac{\sigma_i^2 (U - V - 2h_k)^2 + \sigma_k^2 (U + V)^2}{8\sigma_i^2 \sigma_k^2}\right) \]

\[ h_k = 2\sigma_i = 2\sigma_k \]

\[ h_k = 4\sigma_i = 4\sigma_k \]

\[ h_k = 8\sigma_i = 8\sigma_k \]
Initial magnetization

\[ U \equiv -V \]

\[ U < V \]

Down

Up

\[ \tilde{U} \quad \text{Up} \]

\[ \text{Down} \]

\[ \tilde{U} \]

\[ U < V \]
Minor loop

\[ \dot{U} = -V \quad U < V \]

Down

\[ \dot{U} = -V \quad U < V \]

Down

Up

\[ \dot{U} = -V \quad U < V \]

Down

Up

\[ \dot{U} = -V \quad U < V \]

Down

Up
Conclusion

• Preisach model can be used to describe the magnetic hysteresis using a distribution of hysterons
• It explains full-loop, minor loop, initial magnetization
• The real magnetization can be modeled with a modified Preisach model